HomeRF Specification

HomeRF

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by

The HomeRF™ Technical Committee

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1 INTRODUCTION

This document defines the HomeRF specification defined by the HomeRF Working Group, Inc. The base for this document was the *SWAP-CA 1.3 20000616* specification. The current and future revisions of this specification will be named *HomeRF*. HomeRF provides support for communication of both data and voice in a home environment using the unlicensed 2.4 GHz ISM band. The specification includes components defined by ETSI DECT [3 - 11], and is influenced by the OpenAir™ network [1].

For an introduction into the architecture refer to chapter 3.

1.1 Document Overview

The HomeRF specification supports many features, some of which are optional. This makes the specification attractive to product manufacturers, but requires careful description. In order to present the specification in a coherent fashion, it is described in terms of separate architecture blocks.

Chapter 3 (Architecture) describes what a HomeRF network is, and what the nodes on a HomeRF network are. For each type of node, it describes what architecture blocks it contains. Then, for all the architecture blocks that have been identified, it describes the interfaces they provide to other blocks.

There is then a chapter for each architecture block that describes what it does and how it does it.

There is also a chapter for each type of HomeRF node. They cover points of specification specific to individual types of node. These points mainly define the features that the node must support, the user-interface, top-level management and data-flow of that type of node.

Appendix C defines the HomeRF encryption algorithm. It is available as a separate document from the HomeRF Working Group, Inc. Section 1.7 (Technical Feedback and Document Updates) describes how to obtain a copy of this Appendix.

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1.2 Abbreviations and Acronyms

ACK	Acknowledgment
ADPCM	Adaptive Differential Pulse Code Modulation
ARP	Address Resolution Protocol
BAN	Bridging-Aware Node
CC	Call Control
CCA	Clear Channel Assessment
CFP	Contention Free Period
CP	Connection Point
CPA	Connection Point Assertion
CPB	Connection Point Beacon
CPS	Connection Point Service
CRC	Cyclic Redundancy Check
CSFD	CSMA Start of Frame Delimiter
CSDU	CSMA/CA Service Data Unit
CSMA/CA	Carrier Sense Multiple Access/ Collision Avoidance
CTS	Clear To Send
CW	Contention Window
DA	Destination Address
DDK	Device Driver Kit
DECT	Digital Enhanced Cordless Telecommunications standard
DFT	Default Fragmentation Threshold
DIFS	Default Inter-frame Space[3]
DLC	Data Link Control layer
EFD	End-of-Frame Delimiter
EOC	End of Contention
FER	Frame Error Ratio
FH	Frequency Hopping
FSK	Frequency Shift Key
GAP	DECT Generic Access Profile
GFSK	Gaussian Frequency Shift Key
GHz	Giga Hertz (1×10^9 Hz)
HB	HomeRF Bridge
HRFWG	Home RF Working Group, Inc.
ICBS	Isochronous Connectionless Broadcast Service
ICV	Integrity Check Value
ISDN	Integrated Services Digital Network
IEEE	Institute of Electrical and Electronics Engineers[4]
IFS	Inter-frame Space
IHV	Independent Hardware Vendor
IM_p	Intermodulation Protection
ISI	Inter Symbol Interference
ISM	Industrial, Scientific, and Medical
IV	Initialization Vector
IWU	Interworking Unit
kbps	Kilo-bits per second (1,000 bits per second)
LAN	Local Area Network
LCE	Link Control Entity
LED	Light Emitting Diode
LFSR	Linear Feedback Shift Register
LSB	Least Significant Bit
MAC	Medium Access Control
Mbps	Mega-bits per second (1,000,000 bits per second)
MCEI	MAC Connection Endpoint Identifier (DECT)
MIH	MAC Initial Header
MM	Mobility Management
MPDU	MAC Protocol Data Unit
MSB	Most Significant Bit
MSDU	MAC Service Data Unit
MSP	Media Services Provider
MTR	Maximum Time Reservation with reference to the Priority Asynchronous Data service
mW	Milli-Watt (1×10^{-3} Watt)
NA	Node Address
NDIS	Network Driver Interface Specification
NIC	Network Interface Card
NTR	Nominal Time Reservation with reference to the Priority Asynchronous Data service
NWID	Network ID
NWK	Network Layer
PCI	Peripheral Component Interconnect
PCM	Pulse Code Modulation
PDU	Protocol Data Unit
PHY	Physical layer
PM	Power Management
PMID	Portable Part MAC Identity (DECT)
POTS	Plain Old Telephony Service
PP	Portable Part
PPDU	PHY Protocol Data Unit
ppm	Parts per million

[3] This acronym has a slightly different definition in the 802.11 specification

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PRNG	Pseudo-Random Number Generator
PS	Power Saving
PSDU	PHY Service Data Unit
PSTN	Public Switched Telephone Network
RF	Radio Frequency
RSSI	Received Signal Strength Indication
SA	Source Address
SAP	Service Access Point
SC	Service Control (Parameters)
SFD	Start of Frame Delimiter
SID	Stream ID
SIFS	Short Inter-frame Space
SOC	Start of Contention
SSTQ	Service-Slot Transmit Queue
SWAP-CA	Shared Wireless Access Protocol - Cordless Access
TAPI	Telephony API
TCL	Terminal Coupling Loss
TDMA	Time Division Multiple Access
TELR	Talker's Echo Loudness Rating (DECT)
TPUI	Temporary Portable Unit Identifier (DECT)
TS	Training Sequence
TSP	TAPI Service Provider
TSFD	TDMA Start Frame Delimiter
TTS	TDMA Training Sequence
UAK	User Access Key
USB	Universal Serial Bus
WM	Wireless Medium

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1.3 Definitions

Active Connection Point	The single Connection Point present in a network which is providing control-point services
A-node	A node that uses the CSMA/CA access mechanism and provides the asynchronous data service
Asleep / Sleeping	A node that is asleep (or sleeping) is performing a power-saving protocol, and is not necessarily capable of receiving and transmitting
Asynchronous	Occurring unpredictably, without reference to any other time event
Atomic MPDU Sequence	Either: a single MPDU for which no response is required; or a sequence of two MPDUs separated by a SIFS in which the second MPDU carries a response to the first MPDU.
Awake	A node that is awake is capable of receiving and transmitting
Backoff	The phase of a CSMA/CA transmission during which the node determines accessibility to the radio medium
basic modulation	Nomenclature for the LR 2-FSK modulation type. This is the mandatory default modulation for all HomeRF nodes
Broadcast	A broadcast data transfer that is intended to be received by all nodes. A broadcast IEEE address is all ones.
C-Channel	DECT terminology for mechanisms relating to the control of a U-Plane. The C-Channel SDUs utilize part of the subframe bandwidth provided by the isochronous data services
Class-1 Connection Point	A Connection Point that supports I-nodes, A-nodes, and S-nodes
Class-2 Connection Point	A Connection Point that supports A-nodes and S-nodes
Class-3 Connection Point	A Connection Point that supports A-nodes and S-nodes but is not required to perform A-node power-management services
Codec	Coder/Decoder. Converts between a voice signal and PCM
Conferencing	A voice call in which more than two parties are included. Each party can hear the other parties.
Connection Point	A HomeRF node that is capable of providing control-point services
Contention	An attempted access to the radio medium during a backoff
Downlink	Transmission in the direction Connection Point to Node
Duplication	Referring to the MSDU data service, Duplication means that a single MSDU request results in more than one identical MSDU indication at the receiving MAC.
Extended network	An extended network is an aggregate of individual networks associated with the same network ID (*NWID*).
higher modulation	Nomenclature for all modulation types other than basic modulation
high-rate modulation	Nomenclature for the 2-FSK @ 5Ms/s (HR 2-FSK) and 4-FSK @ 5Ms/s (HR 4-FSK) modulation types

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Host PC	A PC connected to a node.
I-node	A node that uses the TDMA access mechanism and provides the isochronous data service and the isochronous connectionless broadcast data service
Intercom Call	A voice call from an I-node to another I-node
Isochronous	Occurring at a regular rate
Management MPDU	An MPDU that does not directly carry any data services, but is used to manage the data services it provides
Media Service Provider	A Windows ® driver component provided usually by an IHV that provides access to the media streams of telephony hardware
Multicast	A multicast data transfer that is intended to be received by some number of nodes. A multicast IEEE address has the first transmitted bit set to a one.
Node	A device which operates according to the HomeRF specification
Passive Connection Point	A Passive Connection Point is a Connection Point that is not currently acting as a Connection Point because there is already an Active CP on the network. A passive CP can become active if the active CP is removed from the network.
Portable Part	DECT Terminology for a voice handset
S-node	A node that uses the CSMA/CA access mechanism and provides both the asynchronous data service and the priority asynchronous data service
Service Slot	The access mechanism used by I-nodes to transmit management requests to the CP
SID	The *SID* is the stream ID associated with the streaming session. This ID will last the life of the stream and will be used as a means of identifying streams.
Slotted Contention	A Contention during which nodes perform CCA at the same time
super channel	The channel separation utilized to support the high-rate modulation
TAPI	A Windows application programming interface that enables a Windows application to control telephony devices
TAPI Service Provider	A Windows driver component provided usually by an IHV that handles call-control device-specific operations on telephony hardware
Transcoder	Converts between ADPCM and PCM
Unicast	A unicast data transfer that is intended to be received by a single node. A unicast IEEE address has the first transmitted bit set to a zero.
Uniform PCM	A linear coding of the voice signal using PCM
U-Plane	DECT terminology for mechanisms providing the “user” data transport. In HomeRF, the U-plane is associated with the Isochronous data service or the Isochronous Connectionless Broadcast data service.
Uplink	Transmission in the direction Node to Connection Point

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1.4 Document Conventions

The text and diagrams in this specification fall into one of the three classes defined in Table 1.

Table 1 - Documentation Classes

Documentation Class	Contains
Structural	A definition of a HomeRF architectural entity, or a definition of a layout of fields within a structure or PDU
Procedural	A definition of what to do in order to perform some aspect of the HomeRF specification
Informative	Mainly text that provides additional information not required in the specification. Informative sections are intended to make reading and understanding the specification easier.

Structural and Procedural Classes are *normative*. They place requirements on an implementation in terms of what features should be supported or how to implement a feature.

Informative sections of this document are distinguished by having "**(Informative)**" in the section header. The entire section and any sub-sections are there for information only. Everything described in an informative section is defined elsewhere in a normative section. In the case of any inconsistency of description between a normative and an information section, the normative section always takes precedence.

All footnotes are informative.

The language used in structural sections is the present tense. It defines a static relationship between things.

The language used in procedural sections adopts a convention to distinguish between mandatory, recommended and optional procedures, as defined in Table 2.

Table 2 - Language Conventions

Verb	Interpretation
shall	The procedure is mandatory. A compliant HomeRF node must perform the specified procedure.
should	The procedure is recommended. It is recommended that the HomeRF node perform the specified procedure. A HomeRF node that does not perform the procedure may loose some functionality or performance, but is still HomeRF compliant. An implementer should carefully consider the effects before declining to implement a recommended procedure.
can or may	The procedure is optional.

1.5 History of Changes to this Document

Version	Date	Changes
1.0p	17 December 1998	First Release
1.09p	4 March 1999	Changes to accelerate time-to-market. Changes to the PHY layer:

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		Symbol Rate, Differential Symbol Encoding added, Scrambler (4.4.8), Bit-stuffing, PPDU format, Turnround time. Changes to the MAC layer: Reduced CWmin (16.2 (MAC Constants)). CP CWmin signaling added (5.4.16.3.3 (CW Signaling) and 5.17.5 (CWSignaling)) Single/Dual PSDU distinction added to support new PPDU formats (5.4.3 (Different MPDU Formats)).
1.1	30 May 1999	"Erratum" release. Appendix C (Encryption Core Algorithm): the initialization procedure has been changed to address a possible weakness of the algorithm under certain typical usage scenarios. Section 4.4.8: "scrambler" corrected and now defined using normative Verilog code. Section 4.5.1: Meaning of F_d clarified. Nominal values specified for F_d. 2-FSK Maximum F_d changed from 325 to 350 kHz. 2-FSK Carrier Deviation Accuracy values changed from ± 15 to ± 20 kHz. Section 16.1 (PHY Constants): value of *TxRxTurnround* corrected (from 34 to 134 us). Section 16.2 (MAC Constants)*:* value of *MaxMCconnections* corrected (from 6 to 4).
1.15	July - Sept 1999	Draft releases for review by technical committee
1.2	1 October 1999	Section 16 (The HomeRF MIB) Errata. SymbolDuration changed from 1us to 1.25 us DwCountUpdateTolerance changed from 1us to 1 symbol New section 1.7 (Technical Feedback and Document Updates) (technical feedback) gives members-only web page address and email addresses for "info" and "feedback". New Sections added to support bridging: 3.4.2.5 (Bridged Network), 3.4.1.3 (HomeRF Bridges and Bridge-Aware Nodes), 3.5.12 (Bridge Architecture), 5.11.7.1 (Capability Record), 5.12.10 (Capability Record Learning Procedures), 11.6 (Bridging Layer Procedures), 5.4.4.14.5 (Bridged field). Sections modified to support bridging:5.11.3 (Capability Request Procedure), 5.12.4 (MD-SAP Header). Sections new or modified to support multicast fragmentation: 5.4.4.15 (Multicast Payload control field), 5.7.11 (CSDU Transmission Procedures), 5.7.12.3 (CSDU Receive Process) New section added to avoid multicast duplicates: 5.7.12.3.3.3 (Filtering by *MPS Relay*). Tx power levels modified Rx sensitivity modified BaseChannelOffset variable (5.5.2.1 (Hop Management)), signaling and behavior, 5.16.7 (Scanning for a New Network), 5.16.13 (Creating a Network)). *LearnNWIDtimeout* (16.2 (MAC Constants)) changed from 15s to 60s.
1.21	18 February 2000	MPDU header type 4 introduced (5.4.4.4 (MPDU Header Type 4)) and used by the DATA+Sync MPDU.

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		Removed all mention of baseChannelOffset and restored Sync Info to previous (v1.1) structure. Sync Info field moved earlier in MPDU header (to before the address fields). These changes affect both the existing type 3 header and the new type 4 header. Reserved non-US locales (Appendix A - (Localizations)) Modified hopping algorithm and description 5.5.2 (Frequency Hopping). CP Beacon structure: order of variable fields modified 5.4.16.3 (CP2 Beacon Structure). Ad-hoc synchronization behavior uses header types 3 and 4 5.16.17 (Maintaining Synchronization in an Ad-Hoc Network). Sensitivity measurement definition permits sensitivity measurement at 30% FER. Receiver Desensitization requirements relaxed for 4-FSK. Definition of modulation transition time and its measurement modified to make it easier to measure. Unicast payload control field (5.4.4.14 (Unicast Payload control field)) and capability record (5.11.7.1 (Capability Record)) contains sequence number. Behavior defined for insertion of CSDU sequence number (5.12.7.2 (CSDU Numbering)) and duplicate removal (5.12.7.3 (Duplicate Removal)).
1.3	29 February 2000	Long IR/SI mechanism and Proxy SI response removed. Bridging rules simplified (11.6 (Bridging Layer Procedures)). 20ms superframe structure split into 10ms sub-frames ()5.5.3 (Superframe Structure). TDMA slots are now grouped into “all down” followed by “all up” (5.5.3.3 (CFP2 Structure) and 5.5.3.4 (CFP1 Structure)). Adjacent TDMA slots in the same direction are separated by a TIFS. ICBS-channel introduced. Connectionless “down only” main slot reserved for ICBS-channel (5.5.3.3 (CFP2 Structure)). TDMA and Dual-Beacon PSDU types introduced (5.4.3 (Different MPDU Formats)). CP 1 Beacon uses Dual-Beacon format (5.4.16.2 (CP Beacon Formats and Terminology)). TDMA PSDUs use DECT scrambling (4.2 (PHY Layer PDU Structure)). TDMA MPDUs use DECT CRC (5.4.12 (TDMA DATA MPDUs), 5.4.14 (TDMA CPS MPDU) and 5.4.16.4 (TDMA Beacon Structure)). TDMA Request Encryption signaling via CPS request and CP Beacon response. TDMA Connection release removed. Hopset adaption signaling (5.4.4.12 (Superframe Control Field), 5.4.16.3.2 (Channel Management) and 5.4.16.4.6 (TDMA Channel Management)) and algorithm (5.5.2.4.1 (Hop Pattern Array Adaption)) added. ICBS-channel provided by the TDMA access mechanism (5.8.7 (ICBS-channel Procedures)). MB-SAP services (5.2.4 (MB-SAP Data Service (ICBS))) and implementation (5.15 (MB-SAP (ICBS) Services)) rewritten to use the ICBS-channel rather than the CP beacon. PHY timing values are specified in units of Symbols (16.1 (PHY Constants) and 16.3 (MAC Derived Values (Informative))).

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1.3	06 June 2000	Integrated errata file "Ed. NIST03-21-00__ com_130 submission of SWAP 1.3 2000029 errata from NIST 03-21-00" technical and general sections. Integrated errata file "Ed. Siemens04-11-00__ SWAP Errata 1_3 20000229 from Siemens 04-11-00" Integrated errata file "Ed. Siemens04-19-00__ SWAP Errata 1_3 20000229 from Siemens 04-19-00" Integrated errata file "Ed. Siemens06-16-00__ SWAP Errata 1_3 20000229 from Siemens 06-16-00"
2.0 initial draft	29 January 2001	Added High Rate data enhancement: Added mechanism for *Time Reservation* of the medium for high rate data MPDUs; Added support for High Rate modulation; Added Fast Unacknowledged Service Mechanism for tunneling singletom CSDUs onto ACK MPDU Many editorial changes
2.0 final draft	05 March 2001	Editorial: Changed name of specification from SWAP-CA to HomeRF Added support for streaming sessions Added support for roaming Added support for directed Teach/Learn network Finalization of PHY and MAC for high-rate data
2.0	02 April 2001	Incorporated final changes, corrections, and errata fixes.
2.0	10 August 2001	Removed draft status

1.5.1 Status of this draft revision

This is the official ratified and adopted version of the HomeRF 2.0 specification.

1.6 Versions of HomeRF Document Annexes

Associated with this release of the HomeRF specification are the annexes described in Table 3. Section 1.7 (Technical Feedback and Document Updates) describes how to obtain copies of these parts.

Table 3 - Versions of HomeRF Document Annexes

Annex	**Version**	**Contains**	**HomeRF Reference**
AppendixC	2.0	Encryption Core Algorithm	15.5 (Encryption Core Algorithm)
cipher.c	2.0	encryption core algorithm "C" source	15.5 (Encryption Core Algorithm)
cipher.h	2.0	encryption core algorithm interface definition	15.5 (Encryption Core Algorithm)
main.c	1.1	encryption core algorithm test harness	15.5 (Encryption Core Algorithm)
Vec40.txt	2.0	test vector for 40-bit version of encryption core algorithm	15.5 (Encryption Core Algorithm)

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Vec56.txt	2.0	test vector for 56-bit version of the encryption core algorithm	15.5 (Encryption Core Algorithm)
Vec128.txt	2.0	test vector for 128-bit version of the encryption core algorithm	15.5 (Encryption Core Algorithm)
scramble.v	1.1	Verilog code for PHY-layer CSMA scrambler	4.4.8.6 (CSMA Scrambler Code)
unscrmbl.v	1.1	Verilog code for PHY-layer CSMA de-scrambler	4.4.8.7 (CSMA Descrambler Code)
scram_top.v	1.1	Verilog code for test harness for CSMA scrambler and de-scrambler	4.4.8.8 (CSMA Scrambler Test Harness (Informative))
scram.vec	1.1	Test vectors for CSMA scrambler and de-scrambler	4.4.8.9(CSMA Scrambler Test Vectors))

1.7 Technical Feedback and Document Updates

The HomeRF Working Group, Inc. would like to receive your feedback on the contents of this document. This could include the reporting of errors, omissions, inconsistencies and misleading or hard-to-understand text.

New revisions of and errata to this document may be issued by the HomeRF Working Group, Inc. While there is no official schedule for such releases, it is likely that errata will be issued every three months following the initial release of this document.

The HomeRF Working Group, Inc. web site http://www.homerf.org contains the following:

- Instructions on how to get a copy of this document
- New revision and Errata release notifications
- Instructions on how to get a paper copy of Appendix C (Encryption Core Algorithm)
- Instructions on how to provide your feedback.

Members can access this through the members-only web-page http://www.homerf.org/membersonly.html.

Requests for Appendix C (Encryption Core Algorithm) should be sent to info@homerf.org.

Feedback on this specification can be submitted using a form accessible from the members-only pages. Alternatively, feedback can be sent by email to feedback@homerf.org.

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2 REFERENCES

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[6] ETS 300 175-5. DECT Common Interface, Part 5: Network Layer. Second Edition, September 1996.

[7] ETS 300 175-6. DECT Common Interface, Part 6: Identities and Addressing. Second Edition, September 1996.

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3 THE HOMERF SPECIFICATION

3.1 Introduction to HomeRF (Informative)

The HomeRF architecture is a unique combination of data transport via best-effort asynchronous, priority asynchronous, and isochronous mechanisms. The isochronous mechanism is intended for services with strict jitter and latency requirements, such as interactive voice. The priority asynchronous mechanism is intended for streaming services, such as audio and video. The best-effort asynchronous mechanism provides traditional data networking. The HomeRF specification has been optimized to provide the kinds of service that are most needed from untethered devices in the home.

A HomeRF network can include nodes that perform the functions of the following kinds of devices:

- A Connection Point (CP) that acts as the gateway between the personal computer, the PSTN, and HomeRF-compatible devices
- Isochronous data devices (I-nodes)
- Asynchronous data devices (A-nodes)
- Combined Asynchronous / Isochronous devices (AI-nodes)
- Streaming data devices (S-nodes)[5]
- Combined Streaming / Isochronous device (SI-nodes)

The Connection Point may be connected to a PC [6] or may be an integral part of a PC. It can also have a connection to the PSTN. It is capable of performing data transfers to and from other data devices using an asynchronous, contention-based protocol. The Connection Point manages the network to provide priority access to the radio medium for isochronous devices and streaming devices.

A CP or A-node, or S-node can also be a MAC-level bridge - providing extension of other networking technologies into the HomeRF network.

Thus, the HomeRF specification is a hybrid in several ways – it is client-server between the Connection Point and devices using the isochronous and priority asynchronous service, but is peer-to-peer between devices using the asynchronous data service. The isochronous transactions are circuit switched, time division multiple access, while asynchronous and priority asynchronous transactions are packet switched, carrier sense multiple access. It is precisely this richness that gives HomeRF the capability for broad use in the home. It is not designed to support hundreds of users doing similar things in an enterprise, but rather the variety of applications that occur in a residential setting. It will allow the largely untapped power of the home personal computer to be extended throughout the home and into the yard.

[JU_PC]In some configurations, the personal computer will be an integral part of a HomeRF system, although limited functions will be available even when the PC is inoperative. Access to asynchronous, priority asynchronous, and isochronous data from the HomeRF Connection Point will be available to Windows applications via NDIS and TAPI interfaces.

[5] All S-nodes are assumed to handle A-node cabapilites since streaming management messages use the asynchronous data service. Hence all S-nodes are actually SA-nodes. The same holds true for SI-nodes that are actually SAI-nodes.

[6] Typically *via* USB.

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3.2 Summary of HomeRF Features

Table 4 summarizes the main features offered by this specification.

Table 4 - HomeRF Features

Feature	HomeRF Description
Network type	· Non-extended network. An individual network identified by a Network ID · Extended network. An aggregate of individual networks associated with the same Network ID (*NWID*). Individual networks that are manged by roaming capable CPs may support the Asynchronous Data Roaming Procedures within the context of the extended network
Network modes of operation	· As an ad-hoc network of data-only nodes. See section 3.4.2.3 · As a managed network under the control of a Connection Point providing support for isochronous data, priority asynchronous data, and power saving. See section 3.4.2
Main types of service	· Asynchronous (connectionless) data service - used for data networking · Priority asynchronous (session-oriented) data service – used for carrying media streams such as audio and video. Requires the presence of a Connection Point. · Isochronous (connection-oriented) data service - used mainly to carry interactive voice. Requires the presence of a Connection Point. · Isochronous connectionless broadcast service (ICBS) – used to carry broadcast messages such as paging of I-nodes, cadence ringing, caller ID, and voice announcement
MAC-level bridging	· An A-node, S-node or CP can act as a bridge between the HomeRF network and some other network technology · All A-nodes, S-nodes and CPs are “bridging aware” and support the operation of any HomeRF bridges in the network
Network ID	· 24-bit network identifier to allow the concurrent operation of multiple co-located networks
HomeRF device address	· 48-bit IEEE MAC address
Data Integrity	· Reliable unicast data provided using an acknowledgement/retry mechanism · Low-delay good reliability isochronous data service uses a unique time and frequency diversity scheme to overcome interference · Reliable streaming data using maximum time reservation (MTR) for resending packets
Encryption	· Support for encryption of both the isochronous and asynchronous data services
Data Compression	· Compression of asynchronous data
Power Management	· Both A-nodes and I-nodes can achieve power-savings using the power-management services of a CP
Physical Layer	· Frequency-Hopping in the unlicensed ISM band · Two transmit power levels are supported

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Feature	HomeRF Description
Data Rates	· Standard 800 kbps rate for Isochronous and Asynchronous data · 1.6 Mbps rate for Asynchronous data · 5 Mbps rate for Asynchronous data · 10 Mbps rate for Asynchronous data

3.3 Types of Data Service Supported

HomeRF provides four families of data service: Asynchronous data, Priority Asynchronous data, Isochronous data, and Isochronous connectionless broadcast data.

3.3.1 Characteristics of the Asynchronous Data Service

The *asynchronous data service* is provided by the HomeRF MAC layer. It provides the transport of data packets (MSDUs) between peer MAC entities.

The characteristics of the asynchronous data service are described in Table 5.

Table 5 - Characteristics of the Asynchronous Data Service

Characteristic	Description
Connectionless	There is no connection setup associated with using this data service
Reliability	Delivery of unicast MSDUs is generally reliable. Reliability does not degrade significantly with offered network load. Neither does it degrade significantly given realistic levels of radio interference. Delivery of multicast MSDUs is not reliable. Multicast MSDUs can be lost because of radio interference and, to a lesser extent, network load.
Delay	Transit delay is variable. It is affected by network load and radio interference. It is also affected if the destination MAC is power-saving.
Duplication	Unicast MSDUs can be duplicated as a result of packet loss and retry. The MAC layer contains an optional (but recommended) mechanism to detect the duplication of unicast MSDUs. If both transmitter and receiver support this mechanism, duplicate unicast MSDUs will be discarded within the MAC layer. Multicast MSDUs are not duplicated.
Order	The order of unicast MSDUs sent between two MAC entities is usually preserved. A MAC is not allowed to gratuitously re-order MSDUs, but re-ordering may occur as a result of power-saving.
MSDU Size	The maximum length of MSDU is *MaxMSDUlength.*
Throughput	Channel bit rates are 800kbps, 1.6Mbps, 5Mbps, and 10Mbps. MSDU throughput is less than this. It is reduced by the CSMA/CA protocol, by MAC beacons, by interference and collision. It is also reduced by isochronous data connections, any isochronous connectionless broadcast data, and priority asynchronous data, which take priority for bandwidth.
Priority	It has the lowest priority of the supported data services. Priority of the individual asynchronous data service packets is random based on the CSMA/CA backoff process.

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Time Reservation	Support for time reservation resulting from a single contention. This supports an MPDU sequence consisting of multiple MSDUs characterized by uniform MPDU Sequence format and modulation attributes.
Privacy	MSDUs may be encrypted, providing privacy of MSDU contents.

3.3.2 Characteristics of the Priority Asynchronous Data service

The HomeRF MAC supports a priority asynchronous data service. The characteristics of the priority asynchronous data service are described in Table 6.

Table 6 - Characteristics of the Priority Asynchronous Data Service

Characteristic	**Description**
Session-oriented	There is a session setup associated with using this data service
Reliability	Delivery of unicast MSDUs is generally reliable. Reliability does not degrade with offered network load, although priority service may be denied if bandwidth is not available. Nor does reliability degrade significantly given realistic levels of radio interference. Lower priority streams may be bumped if higher priority streams use their maximum time reservation. Delivery of multicast MSDUs is not reliable. Multicast MSDUs can be lost because of radio interference and, to a lesser extent, network load.
Delay	Transit delay is variable. In a non-TDMA network, with nominal conditions all priority streams are granted access every superframe (20 msecs).
Duplication	Unicast MSDUs can be duplicated as a result of packet loss and retry. The MAC layer contains an optional (but recommended) mechanism to detect the duplication of unicast MSDUs. If both transmitter and receiver support this mechanism, duplicate unicast MSDUs will be discarded within the MAC layer. Multicast MSDUs are not duplicated.
Order	The order of unicast MSDUs sent between two MAC entities is usually preserved. A MAC is not allowed to gratuitously re-order MSDUs, but re-ordering may occur as a result of power-saving.
MSDU Size	The maximum length of MSDU is *MaxMSDUlength.*
Throughput	Channel bit rates are 800kbps, 1.6Mbps, 5Mbps, and 10Mbps. MSDU throughput is less than this. It is reduced by the CSMA/CA protocol, by MAC beacons, by interference and collision. It is also reduced by isochronous data connections, which take priority for bandwidth.
Priority	It is prioritized lower than the isochronous data service and the isochronous connectionless broadcast data service. It is given priority over the asynchronous data service via assignment of priority access values, which are CSMA/CA backoff values that are lower than those generated randomly for the asynchronous data service. Priority of the individual priority asynchronous data service packets is fixed based on the priority access value assigned to the associated session.
Time Reservation	Support for time reservation resulting from a single contention. This supports an MPDU sequence consisting of multiple MSDUs characterized by uniform MPDU Sequence format and modulation attributes.

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Privacy	MSDUs may be encrypted, providing privacy of MSDU contents.

3.3.3 Characteristics of the Isochronous Data Service

The HomeRF MAC supports an isochronous data service. This is also known as the U-plane data service following DECT terminology[7][8]. This MAC-level service is used by the DECT DLC, NWK and IWU layers to provide the U-plane services that carry mainly interactive voice.

The characteristics of the isochronous data service are described in Table 7.

Table 7 - Characteristics of the Isochronous Data Service

Characteristic	**Description**
Connection-oriented	A connection setup is associated with using this data service
Reliability	Delivery of unicast SDUs is generally reliable, although not as reliable as the asynchronous data service. The protocol allows a single retry on a different radio channel, which contributes to reliability. Reliability is unaffected by offered asynchronous data network load.
Delay	Transit delay has a strict upper bound a little less than the subframe dwell interval. The delay varies between MAC connections because of the MAC-level retry scheme. The delay is constant for the lifetime of a connection.
Duplication	There is no duplication of isochronous SDUs
Order	The order of isochronous SDUs sent between two MAC entities is preserved.
MSDU Size	The isochronous data SDU size is constant at 40 bytes.
Throughput	One SDU per connection per subframe dwell interval in each direction.
Priority	It has the highest priority of the data services. A single packet is given dedicated bandwidth every subframe and dedicated bandwidth on the succeeding frame if a retransmission is required.
Privacy	Isochronous MPDUs can be encrypted, providing privacy of the Isochronous SDU contents.

The end-to-end U-plane services that the HomeRF architecture defines are described in Table 8.

Table 8 - U-plane Services Defined by the HomeRF Architecture

U-plane service	**Description**
PSTN Call	Voice connection between handset and a PSTN line
Intercom Call	Voice connection between two handsets
PC Call	Voice connection between handset and a host PC
Conferencing	Voice conferencing of multiple handsets onto an external

[7] The "U" in U-plane stands for "User", as it carries the user's data (voice).

[8] Although the C-plane data service (C-channel SDUs) has some differing attributes from the U-plane data service, as far as the characteristics of its TDMA access to the medium, it operates as an additional functionality of the isochronous data service.

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	or intercom call

3.3.4 Characteristics of the Isochronous Connectionless Broadcast Data Service

The HomeRF MAC supports an isochronous broadcast data service. This MAC-level service is used by the DECT DLC, NWK and IWU layers to provide the C-channel and U-plane services that carry broadcast messages, such as, I-node pages, cadence ringing, caller ID, and voice announcement.

The characteristics of the isochronous connectionless broadcast data service are described in Table 9.

Table 9 - Characteristics of the Isochronous Connectionless Broadcast Data Service

Characteristic	**Description**
Connectionless	This service is provided via a connectionless broadcast downlink[9] only channel.
Reliability	*Delivery of broadcast SDUs has limited reliability provided by duplicate transmission of frames (C-channel only). Error detection is provided for via CRC coverage, however, being connectionless, no error correction is provided. Reliability is unaffected by offered asynchronous data network load.*
Delay	Transit delay for U-plane data has an upper bound no greater than the subframe duration. Transit delay for C-channel data is not bound. [10]
Duplication	C-channel SDUs are not duplicated
SDU Priority	The relative order of transmission of queued C-channel SDUs is determined by a QoS priority parameter
Order	The order of isochronous connectionless broadcast U-plane SDUs sent between two MAC entities is preserved. The relative transit order of ICBS C-channel SDUs that have the same QoS is preserved. The relative transit order of ICBS C-channel SDUs that have a different QoS is not necessarily preserved.
MSDU Size	The ICBS C-channel SDU size is constant at 5 bytes. The ICBS U-plane SDU size is constant at 40 bytes.
Throughput	One C-plane SDU set (up to nine) per *ICBSRepeat* subframe dwell intervals. One U-plane SDU per subframe dwell interval.
Priority	It has the second highest priority of the data services. A single packet is given dedicated bandwidth every subframe except in the emergency case. In a subframe emergency case, no access to the subframe will be granted.
Privacy	Not supported

9 *i.e.* From the CP to the I-node

10 Because C-channel SDUs may be delayed by higher priority C-channel SDUs subsequently submitted for transmission.

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3.3.4.1 Uses of the ICBS (Informative)

Table 10 defines how the MAC-layer ICBS is used by higher layers in the HomeRF architecture.

Table 10 - ICBS uses in the HomeRF Architecture

Use	**Description**	**ICBS Service**
I-node paging	Addressing I-nodes for incoming calls	C-channel (QoS = medium priority)
Cadence ringing	Transport of incoming call PSTN ring stimuli to I-nodes	C-channel (QoS = high priority)
Caller ID	Transport of caller ID for an incoming call to I-nodes using DECT NWK CLMS procedures	C-channel (QoS = low priority)
Manufacturer-specific	Transport of manufacturer-specific data using the DECT NWK CLMS procedures	C-channel (QoS = low priority)
Voice announcement	Conveyance of broadcast voice messages (U-plane)	U-plane

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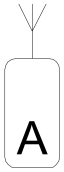
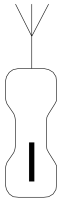
3.4 Network Topology

This section describes how HomeRF devices may be configured in different types of network.

3.4.1 HomeRF Device Types

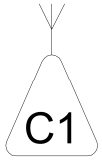
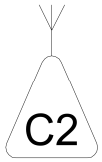
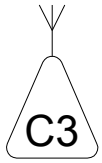
A HomeRF device is one of the node types described in Table 11. The "Icon" is used in network configuration diagrams below and has no other relevance. It is important to understand that a node type is an operational classification. A single device may be capable of simultaneously performing the functionality of different node types. This type of node, namely, AI and SI nodes, are a combination of individual node types. A combination node must support all of the functional capabilities that are required for each individual node type that is part of the combination. An AI node, for example, must support the CSMA access mechanism for the A-node functionality, and must support the TDMA access mechanism for the I-node functionality. Conversely, in the area of a node's performance capabilities, a combination node can choose to define itself solely with one of the individual node types that is part of the combination. For example, an AI node can define itself to perform as an I-node that also supports the functional capabilities of an A-node. Such an AI node would be required to support all functional capability and performance capability requirements of an I-node but would only be required to support the functional capabilities of an A-node. As an example, this AI node could choose not to support the *high-rate* modulation that is a mandatory performance capability of an A-node. A single device type may also be capable of being configured to perform the functionality of different node types at mutually exclusive times. For example, a single device may be configured to function as an A-node in order to operate as part of an ad-hoc network. It may later be configured to function as a CP that manages a network.

Table 11 - HomeRF Device Types

HomeRF Device Type	Description	Icon
A-node	*Asynchronous-node*: A HomeRF device that provides asynchronous data services. This type includes wireless network interface cards (NICs).	
S-node	*Streaming-node.* A HomeRF device that provides priority asynchronous and asynchronous data services. This type includes devices that stream real-time media, such as, audio and video.	
I-node	*Isochronous-node*: A HomeRF device that provides isochronous data (mainly interactive voice) services. This type includes cordless handsets.	
AI-node	A HomeRF device which provides both asynchronous and isochronous data services[11]	

[11] Note that procedures in this document refer generally to I-nodes and A-nodes. When a functional procedure is defined for an I-node or an A-node, it is implied that it shall also be followed by an AI-node. Performance procedures may or may not be supported.

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HomeRF Device Type	Description	Icon
SI-node	A HomeRF device which provides priority asynchronous, asynchronous, and isochronous data services[12]	
Class-1 Connection Point	A HomeRF device that provides management of I-nodes, S-nodes and A-nodes. It provides connectivity to the PSTN and a host PC. I-nodes access isochronous data terminating at the PSTN or PC. S-nodes access session setup services via a CP. Provides support for A-node power-saving. A-nodes access asynchronous data terminating at the PC. Class-1 CP includes base-stations used with cordless handsets, data access points and bridges.	
Class-2 Connection Point	A HomeRF device that provides management of S-nodes and A-nodes. S-nodes access session setup services via a CP. Provides support for A-node power-saving. It provides connectivity to a host PC, providing A-nodes with data access to the PC.	
Class-3 Connection Point	A HomeRF device that provides management of S-nodes and A-nodes S-nodes access session setup services via a CP. Class-3 CP does not support A-node power-saving	

3.4.1.1 Active and Passive CPs

In addition to its class (which never changes), a connection-point may be either active or passive. A CP may transition between active and passive states because of the operation of the MAC-level CP assertion procedures.

The effect of this on the behavior of a CP is defined in Table 12.

Table 12 - CP Passive Behavior

Connection Point Class	Passive Behavior
Class 1	Each Class-1 CP manages its own network. Passive operation of a Class-1 CP is not supported. A class 1 CP will always be active, following the operation of the initial CP assertion procedure (see section 5.17.8 (Connection Point Negotiation)) during its startup.

[12] Note that procedures in this document refer generally to I-nodes and S-nodes. When a functional procedure is defined for an I-node or a S-node, it is implied that it shall also be followed by a SI-node. Performance procedures may or may not be supported.

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Class 2	Operates MAC-level CP assertion procedures (section 5.17.8 (Connection Point Negotiation)) A-nodes, S nodes, and I-nodes are unaware of the existence of passive CPs. [13] In particular, CPs do not provide any management services to other nodes while in the passive state. Passive CPs can continue to provide asynchronous data services and priority asynchronous data services (as managed by the active CP) to their host PC.
Class 3	Operates MAC-level CP assertion procedures (section 5.17.8 (Connection Point Negotiation)) A-nodes, S nodes, and I-nodes are unaware of the existence of passive CPs. [14] In particular, CPs do not provide any management services to other nodes while in the passive state. Passive CPs can continue to provide asynchronous data services and priority asynchronous data services (as managed by the active CP) to their host PC.

3.4.1.2 Switching between Class-1, Class-2, and Class-3 Behavior (Informative)

This document does not specify any mechanism that allows a CP to change between Class-1, Class-2, and Class-3 behavior.

It might be possible for a manufacturer to design such a device. This document does not say whether this is possible.

3.4.1.3 HomeRF Bridges and Bridge-Aware Nodes

An A-node, S-node, or CP can act as a bridge between the HomeRF network and some other network technology. Such a device is known as a *HomeRF Bridge* (HB). A HB shall support the procedures defined in section 11.6 (Bridging Layer Procedures).

Every A-node, S-node and CP shall support the operation of one or more possible HB devices by supporting the procedures defined in sections 5.12.4 (MD-SAP Header) and 5.4.10.3 (Capabilities). Such a device is known as a *Bridging-Aware Node* (BAN).

3.4.2 Supported Configurations of HomeRF Nodes

The services available in a network depend on what kinds of HomeRF devices are present.

The following configurations are recognized and defined in the following sections:

- Class-1 Managed
- Class-2 Managed
- Class-3 Managed
- Ad-hoc
- Bridged

[13] An A-node is unaware of any difference between a passive CP and an A-node. The A-node can exchange asynchronous data with the passive CP as though it were an A-node.

[14] An A-node is unaware of any difference between a passive CP and an A-node. The A-node can exchange asynchronous data with the passive CP as though it were an A-node.

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3.4.2.1 Class 1 Managed Network

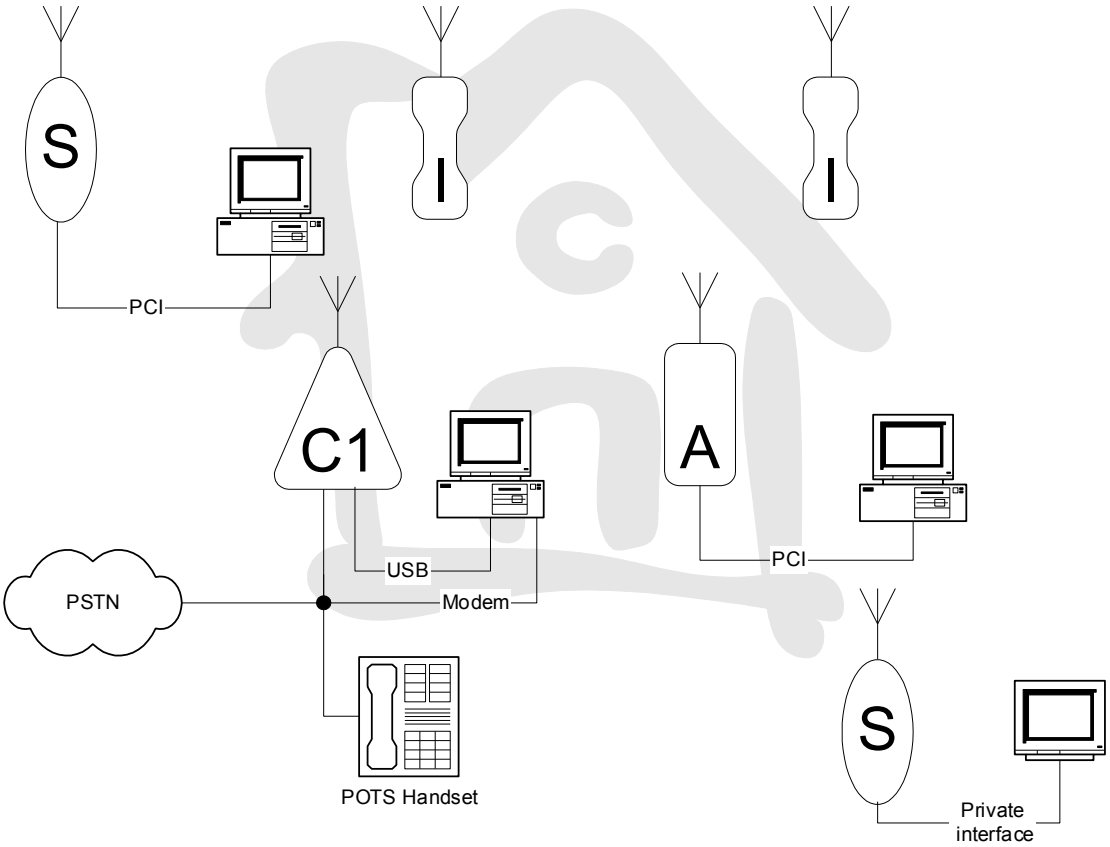


Figure 1 - Example Class-1 Managed Network

Figure 1 shows a typical *Class-1 managed network*. This example network includes two I-nodes (cordless handsets), two S-nodes, a Class-1 Connection-point and an A-node. Other network configurations are possible, provided they meet the requirements of Table 13.

The incoming PSTN line is connected to the Connection-point to handle voice calls. It is also connected to a modem in the PC to provide Internet connectivity, and to a wired handset. The C1 connected PC and the A-node connected PC is networked together using the HomeRF asynchronous data service. The two S-nodes are networked together using the priority asynchronous data service. The CP manages any active streams between the two S-nodes.

Parallel connection of a Connection-point, wired handset and PC modem is possible. It would also be possible to build the modem and wired handset into a Connection-point. How to do either of these is outside the HomeRF architecture, and therefore beyond the scope of this specification.

A Class-1 managed network includes the nodes specified in Table 13.

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Table 13 - Nodes within a Class-1 Managed Network

Node	Role
A single Class-1 CP	Provides connectivity to the PSTN and the PC. Provides power-management services for A-nodes. Provides streaming session management in support of the priority asynchronous data service.
Zero or more Class-2 and Class-3 CPs	These will be operating as passive CPs. In the event of a failure of the Class-1 CP, one of these CPs will take over as the active CP to provide A-node power-management services. In that case the network becomes a Class-2 Managed Network.
Zero or more A-nodes	Users of the MAC asynchronous data service
Zero or more I-nodes	Users of the isochronous data services
Zero or more S-nodes	Users of the priority asynchronous data services

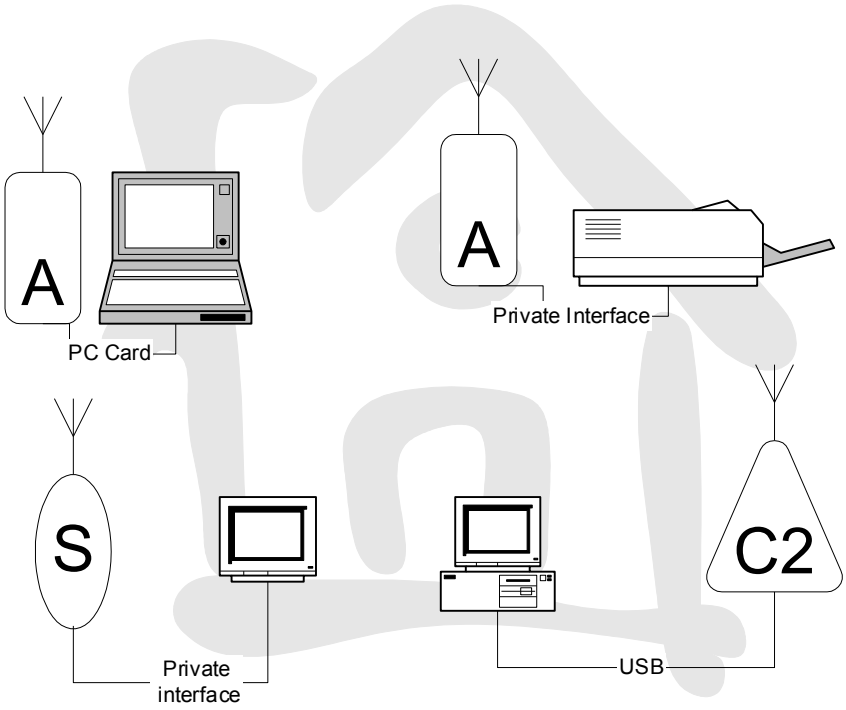
The Class-1 CP manages the network, and provides connections to its host PC (if configured) and one or more PSTN lines.

I-nodes use the isochronous data service to communicate with other I-nodes, a PSTN line, or the connection-point's PC. They can also receive connectionless broadcast messages from the CP via the isochronous connectionless broadcast data service.

A-nodes use the asynchronous data service to exchange asynchronous data with each other and the connection-point's PC. A-nodes can operate power-saving procedures, under the management of the CP.

S-nodes use the priority asynchronous data service to exchange streaming data with each other and the connection-point's PC. S-nodes use the CP to manage streaming sessions.

3.4.2.2 Class 2 Managed Network



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Figure 2 - Example Class-2 Managed Network

Figure 2 shows a typical Class-2 Managed Network.

A *Class-2 managed network* includes the nodes specified in Table 14.

Table 14 - Nodes within a Class-2 Managed Network

Node	**Role**
One or more Class-2 CPs	One will be operating as an active Class-2 CP, providing power-management services to A-nodes and S-nodes. Also, provides streaming session management in support of the priority asynchronous data service. Any remaining CPs will be operating as passive CPs.
Zero or more Class-3 CPs	These will be operating as passive CPs.
Zero or more A-nodes	Users of the MAC asynchronous data service
Zero or more S-nodes	Users of the MAC priority asynchronous data service

A Class-2 CP manages the network, and provides a connection to a host PC (if configured).

A-nodes use asynchronous data services to exchange connectionless data with each other and the connection-point's PC. A-nodes can operate power-saving procedures, under the management of the CP.

S-nodes use the priority asynchronous data service to exchange streaming data with each other and the connection-point's PC. S-nodes use the CP to manage streaming sessions.

3.4.2.3 Class-3 Managed Network

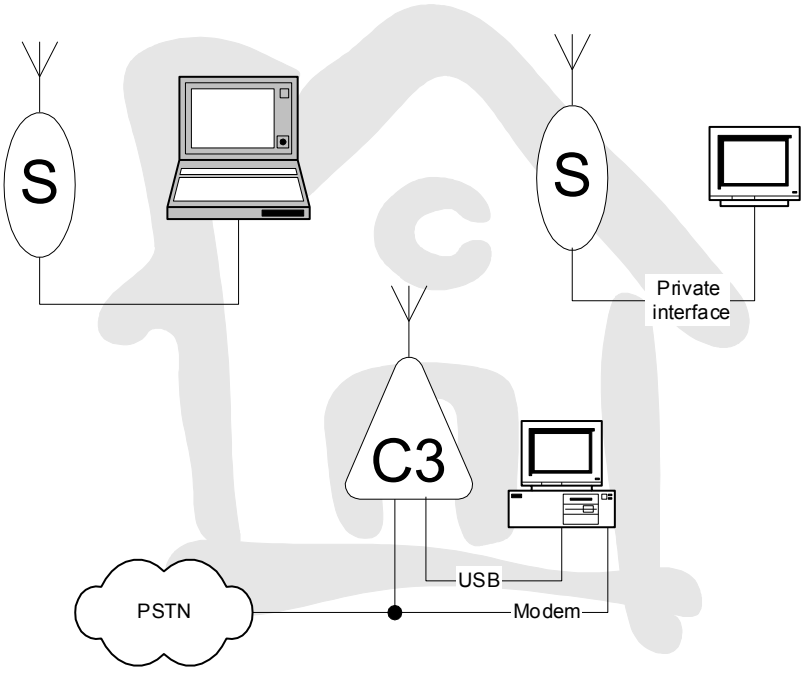


Figure 3 - Example Class-3 managed network

A *Class-3 managed network* includes the nodes specified in Table 15.

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Table 15 -Class-3 managed network

Node	Role
One or more Class-3 CPs	One will be operating as an active Class-3 CP, providing streaming session management in support of the priority asynchronous data service. Any remaining CPs will be operating as passive CPs.
Zero or more A-nodes	Users of the MAC asynchronous data service
Zero or more S-nodes	Users of the MAC priority asynchronous data service

A Class-3 CP manages the network, and provides a connection to a host PC (if configured).

A-nodes use asynchronous data services to exchange connectionless data with each other and the connection-point's PC.

S-nodes use priority asynchronous data services to exchange streaming data with each other and the connection-point's PC. S-nodes use the CP to manage streaming sessions.

Class-3 managed networks will most often be self-contained media networks. In such instances there will be a CP, media servers, and media receivers. The CP may be self-contained, part of the media server, or part of a PC.

3.4.2.4 Ad-hoc Network

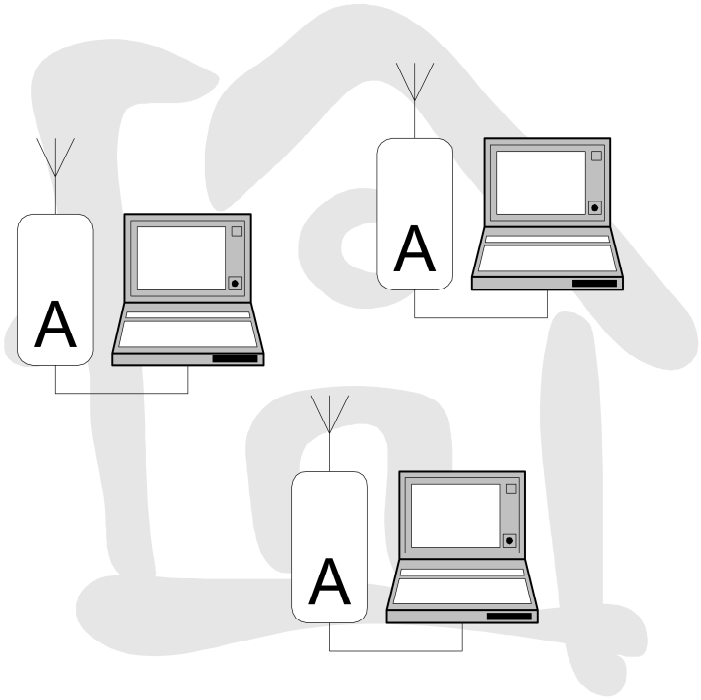


Figure 4 - Example Ad-hoc HomeRF Network

Figure 4 shows a typical ad-hoc network.

An *ad-hoc network* includes the nodes specified in Table 16.

Table 16 - Nodes within an Ad-hoc Network

Node	Role
One or more A-nodes	Users of the MAC asynchronous data service. The A-nodes all operate the ad-hoc procedures defined in ref 5.16.17, sharing the responsibility for beacon generation and synchronization.

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	There is no support for A-node power-saving.

An ad-hoc network is likely to be formed dynamically and run for a short time. This is because nodes in an ad-hoc network are not able to save power. An example of ad-hoc network is the network formed during a meeting in which the participants use PCs equipped with A-nodes to exchange data. Fixed networks are likely to include a CP, and so will not be ad-hoc networks.

3.4.2.5 Bridged Network

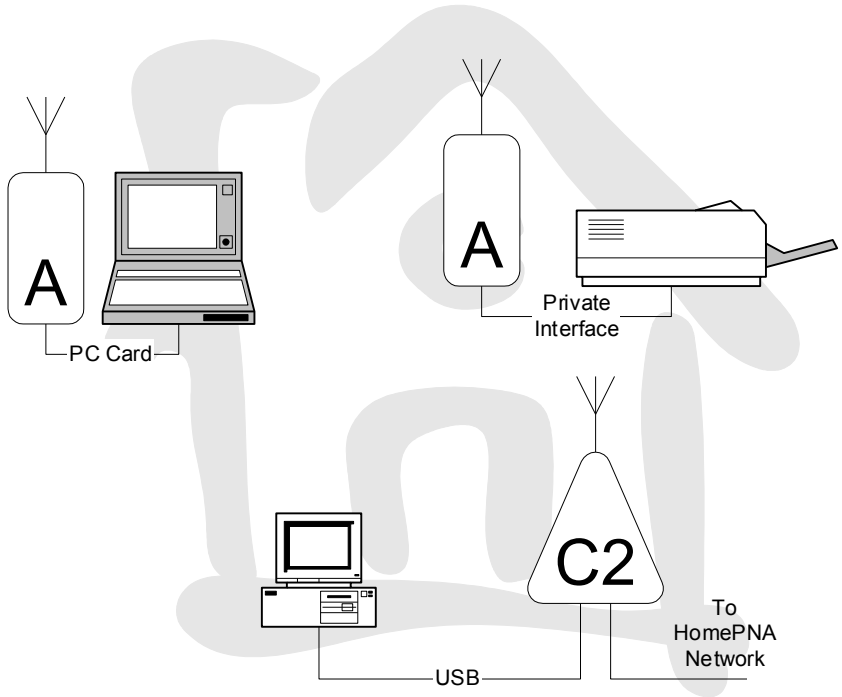


Figure 5 - Example Bridged Network

A *Bridged* network contains one or more HomeRF bridges (HB). A Class-1 CP, Class-2 CP, Class-3 CP, A-node, or S-node can be a HB. The *Bridged* characteristic of the network is independent of the Class-1 Managed, Class-2 Managed, Class-3 Managed, or Ad-hoc characteristic of a network.

Figure 5 shows a typical bridged network. A Class-2 CP is acting as a bridge between the HomeRF network and a HomePNA network. The other devices in the bridged network are bridging-aware nodes that support the operation of the bridge. Devices in the HomePNA network can exchange MAC frames with devices in the HomeRF network through the HB.

3.5 HomeRF Architecture

To support the specification process, the HomeRF architecture is defined in terms of a number of blocks, each of which is responsible for some part of the HomeRF specification.

The interfaces between the blocks are defined in terms of the services that each block offers to its client or higher layers.

These interfaces between architecture blocks are logical interfaces. They are not exposed outside a HomeRF product, so the manufacturer is free to implement them, or even re-define internal architectural boundaries, in any convenient way.

3.5.1 Introduction to HomeRF Architecture

The HomeRF architecture consists of:

- A physical (PHY) layer (radio, modem),
- A medium access controller (MAC) layer that provides four broad classes of data service

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- A HomeRF-profiled version of the DECT GAP DLC, network (NWK) and Interworking Unit (IWU) layers
- A voice interface
- A PC interface

Not all HomeRF device types include all of theses architecture blocks. The behavior of the architecture blocks can also vary between device types.

3.5.1.1 Compatibility with DECT

The HomeRF MAC provides connectionless and connection-oriented data services that are similar to those provided by the DECT MAC. It defines an isochronous connectionless broadcast service to support I-node paging, cadence ringing, caller ID and voice announcement.

To provide the connection-oriented services, the MAC uses a TDMA mechanism in which pairs of slots are allocated to a connection between a CP and an I-node. The isochronous connectionless broadcast service is provided using a transient connectionless TDMA slot.

The implementation of the MAC services differs from DECT MAC. However, because the services it provides are similar, the DECT higher layers (DLC, NWK and IWU) can be hosted on the HomeRF MAC with little modification. The use of the DECT protocol enables the HomeRF network to support call setup for the isochronous data service and to interoperate, through a Connection Point, with the PSTN.

The DECT Generic Access Profile (GAP) [11] specifies the minimum procedures and functionality required to implement a speech call in a DECT network. The HomeRF DECT profile is defined by reference to the DECT GAP, modified where necessary in this specification. Refer to section 6 (DECT DLC and NWK Layers).

3.5.2 A-node Architecture

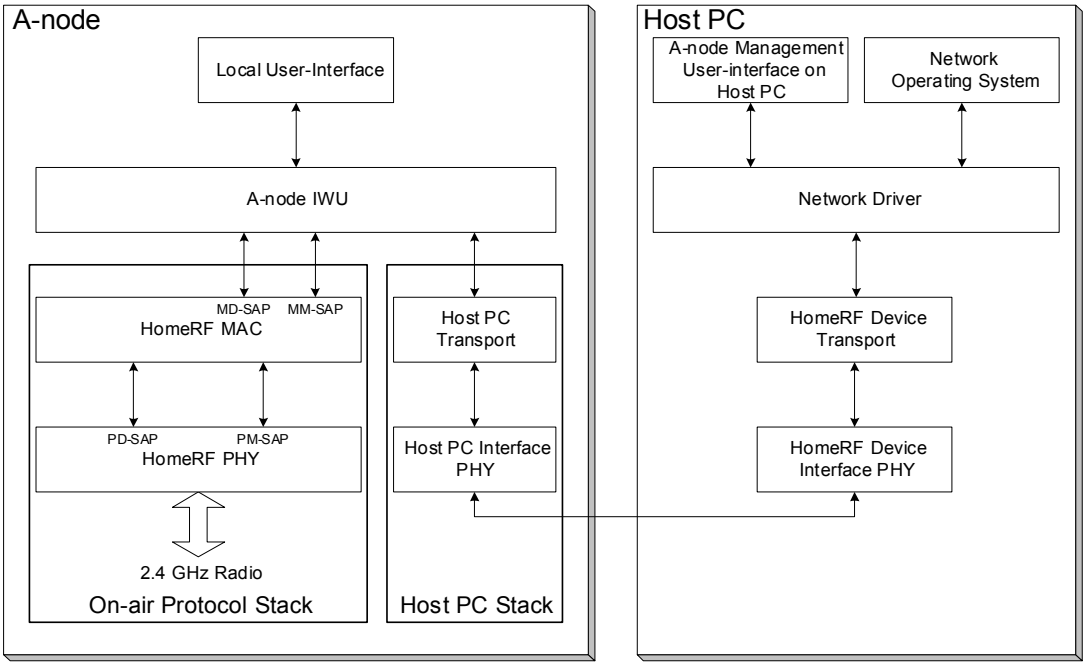


Figure 6 - A-node Architecture

The A-node architecture includes a management user-interface (probably split between a local user-interface and an application on a host PC), a radio interface and an interface to an A-node host device.

Figure 6 shows the A-node client as a host PC connected via some separate physical interface. There are other possible clients, and other possible forms of interface. HomeRF does not specify any mandatory form of interface to the host PC.

An A-node can be integrated into a PC, or some other device, in which case that device must provide all the HomeRF A-node mandatory user-interface requirements.

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In the A-node, the IWU provides support for management of the device and routes primitives between the host PC interface and the other architecture blocks. Its main function is to export the MD-SAP's asynchronous data service into the client device.

3.5.3 S-node Architecture

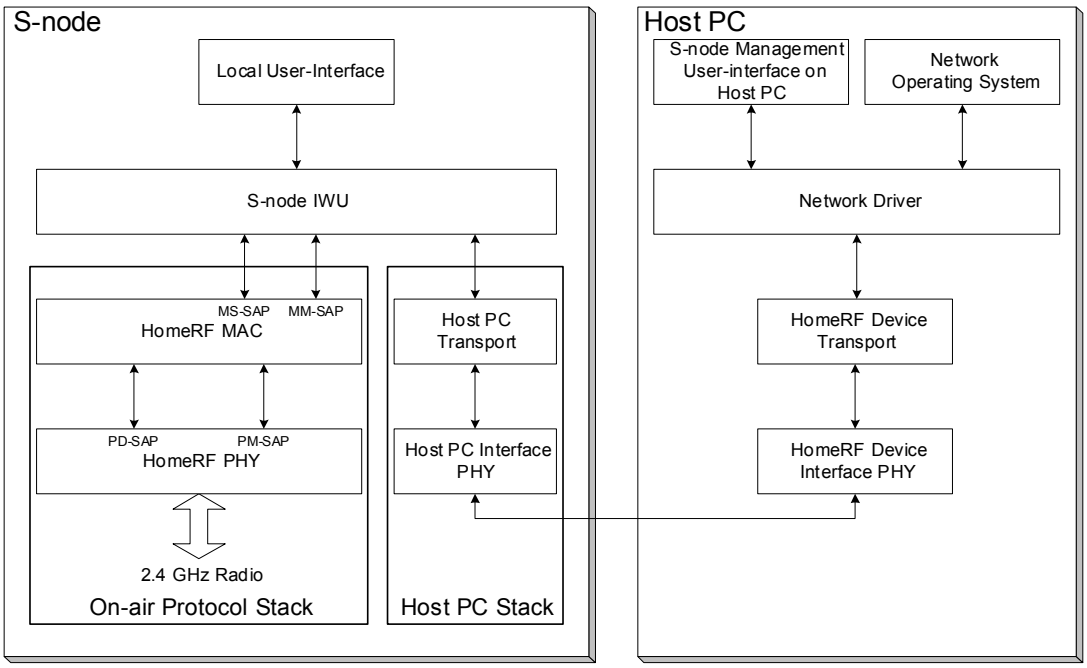


Figure 7- S-node Architecture

The S-node architecture includes a management user-interface (probably split between a local user-interface and an application on a host PC), a radio interface and an interface to an S-node host device.

Figure 6 shows the S-node client as a host PC connected via some separate physical interface. There are other possible clients, and other possible forms of interface. HomeRF does not specify any mandatory form of interface to the host PC.

An S-node can be integrated into a PC, or some other device, in which case that device must provide all the HomeRF S-node mandatory user-interface requirements. It is assumed that S-nodes will often not have a PC as client, but instead will be part of a self-contained consumer electronics product such as a TV capable of handling streaming video.

In the S-node, the IWU provides support for management of the device and routes primitives between the host PC interface and the other architecture blocks. Its main function is to export the MS-SAP's priority asynchronous data service into the client device.

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3.5.4 I-node Architecture

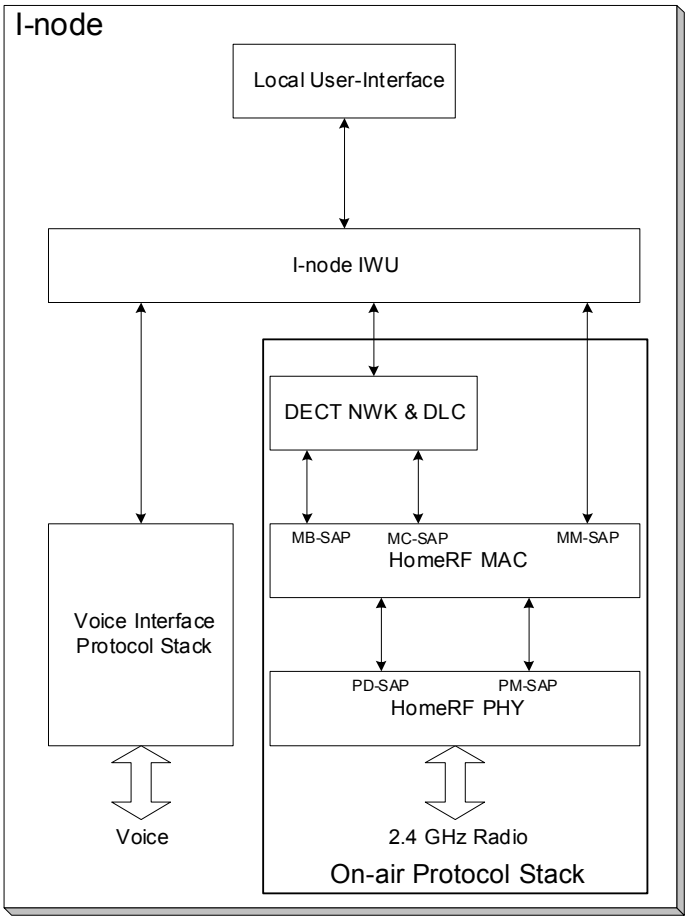


Figure 8 - I-node Architecture

The I-node consists of a user-interface, a *Voice* protocol stack, an *On-air* protocol stack and an *Interworking Unit* to tie them all together.

The IWU has two main functions: to operate the DECT/HomeRF IWU procedures, and to route isochronous data between the voice and on-air protocol stacks.

The on-air protocol stack includes the DECT PP NWK and DLC components profiled by the DECT GAP [11] and modified by section 6 (DECT DLC and NWK Layers). It includes the HomeRF MAC to provide the isochronous data and connectionless broadcast data services.

The U-plane architecture is described separately in section 3.5.5.4.

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3.5.5 CP Architecture

3.5.5.1 Class-1 CP (Separate)

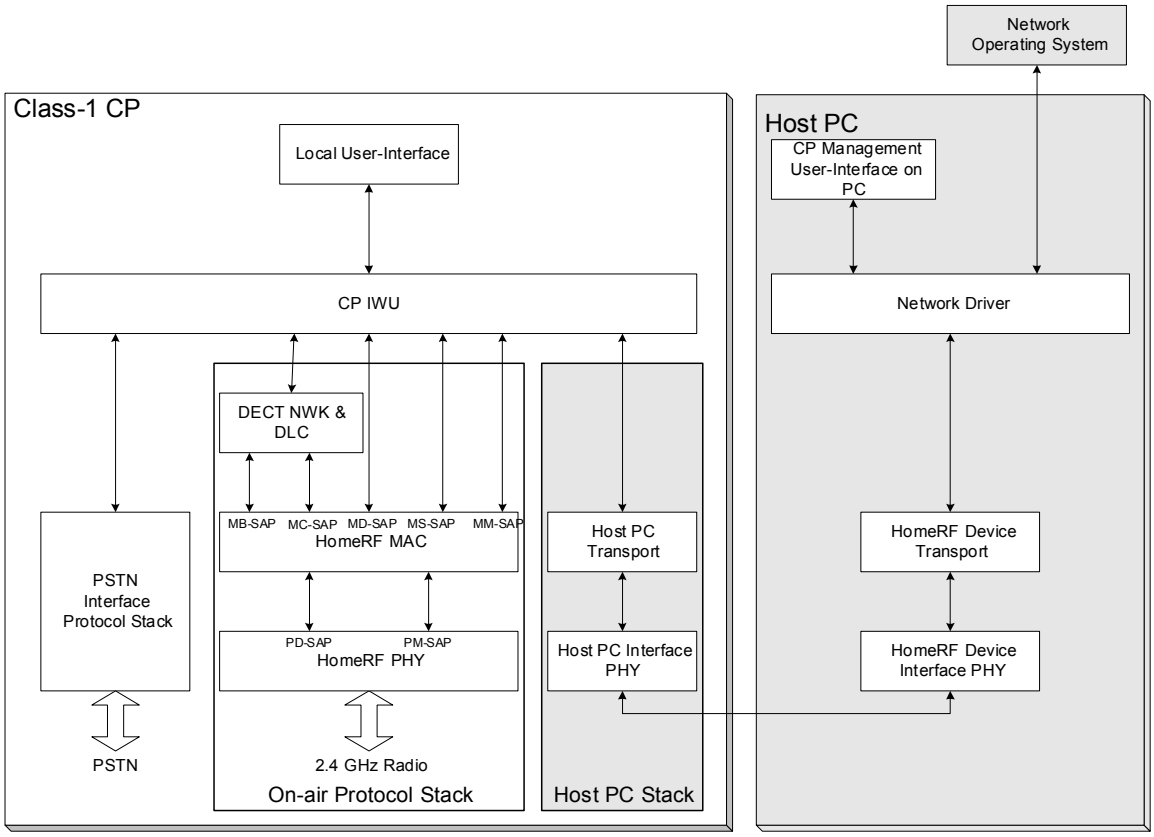


Figure 9 - Class-1 CP Architecture (Separate)

Figure 9 shows the architecture of a Class-1 CP that is connected by a clearly defined physical interface between the CP and a host PC. The shaded areas delineate the architectural elements required to support the host PC and would not be present if a host PC was not configured.

The CP is required to support a defined level of functionality if the Host PC is not connected/operational (see section 12.7 (CP Requirements)).

The CP contains a management user-interface (potentially split between a PC application and a user-interface which is built into the CP), an interface to a host PC, an interface to the radio medium and an interface to a PSTN line.

Linking these together is the Interworking Unit (IWU). This operates interworking procedures that ensure that, for example, an I-node call into the PC is routed properly.

Not shown on Figure 9 are all the U-plane architectural blocks. The U-plane architecture is described separately in section 3.5.5.4.

The blocks identified above are described below in more detail (sections 3.5.7 to 3.5.11).

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3.5.5.2 Class-1 CP (Integrated)

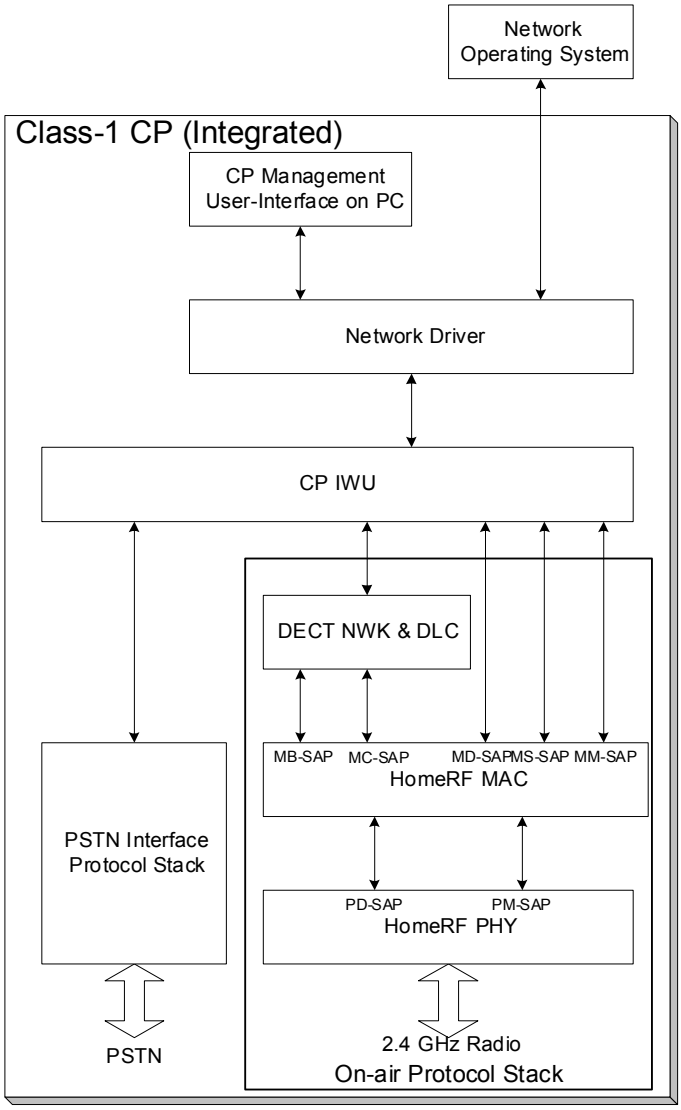


Figure 10 - Class-1 CP (Integrated)

Figure 10 shows the architecture of a Class-1 CP that is integrated into a Host PC. The host network driver can communicate directly with the HomeRF CP IWU.

The *separate* CP potentially splits the user-interface into a "local" and an "on PC" component. The *integrated* CP presents only a single user-interface. It is tightly coupled to its host PC. It could be a plug-in adapter card, or it could be integrated onto the PC's motherboard. The user perceives that the PC *is* the connection-point.

The integrated CP is still required to support mandatory CP procedures, even when the PC appears to be switched off. Refer to section 12.7.

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3.5.5.3 Class-2 CP

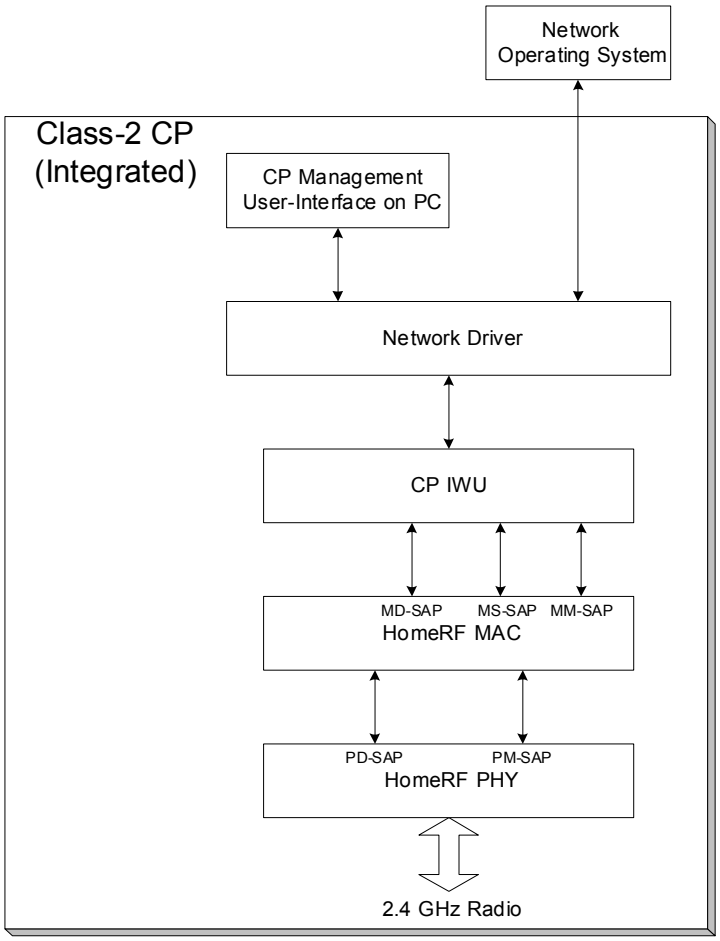


Figure 11 - Class-2 CP (Integrated)

In addition to providing asynchronous data services, like an A-node, and priority asynchronous data services, like a S-node, the Class-2 CP provides power management services for A-nodes and S-nodes in the network.

In architectural terms, a Class-2 CP is a subset of the Class-1 CP. The MAC layer connection-oriented data services and the connectionless broadcast data services accessed through the MC-SAP and MB-SAP respectively are not present.

There is no DECT protocol stack, and the IWU is much simplified.

As is the case for the Class-1 CP, it is possible for a Class-2 CP to be implemented as a separate hardware device or tightly integrated into a host PC.

3.5.5.4 Class-3 CP

Class-3 CPs are a subset of Class-2 CPs. All Class-2 CP services are handled by Class-3 CPs except for A-node power management services.

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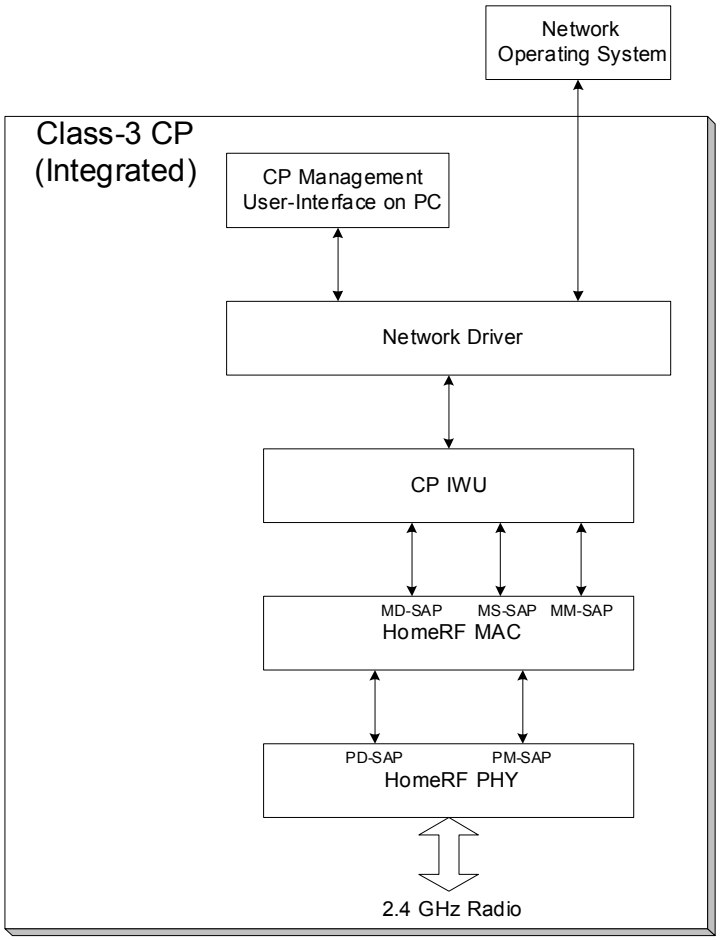


Figure 12 - Class-3 CP (Integrated)

3.5.6 U-Plane Architecture

The U-plane is concerned with the flow of isochronous data through the HomeRF architecture.

The U-plane data passes transparently through the DECT DLC and NWK layers. It then passes through the On-air Voice Processor and the IWU that can provide additional HomeRF functionality. Together the whole stack provides U-plane services.

It should be stressed that these architecture diagrams are intended only to present as clearly as possible the relationships between the HomeRF architectural blocks. A hardware implementation will undoubtedly be designed very differently, but it will still provide the same end-end functionality.

3.5.6.1 I-node U-Plane Architecture

The simplest U-plane architecture is that of the I-node.

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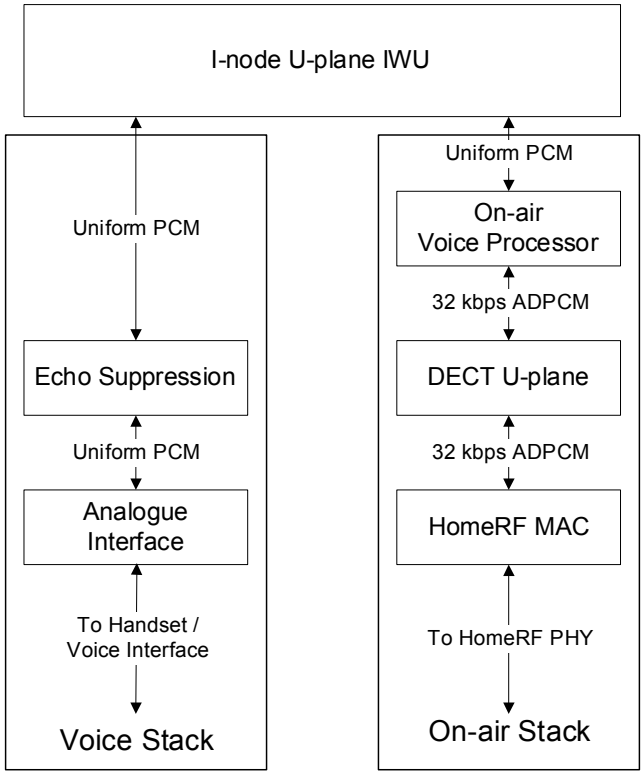


Figure 13 - I-node U-plane Architecture

Once a connection-oriented U-plane has been established and enabled or an ICBS U-plane has been enabled, the HomeRF MAC isochronously transports fixed-size packets of U-plane data. These provide a constant 32kbps U-plane data service at the top of the HomeRF MAC. The DECT NWK and DLC layers transport the U-plane packets without modification. The On-Air Voice Processor converts between 32kbps ADPCM and Uniform PCM (14-bit / sample linear PCM).

The connection-oriented U-plane is duplex and point-point. The ICBS U-plane is simplex and broadcast from CP to I-node.

These components form the I-node's *On-air* stack.

The IWU trivially routes uniform PCM-encoded audio between the top of the *On-air* stack and the top of the voice stack.

The voice stack consists of an interface to the audio transducers (speaker and microphone) and optional echo suppression. The echo suppression may be required to keep the audio coupling between speaker and microphone below a specified value (see section 7.4.1), and it depends on the acoustic design of the I-node "handset".

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3.5.6.2 Class-1 CP U-Plane Architecture

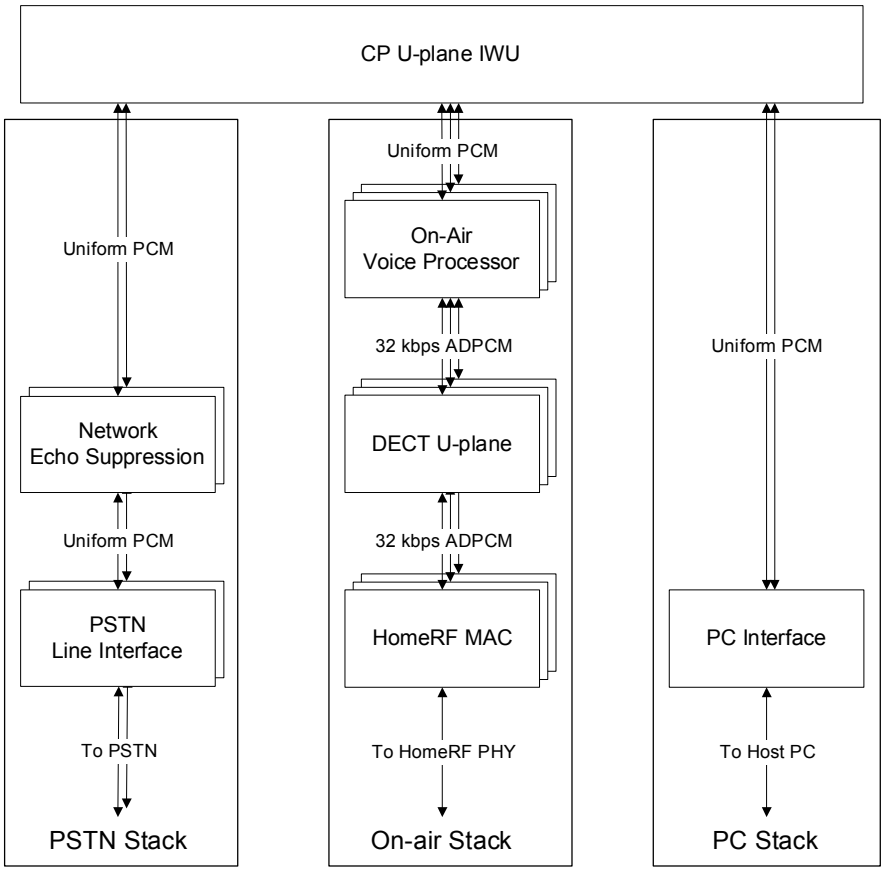


Figure 14 - Connection-Point U-plane Architecture

In the CP, in the U-plane there are three vertical protocol stacks, each of which provides a uniform PCM-encoded full-duplex connection-oriented interface at the top.

The PSTN stack provides connections to one or more PSTN lines. At the bottom is an electrical interface to the PSTN line, and a uniform PCM codec. Above this is a block that provides network echo suppression. This block may vary between a simple suppressor and an echo canceller depending on the amount of echo introduced by the PSTN line and the electrical interface to it. The purpose of the suppressor is to provide an acceptable attenuation of any delayed sidetone returned to the I-node via the On-air Stack.

The On-air stack provides connections to I-nodes. Each connection is a full-duplex isochronous channel to a single I-node. The stack consists of the HomeRF MAC that, by sending and receiving TDMA MPDUs once a subframe dwell, provides a 32 kbps ADPCM connection.

The On-air stack also provides a broadcast simplex (CP to I-node) isochronous channel. The HomeRF MAC supports this ICBS channel by transmitting a TDMA MPDU once per subframe, providing a 32 kbps ADPCM channel.

The 32 kbps ADPCM passes unchanged through the DECT DLC and NWK layers. At the top of the stack sits the On-Air Voice Processor that converts between the On-Air format and uniform PCM.

The PC stack provides one or more U-plane connections to the host PC connected to the CP.

The IWU provides a routing and mixing function. It supports the functions described in Table 17.

Table 17 - U-plane IWU Functions Supported by a Class-1 CP

CP U-plane IWU function	Description
PSTN Call	Connects a PSTN connection to a single On-air connection

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PSTN Conference Call	Connects multiple on-air connections to a single PSTN connection
Intercom Call	Connects two on-air connections together
Intercom Conference Call	Connects more than two on-air connections together
PC Call	Connects an on-air call to the Host PC

It may also support additional routing functions, such as routing a PSTN call into the PC. Such additional functions are beyond the scope of this specification.

The purpose of this architecture is to support a clear description of HomeRF behavior. An implementation would probably have a very different architecture. For example, as drawn above, an intercom call requires two back-to-back ADPCM transcoders connected by a uniform PCM interface. While it is necessary to pass through an ADPCM transcoder for an intercom conference call, it is not necessary for a non-conferenced intercom call. Therefore, an implementation is free to connect an intercom call by routing 32 kbps ADPCM between handsets without going to and from uniform PCM.

3.5.7 Voice / PSTN Interface Stack

At the top of this stack are connection-oriented streams of uniform PCM-encoded duplex audio or connectionless broadcast streams of uniform PCM-encoded simplex audio, plus control over the hardware device at the bottom of the stack.

An I-node supports only a single connection. A Class-1 CP might support more.

3.5.7.1 I-node Echo Cancellation

This provides cancellation of the audio feedback between an I-node's speaker and microphone in order to meet the requirement on minimum terminal coupling loss in the I-node.

3.5.7.2 Network Interface and Network Echo Cancellation

This provides cancellation of the delayed sidetone resulting from echo introduced by the interface to the PSTN network and from the PSTN network itself.

The amount of echo introduced by the interface to the PSTN network varies with the type of interface. A digital interface to the PSTN or a 4-wire interface to the POTS introduces little or no additional echo. In this case, a small amount of echo cancellation or suppression is sufficient to reduce the network echo to levels that can be tolerated by a HomeRF I-node user.

A 2-wire interface to POTS introduces an unavoidable large echo that appears as a delayed sidetone to the handset. This echo would not be a problem for a wired handset connected directly to the POTS, because there is no perceptible delay. However, it is a problem for an I-node due to the roughly 40ms round-trip transit delay introduced by the protocol. Therefore, in a 2-wire interface, the CP is required to include echo cancellation of network interface echo. Refer to section 7.4.2.

3.5.7.3 Voice / PSTN Interface

The *Voice / PSTN interface* provides conversion between the external voice signals and uniform PCM. It also supports control of the external line interface.

An I-node provides an interface to acoustic transducers (speaker and microphone). This interface includes a PCM codec and some simple analogue circuitry. The number of bits resolution in the PCM samples is not defined in this specification.

The PSTN interface supports a wider range of external line interfaces (e.g. POTS, ISDN …). It supports potentially more than one external line. There will be additional signals controlling the external line interface. These signals are described in Table 18.

Table 18 - Voice / PSTN Interface Control Signals

Signal	**Description**
Ring Indication	Incoming signal indicates that there is an incoming call
Hook Control	Outgoing signal to connect to and disconnect from the PSTN line

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3.5.8 On-Air Stack

The On-air stack provides isochronous connection-oriented and connectionless broadcast data services as well as asynchronous connectionless data services to the IWU. It includes the higher layers of the DECT protocol stack, profiled for use in the HomeRF environment that provide control of isochronous calls. It includes a MAC layer that determines who can transmit and when. It includes a physical layer that transmits and receives in the 2.4 GHz radio band.

3.5.8.1 On-Air Voice Processor

This module converts between the 32 kbps ADPCM voice encoding which appears in MAC voice frames and the Uniform PCM encoding used in the IWU, Voice and PC stacks.

3.5.8.2 DECT NWK & DLC

The DECT NWK and DLC layers are defined in the DECT standards [3]-[11] and profiled for use by HomeRF in section 6 (DECT DLC and NWK Layers).

The network layer provides three main functions: mobility management, call control, and connectionless messaging.

Mobility management supports I-node subscription (initial registration on a CP) and location registration (knowing which I-nodes are able to receive calls). It also supports I-node authentication and the generation of derived cipher keys to be used for the encryption of an isochronous call.

Call-control controls signaling of call setup (and call release). It responds to a call-setup request from the IWU and, sets up a DLC connection to carry the call.

Connectionless messaging provides a connectionless broadcast service in support of features, such as, I-node paging, cadence ringing, caller ID delivery, and voice announcement. CLMS fixed messages are converted into one or more 5 byte SDUs and passed on to the DLC. CLMS variable messages can be encoded into the payload of CLMS fixed messages.

The DECT DLC layer provides a reliable link to carry connection-oriented (C-Channel) DECT signaling between DECT network layer entities. It converts large variable-length NWK-layer PDUs into its own short fixed-length PDUs suitable for presentation to the MAC layer.

3.5.8.3 HomeRF MAC

The HomeRF medium access control layer defines procedures that determine access to the radio medium. These procedures provide TDMA priority access for isochronous data. CSMA priority access (Priority Asynchronous Data Service) is provided for streaming data.

The MAC provides the services described in Table 19.

Table 19 - HomeRF MAC Services

Service	SAP	Description
ICBS	MB-SAP	The Isochronous Connectionless Broadcast service supports simplex transport of C-channel SDUs (used by higher layers for paging and connectionless data) and U-plane SDUs (used for voice announcement).
TDMA connection-oriented	MC-SAP	Connection setup and release. Connection-oriented data. Connection-oriented asynchronous data is provided by the C-channel to support higher layer signaling. Connection-oriented isochronous data supports the DECT U-plane service.
Connectionless data	MD-SAP	Connectionless data transmit and receive
Session Oriented Priority Asynchronous Data Service	MS-SAP	Streaming session establishment and destruction. Priority asynchronous data
Management	MM-SAP	Supports control of the MAC-layer management

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		procedures such as scanning for a network and providing access to MAC managed objects

The HomeRF MAC also provides the management features described in Table 20.

Table 20 - HomeRF MAC Management Features

Feature	Description
Network	Starting, scanning-for, joining a network. Finding and roaming to roaming capable associated networks within an extended network.
Power-saving	Reducing power consumption.
Synchronization	Keeping a common time-reference used to operate the hop pattern, and to prioritize access to the radio medium.
Managed Objects	Supports access to parameters within the MAC to allow control of the operation of the MAC, and to provide management information to higher layers (such as statistics)

3.5.8.4 HomeRF PHY

The HomeRF physical layer (PHY) provides the transmission and reception of PHY service data units (PSDUs) in the 2.4 GHz ISM band, using LR 2-FSK, LR 4-FSK, HR 2-FSK, or HR 4-FSK modulation.

The PHY is responsible for data-whitening in one of two forms: TDMA and CSMA. TDMA whitening uses only a simple DECT-derived scrambler. CSMA data-whitening uses bit-stuffing and an advanced scrambling algorithm.

The HomeRF physical layer is defined in section 4 (Physical (PHY) Layer).

3.5.9 The PC Stack and Network Driver

The PC stack and network driver provide a means for the network driver to communicate with the IWU across the electrical interface between the HomeRF device and the PC.

The network driver is provided by the CP manufacturer, and is considered part of the CP, for the purpose of the HomeRF CP architecture.

The network driver exports the functionality of the CP using well-defined operating system APIs. The network driver may be provided with a manufacturer's CP, or may be distributed with the operating system. The network driver can also export functionality to be used by a management application through a private interface.

This specification does not define how the PC stack works. It does describe the functionality that shall be made available to the host driver across the PC stack.

3.5.9.1 PC Stack Implementation (Informative)

Typical electrical interfaces are: USB, PCI, PC Card.

A typical implementation of the PC stack includes:

- A hardware component that provides access to the physical layer;
- A hardware driver that communicates with the hardware, and turns I/O (input/output) software requests into hardware control data-structures and register accesses;
- A software layer above the hardware driver to turn primitives exported to the IWU into I/O requests

3.5.9.2 Network Driver

A network driver operating under the Microsoft Windows operating system shall export the interfaces defined in section 14).

The network driver exports the services described in Table 21.

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Table 21 - Network Driver Services

Network Driver Service	Description
Connectionless data	Connectionless data, Ethernet frame format
Session-oriented data	Session-oriented data, Ethernet frame format
Isochronous Connectionless Broadcast data	CLMS C-plane and Voice Announcement U-plane transmission. There is no specification of this interface in this document.
Connection-oriented data	Isochronous data connections
DECT signaling	Access to some of the DECT messages at the top of the DECT NWK stack
PSTN interface	Access to PSTN events and control of the PSTN connection
IWU control	Call setup control and U-plane routing
Management	Implementation-specific private interface allowing non-standard management features to be accessed. There is no specification of this interface in this document.

3.5.10 User-Interface

The user-interface supports the operation of user-interface procedures defined in this document.

A HomeRF device that is physically separate from a host PC may have its own user-interface (such as LEDs, LCD display, keypad).

An I-node will certainly have its own local user-interface, as it is required to support certain mandatory user-interface procedures.

An integrated device may well support all user-interface procedures through a management application running on the host PC.

Section 9 (User-Interface Procedures) describes what user-interface procedures a node is required to support.

3.5.11 IWU

The IWU contains data-node initialization and management.

It performs a routing function for management and asynchronous data services between the top of the HomeRF MAC and the top of the host transport driver.

The IWU contains I-node initialization, management and user-interface functions. It connects isochronous data emerging from the top of the DECT stack to the hardware isochronous data drivers. It implements value-added functions (such as Baby Call) using DECT NWK messaging.

The procedures for the IWU are defined in section 8 (HomeRF IWU).

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3.5.12 Bridge Architecture

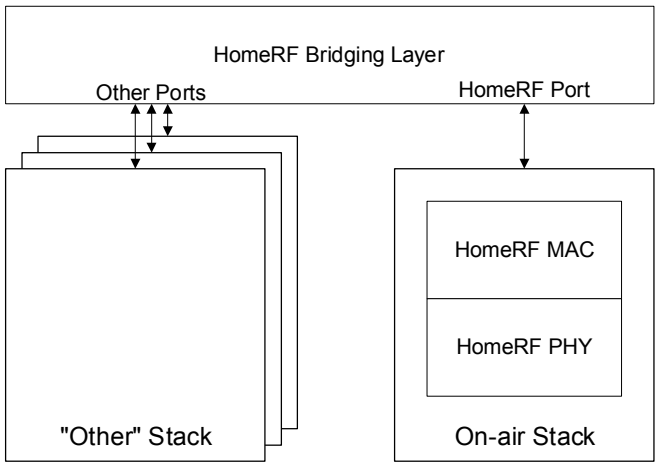


Figure 15 - Bridge Architecture

Figure 15 shows the architecture of a HomeRF Bridge. The HomeRF bridging layer connects the tops of a number of protocol stacks at the MAC level. One of these is a HomeRF stack. The others can be any Ethernet-like technology that provides a compatible data service. The HomeRF stack is accessed through a *HomeRF port*. Other protocol stacks are accessed through another port.

For a data service to be compatible, all the constraints listed in Table 22 shall be met by the "other" stack.

Table 22 - Constraints on Bridging-Compatible Data Services

Constraint	**Description**
MTU size	MSDUs received from an "other" stack that are longer than the HomeRF MTU are discarded, and vice versa. The HomeRF MTU is chosen to be compatible with Ethernet.
Ethertype	The HomeRF data service provides an Ethernet medium type; this includes an *ethertype* transport attribute. Any compatible protocol shall provide a means of transporting this attribute.
Addressing	The data service has destination and source address attributes. The addresses are 6-byte IEEE MAC addresses.
Connectionless	Any suitable data service will provide the transport of MSDUs without requiring any connection setup.

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4 PHYSICAL (PHY) LAYER

This section describes the Physical Layer of the HomeRF On-Air protocol stack.

This layer provides services that are used by the MAC layer.

4.1 PHY Layer Services

The physical layer provides two services, accessed through two service access points. These services are the PHY *Data* service and the PHY *Management* service.

4.1.1 PHY Data Service

The PHY Data SAP (PD-SAP) supports the transport of PHY service data units (PSDUs) of the Asynchronous data service, Priority Asynchronous data service, Isochronous data service, and the Isochronous connectionless broadcast service between PHY-layer entities. The transport characteristics of this service are described in Table 23.

Table 23 - PHY Data Service Characteristics

Characteristic	Description
Reliability	Delivery of PSDUs is unreliable. Delivered PSDUs can contain errors or PSDUs might not arrive at all.
Delay	The PHY introduces delays required to send its PDU header, and delay taken to transmit the PSDU. Apart from this, the PHY does not buffer or otherwise delay a PSDU.
Duplication	None
Order	Preserved
PPDU Format	The PHY data service supports the following PPDU formats: *TDMA PPDU* *Basic Rate Single PSDU* *Extended Preamble High Rate Single PSDU* *Dual PSDU* *Dual Beacon* The *TDMA PPDU* format uses PHY features that support TDMA MPDUs. The *Basic Rate Single PSDU* format is used for CSMA/CA data when the basic modulation is used. The *Extended Preamble High Rate Single* PSDU format is used for CSMA/CA data when a *high-rate modulation* is used. In this format, a *basic modulation* preamble extension is sent prior to the *high-rate modulation* preamble. The *Dual PSDU* format permits the MAC to send the MPDU header using basic modulation and to send the MPDU payload using LR 4-FSK modulation. The *Dual* ***Beacon*** format is a combination of *TDMA* and *Basic Rate Single PSDU* formats. It is used by a Class-1 CP to transmit its CP1 Beacon.
PSDU Size	The PHY introduces no limit, but relies on the limits enforced by the MAC
Modulation	In the case of the *Extended Preamble High Rate Single PSDU* format, the preamble extension is transmitted with the basic modulation and the remainder of the PPDU with the *high-rate* modulation. In the case of the *Dual PSDU* format, basic modulation is used for PSDU1 and LR 4-FSK modulation is used for PSDU2.

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Characteristic	Description
	In the case of the *Dual Beacon* format, basic modulation is used for both PSDU1 and PSDU2.All other formats use basic modulation only.
Channel Bit Rate	800 kbps on-air with the *Basic Rate Single PSDU* format and 1.6 Mbps with the *Dual PSDU* format. 5Mbps or 10Mbps with the *Extended Preamble High Rate Single PSDU* format. Actual throughput is less than the channel bit rate because of PPDU overhead and bit-stuffing

The MAC has to interact with the PHY during the reception of a PHY PDU, in order for the PHY to delimit the fields within its PDU. The region of the MAC header that contains parameters relevant to this process is called the *MAC initial header* (see section 4.2.7 (PSDU1 Field)). The PHY need only know the size of this *MAC initial header*; it need not understand its content. It is included as part of PSDU1. [15]

4.1.1.1 PD_TX_DATA Primitive

Primitive	PD_TX_DATA			
Description	PHY layer data services			
Parameters	**Req**	**Conf**		
PPDU Format	F			
PSDU 1	M			
PSDU 2	O			
Modulation Type	O			
Tx Antenna	D			
Notes:	M – Mandatory T – Present if, and only if the node supports the transmission of TDMA MPDUs F – Present if, and only if more than one PPDU format is supported O – Optional D – Present if, and only if Transmit antenna diversity is supported			

The *PPDU Format* parameter is present if, and only if, more than one PPDU format is supported. It takes one of the values: *TDMA PPDU, Basic Rate Single PSDU, Extended Preamble High Rate Single PSDU, Dual PSDU, Dual Beacon.*

The *PSDU 1* and *PSDU2* parameters are a sequence of bytes containing a PSDU to be transmitted.

The *Modulation Type* parameter is present if the *Extended Preamble High Rate Single PSDU,* or *Dual PSDU* formats are used. It specifies the modulation type of the non-basic modulation portion of the format type.

Depending on the *PPDU Format*, the *PSDU1* and *PSDU2* parameters are interpreted as defined in Table 24.

[15] This architecture complicates the description in this specification, but has no real impact on an implementation.

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Table 24 - Effect of PPDU Format on Interpretation of Parameters

PPDU Format	PSDU1	PSDU2
TDMA PPDU	Contains the entire TDMA MPDU. Length up to *MaxTDMAbeaconLength* bytes	*Not Present*
Basic Rate Single PSDU	Contains the entire MPDU. Length up to *MPDUheaderLength4 + LR2FSKfragmentationThreshold + 4*	*Not Present*
Extended Preamble High Rate Single PSDU	Contains the entire MPDU. Length up to *MPDUheaderLength2 + MaxCSDUlength+4*	*Not Present*
Dual PSDU	Contains the header and header CRC of the MPDU Length up to *MPDUheaderLength4 + 4*	Contains the payload and payload CRC of the MPDU Length up to *LR2FSKfragmentationThreshold + 4*
Dual Beacon	Contains the TDMA Beacon part of the CP1 Beacon Length up to *MaxTDMAbeaconLength*	Contains the CP2 Beacon part of the CP1 Beacon Length up to *MPDUheaderLength3 + MaxCP2beaconPayloadLength + 4*

PSDU 1 of an *Extended Preamble High Rate Single PSDU* is sent using the modulation indicated by the *Modulation Type* parameter. *PSDU1*, in all other formats, is always sent using basic modulation. *PSDU2* is used in the *Dual PSDU* and *Dual Beacon* PPDU formats. In the *Dual PSDU* format, *PSDU2* is always sent using LR 4-FSK modulation. In the *Dual Beacon* format, *PSDU2* is always sent using basic modulation.

The Confirmation is issued when the last symbol of the PPDU has been transmitted.

4.1.1.2 PD_RX_START Primitive

Primitive	PD_RX_START			
Description	PHY layer connectionless data service has detected receive activity.			
Parameters			**Ind**	
Notes:				

The PHY shall issue a PD_RX_START when it has detected the start of receive activity.

The permitted sequence of subsequent PD_RX indications that may be generated by the PHY is defined by the behavior of the state machine defined in section 4.4.4 (PHY Receive State Machine).

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4.1.1.3 PD_RX_END Primitive

Primitive	PD_RX_END			
Description	PHY layer connectionless data service has detected the end of RX activity before the current PSDU has been completely received.			
Parameters			**Ind**	
Notes:				

The PHY can issue a PD_RX_END indication any time after a PD_RX_START indication. It indicates that the current receive activity completed without correctly and completely receiving the current PSDU.

4.1.1.4 PD_RX_MAC_INITIAL_HEADER Primitive

Primitive	PD_RX_MAC_INITIAL_HEADER			
Description	PHY layer data services - received start of PSDU1. The PD_RX_MAC_INITIAL_HEADER primitive is issued by the PHY once an SFD has been detected and the *MAC initial header* (MIH) has been received on-air. The MAC is required to analyze the header and return information that allows the PHY to delimit its PSDUs within its PPDU.			
Parameters			**Ind**	**Resp**
Format			F	
MAC Initial Header			M	
Rx Antenna			D	
Length 1				M
Length 2				M
Modulation Type				O
Notes:	F - Mandatory for Class-1 CP and AI-node M - Mandatory O - Optional D - Present if Rx antenna diversity is supported			

The *Rx Antenna* parameter, if present, indicates on which antenna the PPDU is being received.

The *Format* parameter, if present, indicates either *TDMA* or *non-TDMA* according to whether a TDMA or CSMA SFD has been received.

The *Modulation Type* parameter, if present, indicates the *Modulation Type* signaled in the MPDU header.

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4.1.1.5 PD_RX_PSDU1 Primitive

Primitive	PD_RX_PSDU1			
Description	PHY layer data services - received PSDU1 This indication is generated when PSDU1 has been completely received including any postamble.			
Parameters			**Ind**	**Resp**
PSDU 1			M	
Rx PSDU1 Status				M
Format				O
Modulation Type				O
Notes:	M - Mandatory			

The MAC returns an *Rx PSDU1 Status* containing one of: *Continue, Completed, Bad Header, Skip PSDU2*, or *Set PPDU Attributes* based on whether reception of any *PSDU 2* component is required, whether the MAC header is valid, or whether special PPDU attributes are to be applied to subsequent PPDUs.

The *Format* parameter is optional based on whether the *Status* is *Set PPDU Attributes* and is used to set up the PHY to receive subsequent PPDUs with the indicated format.

The *Modulation Type* parameter is optional based on whether the *Status* is *Set PPDU Attributes* and is used to set up the PHY to receive subsequent PPDUs with the indicated modulation type.

The PHY responds to the *Rx PSDU1 Status* as defined in Table 25. This behavior is defined by the PHY receive state machine described in section 4.4.4 (PHY Receive State Machine).

Table 25 - PHY Behavior dependent on Rx PSDU Status

***Rx PSDU1 Status* Value**	**PHY Behavior**
Continue	A PSDU2 is expected. The PHY shall continue to demodulate until the delimited PSDU2 has been received. The PHY shall emit an PD_RX_PSDU2 indication.
Completed	No PSDU2 is expected. The PHY shall start looking for the start of the next MPDU.
Bad Header	The PPDU is not a valid HomeRF PPDU. The PHY should start looking for the next PPDU to receive. It is likely that a *Dual PSDU* PPDU with a corrupted header will emit a PD_RX_START indication caused by the second half of the PPDU.
Skip PSDU2	A PSDU2 is expected, however it is using a modulation that the PHY cannot demodulate. The PHY repeatedly samples the channel state using the procedure defined in 4.7.2 (End of PSDU Detection) until the end of the PSDU2 is determined before issuing a PD_RX_END primitive.
Set PPDU Attributes	The PHY is directed to expect subsequent PPDUs with the format and modulation type indicated in the *Format* and *Modulation Type* parameters respectively. The default format is the *Basic Rate Single PSDU* and the default modulation is the basic modulation type.

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4.1.1.6 PD_RX_PSDU2 Primitive

Primitive	PD_RX_PSDU2			
Description	PHY layer connectionless data service - received *PSDU 2* This indication is generated when the second PHY SDU has been received completely including any postamble.			
Parameters			**Ind**	
PSDU 2			M	
Notes:	M - Mandatory			

4.1.1.7 PD_RX_SET_PPDU_ATTRIBUTES Primitive

Primitive	PD_RX_SET_PPDU_ATTRIBUTES			
Description	PHY layer data service – received set PPDU attributes request. The MAC MPDU Receive state machine will issue this primitive to direct the PHY to receive subsequent PPDUs according to the indicated *Format* and *Modulation Type* parameters. This primitive may be used to enforce special PPDU attributes or to return back to the default PPDU attributes.			
Parameters	**Req**			
Format	**M**			
Modulation Type	**M**			

The *Format* parameter is used to set up the PHY to receive subsequent PPDUs with the indicated format.

The *Modulation Type* parameter is used to set up the PHY to receive subsequent PPDUs with the indicated modulation type.

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4.1.2 Example of PPDU transmission (Informative)

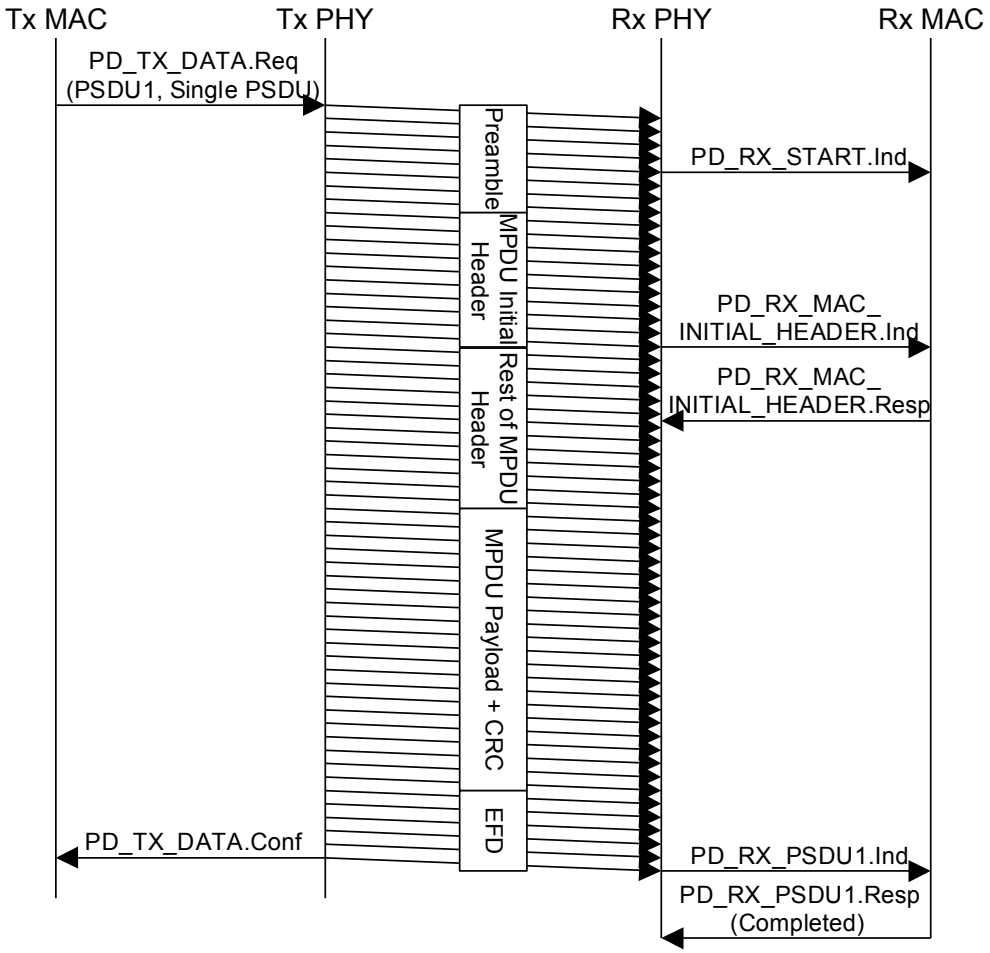


Figure 16 - Example of PPDU transmission (Basic Rate Single PSDU)

Figure 16 shows an example of a successful *Basic Rate Single PSDU* PPDU transmission showing the sequence of primitives exchanged between a transmitting node on the left and a receiving node on the right.

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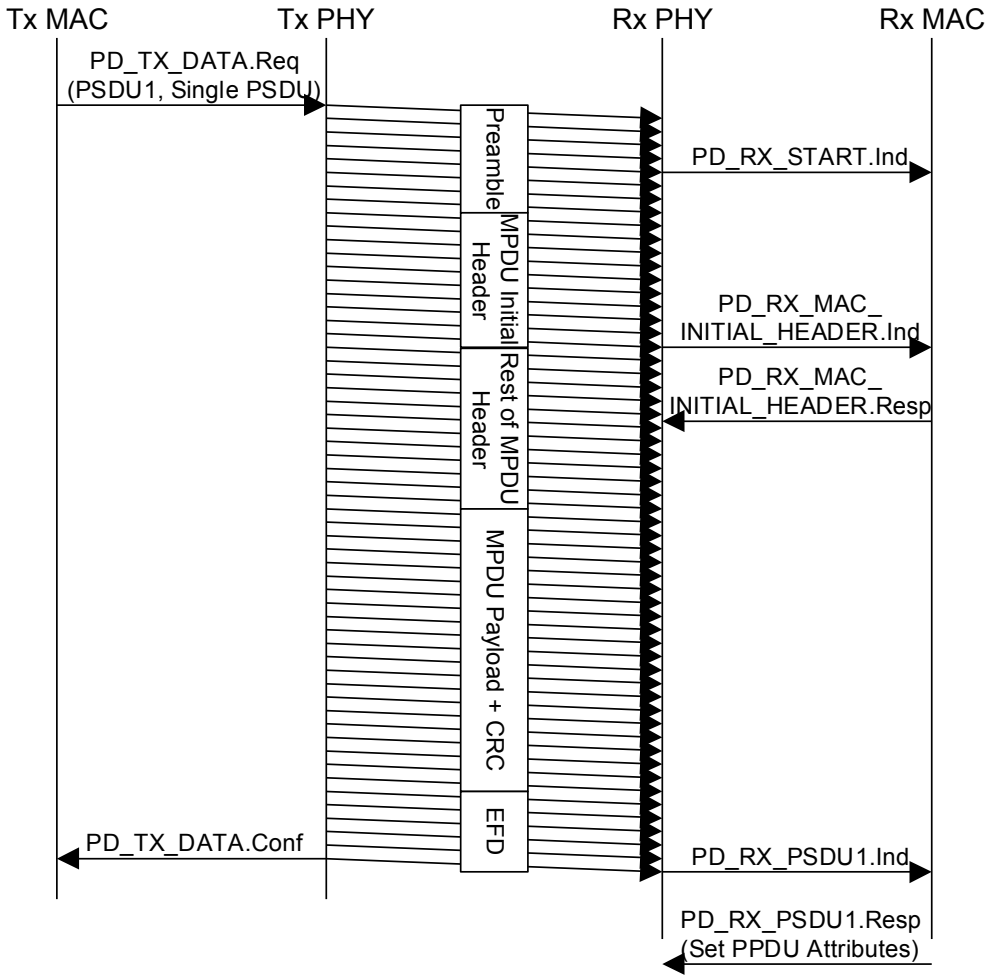


Figure 17 - Example of PPDU transmission (Basic Rate Single PSDU indicating Set PPDU Attributes status)

Figure 17 indicates the sequence when a *Basic Rate Single PSDU* is received resulting in the *Set PPDU Attributes status*. This status prepares the PHY Receive state machine to receive PPDUs with format and modulation attributes that are different from the defaults.

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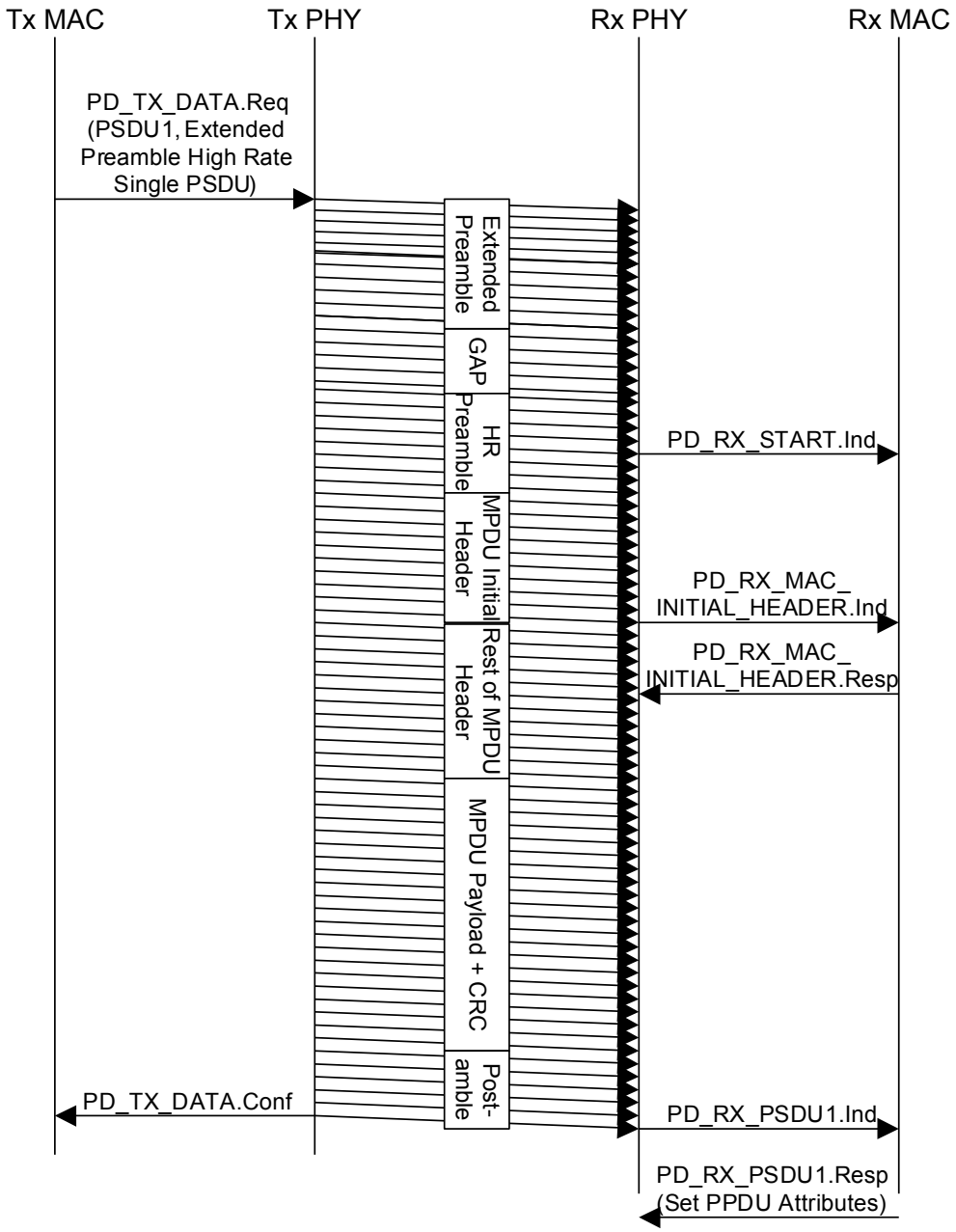


Figure 18 - Example of PPDU transmission (Extended Preamble High Rate Single PSDU indicating Set PPDU Attributes status)

Figure 18 indicates the sequence when an *Extended Preamble High Rate Single PSDU* PPDU is received and the PHY is directed via the *Set PPDU Attributes* status to expect the next PPDU with the attributes indicated. This status prepares the PHY Receive state machine to receive PPDUs with format and modulation attributes that are different from the defaults.

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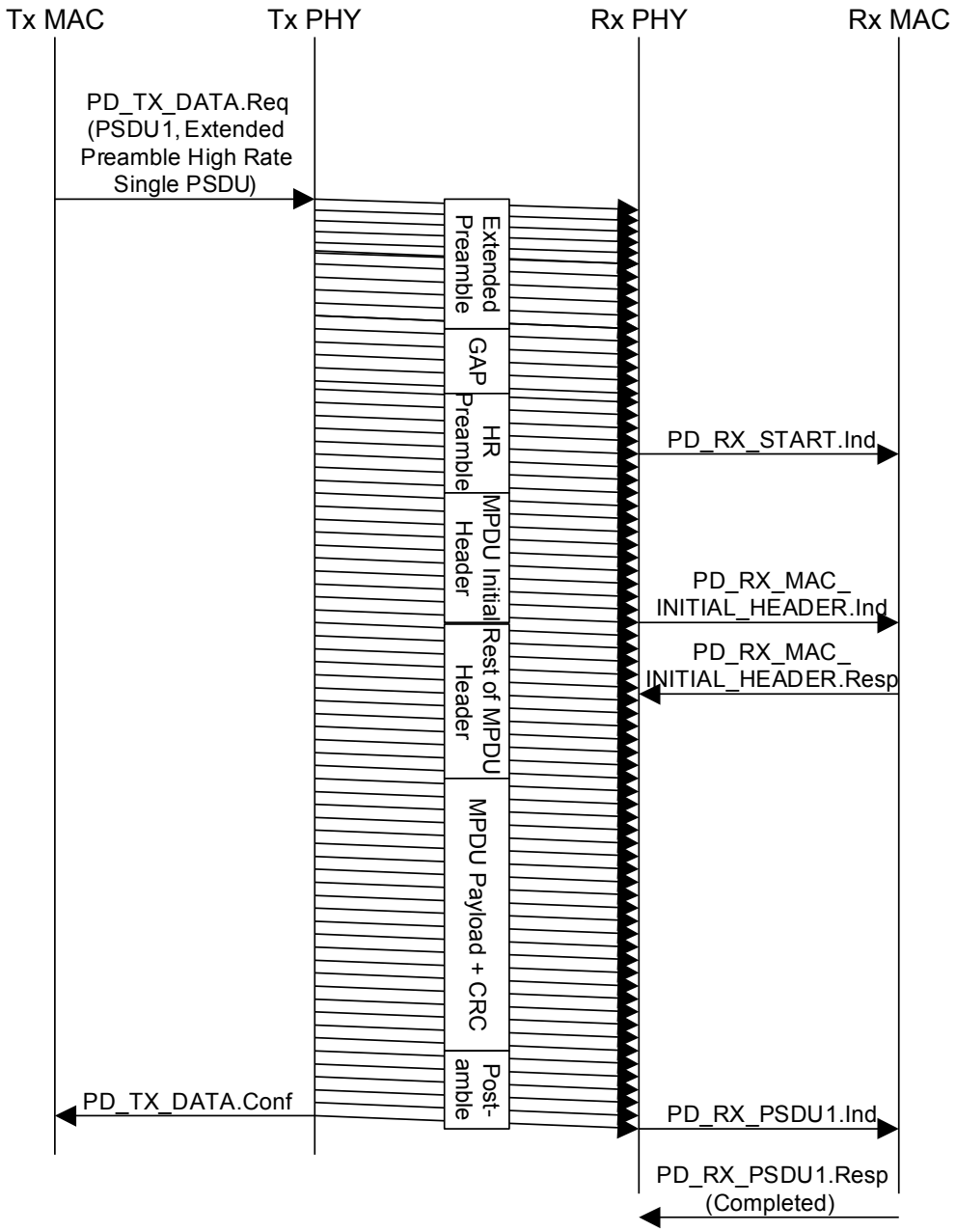


Figure 19 - Example of PPDU transmission (Extended Preamble High Rate Single PSDU indicating Completed status)

Figure 19 indicates the sequence when an *Extended Preamble High Rate Single PSDU* PPDU is received and the PHY is directed via the *Completed status* to expect the next PPDU with the default (*Basic Rate Single PSDU*) attributes. This status directs the PHY Receive state machine to receive PPDUs with the default format and modulation attributes.

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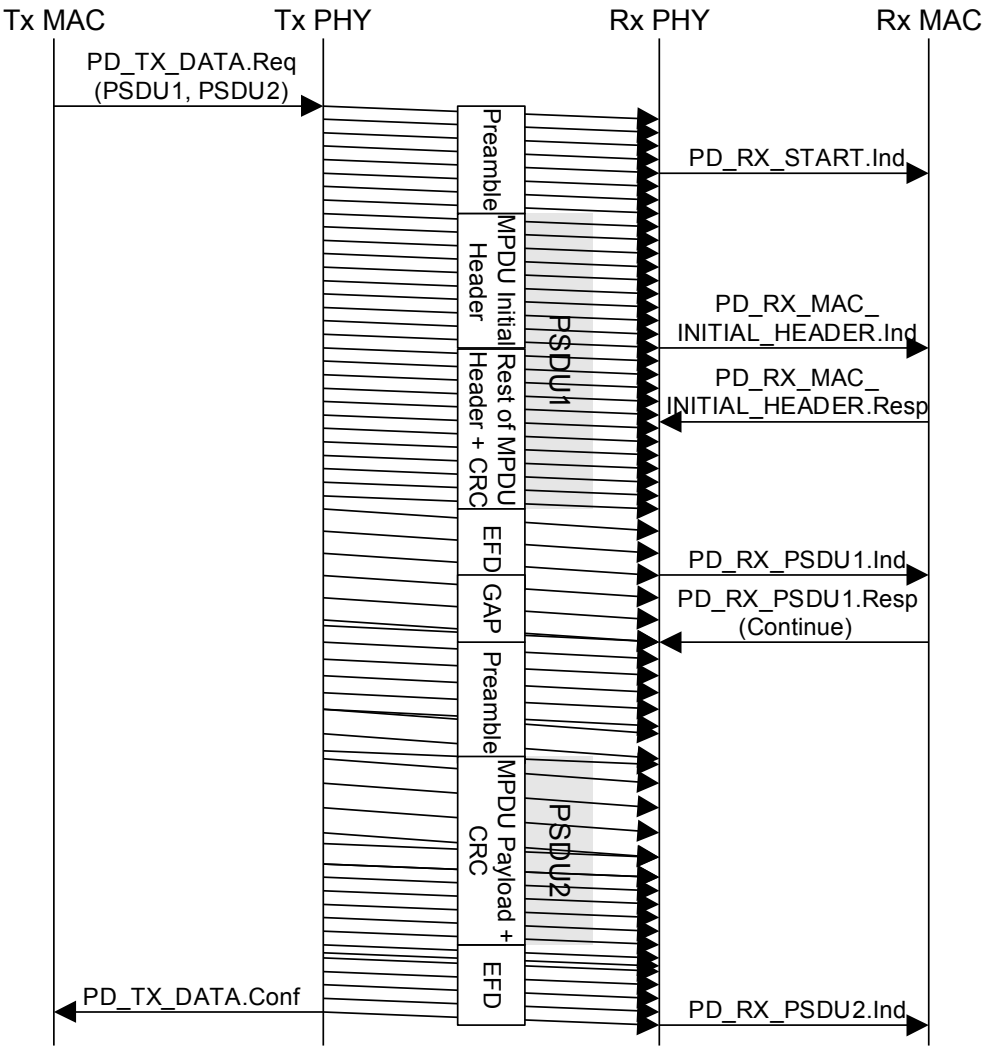


Figure 20 - Example of PPDU transmission (Dual PSDU)

4.1.3 Effect of *Extended Preamble High Rate Single PSDU* on unsupporting nodes

A node that is not capable of receiving the *Extended Preamble High Rate Single PSDU* format and receives one is likely to behave as described in this section.

The node will detect the start of a low rate PPDU preamble, but will indicate an invalid PSDU1 due to an invalid *Modulation Type Field* (see section 5.4.4.9 (Modulation Type Field)). In addition, the PSDU1 CRC check will fail.

4.1.4 Effect of Dual PSDU on a Basic Rate Single PSDU node

A node that is only capable of receiving the *Basic Rate Single PSDU* format and that receives a *Dual PSDU* format PPDU is likely to behave as described in this section.

On completion of PSDU1 (and EFD), the MAC can signal either *Completed* or *Continue.* This is ignored by the PHY which then enters the *Idle* state. The preamble to PSDU2 may or may not cause the PHY to detect preamble. If it does detect preamble, the LR 4-FSK modulation may or may not appear to be a valid basic modulation signal.

So the PHY may issue any number (including zero) of paired (PD_RX_START, PD_RX_END) indications during the PSDU2.

4.1.5 Service Interface for receiving Dual Beacon PSDUs

The service interface described above is not adequate for the reception of *Dual Beacon* PSDUs.

Only an AI-node is required to be able to receive *Dual Beacon* PSDUs.

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The AI-node PD-SAP receive interface includes exchanges between the PHY and MAC layers both to delimit the PSDU1 (TDMA Beacon part) and to delimit the PSDU2 (CP2 Beacon part). This is not described in this document.

4.1.6 PHY Management Service

The PHY Management SAP supports the primitives listed in Table 26.

Table 26 - PHY Management Primitives

PM-SAP Primitive	**Description**
PM_SET_ENABLE	Set the enable state for the PHY
PM_SET_CHANNEL	Set the radio channel for the PHY
PM_GET_CCA	Performs a clear-channel assessment and returns the channel state

The definition of these primitives follows.

4.1.6.1 PM_SET_ENABLE Primitive

Primitive	PM_SET_ENABLE			
Description	Set the operational state for the PHY			
Parameters	**Req**	**Conf**		
Enable State	M			
Notes:	This primitive is optional. It is not supported by an active CP.			

The *Enable State* affects the following PHY characteristics as defined in Table 27.

Table 27 - Effect of PHY Enable State on PHY Characteristics

PHY Characteristic	**When *Enabled***	**When *Disabled***
Ability to transmit	Can Transmit	Cannot Transmit
Ability to receive	Can Receive	Cannot Receive
Ability to save power	Can save power	Cannot save power
Ability to perform CCA	Can perform CCA	Cannot perform CCA

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4.1.6.2 PM_SET_CHANNEL Primitive

Primitive	PM_SET_CHANNEL			
Description	Set PHY to operate on the specified channel			
Parameters	**Req**	**Conf**		
Channel	M			
Notes:	M - Mandatory			

The *Channel* parameter specifies the radio channel on which all subsequent PHY operation is to occur. The range of channels that are valid is dependent on the geographic region. Refer to section 5.5.2.3 (Hopping Frequency Calculation) for the range applicable to the North American geographic region. Refer to Appendix A - (Localizations) for the range applicable to other locales.

Receipt of this primitive causes the PHY to select the specified channel for subsequent operation. The confirmation is issued when the PHY is stable on the new channel.

4.1.6.3 PM_GET_CCA Primitive

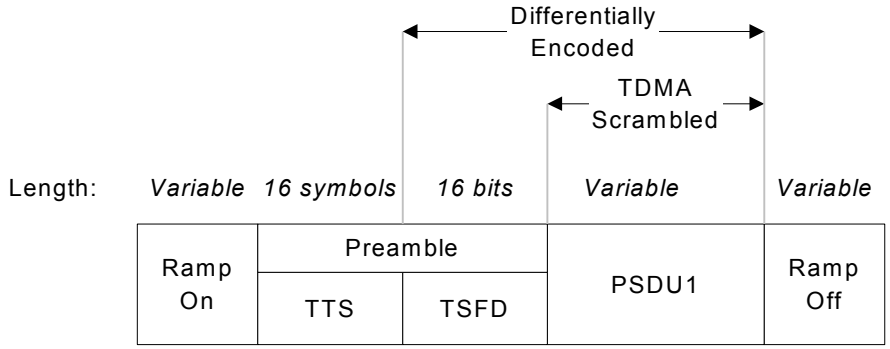
Primitive	PM_GET_CCA			
Description	Performs a clear-channel assessment and returns the channel state			
Parameters	**Req**	**Conf**		
Channel State		M		
Notes:	M - Mandatory			

This primitive causes the PHY to start a clear channel assessment (as defined in section 4.7.1 (Clear Channel Assessment), and to return the result of the assessment. The *Channel State* parameter contains one of two values: *Idle, Busy*.

4.2 PHY Layer PDU Structure

The PHY layer defines five PDU formats corresponding to the values of the *PSDU Format* of the PD_TX_DATA request.

Figure 21 shows the PDU structure for a TDMA PPDU. This consists of a variable length *Ramp On* field, followed by the *TDMA training sequence* (TTS) and *TDMA start frame delimiter* (TSFD) fields. The PSDU1 follows. The PPDU is followed by a *Ramp Off* field. For the purpose of MAC-level timing, the PPDU is defined as starting with the first symbol of the TTS field and ending with the last symbol of the PSDU1 field. The TDMA PPDU format is distinguished from the other formats by the contents of the TSFD field [16]. The TSFD and PSDU1 fields are Differentially Encoded. The PSDU1 field is TDMA scrambled (see 4.4.9 (TDMA Scrambler)). The entire PPDU is sent using basic modulation.



16 And by the shorter training sequence.

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Figure 21 - PPDU Structure (TDMA PPDU)

Figure 22 shows the PDU structure for a *Basic Rate Single PSDU* PPDU. This consists of a variable length *Ramp On* field, followed by a *LR 2-FSK training sequence* (L2TS) field and a *CSMA start of frame delimiter* (CSFD) field. The PSDU1 and the EFD follow. The PPDU is followed by a *Ramp Off* field. For the purpose of MAC-level timing, the PPDU is deemed to start with the first symbol of the L2TS field and end with the last symbol of the EFD field. The *Basic Rate Single* PSDU format is distinguished from the TDMA format by the contents of the CSFD field. The *Basic Rate Single PSDU* and *Dual* PSDU formats are distinguished by the parameters of the PD_RX_MAC_INITIAL_HEADER response issued by the MAC. Distinction of the *Basic Rate Single PSDU* format from the *Extended Preamble High Rate Single* PSDU format is an implicit function of the PHY. The CSFD, PSDU1 and EFD fields are scrambled (see section 4.4.8 (CSMA Scrambler)) and differentially encoded. The PSDU1 field is bit-stuffed. The entire PPDU is sent using LR 2-FSK modulation.

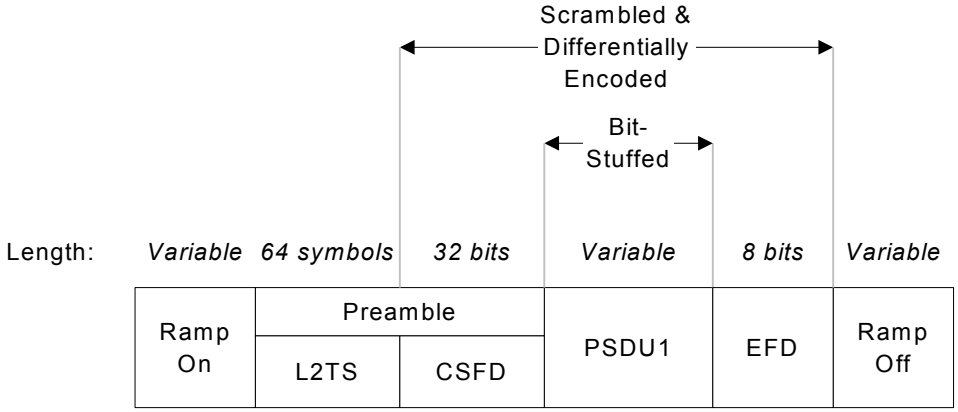


Figure 22 - PPDU Structure (Basic Rate Single PSDU)

Figure 23 shows the PDU structure for the *Extended Preamble High Rate Single PSDU* PPDU format sent with the HR 2-FSK modulation. This consists of a variable length *Ramp On* field, followed by the extended preamble sent with the LR 2-FSK modulation. This extended preamble consists of a *LR 2-FSK training sequence* (L2TS) field, a *CSMA start of frame delimiter* (CSFD) field, a *PDU attributes (PDUA) field*, and an EFD field all sent with the LR 2-FSK modulation. This extended preamble is immediately followed by a fixed GAP field of 20.0 µs duration. Then the HR 2-FSK part begins. It consists of a high-rate preamble. This high-rate preamble consists of a high-rate 2-FSK *training sequence* (H2TS) field and a *CSMA start of frame delimiter* (CSFD) field. The PSDU1 and Postamble fields follow. The PPDU is followed by a *Ramp Off* field. For the purpose of MAC-level timing, the PPDU is deemed to start with the first symbol of the L2TS field and end with the last symbol of the Postamble field. Scrambling and differential encoding is applied to the extended preamble's CSFD, PDUA, and EFD fields. The high-rate CSFD, PSDU1, and Postamble fields are also scrambled and differentially encoded. There is no bit stuffing anywhere in the PPDU.

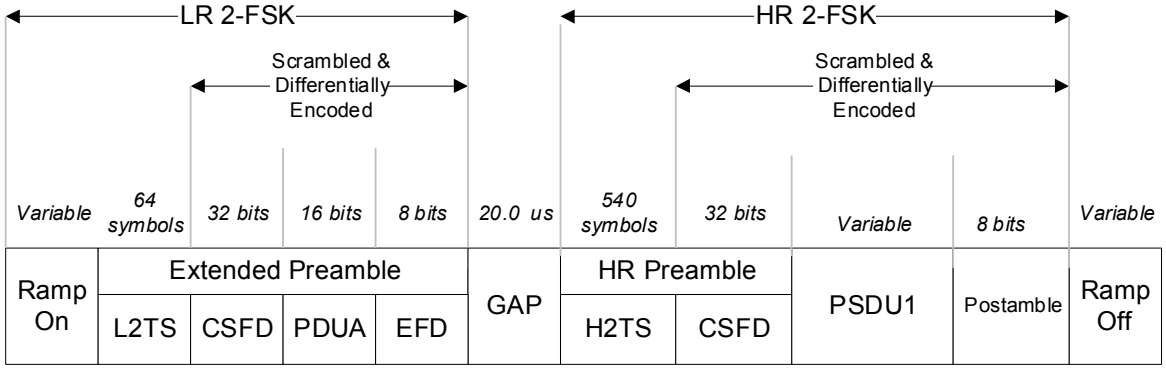


Figure 23 - PPDU Structure (Extended Preamble High Rate Single PSDU using HR 2-FSK modulation)

Figure 24 shows the PDU structure for the *Extended Preamble High Rate Single PSDU* PPDU format sent with the HR 4-FSK modulation. This consists of a variable length *Ramp On* field, followed by the extended preamble sent with the LR 2-FSK modulation. This extended preamble consists of a *LR 2-FSK training sequence* (L2TS) field, a *CSMA start of frame delimiter* (CSFD) field, a *PDU attributes (PDUA) field*, and an EFD field all sent with the LR 2-FSK modulation. This extended preamble is

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immediately followed by a fixed GAP field of 20.0 µs duration. Then the HR 4-FSK part begins. It consists of a high-rate preamble. This high-rate preamble consists of the HR 4-FSK *training sequence* (H4TS) field and a *CSMA start of frame delimiter* (CSFD) field. The PSDU1 and Postamble fields follow. The PPDU is followed by a *Ramp Off* field. For the purpose of MAC-level timing, the PPDU is deemed to start with the first symbol of the L2TS field and end with the last symbol of the Postamble field. Scrambling is applied to the extended preamble's CSFD, PDUA, and EFD fields. The high-rate CSFD, PSDU1, and Postamble fields are also scrambled. There is no bit stuffing anywhere in the PPDU.

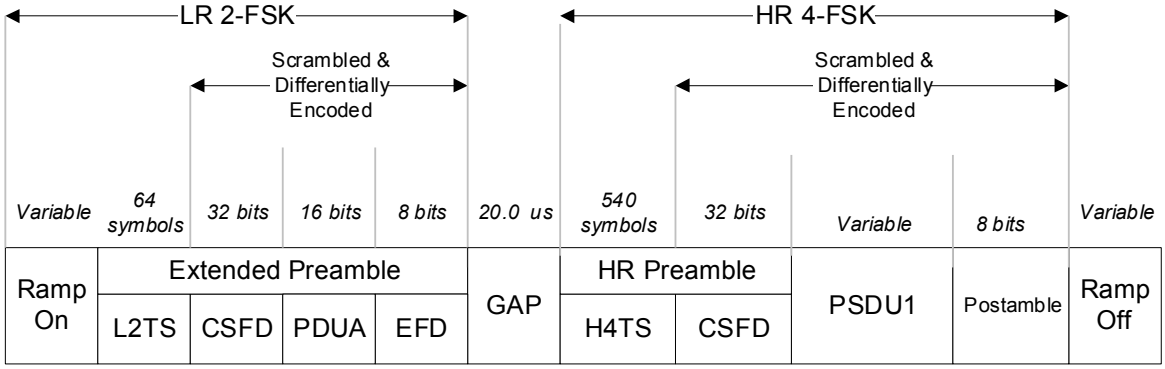


Figure 24 - PPDU Structure (Extended Preamble High Rate Single PSDU using HR 4-FSK modulation)

The *Dual PSDU* structure includes two parts separated by a gap. The first part carries PSDU1 and is identical (from the perspective of the PHY-layer) to the *Basic Rate Single PSDU* structure. It is sent using LR 2-FSK modulation. The second part carries PSDU2 and uses LR 4-FSK modulation. The *PSDU2 Preamble* includes an *LR 4-FSK training sequence* (L4TS) and the *CSMA start of frame delimiter* (CSFD) sent with LR 4-FSK modulation. Figure 25 shows this structure.

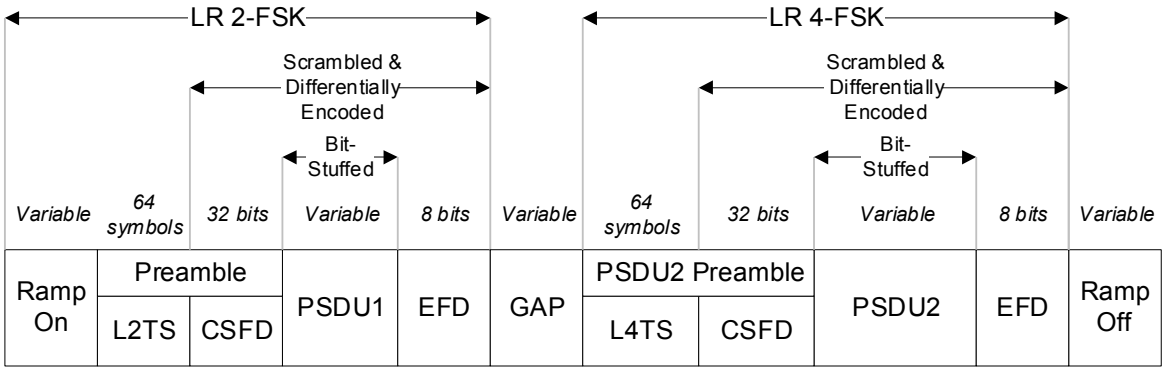


Figure 25 - PPDU Structure (Dual PSDU)

The *Dual Beacon* format includes a TDMA part followed by a non-TDMA part. The TDMA part consists of a L2TS field followed by a TSFD field and then followed by a TDMA scrambled PSDU1. The non-TDMA part consists of a CSFD followed by a bit-stuffed PSDU2. These are followed by an EFD field and a ramp off field. All fields from the TSFD to the EFD inclusive are differentially encoded. The PSDU1 is TDMA scrambled. Fields from the CSFD to the EFD are scrambled via the CSMA scrambler. The PSDU2 is bit-stuffed. The entire PPDU is sent using LR 2-FSK modulation.

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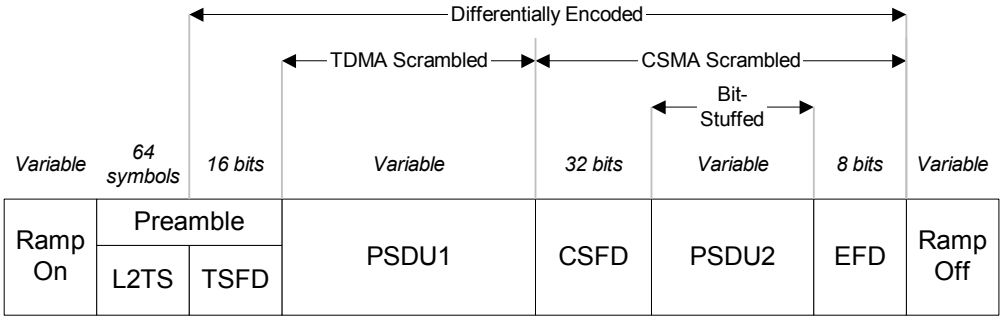


Figure 26 - PPDU Structure (Dual Beacon)

4.2.1 Ramp On Field

The *Ramp On* field is a leftwards extension of the training sequence field that follows it. In all PPDUs, the *Ramp On* field shall have the same contents and modulation as the following L2TS field. The training sequence pattern shall be continuous across the boundary between the *Ramp On* and training sequence fields.

The maximum duration of the *Ramp On* field is (*RxTxTurnaround - 2 * CCAtime*). [17]

4.2.2 Low-Rate Training Sequence Fields

There are three types of low-rate training sequence fields.

4.2.2.1 TDMA Training Sequence Field (TTS)

The TDMA TS field (TTS) contains 16 d-symbols consisting of a repeating LR 2-FSK (0, 1) pattern, starting with 0.

The TTS d-symbols are transmitted directly using the deviations specified in section 4.5.1.1.1 (LR 2-FSK Modulation), with neither bit stuffing nor scrambling.

4.2.2.2 CSMA LR 2-FSK Training Sequence Field (L2TS)

The CSMA L2TS field contains 64 d-symbols consisting of a repeating LR 2-FSK (0,1) pattern, starting with 0. The last symbol of this field must be the same as the last symbol of the TDMA TTS field since the differential encoding of the TSFD field in both the dual beacon (in which the CSMA L2TS field precedes the TSFD) and the TDMA PPDU (in which the TDMA TTS field precedes the TSFD) must be the same.

The L2TS d-symbols are transmitted directly using the deviations specified in section 4.5.1.1.1 (LR 2-FSK Modulation), with neither bit stuffing nor scrambling.

4.2.2.3 CSMA LR 4-FSK Training Sequence Field (L4TS)

The CSMA L4TS field contains 64 d-symbols consisting of a repeating LR 4-FSK (00, 11) pattern, starting with 00.

The L4TS d-symbols are transmitted directly using the modulation specified in section 4.5.1.1.2 (LR 4-FSK Modulation), with neither bit stuffing nor scrambling.

4.2.2.4 Use of the Low-Rate Training Sequence Fields (Informative)

The TDMA TTS and CSMA L2TS fields may be used by the receiver to:

- Determine the LR 2-FSK signal threshold;
- Select the antenna with the strongest signal, if low-rate Rx antenna diversity is supported; and
- Synchronize its clock so it can perform data recovery.

The CSMA L4TS field may be used for similar purposes, with respect to the second part of a *Dual PSDU* PPDU.

The TDMA TTS field has been shortened to permit the maximum number of MAC-layer TDMA connections.

[17] This constraint arises from the need to maintain slotted contention performance. In practice, the *Ramp On* duration will be a lot shorter than this.

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4.2.3 High-Rate Training Sequence Fields

There are two types of high-rate training sequence fields. Of these, H2TS is sent with HR 2-FSK modulation, and H4TS is sent with HR 4-FSK modulation.

These two training sequences are described in terms of a basic two symbol alphabet {n, p}. The definition of this alphabet differs between the HR 2-FSK and HR 4-FSK training sequence versions, as described in sections 4.2.3.1 and 4.2.3.2.

When expressed in terms of the alphabet {n,p}, H2TS and H4TS have the same structure, which is shown in Figure 27. Each training sequence consists of 9 subfields, whose contents are defined in Table 28. The length of the H2TS and H4TS training sequences is 540 symbols (108 μs).

The complete H2TS and H4TS high-rate training sequence is reproduced in Figure 31 . Each training sequence is shown in groups of 15 symbols only for ease of reading, but the inter-group spaces have no physical significance.

Some of the training sequence subfields are defined in terms of the short sequences PN, IPN, and APN. The sequence PN, described in Figure 28, is a pseudo-noise binary sequence of length 15. The sequence IPN, described in Figure 29, is obtained from sequence PN by swapping the symbols n and p (essentially a one's complement operation). The sequence APN, described in Figure 30, is the concatenation of one IPN sequence with one PN sequence.

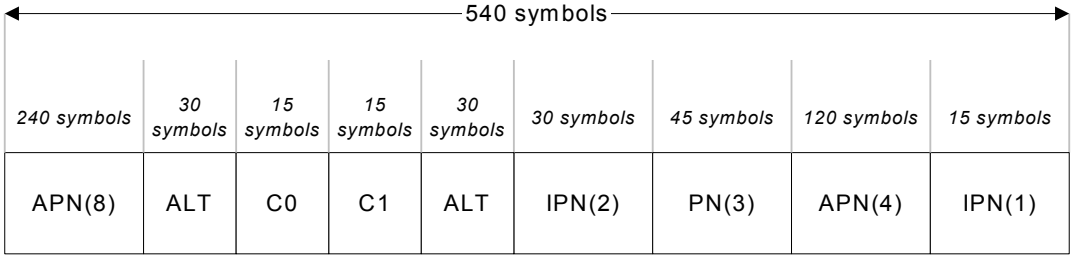


Figure 27 - High-rate Training Sequence Structure (H2TS or H4TS)

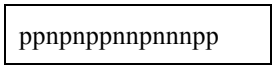


Figure 28 - Sequence PN Structure



Figure 29 – Sequence IPN Structure

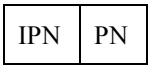


Figure 30 – Sequence APN Structure

Table 28 – High-rate Training Sequence Subfield Definitions

Subfield Name	Subfield Length (d-symbols)	Description
ALT	30	30 d-symbols, consisting of a repeating (p,n) pattern, starting with p
APN(*m*)	30*m*	*m* repetitions of the sequence APN, which is defined in Figure 30
C0	15	15 repetitions of the d-symbol n

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C1	15	15 repetitions of the d-symbol p
IPN(*m*)	15*m*	*m* repetitions of the sequence IPN, which is defined in Figure 29
PN(*m*)	15*m*	*m* repetitions of the sequence PN, which is defined in Figure 28.

```
nnpnpnnppnpppnn ppnpnppnnpnnnpp nnpnpnnppnpppnn ppnpnppnnpnnnpp
nnpnpnnppnpppnn ppnpnppnnpnnnpp nnpnpnnppnpppnn ppnpnppnnpnnnpp
nnpnpnnppnpppnn ppnpnppnnpnnnpp nnpnpnnppnpppnn ppnpnppnnpnnnpp
nnpnpnnppnpppnn ppnpnppnnpnnnpp nnpnpnnppnpppnn ppnpnppnnpnnnpp
pnpnpnpnpnpnpnp npnpnpnpnpnpnpn nnnnnnnnnnnnnnn ppppppppppppppp
pnpnpnpnpnpnpnp npnpnpnpnpnpnpn nnpnpnnppnpppnn nnpnpnnppnpppnn
ppnpnppnnpnnnpp ppnpnppnnpnnnpp ppnpnppnnpnnnpp nnpnpnnppnpppnn
ppnpnppnnpnnnpp nnpnpnnppnpppnn ppnpnppnnpnnnpp nnpnpnnppnpppnn
ppnpnppnnpnnnpp nnpnpnnppnpppnn ppnpnppnnpnnnpp nnpnpnnppnpppnn
```

Figure 31 – Complete High-rate Training Sequence (H2TS or H4TS)

4.2.3.1 CSMA HR 2-FSK Training Sequence Field (H2TS)

For the CSMA high-rate training sequence H2TS, the symbol n is defined as the d-symbol 0, and the symbol p is defined as the d-symbol 1. The H2TS d-symbols are transmitted directly using the HR 2-FSK modulation specified in section 4.5.1.2.1 (HR 2-FSK Modulation), with neither bit stuffing nor scrambling.

4.2.3.2 CSMA HR 4-FSK Training Sequence Field (H4TS)

For the CSMA high-rate training sequence H4TS, the symbol n is defined as the d-symbol 00, and the symbol p is defined as the d-symbol 11. The H4TS d-symbols are transmitted directly using the HR 4-FSK modulation specified in section 4.5.1.2.2 (HR 4-FSK Modulation), with neither bit stuffing nor scrambling.

Although H2TS and H4TS have the same logical structure, H4TS is transmitted with a larger frequency deviation than H2TS.

4.2.3.2.1 Use of the High-Rate Training Sequence Fields (Informative)

The high-rate training sequence may be used by the receiver as follows:

- The first 240 symbols (subfield APN(8)) may be used to select the antenna with the strongest signal, if high-rate Rx antenna diversity is supported, and to perform automatic gain control (AGC) acquisition, if appropriate.
- The next 90 symbols (subfields ALT, C0, C1, and ALT) may be used to determine such signal characteristics as frequency offset, frequency deviation, and slicing thresholds.
- The next 75 symbols (subfields IPN(2) and PN(3)) may be used to perform symbol and frame synchronization, and to initially train an adaptive equalizer, if used.
- The final 135 symbols (subfields APN(4) and IPN(1)) may be used to further train an adaptive equalizer, if used.

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4.2.4 SFD Fields

The *start-of-frame delimiter* (SFD) field precedes a PSDU field. In low-rate PPDUs, the SFD is used to determine the exact start of the following PSDU field. There are two types of SFD fields that distinguish the TDMA from the other PPDU formats.

The TDMA SFD field is called the TSFD field. The other SFD field is called the CSMA SFD (CSFD) field because it is largely used to carry CSMA traffic.

4.2.4.1 TDMA Start of Frame Delimiter (TSFD)

The TSFD consists of the 16-bit pattern defined in Figure 32 transmitted left-most bit first. The TSFD is transmitted unscrambled, but is differentially encoded.

Value before differential encoding	11110011	01000010
Transmitted value after differential encoding	11110111	00101001

Figure 32 – TDMA Start of Frame Delimiter Encoding (TSFD)

4.2.4.2 CSMA Start of Frame Delimiter (CSFD)

The CSFD consists of a 32 bit pattern consisting of four consecutive FLAG characters. A FLAG character consists of the 8 bit sequence "01111110". This is shown in Figure 33.

Transmitted	01111110	01111110	01111110	01111110
Received	XXXXXXXX	XXXXXXXX	01111110	01111110

Figure 33 – CSMA Start of Frame Delimiter Encoding (CSFD)

The CSFD is transmitted scrambled and differentially encoded. The state of the CSMA-scrambler is undefined at the start of the CSFD field so typically the first 9 received bits are undefined. Because this includes all of the first FLAG, and part of the second FLAG character, both initial flag characters are considered to be undefined on receive.

4.2.5 PDU Attributes field (PDUA)

The PDU Attributes field is part of the extended preamble of the *Extended Preamble High Rate Single PSDU* PPDU formats. This field indicates the modulation type of the high-rate PSDU. See Figure 34.

Reserved (8 bits)	Modulation Type (4 bits)	Reserved (4 bits)
00000000	XXXX	0000

Figure 34 – PDU Attributes Field Encoding (PDUA)

The *Reserved* fields insure that no FLAG pattern appears within the PDUA field.

The *Modulation Type* field contains the modulation type of the PSDU. See Table 75.

The *Modulation Type* field contains a value that is an undefined *Modulation Type* for nodes of HomeRF version levels below 2.0. This insures that the MAC of such nodes will not misinterpret the PDUA as part of a valid PSDU1. The PHY of nodes at version level 2.0 or above will not present the PDUA to the MAC.

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4.2.6 End of Frame Delimiter Fields

4.2.6.1 EFD Field

The end of frame delimiter (EFD) consists of a single FLAG character (8 bits), as shown in Figure 35. The EFD field is transmitted scrambled and differentially encoded.

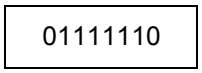


Figure 35 - End of Frame Delimiter (EFD) Encoding

4.2.6.2 Postamble Field

The Postamble field consists of a single FLAG character (8 bits), as shown in Figure 36. The Postamble is transmitted scrambled and differentially encoded.

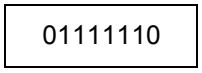


Figure 36 - Postamble Encoding

4.2.6.3 EFD and Postamble Fields (Informative)

The EFD field follows the PSDU field. PSDU fields may or may not be stuffed based on the PPDU format. Because the PSDU fields will already have been delimited by the MAC MPDU Rx process following the *MAC Initial Header* portion of PSDU1, the PHY can check that the MPDU header agrees with the PPDU structure.

In the *Extended Preamble High Rate Single PSDU* format, the end of frame delimiter (EFD) cannot reliably be used for end-of-frame detection, because the PSDU is not bit stuffed. Without bit stuffing, there is no guarantee that the EFD pattern will not occur inside the PSDU. In this case, the receiver must rely on the information in the MPDU header to locate the end of the PSDU field. The EFD is replaced with the Postamble field.

The PD_RX_PSDU1 and PD_RX_PSDU2 indications for associated PPDU formats are issued when the last symbol of the EFD or Postamble field has been received.

Although not described in the service interface presented in this chapter, the MAC can, when possible, save power during the reception of MPDUs that it does not wish to receive by disabling the PHY following the receipt of the *MAC Initial Header*. The MAC then needs to re-enable the PHY based on the known MPDU length. When bit-stuffing has occurred, it will wait to receive an EFD field, otherwise, it will expect the Postamble field.

4.2.7 PSDU1 Field

The PSDU1 field contains the PSDU1 parameter carried across the PD-SAP interface defined in section 4.1.1 (PHY Data Service).

Whether the PSDU1 field is stuffed depends on the PPDU format. The PSDU1 field is always scrambled (using either TDMA or CSMA scrambling) and differentially encoded.

The PHY assumes that the first *MPDUinitialHeaderLength* (see section 16.2 (MAC Constants)) bytes of this field contain sufficient information for the MAC to delimit the entire PPDU.

4.2.8 PSDU2 Field

In a *Dual PSDU* PPDU, the PSDU2 field, which is bit stuffed, carries a MAC payload and payload CRC, as defined in section 5.4.3 (Different MPDU Formats).

4.2.9 Ramp Off Field

The contents of this field are undefined. [18]

The maximum duration of the *Ramp Off* field is (*RxTxTurnround - 2* CCAtime*). [19]

[18] Note, in particular, that this field may look like part of a SYNC field, or may appear to include scrambled FLAG characters. It can also contain unmodulated carrier or any deviations within the range specified in 4.5.1.1.1 (LR 2-FSK Modulation).

[19] This constraint arises from the need to maintain slotted contention performance. In practice, the *Ramp Off* duration will be a lot shorter than this.

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4.2.10 Gap Field

The *Gap* field provides a spacing between sections of the PPDU that are modulated differently.

The contents of this field are undefined.

In the *Extended Preamble High Rate PSDU* PPDU, the duration of the GAP is fixed at 16 low-rate symbol periods, which is equal to 20.0 μs.

In a *Dual PSDU* PPDU, the GAP duration may range between 0 and 16 low-rate symbol periods. The duration of one low-rate symbol period is 1.25 μs. The actual GAP duration may be any number of symbol periods between these two values (inclusive).

4.3 Multi-Rate Support

High-rate modulation types are supported by the *Extended Preamble High Rate Single PSDU* format.

An *Extended Preamble High Rate Single PSDU* PPDU consists of an extended preamble that is transmitted with the basic modulation. The rest of the PPDU will be transmitted at the high-rate modulation indicated on the PD_TX_DATA primitive. The receiving PHY will derive the high-rate modulation type from the extended preamble.

Low rate 4-FSK modulation is supported by the *Dual PSDU* PPDU format. A *Dual PSDU* PPDU includes an initial section transmitted using basic modulation, and a final section transmitted using LR 4-FSK modulation.

All other PPDU formats are transmitted using only basic modulation.

The MAC controls the PPDU format and the modulation type for all transmissions via the PD_TX_DATA primitive parameters. During reception, the MAC indicates to the PHY information related to collecting the PPDU. The MAC delimits the PPDU fields and indicates the modulation type signaled in the MPDU header in response to a PD_RX_MAC_INITIAL_HEADER indication. An exception to this is the *Extended Preamble High Rate Single* PSDU PPDU formats. For these formats, the PHY derives the modulation type of the PSDU from the extended preamble. The MAC provides *status* on the PD_RX_PSDU1 response that directs the PHY as how to receive the data that follows the reception of the current PSDU1.

4.4 PHY Data Architecture

At the upper edge of the PHY, its service interface provides for the transport of PHY SDUs. At the lower edge, it transmits On-Air signals. The PHY is here described by the behavior of processes that provide the mapping between the upper edge and lower edge interfaces.

4.4.1 PHY Transmit Processes

This section describes processing performed by the PHY to provide the PD_TX_DATA service.

A procedure is defined for each PPDU format.

4.4.1.1 TDMA PPDU

Step	Description	Reference
1	Scramble the PSDU1 using the TDMA Scrambler	4.4.9 (TDMA Scrambler)
2	Add the TSFD before the result of 1	4.2.4.1 (TDMA Start of Frame Delimiter (TSFD))
3	Convert bits to 2-FSK symbols (1 bit per symbol)	4.4.10 (Bit/Symbol Conversion)
4	Differentially encode the 2-FSK symbols resulting from 3.[20]	4.4.11.2.1 (2-FSK Differential Encoder)
5	Add the TTS before the result of 4	4.2.2.1 (TDMA Training Sequence Field (TTS))
6	Add any Ramp On and Ramp Off fields to the result of 5	4.2.1 (Ramp On Field), 4.2.9

[20] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the TTS field. The value of this symbol is defined in 4.2.2.1 (TDMA Training Sequence Field (TTS)).

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	and transmit using LR 2-FSK modulation	(Ramp Off Field), and 4.5.1.1.1 (LR 2-FSK Modulation)

4.4.1.2 Basic Rate Single PSDU

Step	Description	Reference
1	Bit-Stuff PSDU1	4.4.5.2 (Stuffing Procedure)
2	Add the CSFD before and the EFD after the results of 1.	4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)) and 4.2.6.1 (EFD Field)
3	Scramble the result of 2	4.4.8 (CSMA Scrambler)
4	Convert bits resulting from 3 to symbols (1 bit per symbol)	4.4.10 (Bit/Symbol Conversion)
5	Differentially encode the 2-FSK symbols resulting from 4. [21]	4.4.11.2.1 (2-FSK Differential Encoder)
6	Add the L2TS before the result of 5	4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS))
7	Add any Ramp On and Ramp Off fields to the result of 6 and transmit using LR 2-FSK modulation.	4.2.1 (Ramp On Field), 4.2.9 (Ramp Off Field), and 4.5.1.1.1 (LR 2-FSK Modulation)

4.4.1.3 Extended Preamble HR Single PSDU Using HR 2-FSK Modulation

Step	Description	Reference
1	Build the extended preamble fields CSFD, PDUA, and EFD	4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)), 4.2.5 (PDU Attributes field (PDUA)), and 4.2.6.1 (EFD Field)
2	Scramble the result of 1	4.4.8 (CSMA Scrambler)
3	Convert bits to 2-FSK symbols (1 bit per symbol)	4.4.10 (Bit/Symbol Conversion)
4	Differentially encode the result of 3. [22]	4.4.11.2.1 (2-FSK Differential Encoder)
5	Add the L2TS before the result of 4	4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS))
6	Add any Ramp On field before the result of 5 and transmit using LR 2-FSK modulation	4.2.1 (Ramp On Field), and 4.5.1.1.1 (LR 2-FSK Modulation)
7	Transmit an implementation-dependent, fixed length *Gap*	4.2.10 (Gap Field)

[21] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the L2TS field. The value of this symbol is defined in 4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS)).

[22] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the H2TS field. The value of this symbol is defined in 4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS)).

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	subject to the constraints of section 4.2.10	
8	Add CSFD before and the Postamble after PSDU1	4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)) and 4.2.6.2 (Postamble Field)
9	Scramble the result of 8	4.4.8 (CSMA Scrambler)
10	Convert bits resulting from 9 to 2-FSK symbols (1 bit per symbol)	4.4.10 (Bit/Symbol Conversion)
11	Differentially encode the 2-FSK symbols resulting from 10. [23]	4.4.11.2.1 (2-FSK Differential Encoder)
12	Add the H2TS before the result of 11	4.2.3.1 (CSMA HR 2-FSK Training Sequence Field (H2TS))
13	Add any Ramp Off field after the result of 12 and transmit using HR 2-FSK modulation	4.2.9 (Ramp Off Field), and 4.5.1.2.1 (HR 2-FSK Modulation)

4.4.1.4 Extended Preamble HR Single PSDU Using HR 4-FSK Modulation

Step	Description	Reference
1	Build the extended preamble fields CSFD, PDUA, and EFD	4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)), 4.2.5 (PDU Attributes field (PDUA)), and 4.2.6.1 (EFD Field)
2	Scramble the result of 1	4.4.8 (CSMA Scrambler)
3	Convert bits to 2-FSK symbols (1 bit per symbol)	4.4.10 (Bit/Symbol Conversion)
4	Differentially encode the result of 3. [24]	4.4.11.2.1 (2-FSK Differential Encoder)
5	Add the L2TS before the result of 4	4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS))
6	Add any Ramp On field before the result of 5 and transmit using LR 2-FSK modulation	4.2.1 (Ramp On Field), and 4.5.1.1.1 (LR 2-FSK Modulation)
7	Transmit an implementation-dependent, fixed length *Gap* subject to the constraints of section 4.2.10	4.2.10 (Gap Field)
8	Add CSFD before and the Postamble after PSDU1	4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)) and 4.2.6.2 (Postamble Field)
9	Scramble the result of 8	4.4.8 (CSMA Scrambler)

[23] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the 2-FSK TS field. The value of this symbol is defined in 4.2.3.1 (CSMA HR 2-FSK Training Sequence Field (H2TS)).

[24] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the L2TS field. The value of this symbol is defined in 4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS)).

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10	Convert bits resulting from 9 to 4-FSK symbols (2 bits per symbol)	4.4.10 (Bit/Symbol Conversion)
11	Differentially encode the 4-FSK symbols resulting from 10. [25]	4.4.11.2.2 (4-FSK Differential Encoder)
12	Add the H4TS before the result of 11	4.2.3.2 (CSMA HR 4-FSK Training Sequence Field (H4TS))
13	Add any Ramp Off field after the result of 12 and transmit using HR 4-FSK modulation	4.2.9 (Ramp Off Field), and 4.5.1.2.2 (HR 4-FSK Modulation)

4.4.1.5 Dual PSDU

Step	Description	Reference
1	Bit-Stuff PSDU1	4.4.5.2 (Stuffing Procedure)
2	Add the CSFD before and the EFD after the results of 1	4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)) and 4.2.6.1 (EFD Field)
3	Scramble the result of 2	4.4.8 (CSMA Scrambler)
4	Convert bits to 2-FSK symbols (1 bit per symbol)	4.4.10 (Bit/Symbol Conversion)
5	Differentially encode the result of 4. [26]	4.4.11.2.1 (2-FSK Differential Encoder)
6	Add the L2TS before the result of 5	4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS))
7	Add any Ramp On field before the result of 6 and transmit using LR 2-FSK modulation	4.2.1 (Ramp On Field), and 4.5.1.1.1 (LR 2-FSK Modulation)
8	Transmit an implementation-dependent *Gap* subject to the constraints of section 4.2.10	4.2.10 (Gap Field)
9	Bit-Stuff PSDU2	4.4.5.2 (Stuffing Procedure)
10	Add the CSFD before and the EFD after the results of 9	4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)) and 4.2.6.1 (EFD Field)
11	Scramble the result of 10	4.4.8 (CSMA Scrambler)
12	Convert bits to 4-FSK symbols (2 bits per symbol)	4.4.10 (Bit/Symbol Conversion)
13	Differentially encode the 4-FSK symbols resulting from 12. [27]	4.4.11.2.2 (4-FSK Differential Encoder)

[25] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the H4TS field. The value of this symbol is defined in 4.2.3.2 (CSMA HR 4-FSK Training Sequence Field (H4TS)).

[26] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the L2TS field. The value of this symbol is defined in 4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS)).

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14	Add the L4TS before the result of 13	4.2.2.3 (CSMA LR 4-FSK Training Sequence Field (L4TS))
15	Add any Ramp Off field after the result of 14 and transmit using LR 4-FSK modulation	4.2.9 (Ramp Off Field), and 4.5.1.1.2 (LR 4-FSK Modulation)

4.4.1.6 Dual Beacon

Step	Description	Reference
1	Scramble PSDU1 using the TDMA Scrambler	4.4.9 (TDMA Scrambler)
2	Add the TSFD before the result of 1	4.2.4.1 (TDMA Start of Frame Delimiter (TSFD))
3	Bit-Stuff PSDU2	4.4.5.2 (Stuffing Procedure)
4	Add the CSFD before and the EFD after the results of 3	4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)) and 4.2.6.1 (EFD Field)
5	Scramble the result of 4 using the CSMA scrambler	4.4.8 (CSMA Scrambler)
6	Concatenate the results of 2 and 5	
7	Convert bits resulting from 6 to 2-FSK symbols (1 bit per symbol)	4.4.10 (Bit/Symbol Conversion)
8	Differentially encode the 2-FSK symbols resulting from 7.[28]	4.4.11.2.1 (2-FSK Differential Encoder)
9	Add the L2TS before the result of 8	4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS))
10	Add any Ramp On and Ramp Off fields to the result of 9 and transmit using LR 2-FSK modulation.	4.2.1 (Ramp On Field), 4.2.9 (Ramp Off Field), and 4.5.1.1.1 (LR 2-FSK Modulation)

[27] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the L4TS field. The value of this symbol is defined in 4.2.2.3 (CSMA LR 4-FSK Training Sequence Field (L4TS)).

[28] The initial previous symbol state of the differential encoder (*Previous d-symbol*) is defined by the last transmitted symbol of the L2TS field. The value of this symbol is defined in 4.2.2.2 (CSMA LR 2-FSK Training Sequence Field (L2TS)).

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4.4.2 PHY Receive Processes

This section defines requirements on the PHY Receive Process according to HomeRF node type.

The node shall be able to receive the PPDU formats as defined in Table 29.

Table 29 - Required Support for PPDU formats as a function of Node Type

Node Type	TDMA PPDU	Basic Rate Single PSDU	Extended Preamble High Rate Single PSDU	Dual PSDU	Dual Beacon
I-node	M	X	X	X	M1
A-node	X	M	M	O	M2
S-node	X	M	M	O	M2
AI-node	M	M	O	O	M3
SI-node	M	M	O	O	M3
Class-3 CP	X	M	M	O	M2
Class-2 CP	X	M	M	O	M2
Class-1 CP	M	M	M	O	X

Notes

M - Support for Receiving this PPDU format is mandatory
O - Support for Receiving this PPDU format is optional
X - The node shall not receive this PPDU format

M1 - The node shall be capable of receiving a *Dual **Beacon*** PPDU as a *TDMA PPDU* format
M2 - The node shall be capable of receiving a *Dual **Beacon*** PPDU as a *Single PSDU* format
M3 - The node shall be capable of receiving a *Dual **Beacon*** PPDU as a *Dual Beacon* format

4.4.3 Effect of Receiving Unsupported PPDU formats (Informative)

An A-node, Class-2 or Class-3 CP that receives a TDMA format PPDU will usually generate a PD_RX_START/END indication pair. However, the TDMA data might contain a bit pattern that descrambles using the CSMA descrambler to the CSFD pattern. In this case, there may be a spurious PD_RX_MAC_INITIAL_HEADER indication. This will probably be rejected by the MAC Rx process as invalid. Alternatively, the PHY will detect loss of carrier before the end of PSDU1.

An A-node, Class-2 CP or Class-3 CP is required to be able to receive a *Dual Beacon* format PPDU as though it were a *Basic Rate Single PSDU* format. Again, the TDMA Beacon part may appear to contain a spurious CSFD, in which case it is likely that the entire beacon PPDU will be discarded. This event will not persistently occur, because the TDMA Beacon part includes near its beginning a field that varies with successive beacons.

An I-node is unlikely to receive non-TDMA frames, except during scanning. This is because the position of a TDMA frame is known in advance with an accuracy of a few microseconds. If it does wrongly receive a non-TDMA frame, the frame will, with high probability, be discarded because of a 16-bit CRC check failure.

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4.4.4 PHY Receive State Machine

This section describes the management of the PHY Receive Processes in the form of a state machine.

An AI-node needs additional receive states not described here to receive a *Dual Beacon* format PPDU.

4.4.4.1 PHY Receive States

PHY Rx State	Description
Idle	There is no Rx activity
Pending SFD	A TS field has been detected
TDMA Pending MIH	An TDMA SFD has been detected
TDMA Receiving PSDU1	The MIH has been received, the remainder of the PSDU1 is being received
CSMA Pending MIH	A CSMA SFD has been detected
CSMA Receiving PSDU1	The MIH has been received, the remainder of the PSDU1 is being received
Pending EFD1	The PSDU has been received, but the EFD has not been received
Skipping PSDU2	The PSDU2 cannot be received because the modulation type is not supported by this PHY. The PHY is waiting for the end of PSDU2 based on channel assessment defined in 4.7.2 (End of PSDU Detection).
Pending SFD2	The first EFD has been received, and the PD_RX_PSDU1 response was *Continue*.
Receiving PSDU2	The second SFD has been received, and the second PSDU is being received
Pending EFD2	The second PSDU has been received, but the EFD has not been received
High Rate Idle	Waiting for High Rate PPDU RX activity
High Rate Pending SFD	A High Rate preamble has been detected
High Rate Pending MIH	A High Rate CSFD has been detected
High Rate Receiving PSDU1	The High Rate MIH has been received, the remainder of the PSDU1 is being received

The three shaded states (and associated transitions) are only supported if the node supports *Dual PSDU* formats.

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4.4.4.2 PHY Receive Events

PHY Rx Event / Condition	Definition
Preamble	HomeRF preamble has been detected. A special case of this event exists for the *Extended Preamble High Rate Single PSDU* PPDU format. With this format, this event indicates that the LR preamble extension plus the high-rate preamble have been detected.
TDMA SFD	An TDMA SFD has been received - see sections 4.2.4.1 (TDMA Start of Frame Delimiter (TSFD)) and 4.4.6 (TDMA SFD Delimiter Procedures)
CSMA SFD	A CSMA SFD has been received - see sections 4.2.4.2 (CSMA Start of Frame Delimiter (CSFD)) and 4.4.7 (CSMA SFD and EFD Delimiter Procedures)
MIH	The first *MPDUinitialHeaderLength* bytes of the PSDU1 have been received. The modulation type of any non-basic modulation PSDU is determined
EFD	An EFD has been received
PSDU1 Completed	*Length 1* bytes of PSDU1 have been received
PSDU2 Completed	*Length 2* bytes of PSDU2 have been received
PSDU2 Clear	The result of a channel assessment using the procedure defined in 4.7.2 (End of PSDU Detection) is *Clear*
Loss of Carrier	The on-air signal has been lost. The criteria that define this event are specific to the implementation. *Loss of Carrier* detection is optional during high-rate (HR 2-FSK or HR 4-FSK) reception.
Continue	The response to a PD_RX_PSDU1 indication specifies *Continue* behavior
Skip	The response to a PD_RX_PSDU1 indication specifies *Skip PSDU2* behavior
HR PPDU Attributes expected	The response to a PD_RX_PSDU1 indication or a PD_RX_SET_PPDU_ATTRIBUTES request specifies *High Rate PPDU attributes* that are expected
PSDU2 Missing	The PSDU2 is not present. The criteria that define this event are specific to the implementation.

4.4.4.3 PHY Receive State Transition Diagram

Figure 37 shows the state transitions of this interface as a state transition diagram. This diagram is simplified by omission of a number of "EFD" transitions. The full state machine is defined in section 4.4.4 (PHY Receive State Machine).

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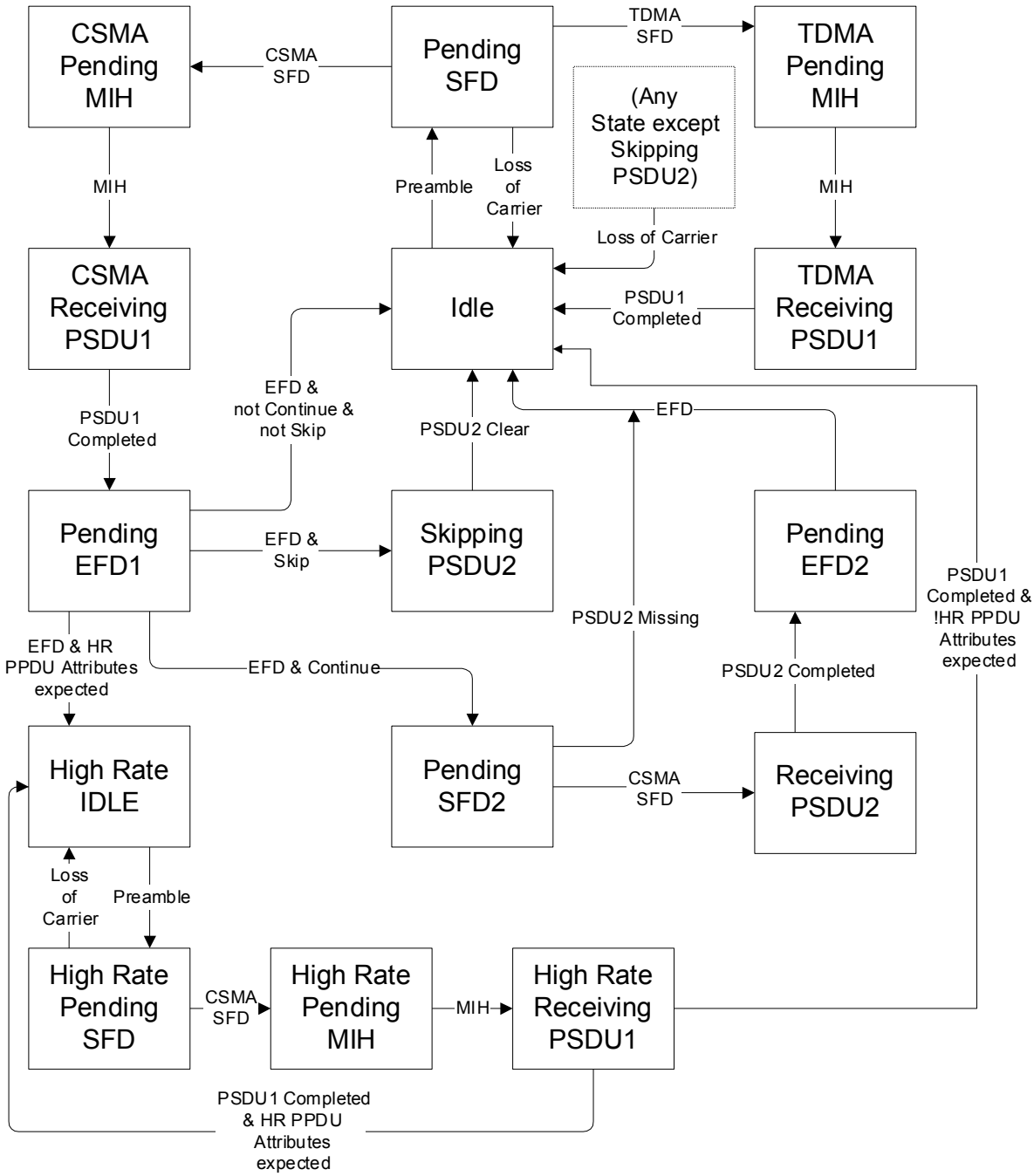


Figure 37 - PHY Receive State Transition Diagram

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4.4.4.4 PHY Receive State Transitions and Indications

Table 30 defines the PHY Receive State machine. It shows the indications that shall be emitted to the MAC layer through the PD-SAP when a transition occurs.

Table 30 - PHY Rx Service Interface State Transitions and Indications

State	Event	Indication	Next State
Idle	Preamble	PD_RX_START	Pending SFD
Pending SFD	Loss of Carrier	PD_RX_END	Idle
	CSMA SFD		CSMA Pending MIH
	TDMA SFD		TDMA Pending MIH
TDMA Pending MIH	Loss of Carrier	PD_RX_END	Idle
	MIH	PD_RX_MAC_INITIAL_HEADER	TDMA Receiving PSDU1
TDMA Receiving PSDU1	Loss of Carrier	PD_RX_END	Idle
	PSDU1 Completed	PD_RX_PSDU1	Idle
CSMA Pending MIH	Loss of Carrier or EFD	PD_RX_END	Idle
	MIH	PD_RX_MAC_INITIAL_HEADER	CSMA Receiving PSDU1
CSMA Receiving PSDU1	Loss of Carrier or EFD	PD_RX_END	Idle
	PSDU1 Completed		Pending EFD1
Pending EFD1	Loss of Carrier	PD_RX_END	Idle
	EFD & Continue	PD_RX_PSDU1	Pending SFD2
	EFD & Not Continue & Not Skip	PD_RX_PSDU1	Idle
	EFD & Skip	PD_RX_PSDU1	Skipping PSDU2
	EFD & HR PPDU Attributes expected	PD_RX_PSDU1	High Rate Idle
Skipping PSDU2	PSDU2 Clear	PD_RX_END	Idle
Pending SFD2	CSMA SFD		Receiving PSDU2
	PSDU2 Missing	PD_RX_END	Idle
Receiving PSDU2	Loss of Carrier or EFD	PD_RX_END	Idle

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State	Event	Indication	Next State
	PSDU2 Completed		Pending EFD2
Pending EFD2	Loss of Carrier	PD_RX_END	Idle
	EFD	PD_RX_PSDU2	Idle
High Rate Idle	Not HR PPDU Attributes expected		Idle
	Preamble	PD_RX_START	High Rate Pending SFD
High Rate Pending SFD	Not HR PPDU Attributes expected		Idle
	Loss of Carrier	PD_RX_END	High Rate Idle
	CSMA SFD		High Rate Pending MIH
High Rate Pending MIH	Not HR PPDU Attributes expected		Idle
	Loss of Carrier	PD_RX_END	High Rate Idle
	MIH	PD_RX_MAC_INITIAL_HEADER	High Rate Receiving PSDU1
High Rate Receiving PSDU1	Not HR PPDU Attributes expected		Idle
	Loss of Carrier	PD_RX_END	High Rate Idle
	PSDU1 Completed & HR PPDU Attributes expected	PD_RX_PSDU1	High Rate Idle
	PSDU1 Completed & Not HR PPDU Attributes expected	PD_RX_PSDU1	Idle

In the *Skipping PSDU2* state, the PHY shall continually perform the procedure defined in section in 4.7.2 (End of PSDU Detection). The PSDU2 clear event is declared when this procedure indicates a *Clear* channel.

The *High Rate* states are used when *high-rate* PPDU formats and modulation types that are supported are being processed. The format and modulation type would have been indicated to the PHY via the PD_RX_PSDU1 response *status* or via the PD_RX_SET_PPDU_ATTRIBUTES request before the *high-rate* PPDU was to arrive. In the case of the *Extended Preamble High Rate Single PSDU* PPDU format, the PHY will derive the actual *high-rate* modulation type from the *extended preamble*.

4.4.5 Stuffing and Stuff Bit Removal

4.4.5.1 Stuffing (Informative)

Bit insertion is used to ensure that the FLAG characters used in the CSFD and the EFD do not appear in the data stream. Bit insertion operates on a sequence of bits and produces another sequence of bits. Since the procedure operates on bits, it is independent of the type of modulation. A HomeRF receiver performs the inverse operation. It removes the inserted bits before passing the data on.

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Stuffing results in data-dependent PPDU length. Stuffing is not used for the TDMA format and the TDMA portion of the *Dual Beacon* PPDU. Stuffing is not used for the *high-rate* formats.

4.4.5.2 Stuffing Procedure

The stuffing process takes as input a single bit and provides as output one or two bits.

The process first copies the input bit to the output. It then generates an additional (stuff) bit with value 0 whenever five consecutive bits with value 1 have been output by this process. Stuffing is restarted at the start of each PSDU.

4.4.5.3 Stuff Bit Removal Procedure

The stuff bit removal procedure takes as input one or two bits and provides as output a single bit.

The process takes the first input bit and copies this to the output. If five consecutive ones have been input by this process, it takes a second input bit and discards it.

4.4.5.4 Example of Bit-Stuffer Operation (Informative)

Figure 38 shows an example of the operation of the Bit-stuffer for a typical input sequence. The inserted (stuffed) bits are shown underlined.

Stuffer input	0 1 0 0 1 0 1 1 0 1 1 1 1 1 0 1 0 1 1 0 0 0 0 1 1 1 1 1 1 1 0 1 0 1
Stuffer output	0 1 0 0 1 0 1 1 0 1 1 1 1 1 0 0 1 0 1 1 0 0 0 0 1 1 1 1 1 0 1 1 0 1 0 1

Figure 38 - Example of Bit-Insertion Operation

4.4.6 TDMA SFD Delimiter Procedures

4.4.6.1 Transmission

The PHY shall transmit a TDMA SFD field containing the pattern defined in section 4.2.4.1 (TDMA Start of Frame Delimiter (TSFD)).

4.4.6.2 Detection

The PHY shall only recognize a TDMA SFD when it matches the receive bits of the TDMA SFD defined in section 4.2.4.1.

The PSDU field starts in the symbol following the TDMA SFD field.

4.4.7 CSMA SFD and EFD Delimiter Procedures

4.4.7.1 Overview (Informative)

The CSMA SFD (CSFD) and EFD are unique words that, due to the bit-insertion procedure, are guaranteed not to appear in the data stream. These fields are used to delimit the PSDUs in the CSMA PPDU formats that employ bit-stuffing.

The end of frame delimiter (EFD) is used to determine the exact end of a frame.

The bit-insertion procedure described in 4.4.5 ensures that FLAG characters do not appear in the data stream. Because the bit-insertion procedure is data dependent, it is difficult to predict the time when the end of frame occurs. The EFD is used to indicate the end of a frame.

The CSMA scrambler is in an unknown state at the start of the transmitted CSFD field, so the first 9 bits of the received CSFD field are undefined.

4.4.7.2 CSFD Detection

The PHY shall only recognize the CSFD field when it matches two FLAG characters followed by an 8-bit sequence that is not a FLAG character.[29] [30]

[29] Because of Descrambler synchronization, the first 9 bits of the received SFD vary from frame to frame.

[30] Note, the receiver may receive between 2 and 4 flag characters in the SFD field.

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The first bit of a (CSMA) low-rate PSDU is the one following the last FLAG character in the CSFD.

In the case of high-rate PPDUs, which are not bit stuffed, the CSFD field serves only to allow the descrambler time to synchronize. The location of the first bit of a high-rate PSDU is determined by synchronizing to other unique symbol patterns within the high-rate training sequence.

4.4.7.3 EFD Detection

The PHY shall detect the EFD when a FLAG character has been matched and the first FLAG characters in a sequence of one or more FLAGS characters is detected.[31] [32] EFD detection does not apply to high-rate PPDUs, which are not bit stuffed.

In bit-stuffed PSDUs, the last bit of the (CSMA) PSDU is the one preceding the EFD field.

4.4.8 CSMA Scrambler

This section defines the CSMA scrambler that is used for the CSMA PSDU formats

4.4.8.1 Presentation (Informative)

The CSMA scrambler and descrambler are defined in this specification using normative Verilog source code. An informative test harness and normative test vectors are supplied that allow correct operation of the CSMA scrambler and descrambler processes to be observed.

4.4.8.2 Overview (Informative)

In order to ensure transitions to aid in clock recovery implementations a scrambling algorithm is used. Scrambling is used on all but the *training sequence* field and any *Ramp On, Gap* and *Ramp Off* fields.

The process involves randomizing the data using a self-synchronizing scrambler based on a 9-bit LFSR. The descrambler is self-synchronizing [33] typically requiring 9 bits to flush its previous state and become synchronized with the scrambler. The first 9 bits output by the descrambler are undefined whenever the scrambler starts up or there is a transition from unscrambled bits to scrambled bits. For this reason, the first 9 received bits of the CSFD following the *training sequence* field are undefined.

The CSMA scrambler incorporates two anti lock-up mechanisms to avoid generating long sequences of ones or alternating 1010…. These sequences should be avoided because when supplied to the differential encoder (see section 4.4.11 (Differential Encoder/Decoder)) they result in a constant deviation that makes it harder for a decoder to maintain symbol clock alignment. The descrambler performs the same procedures as the scrambler (including the lock-up mechanisms) in order to maintain synchronization.

The operation of the anti-lock-up mechanisms can result in a synchronization length longer than 9. Based upon simulations using pseudo-random packets, the probability that the synchronization length exceeds 9 bits is approximately 0.2%.

The scrambler anti-lock-up mechanisms ensure that common sequences of input bits [34] do not produce an “all ones” output sequence. However, for any given initial state of the scrambler there is a unique sequence of input bits that results in an all-ones output.

The CSMA scrambler processes are described in sections 4.4.8.3 to 4.4.9.2 below.

4.4.8.3 CSMA Scrambler Core (Informative)

The CSMA scrambler core takes a single bit of input and produces a single bit of output. This interface is shown in Figure 39.

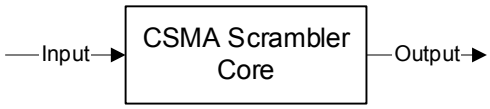


Figure 39 - Interface to CSMA Scrambler Core

[31] More than one FLAG character may be appear starting at the EFD field position. The first is the EFD field. Any subsequent FLAG characters are part of the *Ramp Off* or *Gap* fields. These are ignored by the PHY Rx State Machine.

[32] There is no logical need to predicate the EFD detection on the PHY Rx State. The state machine ignores EFD events that occur when no EFD is expected.

[33] *i.e.* the de-scrambler does not require knowledge of the scrambler’s initial state

[34] Such as all ones or all zeroes, or alternating 1,0.

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The CSMA scrambler core uses the generator polynomial $S(x)$ as defined in Equation 1 plus two anti-lock-up mechanisms.

Equation 1 - CSMA Scrambler Generator Polynomial

$$S(x) = x^9 + x^5 + 1$$

Figure 40 shows the core without any anti-lock-up mechanisms.

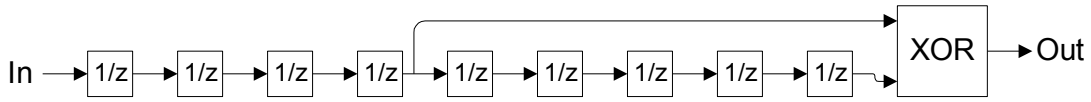


Figure 40 - Simplified view of CSMA Scrambler Core

The first lockup mechanism inverts the state of the output if, in the previous cycle, the shift register bits[35] and the input bit are all zeroes or all ones and the lockup state was not detected in the cycle preceding that.

The second anti-lock-up mechanism forces an input to the shift register bits and the input bit have been all zeroes or all ones for 16 successive cycles.

Figure 41 shows the CSMA scrambler core algorithm including the anti-lock-up mechanisms. The *Count 16* box outputs a 1 if there have been 16 successive ones on the input and then resets itself. [36] Some of the corresponding Verilog "wire" names are also shown on the figure.

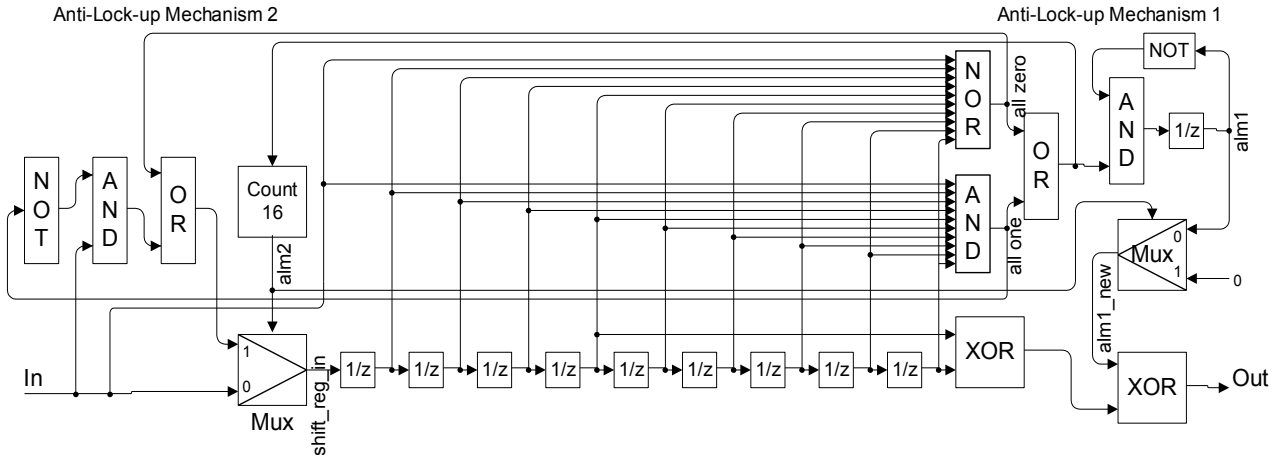


Figure 41 - CSMA Scrambler Core

[35] *i.e.* the 1/z boxes.

[36] *i.e.* it requires another 16 clocks before it can generate a "1" output.

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4.4.8.4 CSMA Scrambler (Informative)

The scrambler process is shown in Figure 42.

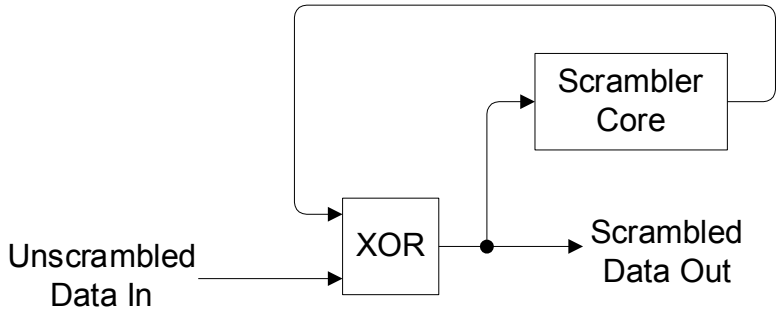


Figure 42 - Scrambler Process

4.4.8.5 Descrambler (Informative)

The descrambler process is show in Figure 43.

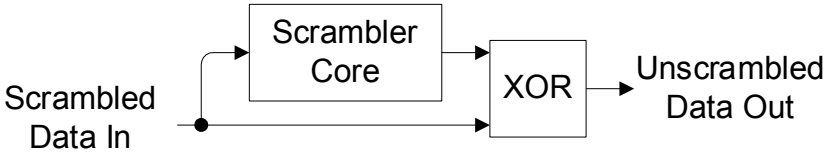


Figure 43 - Descrambler Process

4.4.8.6 CSMA Scrambler Code

The operation of the CSMA scrambler process is defined by the following Verilog code.

```
/*
   scramble.v  HomeRF v1.1

   signal      I/O      Description
   ------------------------------------------------------------
   CLK         Input    scrambler clock input
   CLR         Input    low-true reset signal
   TX_RX       Input    if low (RX), module is in reset state
   TX_ENAB     Input    scrambler enable
   TX_DATA     Input    scrambler serial input
   SCR_DATA    Output   scrambler serial output
*/
module scramble ( CLK, CLR, SCR_DATA, TX_DATA, TX_ENAB, TX_RX );
input       CLK, CLR;
output      SCR_DATA;
input       TX_DATA, TX_ENAB, TX_RX;

// *********
// registers
// *********
reg         SCR_DATA;
reg  [8:0]  shift_reg;
reg         alm1;           // Anti-lockup Mechanism 1
reg         tx_data_p1;     // Registered tx_data
reg         alm2;           // Anti-lockup Mechanism 2 event
reg  [3:0]  lockup_cnt;     // Anti-lockup Mechanism 2 count

// ****************
// wire declaration
// ****************
wire        CLRN;
```

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```
wire        alm1_new;
wire        scr_data_pre;
wire        shift_reg_in;
wire        all_one;
wire        all_zero;

// internal clearN signal for all regs
assign   CLRN     =  TX_RX && CLR;

assign   alm1_new =  alm2 ? 1'b0 : alm1;

// here is the scrambled data bit
assign   scr_data_pre   = tx_data_p1 ^ ( shift_reg[3] ^
                                         (shift_reg[8] ^ alm1_new)
                                        );

assign   shift_reg_in   = alm2 ? (all_zero || (!all_one && scr_data_pre))
                                  : scr_data_pre;

// shift register all one or all zero
assign   all_one  =  (shift_reg == 9'h1FF &&  scr_data_pre);
assign   all_zero =  (shift_reg == 9'h000 && !scr_data_pre);

always   @(posedge CLK or negedge CLRN)
   if (!CLRN) begin
      shift_reg   <= #1 9'b0;
   end
   else if (TX_ENAB) begin
      shift_reg   <= #1 {shift_reg[7:0], shift_reg_in};
   end

always @(posedge CLK or negedge CLRN)
   if (!CLRN)
      tx_data_p1  <= #1 1'b0;
   else if (TX_ENAB)
      tx_data_p1  <= #1 TX_DATA;

// a lockup condition occurs when shift_reg is stuck in all zero or all one
// for 16 clocks.
always @(posedge CLK or negedge CLRN) begin
   if (~CLRN) begin
      lockup_cnt  <= #1 4'b0;
      alm2   <= #1 1'b0;
   end
   else if (TX_ENAB) begin
      if (all_one || all_zero) begin
         lockup_cnt  <= #1 lockup_cnt + 1'b1;
         alm2   <= #1 (lockup_cnt == 4'hf);
      end
      else begin
         lockup_cnt  <= #1 4'b0;
         alm2   <= #1 1'b0;
      end
   end
end

// jump start toggles when shift_reg[8:0] is all one or all zero
always @(posedge CLK or negedge CLRN)
   if (!CLRN)
      alm1     <= 1'b0;
   else if (TX_ENAB)
      alm1     <= #1 (all_one || all_zero) && !alm1;

// clock out SCR_DATA
always @(posedge CLK or negedge CLRN)
   if (!CLRN)
      SCR_DATA   <= 1'b0;
   else if (TX_ENAB)
```

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```
      SCR_DATA   <= #1 scr_data_pre;

endmodule
```

4.4.8.7 CSMA Descrambler Code

The operation of the CSMA descramber process is defined by the following Verilog code.

```
/*
   unscrmbl.v  HomeRF 1.1

   signal      I/O      Description
   ------------------------------------------------------------
   CLK         Input    unscrambler clock input
   CLR         Input    low-true reset signal
   RX_ENAB     Input    unscrambler enable
   SERIN       Input    unscrambler serial input
   SEROUT      Output   unscrambler serial output
*/
module unscrmbl ( CLK, CLR, RX_ENAB, SERIN, SEROUT );
input       CLK, CLR, RX_ENAB, SERIN;
output      SEROUT;

// *********
// registers
// *********
reg  [8:0]  shift_reg;
reg         alm1;
reg         SEROUT;
reg         alm2;
reg  [3:0]  lockup_cnt;

// ****************
// wire declaration
// ****************
wire        all_one;
wire        all_zero;
wire        alm1_new;
wire        shift_reg_in;
wire        serout_pre;

// shift register all one or all zero
assign      all_one  =  (shift_reg == 9'h1FF &&  SERIN);
assign      all_zero =  (shift_reg == 9'h000 && !SERIN);

assign      alm1_new =  (alm2) ? 1'b0 : alm1;

assign      shift_reg_in   =  (alm2) ? (all_zero || (!all_one && SERIN))
                                     : SERIN;
// unscramble is done here
assign      serout_pre     =  SERIN ^ ( shift_reg[3] ^
                                       (shift_reg[8] ^ alm1_new)
                                     );

always @(posedge CLK or negedge CLR)
   if (!CLR)
      shift_reg   <= #1 9'b0;
   else if (RX_ENAB)
      shift_reg   <= #1 {shift_reg[7:0], shift_reg_in};

always @(posedge CLK or negedge CLR)
   if (!CLR)
      alm1  <= #1 1'b0;
   else if (RX_ENAB)
      alm1  <= #1 (all_one || all_zero) && !alm1;
```

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```
always @(posedge CLK or negedge CLR)
   if (!CLR)
      SEROUT   <= #1 1'b0;
   else if (RX_ENAB)
      SEROUT   <= #1 serout_pre;

always @(posedge CLK or negedge CLR) begin
   if (~CLR) begin
      lockup_cnt  <= #1 4'b0;
      alm2   <= #1 1'b0;
   end
   else if (RX_ENAB) begin
      if (all_one || all_zero)
         begin
         lockup_cnt  <= #1 lockup_cnt + 1'b1;
         alm2   <= #1 (lockup_cnt == 4'hf);
      end
      else begin
         lockup_cnt  <= #1 4'b0;
         alm2   <= #1 1'b0;
      end
   end
end

endmodule
```

4.4.8.8 CSMA Scrambler Test Harness (Informative)

The following code permits the test vectors defined in section 4.4.8.9 to be tested with the CSMA scrambler and descrambler processes defined in sections 4.4.8.6 (CSMA Scrambler Code) and 4.4.8.7 (CSMA Descrambler Code).

```
/*
   scram_top.v   HomeRF v1.1

   This module does the following:
   -  instantiation of scramble.v and unscrmbl.v
   -  application of scram.vec to scramble/unscramble
   -  internal states reporting and expected result checking

*/

`timescale  1ns/100ps

`include "scramble.v"
`include "unscrmbl.v"

module   scram_test ;

reg         CLK;
reg         CLR;
reg         TX_DATA;
reg         TX_ENAB;
reg         TX_RX;
reg         RX_ENAB;
reg         SERIN;

wire        SCR_DATA;
wire        SEROUT;

reg [31:0]  scrambler_output;
reg [31:0]  unscrambler_output;

// rtl and vrtl module instantiation
scramble scramble (
   .CLK           (CLK),
   .CLR           (CLR),
```

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```
   .SCR_DATA      (SCR_DATA),
   .TX_DATA       (TX_DATA),
   .TX_ENAB       (TX_ENAB),
   .TX_RX         (TX_RX)
   );

unscrmbl unscrmbl (
   .CLK           (CLK),
   .CLR           (CLR),
   .RX_ENAB       (RX_ENAB),
   .SERIN         (SCR_DATA),    // from scramble
   .SEROUT        (SEROUT)
   );

// clock generation
always   #50   CLK   =  !CLK;

integer  test_id;

initial begin
   CLK      =  1'b0;
   CLR      =  1'b0;
   TX_DATA  =  1'b1;
   SERIN    =  1'b0;
   TX_ENAB  =  1'b0;
   TX_RX    =  1'b1;
   RX_ENAB  =  1'b0;
   test_id  =  0;
   scrambler_output     =  32'b0;
   unscrambler_output   =  32'b0;

   reset;

   `include "scram.vec"

   cyc(10);

   $finish;
end

task  reset;
begin
   cyc(1);
   CLR   =  1'b0;
   cyc(3);
   CLR   =  1'b1;
end
endtask

// logs the serial outputs from scrambler and unscrambler
always   @(negedge CLK) begin
   scrambler_output     <= {scrambler_output[30:0],   SCR_DATA};
   unscrambler_output   <= {unscrambler_output[30:0], SEROUT  };
end

integer        i, j;
```

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```
task  scram;
// the following inputs are defined in HomeRF v1.1 section 4.4.6
input          L;       // synchronization length
input [8:0]    SIS_SR;  // scrambler initial state - shift register
input          SIS_AL;  // scrambler initial state - anti-lock-up mechanism 1
input [3:0]    SIS_CT;  // scrambler initial state - count 16 box
input          SIS_NS;  // scrambler initial state - anti-lock-up mechanism 2
input [31:0]   SI;      // input bit sequence
input [8:0]    SFS_SR;  // scrambler final state - shift register
input          SFS_AL;  // scrambler final state - anti-lock-up mechanism 1
input [3:0]    SFS_CT;  // scrambler final state - count 16 box
input          SFS_NS;  // scrambler final state - anti-lock-up mechanism 2
input [31:0]   SB;      // scrambler output == descrambler input
input [8:0]    DIS_SR;  // descrambler initial state - shift register
input          DIS_AL;  // descrambler initial state - anti-lock-up mechanism 1
input [3:0]    DIS_CT;  // descrambler initial state - count 16 box
input          DIS_NS;  // descrambler initial state - anti-lock-up mechanism 2
input [31:0]   DO;      // descrambler output bits
input [8:0]    DFS_SR;  // descrambler final state - shift register
input          DFS_AL;  // descrambler final state - anti-lock-up mechanism 1
input [3:0]    DFS_CT;  // descrambler final state - count 16 box
input          DFS_NS;  // descrambler final state - anti-lock-up mechanism 2
integer        L;       // original sync length
// internal registers
integer        l;       // calculated sync length
reg   [8:0]    sis_sr, dis_sr;   // initial shift_register conditions
reg   [8:0]    sfs_sr, dfs_sr;   //   final shift_register conditions
reg            sfs_al, dfs_al;   //   final anti-lock-up mechanism 1 value
reg   [3:0]    sfs_ct, dfs_ct;   //   final count 16 box
reg            sfs_ns, dfs_ns;   //   final anti-lock-up mechanism 2 value
reg   [31:0]   sb,     do    ;   //   final scrambler/unscrambler outputs
integer        err;
begin

   $display("\n--- Test#%0d ---", test_id);
   err   =  0;
   i     =  99;
   reset;

   // set up initial condition for scrambler and descrambler
   force_initial_condition (SIS_SR, SIS_AL, SIS_CT, SIS_NS, DIS_SR, DIS_AL, DIS_CT, DIS_NS);

   cyc(1);

   // Note on pipelining...
   // An input bit reaches (affects) the following register after a delay
   // as defined in this table:
   // Clock    Location
   //   1         scramble.tx_data_p1
   //   2         SCR_DATA
   //   3         SEROUT,  scrambler_output
   //   4         unscrambler_output

   // Clock input sequence into the scrambler
   for (i=0; i<32; i=i+1) begin
      if (i==0) begin
         TX_ENAB = 1'b1;
         release_initial_condition_scrambler;
      end
      TX_DATA     =  SI[31-i];      // left-most bit first
      cyc(1);
      if (i==0) begin
         RX_ENAB = 1'b1;
         release_initial_condition_unscrambler;
      end
   end

   // Clock last bit into SCR_DATA
```

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```
   cyc(1);

   // log results from scrambler
   sfs_sr   =  scramble.shift_reg      ;
   sfs_al   =  scramble.alm1_new ;
   sfs_ct   =  scramble.lockup_cnt     ;
   sfs_ns   =  scramble.alm2      ;

   // Clock SCR_DATA into scrambler_output
   // and last bit into SEROUT
   cyc(1);
   sb       =  scrambler_output        ;


   // log results from unscrambler
   dfs_sr   =  unscrmbl.shift_reg      ;
   dfs_al   =  unscrmbl.alm1_new ;
   dfs_ct   =  unscrmbl.lockup_cnt     ;
   dfs_ns   =  unscrmbl.alm2      ;

   // Clock SEROUT into unscrambler_output
   cyc(1);
   do       =  unscrambler_output      ;


   // Calculate sync length
   // Scan from the later bits until we find a
   // difference;
   l        = 0;

   for (i=0; (i<32) && (l==0); i=i+1) begin
      if (do[i] != SI[i]) begin
         l  = 32-i;
      end
   end


   // print out results
   $display("scram(%d, 9'b%b, 1'b%b, 4'd%d, 1'b%b, 32'b%b, 9'b%b, 1'b%b, 4'd%d, 1'b%b, 32'b%b,
9'b%b, 1'b%b, 4'd%d, 1'b%b, 32'b%b, 9'b%b, 1'b%b, 4'd%d, 1'b%b);",
            l                       ,      // L
            SIS_SR, SIS_AL, SIS_CT ,      // SIS_SR, SIS_AL, SIS_CT
            SIS_NS                  ,      // SIS_NS
            SI                      ,      // SI
            sfs_sr                  ,      // SFS_SR
            sfs_al                  ,      // SFS_AL
            sfs_ct                  ,      // SFS_CT
            sfs_ns                  ,      // SFS_NS
            sb                      ,      // SB
            DIS_SR, DIS_AL, DIS_CT ,      // DIS_SR, DIS_AL, DIS_CT
            DIS_NS                  ,      // DIS_NS
            do                      ,      // DO
            dfs_sr                  ,      // DFS_SR
            dfs_al                  ,      // DFS_AL
            dfs_ct                  ,      // DFS_CT
            dfs_ns                  );     // DFS_NS

   // error checking
   if (sfs_sr !=  SFS_SR) begin
      $display("SFS_SR Error ! Exp: %0h, Actual: %0h", SFS_SR, sfs_sr );
      err = err+1;
   end

   if (sfs_al !=  SFS_AL) begin
      $display("SFS_AL Error ! Exp: %0h, Actual: %0h", SFS_AL, sfs_al );
      err = err+1;
   end
```

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```
   if (sfs_ct !=  SFS_CT) begin
      $display("SFS_CT Error ! Exp: %0h, Actual: %0h", SFS_CT, sfs_ct );
      err = err+1;
   end

   if (sfs_ns !=  SFS_NS) begin
      $display("SFS_NS Error ! Exp: %0h, Actual: %0h", SFS_NS, sfs_ns );
      err = err+1;
   end

   if (sb     !=  SB    ) begin
      $display("SB     Error ! Exp: %0h, Actual: %0h", SB    , sb     );
      err = err+1;
   end

   if (dfs_sr !=  DFS_SR) begin
      $display("DFS_SR Error ! Exp: %0h, Actual: %0h", DFS_SR, dfs_sr );
      err = err+1;
   end

   if (dfs_al !=  DFS_AL) begin
      $display("DFS_AL Error ! Exp: %0h, Actual: %0h", DFS_AL, dfs_al );
      err = err+1;
   end

   if (dfs_ct !=  DFS_CT) begin
      $display("DFS_CT Error ! Exp: %0h, Actual: %0h", DFS_CT, dfs_ct );
      err = err+1;
   end

   if (dfs_ns !=  DFS_NS) begin
      $display("DFS_NS Error ! Exp: %0h, Actual: %0h", DFS_NS, dfs_ns );
      err = err+1;
   end

   if (do     !=  DO    ) begin
      $display("DO     Error ! Exp: %0h, Actual: %0h", DO    , do     );
      err = err+1;
   end

   // synchronization comparison
   if (SI[31-L] !== do[31-L]) begin
      $display("Exp: SI = %0b", SI);
      $display("Act: DO = %0b", do);
      err = err+1;
   end

   $display("Total Error = %0d", err);

   cyc(20);

   // increment test_id
   test_id  =  test_id + 1;
end
endtask

reg   force_scrambler;
reg   force_unscrambler;

task  force_initial_condition;
input [8:0]    SIS_SR;  // scrambler initial state - shift register
input          SIS_AL;  // scrambler initial state - anti-lock-up mechanism 1
input [3:0]    SIS_CT;  // scrambler initial state - count 16 box
input          SIS_NS;  // scrambler initial state - anti-lock-up mechanism 2
input [8:0]    DIS_SR;  // descrambler initial state - shift register
input          DIS_AL;  // descrambler initial state - anti-lock-up mechanism 1
input [3:0]    DIS_CT;  // descrambler initial state - count 16 box
input          DIS_NS;  // descrambler initial state - anti-lock-up mechanism 2
```

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```
begin
   force_scrambler               =  1'b1;
   force_unscrambler             =  1'b1;

   force scramble.shift_reg      =  SIS_SR;
   force scramble.alm1           =  SIS_AL;
   force scramble.lockup_cnt     =  SIS_CT;
   force scramble.alm2           =  SIS_NS;
   force SCR_DATA                =  0;
   force scramble.tx_data_p1     =  0;

   force unscrmbl.shift_reg      =  DIS_SR;
   force unscrmbl.alm1           =  DIS_AL;
   force unscrmbl.lockup_cnt     =  DIS_CT;
   force unscrmbl.alm2           =  DIS_NS;
   force SEROUT                  =  0;
end
endtask

task  release_initial_condition_scrambler;
begin
   force_scrambler               =  1'b0;
   release scramble.shift_reg      ;
   release scramble.alm1           ;
   release scramble.lockup_cnt     ;
   release scramble.tx_data_p1     ;
   release scramble.alm2           ;
   release SCR_DATA                ;
end
endtask

task  release_initial_condition_unscrambler;
begin
   force_unscrambler             =  1'b0;
   release unscrmbl.shift_reg      ;
   release unscrmbl.alm1           ;
   release unscrmbl.lockup_cnt     ;
   release unscrmbl.alm2           ;
   release SEROUT                  ;
end
endtask

task  cyc;
input    num;
integer  num, i;
begin
   for (i=0; i<num; i=i+1) begin
      @(negedge CLK);
   end
end
endtask

endmodule
```

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4.4.8.9 CSMA Scrambler Test Vectors

This section contains test vectors for the CSMA scrambler core.

A compliant HomeRF node shall be capable of matching all the test vectors in Figure 44. Each row of the table defines one test for the scrambler and one test for the descrambler.

Table 31defines the fields present in a test vector.

Table 31 - Field Definitions for the CSMA Scrambler Test Vectors

Field	Contains	Representation
L	Synchronization Length	Decimal number
SIS_SR	Scrambler initial state for the shift register	9 bits. The rightmost corresponds to reg[0].
SIS_AL	Scrambler initial state for the anti-lockup mechanism 1	1 bit
SIS_CT	Scrambler initial state for the count-16 box	Integer: 2 decimal digits in range 00 to 15
SIS_NS	Scrambler initial state for the anti-lockup mechanism 2	1 bit
SI	Input bit sequence	32 bits. The left-most bit is fed to the scrambler first.
SFS_SR, SFS_AL, SFS_CT, SFS_NS	Scrambler final state	Same format as corresponding SIS field
SB	Scrambled Bits (Scrambler Output, Descrambler Input)	Same format as SI
DIS_SR, DIS_AL, DIS_CT, DIS_NS	Descrambler Initial State	Same format as corresponding SIS field
DO	Descrambler Output Bits	Same format as SI
DFS_SR, DFS_AL, DFS_CT, DFS_NS	Descrambler Final State	Same format as corresponding SIS field

Figure 44 - CSMA Scrambler Test Vectors

```
/* scram.vec HomeRF v1.1

 CSMA Scrambler and Descrambler test vectors

*/
scram(          0, 9'b000000000, 1'b0, 4'd00, 1'b0, 32'b00000000000000000000000000000000,
9'b011011000, 1'b0, 4'd00, 1'b0, 32'b10001000110010001110101011011000, 9'b000000000, 1'b0,
4'd00, 1'b0, 32'b00000000000000000000000000000000, 9'b011011000, 1'b0, 4'd00, 1'b0);
```

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```
scram(          0, 9'b000000000, 1'b0, 4'd00, 1'b0, 32'b11111111111111111111111111111111,
9'b001001000, 1'b0, 4'd00, 1'b0, 32'b01111000010001111010011001001000, 9'b000000000, 1'b0,
4'd00, 1'b0, 32'b11111111111111111111111111111111, 9'b001001000, 1'b0, 4'd00, 1'b0);

scram(          8, 9'b110011010, 1'b1, 4'd02, 1'b0, 32'b00001111010001111011111000101111,
9'b001111010, 1'b0, 4'd00, 1'b0, 32'b11001001001100000010010001111010, 9'b000000111, 1'b1,
4'd07, 1'b0, 32'b00110010010001111011111000101111, 9'b001111010, 1'b0, 4'd00, 1'b0);

scram(          6, 9'b010011101, 1'b0, 4'd08, 1'b0, 32'b01100111000100010110110110110101,
9'b100111111, 1'b0, 4'd00, 1'b0, 32'b01001110010100110111001100111111, 9'b001111001, 1'b0,
4'd13, 1'b0, 32'b00000011000100010110110110110101, 9'b100111111, 1'b0, 4'd00, 1'b0);

scram(          7, 9'b100101001, 1'b0, 4'd03, 1'b0, 32'b00111001110001111101111101101000,
9'b110100100, 1'b0, 4'd00, 1'b0, 32'b00110011111000000010110110100100, 9'b111110011, 1'b1,
4'd09, 1'b0, 32'b10100011110001111101111101101000, 9'b110100100, 1'b0, 4'd00, 1'b0);

scram(          4, 9'b010110110, 1'b1, 4'd09, 1'b0, 32'b00100101111000110101011010000001,
9'b001111110, 1'b0, 4'd00, 1'b0, 32'b01000111001100111111000001111110, 9'b110000110, 1'b1,
4'd14, 1'b0, 32'b00010101111000110101011010000001, 9'b001111110, 1'b0, 4'd00, 1'b0);

scram(          5, 9'b110011010, 1'b1, 4'd06, 1'b0, 32'b11010010101010111101110101000100,
9'b111011110, 1'b0, 4'd00, 1'b0, 32'b00011001101111001100111111011110, 9'b111100010, 1'b1,
4'd06, 1'b0, 32'b10101010101010111101110101000100, 9'b111011110, 1'b0, 4'd00, 1'b0);

scram(          3, 9'b100001000, 1'b1, 4'd01, 1'b0, 32'b11110111111010000010101001001101,
9'b010010010, 1'b0, 4'd00, 1'b0, 32'b11100001000010000010110010010010, 9'b100101000, 1'b0,
4'd00, 1'b0, 32'b11010111111010000010101001001101, 9'b010010010, 1'b0, 4'd00, 1'b0);

scram(          1, 9'b111011011, 1'b1, 4'd09, 1'b0, 32'b11100101011011100011011111010111,
9'b011110110, 1'b0, 4'd00, 1'b0, 32'b01001010011011011101110011110110, 9'b101011011, 1'b1,
4'd06, 1'b0, 32'b01100101011011100011011111010111, 9'b011110110, 1'b0, 4'd00, 1'b0);

scram(          2, 9'b011101011, 1'b0, 4'd08, 1'b0, 32'b00001010011111111101111001010010,
9'b010011110, 1'b0, 4'd00, 1'b0, 32'b10011000001100001100101010011110, 9'b110101011, 1'b0,
4'd13, 1'b0, 32'b01001010011111111101111001010010, 9'b010011110, 1'b0, 4'd00, 1'b0);

scram(          0, 9'b001001010, 1'b0, 4'd03, 1'b0, 32'b00111101011110100011101110110111,
9'b110100010, 1'b0, 4'd00, 1'b0, 32'b00100101101100111101111110100010, 9'b101001010, 1'b0,
4'd10, 1'b0, 32'b00111101011110100011101110110111, 9'b110100010, 1'b0, 4'd00, 1'b0);

scram(          9, 9'b000010111, 1'b1, 4'd12, 1'b0, 32'b00010101110100001100101110100010,
9'b001100001, 1'b0, 4'd00, 1'b0, 32'b11111111010110101100101001100001, 9'b111101010, 1'b1,
4'd01, 1'b0, 32'b01001010010100001100101110100010, 9'b001100001, 1'b0, 4'd00, 1'b0);

scram(         12, 9'b011110101, 1'b1, 4'd07, 1'b0, 32'b10110101010011111011100010100011,
9'b110101011, 1'b0, 4'd00, 1'b0, 32'b11111111111011101010010110101011, 9'b101000010, 1'b1,
4'd00, 1'b1, 32'b11100010101111111011100010100011, 9'b110101011, 1'b0, 4'd00, 1'b0);

scram(         10, 9'b000011101, 1'b0, 4'd06, 1'b0, 32'b01011101001011111100111100001111,
9'b101000011, 1'b0, 4'd00, 1'b0, 32'b11111111101010101011000101000011, 9'b101011100, 1'b1,
4'd01, 1'b0, 32'b00111100111011111100111100001111, 9'b101000011, 1'b0, 4'd00, 1'b0);

scram(         14, 9'b110001001, 1'b0, 4'd11, 1'b0, 32'b10101001010100010011111100111101,
9'b100111011, 1'b0, 4'd00, 1'b0, 32'b00000000000001010110101100111011, 9'b101111000, 1'b1,
4'd13, 1'b0, 32'b01111010101011010011111100111101, 9'b100111011, 1'b0, 4'd00, 1'b0);

scram(         11, 9'b110001111, 1'b0, 4'd15, 1'b0, 32'b01101111011101011100011100010000,
9'b100111000, 1'b0, 4'd00, 1'b0, 32'b00000000001101101011100111000, 9'b101100010, 1'b0,
4'd00, 1'b0, 32'b00100010100101011100011100010000, 9'b100111000, 1'b0, 4'd00, 1'b0);

scram(         15, 9'b100101110, 1'b1, 4'd05, 1'b0, 32'b00001110101010011001001111101100,
9'b001010010, 1'b0, 4'd00, 1'b0, 32'b11111111111111011011011001010010, 9'b100010111, 1'b1,
4'd01, 1'b0, 32'b00010101010101111001001111101100, 9'b001010010, 1'b0, 4'd00, 1'b0);

scram(         13, 9'b000000000, 1'b0, 4'd12, 1'b0, 32'b10100100001000011000100010001111,
9'b111001000, 1'b0, 4'd00, 1'b0, 32'b00001101111100000111011111001000, 9'b001110001, 1'b1,
4'd04, 1'b0, 32'b01011100001010011000100010001111, 9'b111001000, 1'b0, 4'd00, 1'b0);
```

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```
scram(          8, 9'b011111111, 1'b0, 4'd05, 1'b0, 32'b11101010111010101010101010101010,
9'b111111111, 1'b0, 4'd04, 1'b0, 32'b10101111110000010101111111111111, 9'b100110000, 1'b1,
4'd05, 1'b0, 32'b10000101111010101010101010101010, 9'b111111111, 1'b0, 4'd04, 1'b0);

scram(          7, 9'b010111010, 1'b1, 4'd01, 1'b0, 32'b00111110110101010101010101010101,
9'b011001100, 1'b0, 4'd00, 1'b0, 32'b11001000001100100110101011001100, 9'b011101100, 1'b0,
4'd15, 1'b0, 32'b10101000110101010101010101010101, 9'b011001100, 1'b0, 4'd00, 1'b0);

scram(          8, 9'b101001111, 1'b1, 4'd00, 1'b0, 32'b10011110010101010101010101010101,
9'b101001101, 1'b0, 4'd00, 1'b0, 32'b00100011111110110001100101001101, 9'b000101110, 1'b0,
4'd02, 1'b0, 32'b11011111010101010101010101010101, 9'b101001101, 1'b0, 4'd00, 1'b0);

scram(          3, 9'b001010100, 1'b0, 4'd00, 1'b1, 32'b00110111110101010101010101010101,
9'b101010010, 1'b0, 4'd00, 1'b0, 32'b11101101011101001010010101010010, 9'b010110100, 1'b0,
4'd03, 1'b0, 32'b11010111110101010101010101010101, 9'b101010010, 1'b0, 4'd00, 1'b0);

scram(          8, 9'b110111000, 1'b0, 4'd00, 1'b0, 32'b01010011010101010101010101010101,
9'b100010101, 1'b0, 4'd00, 1'b0, 32'b11100101011100001110001100010101, 9'b111001001, 1'b1,
4'd03, 1'b0, 32'b00000010010101010101010101010101, 9'b100010101, 1'b0, 4'd00, 1'b0);

scram(          4, 9'b101001010, 1'b1, 4'd00, 1'b1, 32'b01010101001010101010101010101010,
9'b011010000, 1'b0, 4'd00, 1'b0, 32'b01011010101011010010111011010000, 9'b110111010, 1'b1,
4'd05, 1'b0, 32'b10100101001010101010101010101010, 9'b011010000, 1'b0, 4'd00, 1'b0);

scram(          8, 9'b110011101, 1'b1, 4'd05, 1'b0, 32'b01100110100101010101010101010101,
9'b100001110, 1'b0, 4'd00, 1'b0, 32'b01001111110011100101011100001110, 9'b100001000, 1'b1,
4'd01, 1'b0, 32'b01010011100101010101010101010101, 9'b100001110, 1'b0, 4'd00, 1'b0);

scram(          7, 9'b101100010, 1'b0, 4'd14, 1'b0, 32'b10010011100101010101010101010101,
9'b111111110, 1'b1, 4'd01, 1'b0, 32'b10101011111111111111111111111111, 9'b110110100, 1'b0,
4'd15, 1'b0, 32'b10000101100101010101010101010101, 9'b111111110, 1'b1, 4'd01, 1'b0);

scram(          8, 9'b110111100, 1'b0, 4'd12, 1'b0, 32'b01010000100101010101010101010101,
9'b000000000, 1'b0, 4'd00, 1'b1, 32'b01101010000000000000000000000000, 9'b001010001, 1'b0,
4'd14, 1'b0, 32'b00011101100101010101010101010101, 9'b000000000, 1'b0, 4'd00, 1'b1);

scram(          7, 9'b011011001, 1'b1, 4'd06, 1'b0, 32'b01001101101010101010101010101010,
9'b111111111, 1'b0, 4'd06, 1'b0, 32'b10111111000001010111111111111111, 9'b010101011, 1'b0,
4'd05, 1'b0, 32'b01111111101010101010101010101010, 9'b111111111, 1'b0, 4'd06, 1'b0);
```

4.4.9 TDMA Scrambler

4.4.9.1 TDMA Scrambler (Informative)

The scrambled data is the exclusive-OR of the original data and a scrambling sequence (SS).

Like DECT, the scrambling sequence varies from subframe to subframe. Unlike DECT, the scrambling sequence is initialised from the radio channel. [37]

The scrambling sequence is based on a pseudo random sequence of length 31 and its inverse repeated alternately. The 31-bit sequence is the maximal length sequence generated by a five stage shift register (Q_0-Q_4). The output bit of the shift register is inverted or not according to the state of an inversion mechanism "*I*". This mechanism changes between inverting and non-inverting states on the falling edge of its input which is the AND of all the Q bits.

4.4.9.2 TDMA Scrambler (Normative)

The TDMA Scrambler is defined in [4, section 6.2.4], except as defined here.

The initial states for the Q registers and the inversion mechanism are dependent on the *Channel* number defined in 5.5.2.1 (Hop Management).[38] Table 32 defines the initial values for those bits that are not dependent on the *Channel* number.

[37] Otherwise it is not possible to decode the TDMA beacon and gain network synchronization.

[38] Note this number starts at zero, regardless of locale.

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Table 32 - Initial Values of DECT Scrambler Registers

Register	Value
Q3, Q4	1
Inversion Mechanism	Inverting

The remaining Q bits shall be set so as to satisfy Equation 2.

Equation 2 - Constraint on initial values for the variable Q bits

$$Q0 + 2 \times Q1 + 4 \times Q2 = Channel \bmod 8$$

4.4.10 Bit/Symbol Conversion

The scramblers generate and accept a stream of bits in "transmission order". This is defined by section 5.4.1.2 (Byte and Bit Ordering (Normative)). The differential encoder accepts a stream of symbols in transmission order. The bit/symbol conversion provides the translation between these two data-streams.

When using 2-FSK modulation (either LR 2-FSK or HR 2-FSK), there is a one-to-one mapping between bits and symbols. When using 4-FSK modulation (either LR 4-FSK or HR 4-FSK), two bits correspond to a single symbol. The first bit in transmission order corresponds to the most significant bit (b1) of the symbol. This specification is illustrated in Table 33 and Table 34.

Table 33 - Mapping between bits and symbols (2-FSK)

Bit	Symbol
0	0
1	1

Table 34 - Mapping between 2-bit sequences and symbols (4-FSK)

2-Bit sequence	Symbol (b1, b0)
0 followed by 0	00
0 followed by 1	01
1 followed by 0	10
1 followed by 1	11

4.4.11 Differential Encoder/Decoder

4.4.11.1 Differential Encoding (Informative)

Differential encoding maps a symbol onto a differential symbol (d-symbol) such that the difference between the current and previous d-symbols allows the symbol to be determined.

Differential decoding takes the current and previous d-symbols to produce an output symbol. It looks at only the difference between two symbols.

With LR 2-FSK and LR 4-FSK modulation, an implementation may use the difference in deviation frequencies in the current symbol period and previous symbol period to generate an output symbol. This may significantly reduce the effect of DC bias or carrier frequency offset on the decoder.

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4.4.11.2 Differential Encoder

This section defines the operation of the Differential Encoder process.

The process takes an input symbol and produces an output d-symbol.

The process maintains a register that holds the value of the previous d-symbol generated (*Previous d-symbol*). *Previous d-symbol* is initialized to the last d-symbol transmitted during the previous *training sequence* field.

4.4.11.2.1 2-FSK Differential Encoder

The 2-FSK differential encoder is used with LR 2-FSK modulation and HR 2-FSK modulation.

The input symbols and output d-symbols are elements of the set {1, 0}.

The encoder is defined by Figure 45. The *NOT* operation is the bitwise one's complement. Addition is performed modulo 2.

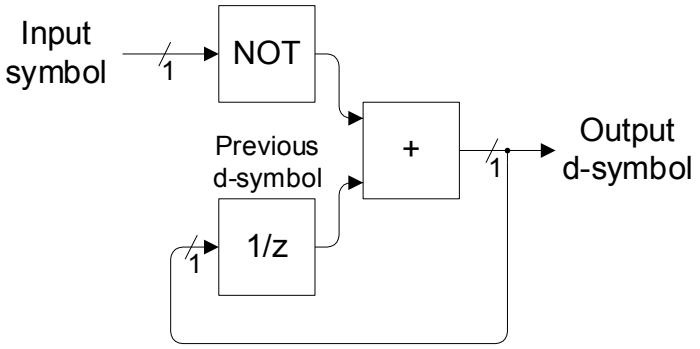


Figure 45 - 2-FSK Differential Encoder

Table 35 shows the possible operations of the encoder.

Table 35 - 2-FSK Differential Encoder Mapping Table

Input Symbol	**NOT*(Input Symbol)***	***Previous d-symbol***	***Output d-symbol***
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1

4.4.11.2.2 4-FSK Differential Encoder

The 4-FSK differential encoder is used with LR 4-FSK modulation and HR 4-FSK modulation.

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The input symbols and output d-symbols are elements of the set {00, 01, 10, 11} representing (b1,b0) where b0 is the least significant bit of the symbol. The encoder is defined by Figure 46. The *NOT* operation is the bitwise one's complement. Addition is performed modulo 4.

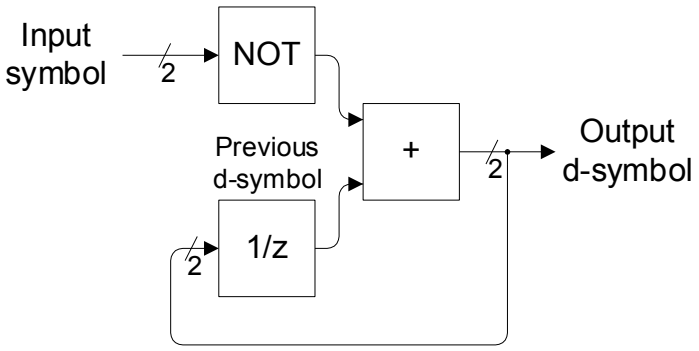


Figure 46 - 4-FSK Differential Encoder

Table 36 shows the possible operations of the encoder.

Table 36 - 4-FSK Differential Encoder Mapping Table

Input symbol **(b1,b0)**	**NOT(*Input symbol*)** **(b1,b0)**	***Previous d-symbol*** **(b1,b0)**	***Output d-symbol*** **(b1,b0)**
00	11	00	11
00	11	01	00
00	11	10	01
00	11	11	10
01	10	00	10
01	10	01	11
01	10	10	00
01	10	11	01
10	01	00	01
10	01	01	10
10	01	10	11
10	01	11	00
11	00	00	00
11	00	01	01
11	00	10	10
11	00	11	11

4.4.11.3 Differential Decoder

This section defines the operation of the Differential Decoder process.

The process takes an input d-symbol and produces an output symbol.

The process maintains a register that holds the value of the previous d-symbol received (*Previous d-symbol*). *Previous d-symbol* is initialized to the last d-symbol received during the previous TS field.

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4.4.11.3.1 2-FSK Differential Decoder

The 2-FSK differential decoder is used with LR 2-FSK modulation and HR 2-FSK modulation.

The input d-symbols and output symbols are logically elements of the set {1, 0}.

The decoder is defined by Figure 47. The *NOT* operation is the bitwise one's complement. Subtraction is performed modulo 2.

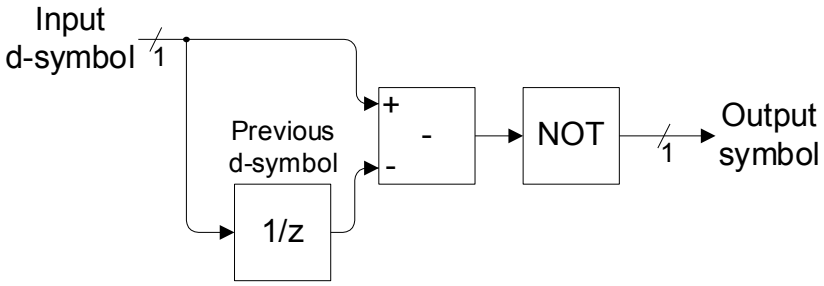


Figure 47 - 2-FSK Differential Decoder

Table 37 shows the possible operations of the decoder.

Table 37 - 2-FSK Differential Decoder Mapping Table

Input d-symbol	***Previous d-symbol***	***Input d-symbol - Previous d-symbol***	***Output symbol***
0	0	0	1
0	1	1	0
1	0	1	0
1	1	0	1

With LR 2-FSK modulation, an implementation may consider the received d-symbols to be continuous or quasi-continuous variables representing frequency deviation, and perform the subtraction in this representation. The result of the subtraction is then quantized according to the deviations specified in section 4.5.1.1.1 (LR 2-FSK Modulation) and then the resulting symbol is then one's complemented.

4.4.11.3.2 4-FSK Differential Decoder

The 4-FSK differential decoder is used with LR 4-FSK modulation and HR 4-FSK modulation.

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The input d-symbols and output symbols are logically elements of the set {00, 01, 10, 11} representing (b1,b0) where b0 is the least significant bit.

The decoder is defined by Figure 48. The *NOT* operation is the bitwise one's complement. Subtraction is performed modulo 4.

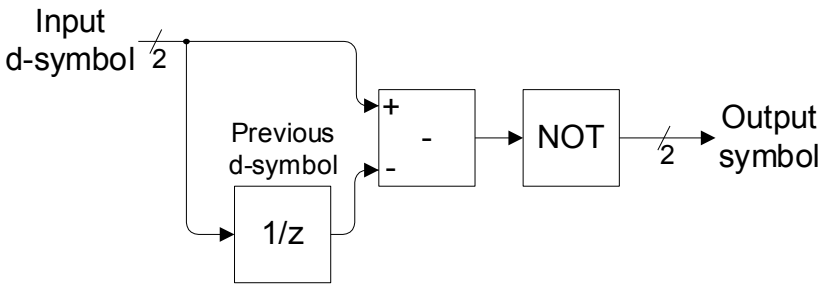


Figure 48 - 4-FSK Differential Decoder

Table 38 shows the possible operations of the decoder.

Table 38 - 4-FSK Differential Decoder Mapping Table

Input d-symbol **(b1,b0)**	***Previous d-symbol*** **(b1,b0)**	***Input d-symbol – Previous d-symbol***	***Output symbol*** **(b1,b0)**
00	00	00	11
00	01	11	00
00	10	10	01
00	11	01	10
01	00	01	10
01	01	00	11
01	10	11	00
01	11	10	01
10	00	10	01
10	01	01	10
10	10	00	11
10	11	11	00
11	00	11	00
11	01	10	01
11	10	01	10
11	11	00	11

With LR 2-FSK modulation, an implementation may consider the received d-symbols to be continuous or quasi-continuous variables representing frequency deviation, and perform the subtraction in this representation. The result of the subtraction is then quantized according to the deviations specified in section 4.5.1.1.1(LR 2-FSK Modulation) and the resulting symbol is then one's complemented.

4.4.12 TS Field Generation

The contents of the *training sequence* fields are defined in sections 4.2.2 (Low-Rate Training Sequence Fields) and 4.2.3 (High-Rate Training Sequence Fields).

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The *training sequence* fields are specified directly in terms of d-symbols. The *training sequence* fields are not stuffed, scrambled or differentially encoded.

The *training sequence* fields TTS or L2TS shall be transmitted using LR 2-FSK modulation. The *Dual* format *training sequence* field L4TS shall be transmitted using LR 4-FSK modulation. The High-Rate *training sequence* fields H2TS or H4TS shall be transmitted with the modulation HR 2-FSK and HR 4-FSK respectively.

4.5 PHY Transmit Requirements

4.5.1 Modulation

4.5.1.1 LR Modulations

The LR modulations section describes how a HomeRF device maps 2-FSK or 4-FSK d-symbols into carrier frequency deviation, for transmissions using the LR 2-FSK or LR 4-FSK modulations. The LR 2-FSK and LR 4-FSK modulations are called low-rate (LR) modulations, since they are based on the same 800 kHz symbol rate. Thus, the LR modulation symbol period is 1.25 μs.

F_d is defined to be the difference between the peak positive frequency deviation and the peak negative frequency deviation occurring within a symbol window consisting of the last 8 symbols of the *training sequence* fields (encoded using either LR 2-FSK or LR 4-FSK modulation). F_d may change from PPDU to PPDU.

The nominal carrier center frequency F_c is defined to be a frequency value for which the peak frequency deviation is within the specified accuracy for any given allowable symbol state (as specified in *Table 40* and *Table 42*). F_c shall not change from symbol to symbol by more than 1KHz/symbol.

Peak frequency deviations shall be measured after the carrier has settled to a new state as described in Section 4.5.1.1.3.

Under no condition shall the maximum positive or negative peak deviation exceed 230 kHz above or below the average carrier frequency, respectively. [39]

4.5.1.1.1 LR 2-FSK Modulation

A HomeRF node shall be capable of transmitting low-rate 2-level Frequency Shift Keying (LR 2-FSK) modulation.

The LR 2-FSK modulator accepts d-symbols from the set {1, 0}. The symbol 0 is encoded with a peak deviation of (F_d/2), giving a peak transmit frequency of (F_c +F_d/2), which is greater than the carrier center frequency (F_c). The symbol 1 is encoded with a peak frequency deviation of (-F_d/2), giving a peak transmit frequency of (F_c -F_d/2), which is less than the carrier center frequency. *Table 39* defines the allowed values of F_d as defined in 4.5.1.1 (*LR Modulations*). *Table 40* defines the mapping between symbol encoding and carrier deviation.

[39] The average carrier may also vary ± 120kHz from the nominal carrier frequency due to the allowed center frequency tolerance.

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Table 39 - Constraints on F_d for LR 2-FSK Modulation

Constraints on F_d (LR 2-FSK)	Value (kHz)
Minimum F_d	200
Nominal F_d	280
Maximum F_d	350

Table 40 - Relationship of Symbol Encoding and Carrier Deviation for LR 2-FSK Modulation

2-Level FSK d-symbol	Nominal Carrier Deviation	Carrier Deviation Accuracy (kHz)
0	$+F_d/2$	± 20
1	$-F_d/2$	± 20

4.5.1.1.2 LR 4-FSK Modulation

A HomeRF node may be capable of transmitting low-rate 4-level Frequency Shift Keying (LR 4-FSK) modulation.

The LR 4-FSK modulator accepts d-symbols from the set {00, 01, 10, 11}. Table 41 defines the constraints on the allowed values of F_d as defined in 4.5.1.1 (LR Modulations). Table 42 defines the mapping between symbol encoding and carrier deviation.

Table 41 - Constraints on F_d for LR 4-FSK Modulation

Constraints on F_d (LR 4-FSK)	Value (kHz)
Minimum F_d	270
Nominal F_d	315
Maximum F_d	380

Table 42 - Relationship of Symbol Encoding and Carrier Deviation for LR 4-FSK Modulation

4-Level FSK d-symbol (b1,b0)	Nominal Carrier Deviation	Carrier Deviation Accuracy (kHz)
00	$+F_d/2$	± 15
01	$+F_d/6$	± 10
10	$-F_d/6$	± 10
11	$-F_d/2$	± 15

4.5.1.1.3 LR Modulation Transition Time and Deviation Accuracy

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For LR modulation, the time taken for the carrier to transition from one deviation state to another in a transition interval (T_r) shall be no longer than 250 ns for 2-FSK and 150 ns for 4-FSK. T_r is measured as the time taken for the frequency to transition between the 20% and 80% points of the excursion. The excursion starts when the carrier exits the accuracy band of the previous state and ends when it first enters the accuracy band of the new state.

The time taken for the carrier to settle to within the specified accuracy of the new state (T_S) shall be no longer than 750 ns. This measurement should be made using a mechanism to band limit the output of the modulation measuring device. This mechanism can be an IF filter, a baseband filter or other equivalent averaging mechanism (such as digital filtering). The equivalent baseband bandwidth of this filter shall be no less than 1.5 MHz. The filter should have linear phase.

These specifications are illustrated in Figure 49.

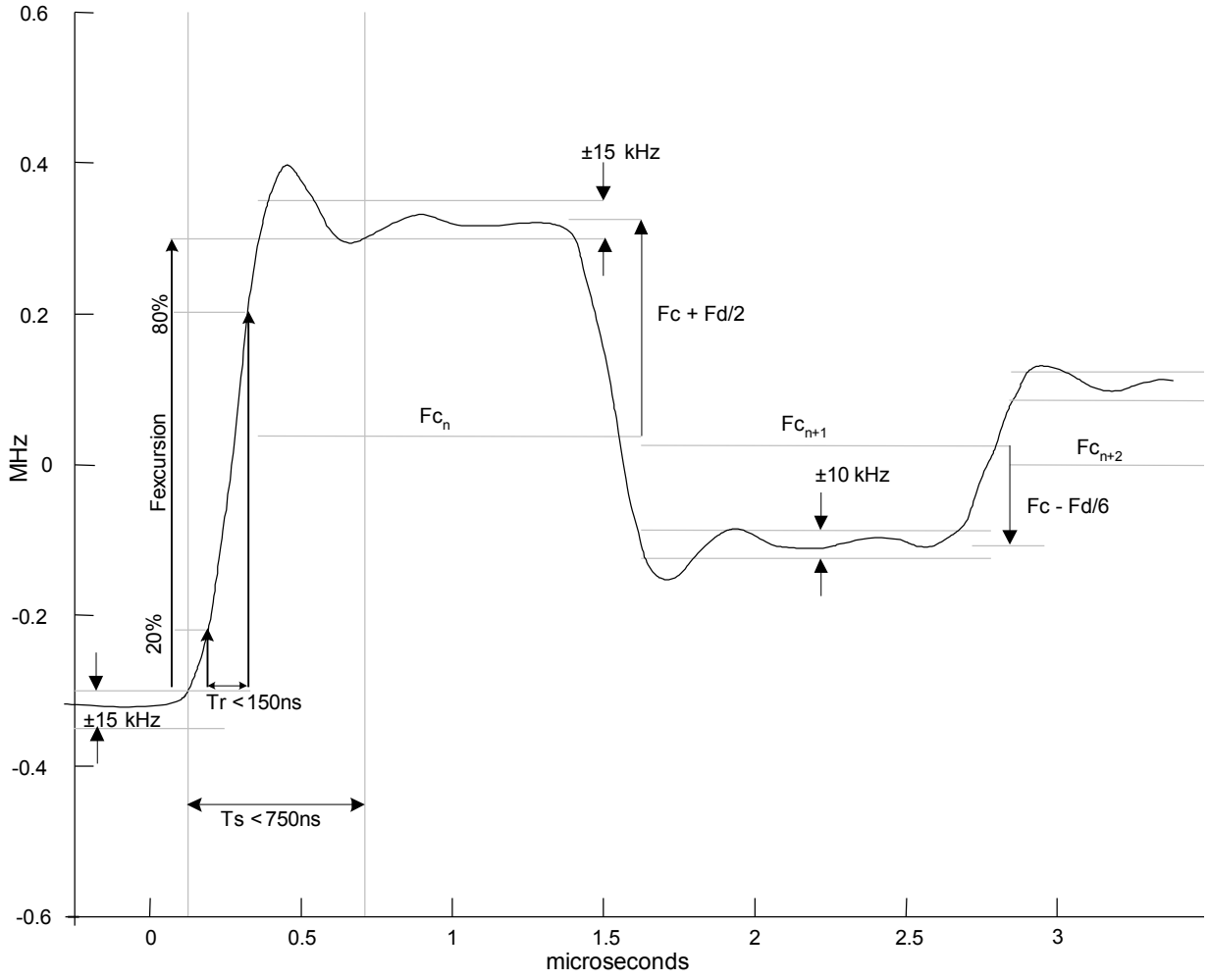


Figure 49 – LR Modulation Transition Time and Deviation Accuracy

4.5.1.2 HR Modulations

The HR modulations section describes how a HomeRF device maps 2-FSK or 4-FSK d-symbols into carrier frequency deviation, for transmissions using the HR 2-FSK or HR 4-FSK modulations. The HR 2-FSK and HR 4-FSK modulations are called high-rate (HR) modulations, since they are based on the same 5 MHz symbol rate. Thus, the HR modulation symbol period is 200 ns.

Like LR modulation, HR modulation is based on multi-level FSK methods. Unlike LR modulation, in HR modulation the digital waveforms derived from the d-symbols are filtered before being converted into carrier frequency deviation. HR modulation uses partial response 2-FSK and 4-FSK modulation.

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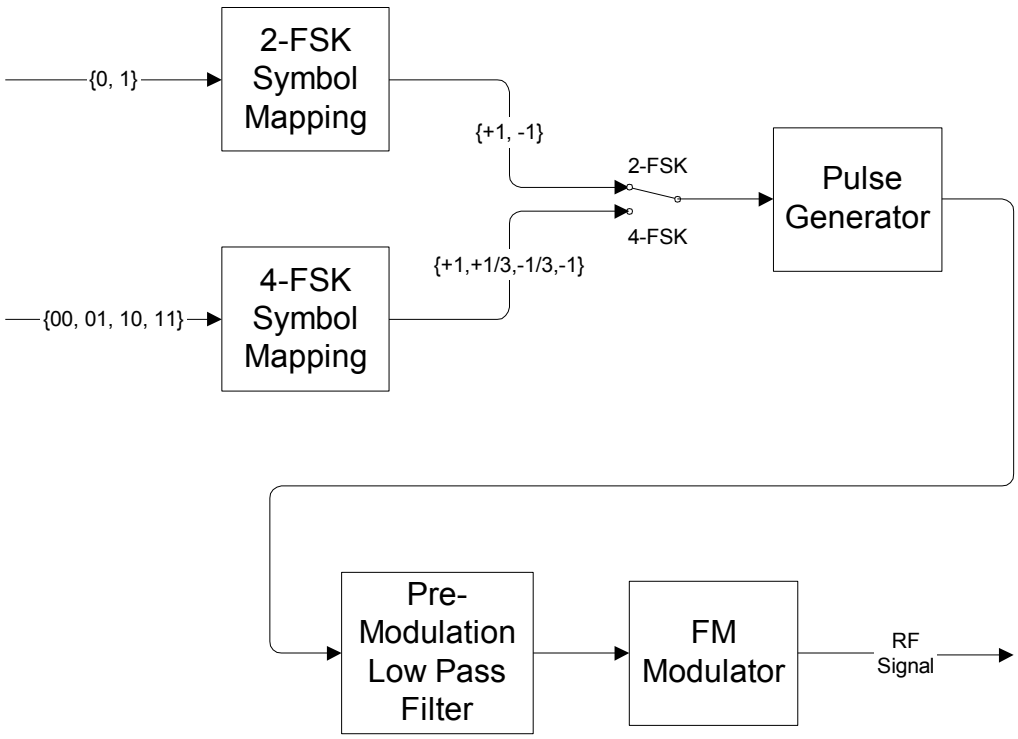


Figure 50 – HR Modulator Conceptual Block Diagram

Figure 50 shows a conceptual model of an ideal HR modulator. The incoming d-symbols are first mapped to voltage levels. The 2-FSK symbols {0, 1} are mapped to levels {+1, -1}, respectively; while the 4-FSK symbols {00, 01, 10, 11} are mapped to levels {+1, +1/3, -1/3, -1}, respectively. The voltage levels are then converted into trains of rectangular pulses. Each pulse produced by the *pulse generator* has a pulse duration of 200 ns and a pulse amplitude equal to the output of the applicable *symbol mapping* block. The pulse train is filtered by a unity DC gain, linear-phase Gaussian *pre-modulation low pass filter*, whose output specifies the instantaneous frequency deviation from the nominal carrier frequency. The filter's output is converted to a frequency-modulated RF signal by the *FM modulator*, which determines both the carrier frequency and the peak frequency deviation.

The *FM modulator* generates a transmit frequency of (F_C -F_d/2) in response to a –1 input level, a transmit frequency of F_C in response to a 0 input level, and a transmit frequency of (F_C +F_d/2) in response to a +1 input level. In general, the transmit frequency varies linearly as a function of the modulator's input voltage. The carrier frequency F_C is determined by the transmit channel. The nominal frequency deviation F_d depends on the modulation type (HR 2-FSK or HR 4-FSK), as specified in sections 4.5.1.2.1 (HR 2-FSK Modulation) and 4.5.1.2.2 (HR 4-FSK Modulation).

The impulse response *h(t)* of the ideal Gaussian pre-modulation filter is given by Equation 3. In practice, the impulse response is evaluated only over a finite time interval, outside of which the value of *h(t)* is considered negligible. Although the HR modulator conceptual model incorporates a Gaussian pre-modulation filter, a practical implementation of the HR modulator may use any suitable lowpass filter response with good phase linearity, such as a Bessel filter response. A Gaussian pre-modulation filter response is not required for compliance with this specification.

Equation 3 – Ideal Gaussian Pre-modulation Filter Impulse Response

$$h(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{t}{\sigma}\right)^2}$$

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$$\sigma = \frac{\sqrt{\ln(2)}}{2\pi B}$$

The bandwidth B of the pre-modulation low pass filter is sufficiently small that the settling time to a steady-state frequency deviation may be longer than one symbol period. Therefore, frequency deviation measurements require the transmission of several consecutive identical symbols. For the purposes of sections 4.5.1.2.1 (HR 2-FSK Modulation) and 4.5.1.2.2 (HR 4-FSK Modulation), the frequency deviation F_d shall be measured during the middle 8 symbols of subfield C0 and the middle 8 symbols of subfield C1 in the high-rate training sequence (H2TS or H4TS), as defined in section 4.2.3 (High-Rate Training Sequence Fields). F_d is defined to be the difference between the peak positive frequency deviation measured during the C0 window and the peak negative frequency deviation measured during the C1 window. F_d may change from PPDU to PPDU.

The recommended nominal 3 dB bandwidth B of the pre-modulation lowpass filter is specified in Table 43. The Table also shows the equivalent BT product for the filter, where B is the filter's 3 dB bandwidth, and T is the symbol period of 200 ns. The pre-modulation filter bandwidth B is constrained by the transition and settling time requirements specified in section 4.5.1.2.3 (HR Modulation Transition Time and Deviation Accuracy).

Table 43 – Recommended Pre-modulation Filter Bandwidth for HR modulation.

Gaussian Filter	Values
3 dB Bandwidth B (MHz)	2.50
Equivalent BT product	0.50

The nominal carrier center frequency F_c is defined to be a frequency value for which the frequency deviation is within the modulation accuracy specified in Table 45 or Table 47, as applicable. F_c shall not change from symbol to symbol by more than 5 kHz/symbol.

Under no condition shall the maximum positive or negative peak deviations exceed 1350 kHz above or below the average carrier frequency.

Figure 51 shows the signal at the ideal FM modulator input for the repeating HR 4-FSK d-symbol test pattern {11, 00, 11, 01, 10, 01, 00, 01, 00, 10, 01}, based on the nominal HR 4-FSK value of F_d = 2.0 MHz. The intersymbol interference (ISI) due to the pre-modulation filter is clearly visible. Note that, after a received signal is filtered by the receiver's channel selection filter, significantly greater ISI may be present, to the extent that the "eye" is closed. Figure 52 shows the signal obtained when each d-symbol in the test pattern is repeated consecutively four times. Note the difference in the time scale between the two figures.

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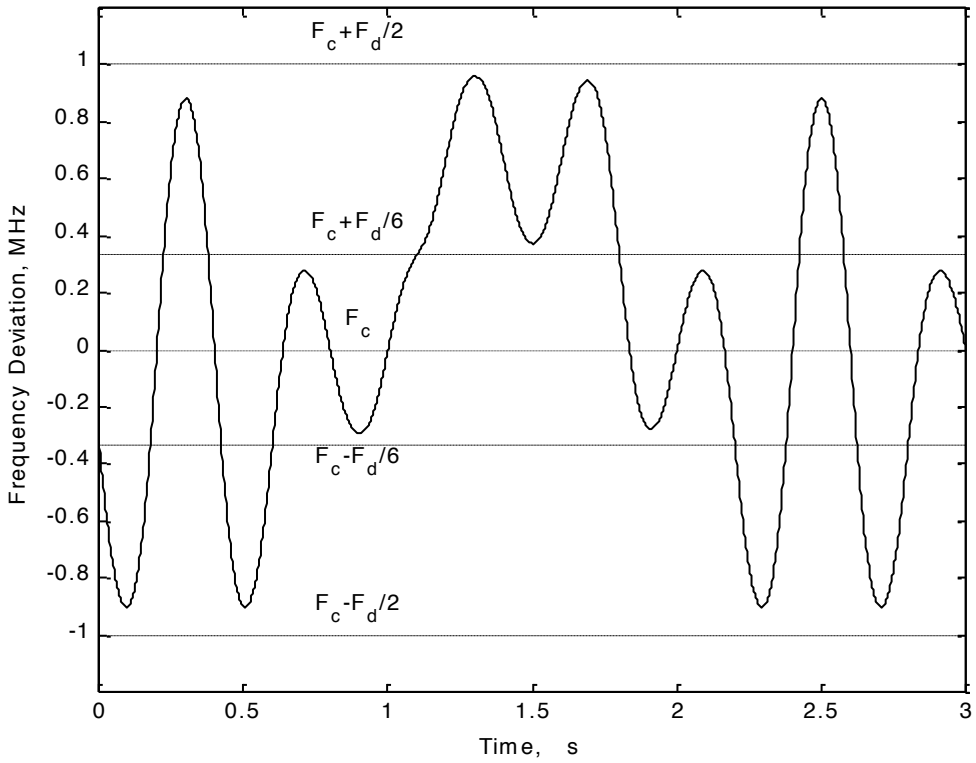
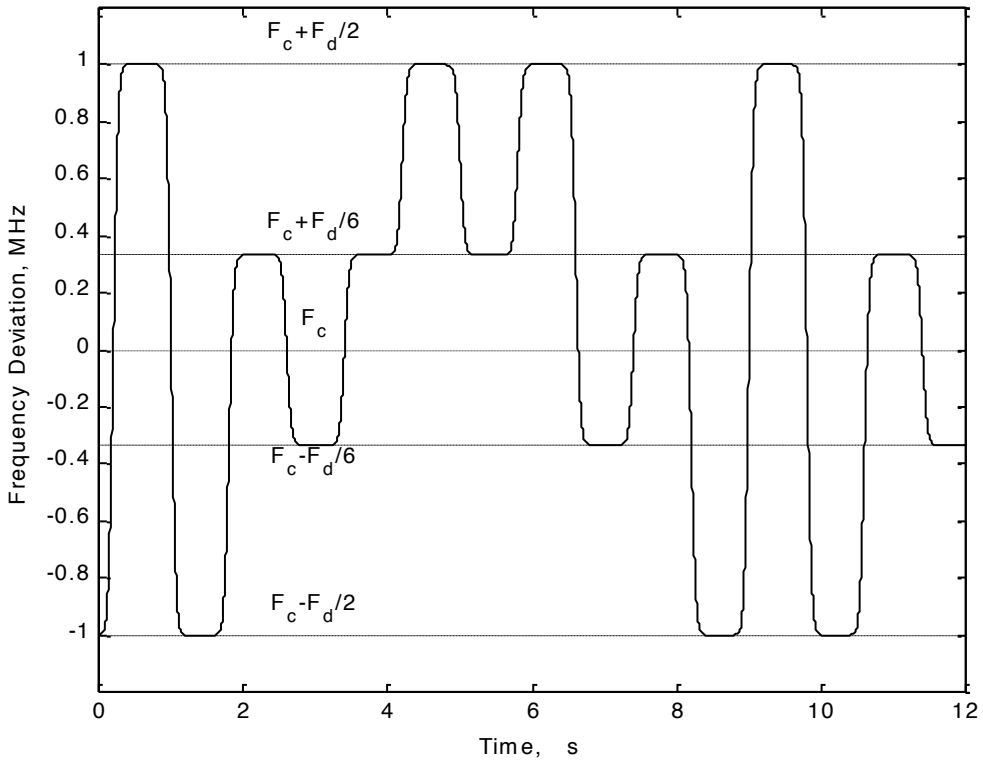


Figure 51 - FM Modulator Input for HR 4-FSK Test Pattern



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Figure 52 - FM Modulator Input for HR 4-FSK Repeated Test Pattern[40]

4.5.1.2.1 HR 2-FSK Modulation

A HomeRF node may be capable of transmitting high-rate 2-level Frequency Shift Keying (HR 2-FSK) modulation.

The HR 2-FSK modulator accepts d-symbols from the set {1, 0}, which are mapped to frequency deviation as described in 4.5.1.2 (*HR Modulation*). *Table 44* defines the allowed values of F_d, and *Table 45* defines the carrier deviation accuracy limits.

Table 44 - Constraints on F_d for HR 2-FSK Modulation

Constraints on F_d (HR 2-FSK)	**Value (kHz)**
Minimum F_d	1400
Nominal F_d	1550
Maximum F_d	1750

Table 45 – Modulation Accuracy Limits for HR 2-FSK Modulation

2-Level FSK d-symbol	**Nominal Carrier Deviation**	**Carrier Deviation Accuracy (kHz)**
0	$+F_d/2$	± 70
1	$-F_d/2$	± 70

4.5.1.2.2 HR 4-FSK Modulation

A HomeRF node may be capable of transmitting high-rate 4-level Frequency Shift Keying (HR 4-FSK) modulation.

The HR 4-FSK modulator accepts d-symbols from the set {00, 01, 10, 11}, which are mapped to frequency deviation as described in 4.5.1.2 (HR Modulation). Table 46 defines the allowed values of F_d, and Table 47 defines the carrier deviation accuracy limits.

Table 46 - Constraints on F_d for HR 4-FSK Modulation

Constraints on F_d (HR 4-FSK)	**Value (kHz)**
Minimum F_d	1800
Nominal F_d	2000
Maximum F_d	2250

Table 47 – Modulation Accuracy Limits for HR 4-FSK Modulation

[40] Each test pattern symbol is repeated four times.

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4-Level FSK d-symbol (b1,b0)	Nominal Carrier Deviation	Carrier Deviation Accuracy (kHz)
00	$+F_d/2$	± 60
01	$+ F_d/6$	± 40
10	$- F_d/6$	± 40
11	$- F_d/2$	± 60

4.5.1.2.3 HR Modulation Transition Time and Deviation Accuracy

For HR modulation, transition time, settling time, and deviation accuracy are measured with methods analogous to those used for LR modulation (see section 4.5.1.1.3), except that the HR modulation test patterns use repeated symbols. For the measurements specified in this section, each symbol in a test pattern must be repeated consecutively at least four (4) times. Symbol repetition is used to isolate each transition from the next.

For HR modulation, the time taken for the carrier to transition from one deviation state to another in a transition interval (T_r) shall fall within the limits specified in Table 48. T_r is measured as the time taken for the frequency to transition between the 20% and 80% points of the excursion. The excursion starts when the carrier exits the accuracy band of the previous state and ends when it first enters the accuracy band of the new state.

The time taken for the carrier to settle to within the specified accuracy of the new state (T_S) shall fall within the limits specified in Table 48. This measurement should be made using a mechanism to band limit the output of the modulation measuring device. This mechanism can be an IF filter, a baseband filter or other equivalent averaging mechanism (such as digital filtering). The equivalent baseband bandwidth of this filter shall be no less than 10 MHz. The filter should have linear phase.

Table 48 - Transition and Settling Time Constraints for HR Modulation[41]

Constraints	Transition Time (Tr)	Settling Time (Ts)
Minimum	70 ns	165 ns
Nominal	85 ns	200 ns
Maximum	105 ns	250 ns

Transition time (T_r) and settling time (T_S) measurements shall be corrected to compensate for the finite rise time of the measuring instruments.

These specifications are illustrated in Figure 53 for a typical HR 4-FSK signal, using a test pattern with a symbol repetition factor of 4. As specified in Table 47, the applicable deviation accuracy band sizes are Δ_1 = ± 60 kHz and Δ_2 = ± 40 kHz.

[41] The allowed transition time (T_r) and settling time (T_S) may also be constrained by local regulations.

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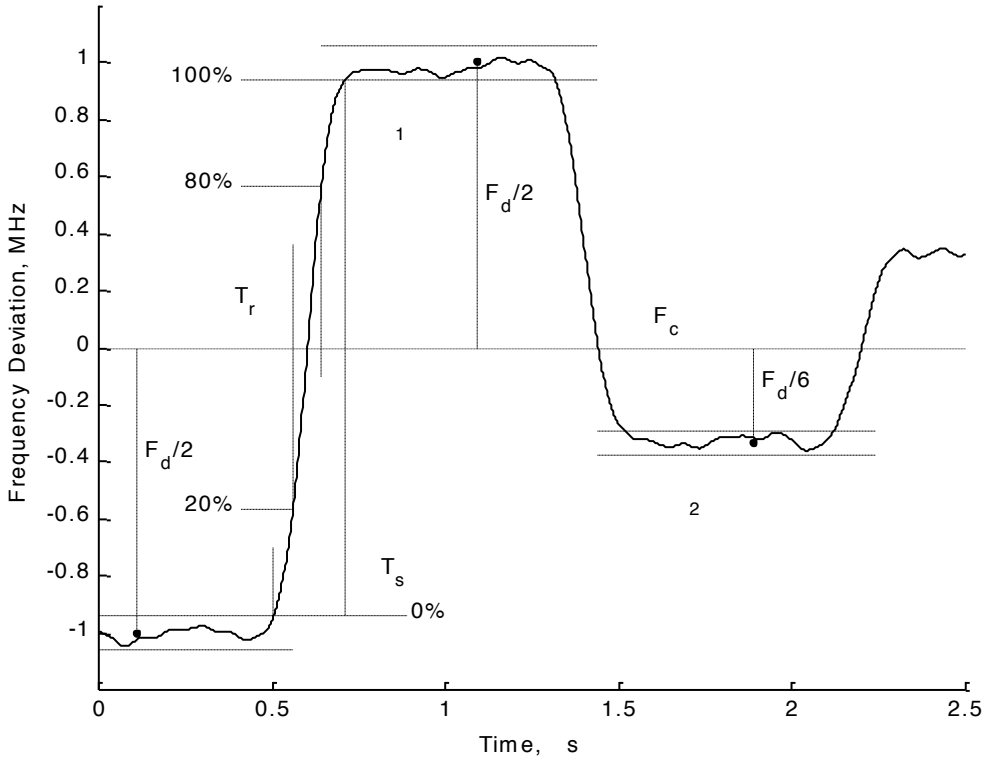


Figure 53 - HR Modulation Transition Time and Deviation Accuracy[42]

4.5.2 Transmit Power Level

The *nominal transmit power level* of a PPDU is defined as the power delivered to the antenna averaged between the start of the first symbol and the end of the last symbol in the PPDU, not including the *Ramp On* and *Ramp Off* fields.

A HomeRF node shall operate such that the *nominal transmit power level* of all transmitted PPDUs falls within either the Class-1 or Class-2 power levels defined in Table 49. [43]

Table 49 – Transmitter Output Power Limits

HomeRF Node Type	Power Class	**Minimum Power Level**	**Maximum Power Level**
I-Node	Class 1 (Normal)	12 dBm	30 dBm
I-Node	Class 2 (Low Power)	0 dBm	4 dBm
Class-1 CP	Class 1 (Normal)	16 dBm	30 dBm for non-contention period transmissions, otherwise 21 dBm[44]

[42] Each test pattern symbol is repeated four times.

[43] Any HomeRF device must conform to applicable local regulations such as those described in the FCC Part 15 rules or ETS 300 328.

[44] This differentiation is to enforce the maximum transmit power of 21 dBm for optimal performance when utilizing the contention based access mechanism. Also, since utilization of the super channels only occurs within the contention period, the associated geopraphically required maximum transmit power is also met. Outside of the contention period, 1 MHz channel separation is always used and the maximum transmit power of 30 dBm applies.

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All except I-node and Class-1 CP	Class 1 (Normal)	16 dBm	21 dBm
All except I-node	Class 2 (Low Power)	0 dBm	4 dBm

4.5.3 Permitted Transmit Power according to HomeRF Node Type

Depending on HomeRF Node Type, the node is permitted to use the transmit power levels as defined in Table 50.

Table 50 - Permitted Power Levels Depending on HomeRF Node Type

HomeRF Node Type	Permitted power levels
Class-1 CP	Normal only
Class-2 CP	Normal only
Class-3 CP	Normal only
A-node	Both Normal and Low
I-node	Both Normal and Low
AI-node	Both Normal and Low

4.5.4 Occupied Channel Bandwidth

For low-rate (LR) operation, the occupied channel bandwidth shall meet all geographically applicable regulations for 1 MHz channel spacing. For high-rate (HR) operation, the occupied channel bandwidth shall meet all geographically applicable regulations for 5 MHz channel spacing.[45]

4.5.5 Unwanted Emissions

A HomeRF node shall limit the emissions that fall outside of the operating frequency range, defined in section 5.5.2 (Frequency Hopping) to geographically applicable limits.

4.5.6 Adjacent Channel Power

A HomeRF implementation shall pass transmit spectrum mask tests. Two different test specifications apply to HomeRF units. The first specification applies when the unit is transmitting only LR modulation. The second specification applies when the unit is transmitting HR modulation.

The duty cycle between Transmit and Receive is nominally 50% and the transmit period duration is nominally 400 μs. A pseudo-random data pattern shall be transmitted. Instead of using the 50% transmit duty cycle and the 400 μs transmit duration test conditions, I-nodes may repeatedly transmit a standard TDMA PPDU within a standard 10 ms TDMA frame, using a pseudo-random data pattern in the PSDU1 field. The pseudo-random data patterns are not specified in this document.

For LR modulation, the adjacent channel power is defined as the sum of the power measured in a 1 MHz band, offset from the transmitter center frequency by 1 MHz. The level given in dBc is measured relative to the transmitter power measured in a 1 MHz band centered on the transmitter center frequency. The adjacent channel power and the transmitter power for LR modulation shall be measured under the following conditions:

- Resolution bandwidth of 100 kHz
- Video bandwidth of 300 kHz,

[45] As of the publication date of this specification, the use of 5 MHz channels is not permitted under the ETSI EN 300.328 rules. However, a request has been made to the ERM TG 11 to change these rules to permit the use of 15 non-overlapping channels, which will enable the use of 5 MHz wide hopping channels as described in this specification. If required, the HomeRF Technical Committee may create a new version of this specification to accommodate the current ETSI EN 300.328 rules.

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- Using a peak detector and the measurement device set to maximum hold.

In addition, I-nodes transmitting standard TDMA PPDUs within standard 10 ms TDMA frames shall use a spectrum analyzer sweep time of 12 seconds.

For HR modulation, the adjacent channel power is defined as the sum of the power measured in a 5 MHz band, offset from the transmitter center frequency by 5 MHz. The level given in dBc is measured relative to the transmitter power measured in a 5 MHz band centered on the transmitter center frequency. The adjacent channel power and the transmitter power for this section of the specification shall be measured under the following conditions:

- Resolution bandwidth of 300 kHz
- Video bandwidth of 300 kHz,
- Using a peak detector and the measurement device set to maximum hold.

For either LR or HR modulation, the adjacent channel power shall be 0 dBm or –20 dBc, whichever is the lower power.

4.5.7 Transmit Center Frequency Tolerance

A node shall have a transmit center frequency accuracy, as measured from F_C, of ± 50 ppm. It shall maintain this stability over the stated operating temperature range.

4.6 PHY Receive Requirements

This section defines requirements that shall be met by a HomeRF node that is receiving.

4.6.1 Receiver Channel Specification Group

The *Receiver Channel Specification Group* comprises the requirements defined in the following sections:

- 4.6.5 (Receiver Input Signal Range)
- 4.6.6 (Receiver Sensitivity)
- 4.6.7 (Receiver Intermodulation)
- 4.6.8 (Receiver Desensitization)

4.6.2 Receive Error-rate Performance Limits

4.6.2.1 Connection Point and A-Nodes

The performance limit for Connection Points and A-Nodes is specified as a Frame Error Ratio (FER) of 3% [46] for PSDUs of 400 bytes generated with pseudo-random data. This pattern is not specified in this document.

In the case of a *Dual PSDU* PPDU, the specification is a FER of 3% for a PSDU2 of 400 bytes transmitted using LR 4-FSK modulation. In the case of an *Extended Preamble High Rate Single PSDU* PPDU, the specification is a FER of 3% for a PSDU1 of 400 bytes transmitted using HR 2-FSK or HR 4-FSK modulation, which shall be individually tested.

4.6.2.2 I-nodes

The performance limit for I-nodes is specified as a FER of 3% for a standard TDMA PSDU generated with pseudo-random data.

4.6.3 Receiver Center Frequency Acceptance Range

A node shall meet all requirements of the *Receiver Channel Specification Group* with an input signal having a center frequency range of ± 50 ppm from nominal.

4.6.4 Receiver Frequency Range

A node shall meet all requirements of the *Receiver Channel Specification Group* across all channels supported in the geography in which it is intended to be used.

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[46] To facilitate practical measurements, it is possible to substitute a 30% FER measurement for the 3% FER as provided that a 1dB margin is added to the respective measurement specification.

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4.6.5 Receiver Input Signal Range

A node shall be capable of recovering a conformant signal from the medium at the level of performance specified in Section 4.6.2 (Receive Error-rate Performance Limits) for receiver input levels in the range from –20 dBm to the receiver sensitivity as specified in Section 4.6.6 (Receiver Sensitivity).

4.6.6 Receiver Sensitivity

A node shall be capable of receiving at the performance limits specified in Section 4.6.2 (Receive Error-rate Performance Limits) at the levels specified in Table 51, according to HomeRF node type and modulation type. [47]

Table 51 - Receiver Sensitivity Threshold

HomeRF Node Type	Modulation Type	Receiver Sensitivity
I-node	LR 2-FSK	< -80 dBm
All except I-node	LR 2-FSK	< -75 dBm
All except I-node	LR 4-FSK	< -65 dBm
All except I-node	HR 2-FSK	< -80 dBm
All except I-node	HR 4-FSK	< -70 dBm

4.6.7 Receiver Intermodulation

Intermodulation protection (IM_p) is a measure of the receiver's ability to reject two nearby interferers whose third-order product occurs at the same frequency as the desired signal. Figure 54 describes this test, with the interferers placed Δf_1 and Δf_2 MHz, respectively, higher than the desired signal at frequency F_c. The desired signal amplitude is set 3 dB above the sensitivity specified in Section 4.6.6 (Receiver Sensitivity) for the test modulation type specified in Table 52. The equal amplitudes of the interferers are then adjusted to a level that produces the error performance specified in Section 4.6.2 (Receive Error-rate Performance Limits). The resulting IM_p is defined as the ratio of the amplitude of each interferer to a signal level 3 dB above the HR 2-FSK reference sensitivity, as specified in Section 4.6.2 (Receive Error-rate Performance Limits). A similar test must also be passed with the interferers placed Δf_1 and Δf_2 MHz lower than the desired signal. The test must be repeated for all PPDU types supported by the receiver.

A node that is receiving a PPDU shall have a measured IM_p greater than or equal to the *Minimum* IM_p value specified in Table 52. For each PPDU format, the table also specifies the appropriate values of Δf_1 and Δf_2, as well as the test modulation type to be used in determining the desired signal sensitivity level from Table 51.

[47] A manufacturer can achieve higher sensitivities in an implementation if so desired.

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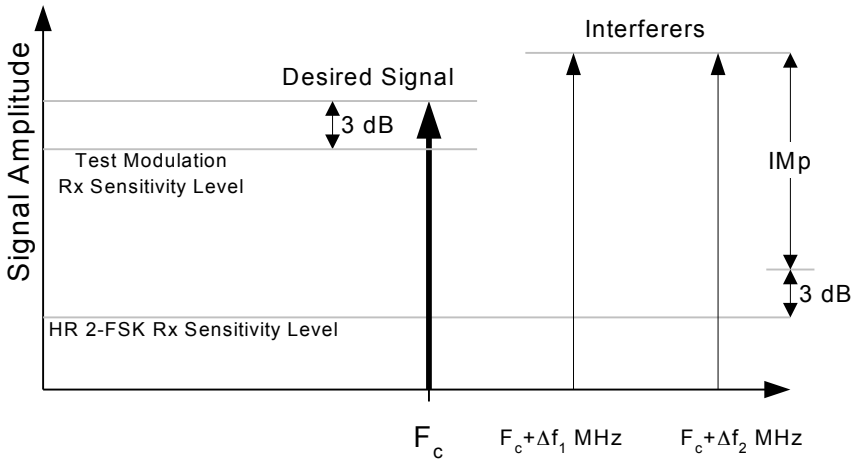


Figure 54 - Receiver Intermodulation Test

Table 52 – Receiver Intermodulation Test Parameters

PPDU Format	Test Modulation Type	Δf_1 (MHz)	Δf_2 (MHz)	Minimum IM_p (dB)
Extended Preamble High Rate Single PSDU	HR 2-FSK	12	24	TBD
Extended Preamble High Rate Single PSDU	HR 4-FSK	12	24	TBD
Dual PSDU	LR 4-FSK	9	18	15
All Others	LR 2-FSK	9	18	20

4.6.8 Receiver Desensitization

Desensitization (D_p) is defined as the ratio to the desired signal strength of the minimum amplitude of an interfering signal that causes the performance limits specified in Section 4.6.2 (Receive Error-rate Performance Limits) to be met, when the desired signal is 3 dB above the sensitivity specified in Section 4.6.6 (Receiver Sensitivity), for the test modulation type specified in Table 53. The interfering signal shall be modulated with data uncorrelated in time to the desired signal, using the same test modulation type as the desired signal. The test shall be repeated for each PPDU type supported by the receiver.

A node shall have a D_p no less than the minimum values defined Table 54, depending on the received PPDU modulation type. The interferer spacing is parameterized in terms of a spacing constant *S*, which depends on the receiver capabilities, but does not vary with the test modulation type. For receivers that support only low rate modulation, *S* is equal to 1 MHz. For receivers that support both low rate and high rate modulation, *S* is equal to 4 MHz.

Table 53 - Receiver Desensitization Test Modulation Type By PPDU Format

PPDU Format	Test Modulation Type	Spacing Constant *S*	Applicable Figure
Extended Preamble High Rate	HR 2-FSK	4 MHz	Figure 55

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Single PSDU			
Extended Preamble High Rate Single PSDU	HR 4-FSK	4 MHz	Figure 56
Dual PSDU	LR 4-FSK	1 or 4 MHz (see text)	Figure 56
All Others	LR 2-FSK	1 or 4 MHz (see text)	Figure 55

Table 54 - Receiver Desensitization Requirements

	Minimum D_p By PPDU Type			
Interferer Frequency (MHz)	***Extended Preamble High-Rate Single PSDU Using HR 2-FSK***	***Extended Preamble High-Rate Single PSDU Using HR 4-FSK***	***Dual PSDU***	***All Other PSDU Types***
$f_I = f_c$ **± 2 S**	0 dB	0 dB	0 dB	0 dB
$f_I = f_c$ **± 3 S**	10 dB	0 dB	0 dB	10 dB
$f_I = f_c$ **± 5 S**	25 dB	15 dB	15 dB	25 dB
$f_I = f_c$ **± 9 S or more**	35 dB	25 dB	25 dB	35 dB

Note

f_I is the interferer frequency

f_c is the desired channel frequency

S is 1 MHz for receivers with no high-rate support or 4 MHz for receivers with high rate support. S does not depend on the PPDU type.

Figure 55 and Figure 56 illustrate this specification.

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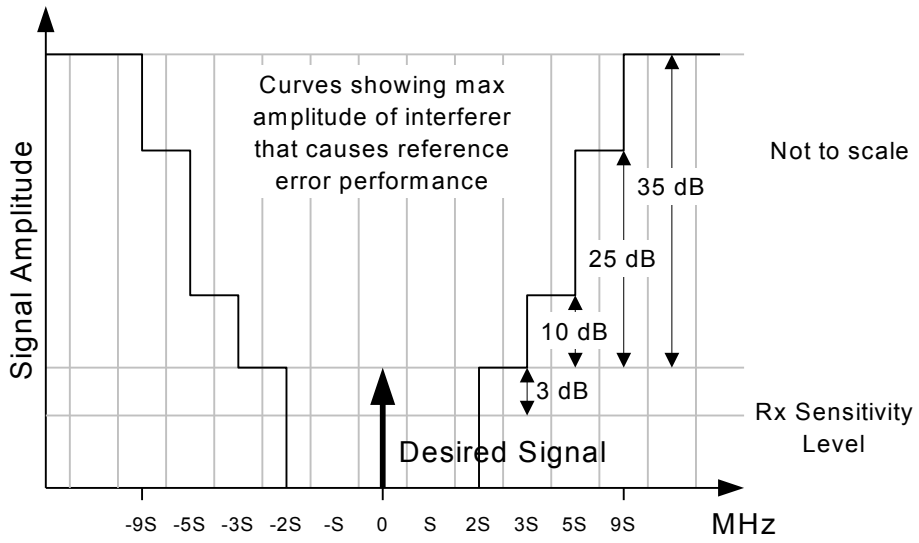


Figure 55 - Receiver Desensitization (LR 2-FSK or HR 2-FSK payload modulation)

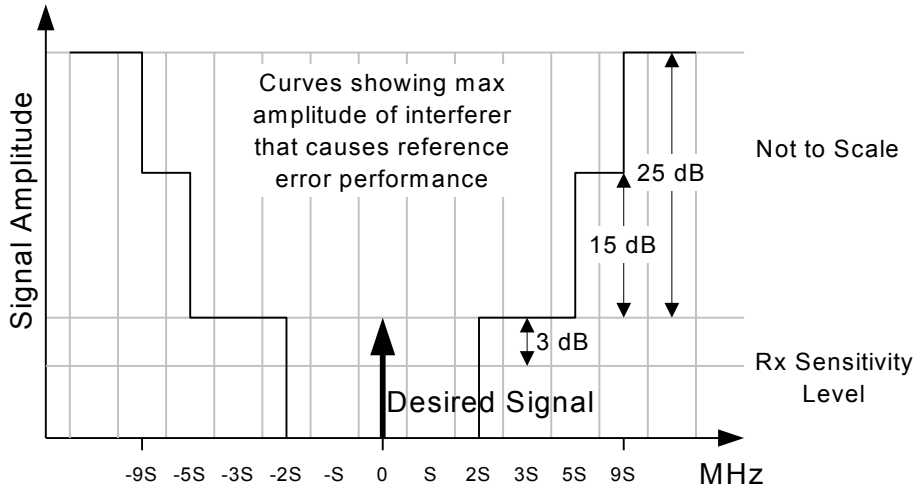


Figure 56 - Receiver Desensitization (LR 4-FSK or HR 4-FSK payload modulation)

4.7 PHY General Requirements

4.7.1 Clear Channel Assessment

A node that supports the CSMA/CA access mechanism shall meet the specification defined in this section.

On receipt of a PM_GET_CCA primitive from the MAC, the node, in the presence of a HomeRF-compliant LR 2-FSK L2TS field, at or above a received power level equal to the *CCA Busy Threshold* specified in Table 55, shall signal *Busy* with a 90% probability within a *CCAtime* defined in 16.1 (PHY Constants). [48]

On receipt of a PM_GET_CCA primitive from the MAC, the node shall, in the presence of a HomeRF-compliant HR 2-FSK H2TS field at or above a received power level of -80 dBm, signal *Busy* with a 90% probability within a *CCAtime* defined in 16.1 (PHY Constants). [49]

[48] There is no requirement to indicate CCA busy based on the presence of a non-HomeRF signal. A node may also indicate channel busy based on detecting non-HomeRF signals according to implementation-specific criteria.

[49] There is no requirement to indicate CCA busy based on the presence of a non-HomeRF signal. A node may also indicate channel busy based on detecting non-HomeRF signals according to implementation-specific criteria.

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Table 55 - CCA Busy Threshold

HomeRF Node Type	CCA Busy Threshold
I-node	-80 dBm
All others	-75 dBm

4.7.2 End of PSDU Detection

A node that supports the CSMA/CA access mechanism shall meet the specification defined in this section.

The PHY state machine requests a channel assessment, and this procedure returns either *Clear* or *Busy*. Upon request from the PHY receive state machine, the node, in the presence of any signal at or above a received power level equal to the *End of PSDU Detection Threshold* specified in Table 56, shall signal *Busy* with a 90% probability within a *CCAtime* defined 16.1 (PHY Constants).

Table 56 - End of PSDU Detection Threshold

HomeRF Node Type	End of PSDU Detection Threshold
I-node	-66 dBm
All except I-node	-61 dBm

4.7.3 Channel Switching / Settling Time

A HomeRF node shall be able to change from any supported operating channel frequency to any other within a *HopDuration* time (16.1 (PHY Constants)). The supported operating channel frequencies are defined in section 5.5.2 (Frequency Hopping). A node meets this switching time specification when the operating channel center frequency has settled to within ± 50 ppm of the nominal channel frequency.

4.7.4 Receive To Transmit Switch Time

A HomeRF PHY shall be able to switch the radio from the receive state to the transmit state and place the start of the first symbol on the air within a *RxTxTurnround* time, defined in 16.1 (PHY Constants). At the end of this time, the RF carrier shall be within the nominal transmit power range, and within the described modulation specifications (section 4.5.1 (Modulation)).

4.7.5 Symbol Rate

A node shall be capable of transmitting and receiving both at a nominal d-symbol rate of 800,000 d-symbols per second ± 50 ppm, for LR modulations, and at a nominal d-symbol rate of 5,000,000 d-symbols per second ± 50 ppm, for HR modulations.

4.7.6 Operating Temperature Range

A compliant implementation shall meet all the requirements of section 4 (Physical (PHY) Layer) over an ambient temperature range of +10 to +40 ^{o}C.

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5 MEDIUM ACCESS CONTROL (MAC) LAYER

5.1 Introduction to the HomeRF MAC (Informative)

This section describes the Medium Access Control (MAC) layer that is part of the HomeRF On-Air stack.

The MAC architecture supports four main data services: an isochronous connection-oriented service, an isochronous connectionless broadcast service, an asynchronous (connectionless) data service, and a session-oriented priority asynchronous data service. The properties of these services are described in section 3.3 (Types of Data Service Supported).

The MAC uses two different medium access methods to provide these services. It uses time division multiple access (TDMA) to provide the isochronous services, and it uses carrier-sense multiple access, collision avoidance (CSMA/CA) to provide the asynchronous services (priority and non-priority). It also defines a time-based access mechanism (the service slot) that is used to manage I-nodes.

The MAC ensures reliable[50] isochronous performance, up to a fixed limit on the number of simultaneous connections. It gives priority to isochronous data over asynchronous data. The MAC includes a unique frequency diversity retry mechanism that gives isochronous performance superior to other competing technologies and that performs well in the presence of microwave oven interference.

The MAC also provides a reliable [51] isochronous [52] connectionless broadcast data service to carry higher layer signaling SDUs, such as, I-node pages, cadence ringing, and caller ID, to I nodes. It also provides an unreliable [53] isochronous connectionless broadcast service for U-plane data used by higher layers to carry voice announcements.

Data being delivered using the priority asynchronous data service is given priority over the non-priority asynchronous data. The number of priority data streams in a given network is bound by a manufacturer set upper limit up to *CWstartMax*. This limit must not result in a higher percentage of the contention period to be utilized by the priority data streams than specified by *MaxPriorityBandwidth*.[54] Isochronous data still has priority over the priority asynchronous data.

The MAC management procedures include power-saving support for I-nodes and A-nodes. Power-management of A-nodes relies on explicit exchange of management MPDUs. Power-management of I-nodes is also supported, although there is no explicit exchange of management MPDUs that supports this.

The MAC management procedures also include procedures to support roaming.

5.1.1 Varying MAC Behavior (Informative)

The MAC behaves differently according to the HomeRF device type.

Table 57 summarizes the main differences in MAC behavior based on the HomeRF node type.

Table 57 - Different MAC Behaviors Depending on HomeRF node type

MAC Procedure	**HomeRF Node Type**							
	Class -1 CP	**Class -2 CP**	**Class -3 CP**	**A-node**	**I-node**	**AI-node**	**S-node**	**SI-node**
Synchronization within an ad-hoc network	X	X	X	O	X	X	X	X

[50] Although not as reliable as the asynchronous data service.

[51] The reliability of this service is higher than the PHY-layer reliability, but the service does not guarantee delivery because there is no positive acknowledgement.

[52] Strictly speaking, the C-channel service is not isochronous. However the closely associated U-plane service is isochronous, and so the ICBS tag is applied to both services.

[53] There are no retries for this data.

[54] It is suggested that CP manufacturers limit the number of priority streams according to the amount of bandwidth that is optimal to be left available for non-priority asynchronous data.

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Synchronization within a managed network	M	M	M	M	M	M	M	M
A-node Power-saving	X	P and OMC	P and OMC	OMC	NA	OMC	OMC	OMC
A-node Power-supporting	M	M	OMC	OMC	NA	OMC	OMC	OMC
A-node power-management services	M	M	NA	NA	NA	NA	NA	NA
Multicast power-supporting	M	M	NA	NA	NA	NA	NA	NA
Connection management	M	NA	NA	NA	M	M	NA	M
Session management	M	M	M	NA	NA	NA	M	M
I-node power-saving	NA	NA	NA	NA	O	O	NA	O
TDMA Access mechanism	M	NA	NA	NA	M	M	NA	M
Isochronous Connectionless Broadcast service	M	NA	NA	NA	C	C	NA	C
Service Slot Access Mechanism	NA	NA	NA	O	M	M	O	M
CSMA/CA Access mechanism	M	M	M	M	NA	M	M	M
Multi-rate data service	OC	OC	OC	M	NA	OC	M	OC
Time Reservation mechanism	M	M	M	M	NA	M	M	M
Time Reservation w. RTS-CTS mechanism	O	O	O	O	NA	O	O	O
CP Assertion	M	M	M	NA	NA	NA	NA	NA
Asynchronous Data Roaming	OMC	OMC	X	OMC	NA	X	X	X
Notes:	X - Not permitted NA – Not Applicable for this node type O - Optional M – MandatoryP - Only permitted when acting as a Passive CP C - Support for ICBS C-Plane data is mandatory; support for ICBS U-plane data is optional OC – Optional behavior as indicated in the Base Capabilities of the Station Information OMC - Optional behavior as indicated in the Managed Capabilities of the Station Information							

5.2 MAC Services

The MAC supports the four main data services described in section 3.3 (Types of Data Service Supported). In addition, it provides ancillary data and management services. These services are accessed through the service access points listed in Table 58.

Table 58 - MAC Service Access Points

MAC Service Access Point	**Service**

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MD-SAP	Connectionless asynchronous data
MS-SAP	Session-oriented priority asynchronous data
MC-SAP	Isochronous connection-oriented U-plane and C-channel data
MB-SAP	Isochronous connectionless broadcast U-plane and C-Plane data
MM-SAP	MAC management

The services are described by SAP in the sections that follow.

5.2.1 MD-SAP Data Service

The primitives listed in Table 62 provide the Connectionless asynchronous data service.

MD-SAP service Primitive	**Description**
MD_DATA	Asynchronous data

5.2.1.1 MD_DATA Primitive

Primitive	MD_DATA			
Description	This primitive carries SDUs of the asynchronous data service.			
Parameters	**Req**	**Conf**	**Ind**	
DA	M	M	M	
SA	MB		M	
Ethertype	M		M	
SC	O	O	O	
MSDU	M		M	
Status		M		
Notes:	M - Mandatory O - Optional MB - Mandatory for a HomeRF Bridge (HB), otherwise not permitted.			

The characteristics of the asynchronous data service are described in section 3.3.1 (Characteristics of the Asynchronous Data Service).

The confirm primitive is issued when the MSDU has been transmitted successfully or has expired.

The *DA* is the IEEE 48-bit MAC address of the destination MAC(s). It may be a unicast or a multicast address.

The *SA* is the IEEE 48-bit MAC address of the MAC entity originating the SDU. In the case of multicast data that has been relayed by a connection-point, this parameter contains the source address of the original sender, not any connection-point that may have re-transmitted the MSDU.

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In the case of a HB, the SA is the address of the HomeRF node for MSDUs originated locally, otherwise it is the SA read from an MSDU being bridged from some other MAC port.

The *Ethertype* contains a 16-bit Ethertype value.

The *SC* parameter contains optional service control parameters. They are defined in Table 59. [55]

Table 59 - Asynchronous Data Service Control Parameters

SC Parameter	Values
Encryption	disabled, enabled
Compression	disabled, enabled
Fast Unacknowledged Service	disabled, enabled

The *Fast Unacknowledged Service* parameter of the Service Control indicates that the MSDU can be sent as a singleton CSDU via the *Fast Unacknowledged Service Mechanism* of the CSMA/CA Access Mechanism. The MSDU length must be within *MaxFUSMSDUlength*.

The *Status* parameter has one of two values: *successful, expired*.

5.2.1.1.1 Effect of MD-DATA Request

A node that receives an MD-DATA Request shall perform the procedures defined in section 5.12 (MD-SAP Service) to transmit the MSDU.

5.2.2 MS-SAP Data Service

The primitives listed in table 56 provide the session oriented priority asynchronous data service.

Table 60 - MS-SAP

MS-SAP service Primitive	Description
MS_DATA	Priority Asynchronous Data
MS_SETUP	Streaming Session Setup
MS_TEARDOWN	Streaming Session Tear down

5.2.2.1 MS_DATA Primitive

Primitive	MS_DATA			
Description	This primitive carries SDUs of the priority asynchronous data service.			
Parameters	**Req**	**Conf**	**Ind**	
DA	M	M	M	
SA	MB		M	
SID	O	O	O	

[55] This specification does not distinguish different meanings of *enabled*. For example, an implementation may choose to implement *enabled* in an MD-DATA request as "select this feature if the destination node supports it".

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Ethertype	M		M	
SC	O	O	O	
MSDU	M		M	
Status		M		
Notes:	M – Mandatory O - Optional MB - Mandatory for a HomeRF Bridge (HB), otherwise not permitted.			

The characteristics of the priority asynchronous data service are described in section 3.3.2.

The confirm primitive is issued when the MSDU has been transmitted successfully or has expired.

The *DA* is the IEEE 48-bit MAC address of the destination MAC(s). It may be a unicast or a multicast address.

The *SA* is the IEEE 48-bit MAC address of the MAC entity originating the SDU. In the case of multicast data that has been relayed by a connection-point, this parameter contains the source address of the original sender, not any connection-point that may have re-transmitted the MSDU.

In the case of a HB, the SA is the address of the HomeRF node for MSDUs originated locally, otherwise it is the SA read from an MSDU being bridged from some other MAC port.

The SID is the 8-bit stream ID associated with the MSDU.

The *Ethertype* contains a 16-bit Ethertype value.

The *SC* parameter contains optional service control parameters. They are defined in Table 59. [56]

Table 61 – Priority Asynchronous Data Service Control Parameters

SC Parameter	**Values**
Encryption	disabled, enabled
Compression	disabled, enabled
Fast Unacknowledged Service	disabled, enabled

The *Fast Unacknowledged Service* parameter of the Service Control indicates that the MSDU can be sent as a singleton CSDU via the *Fast Unacknowledged Service Mechanism* of the CSMA/CA Access Mechanism. The MSDU length must be within *MaxFUSMSDUlength*.

The *Status* parameter has one of two values: *successful, expired*.

5.2.2.1.1 Effect of MS_DATA Request

A node that receives a MS_DATA Request shall perform the procedures defined in section 5.12(MD-SAP Service) to transmit the MSDU.

[56] This specification does not distinguish different meanings of *enabled*. For example, an implementation may choose to implement *enabled* in a MS_DATA request as “select this feature if the destination node supports it”.

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5.2.2.2 MS_SETUP Primitive

Primitive	MS_SETUP			
Description	Session setup. Sessions are established by the S-node.			
Parameters	**Req (S-node only)**	**Conf (S-node only)**		
SDA	M			
SA				
Priority	M			
NTR	M			
MTR	M			
Jitter	O			
Latency	O			
Status		M		
SID		M		
Notes:	M – Mandatory O - Optional			

The S*DA* is the IEEE 48-bit MAC address of the destination MAC(s) that the stream wishes to setup a session with. This is not the address of the CP. It may be a unicast or a multicast address.

The *SA* is the IEEE 48-bit MAC address of the MAC entity initiating the session setup.

The next four parameters are QoS values that will be used by the CP to determine what priority a stream will get. They are discussed further in section 5.4.8.1.1.2 (Priority field).

The *Priority* parameter represents the priority that a stream is requesting for this session.

The *MTR* parameter is the maximum time reservation a node wishes to request.

The *NTR* parameter is the nominal time reservation a node wishes to request.

The *Jitter* parameter should specifiy the maximum allowable jitter this stream can tolerate. This is an optional parameter.

The *Latency* parameter should specifiy the maximum allowable latency this stream can tolerate. This is an optional parameter.

The confirm primitive is issued when either a session setup response MPDU has been received from the CP or has expired.

The MS_SETUP confirm *Status* parameter has one of two values: *successful (access granted), failed (access denied or expired).*

The MS_SETUP confirm SID is the 8-bit stream ID returned by the CP on the session setup response MPDU that identifies the session that has been setup. This ID will last the life of the streaming session and will be used as a means of identifying streams.

5.2.2.2.1 Effect of MS_SETUP Request

A S-node that receives a MS_SETUP request shall attempt to create a streaming session using the procedures described in section 5.21.4.

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5.2.2.3 MS_TEARDOWN Primitive

Primitive	MS_TEARDOWN			
Description	Session tear down			
Parameters	**Req (S-node only)**	**Conf (S-node only)**		
SID	M			
Notes:	M - Mandatory			

The *SID* is the 8-bit stream ID associated with the session. This ID will last the life of the stream and will be used as a means of identifying streams.

The confirmation primitive is issued when the session tear down request MPDU has been transmitted successfully or has expired.

5.2.2.3.1 Effect of MS_TEARDOWN Request

A S-node that receives a MS_TEARDOWN request shall attempt to tear down a streaming session using the procedures described in section 5.21.4.

5.2.2.4 Example of MS_SETUP, MS_DATA, and MS_TEARDOWN Request (Informative)

Figure 57 shows an example primitive and message sequence diagram of a streaming session setup, data, and tear down.

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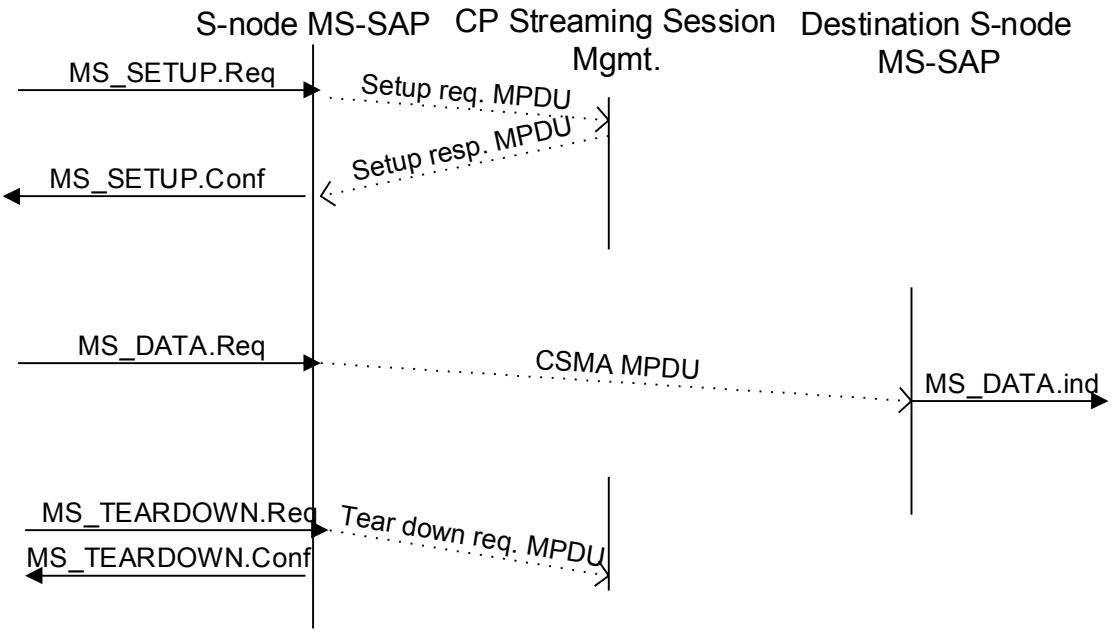


Figure 57 - Example of MS-SAP interface

5.2.3 MC-SAP Data Service

The primitives listed in Table 62 provide the connection-oriented data services.

Table 62 - MC-SAP Service Primitives

MC-SAP service Primitive	Description
MC_CON	Connection Establishment
MC_DIS	Connection Destruction
MC_UCONT	U-plane data control
MC_UDTR	U-plane Data Ready
MC_UDATA	Isochronous U-plane Data
MC_CDATA	C-Channel Data
MC_CDTR	C-Channel Data Ready
MC_KEY	Connection Key setup
MC_ENC	Encryption Control and Key setup

5.2.3.1 Mapping MAC identities onto DECT MC-SAP identities

The DECT *MCEI* (MAC Connection Endpoint Identifier) parameter accompanies several of these primitives. It is used by the CP DLC layer to distinguish between MAC connections. The CP MAC shall maintain a one-to-one mapping between MCEI values and internal connection IDs for the lifetime of a connection.

An implementation can use the MAC-layer connection ID as the MCEI.

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The DECT *PMID* (Portable Part MAC Identity) parameter that accompanies a MC_CON indication identifies an I-node using either the assigned PMID if the I-node has an assigned individual TPUI or the Default PMID with the arbitrary number equal to the least 16 bits of the I-node's IPUI as described in [7, section 6 9.1.2 and 11, section 13.4].

To provide connection oriented services, the DECT DLC interfaces with the LCE entity of the DECT NWK layer which in turn interfaces with the CC (Call Control) entity instances of each connection. Each CC instance is identified by a TID (Transaction ID) and the CC entity by its PID (Protocol ID). The DECT DLC combines the connection TID, NWK entity PD, and the I-node PMID to map to the DLEI (Data Link Endpoint ID) that uniquely identifies the data link connection for each serviced connection. The DLC will provide a mapping between each DLEI and MCEI/PMID.

5.2.3.2 MC_CON Primitive

Primitive	MC_CON			
Description	Connection setup. Connections are established by the I-node. Since the I-node supports only a single connection, the connection does not require a connection identifier.			
Parameters	**Req (I-node only)**	**Conf (I-node only)**	**Ind (CP only)**	
MCEI			M	
PMID			M	
Status		M		
Notes:	M - Mandatory			

The *MCEI* (MAC connection endpoint identifier) parameter identifies the connection that has been set up, and is a constant for the lifetime of the connection. See section 5.2.3.1 (Mapping MAC identities onto DECT MC-SAP identities).

The *PMID* (Portable Part MAC Identity) is 20-bits wide and contains either the assigned PMID if the I-node has an assigned individual TPUI or the Default PMID with the arbitrary number equal to the least 16 bits of the I-node's IPUI which is setting up the connection. The *Status* parameter confirms the success or failure of the MC_CON request.

5.2.3.2.1 Effect of MC_CON Request

An I-node that receives an MC_CON request shall attempt to create a TDMA connection using the procedures defined in section 5.20 (I-Node Management).

5.2.3.3 MC_DIS Primitive

Primitive	MC_DIS			
Description	Disconnection (connection destruction) A connection can be destroyed from either end.			
Parameters	**Req**	**Conf**	**Ind**	
MCEI	CP	CP	CP	
Reason			M	
Notes:	CP - Connection-point only M - Mandatory			

The *Reason* parameter indicates if a disconnection is *normal* or *abnormal*. A normal disconnection is caused by a peer MC_DIS request. An abnormal disconnection results from a local MAC-level procedure, such as a timeout.

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5.2.3.3.1 Effect of MC_DIS request

A node that receives an MC_DIS request shall destroy the TDMA connection using the procedures defined in section 5.20 (I-Node Management).

5.2.3.4 MC_UCONT Primitive

Primitive	MC_UCONT			
Description	U-plane transmit data control This primitive controls the enable state of the U-plane data service in the transmit direction. It has no effect on the receipt of U-plane SDUs from the other end. While the U-plane is enabled, the sending end should present U-plane SDUs isochronously to the MAC. While the U-plane is enabled, the C-channel bandwidth is reduced. Note, the effect of a U-plane enable operation will be delayed if there is any current unacknowledged C-channel data. See section 5.14.2 (MC-SAP Services Connection State Machine).			
Parameters	**Req**			
MCEI	CP			
Enable State	M			
Notes:	CP - Connection-point only M - Mandatory			

The *Enable State* takes one of two values: *enabled* and *disabled.*

5.2.3.4.1 Effect of MC_UCONT Request

A node that receives an MC_UCONT request shall operate the MC-SAP Services Connection state machine as defined in section 5.14.2 (MC-SAP Services Connection State Machine).

5.2.3.5 MC_UDTR Primitive

Primitive	MC_UDTR			
Description	Isochronous U-plane Data Ready			
Parameters			**Ind**	
MCEI			CP	
Notes:	CP - CP only			

The MC_UDTR indication is emitted isochronously by the MC-SAP for an established connection whenever the U-plane is enabled.

5.2.3.6 MC_UDATA Primitive

Primitive	MC_UDATA			
Description	Isochronous U-plane Data			
Parameters	**Req**		**Ind**	

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MCEI	CP		CP	
U-plane SDU	M		M	
Notes:	CP - CP only M - Mandatory			

This transport primitive carries the isochronous connection-oriented data service. Refer to section 3.3.3 (Characteristics of the Isochronous Data Service) for a description of its attributes.

The sending MAC user should issue MC_UDATA requests isochronously in response to MC_UDTR indications.

The peer MAC user receives some or all of these SDUs and issues an MC_UDATA indication for each U-plane SDU received. If the U-plane SDU cannot be received due to transmission errors[57], no indication primitive is issued. There may also be a number of SDUs lost when the U-plane service is enabled (see section 5.14.2 (MC-SAP Services Connection State Machine)).

5.2.3.6.1 Effect of MC_UDATA request

A node that receives an MC_UDATA request shall transmit the U-plane SDU using the procedures defined in section 5.14.4.1 (U-Plane Transmit).

5.2.3.7 MC_CDATA Primitive

Primitive	MC_CDATA			
Description	C-Channel Data This is the transport primitive for the C-Channel associated with an existing connection. The service offers connection-oriented reliable delivery of fixed-length SDUs, with SDU order preserved and no duplication.			
Parameters	**Req**		**Ind**	**Resp**
MCEI	CP		CP	CP
C-Channel SDU	M		M	
Notes:	CP - Connection Point only M - Mandatory			

The *C-Channel SDU* is 5 bytes in length. [58]

The on-air bandwidth is divided between the U-plane and the C-Channel. When the U-plane is disabled, the C-Channel bandwidth increases significantly.

If the node is flow controlling C-plane messages from the other end by deferring acknowledgement, the MC_CDATA response is intended to provide a notification from the higher layers that there is now room to buffer the C-channel SDU indications.

5.2.3.7.1 Effect of MC_CDATA request

A node that receives an MC_CDATA request shall transmit the C-Channel SDU using the procedures defined in section 5.14.3 (C-Channel Data Service).

[57] After the retransmission protocol operated within the MAC layer.

[58] The format of the contents of the C-Channel SDU is defined by the DECT DLC standard [5].

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5.2.3.8 MC_CDTR Primitive

Primitive	MC_CDTR			
Description	C-Channel Data Ready Indicates that the specified connection is able to accept another C-Channel SDU for transmission.			
Parameters			**Ind**	
MCEI			CP	
Number of SDUs			O	
Notes:	CP - Connection Point Only O - Optional			

The *Number of SDUs* parameter indicates how many C-channel SDUs the MAC is able to accept.

This primitive achieves end-to-end C-channel flow-control. The destination MAC will not acknowledge any C-Channel SDUs until they have been indicated to higher layers. As soon as the destination MAC acknowledges a C-channel SDU or SDU set, the originating MAC can issue the appropriate MC_CDTR indication.

5.2.3.8.1 Example of MC_CDTR Interface (Informative)

Figure 58 shows an example message-sequence diagram of a connection setup followed by the transfer of a single C-Channel SDU.

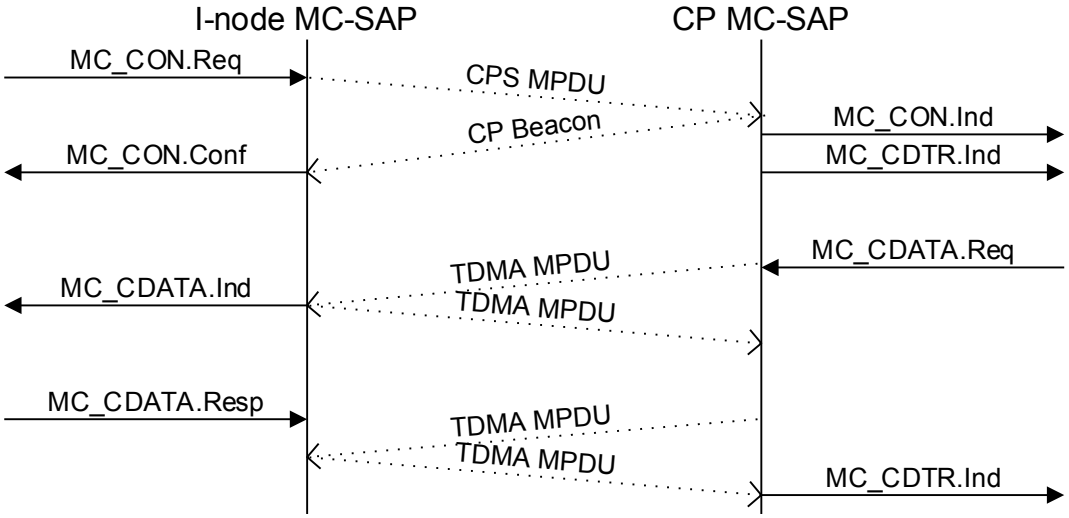


Figure 58 - Example of MC_CDTR Interface

5.2.3.9 MC_KEY Primitive

Primitive	MC_KEY			
Description	This request causes the specified encryption/decryption key to be associated with the connection.			
Parameters	**Req**			
MCEI	CP			
KEY	M			

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Notes:	CP - Connection Point M - Mandatory

5.2.3.9.1 Effect of MC_KEY Request

A node that receives an MC_KEY request shall store the key using the procedures defined in section 5.20.6.3 (Storing the KEY).

5.2.3.10 MC_ENC Primitive

Primitive	MC_ENC			
Description	This request starts transmitting encrypted TDMA frames, as soon as the peer MAC entity is ready to decrypt them.			
Parameters	**Req**	**Conf**	**Ind**	
MCEI	CP	CP	CP	
Status		M		
Notes:	CP - Connection Point M - Mandatory			

The *Status* parameter contains the outcome of the request and has one of two values: *successful* or *no key*. If the request is made without a valid key having been loaded, the MAC shall issue a confirmation with *Status = no key.*

Note, there is no way to revert to transmitting in the clear once encryption is enabled. Encryption set-up should be performed before enabling the U-plane, if it is going to be done at all.

The indication is issued some time after the peer entity issues an encryption request. The confirmation is issued when both ends of the connection have issued an MC_ENC request. All subsequent C-channel and U-plane traffic on the connection are encrypted.

This sequence is illustrated in Figure 59 for the case that the requesting node is the I-node.

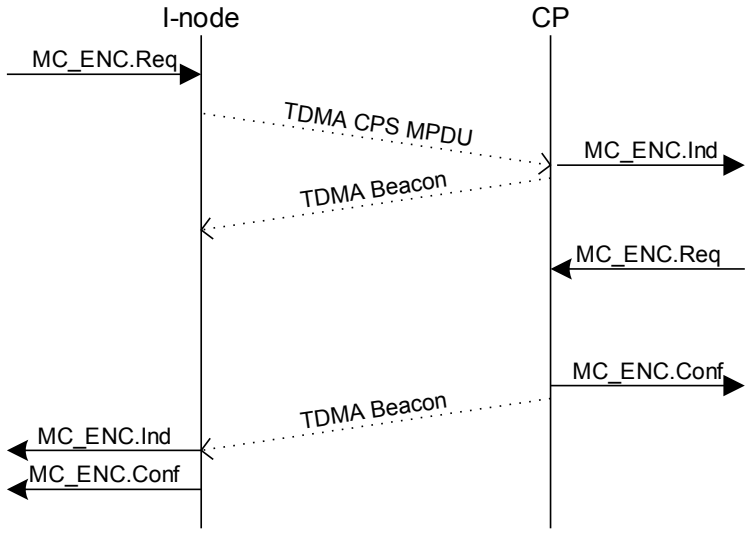


Figure 59 - MC_ENC message sequence

5.2.3.10.1 Effect of MC_ENC Request

A node that receives an MC_ENC request shall start encryption on the connection using the procedures defined in section 5.20.6.4 (Starting Encryption) and described in section 5.20.6.4.1 (Introduction to Starting Encryption (Informative)).

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5.2.4 MB-SAP Data Service (ICBS)

Table 63 describes the primitives supported by the MB-SAP Data Service (ICBS)

Table 63 - Primitives supported by the MB-SAP

MB-SAP service Primitive	Description
MB_CDATA	Provides transport of C-Plane SDUs from the CP to I-nodes
MB_UCONT	Provides control of the U-plane service
MB_UDTR	Provides synchronization for the U-plane service
MB_UDATA	Provides transport of U-plane SDUs from the CP to I-nodes

5.2.4.1 MB_CDATA Primitive

Primitive	MB_CDATA			
Description	Isochronous Connectionless Broadcast C-plane data. Requests are valid only at the CP. Indications are valid only at the I-node. This is a (relatively) reliable point-to-multipoint data transport service for C-plane messages. SDUs are delivered, without duplication, usually without loss, and in order for a given QoS value. The transit delay is typically dominated by the power-saving management procedures of the I-node MAC, and may be up to *IPSinterval* superframes. The transit delay can be increased without bound if subsequent MB_CDATA requests are submitted with a higher priority QoS at a sufficiently high rate.			
Parameters	**Req (CP only)**	**Conf (CP only)**	**Ind (I-node only)**	
QoS	M			
GroupID	O			
Confirmation ID	O	M		
MB SDU	M		M	
Notes:	M – Mandatory O – Optional			

The *QoS* is an ordinal value that defines relative priorities between C-Plane SDUs. The transport of C-Plane SDUs that have the same *QoS* occurs in strict order. C-Plane SDUs having a higher *QoS* will overtake any C-Plane SDUs having a lower *QoS* value that have been queued within the MAC but not yet transmitted.

The *GroupID*, if present, causes any C-Plane SDU with a matching *GroupID* that has been queued but not yet transmitted to be discarded before queuing the requested C-Plane SDU.

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The *ConfirmationID*, if present, causes an MB_CDATA confirmation with the same *ConfirmationID* to be generated when the SDU contained in the request has completed transmission.

The *MB SDU* is a 5-byte SDU, corresponding to a DECT NWK 5-byte B-FORMAT PDU. [59]

5.2.4.1.1 Effect of MB_CDATA Request

A Class-1 CP that receives an MB_CDATA request shall transmit the SDU using the procedures defined in section 5.15.1.3.1 (MB_CDATA Request).

5.2.4.1.2 Effect of MB_CDATA Indication

An I-node that receives ICBS C-plane SDUs as described in the procedures defined in section 5.15.2.9 (MB-SAP C-Plane Rx Process) shall generate this indication to the DLC.

5.2.4.2 MB_UCONT Primitive (CP only)

Primitive	MB_UCONT			
Description	ICBS U-plane data control This request is valid only at a Class-1 CP. This primitive controls the enable state of the U-plane Isochronous Connectionless Broadcast Service. While the U-plane is enabled, and the MB-SAP Tx State machine (see section 5.15.1.4 (MB-SAP Tx State Machine)) is in a state that supports the transport of U-plane SDUs, the MB-SAP will emit MB_UDTR indications isochronously. While the U-plane is enabled, the C-Plane broadcast bandwidth is reduced. Note that the effect of a U-plane enable operation will be delayed until any current C-plane ICBS SDU set has been transmitted. See section 5.15.1.4 (MB-SAP Tx State Machine).			
Parameters	**Req**			
Enable State	M			
Notes:	M – Mandatory			

The *Enable State* takes one of two values: *enabled* and *disabled.*

5.2.4.2.1 Effect of MB_UCONT Request

The MB_UCONT request controls whether the ICBS U-plane is enabled. When enabled, and the MB-SAP Tx State machine is in the *Active* or *Transmitting* state, the MB-SAP emits MB_UDTR indications once per subframe.

The MB_UCONT request does not take the MB-SAP Tx State machine out of its *Idle* state. This can only be achieved by the MB_CDATA request. [60] The MB_UCONT request does prevent the MB-SAP Tx State machine from re-entering its *Idle* state, as long as the U-plane is enabled.

Upon receipt of this request, the MAC shall perform the procedures defined in section 5.15.1.4 (MB-SAP Tx State Machine).

5.2.4.3 MB_UDTR Primitive (CP Only)

Primitive	MB_UDTR

[59] Note, the 3-byte short page is not supported.

[60] The NWK layer requires that a voice announcement is preceded by a C-channel page SDU that indicates a voice announcement.

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Description	ICBS U-plane Data Ready This indication is valid only at a Class-1 CP. Indicates that the ICBS U-plane is able to accept a U-plane SDU for transmission. It is generated only when the MB-SAP Tx State Machine is in the *Active* or *Empty* state with the U-plane enabled.			
Parameters			**Ind**	
Notes:				

5.2.4.3.1 Effect of MB_UDTR Indication

This indication provides an isochronous timing reference from the ICBS channel. It is an indication that an ICBS U-plane SDU can be transmitted in the next ICBS channel TDMA MPDU. The generation of this indication is based on the state of the MB-SAP Tx State Machine, the ICBS U-plane enable variable. See section 5.15.1.4 (MB-SAP Tx State Machine).

The higher layers should respond with an MB_UDATA request.

5.2.4.4 MB_UDATA Primitive

Primitive	MB_UDATA			
Description	Isochronous Connectionless Broadcast U-plane data. Requests are valid only at the CP. Indications are valid only at the I-node. This is an unreliable point-to-multipoint data transport service. Due to the purely isochronous nature of the U-plane data and the available bandwidth, there is no duplication of transmissions. Corrupted U-plane SDUs are not indicated. The transit delay is constant while the ICBS U-plane is enabled and no more than *SubframeDuration*.			
Parameters	**Req (CP Only)**		**Ind (I-node only)**	
MB SDU	M		M	
Notes:	M – Mandatory			

5.2.4.4.1 Effect of MB_UDATA Request

A Class-1 CP that receives an MB_UDATA request shall transmit the SDU using the procedures defined in section 5.15.1.4 (MB-SAP Tx State Machine).

5.2.4.4.2 Effect of MB_UDATA Indication

An I-node that receives an Isochronous Connectionless Broadcast U-plane SDU as described in the procedures defined in section 5.15.2.8 (MB-SAP U-plane Rx Process) shall generate this indication to the DLC.

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5.2.5 MM-SAP Management Service

Table 64 defines the primitives supported by the MAC management service access point.

Table 64 - MAC Management Service Primitives

Service Primitive	Description
MM_TEACH	Signal *LearnNWID* to all stations in "learn" mode
MM_LEARN	Look for networks with *LearnNWID* signaled
MM_DIRECTEDTEACH	Send *Directed Learn NWID* MPDUs to the node that the NWID is being directed to.
MM_DIRECTEDLEARN	Look for networks sending *Directed Learn NWID* MPDUs directed to this node's IEEE MAC address
MM_START	Start/Join a network with a particular NWID
MM_JOIN	Join a network with one of a set of known NWIDs
MM_LOST	Indicates that the station has lost connectivity with its network

The MM-SAP primitives are described in the sections that follow.

5.2.5.1 MM_TEACH Primitive

Primitive	MM_TEACH			
Description	Causes the MAC to signal "Learn NWID" to all stations in "learn" mode Causes the node to send MPDUs with "Learn NWID" signaled for a duration of *LearnNWIDtimeout* The Confirmation is issued when the timeout expires.			
Parameters	**Req**	**Conf**		

5.2.5.1.1 Effect of MM_TEACH Request

A node that receives an MM_TEACH request shall perform the procedures defined in section 5.16.14 (Signaling *LearnNWID*).

5.2.5.2 MM_LEARN Primitive

Primitive	MM_LEARN			
Description	Look for networks with "Learn NWID" signaled. Causes the HomeRF device to collect discovered NWIDs by scanning a number of channels. The confirmation carries the identities of the networks discovered.			
Parameters	**Req**	**Conf**		
Discovered NWIDs		M		
Completion Type	O			
Notes:	M - Mandatory			

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	O - Optional

The *Discovered NWIDs* parameter carries a list of networks discovered.

The optional *Completion Type* parameter has one of two values: *full scan, fast join. Full scan* ensures that a complete scan is performed. The MAC entity will not have synchronized to any discovered network on completion of the scanning procedure. The *fast join* value causes the scanning procedure to stop at the first discovered network. The MAC entity will be synchronized to the network on completion of the scanning procedure. The default behavior is: *full scan.*

5.2.5.2.1 Effect of MM_LEARN Request

A node that receives an MM_LEARN request shall perform the procedures defined in section 5.16.7 (Scanning for a New Network).

5.2.5.3 MM_DIRECTEDTEACH Primitive

Primitive	MM_DIRECTEDTEACH			
Description	Causes the MAC to signal "Directed Learn NWID" to the directed IEEE MAC Address Causes the node to send *Directed Learn NWID* MPDUs for a duration of *DirectedLearnNWIDtimeout* The Confirmation is issued when the timeout expires.			
Parameters	**Req**	**Conf**		
MAC address	**M**			

The *MAC address* parameter carries the IEEE MAC address of the node that the *NWID* is being directed to.

5.2.5.3.1 Effect of MM_DIRECTEDTEACH Request

A node that receives a MM_DIRECTEDTEACH request shall perform the procedures defined in section 5.16.15.

5.2.5.4 MM_DIRECTEDLEARN Primitive

Primitive	MM_DIRECTEDLEARN			
Description	Look for networks with "Directed Learn NWID" signaled. Causes the HomeRF device to collect discovered NWIDs that are signaling a "Directed Learn NWID" with the node's IEEE MAC address by scanning a number of channels. The confirmation carries the identities of the networks discovered.			
Parameters	**Req**	**Conf**		
Discovered NWIDs		M		
Completion Type	O			
Notes:	M - Mandatory O - Optional			

The *Discovered NWIDs* parameter carries a list of networks discovered.

The optional *Completion Type* parameter has one of two values: *full scan, fast join. Full scan* ensures that a complete scan is performed. The MAC entity will not have synchronized to any discovered network on completion of the scanning procedure. The *fast join* value causes the scanning procedure to stop at the first discovered network. The MAC entity will be synchronized to the network on completion of the scanning procedure. The default behavior is: *full scan.*

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5.2.5.4.1 Effect of MM_DIRECTEDLEARN Request

A node that receives a MM_DIRECTEDLEARN request shall perform the procedures defined in section 5.16.8.

5.2.5.5 MM_START Primitive

Primitive	MM_START			
Description	Start or join a network with a particular NWID. Causes the HomeRF device to start or join a network following the procedures defined in section 5.16.9 (Scanning for a Known Network) and 5.16.13 (Creating a Network). The confirmation is issued when the station is in synchronization with the network, or if the operation has failed.			
Parameters	**Req**	**Conf**		
NWID	M			
Start network	O			
Start Status		M		
Notes:	M - Mandatory			

The *Start network* parameter is an optional parameter that if present causes the device to start a network with the supplied *NWID* without first attempting to find that network.

The *Start Status* parameter has one of the values: *Joined, Started, Cannot Join.*

5.2.5.5.1 Effect of MM_START request

A node that receives an MM_START request shall perform the procedures defined in section 5.16.9 (Scanning for a Known Network).

5.2.5.6 MM_JOIN Primitive

Primitive	MM_JOIN (I-node only)			
Description	Join a network with one of a list of known NWIDs Causes the I-node to join a network following the procedures defined in section 5.16.12 (Scanning for a set of Known Networks (I-node only)). The confirmation is issued when the station is in synchronization with the network, or if the operation has failed.			
Parameters	**Req**	**Conf**		
NWID list	M			
NWID found		O		
Join Status		M		
Notes:	M - Mandatory O - Optional			

The *NWID list* parameter contains a list of NWIDs that the I-node can join.

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The *NWID found* parameter contains the NWID of the network joined.

The *Join Status* parameter has one of the values: *Joined, Cannot Join.*

5.2.5.6.1 Effect of MM_JOIN request

An I-node that receives an MM_JOIN request shall perform the procedures defined in section 5.16.12 (Scanning for a set of Known Networks (I-node only)).

5.2.5.7 MM_LOST Primitive

Primitive	MM_LOST (I-node only)			
Description	Indicates that the I-node has lost connectivity with the network. This indication occurs following a timeout on the receipt of CP beacons as defined in section 5.16.5 (Transitions from the Managed Synchronization State).			
Parameters			**Ind**	
NWID			O	
Notes:	O - Optional			

The *NWID* parameter contains the identity of the network with which connectivity has been lost.

5.2.5.8 MM_FIND Primitive

Primitive	MM_FIND			
Description	Find a network with a particular NWID. Causes the HomeRF node to find a specific network following the procedures defined in section 5.16.10 The confirmation is issued when the node has completed its find procedure.			
Parameters	**Req**	**Conf**		
NWID	M			
Find Status		M		
Notes:	M – Mandatory			

5.2.5.8.1 Effect of MM_FIND request

A HomeRF node that receives a MM_FIND request shall perform the procedures defined in section 5.16.10 (Finding Roaming Connection Points). The Finding Roaming Connection Points procedure does not result in the node synchronizing to a new Connection Point, or changing its current synchronization parameters from one Connection Point to another. Rather, the Finding Roaming Connection Points procedure is used to allow the node to create a database of likely Connection Points to which it may choose to synchronize.

5.2.5.9 MM_ROAMTOCP Primitive

Primitive	MM_ROAMTOCP
Description	Synchronize with a particular Connection Point Causes the HomeRF node to synchronize to a Connection Point with a particular IEEE MAC address.

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	The confirmation is issued when the node has synchronized to the Connection Point, or the attempt to synchronize has failed.			
Parameters	**Req**	**Conf**		
NWID	M			
MAC address	M			
RoamToCP Status		M		
Notes:	M – Mandatory			

5.2.5.9.1 Effect of MM_ROAMTOCP Request

A HomeRF node that receives an MM_ROAMTOCP request shall perform the procedures defined in section 5.16.11 (Roaming to a Particular Connection Point).

5.3 MAC Architecture

This section introduces the processes that operate within the HomeRF MAC. This top-level view of the MAC is called the MAC architecture.

Figure 60 shows these top-level processes and the main flow of data units between them. It does not show management flow of control, which can be assumed to connect all processes to the management entity.

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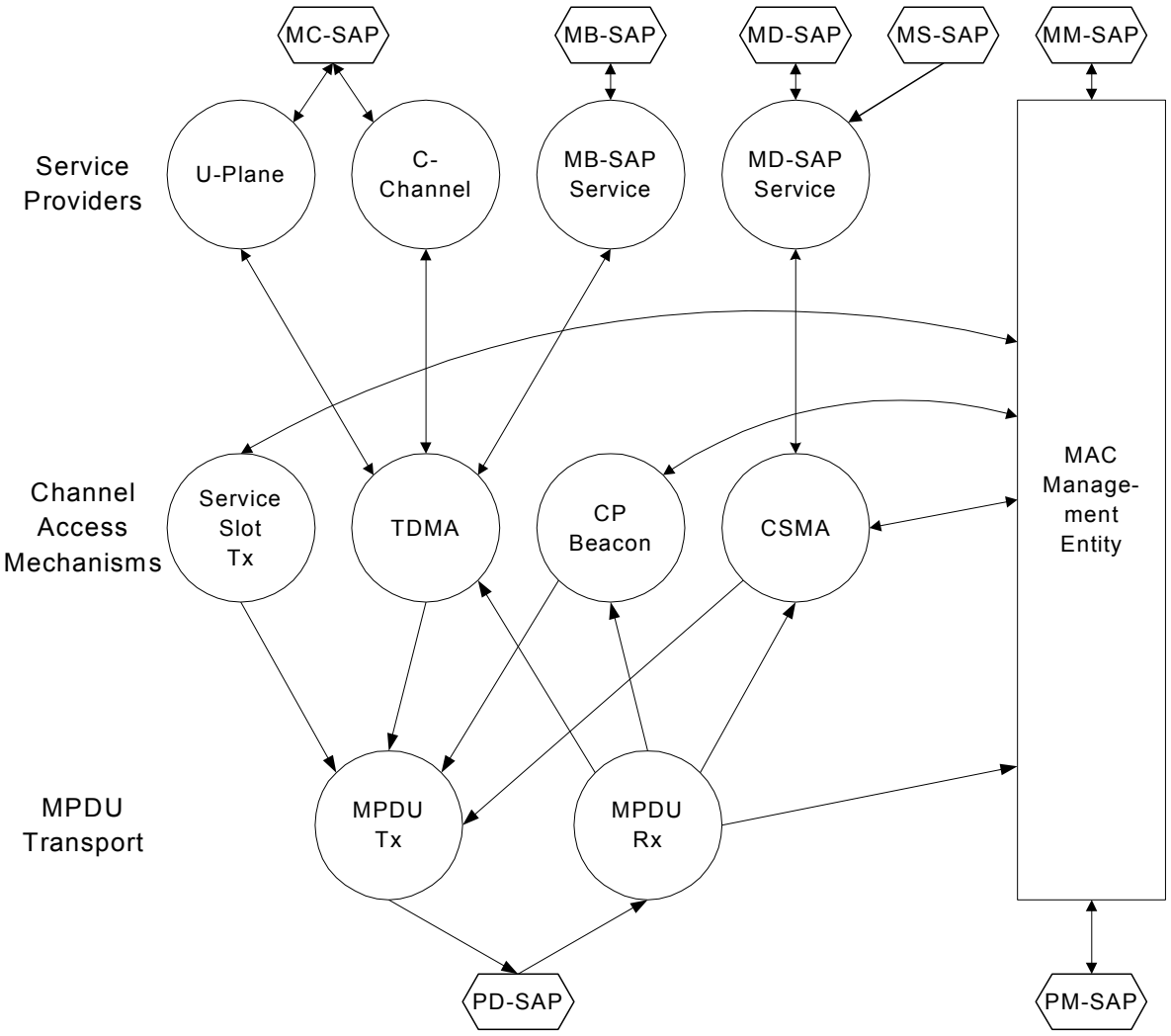


Figure 60 - MAC Architecture

Apart from the MAC Management Entity, the processes within the MAC belong to a number of distinct architectural layers; these are described in Table 65.

Table 65 - MAC Architectural Layers

MAC Architectural Layer	**Responsible For**
Service Providers	Mapping the service primitives onto the exchange of PDUs.
Channel Access Mechanisms	Operating rules that control when and how the node can transmit and receive
MPDU Transport	Providing a transport service for valid MPDUs

The service provider layer exports through the Service Access Point those services defined in section 5.2 (MAC Services).

The four access mechanisms are described in Table 66.

Table 66 - MAC Access Mechanisms

Access Mechanism	**Description**

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CP Beacon	Provides for the periodic transmission of the CP beacon MPDU. *The CP beacon can consist of both a TDMA oriented beacon and a CSMA oriented beacon. The TDMA beacon carries management signaling for the isochronous services. The CSMA oriented beacon carries management signaling for the asynchronous service and the priority asynchronous service.*
TDMA	Provides for the isochronous exchange of TDMA MPDUs using reserved bandwidth. *These TDMA MPDUs carry two types of SDU:* 1. MC-SAP C-Channel and U-plane SDUs 2. MB-SAP C-plane and U-plane SDUs
CSMA	Provides for the asynchronous exchange of management MPDUs, Time Reservation MPDUs and DATA MPDUs. The DATA MPDUs carry CSDUs.
Service Slot Tx	Provides for the asynchronous transmission of management MPDUs from an I-node to a CP.

The management entity performs node management procedures. It provides the management services defined for the MM-SAP. It is the source and sink of all management MPDUs within the node.

5.3.1 "Packet" Types (Informative)

This section introduces the different types of "packets" that flow within and through the MAC layer related to the provision of the asynchronous data service and the priority asynchronous data service. Table 67 lists these packet types.

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Table 67 - "Packet" Types Supporting the Asynchronous Data Service

Packet Type	Description	Contains
MSDU	MAC Service Data Unit	Carries the MAC asynchronous and priority asynchronous data service
CSDU	CSMA/CA service data unit	MSDU + any MD-SAP service protocol overhead. A CSDU can result from a MSDU that was passed from either the MD-SAP or MS-SAP
DATA MPDU	DATA MAC Protocol Data Unit	All or part of a CSDU, plus MAC CSMA/CA protocol overhead
PSDU1 and PSDU2	PHY Data Service Unit (1 and 2)	PSDU1 and PSDU2 between them carry the MPDU header, payload and CRC(s). PSDU2 is only used when the MPDU is divided into portions where the PSDU2 portion is transmitted at a different modulation type than the PSDU1 portion. When only PSDU1 is used, the format is one of the single PSDU formats (*Basic Rate Single PSDU or Extended Preamble High Rate Single PSDU*).. PSDU2 is used for the *Dual PSDU* format.
PPDU	PHY Protocol Data Unit	Carries PSDU1 and PSDU2, plus PHY-layer signaling and framing

Figure 61 shows how an MSDU is embedded in a PPDU. In this example, there is no compression, encryption or fragmentation of the MSDU. The format is *Basic Rate Single PSDU* and the entire PPDU is transmitted using the basic modulation.

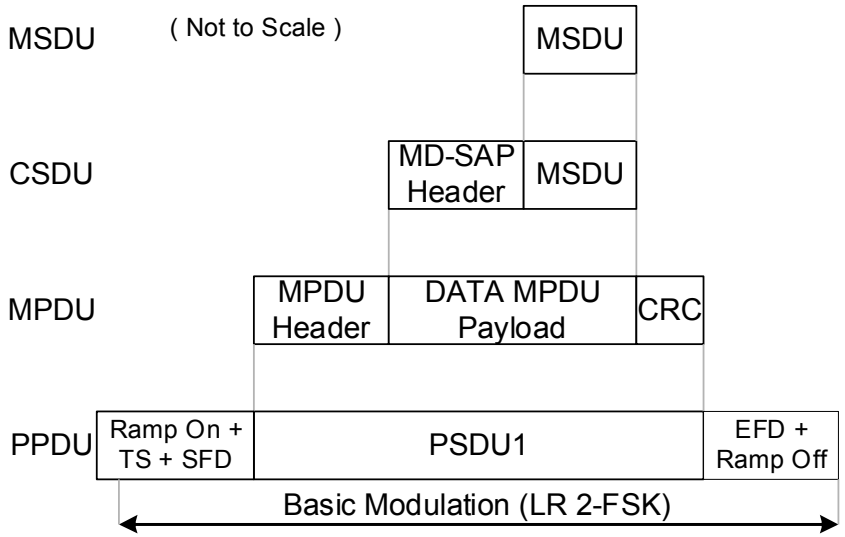


Figure 61 - Embedding an MSDU in a Single PSDU PPDU (basic 2-FSK)

Figure 62 shows how an unfragmented MSDU is transmitted using the (optional) *Dual PSDU* format which indicates that PSDU2 is transmitted with LR 4-FSK modulation type.

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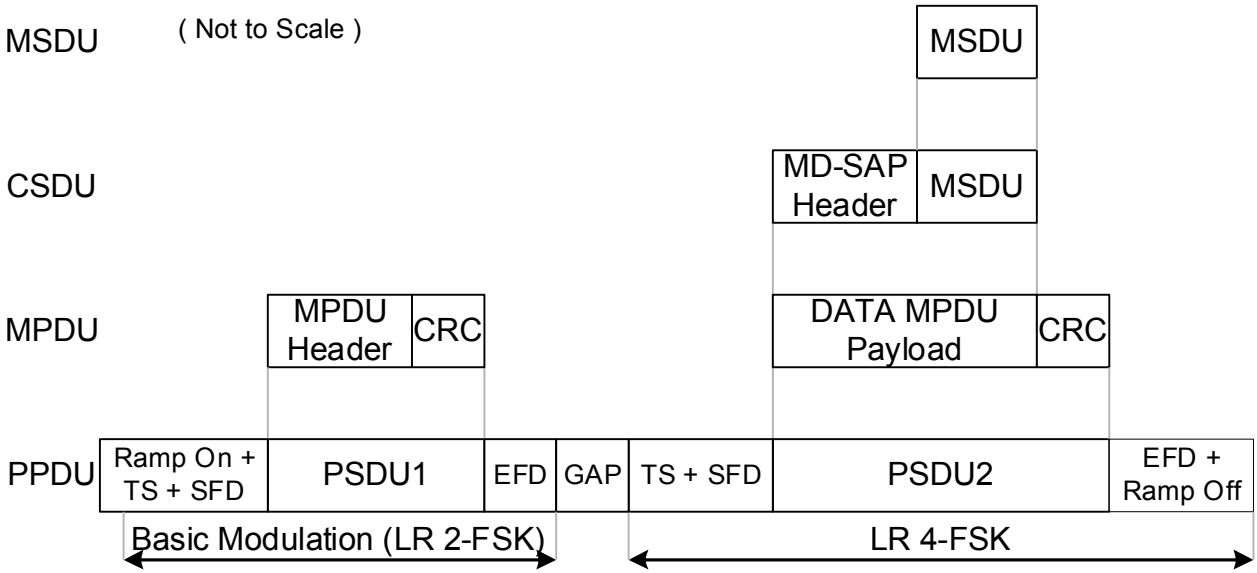


Figure 62 - Embedding an MSDU in a Dual PSDU PPDU)

Figure 63 shows how an unfragmented MSDU is transmitted within a Time Reservation using the *Extended Preamble High Rate Single PSDU* PPDU format and the modulation type that was signaled in the *Time Reservation Establish* MPDU.

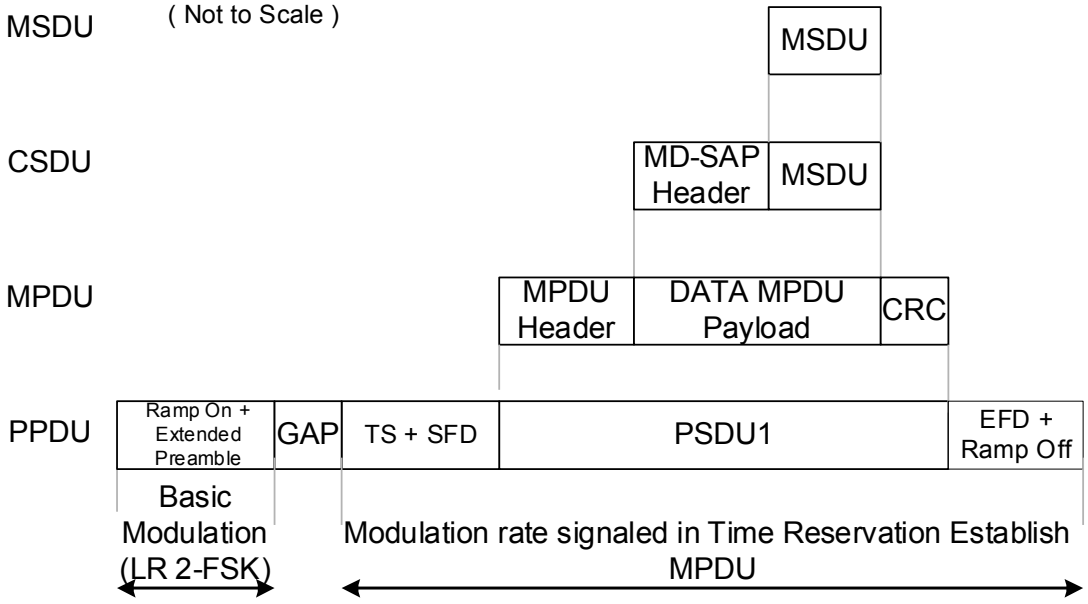


Figure 63 - Embedding an MSDU in an Extended Preamble High Rate Single PSDU PPDU

The contents of the MSDU are not interpreted in any way by the MAC layer. It is likely to carry a TCP/IP packet, but could carry other higher-layer protocols.

The MD-SAP or MS-SAP services take the MSDU transmit request and perform MD-SAP Header insertion and any specified compression and encryption. In the example above, only MD-SAP Header insertion is shown.

The CSDU is fragmented (if necessary) and the fragments are inserted into multiple DATA MPDUs. The DATA MPDU is transmitted as a PPDU. The PPDU format indicates which portions of the MPDU are placed in PSDU1 and PSDU2 if applicable. A *Basic Rate Single PSDU* or *Extended Preamble High Rate Single PSDU* format includes all portions in PSDU1. The *Basic Rate Single PSDU* is always transmitted using the basic modulation type. The *Extended Preamble High Rate Single PSDU* format is transmitted using the *high-rate Modulation Type* indicated in the *Time Reservation Establish* MPDU. For the *Dual PSDU* format, the MPDU isdivided

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into PSDU1 and PSDU2 portions. PSDU1 is always transmitted using the basic modulation type. PSDU2 is transmitted using LR 4-FSK modulation type.

5.4 MPDU Structures

This section defines the structure of the MAC protocol data unit (MPDU) that the MAC entity sends and receives across the PHY data service to provide the MAC services.

5.4.1 Byte and Bit Ordering

5.4.1.1 Introduction (Informative)

A computing device usually manipulates data as bytes. On the other hand, the data is transmitted on-air serially (symbol by symbol). Furthermore, some quantities exchanged between peer MAC entities are larger than one byte, so must be represented on a multi-byte value.

There are two ordering issues:

- Bit ordering: in which order the bits of a Byte are transmitted on the network.
- Byte ordering: in which order the Bytes of a multi-byte quantity are transmitted on the network.

Those orders might not be the same. For example, Ethernet is little-endian for bit order (LSB of Byte first) and big-endian for Byte order (MSB of Ethernet type field first). 802.11 [1] is little-endian for both and that Token Ring is big-endian for both. DECT is big-endian for both as described in [4, section 5.4.5].

On top of that, there is the problem of IEEE 48-bit addresses. In the IEEE specifications, IEEE 48-bit addresses are considered as a bit-field. For those addresses, the transmission order is strictly defined (which bit is transmitted first) and the user presentation might change depending on the transmitter bit order (where those bits appears in the bytes). This can create confusion when interconnecting two technologies that are not using the same bit ordering (for example Ethernet/802.3 [12] and Token-Ring/802.5) because addresses do not appear to the user (and the applications) in the same way.

The transmission order of a IEEE 48 bit address is such that the group/individual bit is always sent first and the global/local bit is sent second. The following 22 bits are the manufacturer ID (registered with the IEEE), and the remaining 24 bits is the device ID (left to the manufacturer). This structure is shown in Figure 64.

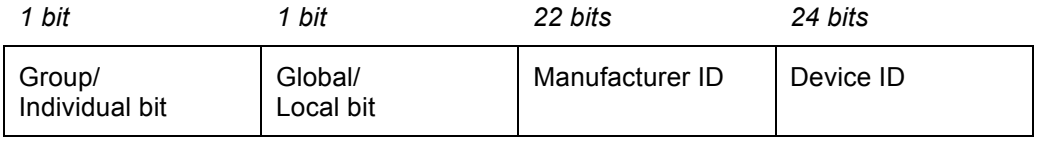


Figure 64 - IEEE 48 bit address - transmission order

The purpose of this ordering is to allow efficient multicast filtering. As Ethernet is little-endian for bit order, this explains why when presenting an Ethernet address to the user it becomes the least significant bit of the first byte of the address (so the least significant bit of the second hexadecimal digit).

The objective for HomeRF ordering for the asynchronous data and priority asynchronous services is to be as close as possible to Ethernet for the interface, to allow a smooth integration and to avoid having to byte swap any quantities.

For the isochronous data services (TDMA), the objective of HomeRF ordering is to be compatible with DECT.

Because both Ethernet and 802.11 are little-endian for the bit order, so HomeRF for the asynchronous data and priority asynchronous services is little-endian for the bit order. To simplify the interpretation of multi-byte quantities, HomeRF is little-endian for the byte order as well. In summary, HomeRF for the asynchronous data and priority asynchronous services is little-endian for both the bit and the byte order.

IEEE addresses are sent the way they are defined, with the group/individual bit sent first. If we treat the address as a string of 6 bytes, the user presentation of it will be the same as Ethernet (group/individual bit as the least significant bit of the first byte).

There is a problem with the Ethernet type/length field. This field is passed to the MAC entity by the higher layers of the protocol stack as a two-byte string, most significant byte first. The MAC carries these two bytes as is, without swapping them, resulting in a big-endian byte order for the Ethernet type/length field. This exception to the rule allows smooth integration with Ethernet.

Because DECT is big-endian for both bit order and Byte order, so HomeRF for the isochronous data services (TDMA) will be big-endian for both.

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All other data passed by the higher layer (IP, DECT) and transmitted in the payload of HomeRF MPDUs are SDUs *(Service Data Unit)* transparently handled by the HomeRF MAC and are considered as a string of bytes. Order does not matter for the MAC as long as we respect it. So, the rules of the higher layers apply (for example, IP will be big-endian for byte order).

5.4.1.2 Byte and Bit Ordering (Normative)

Bit fields shown in this specification shall be transmitted leftmost bit first. Bits within a bit field are numbered starting at zero for the leftmost bit.

Sequences of bytes shown in this specification shall be transmitted leftmost byte first.

Fields within a structure shown in this specification shall be transmitted leftmost field first.

Any multi-bit number shall be transmitted as defined in Figure 65, regardless of its size in bits or bytes.

	1 bit	…	*1 bit*
Asynchronous data[61]	Least significant bit	…	Most significant bit
Isochronous data	Most significant bit	…	Least significant bit

Figure 65 - Multi bit value transmission order

To illustrate this further consider Table 68 on how a hypothetical multi-value field structure as drawn in this specification would be transmitted on the air reading left to right as earliest to latest.

Table 68- Multi-value field bit ordering comparison of asynchronous and isochronous data

Multi-value field Description	Type code (2 bits)	Length (12 bits)	Sequence number (2 bits)
Multi-value field Values	2(decimal) = ”10”(binary)	5A5(hexidecimal) = ”010110100101”(binary)	1(decimal) = ”01”(binary)
Asynchronous data on air transmission	Sequence number (2bits) = 1(decimal) = ”10”(transmitted)	Length (12 bits) = 5A5(hexidecimal) = “101001011010”(transmitted)	Type code (2 bits) = 2(decimal) = “01”(transmitted)
Isochronous data on air transmission	Type code (2 bits) = 2(decimal) = “10”(transmitted)	Length (12 bits) = 5A5(hexidecimal) = ”010110100101”(transmitted)	Sequence number (2 bits) = 1(decimal) = ”01”(transmitted)

IEEE addresses shall be transmitted so that the *Group/Individual* bit is first.

Ethernet type/length fields shall be transmitted as a sequence of two bytes, most significant byte first[62].

5.4.2 Reserved Fields and Values

In the sections that follow, any unused MPDU fields are marked as reserved. All reserved fields shall be transmitted as bit-fields containing zeroes.

[61] In this section, asynchronous and priority asynchronous can be considered the same, and hence what applies to one applies to the other.

[62] Note, this is an exception to the strictly little-ending order. See also the discussion above.

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In the sections that follow, if an enumeration of values for an MPDU field does not cover all possible values that can be encoded in that field, the unused values are reserved. A HomeRF node shall not transmit an MPDU that contains any reserved values.

5.4.3 Different MPDU Formats

This specification defines four different formats of MPDU that directly relate to types of service provided by the PD-SAP. These are shown in Table 69.

The *TDMA PPDU* format is used to carry MPDU types that are transmitted using TDMA PHY-layer options (TDMA scrambling, no bit-stuffing), which provides for a mutual exclusivity from non-TDMA PPDUs. These MPDUs are used to carry the Isochronous data service and use the TDMA access mechanism to determine when they are sent. They consist of an MPDU header and optional payload carried in the PSDU1 parameter of the PD-TX data service. The format of the MPDU payload is determined by the header field.

The *Basic Rate Single PSDU* format is used to carry MPDU types that have no payload or that have a payload that is transmitted using the same basic modulation type as the header. The MPDU header, MPDU payload and MPDU CRC are carried in the PD-SAP data service PSDU1 parameter.

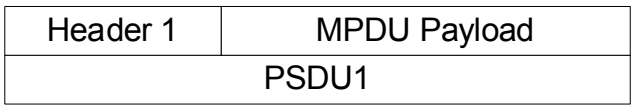
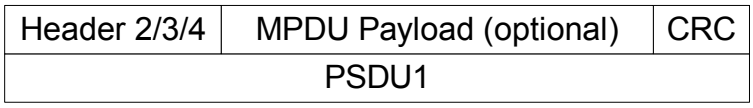
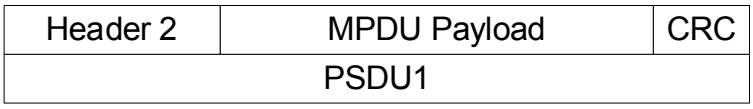
The *Extended Preamble High Rate Single PSDU* format is a special variation of the *Single PSDU* format and is used to carry MPDU types that are transmitted within a time reservation using the high-rate modulation type associated with the time reservation. The MPDU header, MPDU payload and MPDU CRC are carried in the PD-SAP data service PSDU1 parameter.

The *Dual PSDU* format is used to carry MPDU types where the payload is transmitted using a different modulation type than the header. The MPDU header and header CRC are carried in the PD-SAP data service PSDU1 parameter. The MPDU payload and payload CRC are carried in the PSDU2 parameter. The entire PSDU1 is sent using basic modulation. The entire PSDU2 is sent using LR 4-FSK modulation type.

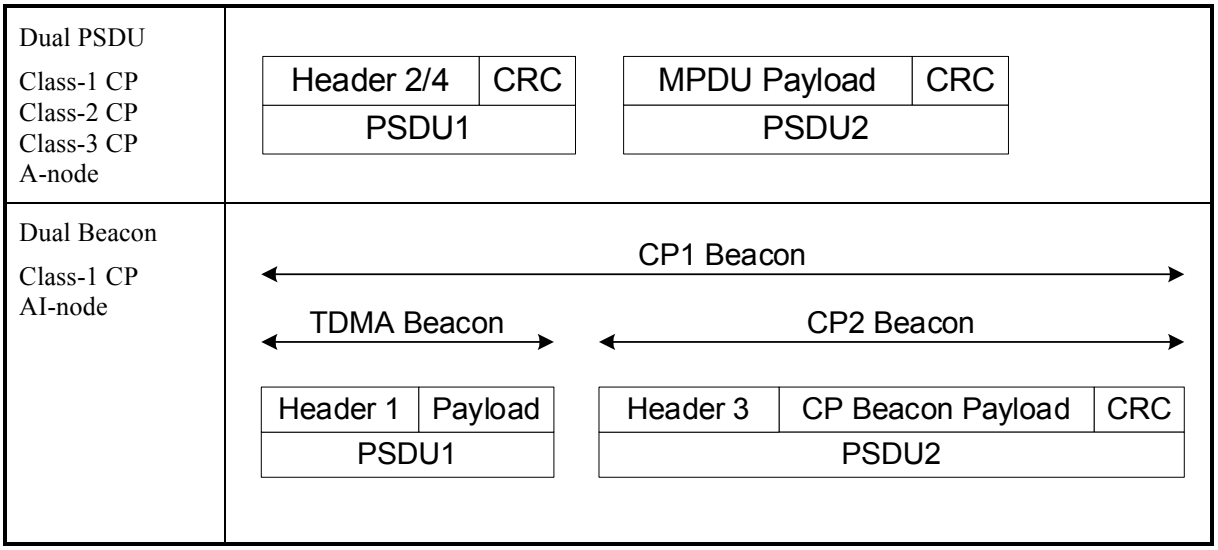
The *Dual Beacon* format is used by a Class-1 CP to transmit the beacon. It consists of two parts. The first is transmitted using TDMA settings for stuffing and scrambling. The second is transmitted using CSMA/CA settings for stuffing and scrambling. The *Dual **Beacon*** format can be received by an AI-node. An I-node receives the *Dual Beacon* as a *TDMA* format MPDU. An A-node receives the *Dual Beacon* as a *Basic Rate Single PSDU* format.

There is a single 32-bit MAC CRC for the *Single PSDU* formats. There are two 32-bit MAC CRCs for the *Dual PSDU* formats. The payload of a TDMA format MPDU includes either 1 or 2 16-bit CRCs, determined by the Header 1 field. The Dual Beacon includes a 16-bit CRC in the payload of PSDU1, and a 32-bit CRC in PSDU2.

Table 69 - MPDU Formats and Structures

MPDU Format / Supported by	**MPDU Structure**
TDMA PPDU Class-1 CP I-node	
Basic Rate Single PSDU Class-1 CP Class-2 CP Class-3 CP A-node	
Extended Preamble High Rate Single PSDU Class-1 CP Class-2 CP Class-3 CP A-node	

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5.4.4 MPDU Headers

Table 70 defines the five types of MPDU header.

Table 70 - MPDU Header Types

Header Type	Length	Used By
1	2 bits	TDMA MPDUs only
2	19 bytes	Non-TDMA MPDUs
3	17 bytes	CP2 Beacon MPDUs carrying network synchronization information
4	23 bytes	DATA MPDUs carrying synchronization information in an ad-hoc network

5.4.4.1 MPDU Header Type 1

The MPDU header type 1 consists of a single field, the *TDMA MPDU Type.*

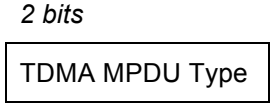


Figure 66 - MPDU Header type 1

5.4.4.1.1 TDMA MPDU Types

Table 71 defines the values for the TDMA MPDU Type field.

Table 71 - TDMA MPDU Type Values

TDMA MPDU Type	Definition
0	MPDU is a Main TDMA MPDU
1	MPDU is a Retry TDMA MPDU

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2	MPDU is a TDMA CPS MPDU
3	PSDU1 is the TDMA Beacon part of a Dual Beacon MPDU.

5.4.4.2 MPDU Header Type 2

Figure 67 defines the structure of an MPDU Header type 2.

12 bits	*12 bits*	*24 bits*	*8 bits*	*48 bits*	*48 bits*
MPDU Control	Length	NWID	Payload control	Dest address	Source address

Figure 67 - MPDU Header type 2

5.4.4.3 MPDU Header Type 3

Figure 68 defines the structure of an MPDU Header type 3.

12 bits	*12 bits*	*24 bits*	*8 bits*	*32 bits*	*48 bits*
MPDU Control	Length	NWID	Superframe control	Sync info	Source address

Figure 68 - MPDU Header type 3

5.4.4.4 MPDU Header Type 4

Figure 69 defines the structure of an MPDU Header type 4.

12 bits	*12 bits*	*24 bits*	*8 bits*	*32 bits*	*48 bits*	*48 bits*
MPDU Control	Length	NWID	Payload control	Sync info	Dest address	Source address

Figure 69 - MPDU Header type 4

5.4.4.5 MPDU Control Field

Figure 70 defines the structure of the MPDU control field.

2 bits	*1 bit*	*5 bits*	*4 bits*
MPDU Version	Learn NWID	MPDU Type	Modulation Type

Figure 70 - MPDU Control Field Structure

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5.4.4.6 MPDU Version Field

The MPDU Version field indicates a version level of the MPDU type. It can be used to indicate that the MPDU contains additional fields from that of earlier versions of the same MPDU type. Table 72 defines values of the MPDU Version field.

Table 72 – MPDU Version Field Values

MPDU Version Field	Description
0	Default value. This value indicates that all fields of the MPDU are supported by all versions that support the MPDU type
1-3	Reserved for future use

5.4.4.7 CSMA MPDU Types

Table 73 defines the following:

- The encoding of the MPDU type field
- The associated MPDU Header Type
- The MPDU formats that may be used to transport that MPDU type (see 5.4.3)

Table 73 - CSMA MPDU Types

MPDU Type value (b0-b4)	MPDU Type	MPDU Class	Associated MPDU Header Type	Allowed MPDU Formats
00000	Time Reservation Establish	Time Reservation Management	Type 2	Basic Rate Single PSDU.
00001	Time Reservation Cancel	Time Reservation Management	Type 2	Basic Rate Single PSDU with no payload.
00010	Time Reservation Establish Request-To-Send	Time Reservation Management	Type 2	Basic Rate Single PSDU.
00011	Time Reservation Establish Clear-To-Send	Time Reservation Management	Type 2	Basic Rate Single PSDU.
00100	Time Reservation Establish + Sync	Time Reservation Management	Type 4	Basic Rate Single PSDU.
00101	Time Reservation Establish Request-To-	Time Reservation Management	Type 4	Basic Rate Single PSDU.

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	Send + Sync			
01000	CPS	Node Management	Type 2	Basic Rate Single PSDU
01001	Streaming Session Management request	Streaming Session Management	Type 2	Basic Rate Single PSDU
01010	Streaming Session Management response	Streaming Session Management	Type 2	Basic Rate Single PSDU
01011	Roam Notify	Node Management	Type 2	Basic Rate Single PSDU with no payload
01100	Directed Learn NWID	Node Management	Type 4	Basic Rate Single PSDU with no payload
01111	CP assertion	Connection Point Management	Type 2	Basic Rate Single PSDU
10000	DATA	Asynchronous and Priority Asynchronous Data Service	Type 2	Basic Rate Single PSDU, Extended Preamble High Rate Single PSDU, or Dual PSDU
10001	ACK	Asynchronous and Priority Asynchronous Data Service	Type 2	Basic Rate Single PSDU or Extended Preamble High Rate Single PSDU
10100	Information request	A-node Peer-Peer Management	Type 2	Basic Rate Single PSDU
10101	Station information	A-node Peer-Peer Management	Type 2	Basic Rate Single PSDU
11000	DATA + Sync	DATA + Sync	Type 4	Basic Rate Single PSDU or Dual PSDU
11011	Ad-hoc beacon	Beacon MPDUs	Type 3	Basic Rate Single PSDU with zero-length payload
11111	Connection Point beacon	Beacon MPDUs	Type 3	Basic Rate Single PSDU or Dual Beacon

A Type 1 header will be preceeded by a TSFD and should only be processed by nodes supporting TDMA access.

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MPDU Header types 2 and 4 are associated with two CSMA/CA data MPDU types. MPDU Header type 4 is only valid for MPDUs using *Simgle PSDU* and *Low Rate Dual PSDU* formats and will contain additional synchronization information. It cannot be used within a time reservation. MPDU Header type 2 is valid for all MPDU formats and can be used within a time reservation.

5.4.4.8 Learn NWID Field

Table 74 defines the values of the *LearnNWID* flag. See section 5.16.2 (Scanning Overview (Informative)), 5.16.14 (Signaling *LearnNWID*) and 5.17.4 (Proxy Signaling of LearnNWID) for a description of the use of this flag.

Table 74 - Learn NWID Flag Values

Learn NWID flag Value	Definition
1	The node is performing the *Signaling LearnNWID Locally* procedure defined in section 5.16.14.1 (Signaling LearnNWID Locally).
0	Otherwise (the usual state)

5.4.4.9 Modulation Type Field

This four-bit field contains a code representing the modulation that is used to transmit the PSDU2 of a *Dual PSDU* format MPDU. It is also used within the *Time Reservation Establish* MPDUs to indicate the modulation used to transmit the DATA MPDU part of atomic MPDU sequences that are transmitted within the time reservation. The permitted modulation types are defined in Table 75. All other values are reserved.

A modulation value of *N=2* indicates that the non-basic modulation part of the PPDU will be transmitted at a rate of (*N * basic modulation type symbol rate*) bits per second via the *Dual PSDU* MPDU format. This rate will always utilize the *Dual PSDU* format and is the only non-basic modulation type that is derivable from the basic modulation type

See Table 75 for a description of the modulation types and their assocation with MPDU formats.

Table 75 - Permitted Modulation Type Values

Modulation Type Value	Modulation Type	MPDU Formats
0	NOT USED	
1	Basic LR 2-FSK (2-FSK @ 800 ks/s)	*Basic Rate Single PSDU* and PSDU1 of the *Dual PSDU*
2	LR 4-FSK (4-FSK @800ks/s)	PSDU2 of the *Dual PSDU*
3	Reserved	
4	Reserved	
5	HR 2-FSK (2-FSK @5Ms/s)	*Extended Preamble High Rate Single PSDU*. Valid only within a time reservation
6	HR 4-FSK (4-FSK @ 5Ms/s)	*Extended Preamble High Rate Single PSDU*. Valid only within a time reservation

Table 76 identifies the uses the Modulation Type field and how it combines with other fields to indicate the MPDU format.

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Table 76 - Modulation Type Field Usage based on Atomic MPDU Sequence Format

Atomic MPDU Sequence Format	Atomic MPDU Sequence Format Characteristics	Modulation Type Field Usage
Basic Rate Single PSDU DATA – *Basic Rate Single PSDU* ACK	Not valid within a time reservation. Modulation type is set to basic. The modulation type is sufficient to implicitly identify this atomic MPDU sequence format	Used only as an indicator that there is no alternate rate PSDU2
Extended Preamble High Rate Single PSDU DATA – *Extended Preamble High Rate Single PSDU* ACK	Valid only within a time reservation that has specified this format in the *Time Reservation Establish* MPDU.	Serves only as an descriptor. The actual modulation of the DATA MPDU was derived from the *Modulation Type* field of the *Time Reservation Establish* MPDU. The modulation of the ACK defaults to HR 2-FSK modulation.
Dual PSDU DATA – *Basic Rate Single PSDU* ACK	Not valid within a time reservation. A different modulation type has been specified for PSDU2. The modulation type is sufficient to implicitly identify this atomic MPDU sequence format since it is the only valid format used outside of a time reservation that specifies a non-basic modulation.	Specifies the modulation of PSDU2. PSDU1 and the ACK default to basic modulation

5.4.4.10 Length Field

This field contains the total number of bytes in the MPDU header and payload fields (*i.e.* it does not include any CRC bytes). Figure 71, Figure 72 and Figure 73 show the region(s) of the MPDU included in the length field.[63]

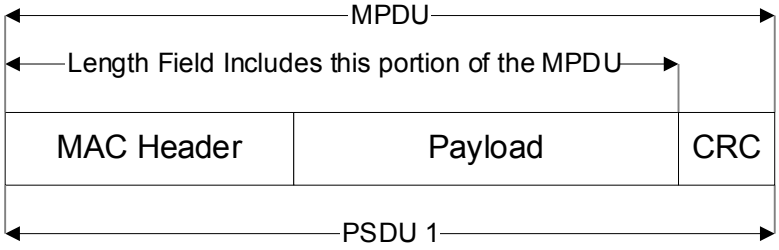


Figure 71 - Definition of MPDU Length Field (Single PSDU Formats)

[63] Note that the *Length* includes only MAC bytes. It does not include any PHY PDU bytes that are transmitted before or after the PSDU(s).

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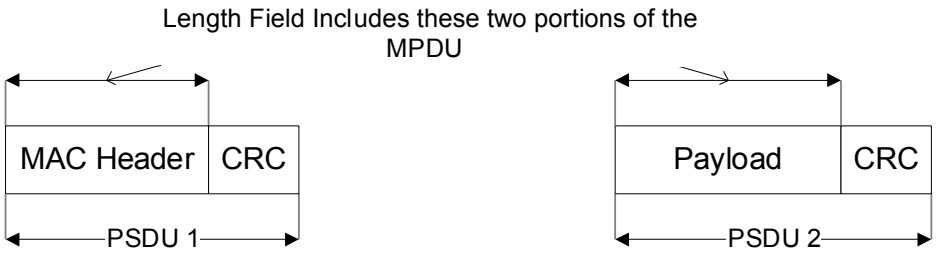


Figure 72 - Definition of MPDU Length Field (Dual PSDU Format)

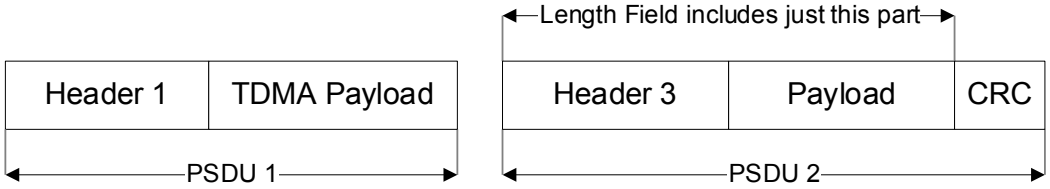


Figure 73 - Definition of MPDU Length Field (Dual Beacon Format)

5.4.4.10.1 Length Field (Informative)

The *Length* field permits a node to determine the length of the (non-TDMA) *Payload* by subtracting a constant based on the value of the MPDU type field.

Because the *Length* field does not include the CRCs, its value is the same for *Single* and *Dual* formats.

A node cannot, for some PPDU formats, determine the duration of a PPDU on-air solely from the MAC header information because of the operation of PHY-layer bit-stuffing.

The length of the TDMA MPDUs depends on the TDMA MPDU type field. The *Main* and *Retry* TDMA MPDUs and the TDMA CPS request MPDU do not include a length field - their length is fixed. The TDMA Beacon part of a *Dual Beacon* MPDU is variable in length. See 5.4.16.4 (TDMA Beacon Structure).

5.4.4.11 NWID Field

The NWID is a three-byte field that uniquely identifies the network with which a node is associated.

5.4.4.12 Superframe Control Field

This field defines the structure of the superframe in a managed network.

1 bit	*1 bit*	*1 bit*	*5 bits*
SubframesPresent	SubframeIndex	HopsetAdapted	Reserved

Figure 74 – Definition of Superframe Control Field

5.4.4.12.1 SubframesPresent

This field shall contain the value of the transmitting node's *SubframesPresent* variable defined in 5.5.2.1 (Hop Management).

5.4.4.12.2 SubframeIndex

This field shall contain the value of the transmitting node's *SubframeIndex* variable defined in 5.5.2.1 (Hop Management).

5.4.4.12.3 HopsetAdapted

This field shall contain the value of the transmitting node's *HopsetAdapted* variable defined in 5.5.2.1 (Hop Management).

5.4.4.13 Payload Control Field

This field is only utilized by the DATA, DATA+Sync, and ACK MPDU types. For all other MPDU types, this field shall be set to a value of zero.

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The structure of this field depends on whether the MPDU destination address is unicast or multicast.

When the destination address is unicast, this field contains the *Unicast Payload Control Field* defined in 5.4.4.14 (Unicast Payload control field).

When the destination address is multicast, this field contains the *Multicast Payload Control Field* defined in 5.4.4.15 (Multicast Payload control field).

5.4.4.14 Unicast Payload control field

The Unicast Payload Control field controls the interpretation of the MPDU payload field for MPDU Header types 2 and 4.

Figure 75 defines the structure of the Unicast Payload Control field.

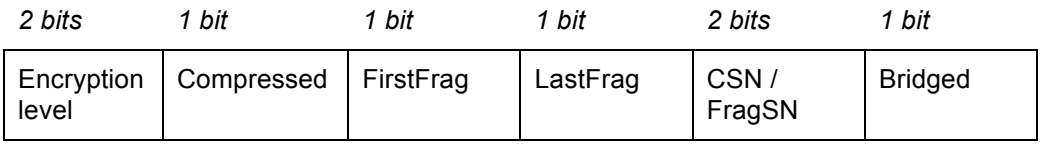


Figure 75 - Unicast Payload Control Field Structure

5.4.4.14.1 Encryption Level Field

Table 77 defines values for the Encryption Level field within the unicast payload control field.

Table 77 - Encryption Level Values

Value	Security level	Encryption type
0	Basic	Not encrypted
1	Enhanced	Algorithm defined in section 15 (HomeRF Security architecture)
2		*Reserved*
3		*Reserved*

5.4.4.14.2 Compressed Field

Table 78 defines values for the Compressed field within the unicast payload control field.

Table 78 - Compressed Field Values

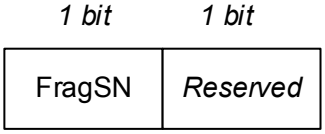
Compressed Field Value	Definition
0	The MPDU payload is not compressed
1	The MPDU payload contains data which has been compressed using the procedures defined in section 5.12.6 (Compression)

5.4.4.14.3 CSN / FragSN Field

The *FirstFrag* field controls the interpretation of this field as either the *CSDU Sequence Number* (CSN) or *FragSN* fields as defined in Table 79.

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Table 79 - Interpretation of CSN / FragSN Field Depending on FirstFrag Value

FirstFrag Value	Interpretation
1	CSN
0	

The *FragSN* field values are defined in section 5.4.4.14.4 (*FirstFrag*, *LastFrag* and *FragSN* fields).

The CSN, when present, contains a CSDU sequence number. This number applies to the entire CSDU of which the MPDU is the first or only fragment. This number follows a sequence kept at the transmitting node per unicast destination address. A CSN value of 0 is sent either at the start of a CSN sequence, or for all CSDUs, if the transmitting node does not support the CSN mechanism.

The receiving node uses the CSN sequence number to remove duplicate CSDUs. A CSDU is a duplicate when the CSN is non-zero and matches the previous CSN received from that source node. Table 80 describes the CSN values.

Table 80 - CSN Values

CSN Value	Description
0	No CSN or new CSN sequence
1-3	Part of CSN Sequence

5.4.4.14.4 *FirstFrag*, *LastFrag* and *FragSN* fields

These fields are used for the fragmentation and reassembly mechanism, to indicate the fragment type. Description of the fragmentation process and the use of those bits is in section 5.7.11 (CSDU Transmission) and section 5.7.12.3 (CSDU Receive Process).

In a DATA MPDU or an ACK MPDU with a tunneled payload, the three fragmentation fields are set as defined in Table 81. In an ACK MPDU without a tunneled payload or in all other unicast MPDUs, the fragmentation fields are zeroes.

Table 81 - Fragmentation Fields Values

DATA MPDU payload contents	*FirstFrag*	*LastFrag*	*FragSN*
Complete unfragmented CSDU	1	1	CSN lsb
First fragment of a fragmented CSDU	1	0	CSN lsb
Intermediate fragments of a fragmented CSDU	0	0	toggles [64]
Last fragment of a fragmented CSDU	0	1	toggles

5.4.4.14.5 Bridged field

A *bridged* MSDU carries the long MD-SAP header (see section 5.12.4.1 (MD_SAP Header Structure)). The *Bridged* field is used to carry a service attribute of the CSMA_CA_DATA data service (see section 5.7.3 (CSMA/CA Service)). This attribute shall be used by the MD_DATA data service (see section 5.2.1) to signal the presence of the long MD-SAP header.

Table 82 defines values for the *Bridged* field within the payload control field.

[64] Alternately selects the values 0 and 1 with the first intermediate fragment being set to 1.

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Table 82 - Bridged Field Values

Bridged Field Value	Definition
0	The MD-SAP header is the short form (does not carry bridging addresses)
1	The MD-SAP header is the long form (includes bridging addresses)

5.4.4.15 Multicast Payload control field

The Multicast Payload Control field controls the interpretation of the MPDU payload field for MPDU Header types 2 and 4 addressed to multicast destinations.

Figure 76 defines the structure of the Multicast Payload Control field.

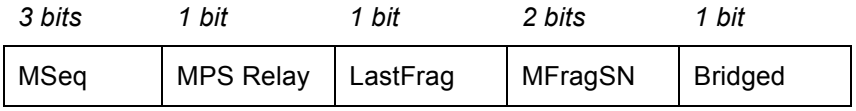


Figure 76 - Multicast Payload Control Field Structure

5.4.4.15.1 MSeq Field

This field contains the value of the sender's *MulticastSequenceNumber* variable (see section 5.7.11.2.1 (CSDU Fragmentation State)). It is used to detect missing multicast fragments. [65]

5.4.4.15.2 MPS Relay Field

This field is set to a 0 in multicast MPDUs transmitted by the originator node. It is set to a 1 in multicast MPDUs transmitted by a CP that is providing multicast power-saving support using the procedures defined in section 5.18.8.3 (CP Multicast Power-Management Service).

5.4.4.15.3 *LastFrag* and *MFragSN* fields

These fields are used by the fragmentation and reassembly mechanism, to indicate the fragment type and to detect missing fragments. Description of the fragmentation process and the use of those bits is in section 5.7.11.2 (CSDU Transmit) and section 5.7.12.3 (CSDU Receive Process).

In a multicast DATA MPDU, the two fragmentation fields are set as defined in Table 83. In all other multicast MPDUs, the fragmentation fields are zeroes.

Table 83 - Multicast Fragmentation Fields Values

Multicast DATA MPDU payload contents	*LastFrag*	*MFragSN*
Complete unfragmented multicast CSDU	1	0
First fragment of a fragmented multicast CSDU	0	0
Intermediate fragments of a fragmented multicast CSDU	0	increments [66]
Last fragment of a fragmented multicast CSDU	1	increments

[65] The particular case it detects is when the final fragment of some fragmented multicast CSDU and the initial fragment of some fragmented multicast CSDU from the same *SourceAddress* are not received.

[66] No wrapping occurs because the maximum number of fragments that may be transmitted is strictly limited.

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5.4.4.15.4 Bridged field

This is defined in section 5.4.4.14.5 (Bridged field).

5.4.4.16 Source and Destination Address Fields

These fields contain IEEE 48 bit MAC addresses. Figure 77 shows the structure of an IEEE 48-bit address field.

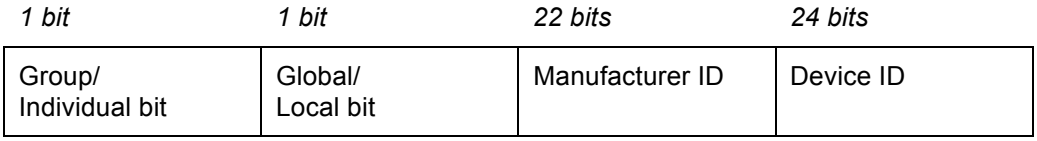


Figure 77 - IEEE 48-bit Address Format

The destination address contains the unicast address of the node that is to receive the MPDU, or a multicast address.

The source address contains either the MAC address of the node that originated the MPDU. In the case of an MPDU containing a relayed multicast MSDU, this address is the MAC address of the node that first transmitted the MSDU. In all other cases, the address is the MAC address of the transmitting node.

5.4.4.16.1 IEEE Address Management (Informative)

Globally unique IEEE 48 bit addresses are managed by the IEEE. The HomeRF equipment manufacturer is required to request globally unique addresses from the IEEE. The IEEE allocates addresses by giving individual blocks of 24 bits to each manufacturer.

5.4.4.17 Synchronization Information Field

Figure 78 defines the structure of the *Synchronization Information* field that is present in MPDU type 3 and 4 headers. It contains sufficient information for a HomeRF receiver node to synchronize to the hop pattern of the transmitter node.



Figure 78 - Synchronization Information Field Structure

5.4.4.17.1 Hop Pattern

Frequency hopping is described in section 5.5.2 (Frequency Hopping). The *Hop Pattern* distinguishes between a number of different sequences of radio channels. Hopping patterns are dependent on the device localization associated with the HomeRF device, which indicates in which regions the device may operate. This field contains the hopping pattern number currently in use by the network.

5.4.4.17.2 Hop Index

This is the index of the current channel in the current hop pattern, and is incremented with each frequency hop as described in section 5.5.2.1 (Hop Management).

5.4.4.17.3 DwCount

The *DwCount* value is the number of symbol periods remaining in the dwell just before the first PHY symbol corresponding to the MPDU header is transmitted.

The dwell period is defined in section 5.5.3 (Superframe Structure).[67] Figure 79 shows the point within transmission of the MPDU on-air at which the contents of its *DwCount* field are equal to the contents of the node's *DwCount* variable, defined in 5.5.2.1 (Hop Management).

[67] The transmitting node sets the *DwCount* value to reflect the exact time at which it will be sent by adjusting for delays through the PHY from the MAC-PHY interface to the antenna. The receiving node corrects the time by subtracting an amount equal to the receiving node's delay through its local PHY components plus the time since the first bit of the timestamp was received at the MAC-PHY interface.

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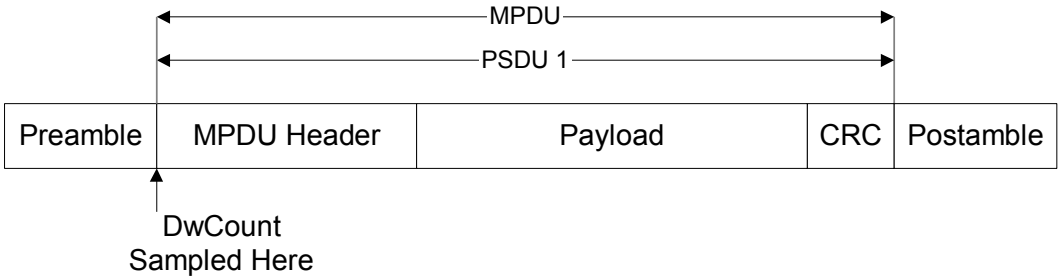


Figure 79 - DwCount Sample Point

5.4.5 MPDU CRCs

All *Single PSDU* MPDU formats have a single 32-bit MAC CRC. All *Dual PSDU* MPDU formats have two 32-bit MAC CRCs. The TDMA MPDUs have one or two 16-bit CRCs. The CP1 Beacon has a single 16-bit and a single 32-bit CRC.

5.4.5.1 MPDU fields Included in the MAC CRCs

Table 84 defines the MPDU fields that are included in the CRC calculation according to MPDU type and CRC location. The sequence of bits that are included in a CRC calculation is called the *Protected Bits*. This sequence of bits is formed from the fields defined in Table 84 in transmission order.

Table 84 - MPDU Fields Included in the CRC

MPDU Format (& CRC Location)		**MPDU Fields Included in the CRC**	**CRC type**
Single PSDU formats		MPDU Header + MPDU Payload	32-bit
Dual PSDU	Header CRC	MPDU Header	32-bit
	Payload CRC	MPDU Payload	32-bit
Dual Beacon	TDMA Beacon CRC	All of the TDMA MPDU except the CRC	16-bit
	CP2 Beacon CRC	The MPDU Header and MPDU Payload	32-bit
main TDMA MPDU	A-field CRC	TDMA Header, C-Channel control and C-SDU field.	16-bit
	B-field CRC	B-field (C-Channel/C-Plane SDUs)	16-bit
retry TDMA MPDU		TDMA Header and B-field	16-bit
TDMA CPS MPDU		All of the TDMA CPS MPDU except the CRC	16-bit

5.4.5.2 Mapping Between a Bit Sequence and a Polynomial

If a bit sequence is to be represented as a polynomial or vice-versa, the following mapping rules shall apply:

- The bit sequence is represented as $b_0, b_1, \ldots b_{k-1}$ where there are k bits in the sequence and b_0 is transmitted first.

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- The bit sequence is used as the coefficients of a polynomial: $b_0 x^{k-1} + b_1 x^{k-2} + ... + b_{k-1}$

5.4.5.3 32-bit CRC Algorithm

When a 32-bit CRC is employed, the *Protected Bits* are protected by a 32-bit CRC based on the polynomial defined in Equation 4. [68]

Equation 4 - Generator Polynomial for MPDU payload

$$G(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

The CRC shall be the one's complement of the sum of the following:

- The remainder of x^k. $(x^{31} + x^{30} + ... + x + 1)$ divided by $G(x)$, where k is the number of protected bits, and
- The remainder after multiplication by x^{32} and then division by $G(x)$ of the payload, mapped to a polynomial in x. See section 5.4.5.2 for this mapping.

All operations on the coefficients of x are performed modulo 2. The first transmitted bit of the CRC field corresponds to the x^{31} term of the CRC.

5.4.5.3.1 32-bit CRC Implementation (Informative)

This section describes one possible implementation of the payload CRC, assuming an LFSR implementation.

In generating mode, the CRC shift register is initialized to all ones. The *Protected Bits* are clocked through in transmission order. The contents of the shift register are inverted and appended to the data stream as the CRC.

In checking mode, the CRC shift register is initialized to all ones. The *Protected Bits* and CRC are clocked through the shift register in transmission order. If the CRC is correct, the remainder is as defined in Equation 5. [69]

Equation 5 - Payload CRC Remainder Polynomial

$$R(x) = x^{31} + x^{30} + x^{26} + x^{25} + x^{24} + x^{18} + x^{15} + x^{14} + x^{12} + x^{11} + x^{10} + x^8 + x^6 + x^5 + x^4 + x^3 + x + 1$$

5.4.5.3.2 32-bit CRC Test Vectors (Informative)

This section defines four test vectors that can be used to demonstrate the operation of the CRC. Table 85 contains the test vectors. The input sequence is 32 bytes (each represented as 2 hexadecimal characters) shown from left to right in transmission order. Following the conventions of this document, the least significant bit of each byte is transmitted first.

The CRC is shown as a 32-bit number (represented by 8 hexadecimal characters). Following the conventions of this document, the least significant bit of this number corresponds to the x^{31} term of the CRC. Using the same conventions, the remainder has the value `debb20e3`.

Table 85 - CRC Test Vectors

Vector	Input Sequence	CRC
1	`00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00`	`ecbb4b55`
2	`ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff`	`3fb3c61a`
3	`12 34 56 78 9a bc de f0 01 23 45 67 89 ab cd ef`	`bd6b4f46`
4	`00 20 62 9e 2b f5 b3 ca a5 7e 59 b7 6b 06 9b 07`	`0dbeb961`

68 The binary bit pattern which represents this polynomial is:

00000100110000010001110110110111

69 The binary bit pattern representing this polynomial is:

11000111000001001101110101111011

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5.4.5.4 DECT CRC

The DECT CRC is the 16-bit R-CRC defined in [4, section 6.2.5.2].

The bits that are protected by a DECT CRC are identified in sections 5.4.12 (TDMA DATA MPDUs), 5.4.14 (TDMA CPS MPDU) and 5.4.16.4 (TDMA Beacon Structure).

5.4.6 MPDU Payload

The length of the MPDU payload field is a variable, ranging from 0 to *MaxCSDUlength* bytes.

5.4.7 Time Reservation MPDUs

Time Reservation MPDUs are used to signal a CSMA/CA time reservation establish preface to CSMA/CA data MPDU types sent within that time reservation or to cancel an existing time reservation. The time reservation MPDUs are transmitted with the Basic Rate Single PSDU format and basic modulation. The modulation type of the MPDUs sent within the time reservation are indicated by the *Time Reserved Atomic MPDU Sequence Format and Modulation Type* fields.

The *Time Reservation Establish* and *Time Reservation Cancel* MPDU types are transmitted as an atomic sequence that does not include an ACK MPDU. The *Time Reservation Cancel* MPDU type is transmitted utilizing the super channel of the established time reservation.

An implementation can optionally deploy a Request-To-Send (RTS) Clear-To-Send (CTS) method of time reservation to better mitigate against collisions caused by a node that is within the range of the destination node but hidden to the origination node. The RTS-CTS exchange acts as an acknowledged establishment of a time reservation and is intended to insure that any nodes within the range of either the originating node or the destination node will observe the signaled time reservation. The *Time Reservation Establish Request-To-Send* and *Time Reservation Establish Clear-To-Send* MPDUs constitute an atomic sequence, in which, the *Time Reservation Establish Clear-To-Send* MPDU acts as an explicit ACK to the *Time Reservation Establish Request-To-Send* MPDU. The *Time Reservation value* field returned on the *Time Reservation Establish Clear-To-Send* MPDU will be set to the value indicated in the *Time Reservation Establish Request-To-Send* MPDU minus its duration.

5.4.7.1 Time Reservation Establish MPDUs

These MPDUs are used to establish a time reservation. The MPDU type can be either Time Reservation Establish or Time Reservation Establish Request-To-Send when MPDU Header Type 2 is used. The MPDU type can be either Time Reservation Establish+Sync or Time Reservation Establish Request-To-Send+Sync when MPDU Header Type 4 is used. Figure 80 defines the Time Reservation Establish MPDU format.

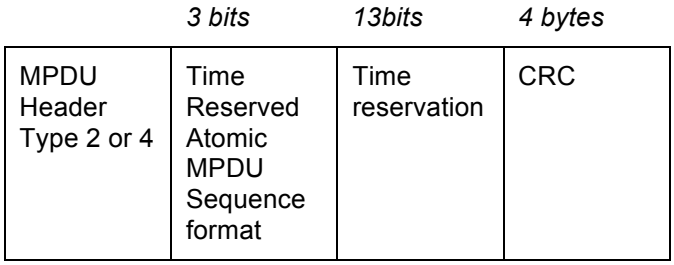


Figure 80 - Time Reservation Establish MPDU format

5.4.7.1.1 Time Reserved Atomic MPDU Sequence Format Field

This field indicates the format of the atomic MPDU sequences that will be used within the time reservation.

Table 86 specifies the Time Reserved Atomic MPDU Sequence formats.

Table 86 – Time Reserved Atomic MPDU Sequence formats

Time Reserved Atomic MPDU Sequence format	Description

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0	*Extended Preamble High Rate Single PSDU* DATA – *Extended Preamble High Rate Single PSDU* ACK

5.4.7.1.2 Time Reservation Field

This field contains the time reservation value in basic modulation type symbol periods (LR 2-FSK equals 1.25 μs.) up to *MaxTimeReservation*.

5.4.7.2 Time Reservation Establish Clear-To-Send MPDU

This MPDU is used to acknowledge the Time Reservation Establish Request-To-Send MPDUs. Figure 81 defines the Time Reservation Establish Clear-To-Send MPDU format.

	3 bits	*13bits*	*4 bytes*
MPDU Header Type 2	Reserved	Time reservation	CRC

Figure 81 - Time Reservation Establish Clear-To-Send MPDU format

5.4.7.3 Time Reservation Cancel MPDU

This MPDU is used to cancel a time reservation. This MPDU type consists of only MPDU header type 2. It has no payload.

5.4.8 Streaming Session Management MPDUs

These MPDUs are used to setup or tear down streaming sessions (refer to 5.4.8.1.1 (Streaming Session Management Request – Setup MPDU)) to facilitate the management by the CP of the Priority Aysynchronous Data Service.

5.4.8.1 Streaming Session Management Request MPDU

The Streaming Session Management Request MPDU is initiated by a S-node to request access to the Priority Asynchronous Data Service for a streaming session. The S-node may request the CP to setup a new streaming session or to tear down an existing one via the Streaming Session Management Request – Setup MPDU or Streaming Session Management Request – Tear Down MPDU respectively.

5.4.8.1.1 Streaming Session Management Request – Setup MPDU

Figure 82 defines the Streaming Session Management Request – Setup MPDU.

	2 bits	*6 bits*	*3 bits*	*13 bits*	*3 bits*	*13 bits*	*1 byte*	*1 byte*	*4 bytes*
MPDU Header Type 2	Streaming Session Management Request value – Setup	Priority	Reserved	Maximum Time Reservation value	Reserved	Nominal Time Reservation value	Jitter	Latency	CRC

Figure 82 - Streaming Session Management Request - Setup MPDU

5.4.8.1.1.1 Streaming Session Management Request value field

Table 87 defines the Streaming Session Management Request values.

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Table 87 - Streaming Session Management Request values

Streaming Session Management Request value	Description
0	Setup a stream session
1	Tear Down a stream session
2-3	Reserved

5.4.8.1.1.2 Priority field

This field indicates the requested priority to be associated with the streaming session. Highest priority value is equated to the highest priority level.

5.4.8.1.1.2.1 Priority field (informative)

Priority field values used when setting up a session should be based off of the 802.1D specification [15]. Table 88 describes the mapping of 802.1D priorities to *Priority* field values going from lowest to highest in priority.

Table 88 - Mapping 802.1D priorities to Priority field values

Priority field value	802.1D priority description
0	Background traffic
1	“Best-effort”
2	Reserved
3	“Extra-effort”
4	Controlled-load traffic
5	Audio and Video traffic < 100 ms latency
6	Audio traffic < 10 ms latency
7	Network Management

5.4.8.1.1.3 Maximum Time Reservation value field

This field contains the requested maximum time reservation value in basic modulation type symbol periods up to *MaxTimeReservation*. This value represents the maximum time reservation that the streaming session envisions being used. The maximum time reservation is used when an overflow condition is being mitigated.

5.4.8.1.1.4 Nominal Time Reservation value field

This field contains the requested nominal time reservation value in basic modulation type symbol periods up to *MaxTimeReservation.* This value represents the amount of time reservation required to meet the normal flow requirements of the streaming session.

5.4.8.1.1.5 Jitter Field

This field contains the maximum allowable jitter for this stream calculated in milliseconds up to *MaxJitter*. This field is optional, but if used it will be a determining factor in how the CP dictates priorities. If this field is not used, then the CP will dictate priority based on the *Priority* field and any *Latency* field.

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Jitter	Description
0	A value of 0 indicates this field is not being used
1-255	Allowable jitter in milliseconds up to *MaxJitter*

5.4.8.1.1.6 Latency Field

This field contains the maximum allowable latency for this stream calculated in milliseconds up to *MaxLatency*. This field is optional, but if used it will be a determining factor in how the CP dictates priorities. If this field is not used, then the CP will dictate priority based on the *Priority* field and any *Jitter* field.

Latency	Description
0	A value of 0 indicates this field is not being used
1-255	Allowable latency in milliseconds up to *MaxLatency*

5.4.8.1.2 Streaming Session Management Request – Tear Down MPDU

Figure 83 defines the Streaming Session Management Request – Tear Down MPDU.

	2 bits	*6 bits*	*8 bits*	*4 bytes*
MPDU Header Type 2	Streaming Session Management Request value – Tear Down	Reserved	SID	CRC

Figure 83 - Streaming Session Management Request - Tear Down MPDU

5.4.8.1.2.1 Streaming Session Management Request value field

Refer to section 5.4.8.1.1.1.

5.4.8.1.2.2 SID field

This value was assigned by the CP as part of the Streaming Session Management Setup Process. Refer to 5.4.9.1 and 5.4.9.1.1.2.

5.4.9 Streaming Session Management Response MPDU

The Streaming Session Management Response MPDU is returned by the CP to the S-node to grant or deny access to the Priority Asynchronous Data Service for a streaming session. In the case of granting access, the CP will analyze the time reservation demands of the Streaming Session Management Request – Setup and will return via the Streaming Session Management Response – Access Granted MPDU an access granted response indicating the maximum time resevation allowed by the CP. In the case of access denial, the CP will return via the Stream Session Management Response – Access Denied MPDU an access denied response.

5.4.9.1 Streaming Session Management Response - Access Granted MPDU

Figure 84 defines the Streaming Session Management Response– Access Granted MPDU.

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	2 bits	6 bits	8 bits	3 bits	13 bits	4 bytes
MPDU Header Type 2	Streaming Session Management Response value – Access Granted	Reserved	SID	Reserved	Maximum Time Resevation Allowed value	CRC

Figure 84 - Streaming Session Management Response - Access Granted MPDU

5.4.9.1.1.1 Streaming Session Management Response value field

Table 89 defines the Streaming Session Management Request values.

Table 89 - Streaming Session Management Response values

Streaming Session Management Response value	Description
0	Access Granted
1	Access Denied
2-3	Reserved

5.4.9.1.1.2 SID field

This value is returned by the CP to identify the streaming session that was granted access as part of the Streaming Session Management Setup Process.

5.4.9.1.1.3 Maximum Time Reservation Allowed value field

This field contains the maximum time reservation allowed value in basic modulation type symbol periods. This value represents the maximum time reservation that the CP allows the streaming session to use when an overflow condition is being mitigated.

5.4.9.2 Streaming Session Management Response - Access Denied MPDU

Figure 85 defines the Streaming Session Management Response – Access Denied MPDU.

	2 bits	6 bits	4 bytes
MPDU Header Type 2	Streaming Session Management Response value – Access Denied	Reserved	CRC

Figure 85 - Streaming Session Management Response - Access Denied MPDU

5.4.9.2.1.1 Streaming Session Management Response value field

Refer to Table 89.

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5.4.10 IR and SI MPDUs

The *Information Request* (IR) MPDU is sent by a node to a station in order to request that station to respond with a *Station Information* (SI) MPDU.

Figure 86 shows the format of both IR and SI MPDUs.

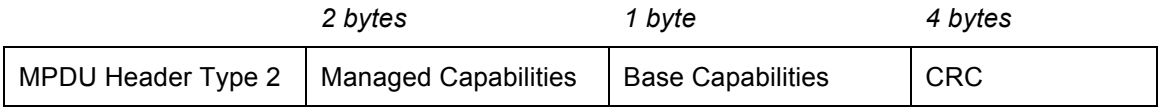


Figure 86 - Information Request and Station Information MPDU Formats

5.4.10.1 Information Request MPDU

The fields of the IR MPDU are set as described in Table 90.

Table 90 - Contents of IR MPDU Fields

Field	Contents
Destination Address (in MPDU header)	Address of node for which information is requested
Managed Capabilities	Capabilities of the node transmitting the IR MPDU
Base Capabilities	Capabilities of the node transmitting the IR MPDU

5.4.10.2 Station Information MPDU

The fields of the SI MPDU are set as described in Table 91.

Table 91 - Contents of SI MPDU Fields

Field	Contents
Destination Address (in MPDU header)	Unicast or broadcast MAC address. See note
Managed Capabilities	Capabilities of the node transmitting the SI MPDU
Base Capabilities	Capabilities of the node transmitting the SI MPDU
Note: The broadcast MAC address shall be used when performing the slow SI/IR procedure (see section 5.7.12.5 (Slow SI Response)). The unicast MAC address shall be used when performing the fast SI/IR procedure (see section 5.7.12.4 (Fast SI Response)).	

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5.4.10.3 Capabilities

The capabilities fields define the optional features supported by a HomeRF node, and the operational state of those features.

The Base Capabilities define support for the exchange of data (Isochronous or Asynchronous) between nodes.

The Managed Capabilities define support for features that are managed by a CP.

5.4.10.3.1 Base Capabilities

The Structure of the Base Capabilities field is defined in Figure 87.

4 bits	*2 bits*	*1 bits*	*1 bit*	*8 bits*
Modulation Capability	Encryption Capability	Compression Capability	Transmit Power Capability	Time Reserved Atomic MPDU Sequence Format Capability

Figure 87 - Base Capabilities Structure

Table 92 defines values for the Encryption Capability field.

Table 92 - Encryption Capability Values

Encryption Capability	**Security level**	**Definition**
0	Basic	No Encryption supported
1	Enhanced	HomeRF encryption core algorithm (defined in 15 (HomeRF Security architecture)) is supported
2-3		*Reserved*

Table 93 defines values for the Modulation Capability.

Table 93 - Modulation Capability Values

Modulation Capability	**Definition**
0	Node supports Basic (LR 2-FSK) operation only
1	Node supports Basic & LR 4-FSK operation
2	Node supports Basic, LR 4-FSK & HR 2-FSK
3	Node supports Basic, LR 4-FSK, HR 2-FSK, & HR 4-FSK
4	Node supports Basic & HR 2-FSK
5	Node supports Basic, HR 2-FSK, & HR 4-FSK

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6-15	Reserved

Table 94 defines values for the Compression Capability.

Table 94 - Compression Capability Values

Compression Capability	Definition
0	None supported
1	Supports the procedures defined in 5.12.6 (Compression).

Table 95 defines values for the Transmit Power Capability.

Table 95 - Transmit Power Capability Values

Transmit Power Capability	Definition **See section 4.5.2 (**Transmit Power Level**)**
0	Node transmits using Class 1 Transmit power
1	Node transmits using Class 2 Transmit power

The *Time Reserved Atomic MPDU Sequence Format Capability* field is a bit mask that indicates which time reserved atomic MPDU sequences are supported. A bit mask of zero indicates that this node does not support any Rx or Tx activity within a time reservation. Table 96 defines values for the Time Reserved Atomic MPDU Sequence Format Capability field. See Table 86 for a description of the *Time Reserved Atomic MPDU Sequence* formats.

Table 96 – Time Reserved Atomic MPDU Sequence Format Capability Definition

Bit Position	Description
0	Time Reserved Atomic MPDU Sequence format 0 supported
1-7	Reserved

5.4.10.3.2 Managed Capabilities Field

The *Managed Capabilities* field contains capabilities that relate to operation in a managed network. Figure 88 defines the structure of this field.

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1 bit	*1 bit*	*1 bit*	*4 bits*	*1 bit*
PS mode enabled	PS Supporter Capability	Asynchronous Data Roaming enabled	Reserved (set to 0)	TDMA Capability

Figure 88 - Node Managed Capabilities Field Structure

The *PS Mode Enabled* field takes the values defined in Table 97.

Table 97 - PS Mode Enabled Values

PS Mode Enabled	**Definition**
0	The node is not operating any power-saving procedures.
1	The node is operating the A-node power-saving procedures defined in section 5.18 (A-node Power-Management and Power-Saving)

The *PS Supporter Capability* values are defined in Table 98. Refer also to section 5.18.7.4.1 (PS Supporter Capability).

Table 98 - PS Supporter Capability Values

PS Supporter Capability	**Definition**
0	The node does not operate any of the PS supporter procedures. It transmits without regard to any power-saving state of the destination node.
1	The node operates the PS supporter procedures

The Asynchronous Data Roaming enabled values are defined in Table 99.

Table 99 - Asynchronous Data Roaming enabled values

Asynchronous Data Roaming enabled values	**Definition**
0	The node is not operating any roaming procedures.
1	The node is operating the Asynchronous Data Roaming procedures defined in section 5.19)

5.4.11 Data MPDU

The DATA MPDU is used by the CSMA/CA access mechanism to carry CSMA/CA SDUs (CSDUs). All or part of a CSDU occupies the MPDU payload field. Figure 89 defines the structure of the DATA MPDU.

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	variable length	*4 bytes*
MPDU Header Type 2 or 4	Entire CSDU or CSDU fragment	CRC

Figure 89 - DATA MPDU Structure

The selection of a header type 2 or header type 4 depends on the operation of the synchronization procedures defined in 5.16 (Synchronization Management).

The MPDU header destination address is the MAC address of an individual node or a multicast address. [70]

The MPDU header source address contains the MAC address of the node originating the CSDU. This is normally the MAC address of the node transmitting the MPDU, but may also be the MAC address of some other node when a CP retransmits a multicast CSDU.

The MPDU payload contains either the entire CSDU or a fragment of the CSDU.

The interpretation of the MPDU payload is controlled by the MPDU header (payload control field) fragmentation flags, and defined in the fragmentation and reassembly procedures. See sections 5.7.11 (CSDU Transmission) and 5.7.12.3 (CSDU Receive Process).

5.4.12 TDMA DATA MPDUs

TDMA DATA MPDUs are transmitted in the TDMA downlink/uplink slots to provide isochronous communication between a Connection Point and an I-node. Pairs of TDMA MPDUs are exchanged to support a TDMA connection. A single TDMA MPDU is transmitted in a downlink slot to support the ICBS channel.

These MPDUs are always transmitted using the *TDMA* PPDU format.

There are two formats for the TDMA DATA MPDUs: *Main* and *Retry*. The main TDMA MPDU is used for initial transmit attempts during CFP2 and by the ICBS channel. The retry TDMA MPDU is used during retransmission attempts during CFP1. [71]

The main TDMA MPDU structure is defined in Figure 90. There are two variants of this format referred to as “fastC=0” and “fastC=1”, based on the setting of the fastC field within the C-Channel Control field, defined in 5.4.12.2 (C-Channel Control).

The “fastC=0” form supports the transport of at most 1 C-Channel/C-Plane SDU per frame, plus 1 B-Field. This form is used during a voice call once the call-setup signaling has been completed or during a connectionless broadcast containing a voice announcement. The “fastC=1” form supports the transport of up to 9 C-channel SDUs per frame, with no B-Field. It is used during call-setup or during a connectionless broadcast to provide a higher C-Channel/C-Plane bandwidth, and is used when there is no B-field to transmit.

The A-field CRC is calculated over the first 7 bytes of the main TDMA MPDU regardless of the setting of the *fastC* field. The B-field CRC is calculated over the next 40 bytes of the TDMA MPDU, regardless of the setting of the *fastC* field. These 2-byte CRCs are calculated according to the DECT CRC algorithm defined in 5.4.5.4 (DECT CRC).

The term *TDMA Payload* is the region of the TDMA MPDU that is protected by TDMA encryption [72]. In the main TDMA MPDU, the TDMA payload includes the C-SDU and B-Field/C-SDUs fields.

[70] The broadcast address is a special case of the multicast address.

[71] ICBS transmissions do not use the retry TDMA MPDU.

[72] Encryption is only used by TDMA connections, not the ICBS channel.

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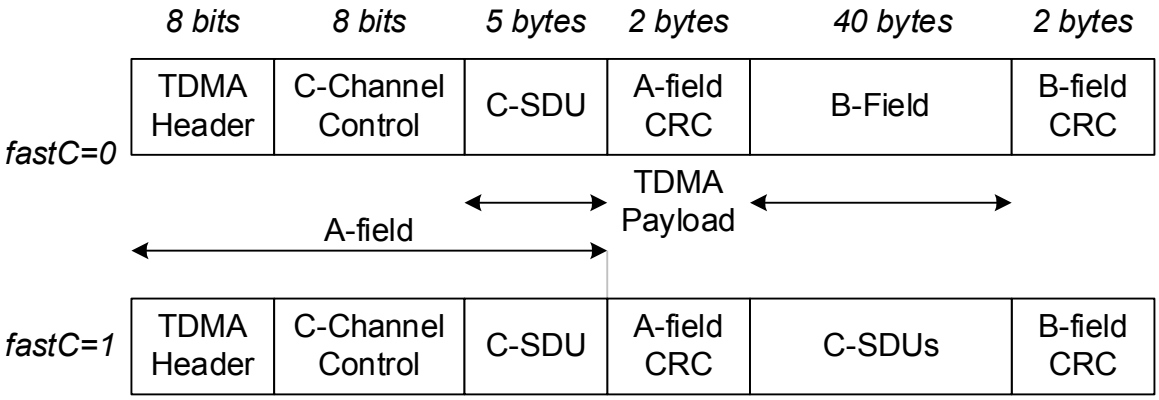


Figure 90 - Main TDMA MPDU Structure

The retry TDMA MPDU structure is defined in Figure 91. This includes the header, a B-Field and a 2-byte DECT CRC. The CRC is calculated over the first 41 bytes of the MPDU.

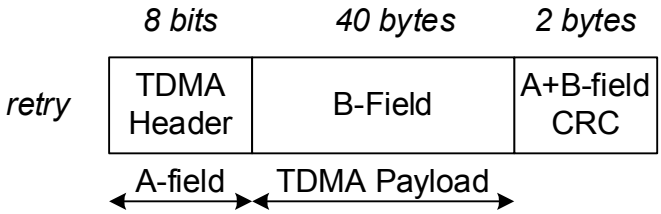


Figure 91 - Retry TDMA MPDU Structure

5.4.12.1 TDMA Header

Figure 92 defines the structure of the TDMA Header field.

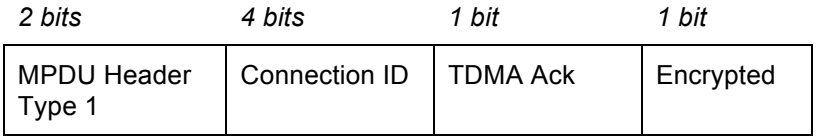


Figure 92 - TDMA Header Structure

The TDMA MPDU type field within the MPDU Header type 1 distinguishes between *Main* and *Retry* formats.

The *Connection ID* field contains the Connection ID allocated by the CP for the TDMA connection or ICBS channel (see section 5.17.2.1 (Connection ID)).

The *Encrypted Payload* field indicates whether the TDMA payload is encrypted.

Table 100 - Encrypted Payload Values

Encrypted Payload Value	Definition
0	The TDMA payload is not encrypted
1	The TDMA payload is encrypted [73]

[73] Note, this does not require that the payload is encrypted using any particular encryption algorithm. The DECT NWK layers negotiate the type of encryption that will be used before the MAC layer is instructed to start encryption.

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The rules for the setting of the *TDMA Ack* field depend upon node type (I-node or Class-1 CP). See section 5.8 (TDMA Access Mechanism) for the protocol associated with this field.

Table 101 - TDMA Ack Field Values (sent by an I-node)

TDMA Ack Field Value	Definition
1	A TDMA MPDU was received correctly with this connection ID during the current TDMA epoch
0	Otherwise

Table 102 - TDMA Ack Field Values (sent by a Class-1 CP)

TDMA Ack Field Value	Definition
1	A TDMA MPDU was received correctly with this connection ID during the previous TDMA epoch, or otherwise the CP does not support full-featured operation of this field (as defined in section 5.8.6.2.6 (TDMAack Field Values)).
0	Otherwise

5.4.12.2 C-Channel Control

Figure 93 defines the structure of the *C-Channel Control* field.

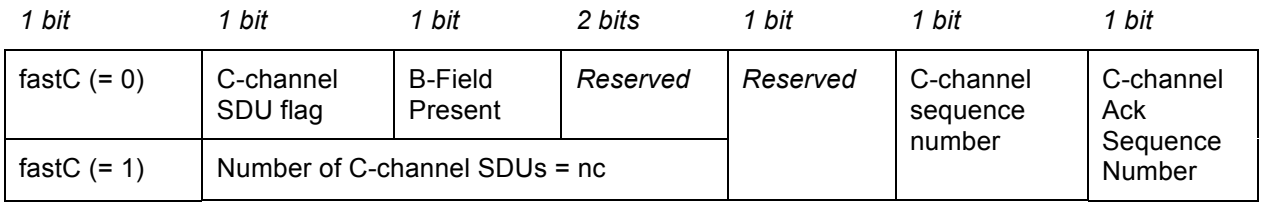


Figure 93 - C-Channel Control Field Structure

The *fastC* flag affects the interpretation of the main TDMA MPDU format as defined in Table 103.

Table 103 - Interpretation of TDMA Header and Payload depending on FastC Field Values

fastC Value	TDMA Header	TDMA Payload
0	Can signal at most one C-Channel/C-Plane SDU	Contains up to one C-channel/C-Plane SDU followed by a HomeRF B-field
1	Can signal multiple C-channel/C-Plane SDUs	Contains up to 9 C-channel/C-Plane SDUs

The *C-Channel SDU* flag is set if and only if the TDMA Payload contains a single C-Channel/C-Plane SDU.

The *B-Field Present* flag is set if and only if the B-Field carries U-plane data. If this flag is not set, the contents of the U-plane are undefined. The B-field CRC contains the CRC correctly calculated over the B-field, even if the contents of the B-field are undefined.

The *Number of C-Channel SDUs* field contains the number of C-Channel/C-Plane SDUs that are contained in the TDMA payload. The valid range of values is 0 to 9. Other values are reserved.

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The *C-Channel Sequence Number* carries a sequence number that applies to the set of all C-Channel SDUs contained in the TDMA MPDU. If there are no C-Channel/C-Plane SDUs contained in the MPDU, the *C-Channel Sequence Number* is undefined.

The *C-Channel Ack Sequence Number* carries the *C-Channel Sequence Number* of the set of C-Channel SDUs that are being acknowledged.

5.4.12.3 B-Field

The B-Field contains a 40-byte U-plane SDU. [74]

5.4.13 CPS MPDU

The Connection Point Service (CPS) MPDU is used by a HomeRF node to manage (request or end) services provided to it by a CP. Figure 94 defines the structure of the CPS MPDU.

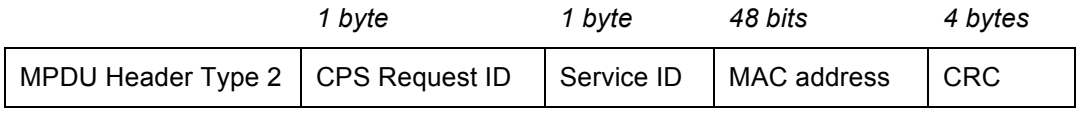


Figure 94 - CPS MPDU Structure

The MPDU header *Destination Address* depends on the type of node sending the MPDU. See Table 104 - CPS Destination Address Values based on HomeRF node type

Table 104 - CPS Destination Address Values based on HomeRF node type

HomeRF node type	Destination Address Value
I-node	MAC address of Class-1 CP
Other nodes	MAC address of the CP, or the Broadcast Address

The MPDU header *Source Address* is set to the address of the sending node.

The *Service ID* field takes values defined in Table 105.

The *Request ID* defines the services that are being requested or ended. Table 105 defines its values.

The MAC address field is a CPS request associated parameter as defined in Table 105.

Table 105 - CPS Request ID Values and associated Parameters

CPS Request ID	CPS request definition	Service ID Field	MAC Address
0	Request power management service	*Service ID* of power-management services requested. See section 5.17.2.2 (PS service ID)	*Reserved*
1	Terminate power management service	*Reserved*	*Reserved*
2	Request the CP to wake-up a specified PS node	*Reserved*	The MAC address of the node to be woken up

[74] If there is no U-plane SDU to transmit, the *fastC=1* format is used.

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3	Acknowledge a PS wake-up notification	*Reserved*	*Reserved*
8	Request the CP to signal *LearnNWID*	*Reserved*	*Reserved*
9	Request the CP to signal *DirectedLearnNWID*	*Reserved*	*The MAC address of the node that the NWID is being directed to*

5.4.14 TDMA CPS MPDU

The TDMA Connection Point Service (CPS) MPDU is used by a HomeRF I-node to manage (request or end) services provided to it by a CP. Figure 95 defines the structure of the TDMA CPS MPDU.

2 bits	*2 bits*	*4 bits*	*24 bits*	*1 byte*	*48 bits*	*2 bytes*
MPDU Header Type 1	*Reserved*	Connection / Service ID	NWID	CPS Request ID	Source Address	CRC

Figure 95 - TDMA CPS MPDU Structure

The *TDMA MPDU Type* field of the MPDU Header Type 1 contains the value *TDMA CPS MPDU*.

The *Connection/Service ID* contains the value defined in Table 106.

The *Source Address* is set to the MAC address of the sending node.

The *CPS Request ID* defines the services that are being requested or ended. Table 106 defines its values.

Table 106 - TDMA CPS Request ID Values and associated Parameters

CPS Request ID	CPS request definition	Connection / Service ID Field
8	Request the CP to signal *LearnNWID*	*Reserved*
16	Request TDMA connection	TDMA service ID of service requested. See section 5.20.2 (TDMA Service ID)
32	Request Encryption	TDMA connection ID of connection to be encrypted

The *CRC* is calculated over the entire contents of the MPDU, excluding the CRC itself, using the DECT CRC defined in 5.4.5.4 (DECT CRC).

5.4.15 Ad-hoc Beacon MPDU

The *Ad-hoc Beacon* is used by an ad-hoc network to maintain synchronization. See section 5.16.17 (Maintaining Synchronization in an Ad-Hoc Network).

This MPDU is sent with an MPDU header type 3. There is no MPDU payload.

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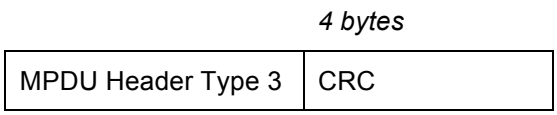


Figure 96 - Ad-hoc Beacon Structure

The MPDU header *Source Address* is the MAC address of the transmitting node.

5.4.16 CP Beacon MPDUs

5.4.16.1 Purpose of CP Beacon (Informative)

The CP beacon is transmitted periodically by the CP to provide support for these features:

- Network Synchronization
- A-node Power-saving and CSMA/CA performance management
- S-node priority access management via the CW Signaling
- I-node connection management and ICBS management

5.4.16.2 CP Beacon Formats and Terminology

A Class-2 or Class-3 CP transmits CP2 Beacons as shown in Figure 97. These shall be sent using the *Basic Rate Single PSDU* PD-SAP service format.

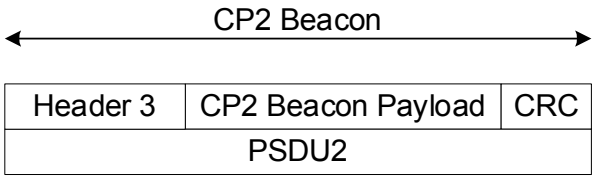


Figure 97 - CP2 Beacon Format

A Class-1 CP transmits CP1 Beacons as shown in Figure 98.

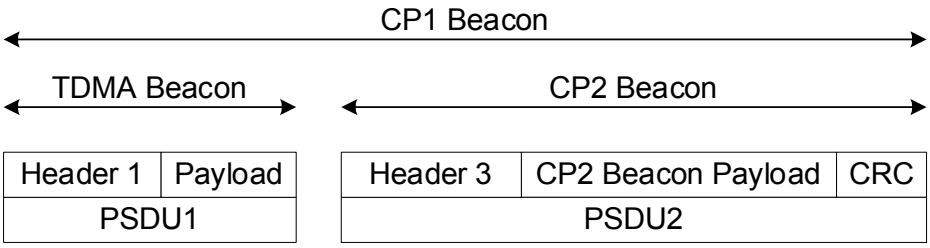


Figure 98 - CP1 Beacon Format

An A-node, S-node or CP will receive CP1 Beacons as CP2 Beacons - the operation of the PD-SAP services results in the TDMA Beacon part of a CP1 Beacon being discarded.

An I-node will receive only the TDMA Beacon part of a CP1 Beacon.

An AI-node will receive both parts of a CP1 Beacon.

Where this document refers to a “CP Beacon”, it is a generic term that includes TDMA Beacon, CP1 Beacon and CP2 Beacon.

5.4.16.2.1 Variable-Length Beacon Field Structure

This section defines the structure of any variable-length fields present in the TDMA or CP2 beacon payload.

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Each variable-length beacon field starts with a size byte that is followed by the content of the field.[75] This is shown in Figure 99.

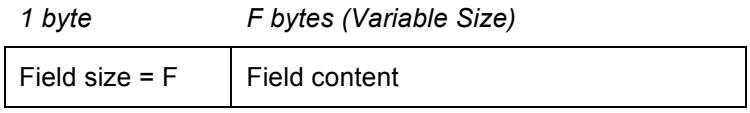


Figure 99 - CP Beacon Field Structure (with content)

A variable-length beacon field that has no content is represented by a size byte containing 0 and no Field Content. This is shown in Figure 100.

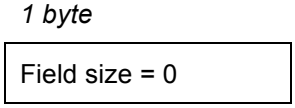


Figure 100 - CP Beacon Field Structure (no Field Content)

5.4.16.3 CP2 Beacon Structure

5.4.16.3.1 CP2 Beacon Payload Structure

The CP2 beacon payload contains a number of fields, each of which may have a variable size or be absent. The CP2 beacon payload has a variable size, depending on its content, up to a fixed limit.

The maximum size of the CP2 Beacon payload is defined to be *MaxCP2beaconPayloadLength* bytes.

Additional constraints on the size of the CP2 beacon payload can apply when TDMA connections are present. See section 5.17.3.3 (CP Beacon Packing Rules).

All trailing empty fields of the CP2 beacon are omitted.

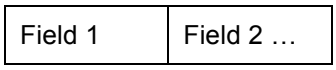


Figure 101 - CP2 Beacon Payload Structure (not empty)

A CP2 beacon with all fields omitted has a zero-length CP2 Beacon payload.

The generic structure of a CP2 Beacon Field is defined in section 5.4.16.2.1 (Variable-Length Beacon Field Structure).

The CP2 Beacon fields are identified by their order within the CP2 Beacon.[76] The order is defined in Table 107.

Table 107 - CP2 Beacon Field Positions

CP2 Beacon Field Position	Contains
1	Channel Management
2	CW Signaling
3	A-node Power Management

The MPDU header *Source Address* is the address of the Connection Point.

[75] The size field permits a node to skip a field without the need to parse its contents.

[76] The field that is the most commonly used is placed in front of the CP Beacon and the fields likely to be large are placed at the end. These two rules aim to simplify the parsing of the beacon.

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5.4.16.3.2 Channel Management

The Channel Management field contains signaling for the position of the contention period, and for hopset adaption.

This field exists in one of three forms distinguished by the field size byte: empty, short and long. These forms are defined in Figure 102, Figure 103 and Figure 104.

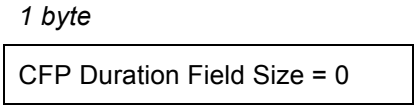


Figure 102 - CFP Durations Field Structure (empty)

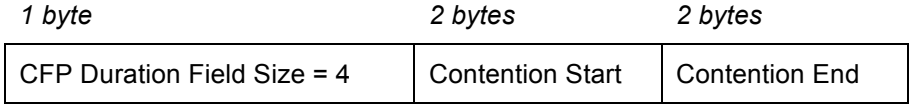


Figure 103 - CFP Durations Field Structure (short)

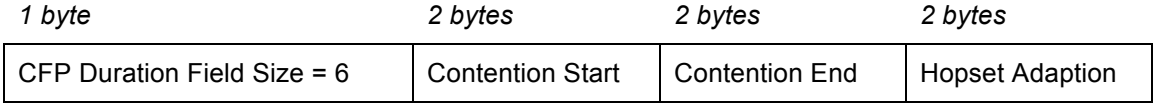


Figure 104 - CFP Durations Field Structure (long)

The *Contention Start* field contains the *DwCount* value for the first symbol in the contention period.

The *Contention End* field contains the *DwCount* value for the last symbol in the contention period.

The *Hopset Adaption* field is defined in 5.4.16.3.2.1 (Hopset Adaption Field).

The empty form shall be used in any of the following cases:

- In a CP2 Beacon transmitted by a Class-2 or Class-3 CP
- If the *SubframesPresent* bit in the MPDU Header type 3 is a zero

The long form shall not be used if the signaled *HopsetAdapted* field is zero.

Otherwise either the short or long forms can be used. Section 5.12.4.1 (MD_SAP Header Structure) defines additional constraints on the selection of the short or long forms.

5.4.16.3.2.1 Hopset Adaption Field

The structure of the *Hopset Adaption* field is defined in Figure 105. These parameters define the position and width of a single band of interference.

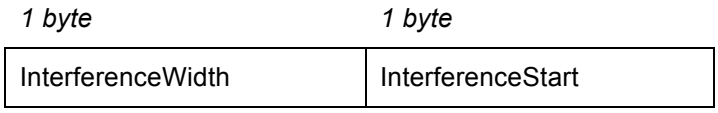


Figure 105 - Hopset Adaption Structure

The *InterferenceWidth* field defines the width of the interference band in radio channels.

The *InterferenceStart* field defines the lowest numbered radio channel in the interference band.

The interference band occupies radio channels from *InterferenceStart* to (*InterferenceStart* + *InterferenceWidth* - 1) inclusive.

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5.4.16.3.3 CW Signaling

Figure 106 defines the structure of the CW Signaling field. This field is used by the CP to signal a new value for the CW variables defined in section 5.7.4.2 (CW Variables). It is decoded by A-nodes and S-nodes and affects the operation of the CSMA/CA Access Mechanism as described in section 5.7.4.2 (CW Variables).

1 byte	*5 bits*	*3 bits*	*1 byte*	*...*	*1 byte*
			Priority Access value 0	...	Priority Access value (# Priority Access value fields – 1)
Field size = # Priority Access value fields +1	CWmin	CWstart	SID	...	SID

Figure 106 - CW Field Structure

5.4.16.3.4 A-node Power Management Field

The *A-node Power Management* field indicates events associated with the A-node power-management service. The structure of this field is defined in Figure 107.

1 byte	*1 byte*	*48 bits*	*8 bits*	*...*	*48 bits*	*8 bits*
		Node 1		...	Node (pm-1)/7	
Field size = pm	Multicast PS Management	IEEE address	PM Events	...	IEEE address	PM Events

Figure 107 - A-node Power Management Field Structure

If no node has requested the multicast PM service and no power management events are active for any node, the power management field is empty (pm = 0).

If the multicast PM service has not been requested and one or more PM events are present, the *multicast PS management* field is present and the contents of this field are zeroes.

If the multicast PM service has been requested, the *multicast PS management* field is present and contains the fields according to the structure shown in Figure 108 and defined in Table 108.

7 bits	*1 bit*
Multicast PS period countdown	Multicast PS period active

Figure 108 - Multicast PS Management Field Structure

Table 108 - Multicast PS Management Fields

Field	**Definition**
Multicast PS period countdown	The number of superframes to wait before the start of the next multicast PS period
Multicast PS period active	1 = this superframe is part of a multicast PS period

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	0 = otherwise

The structure of the Event Field is defined in Figure 109. Multiple flags can be set to signal multiple events.

1 bit	*1 bit*	*1 bit*	*1 bit*	*1 bit*	*3 bits*
Power management service request accepted	Power management service terminated	Wake-up notification	Wake-up denied	Wake-up successful	*Reserved*

Figure 109 - Power Management Service Event Field Structure

The power-management events are defined by Table 109.

Table 109 - Power Management Event Definitions

Power-Management Event	**Definition**
Power Management Service Request Accepted	The CP has accepted a request for power-management services from the specified node
Power Management Service Terminated	The CP has terminated providing power-management services for the specified node
Wake-up Notification	The specified node is being requested to wake-up
Wake-up Denied	The CP cannot wake up the specified node because it is not providing power-management services for that node
Wake-up Successful	The CP has received a wake-up notification from the node with the specified address.

The event is signaled if the appropriate bit in the *Power Management Service Event* Field has a value equal to 1.

5.4.16.4 TDMA Beacon Structure

The TDMA beacon payload contains a fixed-size header, a number of fields, each of which may have a variable size or be absent, followed by a 16-bit CRC. [77] The CRC protects the entire contents of the MPDU, excluding the CRC itself. It is calculated as defined in section 5.4.5.4 (DECT CRC).

The TDMA beacon payload has a variable size, depending on its content. All trailing empty fields of a TDMA beacon are omitted, except the CRC.

The maximum length of the TDMA beacon part is *MaxTDMAbeaconLength* bytes. This includes all the fields shown in Figure 110, TDMA MPDU Header, TDMA Beacon Header, any variable fields and the 16-bit CRC.

[77] The CRC is viewed as part of the payload, because the region over which the CRC is calculated depends on packet format.

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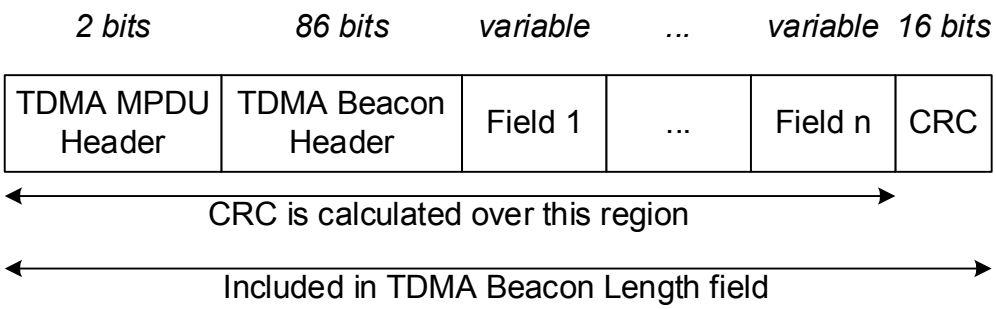


Figure 110 - TDMA Beacon Structure

The generic structure of a Beacon Field is defined in section 5.4.16.2.1 (Variable-Length Beacon Field Structure).

The TDMA Beacon fields are identified by their order within the TDMA Beacon.[78] The order is defined in Table 110.

Table 110 - TDMA Beacon Field Positions

TDMA Beacon Field Position	**Contains**
1	Main Slot
2	Retry Downlink
3	Retry Uplink
4	Connection Management
5	TDMA Channel Management

5.4.16.4.1 TDMA Beacon Header Structure

The TDMA Beacon Header includes all fixed signaling fields in the TDMA Beacon. The structure of this field is defined in Figure 111.

32 bits	*8 bits*	*1 bit*	*1 bit*	*12 bits*	*8 bits*	*24 bits*
Synchronization Information	Superframe Control Field	Learn NWID	*Reserved*	CFP1 Offset	TDMA Beacon Length	NWID

Figure 111 - TDMA Beacon Header Structure

The *Synchronization Information* field is defined in 5.4.4.17 (Synchronization Information Field)

The *SuperframeControlField* is defined in 5.4.4.12 (Superframe Control Field).

The *Learn NWID* field is defined in 5.4.4.8 (Learn NWID Field).

The *CFP1 Offset* field defines the position of CFP1. It contains the number of symbols between the start of the subframe and the start of CFP1.

The *TDMA Beacon Length* field contains the length of the TDMA MPDU in bytes, including the CRC.

The *NWID* field contains the NWID of the CP.

[78] The field that is the most commonly used is placed in front of the CP Beacon and the fields likely to be large are placed at the end. These two rules aim to simplify the parsing of the beacon.

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5.4.16.4.2 Main Slots Field Structure

The structure of the main slots field is defined in Figure 112.

1 byte	*4 bits*	*4 bits*	*4 bits*	*4 bits*	
Main Slots Field Size	*Reserved*	Connection ID for main slot 1	*Reserved*	Connection ID for main slot 2	…

Figure 112 - Main Slots Field Structure

The *MainSlotsFieldSize* field contains the number of bytes in the main slots field structure (excluding itself). Valid values for this are from 0 to 5.

An entry shall be signaled for each TDMA connection that is in the *Active* state.

5.4.16.4.3 Downlink Retry Slots Field Structure

The structure of the downlink slots field is defined in Figure 113.

1 byte	*4 bits*	*4 bits*	*4 bits*	*4 bits*	
Downlink Retry Slots Field Size	*Reserved*	Connection ID for downlink retry slot 1	*Reserved*	Connection ID for downlink retry slot 2	…

Figure 113 – Downlink Retry Slots Field Structure

The *DownlinkRetrySlotsFieldSize* field contains the number of bytes in the downlink retry slots field structure (excluding itself). Valid values for this are from 0 to 4.

There is no correlation between uplink and downlink retry slots. A TDMA connection can be present in both, one or neither field. If present in both uplink and downlink retry slot fields, the TDMA connection can be allocated different slot numbers for uplink and downlink slots.

5.4.16.4.4 Uplink Retry Slots Field Structure

The structure of the uplink slots field is defined in Figure 114.

1 byte	*4 bits*	*4 bits*	*4 bits*	*4 bits*	
Uplink Retry Slots Field Size	*Reserved*	Connection ID for uplink retry slot 1	*Reserved*	Connection ID for uplink retry slot 2	…

Figure 114 – Uplink Retry Slots Field Structure

The *UplinkRetrySlotsFieldSize* field contains the number of bytes in the downlink retry slots field structure (excluding itself). Valid values for this are from 0 to 4.

5.4.16.4.5 Connection Management field

This field is used to manage TDMA connection setup and destruction. Figure 115 defines the structure of this field.

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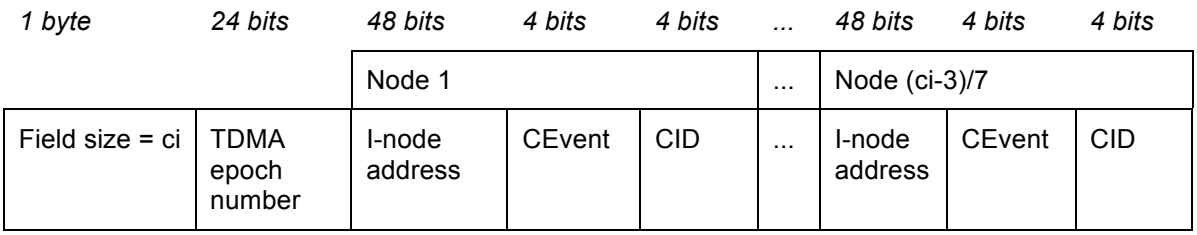


Figure 115 - Connection Management Field Structure

If no TDMA connection management events are active for any node, the TDMA connection information field is empty (ci = 0).

If some TDMA connection event is to be transmitted, the field includes the TDMA epoch number (defined in section 5.20.4.9 (TDMA Epoch Number)) and a Connection Management sub-field for each separate node for which connection management events are pending. This field shall not include more than one sub-field addressed to the same node.

Table 111 defines values for the *CEvent* field.

Table 111 - CEvent Field Values

CEvent Field Value	Event Name	Definition
1	Connection Denied	A connection setup request has been rejected
2	Connection Established	A connection setup request has been accepted
4	Request Encryption	The CP requests the I-node to enable encryption on the connection

Table 112 defines the interpretation of the CID field, depending on the Connection Management Event present.

Table 112 - CID Values in the Connection Management Field

Connection Management Event	CID Value
Connection Denied	*Reserved*
Otherwise	The Connection ID of the connection associated with the event

The I-node address field contains the IEEE MAC address of the I-node to which the connection management event is addressed.

5.4.16.4.6 TDMA Channel Management

The TDMA Channel Management field contains signaling of hopset adaption.

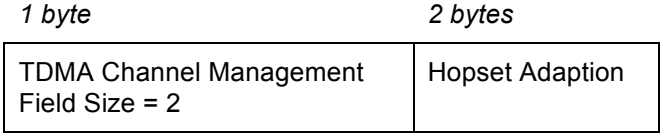


Figure 116 - TDMA Channel Management Field Structure (non-empty)

The *Hopset Adaption* field is defined in 5.4.16.3.2.1 (Hopset Adaption Field).

5.4.17 Connection Point Assertion MPDU

The *Connection Point Assertion* management MPDU is broadcast by the *active* CP. It is used by the CP management procedures to ensure that there is only one active CP on the network. The structure of the *CP Assertion MPDU* is defined in Figure 117.

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	4 bytes	*4 bits*	*4 bits*	*4 bytes*
MPDU Header Type 2	ACP Superframe Counter	Connection Point Priority	Connection Point Type	CRC

Figure 117 - CP Assertion MPDU Structure

Table 113 defines values for the *Connection Point Type* field.

Table 113 - Connection Point Type Field Values

Connection Point Type	CP Class
0	*Reserved*
1	Class-1 CP
2	*Reserved*
3	Class-2 CP
4	Class-3 CP
5 - 15	*Reserved*

The *Connection Point Priority* field is used to arbitrate between CPs of the same type. 0 is the lowest priority and 15 is highest priority. [79]

The *ACP Superframe Counter* contains the number of superframes since the first CP beacon transmitted by this node. It saturates at the value 2^{32} -1.

5.5 Channel Access Management

This section defines procedures that shall be followed by the MAC management entity to manage the operation of the MAC channel access mechanisms.

5.5.1 Introduction to Channel Access Management (Informative)

The HomeRF MAC architecture can support both *ad-hoc* networks and *managed* networks. A managed network is controlled and managed by a Connection Point. In an ad-hoc network, the MAC protocol support only asynchronous data service (using CSMA/CA). In a managed network, the MAC also provides support for isochronous services (using TDMA).

In order to support those services, the MAC protocol defines a *superframe*, which is a periodic division of the time, allocating specific parts of the superframe for the different functions. A synchronization mechanism is defined (see section 5.16.16 (Synchronization in a Managed Network) and 5.16.17 (Maintaining Synchronization in an Ad-Hoc Network), allowing the nodes of the network to agree on the superframe timing.

The MAC defines a number of procedures for accessing the medium that depend on superframe timing.

The HomeRF MAC uses *frequency hopping*. Frequency hopping is a form of spread-spectrum that allows a system to use a defined bandwidth, to avoid interferers and to share the bandwidth with other systems. A Class-1 CP can adapt its frequency hopping pattern to reduce the effect of a single interference band on voice quality.

The use of frequency hopping is constrained by national regulatory bodies. The procedures to be followed by nodes in North America are defined in these sections. Localizations for other locales are defined in Appendix A - (Localizations).

All nodes change frequency (hop to a new channel) periodically. The aim is to trade bandwidth and throughput for reliability and reduce the probability of devices using a portion of the frequency spectrum in which there is a lot of interference and hence poor throughput. A node hops periodically between a set of channels (75 channels in North America) to avoid interference and bad channel conditions.

[79] The selection of priority is up to the implementation.

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The frequency hopping mechanism is controlled by the following parameters: the Hop Pattern (fixed within the network), the Hop Index (incremented at each hop), the DwCount, the Subframe Index, the Subframes present indicator and the *HopsetAdapted, InterferenceWidth* and *InterferenceStart* parameters.

All nodes in the network hop at the same time. This is synchronized by the *DwCount* parameter. This indicates the number of symbols remaining in the dwell before the next hop. The time taken by the PHY to perform the hop is *HopDuration*. This is the time to change from one operating channel frequency and settle on the new channel (defined in section 16.1 (PHY Constants)). The next dwell period begins *HopDuration* after the previous dwell ended. A single MPDU transmission cannot cross the dwell boundary. The dwell period is the usable part of the time between two successive hops.

All nodes in the network hop at the same rate. There are two rates supported: a slower rate is used when there are no voice calls; a faster rate is used when there are one or more voice calls. The two rates are distinguished by the *Subframes Present* indicator.

All nodes in the network hop using the same pattern. This is defined using the *HopPattern* parameter. A Class-1 CP can signal an interference band using the *HopsetAdapted, InterferenceStart* and *InterferenceWidth* parameters, causing all nodes[80] to perform the same adaption to the hopset to maintain voice connection quality.

5.5.2 Frequency Hopping

A node that in the *Managed* or *Ad-hoc* synchronization states (see 5.16.4 (Synchronization State)) shall perform the procedures defined in this section.

5.5.2.1 Hop Management

The node shall keep the variables defined in Table 114 that control the Frequency Hopping process.

Table 114 - Hop Management Variables

Variable	Definition
NumberOfChannels	The number of hop channels supported in the current locale
HopPattern	The Hopping Pattern. This variable controls the sequence of channels used. Values: 0 to (*NumberOfChannels*-1) See section 5.5.2.3 (Hopping Frequency Calculation)
HopIndex	The current position within the sequence of radio channels that are defined by the Hop Pattern. Values: 0 to (*NumberOfChannels*-1) See section 5.5.2.3 (Hopping Frequency Calculation)
DwCount	The number of PHY symbols (each of duration *BasicModulationSymbolDuration* (defined in section 16.1 (PHY Constants)) until the start of the next hop. If *SubframesPresent = 0* Values: (*SuperframeDuration/BasicModulationSymbolDuration*) to 1 If *SubframesPresent = 1* Values: (*SubframeDuration/BasicModulationSymbolDuration*) to 1
BaseChannel	The hop pattern channel base. Defined by the locale in which the HomeRF node is operating. Values: 3 to 73 corresponding to 2.403 to 2.473 GHz

[80] It is possible for a node (e.g. a power-saver) to miss a change of adaption parameters. Because the adapted hopset and unadapted hopset differ only in a small number of places, the unadapted station will be able to receive most of the CP Beacons transmitted on the adapted hopset, and therefore rapidly acquire the adapted hopset.

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Variable	Definition
SubframesPresent	Indicates whether subframes are present or absent. [81] Values: 0 (no sub-frames), 1 (sub-frames are present) This variable shall have the value zero when the synchronization state is not *Managed.*
SubframeIndex	The current position of the subframe within the superframe. This variable shall take the value 1 when *SubframesPresent* is 1 and the sub-frame is the last sub-frame of a super-frame. Otherwise it shall take the value 0. This variable shall have the value zero when the synchronization state is not *Managed.*
HopsetAdapted	This variable indicates whether the hopset is adapted or not. Values: 0 (not adapted), 1 (adapted) The *InterferenceWidth* and *InterferenceStart* variables are only defined when *HopsetAdapted*=1. The *HopsetAdapted, InterferenceWidth* and *InterferenceStart* variables are called the *Hopset Adaption Variables*.
InterferenceWidth	The width of a single band of interference to which the hopset is adapted. Values: *MinInterferenceWidth* to *MaxInterferenceWidth* (Units are radio channels). The value is only defined when *HopsetAdapted*=1.
InterferenceStart	The starting position of the interference band to which the hopset is adapted. Values: 0 to 66. Units are radio channels. Radio channels from (*InterferenceStart*) to (*InterferenceStart* + *InterferenceWidth* - 1) are included in the interference band. The value is only defined when *HopsetAdapted*=1.
HopPatternArray	This is an array of length that varies with the locale. Each element holds a radio channel. The *HopPatternArray* is derived from the *HopPattern*, *HopsetAdapted, InterferenceStart* and *InterferenceWidth* parameters as defined in 5.5.2.4 (HopPatternArray Calculation).

The node shall decrement *DwCount* every *BasicModulationSymbolDuration*.

When *DwCount* is decremented to zero, the node shall operate as defined in Table 115 according to whether *SubframesPresent* is 0 or 1.

[81] Sub-frames are only present in a HomeRF network that has a Class-1 CP and I-nodes.

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Table 115 - Procedures for Updating the Hop Variables

SubframesPresent = 0	***SubframesPresent = 1***
1. Increment *HopIndex* (modulo *NumberOfChannels*) 2. Determine the radio channel from the *HopPattern*, *HopIndex, SubframeIndex* and *BaseChannel* using the algorithm defined in section 5.5.2.1 (Hop Management). 3. Issue a PM_SET_CHANNEL request to the PHY containing the radio channel determined in step 2. 4. Reset *DwCount* to (*SuperframeDuration*/*BasicModulationSymbolDuration*)	1. Increment *SubframeIndex* (modulo *NumberOfSubframes*) 2. If *SubframeIndex* is zero, increment *HopIndex* (modulo *NumberOfChannels*) 3. Determine the radio channel from the *HopPattern*, *HopIndex, SubframeIndex* and *BaseChannel* using the algorithm defined in section 5.5.2.1 (Hop Management). 4. Issue a PM_SET_CHANNEL request to the PHY containing the radio channel determined in step 3. 5. Reset *DwCount* to (*SubframeDuration*/*BasicModulationSymbolDuration*)

5.5.2.2 Geographic Region of Operation

The body of this document specifies Frequency Hopping procedures to be followed in the North American Locale. Procedures to be followed in other locales are defined in Appendix A - (Localizations).

A HomeRF node shall follow the procedures defined within this specification for the locale in which it is to be used.[82]

A HomeRF node shall follow all the applicable regulations in the locale in which it is to be used.

5.5.2.3 Hopping Frequency Calculation

This section defines the hopping frequency calculation for the North American locale.

Appendix A (Localizations) lists the countries for which this hopping frequency information can be used. Appendix A also gives separate hopping frequency information for selected countries.

Given the hopping variables defined in 5.5.2.1 (Hop Management), the *PatternPosition* is defined by Equation 6. [83]

Equation 6 - Pattern Position Calculation

$$PatternPosition = ((HopIndex \times NumberOfSubframes) + SubframeIndex) \bmod NumberOfChannels$$

The pattern position indexes into a pseudo-random hopping table called the hop pattern array (*HopPatternArray*). This array is calculated using the procedures defined in 5.5.2.3 (Hopping Frequency Calculation).

A Channel number is derived from the *PatternPosition* and *HopPatternArray* as defined in Equation 7.

Equation 7 - Channel Calculation

$$Channel = HopPatternArray(PatternPosition)$$

Finally the *Channel* is converted to a radio frequency (MHz) as defined in Equation 8.

Equation 8 - Frequency Calculation

$$Frequency = BaseFrequency + (BaseChannel + Channel) \times ChannelSeparation$$

[82] Local Regulations might require that a HomeRF node shall not be capable of being operated using settings that are inappropriate for the current locale.

[83] This results in sequences (for the 75 hop pattern) of:
0, 2, 4 … 74, 1, 3 … 73 when *SubFramesPresent* is 0 (20ms interval), and
0, 1, 2 … 74 when *SubFramesPresent* is 1 (10ms interval)

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The parameters that are a constant of the North American locale, used in the hop calculation are defined in Table 116

Table 116 - Channel Parameters for North America

Region	BaseFrequency (MHz)	ChannelSeparation (MHz)	NumberOfChannels	BaseChannel
North America	2400	1	75	3

In support of the high-rate (HR 2-FSK and HR 4-FSK) modulation types, the *Channel Parameters for North America* are as described in Table 117.

Table 117 - HR Modulation Type Channel Parameters for North America

Region	BaseFrequency (MHz)	ChannelSeparation (MHz)	NumberOfChannels	BaseChannel
North America	2400	5	15	3

The *Hopping Channel number* can be used to calculate the *Channel Number* for the 5MHz channels used for the HR Modulation Types. This calculation is defined in Equation 9.

Equation 9 - 5 MHz Channel Calculation

$$5MHzChannel = 5 * INT(Channel / 5) + 2$$

5.5.2.4 HopPatternArray Calculation

This section defines how the *HopPatternArray* variable is derived from the *HopPattern*, *HopsetAdapted, InterferenceStart*, and *InterferenceWidth* variables for the North America locale.

A node shall re-calculate its *HopPatternArray* variable whenever either of the *HopPattern* or HopsetAdapted variables changes value. When *HopsetAdapted*=1, it shall re-calculated its *HopPatternArray* whenever either of the *InterferenceStart* or *InterferenceWidth* variables changes value.

A CP shall delay any re-calculation resulting from a change it makes to its hopset adaption variables until the new hopset adaption variables have been signaled in a CP Beacon[84]. See also section 5.5.2.4.1 (Hop Pattern Array Adaption).

When the *HopsetAdapted* is zero, the I-th element of *HopPatternArray* is defined by Equation 10 for values of I from 0 to (*NumberOfChannels*-1). In this case the *HopPatternArray* holds the unadapted hop pattern.

Equation 10 - Calculation of HopPatternArray

$$HopPatternArray(I) = \left(b(I) + HopPattern\right) \bmod NumberOfChannels$$

Where b(I) is the I-th element of the base hopping sequence. The base hopping sequence for the North America locale is defined in Table 118.

[84] This requirement means that the CP and its managed nodes are likely to update their hopset adaption at the same time.

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Table 118 - Base Hopping Sequence for North America

Base Hopping Sequence b(I) for North America															
I	**b(I)**	**I**	**b(I)**	**I**	**b(I)**	**I**	**b(I)**	**I**	**b(I)**	**I**	**b(I)**	**I**	**b(I)**	**I**	**b(I)**
0	0	10	33	20	74	30	9	40	8	50	27	60	58	70	73
1	14	11	48	21	54	31	19	41	23	51	44	61	6	71	18
2	41	12	35	22	12	32	61	42	51	52	34	62	47	72	50
3	1	13	24	23	45	33	5	43	15	53	56	63	20	73	26
4	39	14	40	24	13	34	25	44	49	54	29	64	70	74	38
5	72	15	11	25	57	35	46	45	28	55	69	65	30		
6	32	16	67	26	37	36	2	46	71	56	55	66	52		
7	60	17	22	27	66	37	62	47	10	57	21	67	42		
8	16	18	3	28	36	38	17	48	63	58	7	68	4		
9	68	19	64	29	53	39	65	49	43	59	31	69	59		

When the *HopesetAdapted=1*, the node shall calculate the *HopPatternArray* as defined in Equation 10 and then adapt it using the procedure defined in 5.5.2.4.1 (Hop Pattern Array Adaption). The resulting adapted *HopPatternArray* shall be used for the frequency calculation defined in 5.5.2.3 (Hopping Frequency Calculation).

5.5.2.4.1 Hop Pattern Array Adaption

The algorithm defined in this section takes the unadapted *HopPatternArray* and an interference band and modifies the *HopPatternArray* to remove adjacent dwells that lie within the interference band.

A dwell that lies within the interference band is called a *bad* dwell. The modification consists of swapping the radio channel used by one of the adjacent bad dwells with the radio channel used by a good dwell. The good dwell is selected so as to avoid introducing neighboring bad-bad dwells.

The adaption algorithm is defined using ANSI “C”. The adaption is performed by a call to vHopsetAdapt().

```
#define N_DWELLS 75
#define N_DWELLS_SHIFT (N_DWELLS >> 1)
#define IN_RANGE(val,start,end) (((val)>=start) && (val<=end))

void vHopsetAdapt
(
   int * piHopset,      /* in:  unadapted HopPatternArray[N_DWELLS],
                           out: adapted HopPatternArray  */
   int iIntStart,       /* Lowest radio channel in the interference band */
   int iIntEnd,         /* Highest radio channel in the interference band */

   int * piSwaps,       /* out: number of channel swaps */
   int * piTests        /* out: number of alias channel tests */
)
{
   /* Positions of current dwell and following two */
   int iDwell, iDwell1, iDwell2;

   /* Original channel and swapped channel (alias) */
   int iChannelOriginal;
```

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```
   int iAliasChannel,  iAliasDwell;


   /* For each position in the hop pattern ... */
   for (iDwell=0; iDwell < N_DWELLS; )
   {
      if (IN_RANGE(piHopset[iDwell],iIntStart,iIntEnd))
      {
         /* Bad */
         iDwell1 = (iDwell + 1) % N_DWELLS;
         if (IN_RANGE(piHopset[iDwell1],iIntStart,iIntEnd))
         {
            /* Bad Bad */
            iDwell2 = (iDwell + 2) % N_DWELLS;
            if (IN_RANGE(piHopset[iDwell2],iIntStart,iIntEnd))
            {
               /* Bad Bad Bad - change "middle" bad channel */
               iChannelOriginal = piHopset[iDwell1];

               *piTests += iChannelReplacementGet(  piHopset,
                                                    iChannelOriginal,
                                                    &iAliasChannel,
                                                    &iAliasDwell,
                                                    iIntStart,
                                                    iIntEnd
                                                 );

               piHopset[iDwell1] = iAliasChannel;
               piHopset[iAliasDwell] = iChannelOriginal;
               *piSwaps +=1;
               iDwell = iDwell + 2;
            }
            else
            {
               /* Bad Bad Good - change "first" bad channel */
               iChannelOriginal = piHopset[iDwell];
               *piTests += iChannelReplacementGet(  piHopset,
                                                    iChannelOriginal,
                                                    &iAliasChannel,
                                                    &iAliasDwell,
                                                    iIntStart,
                                                    iIntEnd
                                                 );

               piHopset[iDwell] = iAliasChannel;
               piHopset[iAliasDwell] = iChannelOriginal;
               *piSwaps +=1;
               iDwell = iDwell + 3;
            }
         }
         else
         {
            /* Bad Good */
            iDwell = iDwell + 2;
         }
      }
      else
      {
         /* Good */
         iDwell = iDwell + 1;
      }
   }
}


/* return position of the specified channel in the hopset */
int iAliasDwellFind(const int * piHopset, int iAliasChannel)
{
```

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```
   int i;
   for (i=0; i< N_DWELLS; i++)
   {
      if (piHopset[i] == iAliasChannel)
      {
         return i;
      }
   }
}


/* find a replacement channel (alias) for the original channel */
int iChannelReplacementGet
(
   const int * piHopsetAdapted,  /* The hopset being adapted */
   int iChannelOriginal,         /* The radio channel to change */
   int * piAliasChannel,         /* The returned radio channel ... */
   int * piAliasDwell,           /* ... and position in the hopset */
   int iIntStart, int iIntEnd    /* Interference band position */
)
{
   /* Returns number of aliases tested (minus one) */

   /* Position of potential alias and neighbors in the hop pattern */
   int iAlias1, iAlias2, iAlias3;

   /* Radio channel of potential alias */
   int iChan2;

   /* Number of dwells between original and alias */
   int iShiftValue;

   /* Number of attempts to find an alias without introducing bad-bad hops */
   int iAttemptCount;

   /* Start with a shift equal to half the whole band */
   iShiftValue = N_DWELLS_SHIFT;

   for(iAttemptCount=0;;iAttemptCount++)
   {
      iChan2 = (iChannelOriginal + iShiftValue) % N_DWELLS;
      iAlias2 = iAliasDwellFind(piHopsetAdapted, iChan2);

      /* Determine both the position before (alias1) and the position
         after (alias3)the current position (alias2)
       */

      iAlias1 = (N_DWELLS + iAlias2 - 1) % N_DWELLS;
      iAlias3 = (iAlias2 + 1) % N_DWELLS;

      if
      (
         /* Reject if hop prior to alias is bad */
         IN_RANGE(piHopsetAdapted[iAlias1],iIntStart,iIntEnd) ||

         /* Reject if hop after alias is bad */
         IN_RANGE(piHopsetAdapted[iAlias3],iIntStart,iIntEnd) ||

         /* Reject if alias itself it bad */
         IN_RANGE(iChan2,iIntStart,iIntEnd)
      )
      {
         /* Try the next position in the hop pattern */
         iShiftValue = (iShiftValue + 1) % N_DWELLS;
      }
      else
      {
         /* Found a suitable replacement */
```

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```
            break;
         }

         /* If we have not found a good replacement,  use half-band shift,
            Knowing that it will introduce a bad-bad pair.
          */
         if(iAttemptCount >= N_DWELLS)
         {
            iShiftValue = N_DWELLS_SHIFT;
            break;
         }
      }

      *piAliasChannel = (iChannelOriginal + iShiftValue) % N_DWELLS;
      *piAliasDwell = iAliasDwellFind(piHopsetAdapted, *piAliasChannel);
      return iAttemptCount;
}
```

5.5.2.4.2 Properties of the Hop Pattern Adaption Algorithm (Informative)

This section describes some of the properties of the adaption algorithm. The adaption algorithm is defined for 1 MHz channels, since that is the fundamental hopping mechanism for HomeRF. The reduction of bad-bad pairs for wider channels is similar to that for 1 MHz channels.

The algorithm removes all bad-bad pairs in a hop pattern, given an interference bandwidth no more than 31 channels.

Figure 118 shows the average [85] number of bad-bad pairs for unadapted hopsets.

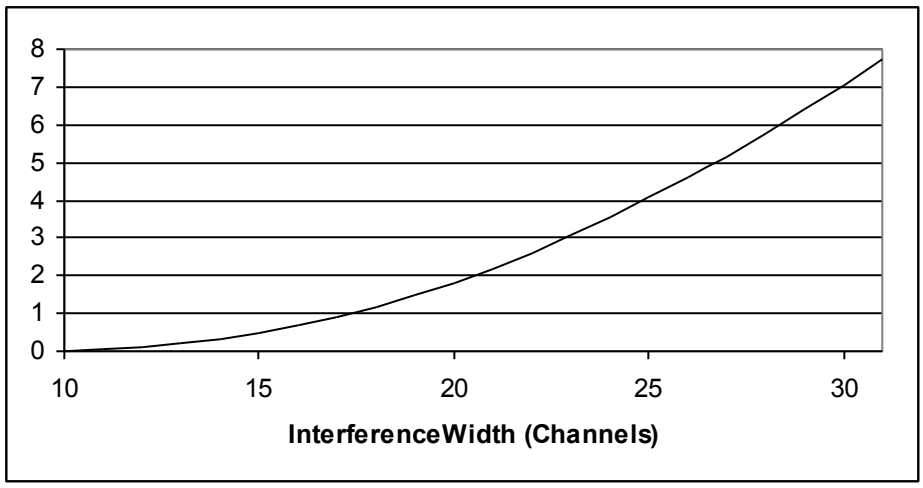


Figure 118 - Number of Bad-Bad Pairs for Unadapted Hopsets

Figure 119 shows the average number of channels that are swapped. When *InterferenceWidth* is 31, an average of 6 channels are swapped. This result shows that there is at least a 75% correlation between unadapted and the most heavily adapted hopsets.

[85] The Average was calculated over all possible hop patterns and interference band positions.

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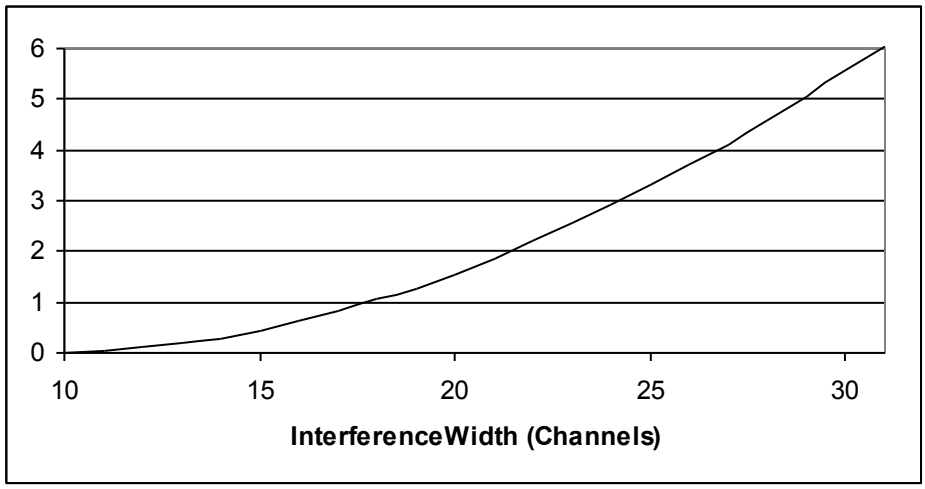


Figure 119 - Number of Channels Swapped

Figure 120 shows the average number of additional candidate alias positions that are tested to find an alias position that is not bad or adjacent to a bad dwell. At a width of 31 channels, 69 alias channel positions are tested.

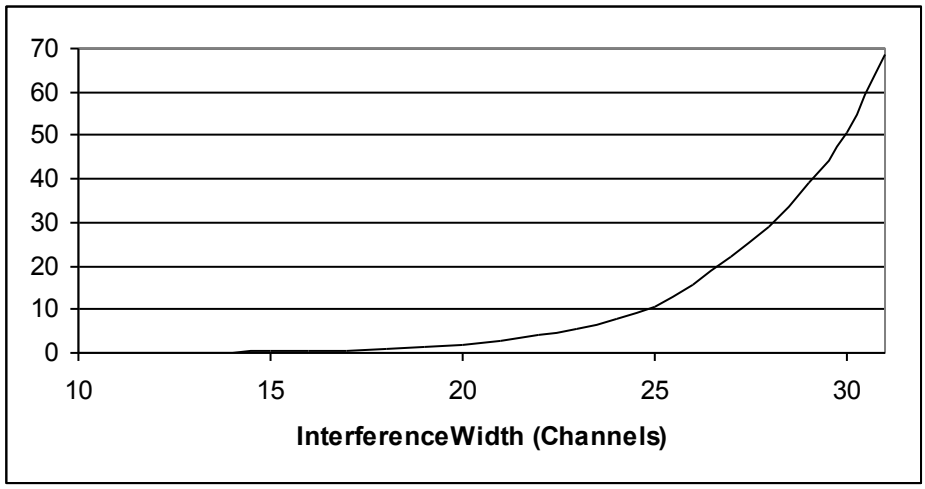
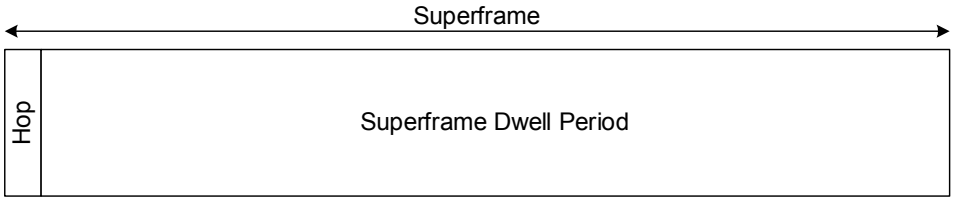


Figure 120 - Number of Additional Alias Tests

5.5.3 Superframe Structure

The superframe exists in two forms: with and without subframes. [86]

When subframes are not present, the superframe is synchronized with the frequency hopping mechanism. A superframe corresponds to the time spent on a channel (dwell) plus the hop duration. The start of the superframe is the point at which a node begins to hop to a new channel and ends immediately before the node starts to hop to the next channel. This is illustrated in Figure 121.



[86] Subframes are present only when the network is managed by a Class-1 CP that has I-node connections.

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Figure 121 - Superframe Structure, No Subframes Present

When subframes are present, the superframe is split into two subframes. Each subframe starts with a hop. Subframes within the superframe are labeled with increasing numbers starting from zero.

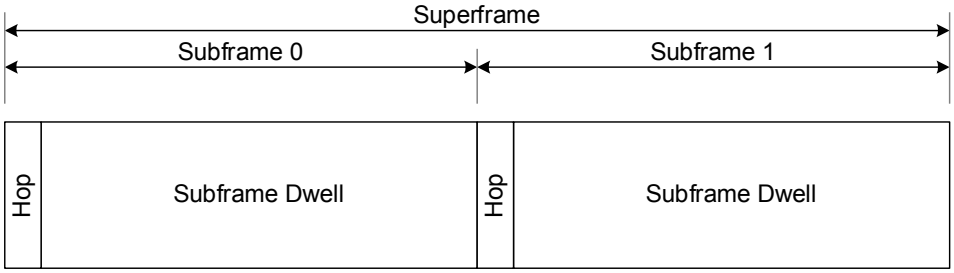


Figure 122 - Superframe Structure, Subframes Present

In an ad-hoc network, the contention period fills the entire superframe dwell period. This is shown in Figure 123.

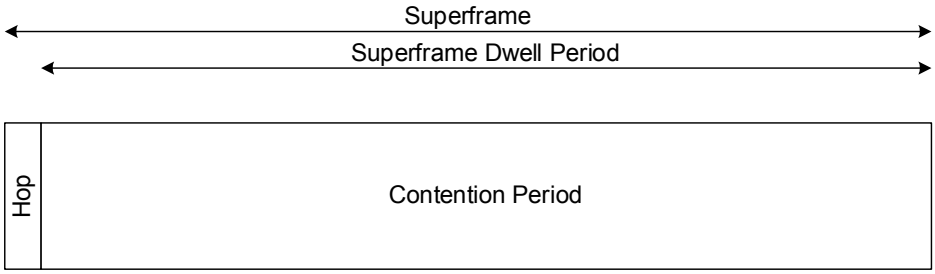


Figure 123 - Superframe Structure in an Ad-hoc Network

In a managed network, without subframes, the CP transmits a beacon in the beacon interval just after the hop. The start of the contention period is also used to carry MPDUs transmitted using the service slot access mechanism.

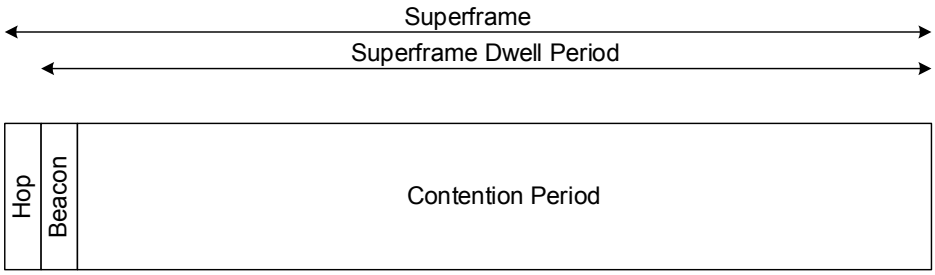


Figure 124 - Superframe Structure in a Managed Network, No Subframes Present

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When subframes are present, the subframe is divided into a hop, beacon interval, two contention-free periods (CFP1 and CFP2), and a contention period. The start of the contention period is also used to carry MPDUs transmitted using the service slot access mechanism. This is illustrated in Figure 125.

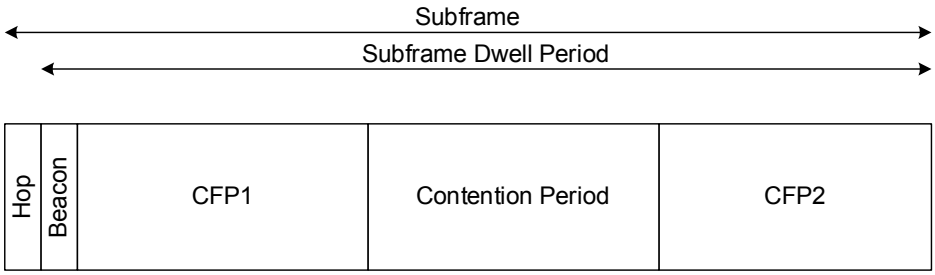


Figure 125 - Subframe Structure

An additional term is defined, the *TDMA epoch* as defined in Figure 126. The TDMA epoch is used in the TDMA access mechanism.

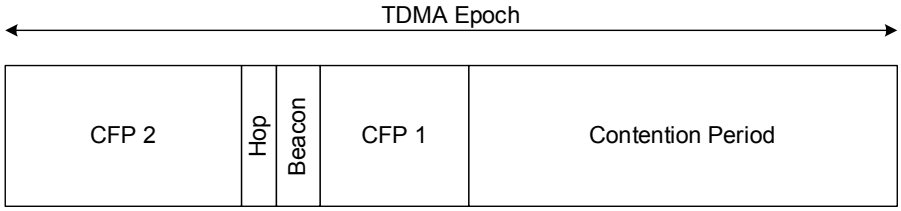


Figure 126 - Definition of TDMA Epoch

Table 119 defines the access methods that are used based on the position within the superframe/subframe.

Table 119 - Channel Access Methods Based on Position

Position	**Method**	**Carries**
During Contention-free periods	Time Division Multiple Access (TDMA)	Isochronous Data
Following CFP1	Service Slot	I-node management
During Contention period	Carrier-sense Multiple Access (CSMA/CA)	Asynchronous Data and management

5.5.3.1 MAC Timing Parameters

This section defines timing parameters used by the MAC.

The PHY layer defines the timing constants listed in Table 120.

Table 120 - Timing Constants defined by the Physical Layer

PHY constant	**Descriptions**
TxRxTurnround	Time to switch from transmission to reception
RxTxTurnround	Time to switch from reception to transmission
CCAduration	Time Required by the PHY to perform a *Clear Channel Assessment* procedure
HopDuration	Time taken to change the operating radio channel
TIFS	Time between two TDMA PPDUs in the same

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	direction [87]

The MAC defines the constants defined in Table 121 that are derived from the PHY constants that are used by its access mechanisms.

Table 121 - Timing Constants Defined by the MAC derived from PHY Constants

MAC constant	Description	Definition
SIFS	Shortest possible delay between two PPDUs. A SIFS delay is used when there is no need to perform a CCA procedure before starting a transmission.	*RxPHYdelay* + *MAC_CRCdelay* + *RxTxTurnround*
SlotDuration	Time taken to perform a CCA procedure and start a transmission	*RxPHYdelay* + *CCAduration* + *MAC_CCAdelay* + *RxTxTurnround*
DIFS	Shortest possible delay between the last symbol on air of a PPDU and the first symbol of a PPDU that is part of a separate CSMA/CA MPDU sequence. This interval includes the time to recover from any prior transmission, perform a CCA procedure and start a transmission.	*SIFS* + *SlotDuration*

5.5.3.1.1 Relative values of *TxRxTurnround* and *RxTxTurnround* (Informative)

The MAC places a constraint on the relative values of *TxRxTurnround* and *RxTxTurnround*. When sending an MPDU sequence, the originating node switches between transmit and receive in order to catch any response. The recipient node must switch between receive and transmit at the same time. Therefore, the MAC requires that the PHY parameters for *TxRxTurnround* and *RxTxTurnround* shall be the same.

5.5.3.1.2 SIFS Period (informative)

The SIFS (Short Inter Frame Space) is a fundamental design parameter of the HomeRF MAC protocol. The SIFS is constrained by the PHY layer performance, and is the time it takes for the PHY layer to be ready for transmission or reception. It is the time to receive the last symbol of a PHY PDU (at the air interface), process the PPDU, turn around the transceiver and respond with the first symbol of a PPDU on the air interface. It does not include any ramp-down or ramp-up times - these are considered not to be part of the PPDU.

Because of this PHY layer constraint, the SIFS is the minimum time that can separate two independent MAC transmissions on the channel. This explains why most MAC transmissions (like TDMA slots, or data fragments) are separated by a SIFS.

5.5.3.1.3 CSMA/CA Slot Duration (informative)

The Slot Duration is constrained by the performance of the PHY layer. It is the time taken by the PHY layer to estimate the state of the channel (idle or busy) and to be ready for transmission or reception. It is the CCA time (Clear Channel Assessment) plus the SIFS time.

The CSMA/CA access mechanism uses carrier sense to avoid collisions. The Slot Duration defines when the CSMA/CA mechanism can start a transmission. Access to the medium is controlled using contention slots. [88] Nodes schedule the transmission of their MPDUs after a random number of contention slots. The Slot Duration is designed to allow a node to detect another node starting transmission in a slot before their scheduled transmission position, and thus hold off.

[87] *i.e.* the time between any two adjacent uplink TDMA PPDUs or any two adjacent downlink TDMA PPDUs.

[88] These are quite different from TDMA slots.

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5.5.3.1.4 DIFS Period (Informative)

This timing is also used by the CSMA/CA mechanism. The DIFS is one *SlotDuration* longer than a SIFS period. When the channel is free for a DIFS period, it indicates that the previous MPDU exchange is complete and other nodes may contend for the channel.

5.5.3.1.5 TIFS Period (Informative)

The TIFS period is the time between two adjacent uplink or between two adjacent downlink TDMA PPDUs. It is shorter than SIFS because it is not necessary to perform an RxTx turnround. It has to be long enough to allow the transmitting physical layer to ramp up and down, and for the receiving physical layer to complete processing of the previous PPDU and become ready to receive the next PPDU [89].

5.5.3.2 Connection Point Beacon Timing

Two forms of CP Beacon timing are defined according to whether the CP is a Class-1 CP or the CP is a Class-2 or Class-3 CP.

5.5.3.2.1 Class-1 CP Beacon Timing

The Class-1 CP transmits the first symbol of the *Dual Beacon* format PHY PDU containing a CP1 beacon just after the end of the hop. The duration of the CP1 beacon transmission is variable and depends on the length of the CP1 beacon MPDU (defined in section 5.4.16 (CP Beacon)).

The Beacon Period ends at the last symbol of the PPDU. Figure 128 illustrates these the Beacon Period Timing.

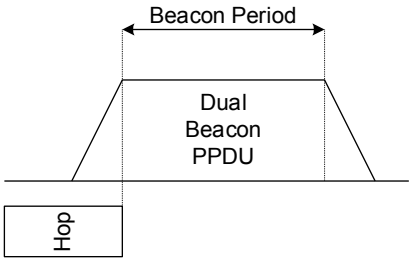


Figure 127 - Beacon Period Timing

Note that a PHY implementation can lengthen the preamble by an implementation-defined amount and start transmission early by the same amount up to a limit defined in sections 4.1.1 (PHY Data Service). Any extra preamble is considered to be part of the hop period and not part of the beacon period.

5.5.3.2.2 Class-2 or Class-3 CP Beacon Timing

The Class-2 or Class-3 CP transmits the first symbol of the *Basic Rate Single PSDU* PHY PDU containing the CP2 beacon a CP2IFS after the end of the hop. The duration of the CP2 beacon transmission is variable and depends on the length of the CP2 beacon MPDU (defined in section 5.4.16 (CP Beacon)).

The Beacon Period ends at the last symbol of the PPDU. Figure 128 illustrates these the Beacon Period Timing.

[89] This may involve opening and closing a carrier-tracking loop.

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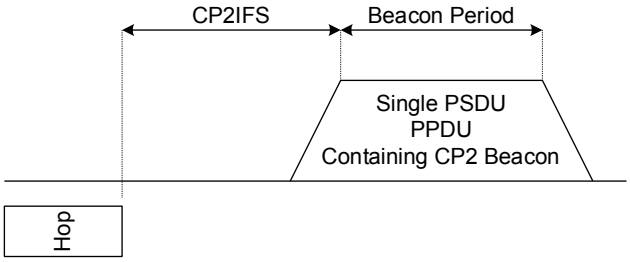


Figure 128 - Beacon Period Timing

Note that a PHY implementation can lengthen the preamble by an implementation-defined amount and start transmission early by the same amount up to a limit defined in sections 4.1.1 (PHY Data Service). This preamble may extend into and fill the CP2IFS delay, and even extend into the hop.

5.5.3.2.2.1 CP2 Beacon Timing (Informative)

The purpose of the CP2IFS delay is to relax the effective hop performance requirements on Class-2, Class-3 CPs and A-nodes to (*HopDuration + CP2IFS*). In the presence of a Class-1 CP, the start of the CP2 Beacon portion of the *Dual Beacon* format CP1 Beacon occurs after at least a CP2IFS after the end of the hop.

5.5.3.3 CFP2 Structure

CFP2 carries TDMA MPDU initial transmissions. It consists of a sequence of downlink slots followed by a sequence of uplink slots. Adjacent uplink and downlink PPDUs are separated by a TIFS. The first TDMA PPDU is separated by at least a SIFS from the previous on-air PPDU. The downlink slots are separated by a SIFS from the uplink slots. The hop interval starts immediately after the last symbol of the last TDMA PPDU.

There are at most 5 downlink slots (*nMainDown*) followed by at most 4 uplink slots *(nMainUp*). The values for *nMainDown* and *nMainUp* are derived from the signaling in the *Main TDMA Slots* field of the TDMA Beacon as defined in Table 122.

Table 122 - Definition of Main Downlink and Uplink Sizes

Name	Definition
nMainDown	Number of main downlink slots present. Derived from the TDMA Beacon by counting the number of main slots with a non-zero connection ID.
nMainUp	Number of main uplink slots present. Derived from the TDMA Beacon by counting the number of main slots with a connection ID that is valid for a TDMA connection. See section 5.8.3 (Connection ID) for a definition of connection IDs.

nMainDown and *nMainUp* are constrained so that either:

- *nMainDown* = *nMainUp*, or
- *nMainDown* = (*nMainUp*+1)

Main TDMA downlink and uplink slots used by a TDMA connection are implicitly connected - the uplink slot and downlink slot have the same number. The highest-numbered used downlink slot can be allocated to the ICBS channel. In that case, there is no matching uplink for that slot number.

The slots are numbered to the left from 1 closest to the hop.

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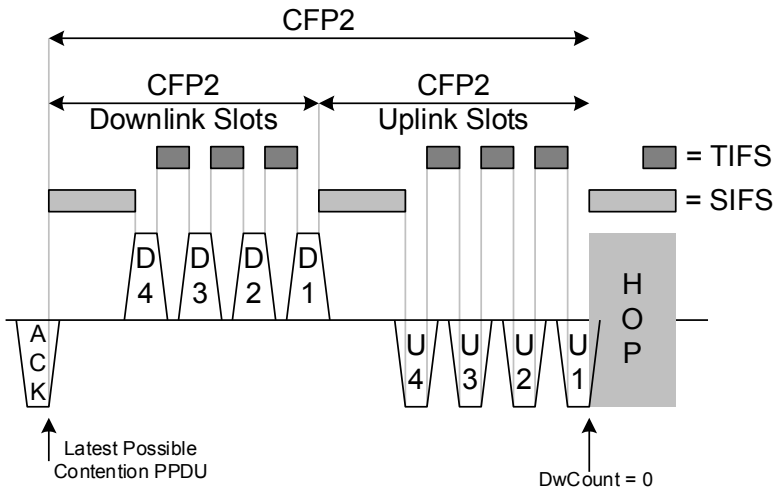


Figure 129 - Example CFP2 Structure (nMain = 4)

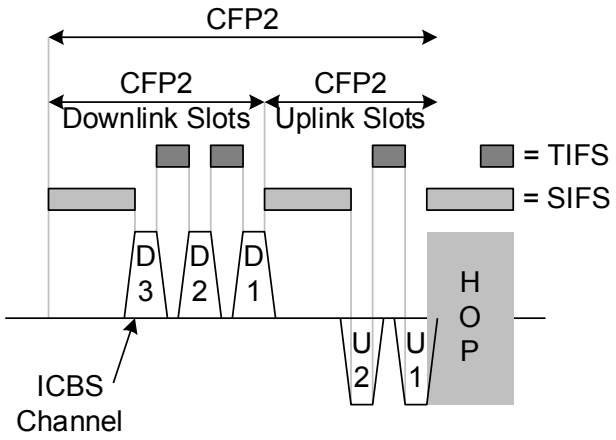


Figure 130 - Example CFP2 Structure (nMain = 2, with ICBS channel)

The duration of CFP2 is defined to be the duration of the CFP2 downlink plus the duration of the CFP2 uplink. These are defined in Table 123 and Table 124 where *MainDuration* is the duration of the main TDMA MPDU.

Table 123 - CFP1 Downlink Duration

Condition	**CFP2 Downlink Duration**
nMainDown = 0	zero
nMainDown > 0	$nMainDown \times MainDuration + (nMainDown - 1) \times TIFS + SIFS$

Table 124 - CFP1 Uplink Duration

Condition	**CFP2 Uplink Duration**
nMainUp = 0	zero
nMainUp > 0	$nMainUp \times MainDuration + (nMainUp - 1) \times TIFS + SIFS$

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5.5.3.4 CFP1 Structure

CFP1 carries TDMA MPDU retry transmissions. It consists of a sequence of downlink slots followed by a sequence of uplink slots. Adjacent uplink and downlink PPDUs are separated by a TIFS. The first TDMA PPDU is separated by a SIFS from the end of the Beacon period. The downlink slots are separated by a SIFS from the uplink slots. The contention period starts immediately following the last symbol of the last uplink TDMA PPDU.

The slots are numbered to the right from 1 closest to the Beacon period. The number of uplink (*nUp*) and downlink (*nDown*) slots can be different, and either or both can be zero.

nUp is defined to be the number of non-zero entries in the TDMA Beacon's *Uplink Retry Slots* field.

nDown is defined to be the number of non-zero entries in the TDMA Beacon's *Downlink Retry Slots* field.

An I-node shall determine the position of the start of CFP1 from the *CFP1 Offset* field of the TDMA Beacon. [90]

An A-node shall consider the start of CFP1 to follow the last symbol of the CP2 Beacon PPDU. [91]

An AI-node shall use one of these two methods to determine the start of CFP1.

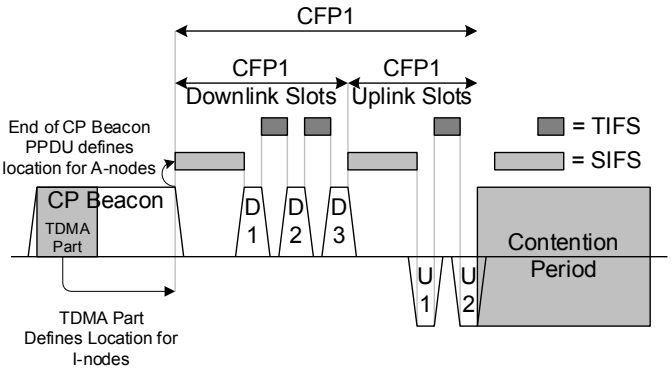


Figure 131 - Example CFP1 Structure (nDown=3, nUp=2)

The duration of CFP1 is defined to be the duration of the CFP1 downlink plus the duration of the CFP1 uplink. These are defined in Table 125 and Table 126. Note that the duration of the retry TDMA MPDU (*RetryDuration*, derived in 16.3 (MAC Derived Values (Informative))) is shorter than the main T DMA MPDU, and so the retry slot durations are shorter than the main slot durations.

Table 125 - CFP1 Downlink Duration

Condition	CFP1 Downlink Duration
nDown = 0	Zero
nDown > 0	$nDown \times RetryDuration + (nDown - 1) \times TIFS + SIFS$

Table 126 - CFP1 Uplink Duration

Condition	CFP1 Uplink Duration
nUp = 0	Zero
nUp > 0	$nUp \times RetryDuration + (nUp - 1) \times TIFS + SIFS$

[90] This is because the I-node is not capable of receiving the non-TDMA part of the CP Beacon, and cannot determine its last symbol.

[91] This is because the A-node is not capable of receiving the TDMA part of the CP Beacon.

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5.5.3.5 Permitted CFP Sizes

CFP2 shall contain 0 to 5 downlink slots (*nMainDown*) and 0 to 4 uplink slots (*nMainUp*).

CFP1 shall contain 0 to *nMainUp* downlink slots, and 0 to *nMainUp* uplink slots.

The term *Emergency Case* is defined to mean a subframe in which the CFP1 contains 4 downlink and 4 uplink slots.

In the emergency case, any ICBS channel is temporarily suspended. In the emergency case, there is only room for the mandatory variable-length fields in the CP Beacon.

The CP can limit the number of CFP1 slots is uses to allow a longer CP Beacon to be transmitted.

5.5.3.6 Contention Period Timing

In a managed network, the contention period starts immediately after CFP1 (subframes present) or the beacon period (subframes not present).

The contention period ends immediately before CFP2 (subframes present), or at the scheduled time to perform the Hop (subframes not present).

The contention period includes an initial DIFS for MPDUs transmitted using the CSMA/CA mechanism. [92] PPDUs can be transmitted during contention using the CSMA/CA mechanism right up to the end of the contention period.

In an ad-hoc network, the contention period occupies the entire superframe dwell period.

5.5.3.7 Detailed Subframe structure (Informative)

The timing and structure of the contention-free and contention periods is defined elsewhere. Figure 132 summarizes the timing of a subframe, including that of the contention-free and contention periods.

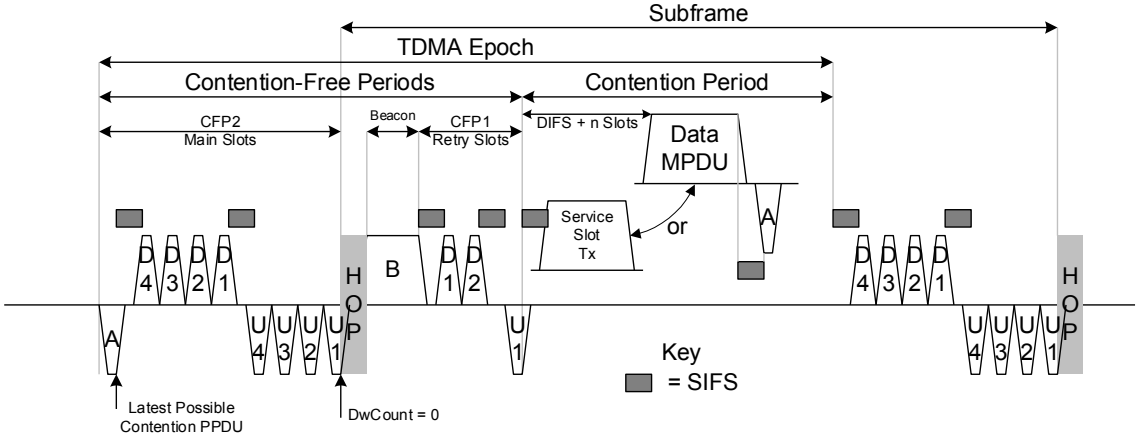


Figure 132 - Detailed Subframe Timing

5.6 MPDU Exchange Procedures

5.6.1 MPDU Rx

This section defines procedures that shall be performed by a node in order to receive MPDUs.

5.6.1.1 MPDU Rx Architecture

Figure 133 shows the data-flow architecture of the MPDU Rx process. The processes identified in this figure are described in the sections below.

[92] Thereby giving priority to Service Slot transmissions because they use an initial SIFS.

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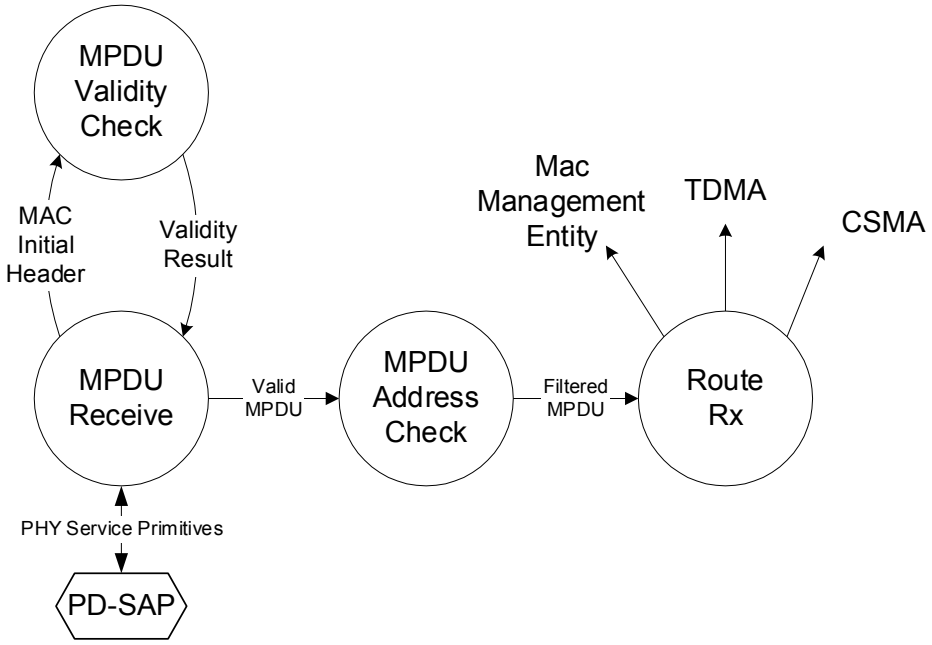


Figure 133 - MPDU Rx Architecture

5.6.1.2 MPDU Receive Process

The MPDU Receive process uses the PHY PD-SAP service primitives to receive MPDUs from the PHY. It discards MPDUs that are not valid, and passes valid MPDUs on to the *MPDU Address Check* process. [93]

5.6.1.2.1 MPDU Receive States

The MPDU receive process is specified by a state machine with the states described in Table 127.

Table 127 - States of the MPDU Receive Process

State	Description
Idle	Not receiving (The initial state of the state machine)
Preamble	The PHY has emitted a PD_RX_START indication
Receiving PSDU1	The PHY has emitted a PD_RX_MAC_INITIAL_HEADER indication. Pending completion of PSDU1
Skipping PSDU2	Pending completion of PSDU2 for an unsupported modulation
Receiving PSDU2	Pending completion of PSDU2
Time Reservation Waiting Start	Waiting for the start of a PPDU within a Time Reservation
Time Reservation Preamble	The PHY has emitted a PD_RX_START indication within a Time Reservation
Time Reservation	The PHY has emitted a

[93] The MPDU Receive Process is not responsible for monitoring carrier-sense, but does generate events used by the CSMA/CA carrier-sense state machine.

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Receiving PSDU1	PD_RX_MAC_INITIAL_HEADER indication. Pending completion of PSDU1 within a Time Reservation

The *Receiving PSDU2* state (and associated transitions) is only supported by nodes that support *Dual PSDU* operation. The "Skipping PSDU2" state shall be supported by all nodes, including those that support the highest modulation type defined in this specification [94]

The Time Reservation states are only supported by nodes that support the *Time Reservation* mechanism (see Table 57). A node can support the *Time Reservation* mechanism but may not support all or any of the MPDU formats or modulation types used within a time reservation. A node that does not support any of the MPDU formats or modulation types used within a time reservation should not have been addressed by the Time Reservation Establish MPDU. In any case, this node will not participate in the time reservation but will simply avoid contending during the time reservation. A node that has been addressed by the Time Reservation Establish MPDU will expect to receive MPDU formats and modulation types that are part of its capabilities (see Table 96). The Time Reservation states indicate that multiple MPDUs within a time reservation are being received or that a non-addressed node is avoiding contending. These states affect the Carrier Sense state machine (5.7.8) and the PHY Receive state machine (4.4.4). The Carrier Sense state machine is kept in the *Rx* state during the time reservation. If the node has been addressed, it will keep the PHY Receive state machine in its *High Rate* states during the time reservation. If the node has not been addressed, it will trigger the PHY Receive state machine back to its*Idle* state.

An AI-node will need additional states in its receive state machine in order to receive a *Dual Beacon* format PPDU. These are not described in this document.

Table 128 below shows the mapping between the MPDU Receive states and the states of the Carrier Sense state machine and the PHY Receive state machine.

Table 128 - MPDU Receive states mapping to Carrier Sense and PHY Receive states

MPDU Receive state	Carrier Sense state(s)	PHY Receive state(s)
Idle	Not In Contention	Idle
Preamble	Rx	Pending SFD, CSMA Pending MIH
Receiving PSDU1	Rx	CSMA Receiving PSDU1, Pending EFD1
Skipping PSDU2	Rx	Skipping PSDU2
Receiving PSDU2	Rx	Pending SFD2, Receiving PSDU2
Time Reservation Waiting Start	Rx	Idle, High Rate Idle
Time Reservation Preamble	Rx	High Rate Pending SFD, High Rate Pending MIH
Time Reservation Receiving PSDU1	Rx	High Rate Receiving PSDU1

[94] This permits these nodes to interwork with later revisions of this specification that define support for other modulation types.

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5.6.1.2.2 MPDU Receive Events

The events that drive the process are defined in Table 129.

Table 129 - Events and Conditions that drive the MPDU Receive Process

Event / Condition	Definition
Rx Starts	A PD_RX_START indication has been received
MIH Indication	A PD_RX_MAC_INITIAL_HEADER indication has been received
PSDU1 Indication	A PD_RX_PSDU1 indication has been received
PSDU2 Indication	A PD_RX_PSDU2 indication has been received
End Indication	A PD_RX_END indication has been received
Header Valid	The MPDU Validity Check process (defined in section 5.6.1.3 (MPDU Valid Check) does not reject the MPDU
PSDU2 Expected	Based on the received format and MAC initial header, a PSDU2 is expected.
Bad Modulation	The MPDU is using a modulation type that is not supported by this node (see Table 75 and Table 76)
Unsupported Atomic MPDU Sequence format	The Atomic MPDU Sequence format is not supported by this node
Time Reservation establish	A *Time Reservation Establish* MPDU for the current *NWID* has been received
Time Reservation Destination	A *Time Reservation Establish* MPDU has been received specifying the current node as the destination of the time reservation (Destination Address)
Time Reservation expired	The time reservation has expired
Time Reservation cancelled	A *Time Reservation Cancel* MPDU has been received
Tx ACK in progress	The Tx ACK part of an atomic MPDU sequence is currently being sent. This condition is set by the CSDU Receive process
Notes: ! = logical negation	

5.6.1.2.3 MPDU Receive State Transition Diagram

The state transition diagram is shown in Figure 134.

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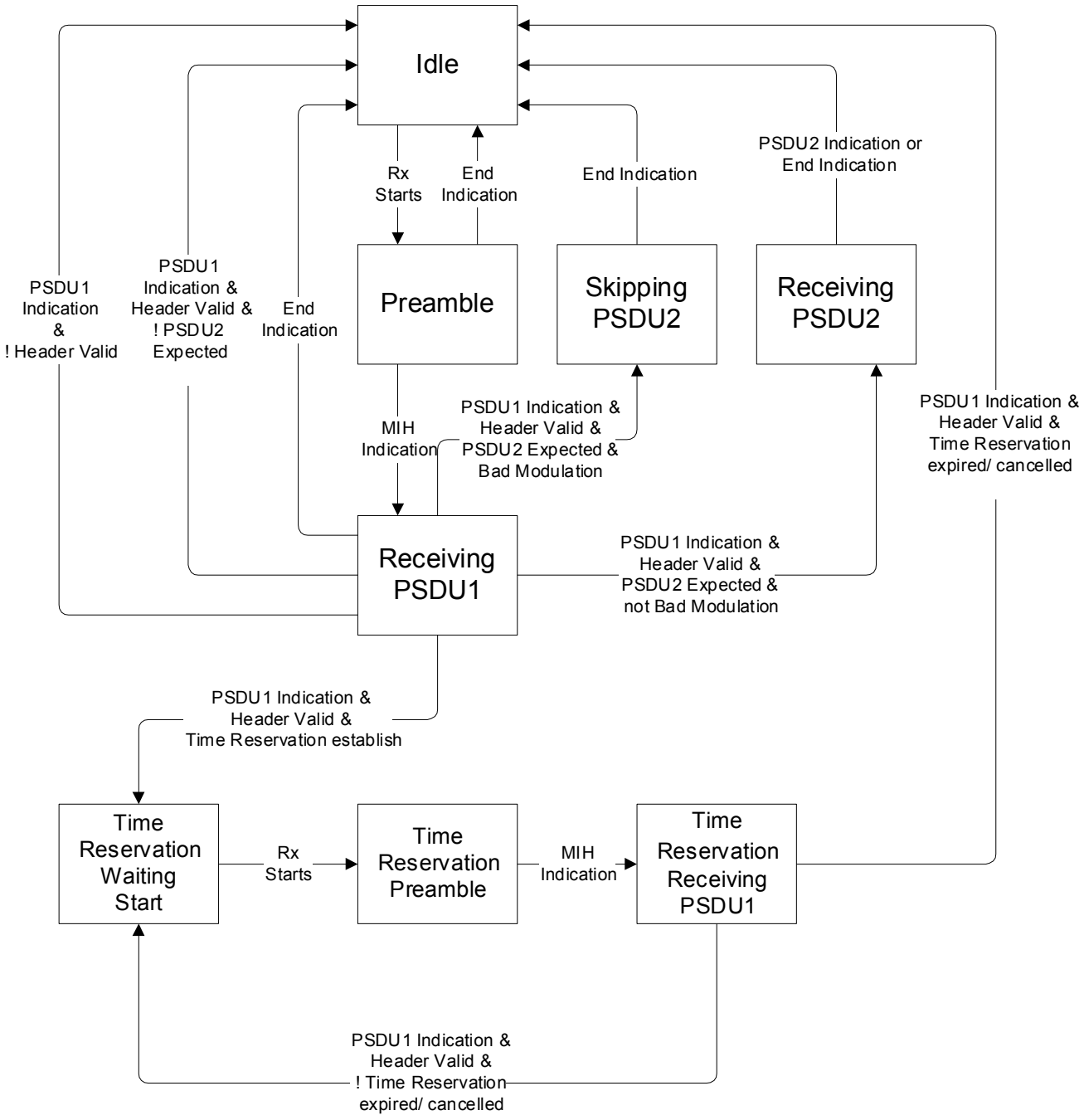


Figure 134 - MPDU Receive Process State Transition Diagram

The operation of the state machine is defined according to the MPDU receive state in the sections 5.6.1.2 (MPDU Receive Process) to 5.6.1.2.7 (Skipping PSDU2).

5.6.1.2.4 Idle

Event	Action	Next State
Rx Starts	Generate a *Rx Starts* event to the Carrier Sense state machine	Preamble

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5.6.1.2.5 Preamble

Event	Action	Next State
MIH Indication	Decode the format (if present) and MPDU initial header to determine the size of the PSDU1 and PSDU2 parts, and the Modulation Type. Issue a PD_RX_MAC_INITIAL_HEADER response containing the PPDU parameters	Receiving PSDU1
End Indication	Generate a *Rx Halts* event to the Carrier Sense state machine	Idle

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5.6.1.2.6 Receiving PSDU1

Event	Action	Next State
End Indication	Generate a *Rx Halts* event to the Carrier Sense state machine	Idle
PSDU1 Indication & !Header Valid	Issue a PD_RX_PSDU1 response containing *Bad Header* status Generate a *Rx Halts* event to the Carrier Sense state machine	Idle
PSDU1 Indication & Header Valid & !PSDU2 Expected & !Time Reservation establish	Pass the MPDU to the *MPDU Address Check* process. Issue a PD_RX_PSDU1 response containing *Completed* status Generate a *Rx Halts* event to the Carrier Sense state machine	Idle
PSDU1 Indication & Header Valid & PSDU2 Expected & not Bad Modulation	Issue a PD_RX_PSDU1 response containing *Continue* status	Receiving PSDU2
PSDU1 Indication & Header Valid & PSDU2 Expected & Bad Modulation	Issue a PD_RX_PSDU1 response containing *Skip PSDU2* status	Skipping PSDU2
PSDU1 Indication & Header Valid & Time Reservation establish & (!Time Reservation DA or Bad Modulation or Unsupported Atomic MPDU Sequence format)	Issue a PM_SET_CHANNEL request w. *channel* set to calculated *high rate* value (see Equation 9) Issue a PD_RX_PSDU1 response containing *Completed* status Start the *Time Reservation* timer Extract the *Time Reserved Atomic MPDU Sequence Format* field from the *Time Reservation Establish* MPDU	Time Reservation Waiting Start
PSDU1 Indication & Header Valid & Time Reservation establish & (Time Reservation Destination & !Bad Modulation & !Unsupported Atomic MPDU Sequence format)	Issue a PM_SET_CHANNEL request w. *channel* set to calculated *high rate* value (see Equation 9) Issue a PD_RX_PSDU1 response containing *Set PPDU Attributes* status w. *Format* and *Modulation Type* set to values in *Time Reservation Establish* MPDU Start the *Time Reservation* timer	*Time Reservation Waiting Start*

5.6.1.2.7 Skipping PSDU2

Event	Action	Next State

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End Indication	Generate a *Rx Halts* event to the Carrier Sense state machine	Idle

5.6.1.2.8 Receiving PSDU2

Event	Action	Next State
End Indication	Generate a *Rx Halts* event to the Carrier Sense state machine	Idle
PSDU2 Indication & payload CRC OK	Pass the MPDU to the *MPDU Address Check* process. Generate a *Rx Halts* event to the Carrier Sense state machine	Idle
PSDU2 Indication & !payload CRC OK	Generate a *Rx Halts* event to the Carrier Sense state machine	Idle

5.6.1.2.9 Time Reservation Waiting Start

Event	Action	Next State
Rx Starts		Time Reservation Preamble
Time Reservation Expired & !Time Reservation Destination	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Generate a *Rx Halts* event to the Carrier Sense state machine	Idle
Time Reservation Expired & Time Reservation Destination & !Tx ACK in progress	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Issue a PD_RX_SET_PPDU_ATTRIBUTES request w. *Format* and *Modulation Type* values set to defaults Generate a *Rx Halts* event to the Carrier Sense state machine	Idle

5.6.1.2.10 Time Reservation Preamble

Event	Action	Next State

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End Indication		Time Reservation Waiting Start
MIH Indication	Decode the MPDU initial header to determine the size of the PSDU and the Modulation Type. Issue a PD_RX_MAC_INITIAL_HEADER response containing the PPDU parameters	Time Reservation Receiving PSDU1
Time Reservation Expired & !Time Reservation Destination	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Generate a *Rx Halts* event to the Carrier Sense state machine	Idle

5.6.1.2.11 Time Reservation Receiving PSDU1

Event	**Action**	**Next State**
End Indication		Time Reservation Waiting Start
PSDU1 Indication & ! Header Valid	Issue a PD_RX_PSDU1 response containing *Bad Header* status	Time Reservation Waiting Start
PSDU1 Indication & Header Valid & Time Reservation cancelled	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Issue a PD_RX_PSDU1 response containing *Set PPDU Attributes* status w. *Format* and *Modulation Type* set to defaults Generate a *Rx Halts* event to the Carrier Sense state machine Cancel the *Time Rservation* timer	Idle
PSDU1 Indication & Header Valid & (!Time Reservation cancelled & !Time Reservation Destination)	Discard MPDU Issue a PD_RX_PSDU1 response containing *Completed* status	Time Reservation Waiting Start
PSDU1 Indication & Header Valid & (!Time Reservation cancelled & Time Reservation Destination)	Pass the MPDU to the *MPDU Address Check* process. Issue a PD_RX_PSDU1 response containing *Set PPDU Attributes* status w. *Format* and *Modulation Type* set to values in *Time Reservation Establish* MPDU	Time Reservation Waiting Start

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5.6.1.3 MPDU Valid Check

This process determines, based on the contents of the format and complete MPDU header, whether an MPDU is valid or not. A non-TDMA MPDU is not valid if any of the conditions for rejection defined in Table 130 apply to it.

Table 130 - Conditions for Rejection of a Received non-TDMA MPDU based on MPDU Validity

Condition for Rejection
Invalid PSDU1 CRC
The *Modulation Type* is undefined
A *Source Address* with the *Individual/Group* bit set
A *MPDU Type that* is not listed in 5.7.6 (CSMA/CA MPDU Types).
Invalid MPDU length (out of range for the MPDU type)

A TDMA MPDU shall be rejected if its type is TDMA Beacon, and the length of the MPDU signaled by the TDMA Beacon Length field outside the range permitted by 5.4.16.4 (TDMA Beacon Structure).

5.6.1.4 MPDU Address Check

This process determines whether an MPDU should be rejected based on the destination address fields contained within the MPDU header and the network synchronization state.

When the network synchronization state is not in the *Managed* or *Ad-hoc* state the process shall accept all MPDUs. [95]

Time Reservation MPDUs contain *Time Reservation* information that is processed by all CSMA/CA nodes on the network and that is only utilized by the MPDU Receive state machine. These MPDUs are not forwarded on to this process.

When the network synchronization state is in the *Managed* or *Ad-hoc* state the process shall reject an MPDU if it meets any of the conditions defined in Table 131. [96]

Table 131 - Conditions for Rejection of a Received MPDU based on Addresses

MPDU Header Type	**Condition for Rejection**
Any	NWID that does not match the node's current NWID
2 & 4	A unicast destination address that does not match the node's MAC address
1	A connection ID does not match that of an active TDMA connection at this node

MPDUs that are rejected shall be discarded. MPDUs that are accepted shall be passed on to the *Route Rx* process.

5.6.1.5 Route Rx

This process routes incoming MPDUs according to the current time position within the superframe as defined in section 5.5.3 (Superframe Structure) and the network synchronization state defined in section 5.16.4 (Synchronization State Machine).

When the network synchronization state is not in the *Managed* or *Ad-hoc* state the process shall pass all MPDUs on to the MAC management entity.

[95] These all end up routed to the Management Entity.

[96] The CSMA/CA receive process defines additional rejection reasons for DATA MPDUs.

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When the network synchronization state is in the *Managed* or *Ad-hoc* state the process shall pass on a received MPDU to the destination specified in Table 132 based upon time the MPDU was received.

Table 132 - Destination of Rx Route for MPDU

Time Position within Superframe	Destination for MPDU
Beacon Period	CP Beacon Process
CFP1 or CFP2	TDMA Process
Otherwise [97]	CSMA/CA Access Mechanism

5.6.1.6 Opportunities to Save Power During Receive

The behavior described in section 5.6.1.1 (MPDU Rx Architecture) to 5.6.1.5 (Route Rx) and in the PHY service description in section 4.1.1 (PHY Data Service) assumes that the node fully receives an MPDU regardless of its address and then discards it if it is rejected by the *MPDU Address Check*. This behavior is logically correct, but misses an implementation opportunity to save power during the reception of unwanted MPDUs. The procedures defined in this section can be used by a node to save power. An implementation of these procedures requires additions to the PHY receive state machine (4.4.4 (PHY Receive State Machine)), the MPDU Rx State machine (5.6.1.2 (MPDU Receive Process)) and the PHY service interface (4.1 (PHY Layer Services)).

It must be noted that a node that has recognized a *Time Reservation Establish* MPDU must remain active during the time reservation and cannot operate the power saving mechanism described here. This is due to the fact that a *Time Reservation Cancel* MPDU might be sent during this time.

A node that has received a *MAC initial header* can, in part, determine from that header whether it can skip the MPDU. An implementation can lengthen the *MAC initial header* to include the MPDU destination address field and thereby provide a better address filter.

A node that has decided to skip an MPDU, and that supports the modulation used in the PPDU, can disable the demodulator for a period of time based on the received *MPDU Length* and *Modulation Type* fields, assuming no PHY bitstuffing. The node should also allow for the synchronization length of the PHY CSMA scrambler. The node shall then enable the demodulator and look for both an EFD and loss of carrier using the procedure defined in 4.4.4 (PHY Receive State Machine). The first to occur determines the end of the PPDU.

A node that has decided to skip an MPDU, and that does not support the modulation used in the PPDU, can disable the demodulator for a period of time based on the received *MPDU Length* and *Modulation Type* fields, assuming no PHY bitstuffing. This is possible since the modulation types used outside of a time reservation are a direct factor of the basic modulation type. The node shall then look for loss of carrier using the procedure defined in 4.4.4 (PHY Receive State Machine).

The MPDU Receive state of an implementation that supports this behavior shall not be in the *Idle* state until the end of the PPDU has been determined. [98]

5.6.1.7 Effect of Unsupported *Dual PSDU* Operation (Informative)

A node that does not support *Dual PSDU* operation and that receives a *Dual PSDU* MPDU will behave as described in this section.

The PHY will deliver PSDU1 correctly to the MPDU Rx process that will then reject the MPDU based on the modulation. The MAC causes the PHY to look for the end of the PSDU2 based on carrier-sense. At the end of the PPDU, the PHY will emit a PD_RX_END.

The node can save power during reception of the unwanted PSDU as described in section 5.6.1.6 (Opportunities to Save Power During Receive), provided that it understands the MPDU modulation type field.

The node cannot identify precisely the last symbol of the PSDU, but can only identify the end of the PHY Off-ramp with a granularity of one CCA. If the transmitter transmits an extended Off-ramp, the detection of the end if the PPDU is delayed compared to LR 4-FSK-capable nodes.

---

[97] This entry is for MPDUs transmitted using either the CSMA/CA or the Service Slot Access Mechanisms. The receiver makes no distinction between these two access mechanisms.

[98] This causes the Carrier Sense state machine to stay in its *Rx* state during the entire PPDU.

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The effect of this delay is to lose slot alignment between nodes that correctly received the PPDU and nodes that did not. Any subsequent contention between these nodes will suffer a higher probability of collision than between nodes that have maintained slot alignment.

A relative misalignment of size *CCAtime* can double the collision rate, as a transmission started in one slot period can collide with unaligned slot periods before and after it.

5.6.1.8 Effect of Unsupported Time Reservation (Informative)

A node that does not support a *Time Reservation* MPDU that it receives will behave as described in this section.

The PHY will deliver PSDU1 correctly to the MPDU Rx process that will then reject the MPDU based on the *Time Reservation* MPDU type. The MAC causes the PHY to look for the next PPDU by responding to the current MPDU with a *Bad Header* status.

No power saving operation is permissible due to the fact that the node is unable to understand the duration of the time reservation.

It is conceivable that the carrier-sense mechanism will not function properly for the types of modulation types used within a time reservation resulting in a potential increased collision rate during the time reservation. Since all time reservations are initiated via the *Time Reservation Establish* MPDUs transmitted at the basic modulation type, the carrier sense mechanism should operate properly once the time reservation has expired.

5.6.2 MPDU Transmit Process

The MPDU Transmit process passes MPDU transmit requests downward as a PD_TX_DATA request.

This process exports the notional service interface defined in section 5.6.2.1.

This process shall calculate the PSDU1 CRC and any PSDU2 CRC for non-TDMA formats using the procedure defined in 5.4.5 (MPDU CRCs).

The process sets the parameters of the PD_TX_DATA request as defined in Table 133.

Table 133 - PD_TX_DATA Parameter Settings

PD_TX_DATA Parameter	**TDMA Format**	**Basic Rate Single PSDU Format**	**High Rate Single PSDU Format**	**Dual PSDU Format**
PSDU 1	The MPDU header followed by the MPDU payload	The MPDU header, MPDU payload and the CRC	The MPDU header, MPDU payload and the CRC	The MPDU header and header CRC
PPDU Format	TDMA PPDU	Basic Rate Single PSDU	Extended Preamble High Rate Single PSDU	Dual PSDU
PSDU 2	Not present	Not present	Not present	The MPDU payload followed by the payload CRC
Modulation Type	Not present	Not present	The high-rate modulation type	The requested *Payload Modulation Type*
Tx Antenna	The requested *Tx Antenna*			

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5.6.2.1 MPDU Tx Service Interface

Primitive	MPDU_TX_DATA			
Description	Bottom of MAC layer data service			
Parameters	**Req**			
PSDU Format	F			
MPDU Header	M			
Payload	M			
Modulation Type	H			
Tx Antenna	D			
Notes:	F - Present if, and only if, more than on PSDU format is supported M - Mandatory H - Present if, and only if, a different modulation type than the basic modulation type is supported and being utilized D - Present if, and only if, Transmit antenna diversity is supported			

5.7 CSMA/CA Access Mechanism

This section describes procedures associated with the carrier-sense multiple-access (collision avoidance) access mechanism of the HomeRF MAC.

5.7.1 Introduction (Informative)

The CSMA/CA access mechanism is used during the contention period of the superframe.

The CSMA/CA access mechanism provides two data services, namely, the Aysnchronous Data Service and the Priority Aysnchronous Data Service.

In the case of the Aysnchronous Data Service, the purpose of the CSMA/CA access mechanism is to distribute access to the medium in an uncoordinated way as fairly as possible between A-nodes that have MPDUs ready to transmit.

In the case of the Priority Aysnchronous Data Service, the purpose of the CSMA/CA access mechanism is to grant a priority access to the medium for S-nodes based on a priority access value determined by the CP.

The CSMA/CA protocol attempts to avoid collision by sensing transmissions on the radio medium and only starting transmission when there is no such activity. It is based on the carrier sense [99] mechanism provided by the PHY layer and uses slotted contention

CSMA/CA SDUs are transmitted as one or more DATA MPDUs. Unicast MPDUs are acknowledged. Unacknowledged unicast MPDU transmissions are retried, thereby achieving an increase in reliability over the PHY DATA service.

The CSMA/CA Access Mechanism supports a *Multi-rate data service*. This service provides for the delivery of CSDUs using LR 4-FSK modulation via the *Dual PSDU* PPDU format. This service also provides for the delivery of CSDUs using the *high-rate* modulation types supported via the *Time Reservation* mechanism and the *Extended Preamble Single PSDU* PPDU format.

The CSMA/CA Access Mechanism supports a *Time Reservation* mechanism that provides for the delivery of multiple CSDUs to be effected within an optimized CSMA/CA access method. This mechanism allows multiple CSDUs to be constructed into an associated multiple CSDU MPDU sequence that minimizes the overhead contending for the media which is part of the CSMA/CA multiple access. The *Time Reservation* mechanism, when invoked, will signal to all nodes a period of time reservation that is to be contention free for the nodes associated with that time reservation.

[99] Carrier sense gives an indication of the state of the channel, idle or busy.

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A fast, unacknowledged CSDU delivery service is provided by the *Fast Unacknowledged Service Mechanism*. This service provides for the fast, but unreliable, delivery of small CSMA/CA SDUs. This service is provided by the tunneling of singleton CSDUs as the payload of ACK MPDUs. These ACK MPDUs are not acknowledged by the MAC at the receiving end.

Refer also to B.3 (CSMA/CA Terminology (Informative)) for terminology relating to the CSMA/CA access mechanism.

5.7.2 CSMA/CA Architecture

Figure 135 shows the architecture of the CSMA/CA Channel Access Mechanism that will be used to define its operation.

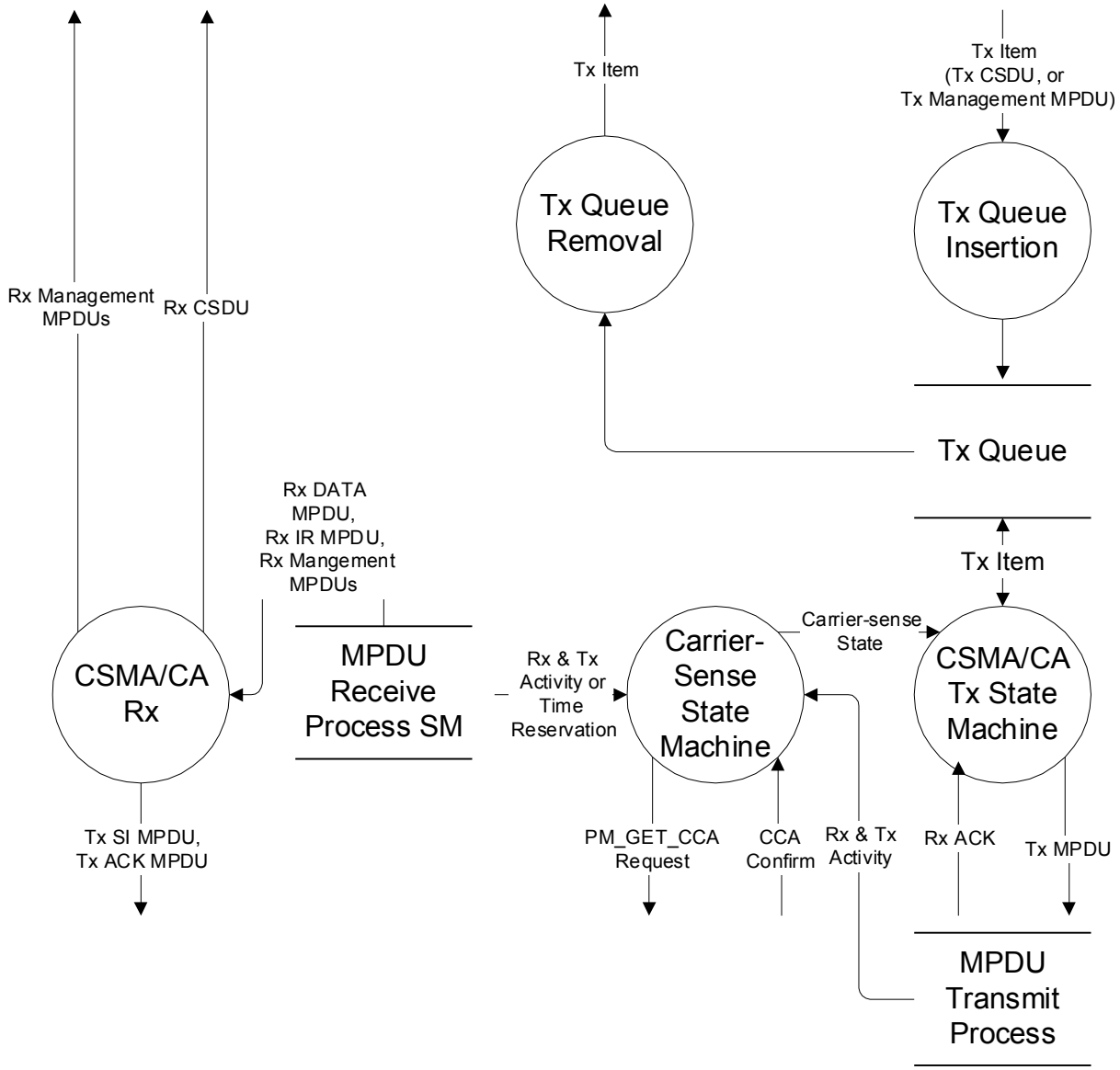


Figure 135 - CSMA/CA Channel Access Mechanism Architecture

The *Tx Queue* holds a number of *Tx Items*. Types of *Tx Items* are defined in Table 134.

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Table 134 - Tx Item Types

Tx Item Type	Definition
Management MPDU	Holds just the information present in the management MPDU
CSDU	Holds the CSDU DATA request service parameters (see section 5.7.3.1 (CSMA_CA_DATA Primitive)) and any CSDU fragmentation state variables (see section 5.7.11.2.1 (CSDU Fragmentation State)).

The functions of these processes are described in Table 135.

Table 135 - CSMA/CA Procedures and their Responsibilities

Procedure	Responsible For
CSMA/CA Rx	Reassembly of fragmented CSDUs Transmission of ACK MPDUs with or without tunneled singleton CSDUs as payload. Transmission of fast-response SI MPDUs (see section 5.7.12.4 (Fast SI Response))
Carrier-sense State Machine	Monitoring Rx and Tx activity Performing CCA requests at the right times. Time Reservation is treated as Rx activity
CSMA/CA Transmit State Machine	Fragmentation of CSDUs Transmission of MPDU sequences Transmission of *Time Reservation* MPDUs Reception of ACK MPDUs with or without tunneled CSDUs as payload, and operation of ACK reception timeout
Tx Queue Removal	Removal of Tx Items from the Tx Queue that have started or not started transmission
Tx Queue Insertion	Insertion of Tx items (Management MPDUs or CSDU MPDUs) into the Tx Queue

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5.7.3 CSMA/CA Service

The CSMA/CA access mechanism supports the transport of CSDUs, used by the MD-SAP services to provide the asynchronous data service and used by the MS-SAP services to provide the Priority Asynchronous Data Service. It also provides for the exchange of management frames and Time Reservation MPDUs.

5.7.3.1 CSMA_CA_DATA Primitive

Primitive	CSMA_CA_DATA			
Description	This primitive transports CSDUs of the asynchronous connectionless data service.			
Parameters	**Req**	**Conf**	**Ind**	
DA	M		M	
SA	CP		M	
MPS Relay	CP			
CSN	D		D	
Compressed	C		C	
Encrypted	E		E	
Bridged	M		M	
CSDU	M		M	
Modulation	O			
Fast Unacknowledged Service	O			
SID	MS		MS	
Status		M		
Notes:	CP - CP only [100] M – Mandatory MS – Mandatory for streaming session CSDUs O - Optional D - Present if duplicate removal is supported and only for unicast destination addresses C - Present if compression is supported E - Present if encryption is supported			

The *DA* parameter is the destination MAC address. It can be either a unicast or a multicast address.

The *SA* parameter is the source MAC address, and can be only a unicast address. The *MPS Relay* field indicates that this CSDU is being transmitted by the CP using the multicast power-saving support procedures defined in 5.18.8.3 (CP Multicast Power-Management Service).

The *CSN* (CSDU Sequence Number) is an optional transported attribute of this service. It is defined in section 5.4.4.14.3 (CSN / FragSN Field). Section 5.12.7 (CSDU Numbering and Duplicate Removal) describes how this is used to remove duplicates.

[100] Will only be different from the CP's MAC address when relaying a multicast MSDU

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The *Compressed*, *Encrypted* and *Bridged* flags are transported attributes of this service. These flags do not affect the operation of the CSMA_CA_DATA service in any way; they are merely transported by the data service from local request to peer indication. Section 5.12 (MD-SAP Service) describes how these flags are used by the MD-SAP service.

The optional *Modulation* parameter indicates the modulation type that is to be used to transmit the CSDU. Basic modulation type is the default. The operation of the CSDU transmit procedures can override this setting because of DATA MPDU transmit failures.

The optional *Fast Unacknowledged Service* parameter indicates that the CSDU is a singleton CSDU that can be sent using the *Fast Unacknowledged Service Mechanism*. The *Fast Unacknowledged Service Mechanism* sends the CSDU as a payload tunneled onto an ACK MPDU.

The SID parameter indicates the stream session that the CSDU is associated with.

The *Status* parameter is one of the following: *success* or *failure*.

5.7.3.2 CSMA_CA_MANAGEMENT Primitive

Primitive	CSMA_CA_MANAGEMENT			
Description	This primitive transports management MPDUs during the contention period			
Parameters	**Req**	**Conf**	**Ind**	
MPDU	M		M	
Notes:	M – Mandatory			

5.7.3.3 Tx Queue Management Primitives

This primitive enables an MD-SAP service that is operating the power-supporter procedures defined in section 5.18.7.4 (Unicast Power-Supporting Node) to remove CSDUs from the Tx Queue. The removed CSDUs may be re-queued using the CSMA_CA_DATA request.

A CSDU that has been on the Tx Queue can either:

- Not have been transmitted at all
- Have been transmitted partially [101]

A CSDU shall always be returned as the entire CSDU regardless of whether it has been transmitted at all. [102] [103] [104]

[101] *i.e.* one or more fragments of a fragmented CSDU have been transmitted

[102] So that when it is re-submitted using a CSMA_CA_DATA request, any initial fragments that had been transmitted will be resent.

[103] Note, that as far as the CSMA/CA transmit process is concerned, this is a new CSDU. The MPDUs transmitted for a retransmitted CSDU need not have the same fragment size or modulation level as the originals.

[104] The reason for this behavior is that, while the CSDU is held by the MD-SAP services pending operation of the power-supporting procedures, any initial fragments received at the destination node might be discarded following the operation of the *CSDUtimer* associated with the incompletely-reassembled CSDU.

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Primitive	CSMA_CA_GET_TXCSDU			
Description	This primitive removes the earliest CSDU for a specified unicast destination address from the Tx Queue			
Parameters	**Req**	**Conf**		
Destination Address	M			
CSN		D		
Compressed		C		
Encrypted		E		
CSDU		M		
Status		M		
Notes:	M - Mandatory D - Present if duplicate removal is supported C - Present if compression is supported E - Present if encryption is supported			

The *Destination Address* is the MAC address of the node for which Tx Items are to be retrieved.

The *CSN, Compressed*, *Encrypted* and *CSDU* parameters correspond with the values specified to an earlier CSMA_CA_DATA request.

The *Status* parameter takes one of the following values: *Success, NoSuchCSDU.* The latter value is returned if no CSDU exists for the specified destination address.

5.7.4 Contention Period Management

The superframe structure described in section 5.5.3 (Superframe Structure) defines the contention period during which the CSMA/CA access mechanism can transmit. Time is divided into a sequence of contention periods, which can vary in size.

The contention period occupies the time defined in Table 136

Table 136 - Conditions affecting the Contention Period

Condition	**Contention Period Occupies**
Ad-hoc network	The entire superframe dwell
Managed network, no subframes	The remainder of the superframe dwell following the beacon.
Managed network, subframes present	The contention period signaled in the CP2 Beacon

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In a managed network, the position of each contention period shall be calculated from the contents of the preceding CP beacon. See 5.7.4.1 (Missing CP Beacon) for procedures to be followed if the CP beacon is not received. Figure 136 illustrates this behavior.

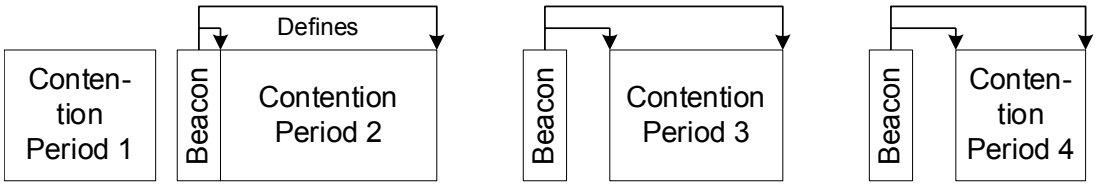


Figure 136 - Contention Period Timing

5.7.4.1 Missing CP Beacon

If an A-node has failed to receive a CP2 Beacon, and subframes were previously present, it shall use the previous value for *Contention End*.

A *Start of Contention* event (see section 5.7.9 (CSMA/CA Transmit State Machine)) shall be signaled as soon as the missing CP2 Beacon condition has been detected.

Any of the cases defined in Table 137 can be used to determine the missing CP2 Beacon condition.

Table 137 - Events that Indicate a Missing CP2 Beacon

Missing CP2 Beacon Event Case	**Description**
No Start Detected	No start of CP2 Beacon is detected
Invalid MPDU detected	An MPDU is received when the beacon is expected. This MPDU is invalid for any of the following reasons: · Bad header or payload CRC. · Wrong MPDU type. · Invalid length or MPDU control · Invalid destination address · Wrong NWID · Invalid payload structure

5.7.4.2 CW Variables

A node that uses CSMA/CA shall keep the variables defined in Table 138 that control the generation of backoff values. There is one instance of these variables in the node.

Table 138 - Contention Window Variables

Variable	**Definition**	**Initial Value**
CWminCurrent	Starting size of contention window.	*CWminDefault or CWmin*
CWstartCurrent	Minimum value for a valid non-priority contention. Represents the lowest *Backoff* value for a non-priority contention	*CWstartDefault or CWstart*
CWpriorityBackoffcurrent [N]	An array of backoff values that are associated with SIDs in support of priority access	*CWpriorityBackoff [N]*

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When the node receives a CP2 Beacon that contains a *CW* signaling field, it shall update its *CWminCurrent* from the beacon's *CWmin* field, its *CWstartCurrent* from the *CWstart* field, and its *CWpriorityBackoffcurrent* array from the *CwpriorityBackoff* field.

5.7.5 CSMA/CA Transmit Queue

Each MAC entity shall keep a queue of *Tx Items* (defined in section 5.7.2 (CSMA/CA Architecture)) to be transmitted during the contention period using the CSMA/CA mechanism.

5.7.6 CSMA/CA MPDU Types

The HomeRF MPDU types are defined in section 5.4.4.7 (CSMA MPDU Types).

The MPDU types that can be transported using the CSMA_CA_MANAGEMENT Service are defined in Table 139.

Table 139 - Management MPDU types supported by the CSMA_CA_MANAGEMENT Service

MPDU Type	Description
IR	Information request MPDU. Requests its destination node to respond with an SI MPDU.
SI	Station Information MPDU. Carries capability information of its transmitting node.
CPS	Carries management requests from a node to the connection point.
CP Assertion	Connection Point Assertion MPDU. Carries connection point type and priority.

The MPDU types defined in Table 140 are used to provide the CSDU DATA service.

Table 140 - MPDU Types used to provide the CSMA_CA_DATA Service

MPDU Type	Description
DATA	Carries all of or part of a CSDU. If it carries part of a CSDU, that part is called a *fragment* of the CSDU.
ACK	Indicates successful reception of the preceding DATA MPDU.
Time Reservation	Manages the time reservation for MPDUs sent within a time reservation
Streaming Session Management	Facilitates the management by the CP of the Priority Aysynchronous Data Service

5.7.7 MPDU Sequences

MPDUs are transmitted in MPDU sequences. The rules for transmission of an MPDU sequence are defined in these sections.

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5.7.7.1 Atomic Sequences

An *atomic* MPDU sequence is a sequence of one or more MPDUs that have defined order and timing. The possible atomic MPDU sequences are listed in Table 141.

Table 141 - Atomic MPDU Sequences

Atomic MPDU sequence	**Description**
DATA-ACK	Unicast DATA MPDU (carrying part or all of a CSDU), followed by an ACK MPDU. See note 1. Within a time reservation, the DATA-ACK atomic MPDU sequence can exist in various format and modulation type combinations. See Table 86 and Table 75.
Time Reservation Establish MPDU	*Multicast or unacknowledged unicast Time Reservation Establish MPDU*
Time Reservation Cancel MPDU	*Multicast or unacknowledged unicast Time Reservation Cancel MPDU*
Time Reservation Establish RTS-Time Reservation Establish CTS	*Multicast or unicast Time Reservation Establish RTS MPDU followed by a Time Reservation Establish CTS MPDU*
Streaming Session Management Request-Streaming Session Management Response	Streaming Session Management Request MPDU followed by a Streaming Session Management Response MPDU
IR-SI	Information Request MPDU followed by a Station Information MPDU response. See note 2.
DATA	Multicast DATA MPDU (carrying part of or all of a multicast CSDU).
Management MPDU	CPS MPDU, Station Information MPDU (that is not transmitted as part of an IR-SI sequence)
Notes:	1. A node that sends a unicast DATA MPDU expects an ACK response. A missing ACK is classified as an abnormal DATA-ACK sequence with status "missing ACK". 2. A node that receives a Streaming Session Management Request MPDU can respond with a Streaming Session Management Response MPDU as part of an atomic MPDU sequence, or can respond some time later with a separate Streaming Session Management Response MPDU. The originator does not know in advance what type of response will occur. 3. A node that receives an IR MPDU can respond with an SI MPDU as part of an atomic MPDU sequence, or can respond some time later with a separate SI MPDU. The originator does not know in advance what type of response will occur.

For the DATA/ACK, Time Reservation Establish RTS/Time Reservation Establish CTS, Streaming Session Management Request/Streaming Session Management Response and IR/SI sequences, the two MPDUs are separated by a SIFS time. The second MPDU is sent without regard to carrier-sense. Figure 137 illustrates the timing of an atomic MPDU sequence.

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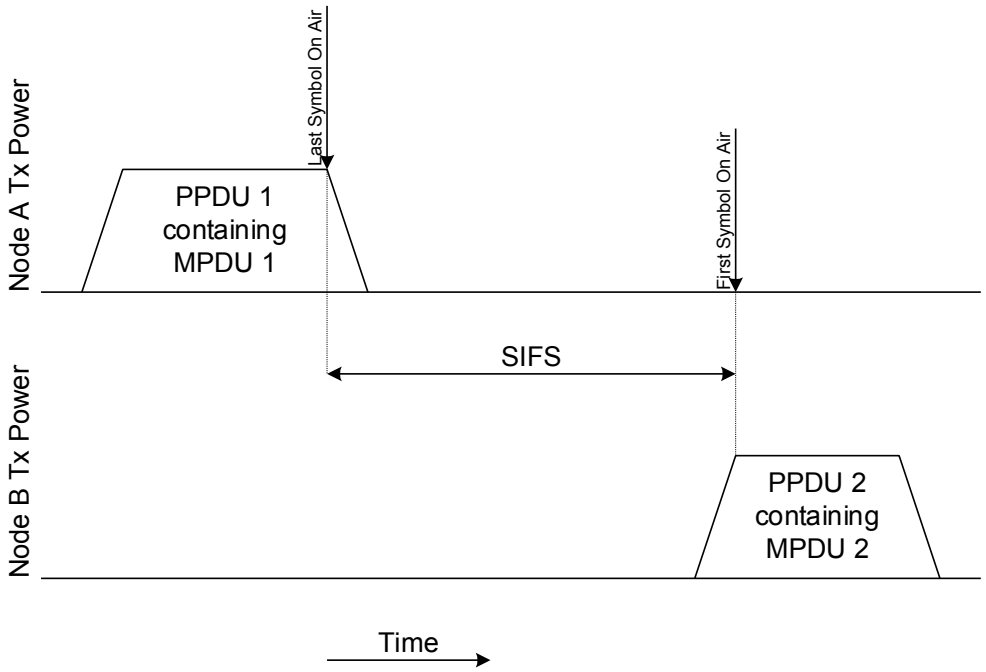


Figure 137 - The Timing of an Atomic MPDU Sequence

5.7.7.2 Transmission of MPDU Sequences (Informative)

An *MPDU Sequence* is the unit of attempted MAC access to the medium. This *MPDU Sequence* may be determined by Tx items, such as a CSDU, or may be determined by a time reservation and consist of Tx items defined to be transmitted within that time reservation.

A time reserved *MPDU Sequence* will uniformly maintain throughout the time reservation the atomic MPDU Sequence format and modulation attributes that were indicated in the *Time Reservation Establish* MPDU.

The MPDU sequence starts with an optional *backoff* phase, followed by a one or more atomic MPDU sequences, each separated by a SIFS.

The backoff is a number of CSMA/CA slots. The number of slots is randomly selected from *CWstartCurrent* to *CW*. *CW* starts at *CWminCurrent* and increases up to *CWmax* when transmit failures occur. See Table 138.

The CSMA/CA and carrier-sense state machines define the required behavior.

5.7.7.3 Status of the CWstart Behavior (Informative)

The signaling of CWstart is present in this version of HomeRF in order to allow the CP to prioritize access to the contention period by signaling a lower-bound on backoff values that is operated by all nodes compliant to HomeRF 1.3.

5.7.7.3.1 Permitted MPDU Sequences

The rules for composing an MPDU sequence are as follows. Following any initial backoff, the node can transmit a data, Time Reservation, or management MPDU. That MPDU and any response it receives form the first atomic MPDU sequence.

In the case of a successful unicast DATA-ACK sequence or a multicast DATA “sequence”, the MAC can then continue with the transmission of a subsequent DATA MPDU, provided that it contains the next fragment of the same CSDU or succeeding CSDUs associated with the same time reservation.

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5.7.7.3.2 Example MPDU sequence Transmission (Informative)

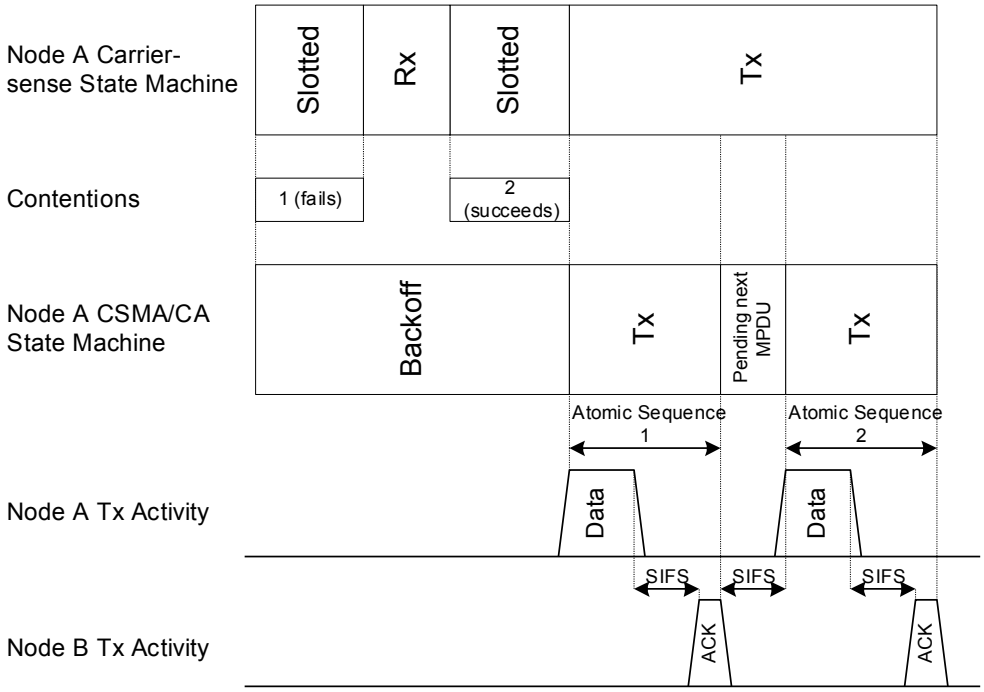


Figure 138 - Example MPDU sequence (Informative)

Figure 138 shows an example of transmission. A fragmented CSDU is transmitted using two DATA/ACK atomic MPDU sequences. The entire MPDU sequence follows a CSMA/CA Transmit state machine *backoff* state, during which the carrier-sense state machine *slotted* state was interrupted by an *Rx* state (due to a HomeRF MPDU or carrier-sense).

The combination of the CSMA/CA Transmit state machine in the *backoff* state and the carrier-sense state machine in the *slotted* state is an attempted access to the medium, or a *contention*.

A contention that ends with the CSMA/CA Transmit state machine still in the *backoff* state is a failed contention attempt. A contention that ends with the CSMA/CA Transmit state machine not in the *backoff* state is a successful contention.

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5.7.7.3.3 Example Time Reserved MPDU sequence Transmission (Informative)

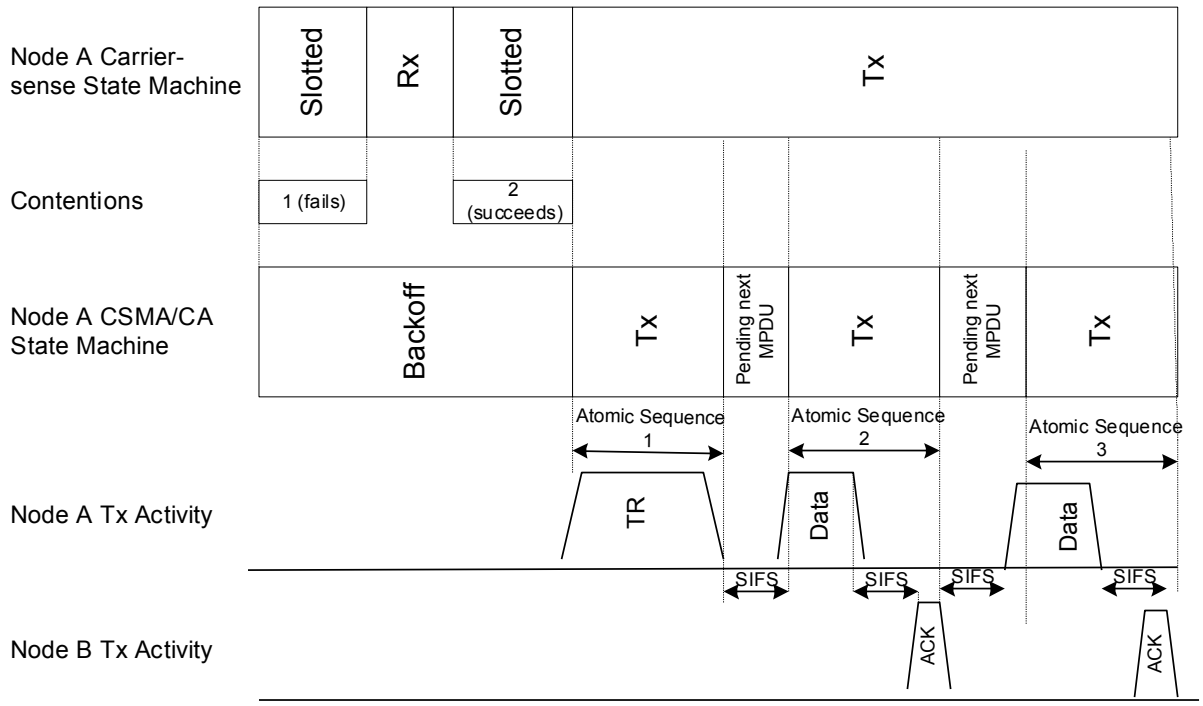


Figure 139 - Example of a Transmission within a Time Reservation

Figure 139 shows an example of transmission within a time reservation. A Time Reservation MPDU (TR) is transmitted followed by two unfragmented CSDUs. This MPDU sequence uses a *Basic Rate Single PSDU* DATA (unacknowledged) atomic MPDU sequence to carry the *Time Reservation Establish* MPDU followed by two *Extended Preamble High Rate Single PSDU* DATA/*Extended Preamble High Rate Single PSDU* ACK atomic MPDU sequences which carry the high-rate CSDUs associated with the time reservation. The entire MPDU sequence follows a CSMA/CA Transmit state machine *backoff* state, during which the carrier-sense state machine *slotted* state was interrupted by an *Rx* state (due to a HomeRF MPDU or carrier-sense).

5.7.7.3.4 Example Streaming Session Management Request / Streaming Session Management Response MPDU sequence (Informative)

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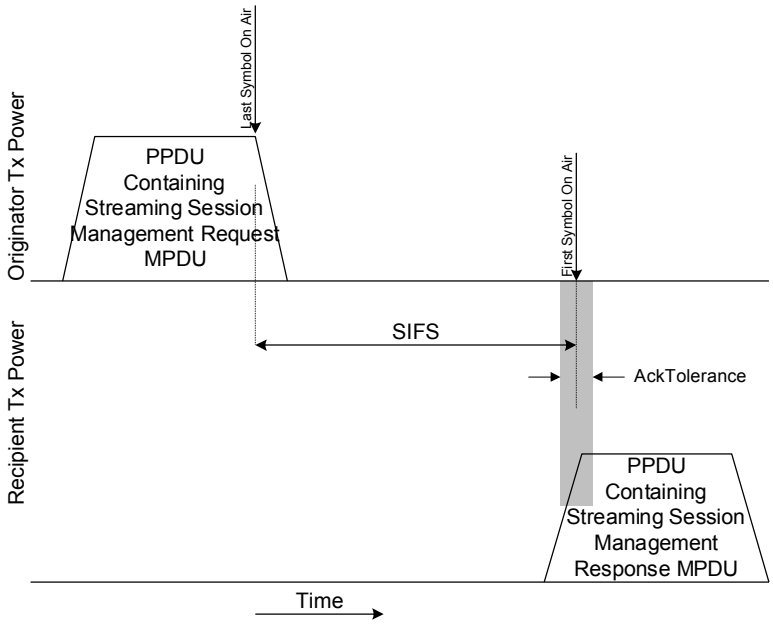


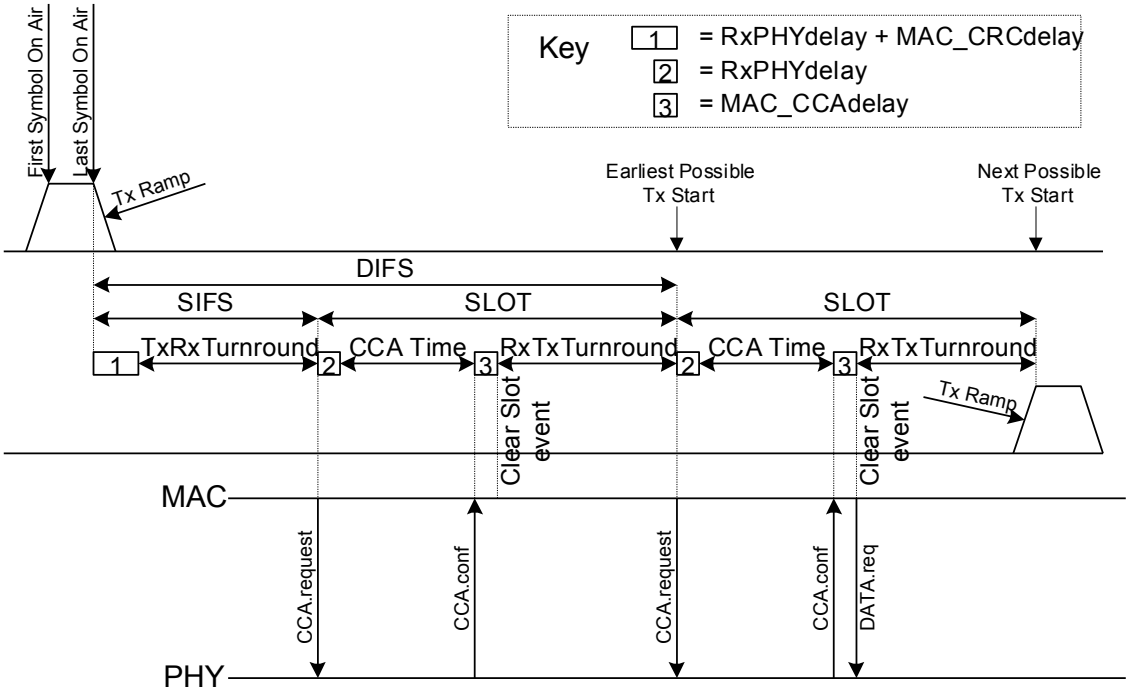
Figure 140 - Streaming Session Management Request / Streaming Session Management Response Atomic Sequence

5.7.7.4 Timing of CCA requests during a Contention (Informative)

To gain access to the medium at the start of the first atomic MPDU sequence of an MPDU sequence, the node performs a backoff consisting of one or more contentions. This section introduces the terms and defines the relationship between the timing defined by the PHY and the timing of the MAC state machines during a contention.

This informative section describes the sequence of events surrounding a contention. The actual behavior is defined by the Carrier-sense and CSMA/CA Transmit state machines.

Figure 141 shows the detailed timing of a single contention.[105]



105 This is not related in any way to Figure 138.

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Figure 141 - Example of MAC-PHY Timing during a Contention

Following the last symbol on-air of the previous PPDU, the MAC waits for a SIFS and then requests the PHY to perform a CCA.

The PHY responds with the result following a *CCA Time* + *RxPHYdelay*. The MAC decides based on this result, and its own backoff state, whether to start transmission.

If the size of a previous received MPDU is known (i.e. its header was received correctly), then the start of the contention depends upon the time of the last symbol of the MPDU. Otherwise, the start position depends upon the received signal strength in an implementation dependent fashion.

There then follows a sequence of slots (only one is shown in Figure 141), each of which consists of:

RxPHYdelay	+	Time for on-air symbols to pass through PHY
CCAtime	+	Time for PHY to perform a CCA procedure
MAC_CCAdelay	+	Time for MAC to respond to the result of the CCA procedure
RxTxTurnround		Time for PHY to start transmitting the first symbol of a PPDU

The MAC decides within each slot whether to start transmission at the end of the slot, based on the result of the CCA, and its own internal state.

The MAC can start transmission at the end of the initial DIFS, or at the end of a subsequent slot boundary. In the example shown above, the MAC decides to transmit after a single slot of backoff. The alignment of slot timing between MAC entities can be disturbed by the presence of noise or nodes in marginal range. In this case, the CSMA/CA procedures still allow contention for access to the medium, but the probability of collision is increased.

All CCA procedures are performed at slot boundaries based either on a valid preceding HomeRF MPDU, the start of the contention-period or carrier sense. The timing based on the HomeRF PPDU and start of contention period is determined accurately (*i.e.* with uncertainty much less than the *CCA time*). Timing based solely on changes in carrier sense is used following a corrupted HomeRF MPDU or a non-HomeRF signal, and is less precisely aligned.

Note that *idle* [106] time is slotted. HomeRF Stations maintain accurate registration of CSMA/CA slot boundaries over a whole idle dwell (based on required timer accuracy and dwell duration).

5.7.8 Carrier-Sense State Machine

5.7.8.1 Overview (Informative)

The CSMA/CA Transmit Process includes a state machine that ensures that the PHY CCA procedure is performed at defined times. The state machine keeps, where possible, the CCA procedures of all HomeRF nodes performed at the same time. This gives to the contention the superior performance of a slotted contention scheme over an unslotted scheme.

Some of the events that drive the Carrier-Sense state machine are local to the MAC, and so this state machine is architecturally part of the MAC, rather than part of the PHY.

CCA procedures are not performed while the PHY is transmitting or receiving. CCA procedures will also be suspended while a node is observing the time reservation of other nodes.

The outputs of the carrier-sense state machine are a sequence of *Clear Slot* events terminated by an *End of Slotted* event.

The *Clear Slot* events start a DIFS minus the *RxTxTurnround* time (the *RxTxTurnround* time is effected at the PHY) *after* the end of an MPDU on-air and stop when the channel is detected busy. The *End of Slotted* event is emitted when the medium becomes busy.

5.7.8.1.1 Effects of Power-Saving (Informative)

Section 5.6.1.6 (Opportunities to Save Power During Receive) describes how power can be saved during the reception of a PPDU that does not have to be received. Because the MPDU Rx state machine does not enter its *Idle* state until the end of the PPDU has been determined or until an established time reservation has expired, no additional behavior needs to be specified in the Carrier-sense state machine.

[106] The time when a node has no MPDUs to transmit using the CSMA/CA mechanism.

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An A-node that saves power using the procedures defined in section 5.18 (A-node Power-Management and Power-Saving) might not know the position of the contention period when it wakes to transmit using the CSMA/CA mechanism. It can assume that the contention period fills the dwell. The node relies on the CCA procedure returning channel busy indications to prevent transmission outside the contention period.

5.7.8.2 Carrier-Sense Events

The Carrier-Sense state machine is driven by the events defined in Table 142.

Table 142 - Carrier-Sense State Machine Events

Carrier-Sense External Event	**Definition**
Start Of Contention (SOC)	Start of the Contention Period as determined by the MAC management entity
End Of Contention (EOC)	End of the Contention Period as determined by the MAC management entity
Rx Starts	The MPDU Receive state machine has left its *Idle* state
Rx Halts	The MPDU Receive state machine has entered its *Idle* state
Tx Starts	A PD_TX_DATA request has been issued to the PHY
Tx Halts	A PD_TX_DATA confirmation has been issued by the PHY
CCA confirm	Result of a CCA request sent to the PHY

5.7.8.3 Carrier-Sense States

The states of the Carrier-Sense state machine are defined in Table 143.

Table 143 - Carrier-Sense State-Machine States

Carrier-Sense State	**Description**
Not In Contention	Not in the contention period
Rx	Carrier-sense due to receive activity
Tx	In an MPDU sequence originated at this node
Slotted	Performing CCA on slot boundaries
TxRxWait (substate)	Waiting for *TxRxTurnround* duration
CCA Wait (substate)	Waiting for result of CCA procedure
RxTxWait (substate)	Waiting for *RxTxTurnround* duration

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5.7.8.4 Carrier-Sense State Transition Diagram

Figure 142 shows the transitions of the Carrier-Sense state machine.

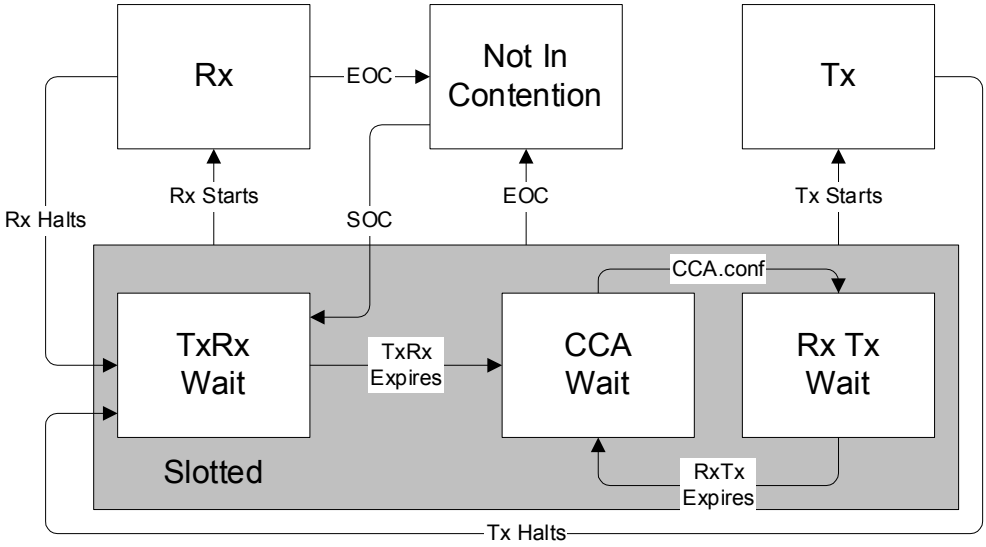


Figure 142 - Carrier-Sense State Machine State Transition Diagram

5.7.8.5 Carrier-Sense State Procedures

The procedures that are followed by the Carrier-Sense state machine are defined in the following sub-sections by state.

5.7.8.5.1 Not In Contention

Event	Action	Next State
Start of Contention		TxRx Wait

5.7.8.5.2 Rx

Event	Action	Next State
Rx Halts		TxRx Wait
EOC [107]		Not In Contention

5.7.8.5.3 Tx

The carrier-sense is in this state for the on-air duration of a PPDU that is transmitted by this node.

Event	Action	Next State
Tx Halts		TxRx Wait

5.7.8.5.4 Slotted and its Sub-states

The purpose of this state is to generate *Clear Slot* events to the CSMA/CA Transmit state machine.

[107] This can only occur when the transmitting and receiving nodes differ as to the end of contention. This can arise if one of them did not receive a CP beacon. The receiving node will continue to receive the MPDU, even though the carrier-sense state machine is in the *Not In Contention* state.

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If an *End of Contention* event occurs, the state machine shall leave any of these states and enter the *Not in Contention* state immediately.

If the PHY generates a PD_RX_START indication, the state machine shall leave any of these states and enter the *Rx* state immediately.

On leaving the slotted state, the *End of Slotted* event shall be signaled to the CSMA/CA Transmit state machine.

Initially in the *TxRx Wait* state. The state machine shall enter the *CCA wait* state after a SIFS delay.

5.7.8.5.4.1 TxRx Wait

This is a transient slotted sub-state that will insure a SIFs delay from the start of contention or the last TX or RX activity.

5.7.8.5.4.2 CCA Wait

On entry to the *CCA wait* state, the state machine shall send a CCA request to the PHY. The PHY responds with a CCA confirm after a *CCAtime*. On receipt of the CCA confirmation, the state machine shall perform the action defined in Table 144 according to the CCA confirmation channel state.

Table 144 - Actions to Perform Based on CCA confirm result

CCA confirm Channel State	**Action**
Idle	Signal a *Clear Slot* event to the CSMA/CA Transmit state machine. Enter the *RxTx Wait* state
Busy	Enter the *RxTx Wait* state.

5.7.8.5.4.2.1 Effect of CCA Busy (Informative)

If a CCA returns a *Busy* confirmation, the PHY can also generate a PD_RX_START indication either before or after the CCA confirmation. This specification does not define a relative order for these two events.

If the PD_RX_START occurs earlier than the CCA confirmation, the CCA *Busy* confirmation is received in the context of the *Rx* state and ignored.

5.7.8.5.4.3 RxTx Wait

The state machine returns to the *CCA Wait* state a *RxTxTurnround* delay after entering this state. The total time spent in the *CCA Wait* and this state insures a*SlotTime* duration between *CCA* requests to the PHY.

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5.7.9 CSMA/CA Transmit State Machine

The CSMA/CA transmit state machine controls all use of the contention period. The non-transient states are described in Table 145.

Table 145 - CSMA/CA Transmit States

CSMA/CA Transmit State	Description
Idle	Nothing to transmit. Carrier sense state machine has not signaled a *Clear Slot* event since the last *End of Slotted*[108]
No Backoff Required	One or more *Clear Slot* events have been received since the last "End of Slotted" event.[109] A transmission may be started without a preceding backoff.
Backoff	Performing Backoff procedure for an item on the transmit queue
Dispatch Tx	This is a transient state, in which, it is determined whether there is enough time in the contention period for the current atomic MPDU sequence
Transmitting	Transmitting an atomic MPDU sequence
Pending next MPDU	In the SIFS interval between the completion of the previous atomic MPDU sequence, and the start of the next
Time Reserved Transmitting	Transmitting an atomic MPDU sequence within the context of a time reservation
Time Reserved Pending next MPDU	In the SIFS interval between the completion of the previous atomic MPDU sequence, and the start of the next within the context of a time reservation
Pending Start of Contention Period	Cannot start an atomic MPDU sequence because there is not enough time left in the current contention period. Waiting for the start of the next contention.

[108] This condition is equivalent to saying that the medium has not been idle for a DIFS duration.

[109] This condition is equivalent to saying that the medium has been idle for a DIFS duration.

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5.7.9.1 CSMA/CA Transmit State Machine Events

The events and conditions that drive the state machine are defined in Table 146.

Table 146 - Events and Conditions that Drive the CSMA/CA Transmit State Machine

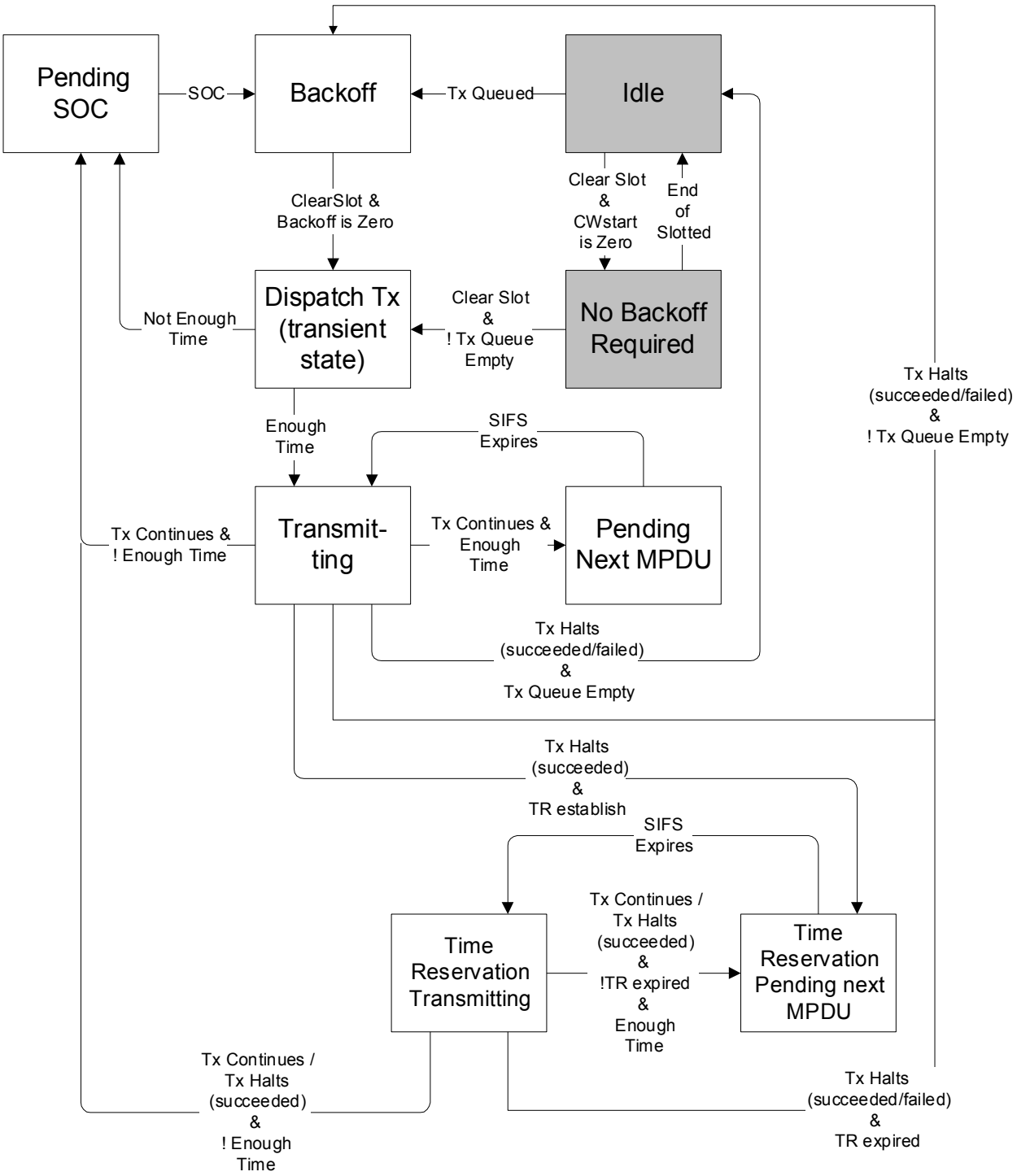
Event / Condition	Type	Definition
SOC	Event	Start of the contention period
End of Slotted	Event	The carrier-sense state machine has left one of the slotted states. Carrier-sense will be busy. This event will be generated by the Carrier-Sense State Machine upon EOC.
Clear Slot	Event	Event generated by the Carrier-sense state machine
Tx Item Expired	Event	A CSDU on the Tx Queue which had started transmission was not completed successfully within a timeout period (see section 5.7.11.2.2 (CSDU Tx State Machine))
SIFS expires	Event	The state machine has been in the *Pending Next MPDU* state for a SIFS interval
Tx Continues	Event	All of these: · The current atomic MPDU sequence transmission completes with success status · The current Tx item is a CSDU and transmission of the CSDU is incomplete · The MAC entity has elected to continue with transmission of the current Tx item sequence · The current Tx item has not expired
Tx Halts (succeeded)	Event	The current atomic MPDU sequence transmission completes with success status & ! (Tx Continues)
Tx Halts (failed)	Event	The current atomic MPDU sequence transmission failed
Tx Queued	Event	An item is placed on the Tx Queue
Tx Queue Empty	Condition	No items are on the Tx Queue
Enough Time	Condition	See section 5.7.10.4 (Transmitting an MPDU near the end of the Contention Period)
Not Enough Time	Condition	! (Enough Time)
CWstart is zero	Condition	CWstart value is zero
Backoff is zero	Condition	The number of slots of backoff for access to the medium to be granted has expired
TR required	Condition	The current Tx item is a CSDU that requires a time reservation
TR establish	Condition	The MPDU just sent was a *Time Reservation Establish* MPDU
TR cancel	Condition	The MPDU just sent was a *Time Reservation Cancel* MPDU
TR expired	Condition	The time reservation expired

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TR Tx items	Condition	There are more Tx items associated with the active time reservation on the TX Queue
Notes:	& = logical AND ! = logical negation	

5.7.9.2 CSMA/CA Transmit State Transition Diagram

Figure 143 shows the transitions of the CSMA/CA Transmit State Machine



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Figure 143 - CSMA/CA Simplified Tx State Machine

The state machine is simplified regarding Tx item expiry. In all the unshaded states, a Tx item has been selected for transmission and a Tx item expiry event can occur. See section 5.7.11.2.2 (CSDU Tx State Machine).

The following sections describe the procedures to be performed resulting from transitions between states.

5.7.9.3 Variables associated with the CSMA/CA Access Mechanism

The following variables are associated with the CSMA/CA Access Mechanism.

Table 147 - Variables Associated with the CSMA/CA Access Mechanism

Variable	Range	Description
CSMA/CA Transmit State		State variable for the state machine that manages access to the medium
CWstartCurrent	0 to *CWstartMax*	This value indicates the minimum value used to select an initial backoff value for non-priority access. It is set to the *CWstart* value signaled in the CP2 beacon or defaults to *CWstartDefault* if *CWstart* is not signaled
CW	*CWminCurrent* to *CWmax*	The *Contention Window*. Indicates the maximum value offset by *CWstartCurrent* used to select an initial backoff value *Units: slots*
Backoff	*CWstartCurrent* to (*CW* + *CWstartCurren t* -1) for non-priority access or *CWstartPriorityDefa ult* to *CWstartCurrent* for priority access	The number of slots of backoff yet to expire before access to the medium is granted. It is to be noted that whereas the *Backoff* value is dynamically calculated for non-priority access, it is generated from the associated value in the *CWpriorityBackoffcurrrent*array for priority access
LastBackoff (Optional)	*CWstartCurrent* to (*CW* + *CWstartCurrent* -1)	The value of the *Backoff* variable at end of the last failed contention

5.7.9.4 CSMA/CA Transmit State Procedures

The subsections of this section define procedures that shall be followed by the CSMA/CA Transmit state machine according to its state.

5.7.9.4.1 Idle

Event	Action	Next State
Tx Queued	Select item to transmit from Transmit Queue (see section 5.7.10.1 (Selection of an Item to Transmit)) Generate backoff value (see section 5.7.10.3 (Backoff Value)) If the selected item is a CSDU, prepare CSDU for transmission (see section 5.7.11.2.3 (CSDU Transmit Preparation))	Backoff

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Clear Slot & CWstart is zero		No Backoff Required

5.7.9.4.2 No Backoff Required

Event	Action	Next State
Clear Slot & ! Tx Queue Empty	Select item to transmit from Transmit Queue (see section 5.7.10.1 (Selection of an Item to Transmit)) Generate backoff value (see section 5.7.10.3 (Backoff Value)) If the selected item is a CSDU, prepare the CSDU for transmission (see section 5.7.11.2.3 (CSDU Transmit Preparation))	Dispatch Tx
End of Slotted		Idle

5.7.9.4.3 Dispatch Tx

This is a transient state, which is left immediately. The purpose of the state is to distinguish atomic MPDU transmissions that cannot be started because there is not enough time in the contention period left to contain the atomic MPDU sequence.

An implementation is permitted to modify the *FragmentLength* so that an atomic MPDU sequence fits in the contention period.

If the selected Tx item is a CSDU that requires a time reservation, this state will determine if both the first CSDU atomic sequence and the additional *Time Reservation Establish* singleton MPDU sequence can fit within the current contention period. If there is *Enough Time*, then the transmission of the *Time Reservation Establish* MPDU sequence will be started.

Table 148 - Dispatch Tx Conditions

Condition	Action	Next State
Enough Time	Start transmission of the MPDU	Transmitting
Enough Time & TR required	Prepare a *Time Reservation Establish* MPDU. Refer to 5.7.11.2.4, 5.7.11.2.5 and 5.7.11.2.6	Transmitting
Not Enough Time	Generate a new backoff value (see section 5.7.10.3 (Backoff Value))	Pending SOC

5.7.9.4.4 Backoff

On entry to this state, the *backoff* variable holds the number of slots to go.

Event	Action	Next State
Clear Slot event and *backoff* is zero		Dispatch Tx
Clear Slot event and *backoff* is	Decrement *backoff* variable	

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non-zero		

5.7.9.4.5 Transmitting

On entry to the transmitting state, the MAC entity issues a MPDU_TX_DATA request to cause transmission of the next MPDU associated with the currently selected Tx Item.

The timing of this request shall result in the first symbol of the PPDU being transmitted as defined in Table 149.

Table 149 - Timing of the First Symbol of the PPDU

Condition	**Timing of first symbol of PPDU**
Entered from the *Pending Next MPDU* state	*A SIFS interval after the last symbol received on air of the ACK MPDU*
Otherwise	A *RxTxTurnround* interval after the previous *Clear Slot* event (the *Clear Slot* event has already incurred a *MAC_CCAdelay* from the actual PHY CCA procedure) issued by the carrier-sense state machine (see Figure 141)[110].

In the transmitting state, the MAC is transmitting an atomic MPDU sequence.

[110] This results in transmission starting on the next slot boundary and insures a DIFs from any RX activity.

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The transmitting state shall signal a completion event to this state machine as defined in Table 150.

Table 150 - CSMA Tx Completion Events

Condition	**Signaled Event**	**Timing of Signal**
Non-DATA MPDU transmission completes	Tx Halts (succeeded)	When the last symbol of the MPDU has been transmitted on-air
Multicast DATA MPDU transmission completes and the entire Tx Item has been transmitted	Tx Halts (succeeded)	When the last symbol of the MPDU has been transmitted on-air
Multicast Time Reservation MPDU transmission completes	Tx Halts (succeeded)	When the last symbol of the MPDU has been transmitted on-air
Multicast DATA MPDU transmission completes and there are more fragments of the current Tx Item to transmit	Tx Continues, or Tx Halts (succeeded) See note (below).	When the last symbol of the MPDU has been transmitted on-air
Unicast DATA MPDU transmission completes and no response has been received. This condition also includes the *Tx item expired* event	Tx Halts (failed)	Implementation dependent. See section 5.7.11.2.10 (Tx DATA MPDU Transmit Fails).
Unicast DATA MPDU transmission completes and an invalid response MPDU is received	Tx Halts (failed)	Any time up to the end of the last symbol of the response MPDU
Unicast DATA MPDU transmission completes and a valid response MPDU is received and the entire Tx Item has been transmitted	Tx Halts (succeeded)	When the last symbol of the response MPDU has been received
Unicast DATA MPDU transmission completes and a valid response MPDU is received and there are more fragments of the current Tx Item to transmit	Tx Continues, or Tx Halts (succeeded) See note (below).	When the last symbol of the response MPDU has been received
Unicast Time Reservation MPDU transmission completes	Tx Halts (succeeded)	When the last symbol of the MPDU has been transmitted on-air
Note: The Transmit State Machine usually selects *Tx Continues,* but can select *Tx Halts* using the procedures of section 5.7.10.5 (Elective Tx Item Selection)).		

The actions and state transitions are defined by Table 151.

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Table 151 - Actions and Transitions for the Transmitting State

Event	Action	Next State
Tx Continues & Enough Time	Update CW using the procedures defined in section 5.7.10.2 (CW Update) Prepare the next MPDU for transmission	Pending Next MPDU
Tx Continues & ! Enough Time	Update CW Prepare the next MPDU for transmission Generate backoff (see section 5.7.10.3 (Backoff Value))	Pending SOC
Tx Halts (succeeded) & TR establish & TR Tx items	Issue a PM_SET_CHANNEL request w. *channel* set to calculated *high rate* value (see Equation 9) Start the *Time Reservation* timer based on the lesser of the *Time Reservation* or the time left in the contention period Select next item to transmit associated with the time reservation from the Transmit Queue (see section 5.7.10.1 (Selection of an Item to Transmit)) Prepare the CSDU for transmission (see section 5.7.11.2.3 (CSDU Transmit Preparation))	Time Reservation Pending Next MPDU
(Tx Halts (succeeded) OR Tx Halts (failed)) & ! Tx Queue Empty	Update CW If the current Tx Item failed and is a fragmented CSDU, any CSDU fragmentation state variables for the current Tx Item can be discarded Select Tx Item for transmission Generate backoff (see section 5.7.10.3 (Backoff Value))	Backoff
(Tx Halts (succeeded) OR Tx Halts (failed)) & Tx Queue Empty (This only occurs if the current Tx item completes successfully or expires)	Update CW	Idle

5.7.9.4.6 Pending next MPDU

On entry to this state, a timer is started which expires after a SIFS period.

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Event	Action	Next State
SIFS expires	Start transmission of current MPDU	Transmitting

5.7.9.4.7 Time Reservation Transmiting

On entry to the transmitting state, the MAC entity issues a MPDU_TX_DATA request to cause transmission of the next MPDU associated with the currently selected Tx Item.

The timing of this request shall result in the first symbol of the PPDU being transmitted as defined in Table 149.

In the transmitting state, the MAC is transmitting an atomic MPDU sequence.

The transmitting state shall signal a completion event to this state machine as defined in Table 150.

The actions and state transitions are defined by Table 152.

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Table 152 - Actions and Transitions for the Time Reservation Transmitting State

Event	Action	Next State
Tx Continues & Enough Time	Update CW using the procedures defined in section 5.7.10.2 (CW Update) Prepare the next MPDU for transmission	Time Reservation Pending Next MPDU
Tx Continues & ! Enough Time	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Cancel the *Time Reservation* timer Update CW Prepare the next MPDU for transmission Generate backoff (see section 5.7.10.3 (Backoff Value))	Pending SOC
Tx Halts (succeeded) & (! TR cancel & TR Tx items) & Enough Time	Select next item to transmit associated with the time reservation from the Transmit Queue (see section 5.7.10.1 (Selection of an Item to Transmit)). Prepare the CSDU for transmission (see section 5.7.11.2.3 (CSDU Transmit Preparation))	Time Reservation Pending Next MPDU
Tx Halts (succeeded) & (! TR cancel & TR Tx items) & ! Enough Time	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Cancel the *Time Reservation* timer Update CW Prepare the next MPDU for transmission Generate backoff (see section 5.7.10.3 (Backoff Value))	Pending SOC
Tx Halts (succeeded) & (! TR cancel & ! TR Tx items) & Enough Time	Cancel the *Time Reservation* timer Prepare a *Time Reservation Cancel* MPDU for transmission	Time Reservation Pending Next MPDU
Tx Halts (succeeded) & (! TR cancel & ! TR Tx items) & ! Enough Time & ! Tx Queue Empty	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Cancel the *Time Reservation* timer Update CW Select Tx Item for transmission Generate backoff (see section 5.7.10.3 (Backoff Value))	Backoff

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Tx Halts (succeeded) & (! TR cancel & ! TR Tx items) & ! Enough Time & Tx Queue Empty	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Cancel the *Time Reservation* timer Update CW	Idle
Tx Halts (succeeded) & TR cancel & ! Tx Queue Empty	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Update CW Select Tx Item for transmission Generate backoff (see section 5.7.10.3 (Backoff Value))	Backoff
Tx Halts (succeeded) & TR cancel & Tx Queue Empty	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Update CW	Idle
Tx Halts (failed) & !TR expired Enough Time	Cancel the *Time Reservation* timer Prepare a *Time Reservation Cancel* MPDU for transmission	Time Reservation Pending Next MPDU
Tx Halts (failed) & !TR expired ! Enough Time & ! Tx Queue Empty	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Update CW If the current Tx Item failed and is a fragmented CSDU, any CSDU fragmentation state variables for the current Tx Item can be discarded Select Tx Item for transmission Generate backoff (see section 5.7.10.3 (Backoff Value))	Backoff
Tx Halts (failed) & !TR expired ! Enough Time & Tx Queue Empty	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Update CW	Idle
(Tx Halts (succeeded) OR Tx Halts (failed)) & TR expired & ! Tx Queue Empty	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Update CW If the current Tx Item failed and is a fragmented CSDU, any CSDU fragmentation state variables for the current Tx Item can be discarded Select Tx Item for transmission	Backoff

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	Generate backoff (see section 5.7.10.3 (Backoff Value))	
(Tx Halts (succeeded) OR Tx Halts (failed)) & TR expired & Tx Queue Empty	Issue a PM_SET_CHANNEL request w. *channel* set to *Hopping Channel number* Update CW	Idle

5.7.9.4.8 Time Reservation Pending next MPDU

On entry to this state, a timer is started which expires after a SIFS period.

Event	Action	Next State
SIFS expires	Start transmission of current MPDU	Time Reservation Transmitting

5.7.9.4.9 Pending Start of Contention Period

Event	Action	Next State
SOC		Backoff

5.7.10 CSMA/CA Related Procedures

5.7.10.1 Selection of an Item to Transmit

The MAC shall select an item to transmit from the transmit queue subject to the following constraints:

- The earliest unicast or multicast CSDU that is associated with an active time reservation should be selected
- A unicast CSDU should be selected to preserve CSDU order for each unicast destination address and SID (only applicable for streaming CSDUs)[111]. A later CSDU shall not be selected while there is an earlier CSDU for the same destination address and SID (if applicable) that has not yet completed transmission.
- A multicast CSDU should be selected to preserve CSDU order for all multicast addresses and associated SID, if applicable.
- Any management MPDU can be selected.

5.7.10.2 CW Update

Table 153 defines the effects that a CSMA/CA event can have on the CW.

Table 153 - Effects of Updating the CW

Effect	Description
Reset	Reset *CW* to *CWminCurrent*
Increase	If (*CW* < *CWmax*), set *CW* = *CW* * 2, otherwise leave *CW* unaltered

Events that affect the CW are defined in Table 154. All other events shall have no effect.

[111] Failure to preserve order is likely to significantly degrade higher-layer (e.g. TCP/IP) performance.

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Table 154 - Events that affect the CW

Event	Effect
Tx Halts (failed)	Increase
Tx Halts (succeeded)	Reset
Tx Item Expired (see section 5.7.11.2.2 (CSDU Tx State Machine))	Reset

5.7.10.3 Backoff Value

For priority access, the SID associated with the Tx item is used to reference the *Backoff* value in the *CwpriorityBackoffcurrent array*.

For non-priority access, a *backoff* value shall be selected randomly so that numbers in the range *CWstartCurrent* to (*CW + CWstartCurrent* -1) are generated with equal probability. Alternatively, in the case where the end of contention prematurely ended an active time reservation, an implementation may set the *backoff* value to *CWstartCurrent* to support the continuation of the time reservation at the start of the non-priority access of the next contention period.

5.7.10.4 Transmitting an MPDU near the end of the Contention Period

The MAC entity shall not transmit using the CSMA/CA mechanism outside the contention period.

The source MAC entity shall not cause a destination node to transmit outside the contention period using CSMA/CA.

The MAC shall follow either the Upper Bound Procedure (5.7.10.4.1 (Upper Bound Procedure)) or the Assumed Factor Procedure (5.7.10.4.2 (Assumed Factor Procedure)) to ensure that this requirement is met.

Following a successful contention, or perhaps following a unicast or multicast atomic MPDU sequence, the MAC may have more fragments to sendor CSDUs to send that are part of an active time reservation, but might be prevented from starting a transmission because of the requirements of this section. The MAC can reduce the length of the next CSDU fragment that it transmits in order to meet this requirement or in the case of a prematurely ended time reservation, an implementation can choose to calculate the amount of time that is remaning in the time reservation and post a *Time Reservation Establish* to be sent on the next contention period. A *backoff* value will be generated that gives the continuation of the time reservation immediate non-priority access on the next contention period.

5.7.10.4.1 Upper Bound Procedure

The MAC entity should only start the transmission of an MPDU if it and any expected response (*i.e.* the whole atomic MPDU sequence) lie within the current contention period. To satisfy this requires that the MAC knows an upper bound on the on-air duration of the PPDU. This upper bound can be determined from either knowledge of the PHY-layer bitstuffing and the MPDU contents, or a worst-case bitstuffing assumption can be made.

The *Enough Time* criterion used by the CSMA/CA Transmit state machine is defined here to mean that, following any adjustment of fragment length, there is enough time to transmit the MPDU and any expected response MPDU using an upper bound for the MPDU duration and response MPDU duration calculation.

5.7.10.4.2 Assumed Factor Procedure

Alternatively, the MAC can start transmission of an MPDU if it and any expected response are expected to lie within the current contention period based on an assumed bit-stuffing expansion factor. This factor is defined by the implementation, but shall be no less than 1. The MAC shall abort any active transmission either:

- If no response is expected, at the end of the contention period, or
- If a response is expected, at the end of the contention period less the expected on-air duration of the response MPDU.

The *Enough Time* criterion used by the CSMA/CA Transmit state machine is defined here to mean that following any adjustment of fragment length, there is enough time to transmit the MPDU and any expected response MPDU using an assumed bit-stuffing expansion factor for the MPDU duration and response MPDU duration calculation.

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5.7.10.5 Elective Tx Item Selection

On completion of an atomic MPDU transmission, the MAC entity can elect to halt transmission of the MPDU sequence in progress and select an item to transmit as described in section 5.7.10.1 (Selection of an Item to Transmit).

5.7.10.6 Transmission Failure (Missing ACK)

A node that has transmitted a unicast DATA MPDU expects to receive an ACK MPDU. A node that does not receive an ACK MPDU in response to a transmitted unicast DATA MPDU shall signal a *Tx MPDU Fails* event to the CSDU Tx state machine.

This specification does not define any particular mechanism for determining a missing ACK MPDU.

Table 155 describes some possible conditions that can be used by an implementation to determine a missing ACK.

Table 155 - Possible Conditions for Missing ACK Detection

Time Detected (relative to last symbol of DATA MPDU On-air)	**Condition**
SIFS + *AckTolerance* + *CCAtime*	No preamble detected
SIFS + *AckTolerance* + PPDU header duration	No SFD match
SIFS + *AckTolerance* + ACK MPDU duration	Bad MPDU header CRC, Unexpected Source Address, Fragmentation fields do not match the DATA MPDU.

5.7.10.7 IR MPDU Transmit

Having transmitted an IR MPDU, the CSMA/CA Transmit state machine shall declare a *Tx Halts (succeeded)* event immediately. The state machine does not wait for any possible SI response.

The CSMA Rx process shall be prepared to receive an SI MPDU response a SIFS interval after transmitting the IR MPDU.

5.7.10.8 Ad-hoc Beacon Transmit

In order to transmit an ad-hoc beacon, the A-node shall use a CW of size *CWadhoc.* The CSMA/CA Transmit state machine shall be reset to the *Idle* state.[112] The Tx Item representing the ad-hoc beacon shall be queued to the Tx Queue.

5.7.11 CSDU Transmission Procedures

This section defines procedures that shall be performed by the CSMA/CA Transmit State Machine in order to transmit a CSDU.

CSDUs are classified as unicast or multicast according to the *Individual/Group* bit of their destination address. See Figure 64 for a definition of this bit.

5.7.11.1 Overview (Informative)

CSDUs are transmitted as the payload of one or more DATA MPDUs. This applies to both unicast and multicast CSDUs.

As described already, CSDUs are transmitted as a MPDU sequence, which represents the unit of contention. A MPDU sequence may be a single CSDU or an aggregation of CSDUs with the same *Time Reservation association parameters*. See Table 159. A multiple CSDU MPDU sequence is only supported within a time reservation. A time reservation is established for a duration based on the MPDU sequence associated with that time reservation. A MPDU sequence consists of one or many Atomic MPDU sequences. A unicast atomic sequence is either a DATA MPDU/ACK sequence or a DATA fragment MPDU/ACK sequence. A multicast atomic sequence is either a DATA MPDU sequence or a DATA fragment MPDU sequence.

Aggregation of CSDUs is only supported within the context of a time reservation. A requested time reservation is required to be long enough to handle the aggregate size of the CSDUs associated with it. Nevertheless, it is possible that the time reservation was shortened due to the amount of contention period remaining. In this case, there may fragmentation of the last CSDU sent in the current contention period.

[112] Thereby ensuring that the ad-hoc beacon is transmitted with a backoff.

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Fragmentation supports better channel utilization given the short contention period, and limits the duration of an atomic MPDU sequence so that it can fit into a contention period even when the maximum number of main TDMA slots are allocated to the isochronous data service.

Unicast DATA CSDUs may also be fragmented to increase the probability of MPDUs being transmitted successfully over a noisy link.

Fragmentation of multicast DATA CSDUs reduces reliability when the CSDU is transmitted using more than one backoff. This is the case if the transmission of the CSDU cannot be completed within a single contention period. Manufacturers can address issues of reduced reliability in the architectural layers above the MD-SAP.

A DATA MPDU that contains an entire CSDU is referred to as a *singleton* MPDU. A unicast singleton has both *FirstFrag* and *LastFrag* MPDU fields set to 1. A multicast singleton has the *MFragSN* field set to 0, and the *LastFrag* field set to 1.

Unicast DATA MPDUs are acknowledged by an ACK MPDU. Outside of a time reservation, the ACK MPDU is expected in the *Basic Rate Single PSDU* format and at the basic modulation type. Inside of a time reservation, the ACK MPDU will be received based on a *Modulation Type* of 2-FSK at the rate (low or high) indicated by the *Atomic MPDU Sequence format* attribute associated with the time reservation.

DATA MPDUs are sent using the CSMA/CA access mechanism, so most of the time starting with a backoff. The number of backoff slots is a function of the contention window and evolves with the failure or success of unicast data transmissions (see section 5.7.10.2 (CW Update)).

If the MPDU is part of a unicast CSDU fragment train, it follows the reception of the ACK of the previous fragments by a SIFS (see section 5.7.11.2 (CSDU) for details of the fragmentation process).

The ACK MPDU is sent by the recipient of the unicast DATA MPDU a SIFS after the end of the transmission of the related unicast data MPDU.

If the sender successfully receives an ACK MPDU a SIFS after the end of its DATA MPDU transmission, it signals a successful transmission and continues with transmission of the next fragment.

Additionally, the ACK MPDU can be carrying a tunneled singleton CSDU as its payload. When this is the case, the CSDU was sent via the *Fast Unacknowledged Service Mechanism* of the CSMA/CA Access Mechanism.

Otherwise, the transmission of the unicast DATA MPDU has failed and the MPDU is retransmitted, following a backoff. The failure may cause the contention window to be increased, and the retransmitted fragment size and modulation type to be reduced.

There is an upper limit of the retransmission attempts. A timer is started when the first MPDU is transmitted on air. When it reaches *CSDUtimeout*, the CSDU is discarded.

Multicast CSDUs can also be fragmented and transmitted as one or more fragment trains. In this case, a fragment train consists of the initial DATA MPDU is followed by a SIFS interval and another DATA MPDU, and so on. Because there is no ACK MPDU to go missing, it is not possible for the transmitting node to know that a multicast DATA transmission has failed. Therefore, a completed multicast DATA MPDU is always assumed to have succeeded.

5.7.11.2 CSDU Transmit

A CSDU shall be transmitted using the procedures defined in this section.

A CSDU shall be transmitted in one or more DATA MPDUs.

5.7.11.2.1 CSDU Fragmentation State

Table 156 defines variables associated with the fragmentation of a CSDU.

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Table 156 - State variables associated with the fragmentation of a CSDU

Variable	Description
CSDUstate	State machine variable. See section 5.7.11.2.2 (CSDU Tx State Machine).
CSDUtimer	*CSDU* expiry timer
CSDUlength	byte length of the *CSDU* to transmit
CSDUoffset	byte offset into the *CSDU* which identifies the next byte to be transmitted
CSN	CSDU Sequence Number
FragmentNumber	The number of the current transmit fragment. The first fragment is numbered zero.
MulticastSequenceNumber	The number of the current multicast transmit CSDU.
Time Reserved Atomic MPDU Sequence format	The atomic MPDU sequence format being used within the current time reservation, if applicable
ModulationType	See Table 75
FragmentThreshold	Sets an upper bound for the fragment length
FragmentLength	The size of the current fragment in bytes
Failures	Number of transmission attempts which failed

With the exception of the *MulticastSequenceNumber,* each CSDU in the Tx Queue has its own set of variables as defined above. There is only a single instance of the *MulticastSequenceNumber*.

5.7.11.2.2 CSDU Tx State Machine

The CSDU Tx State Machine describes the processing related to the transmission a single MPDU sequence. It is a more detailed view of the CSMA/CA Transmit state machine *Transmitting, Pending next MPDU, Tx, Time Reservation Transmitting,* and *Time Reservation Pending next MPDU* states.

The *CSDUstate* variable follows the state transitions defined in Figure 144

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5.7.11.2.2.1 CSDU Tx State Transition Diagram

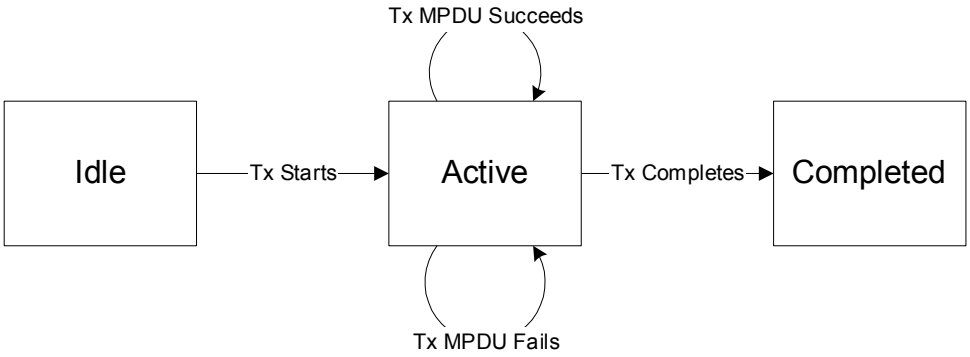


Figure 144 - CSDU Tx State Transitions

5.7.11.2.2.2 CSDU Tx State Events

The relevant events are defined in Table 157.

Table 157 - Events relevant to the fragmentation of a CSDU

Event	Definition
Tx Starts	The transmission of the first MPDU of the *CSDU* has started
Tx Completes	Either the *CSDU* has been transmitted successfully, or the *CSDUtimer* has expired
Tx MPDU Succeeds	The transmission of an MPDU completes successfully
Tx MPDU Fails	The transmission of an MPDU completes with failure status

On entry to the *Active* state, the *CSDUtimer* shall be set to expire after a *CSDUtimeout* period (defined in section 16.2 (MAC Constants)).

In the *Active* state, the Tx Completes event will be triggered upon successful transmission of the last CSDU fragment or if the CSDU timer expires. If the Tx Completes event was the result of a successful transmission of the CSDU, the state machine shall signal a *Tx Halts (successful)* event to the CSMA/CA Transmit state machine, and the item is removed from the Tx Queue. If the Tx Completes event was the result of a CSDU timeout, the state machine shall signal a *Tx Item Expired* event to the CSMA/CA Transmit state machine, and the item is removed from the Tx Queue.

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5.7.11.2.3 CSDU Transmit Preparation

Before transmitting a *CSDU* for the first time, the MAC entity shall select initial values for the fragmentation state variables as defined in Table 158.

Table 158 - Initial Values for Fragmentation Variables

Variable	Initial Value
CSDUlength	As present in the CSMA_CA_DATA request
CSDUoffset	Initially zero
CSN	As present in the CSMA_CA_DATA request if duplicate removal is supported, otherwise zero.
*FragmentNumb*er	Initially zero
MulticastSequenceNumber	Multicast CSDU: *(MulticastSequenceNumber + 1)* Unicast CSDU: unchanged
Time Reservation value	The duration of the current time reservation, if applicable. See section 5.7.11.2.4
Time Reserved Atomic MPDU Sequence format	The atomic MPDU sequence format being used within the current time reservation, if applicable. See section 5.7.11.2.5
ModulationType	A value as close to the performance that the source MAC entity knows can be received by the destination. See section 5.7.11.2.6)
FragmentThreshold	Initially *LR4FSKfragmentationThreshold* for LR 4-FSK modulation, *LR2FSKfragmentationThreshold* for LR 2-FSK modulation, *HR4FSKfragmentationThreshold* for HR 4-FSK, or *HR2FSKfragmentationThreshold* for HR 2-FSK
Failures	Initially zero

5.7.11.2.4 Time Reservation value

The duration of the current time reservation is determined based on the number of CSDUs that are currently on the Tx item Queue with the same *Time Reservation association parameters*. See Table 159. The *Time Reservation value* is calculated as described in Equation 11.

Table 159 - CSDU Time Reservation association parameters

Time Reservation association parameters
Destination Address
Stream ID (associated only with CSDUs of MS-SAP)

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Equation 11 - Time Reservation value calculation

$$MPDU\ sequence\ size <= Time\ \mathrm{Re}servation\ value <= MaxTime\ \mathrm{Re}servation$$

where :

$$MPDU\ sequence\ size =$$
$$(nTx\ itemsSize \times (Modulation\ Type\ symbol\ duration / Basic\ Modulation\ Type\ symbol\ duration)) +$$
$$(n \times ACKSize \times (ACK\ Modulation\ Type\ symbol\ duration / Basic\ Modulation\ Type\ symbol\ duration)) +$$
$$(n \times SIFS)$$

$$n = Number\ of\ Time\ \mathrm{Re}servation\ Associated\ Tx\ items\ on\ the\ Tx\ item\ Queue$$

$$n\ Tx\ itemsSize = Total\ bit\ size\ of\ the\ Tx\ items\ on\ the\ Tx\ item\ Queue\ associated\ with\ the\ time\ reservation$$

5.7.11.2.5 *Time Reserved Atomic MPDU Sequence format*

The node shall select a *Time Reserved Atomic MPDU Sequence format* based on its own capabilities and the capabilities of the destination.

5.7.11.2.6 *ModulationType* Selection

The node shall select an initial *Modulation Type that* is as close to the performance that it supports and that it knows can be received by the destination MAC entity. It can use any local information to make this decision. This information could include the destination's MAC capabilities, the history of previous communication attempts and signal strength. The capability exchange procedure enables a MAC entity to determine the capabilities of another MAC entity.

5.7.11.2.7 DATA MPDU Transmit

On transmitting a DATA MPDU, the MAC entity selects a *FragmentLength* no greater than the smaller of *FragmentThreshold* and (*CSDUlength* - *CSDUoffset*), and sets the MPDU fields as defined in Table 160 (Unicast CSDU) and Table 161 (Multicast CSDU) respectively.

For a multicast CSDU, the *FragmentLength* shall be selected so that the number of fragments is no greater than 4.

Table 160 - DATA MPDU Field Settings for a Fragmented Unicast CSDU

MPDU Field	**Contains**
Modulation Type	Value appropriate to selected modulation type
FirstFrag	1 if the *CSDU* offset is zero, 0 otherwise
LastFrag	Indicates if the fragment contains the last byte of the *CSDU*. 1 if (*CSDUoffset* + *FragmentLength*) equals *CSDUlength*, 0 otherwise.
CSN	(Present only in the first fragment) Set to the CSDU's *CSN* variable.
FragSN	(Present only in non-first fragments) *FragmentNumber* modulo 2
Payload	*Fragment Length* bytes from the CSDU starting at *CSDUoffset* bytes from the start of the CSDU.

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Table 161 - DATA MPDU Field Settings for a fragmented multicast CSDU

MPDU Field	Contains
Modulation Type	Value appropriate to selected modulation type
LastFrag	Indicates if the fragment contains the last byte of the *CSDU*. 1 if (*CSDUoffset* + *FragmentLength*) equals *CSDUlength*, 0 otherwise.
MFragSN	*FragmentNumber*
MSeq	*MulticastSequenceNumber*
MPS Relay	1 if the node is a CP, and the CSMA/CA service request *MPS Relay* parameter was set to 1. 0 otherwise
Payload	*Fragment Length* bytes from the CSDU starting at *CSDUoffset* bytes from the start of the CSDU.

5.7.11.2.8 *FragmentLength* Selection (Informative)

A node may select any DATA MPDU *FragmentLength* meeting the requirements of section 5.7.11.2.7 (DATA MPDU).

How the node does this is implementation dependent. This section describes a number of possible decision techniques.

The decision is made logically when the node has gained access to the medium and is about to transmit. At that point, the node knows the *FragmentThreshold*, the length of the remaining CSDU to be transmitted, and the maximum length that will fit in the current contention period. The smallest of these three quantities defines what can be transmitted immediately.

The node calculates an MPDU length from available duration using either the *Upper Bound* or *Average Expansion* techniques described in sections 5.7.10.4.1 (Upper Bound Procedure) and 5.7.10.4.2 (Assumed Factor Procedure).

A node can choose not to adjust fragment size based on time left in the contention period. This permits it to calculate fragment sizes prior to MPDU transmission. In this case, if it gains access to the medium, and the next fragment to be transmitted does not fit, the node waits. This behavior is described in the CSMA/CA Transmit state machine (section 5.7.9 (CSMA/CA Transmit State Machine)).

There are two obvious selection mechanisms:

- In the simplest mechanism, each fragment is set to the maximum permitted length at that time. This will be the current value of *FragmentThreshold*, perhaps reduced near the end of contention. The final fragment holds the residue and might be very short.
- Alternatively, the node might attempt to divide the remaining payload equally between the predicted number of fragments, thereby avoiding a very short final fragment.

If an entire unicast CSDU fits, it can be transmitted as a singleton with both *FirstFrag* and *LastFrag* set. Note in this case, that if the MPDU transmission fails, the CSDU can subsequently become fragmented if the *FragmentThreshold* is reduced below the CSDU length.

There is no reliability benefit to be gained from fragmenting a multicast CSDU.

The number of fragments used to transport a unicast CSDU is not limited in any way. The number of fragments used to transport a multicast CSDU is limited to 4 by the width of the *MFragSN* field.

5.7.11.2.9 Tx DATA MPDU Transmit Succeeds

On receiving an ACK in response to a unicast DATA MPDU or on completing the transmission of a multicast DATA MPDU, the MAC shall perform these procedures.

If the DATA MPDU has *LastFrag* asserted, the CSDU has been transmitted successfully, and it shall be removed from Tx Queue. A *Tx Completes* event shall be signaled to the CSDU Tx state machine.

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Otherwise, the variables associated with the CSDU shall be updated as defined in Table 162.

Table 162 - Effect of Tx DATA MPDU Transmission Succeeds on Fragmentation Variables

Variable	New Value
CSDUoffset	*CSDUoffset + FragmentLength*
FragmentNumber	*FragmentNumber + 1*

Additonally, if the *Fast Unappreciated Service Mechanism* of the CSMA/CA Access Mechanism is supported, the received ACK may indicate that a payload carrying a tunneled singleton CSDU is present. In this case, the CSDU will be indicated to the MD-SAP services as a CSMA_CA_DATA indication immediately.

5.7.11.2.10 Tx DATA MPDU Transmit Fails

Following the transmission of a unicast DATA MPDU, if an ACK MPDU is not received within an *ACKtimeout* interval following the transmission of the last symbol of the DATA MPDU, the transmission of that MPDU has failed[113].

When a failure occurs, the MAC shall increment the *Failures* variable associated with the CSDU.

When a failure occurs, *FragmentThreshold* and *Modulation Type* values shall be modified to mitigate the failures. These values shall be updated differently based on whether a time reservation is in effect or not.

Outside of a time reservation, the MAC shall update the *FragmentThreshold* and *ModulationType* [114] as defined in Table 163.

Table 163 - Effect of Tx DATA MPDU Transmission Failures on Fragmentation Variables outside of a Time Reservation

Failures	FragmentThreshold	ModulationType
1	unchanged	Unchanged
2	*DefaultLR2-FSKFragmentThreshold / 2*	LR 2-FSK
3	*DefaultLR2-FSKFragmentThreshold / 4*	LR 2-FSK
> 3	*DefaultLR2-FSKFragmentThreshold / 8*	LR 2-FSK

[113] If a unicast DATA MPDU transmission fails, the cause might be that the point-point radio link is poor (marginal range), there is a powerful interferer, or the destination station is not reachable.

An MPDU retransmission strategy would ideally be based on knowing the cause of the failure. Unfortunately the cause cannot generally be known. This section defines a strategy based upon the assumption that the most likely cause of occasional packet loss is interference or collision.

[114] The rationale for reducing the fragment threshold is that there is a higher probability of smaller MPDUs being received correctly, since the channel is susceptible to bursts of noise and the packet time on the channel is minimized. Reducing the modulation increases the channel time to transmit an MPDU, so a reduction in the MPDU length is required to maintain the same channel time when the modulation switches from 4-FSK to 2-FSK.

After the first failure, there is no change because a single failure is probably due to a collision. Subsequent failure is a sign of a noisy channel that would benefit from reduction in these fragmentation parameters.

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Inside of a time reservation, the changing of the *Modulation Type* value is not supported. The *FragmentThreshold* shall be modified as defined in Table 164.

Table 164 - Effect of Tx DATA MPDU Transmission Failures on Fragmentation Variables inside of a Time Reservation

Failures	**FragmentThreshold**
1	Unchanged
2	*FragmentThreshold/2*
3	*FragmentThreshold/4*
> 3	*FragmentThreshold/8*

5.7.11.2.10.1 Notes on Tx DATA MPDU Fails (Informative)

The operation of this procedure can cause a unicast *CSDU* that was initially transmitted in a single MPDU to become fragmented.

It is up to the implementation to select a *FragmentLength* given a *FragmentThreshold*, which it can do in any implementation-dependent way.

The *CSDU* remains eligible for transmission regardless of the number of transmit failures it has experienced. It may eventually be removed from the Tx Queue if the *CSDU* expires.

A multicast DATA MPDU transmission cannot fail (at least from the CSDU transmit state machine's point of view), and therefore its *FragmentThreshold* and *ModulationType* are never modified.

5.7.12 CSMA/CA Rx Procedures

This section describes procedures that shall be performed by the node on receiving management and DATA MPDUs from the MPDU Rx process (section 5.6.1 (MPDU Rx)).

5.7.12.1 CSMA/CA Receive Architecture

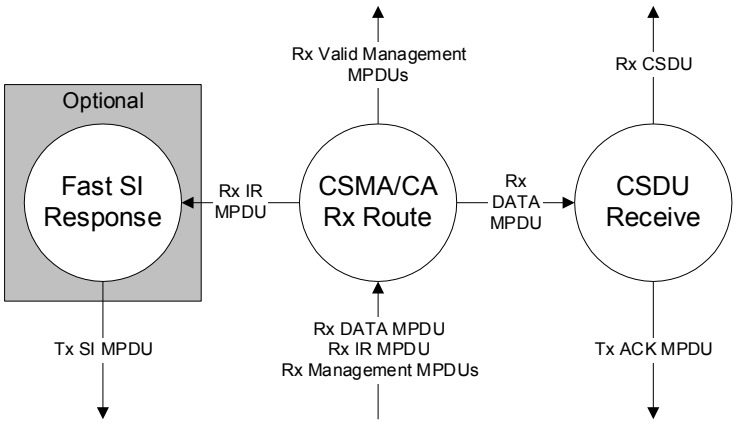


Figure 145 - CSMA/CA Receive Architecture

The CSMA/CA Rx Route process passes DATA MPDUs to a *CSDU* receive process, and management MPDUs to the MAC management entity. The Rx Route process can pass received IR MPDUs to a Fast SI response process that transmits an SI MPDU.

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The *CSDU* receive process re-assembles fragmented *CSDU*s from DATA MPDUs. ACK MPDU transmission is performed by the *CSDU* receive process. [115]

5.7.12.2 CSMA/CA Rx Route Process

The CSMA/CA Rx Route process shall pass all DATA MPDUs to the *CSDU* receive process.

An A-node that receives an IR MPDU can pass the received IR MPDU to the fast SI response procedure (if it is supported). Otherwise, the IR MPDU is routed to the MAC management entity.

All other management MPDUs are passed to the MAC management entity.

5.7.12.3 CSDU Receive Process

This section defines procedures that shall be performed by the CSDU Receive Process.

5.7.12.3.1 Discard Invalid MPDU

The node shall discard an MPDU in which any of the rejection conditions defined in Table 165 apply. The discarded MPDU shall have no other effect. [116]

Table 165 - CSDU Conditions for MPDU rejection

Condition for Rejection
Payload length greater than: *LR4FSKfragmentationThreshold* for LR 4-FSK MPDUs, or *LR2FSKfragmentationThreshold* for LR 2-FSK MPDUs, or *HR4FSKfragmentationThreshold* for HR 4-FSK MPDUs, or *HR2FSKfragmentationThreshold* for HR 2-FSK MPDUs
Multicast Address - according to implementation-dependent criteria. A CP should not discard any multicast MPDUs.[117]
Encryption level not supported by this node
Compression level not supported by this node
Multicast DATA frame and *MPS Relay* field does not match current setting. See section 5.7.12.3.3 (Filtering by *MPS Relay*)

5.7.12.3.2 Promiscuous DATA Reception (Informative)

A node receives *Promiscuously* when it receives unicast MPDUs regardless of the MPDU header destination address field. Promiscuous reception is a common feature of Ethernet hardware, and so it is reasonable to question whether a HomeRF node that appears to the OS to be a “wireless Ethernet” can also provide this feature.

An implementation can support a mode in which a node receives data promiscuously. The specification of how to operate this mode is beyond the scope of this specification.

A node that complies with the requirements of this specification does not transmit any ACK MPDUs except for DATA MPDUs addressed to that node. A node that receives unicast DATA MPDUs promiscuously cannot be sure that a re-assembled CSDU includes all its fragments, and therefore cannot be sure about the integrity of a promiscuously received MSDU.

Note that the higher layers of a protocol stack that is treating the HomeRF node as an Ethernet media type will probably be unprepared to receive any incomplete PDUs, because this is not a characteristic of an Ethernet network.

---

[115] ACK MPDU reception is handled by the CSMA/CA transmit process.

[116] Filtering by unicast destination address has already happened, following the procedures defined in section 5.6.1.2 (MPDU Receive Process).

[117] So that they can be retransmitted for power-saving A-nodes.

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5.7.12.3.3 DATA MPDU Receive

This section describes procedures to be performed to receive a DATA MPDU and reassemble it (if necessary) into a CSDU.

5.7.12.3.3.1 Overview (informative)

Unicast CSDU fragments are received in order, with the first *FragSN* set to zero, and the rest alternating between one and zero to enable the receiver to distinguish a fragment from the previous fragment. The last fragment is identified by its *Last Fragment* bit being set.

Multicast CSDU fragments are received in order, with the first *MFragSN* set to zero, and the rest incrementing to allow the reassembly process to detect missing fragments. Each fragment in a multicast CSDU is transmitted with the same *MSeq* value. This allows the reassembly process to discard an incompletely-reassembled multicast CSDU when a subsequent CSDU is received.

The re-assembly process accepts fragments of varying size and accommodates the duplication of fragments, including duplicates that are a different size. Duplicates can only occur for unicast CSDUs.

The re-assembly of a fragmented CSDU requires intermediate state to be stored per source address. [118] An implementation can support any number of these state vectors, from one upwards. The reassembly process will ignore MPDUs that it cannot process due to a limit on the resources of the re-assembly process.

If not all fragments of a fragmented CSDU are received within a defined time (*CSDUtimeout*), the partially received CSDU is discarded.

Limited re-assembly resources are not allowed to prevent the reception of singleton CSDUs and MAC management MPDUs.

Reception of singleton CSDUs and MAC management MPDUs are not allowed to cause any fragments of a partially received CSDU to be discarded.

5.7.12.3.3.2 ACK MPDU Transmit

On receiving a unicast DATA MPDU, the CSDU receive process shall check to see if there are sufficient resources to accept the MPDU based on its source address, fragmentation flags and payload length.

Possible resource constraints include:

- insufficient buffer space to hold the payload
- insufficient CSDU reassembly resources to start a new CSDU

If and only if there are sufficient resources to receive the MPDU, the MAC entity shall transmit an ACK MPDU addressed to the originator of the DATA MPDU. The fields of the ACK MPDU are set as defined in Table 166.

Table 166 - ACK MPDU Field Settings

Field	**Contains**
Payload Control	If there is a tunneled payload, this field is set as a Unicast Payload Control field as for a DATA MPDU transmit (see Table 160); otherwise it is set to zero.[119]
Destination Address	Source address of received MPDU
Source Address	MAC Address of receiving MAC entity

If the ACK is part of an atomic MPDU sequence within a time reservation, the format and modulation attributes of the ACK will be set to those associated with the time reservation. The *Modulation Type* will be 2-FSK at the rate (low or high) indicated by the *Atomic MPDU Sequence format* attribute.[120]

[118] Strictly, this is arranged by (Source Address, I/G bit of Destination Address)

[119] Tunneled payloads will not be fragmented such that the ACK MPDU will be a singleton.

[120] It is deemed desirable for higher reliability to specify ACK MPDUs to use 2-FSK modulation.

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Additionally, a CSDU Tx item with *Fast Unacknowledged Service* enabled that has the same *Destination Address as* the *Source Address* of the received MPDU can be tunneled onto the ACK MPDU as its payload. In this case, the CSDU Tx item that is earliest on the Tx Queue with *Fast Unacknowledged Service* enabled that has the same *Destination Address as* the *Source Address* of the received MPDU will be selected.

If the PHY supports antenna diversity on both transmit and receive, the *Tx Antenna* parameter of the PD_TX_DATA request primitive shall be set to the value in the PD_RX_MAC_INITIAL_HEADER indication primitive that started the received MPDU.

The ACK MPDU shall be transmitted a SIFS after the end of the received PPDU containing the DATA MPDU as shown in Figure 146. The tolerance permitted in the timing of this response is ±*AckTolerance* defined in 16.2 (MAC Constants).

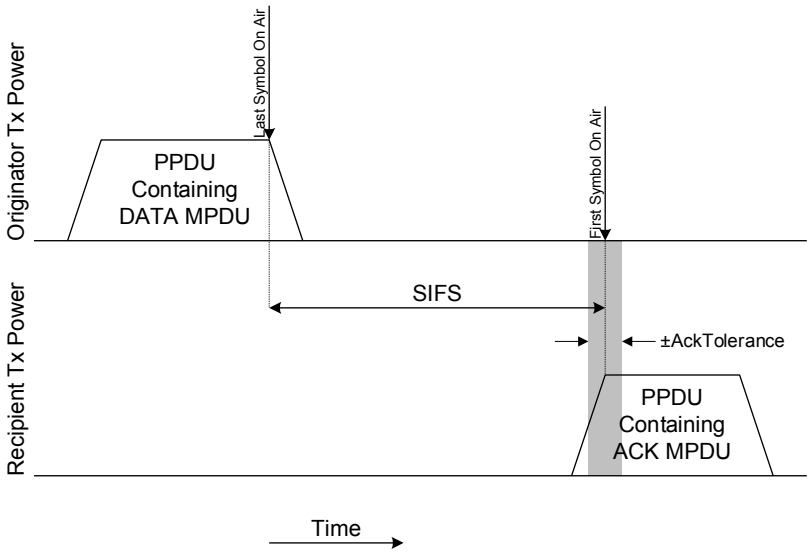


Figure 146 - ACK Transmission

An ACK shall be transmitted for duplicate fragmented DATA MPDUs correctly received.

If the ACK is part of an atomic MPDU sequence within a time reservation and it has a tunneled CSDU as its payload, the payload will be removed if the ACK cannot fit within the remainder of the time reservation plus a tolerance defined by *TRextensionTolerance*. If the ACK without any payload cannot fit within the remainder of the time reservation, the ACK itself will still be transmitted. In this case, the *Tx ACK in progress* condition will be indicated to the MPDU Receive process for the duration of the ACK transmission.

If a CSDU has been tunneled onto the ACK as its payload, it will be removed if it causes the ACK to be transmitted outside of the contention period.

The node shall not transmit the ACK outside the contention period. A node shall ensure this by supporting one of the following procedures:

- Discard an ACK without transmitting it if the last symbol of the ACK would fall outside the contention period.
- Start transmitting the ACK if currently within the contention period. Force a premature end of transmission at the end of contention of any pending ACK transmission.

5.7.12.3.3.3 Filtering by *MPS Relay*

An A-node has a variable called *Expected MPS Relay* that is used to manage filtering of received multicast DATA MPDUs by the value of their *MPS Relay* field.

An A-node shall select a value of *Expected MPS Relay* (either 0 or 1). The node shall select this value when it enters the *Managed* synchronization state (see section 5.16.4 (Synchronization State Machine)). It can also select a value whenever its power-management state machine changes state (see section 5.18.5 (PS Node Power-Management State Machine)). [121]

[121] A node that is not in a power-managed state will set *Expected MPS Relay* to 0. A node that is in a power-managed state and has been granted multicast power-management by the CP will set *MPS Relay* to 1.

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An A-node that receives a multicast DATA MPDU containing a value of *MPS Relay* that does not match the value of its *Expected MPS Relay* variable shall discard the MPDU with no further effect. [122]

5.7.12.3.3.4 CSDU Reassembly

On receiving a DATA MPDU, the MAC entity shall reassemble it into a CSDU according to these procedures.

5.7.12.3.3.4.1 CSDU Reassembly Variables

During re-assembly, a partially received CSDU is described by variables that define the CSDU reassembly state. These variables are defined in Table 167.

Table 167 - Variables Associated with the Reassembly of a CSDU

Variable	Definition
SourceAddress	MAC address of the originating MAC entity
GroupFlag	Individual/group (I/G) bit of the destination MAC address. See Figure 64 for a definition of the I/G bit.
CSDUstate	CSDU Reassembly state machine (see section 5.7.12.3.3.4 (CSDU Reassembly))
CSDUtimer	CSDU expiry timer
CSDUlength	byte length of the CSDU received thus far including the current fragment
CSDUoffset	byte offset into the *CSDU* which identifies the first byte of the current fragment
CSN	CSDU Sequence Number
FragmentNumber	The number of the current fragment. The first fragment is numbered zero.
MulticastSequenceNumber	The sequence number of the current multicast CSDU. Undefined if the current reassembly CSDU is a unicast CSDU.
CSDU	The service data unit

The HomeRF node can have any number of these *CSDU* Reassembly records. The minimum requirement is that it supports a single reassembly record.

The database of these records is organized using both *SourceAddress* and *GroupFlag* as keys.

[122] This behavior prevents duplicates of multicast CSDUs arising from the operation of the multicast power-saving services at the CP.

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5.7.12.3.3.4.2 CSDU Reassembly Events

The events that are significant to the re-assembly process are defined in Table 168.

Table 168 - Events Relevant to the Reassembly of a CSDU

Event	Definition
Rx Singleton	Unicast DATA MPDU received with both *FirstFrag* and *LastFrag* fields set to a 1 Multicast DATA MPDU received with *MFragSN* set to zero and *LastFrag* set to 1.
FirstFrag	Unicast DATA MPDU received with *FirstFrag* field set to a 1 Multicast DATA MPDU received with *MFragSN* set to 0.
MiddleFrag	Unicast DATA MPDU received with both *FirstFrag* and *LastFrag* fields set to a 0 Multicast DATA MPDU received with *MFragSN* non-zero and *LastFrag* set to 0
LastFrag	DATA MPDU received with the *LastFrag* field set to a 1
Rx *CSDU* Expires	Receive *CSDU* timer expires

5.7.12.3.3.4.3 CSDU Reassembly State Transition Diagram

A simplified state machine is shown in Figure 147.

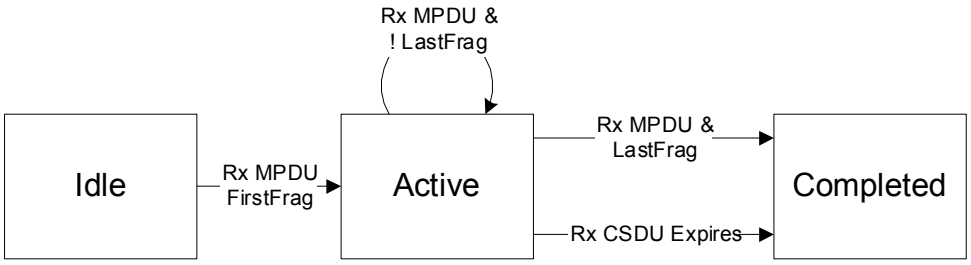


Figure 147 - Rx CSDU *State Machine (partial)*

Events are handled as described in the following sections.

5.7.12.3.3.5 Rx Singleton Event

The DATA MPDU payload shall be indicated to the MD-SAP services as a CSMA_CA_DATA indication immediately.

This event shall have no effect on the reassembly records.[123]

5.7.12.3.3.6 FirstFrag Event

On a FirstFrag event, the MAC shall discard any non-Idle *CSDU* reassembly records with the same *SourceAddress* and *GroupFlag*.

The MAC shall then attempt to allocate an *Idle CSDU* reassembly record. If one is found, it shall set the fields of the record as defined in Table 169.

[123] Note that this means that a singleton CSDU that is received from the same source address as a partly-assembled fragmented CSDU has no effect on the partly-fragmented CSDU. The most likely cause for this is the elective transmission of a multicast CSDU part way through a unicast CSDU.

Note also that a management MPDU has no effect on the reassembly process.

Note also that *has no effect* means that any incompletely-assembled CSDUs are not discarded, and may be completed successfully by subsequent DATA MPDUs.

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Table 169 - Effect of a FirstFrag Event on the Reassembly Variables

Variable	Setting
SourceAddress	Source address from the MPDU
GroupFlag	Copied from the I/G bit of the Destination Address of the MPDU
CSDUstate	Set to the Active State
CSDUtimer	Initialized so that it generates an Rx CSDU expiry event after a delay of *CSDUtimeout.*
CSDUlength	Set to the payload length of the current fragment
CSDUoffset	Set to zero
CSN	Set to the number contained in the MPDU Unicast Payload Control field
FragmentNumber	Set to zero
MulticastSequenceNumber	Multicast CSDU only: set to the *MSeq* field from the current CSDU
CSDU	Payload from the DATA MPDU

If MAC fails to allocate a *CSDU* reassembly record, it shall discard the received DATA MPDU.

5.7.12.3.3.7 MiddleFrag and LastFrag Events

On receiving either of these events, the MAC shall first locate any non-Idle *CSDU* reassembly record with the same *SourceAddress* and *GroupFlag*.

If no such record is found, the MPDU shall be discarded.

If a matching record is found, the tests defined in Table 170 are performed. If any of these conditions are met, both the partly assembled CSDU and the received fragment are discarded. The receive procedure terminates at this point.

Table 170 - Tests to Discard a Multicast CSDU and Fragment

Test	Condition
Missing Multicast Fragment	Multicast *DestinationAddress* and *MFragSN* > (*FragmentNumber + 1)*
Change of multicast sequence number	Multicast *DestinationAddress* and *MSeq* not equal to *MulticastSequenceNumber*

If the fragment is not discarded, the MPDU is either a unicast duplicate fragment or the next fragment in sequence. A duplicate unicast fragment has the same *FragmentNumber* (compared modulo 2) as the *CSDU* reassembly record *FragSN* field. A duplicate fragment always replaces the current fragment.

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The fields in the *CSDU* reassembly record shall be updated in sequence as defined in Table 171.

Table 171 - Effect of a MiddleFrag or LastFrag Event on the Reassembly Variables

Variable	Duplicate Fragment Case	Next Fragment Case
CSDUoffset	unchanged	*CSDUlength*
CSDUlength	*CSDUoffset + payload length*	*CSDUlength + payload length*
FragmentNumber	unchanged	*FragmentNumber + 1*
CSDU	Delete the bytes in the *CSDU* from *CSDUoffset* to the end. Append the bytes from the fragment payload.	Append the bytes from the fragment payload.

Following update of the *CSDU* reassembly record, if the event is a *LastFrag* event, the *CSDU* shall be set to the *Completed* state and a *CSDU* indication shall be passed upwards to the MD-SAP service process.

5.7.12.3.3.8 CSDU Indication

A CSDU indication shall contain the source address and destination addresses, the assembled payload and any other CSMA_CA_DATA service parameters [124].

The indication is passed to the MD-SAP service.[125]

5.7.12.3.3.9 CSDU Receive Expiry Event

If the *CSDUtimer* of a CSDU reassembly record expires, that CSDU reassembly record is set to the *Idle* state and any associated resources are released, including the partially-reassembled CSDU.

5.7.12.4 Fast SI Response

This is an optional procedure.

If the PHY supports antenna diversity on both transmit and receive, the *Tx Antenna* parameter of the PD_TX_DATA request primitive shall be set to the value in the PD_RX_MAC_INITIAL_HEADER indication primitive that started the received MPDU.

On receiving a short information request (IR) MPDU, the *Fast SI Response* process shall transmit a short station information (SI) MPDU following a SIFS interval (measured between the last symbol of the PPDU containing the IR MPDU and the first symbol of the PPDU containing the SI MPDU). The tolerance permitted in the timing of this response is *AckTolerance*. Figure 148 illustrates this specification.

The SI MPDU shall contain the capabilities of the HomeRF node as defined in section 5.4.10.3 (Capabilities).

The address fields of the MPDU shall be as defined in Table 172.

Table 172 - Fast Response SI MPDU Field Settings

Field	Contains
Destination Address	Source address of received IR MPDU
Source Address	MAC Address of local MAC entity

[124] These are present only for unicast CSDUs.

[125] Which is responsible for performing any necessary decryption and decompression procedures.

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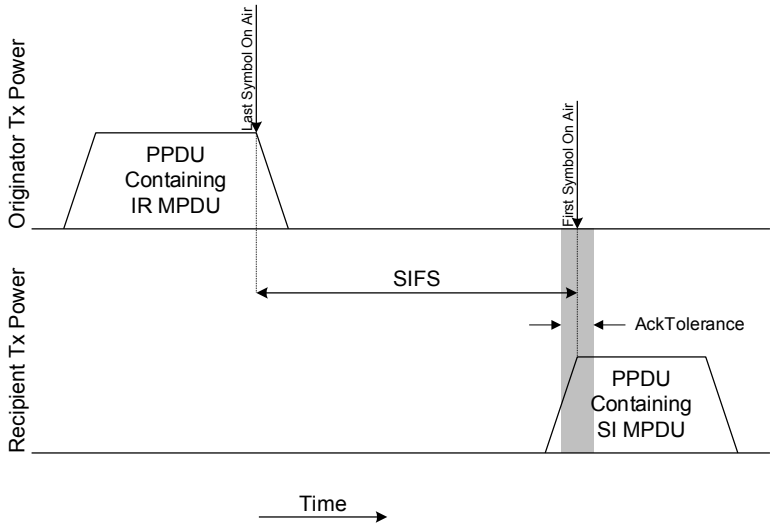


Figure 148 - IR/SI Atomic Sequence

The node shall not transmit the SI outside the contention period. A node shall ensure this by supporting one of the following procedures:

- Discard an SI without transmitting it if the last symbol of the SI would fall outside the contention period
- Start transmitting the SI if currently within the contention period. Force a premature end to the transmission of any pending SI transmission at the end of contention.

5.7.12.5 Slow SI Response

On receiving an IR MPDU from the CSMA/CA Rx process, the MAC management entity shall do one of the following:

- Queue an SI MPDU to the CSMA/CA transmit queue
- Ignore it

The management entity shall only ignore the IR MPDU if the CSMA/CA transmit queue already contains an SI MPDU.

The SI MPDU shall contain the capabilities of the HomeRF node as defined in section 5.4.10.3 (Capabilities)

The address fields of the MPDU shall be as defined in Table 173.

Table 173 - Slow Response SI MPDU Field Settings

Field	**Contains**
Destination Address	Broadcast address (all ones)
Source Address	MAC Address of local MAC entity

5.8 TDMA Access Mechanism

The access mechanism used during contention-free periods is *Time Division Multiple Access* (TDMA). The contention-free periods are available only in a Class-1 managed network. The Class-1 CP manages access to the medium during contention-free periods by sending a regular CP1 beacon that contains TDMA signaling.

This section defines procedures that enable an I-node and a CP to exchange TDMA MPDUs during contention-free periods.

There are two uses of this access mechanism: connection-oriented (section 5.8.6 (Connection-Oriented TDMA Procedures)) and connectionless (section 5.8.7 (ICBS-channel Procedures)). The connection-oriented use supports a TDMA connection to carry an I-node voice call. The connectionless use supports broadcast signaling from a Class-1 CP to I-nodes that carries mainly paging information.

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A TDMA connection has a TDMA MPDU Exchange State that is derived from the Connection management state as defined in Table 174. See section 5.20 (I-Node Management) for connection management procedures.

Table 174 - TDMA Exchange Enable State

Connection State	**TDMA MPDU Exchange State**	
	Class-1 CP	***I-node***
Idle	Disabled	Disabled
Setup	Enabled	Disabled
Active	Enabled	Enabled

The procedures in this section shall be performed for each connection that is enabled for TDMA MPDU exchange. A node that has a TDMA MPDU Exchange state that is *Disabled* shall not transmit any TDMA MPDUs on that connection.

5.8.1 Use of the Contention Free Periods

Section 5.5.3 (Superframe Structure) defines the structure of the subframe and the contention-free periods CFP1 and CFP2.

CFP2 is used for the initial transmission of the TDMA data. CFP1 is used for the retransmission of TDMA data that was not received correctly by either the node or the CP in the previous CFP2.[126]

Main TDMA MPDUs are transmitted in the main slots. Retry TDMA MPDUs are transmitted in the retry slots.

5.8.2 TDMA DATA MPDU timing

The defined position of a transmitted TDMA DATA MPDU is referenced to the node's *DwCount* variable as defined in 5.5.2.1 (Hop Management). The actual on-air position shall be accurate to within a tolerance of plus or minus a *TDMAtolerance* of the defined local *DwCount.* This value is defined in 16.2 (MAC Constants).

Table 175 - Slot Positions

Slot	***DwCount* at the first symbol of the TDMA PPDU** [127]
Main Downlink *n*	*nMainUp > 0: (n+nMainUp)* x *MainDuration* + *(n+nMainUp-2)* x *TIFS* + *SIFS* *nMainUp = 0: n* x *MainDuration* + *(n-1)* x *TIFS*
Main Uplink *n*	*n* x *MainDuration* + *(n-1)* x *TIFS*
Retry Downlink *n*	*CFP1 - ((n-1)* x *RetryDuration* + *(n-1)* x *TIFS* + *SIFS)*
Retry Uplink *n*	*nDown > 0: CFP1 - ((n+nDown-1)* x *RetryDuration* + *(n+nDown-2)* x *TIFS* + *2* x *SIFS)* *nDown = 0: CFP1 - ((n-1)* x *RetryDuration* + *(n-1)* x *TIFS* + *SIFS)*
Where: *nMainUp* - is the number of main uplink slots allocated *nDown* - is the number of retry downlink slots allocated *CFP1* - is the *DwCount* value at the start of CFP1, equal to *(SubframeDuration/BasicModulationSymbolDuration) - CFP1 Offset* (see section 5.4.16.4.1 (TDMA Beacon Header Structure)).	

[126] The two CFPs are separated by a hop, giving frequency diversity to reduce the impact of interference, and since retransmission of a TDMA slot occurs soon after initial transmission, retransmission delays are minimized.

[127] This is the first symbol of the TTS field, and does not include any preceding transmitter ramp-on.

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5.8.3 Connection ID

The connection ID is a 4-bit field signaled in various fields of the TDMA Beacon and in the TDMA data MPDUs. Certain values of connection ID are used for special purposes.

Table 176 defines these values and purposes, and also defines in which fields of the TDMA Beacon the value may be signaled. ICBS_CID is defined in 16.2 (MAC Constants)

Table 176 - Connection ID Values

Connection ID Value	Identifies	Signaled in
0	A slot that is not used	Main, Retry Downlink, Retry Uplink fields
1 - (ICBS_CID-1)	A TDMA Connection	Main, Retry Downlink, Retry Uplink fields. Connection Established and Connection Denied events. Main and retry TDMA MPDUs.
ICBS_CID	The ICBS channel	Main slots field. Main TDMA MPDU.

Active connections are assigned a Connection ID in the range 1- (ICBS_CID-1) by the CP.[128] The identifier is valid only for the lifetime of the connection, and identifies only one specific connection.[129]

5.8.4 CP Beacon Transmission

This section defines how the CP shall signal events related to the operation of the TDMA access mechanism in the CP Beacon.

5.8.4.1 Signaling Slots in the TDMA Beacon

The *main slots* field of the TDMA Beacon transmitted during the Beacon Interval shall include, for each main slot in the *Active* state (see section 5.20.3.12 (Main Slot Management)), the Connection ID of the associated TDMA connection or ICBS-channel. When the *emergency case* applies (defined in section 5.5.3.5 (Permitted CFP Sizes)), any main slot associated with the ICBS-channel shall be considered not to exist and shall not be signaled in the TDMA Beacon.

The *downlink retry slots* field of the TDMA Beacon transmitted during the Beacon Interval shall include, for each downlink slot to which a connection has been allocated, the Connection ID of that connection.

The *uplink retry slots* field of the TDMA Beacon transmitted during the Beacon Interval shall include, for each uplink slot to which a connection has been allocated, the Connection ID of that connection.

5.8.4.2 Signaling CFP1 offset in the TDMA Beacon

The CP shall calculate the starting position of CFP1 based upon the calculated duration on-air of the CP1 Beacon PPDU and signal this in the CFP1 Offset field of the TDMA beacon.

The CP shall signal a *CFP1 Offset* value equal to (*BeaconDuration + HopDuration)* to within a tolerance of *CFP1Tolerance* [130] either side of the actual value. *BeaconDuration* is the actual on-air duration of the Dual Beacon PPDU, measured in symbols and *CFP1Tolerance* is defined in 16.2 (MAC Constants).

5.8.4.2.1 Signaling CFP1 offset in the TDMA Beacon (Informative)

The purpose of the tolerance in this signaling is to allow the duration of the CP2 Beacon part to be calculated using an estimate for the bit-stuff ratio.

---

[128] This specification defines no procedure for how the CP should make this assignment.

[129] The next time a node makes a connection, it may be allocated a different Connection ID from the previous time.

[130] The purpose of this tolerance is to allow the MAC to estimate the effect of the PHY-layer bitstuffing.

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Because this estimate is used in signaling both the start of CFP1 for I-nodes and the end of CFP1 for A-nodes and S-nodes, the nodes will agree to within the *DwCount* update tolerance as to the position of the service slot.

5.8.4.3 Signaling the Contention Period in the CP2 Beacon

If there are any main slots that are in the *Active* state, the CP shall format a Contention Period Signaling field in the CP2 Beacon.

The CP shall set the *Contention Start* field equal to:

Equation 12 - Contention Start calculation

$$ContentionStart = (SubframeDuration / BasicModulationSymbolDuration) - CFP1\ Offset - CFP1\ Duration$$

Where *CFP1 Offset* is the value signaled in the TDMA Beacon part, and *CFP1 Duration* is calculated as defined in 5.5.3.4 (CFP1 Structure).

The CP shall set the *Contention End* field equal to a value no less than the *CFP2 Duration* (expressed in symbols).

5.8.5 TDMA Beacon Receive

This section defines procedures that shall be supported by an I-node that is not in the *ISS Asleep* power-saving state (see section 5.20.5 (I-node Power-Saving)).

The I-node shall be enabled to receive the TDMA beacon during the beacon period.

For a received TDMA beacon MPDU to be considered valid:

- It shall have the correct CRC
- The MPDU NWID field shall match the I-node's current NWID.

Based upon a valid received TDMA beacon, the I-node shall determine, for the current subframe:

- Its retry slot allocations, if any
- Its main slot allocation, if any
- The ICBS-channel slot allocation, if any

The TDMA Beacon Receive process shall signal an *ICBS-channel ended* event to the MB-SAP Rx State Machine (defined in section 5.15.2.3 (MB-SAP Rx State Machine)) if the following are all true:

- The slot allocation fields of the Beacon do not signal the *emergency case* (defined in section 5.5.3.5 (Permitted CFP Sizes))
- No ICBS-channel slot allocation is signaled
- The MB-SAP Rx State Machine is not in the *Idle* state

5.8.6 Connection-Oriented TDMA Procedures

This section describes procedures that are performed at both the Class-1 CP and I-node in order to provide TDMA connections.

5.8.6.1 Overview of Connection-Oriented TDMA Procedures (Informative)

The Connection-oriented TDMA access mechanism operates a "single retransmission after hop" retry protocol that gives the HomeRF specification its unique isochronous data service. This service supports high quality voice, increasing reliability over the raw PHY data service while keeping the transit delay bounded.

The CP allocates a main slot position to every active connection. This may change during the lifetime of the connection, but only changes when some other connection is shut down.

The position of the downlink depends on the number of other connections. These can come and go without any other signaling seen by the I-node. For this reason, the I-node has to decode the main slot allocation and, if necessary, respond to any changes by the following CFP2.

The TDMA acknowledgement mechanism is a simple piggyback acknowledgement of a TDMA MPDU in a later TDMA MPDU in the reverse direction, using the *TDMAack* bit in the MPDU header. This mechanism is used by the "single retransmission after hop" retry protocol to provide limited error correction for U-plane SDUs.

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This mechanism works because the TDMA mechanism is predictable [131], and because the connection is bi-directional (for each MPDU received there is an MPDU transmitted).

An I-node that has successfully received an expected TDMA MPDU sets the *TDMAack* field to a 1 in header of the next TDMA MPDU it transmits. An I-node that fails to receive an expected TDMA MPDU sets the *TDMAack* field to 0 in the next TDMA MPDU it transmits.

Since this bit has no ARQ significance in the CP to I-node direction (defaults to 1 for *minimum* behavior), the CP can also optionally utilize this bit to provide the TDMA node with feedback on the quality of the connection (*full feature* behavior).

If the CP fails to receive a valid TDMA MPDU on a connection, or that MPDU does not carry a TDMA acknowledgement, the CP schedules a retry slot for the connection. Downlink and uplink retry slots are allocated separately. The CP schedules a downlink retry if it received a TDMA MPDU with *TDMAack* set to 0 or if it received a TDMA MPDU with an invalid A-field CRC. The CP schedules an uplink retry if it received a TDMA MPDU with an invalid B-field CRC covering a U-plane SDU.

The scheduled retry slots are signaled in the TDMA Beacon part of the CP1 Beacon.

Only a single re-transmission of a TDMA MPDU is supported. If the re-transmission of a TDMA MPDU fails, the failed MPDU is discarded. Therefore, in CFP2 the I-node and the CP always transmit the next TDMA MPDU in sequence. This behavior ensures the bounded delay property of the connection-oriented data services.

5.8.6.2 Connection-Oriented TDMA Procedures - at the CP

A Class-1 CP shall operate the procedures defined in this section.

5.8.6.2.1 CP TDMA Definitions

Table 177 defines terms that are used in later sections.

Table 177 - CP TDMA Terms

Term	Definition
TDMA received event	A TDMA MPDU is received with a correct A-field CRC
Acknowledgement Event	A TDMA received event occurs and the TDMA MPDU has the *TDMAack* bit set.
Unacknowledged main connection	A connection that was allocated a main slot position in the last TDMA beacon and for which no acknowledgement event with a matching connection ID has been received by the end of CFP2.
Good B-field Event	A TDMA received event occurs and the TDMA MPDU has either a correct B-field CRC, or (optionally) an unused B-field.
Bad uplink main connection	A connection that was allocated a main slot position in the last TDMA beacon and for which no good B-field event with a matching connection ID has been received by the end of CFP2.
Missing connection	A connection that was allocated a main slot position in the last TDMA beacon and for which no *Good B-field* event occurred in either CFP2 or CFP1.

5.8.6.2.2 Transmission of Main Downlink

During CFP2, the CP shall transmit a TDMA MPDU for each main slot position that is in the *Active* state. The TDMA MPDU shall be for the connection associated with the main slot position. Main slot states are defined in 5.20.3.12 (Main Slot Management).

[131] Each end of the TDMA connection expects to receive a TDMA packet in its main slot pair.

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5.8.6.2.3 Allocation of CP Retry Slots

At the end of the CFP2, the CP shall allocate uplink and downlink retry slots to active connections according to the conditions defined in Table 178.

Table 178 - Conditions for Allocating Retry Slots

Condition	Allocate
Unacknowledged main connection	Downlink retry slot
Bad uplink main connection	Uplink retry slot

The CP shall allocate retry slot numbers in increasing numeric order starting with 1. To minimize the worst case distance between a main slot and its assigned retry slot, retry slots will be allocated in the same temporal order within the frame as the corresponding main slot (i.e. a main slot number *n* requiring a retry shall be assigned a retry slot number no greater than [5-*n*]). Refer to Figure 149.

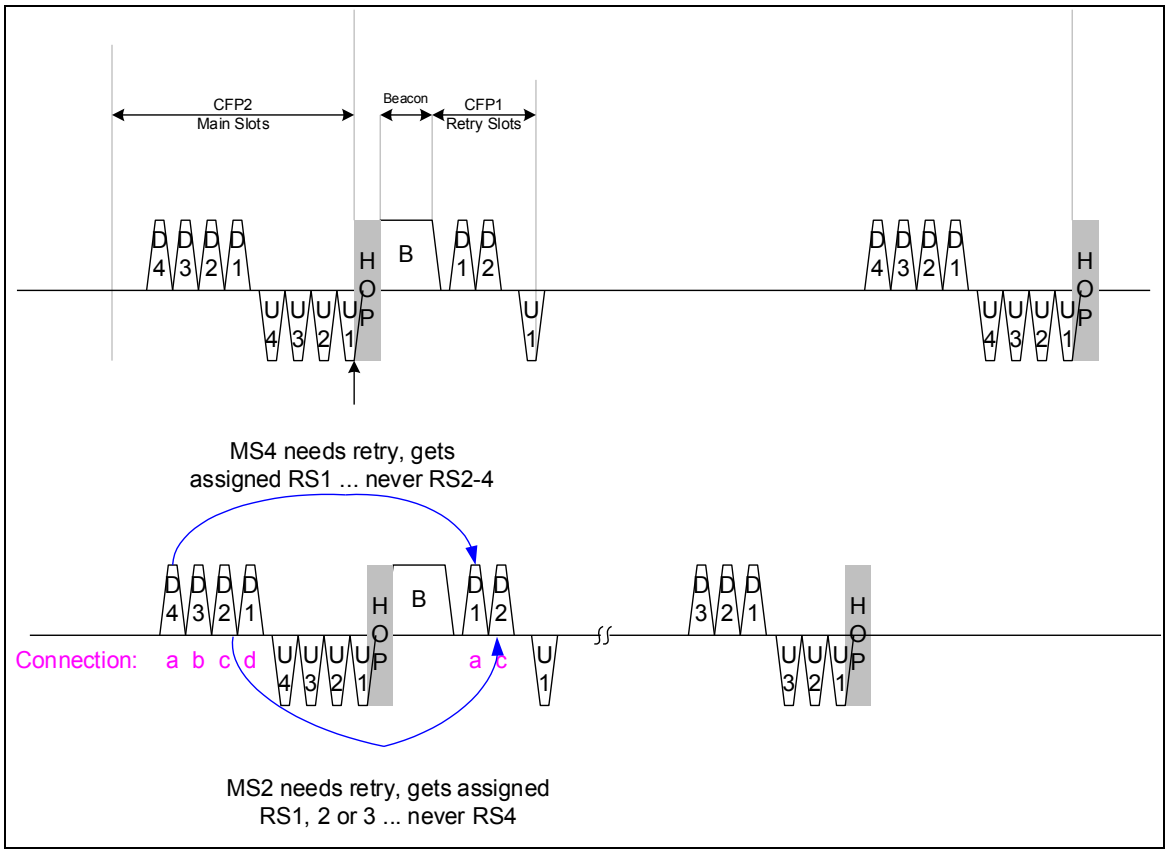


Figure 149Retry Slot Allocation at the CP

5.8.6.2.4 Transmission of Retry Downlink

During CFP1, the CP shall transmit a TDMA MPDU for each retry downlink slot that it has allocated to a connection. The TDMA MPDU shall be for the connection associated with the retry downlink position.

5.8.6.2.5 Reception of Retry Uplink

During CFP1, the CP shall be enabled to receive a TDMA MPDU for each retry uplink slot that it has allocated to a connection.

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5.8.6.2.6 TDMAack Field Values

A CP shall support either *minimum* or *full-feature* behavior setting of the *TDMAack* field in its transmitted TDMA MPDUs. [132]

A CP that supports *minimum* behavior shall always transmit the *TDMAack* set to 1.

A CP that supports *full-feature* setting of this field shall transmit the *TDMAack* field as defined in Table 179.

Table 179 - TDMAack Value Transmitted by a CP (full-feature behavior)

***TDMAack* Value**	**Condition**
0	The connection associated with the TDMA MPDU has experienced a *missing connection* condition in the previous TDMA epoch
1	Otherwise

5.8.6.2.7 CP TDMA MPDU Receive Procedures

A Class-1 CP that receives a TDMA MPDU with correct A-field and B-field CRCs shall either indicate it to the MC_SAP services (see section 5.14(MC-SAP Services)), or discard it. The first such MPDU on a connection per TDMA epoch shall be indicated. Any subsequent valid MPDUs on a connection during the same TDMA epoch shall be discarded. [133]

A Class1-CP that:

- Has received by the end of the TDMA epoch a TDMA MPDU with correct A-field which indicates a single C-SDU for a connection; or
- Has received a TDMA MPDU by the end of the TDMA epoch with correct A-field and B-field containing C-SDUs for a connection

can indicate this TDMA MPDU to the MC-SAP services showing C-SDUs to be present

A Class1-CP that:

- Has received a TDMA MPDU by the end of the TDMA epoch with correct B-field for a connection

can indicate this TDMA MPDU to the MC-SAP services showing a U-plane SDU to be present.

5.8.6.3 Connection-Oriented TDMA Procedures - at the I-node

An I-node that has a connection in the *Setup* or *Active* states shall operate the procedures defined in this section.

5.8.6.3.1 I-node Retry Slot Procedures

An I-node that:

- Has a downlink retry slot allocated to its connection, and
- Has not received a TDMA MPDU with correct A-field and B-field CRCs in the current TDMA epoch

shall be enabled to receive during the allocated downlink retry slot of the current superframe.

An I-node that has an uplink retry slot allocated to its connection shall re-transmit its previous uplink TDMA MPDU in that uplink retry slot of the current superframe. See also section 5.8.6.3.5 (Effect of Missing TDMA Beacon).

5.8.6.3.2 I-node Main Slot Procedures

An I-node that has a main slot allocated to its connection shall:

- Be enabled to receive during its main downlink slot of the current superframe.
- Transmit a new TDMA MPDU uplink in its main uplink slot of current superframe.

---

[132] The purpose of the TDMA Ack bit in the downlink TDMA MPDU is to permit the I-node to monitor the quality of the uplink to the CP. The I-node can monitor the quality of the downlink based on the number of *missing main TDMA MPDU* conditions it detects.

[133] These are duplicates of the first TDMA MPDU.

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5.8.6.3.3 I-node *TDMAack* Setting

The value of the *TDMAack* field transmitted in a TDMA MPDU by an I-node is defined in Table 180.

Table 180 - TDMAack value transmitted by an I-node

***TDMAack* Value**	**Condition**
1	If the I-node does not expect (based on criteria defined in the note below) a U-plane SDU or if the I-node has correctly received a downlink TDMA MPDU U-plane SDU during this TDMA epoch
0	Otherwise
Notes: A U-plane SDU is *expected* unless a valid A-field is received that indicates that a B-field is not present. A U-plane SDU is *correctly received* if all of the following are true: · It receives a TDMA MPDU · A U-plane SDU is expected · The B-field CRC is correct	

5.8.6.3.4 I-node TDMA MPDU Receive

The I-node TDMA MPDU receive process depends on whether it received the TDMA Beacon correctly or not.

If the TDMA Beacon is received correctly, the connection ID/slot # mapping that it indicates is considered sufficient and consequently removes the need to validate the connection ID within the A-field of the slot. If the TDMA Beacon is received incorrectly, a valid A-field must be received indicating the correct connection ID, otherwise, the TDMA MPDU shall be discarded.

The A-field must be valid to determine if a B-field is present. If the A-field CRC is incorrect, the TDMA MPDU will be discarded.

An I-node that:

- Has received by the end of the TDMA epoch a TDMA MPDU with correct A-field which indicates a single C-SDU for a connection; or
- Has received a TDMA MPDU by the end of the TDMA epoch with correct A-field and B-field containing C-SDUs for a connection

can indicate this TDMA MPDU to the MC_SAP services showing C-SDUs to be present

A I-node that:

- Has received a TDMA MPDU by the end of the TDMA epoch with correct B-field for a connection

can indicate this TDMA MPDU to the MC_SAP services showing a U-plane SDU to be present.

5.8.6.3.5 Effect of Missing TDMA Beacon

An I-node that has a connection in the *Setup* or *Active* states and that does not receive a valid TDMA beacon during the beacon interval shall (except as described below) assume that its main slot allocation is unchanged and that it has no retry slot allocation.

If the I-node both fails to receive a TDMA beacon and receives a main slot downlink with the wrong connection ID in what it believes to be its slot, the I-node can infer that its main slot allocation has changed and not send the main slot uplink.

5.8.6.3.6 I-node Connection Re-ordering Capabilities

An I-node shall be capable of operating the procedures defined in section 5.8.6.3 (Connection-Oriented TDMA Procedures - at the I-node) subject to the constraint that its main slot number does not increase.

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The behavior of the I-node is undefined should it encounter an increasing main slot number.

5.8.7 ICBS-channel Procedures

5.8.7.1 Overview of ICBS-channel Procedures (Informative)

The ICBS-channel provides for the isochronous (once per subframe) transport of a main TDMA MPDU.

The ICBS-channel, based on the data requests, partitions its bandwidth into a C-channel for ICBS C-plane SDUs and B-field for U-plane SDUs according to the *Main TDMA MPDU Structure* (see section 5.4.12 (TDMA DATA MPDUs)).

The ICBS channel is provided by a downlink only TDMA slot that is allocated by the MB-SAP Tx State Machine (see section 5.15.1.4 (MB-SAP Tx State Machine)) using the procedures defined in section 5.20.3.12 (Main Slot Management) and signaled in the Main Slot field of the TDMA Beacon using the dedicated ICBS_CID (see section 5.8.3 (Connection ID)).

The slot position may change from sub-frame to sub-frame as a result of TDMA connections coming and going. During the *emergency case*, (defined in 5.5.3.5 (Permitted CFP Sizes)) there is no room for the ICBS-channel, and so it is absent from the signaled main slots field. As soon as the *emergency case* disappears, the ICBS-channel reappears.

The I-node has to decode the main slot allocation and, if necessary, respond to any changes by the following CFP2.

The ICBS-channel discards (some or all of) TDMA MPDUs received with error. There is no retransmission protocol for the ICBS-channel.

5.8.7.2 ICBS-channel procedures at the CP

This section defines the procedures that shall be supported by the CP.

During CFP2, if there is a main slot in the *Active* state whose associated connection ID identifies the ICBS-channel, the CP shall transmit a main TDMA MPDU carrying the payload supplied by the MB-SAP Tx State Machine.

5.8.7.3 ICBS-channel procedures at the I-node

This section defines the procedures that shall be supported by the I-node.

5.8.7.3.1 Introduction (Informative)

When the TDMA Beacon Rx process detects that the ICBS-channel is activated, the ICBS-channel Rx process is enabled to receive TDMA MPDUs in the main downlink slot allocated to the ICBS-channel.

The process remains enabled until a TDMA Beacon is received correctly that, except in the *emergency case*, does not carry a main slot allocated to the ICBS-channel connection ID.

The ICBS-channel connection ID is sent in every ICBS-channel TDMA MPDU. It is used by the ICBS-channel Rx Process as a validation that an ICBS-channel TDMA MPDU has been received in the ICBS channel slot that was designated in the TDMA beacon. It validates the slot position if the TDMA beacon had not been correctly received.

The ICBS-channel Rx Process is also responsible for checking the CRCs of the TDMA MPDU. If the header CRC is bad, the whole TDMA MPDU is discarded. The B-field CRC is used to cover either additional C-plane SDUs or a U-plane SDU. If C-plane SDUs are covered and the B-field CRC is bad, the whole TDMA MPDU is discarded. If a U-plane SDU is covered and the B-field CRC is bad and the A-field contains a C-channel SDU, the TDMA MPDU is passed up, having modified its contents to remove the corrupted U-plane SDU.

5.8.7.3.2 ICBS-channel Rx Process

If the previous correctly-received TDMA Beacon indicates that the ICBS-channel is present, the I-node shall be enabled to receive during the main slot allocated to the ICBS-channel. [134]

Depending on conditions specified in Table 181, an I-node that receives a TDMA MPDU in this slot shall either discard it or pass all or some of it up to the MB-SAP Rx State Machine (defined in section 5.15.2.3 (MB-SAP Rx State Machine)).

[134] Note that if a CP Beacon is not received correctly, this process continues to attempt to receive the ICBS-channel in its last known slot position.

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Table 181 - ICBS-channel Rules for Interpreting a Received TDMA MPDU

Condition	Action
MPDU type not equal to *main TDMA MPDU*	Discard
Connection ID not equal to ICBS_CID. See Note.	Discard
Bad A-field CRC	Discard
Good A-field CRC, Good B-field CRC	Indicate MPDU to MB-SAP services
Good A-field CRC, Bad B-field CRC, Number of C-Plane SDUs > 1	Discard
Good A-field CRC, Bad B-field CRC, Number of C-Plane SDUs <= 1	Either [135] discard or modify the MPDU to show the B-field to be absent and indicate to the MB-SAP services
Note: This condition need not be tested if a beacon is received that allocates the slot on which the TDMA MPDU was received to the ICBS_CID.	

5.9 Service Slot Access Mechanism

5.9.1 Introduction (Informative)

The service slot provides a means of transmitting a management request for nodes that do not support CSMA/CA. This request is carried in the TDMA CPS MPDU.

The service slot access mechanism provides an unreliable transfer mechanism. There is no acknowledgement at this level.

The service slot access mechanism uses the time just after the end of any CFP1 in the contention period, and so follows immediately after the Beacon period and any retransmission slots. The node is required to successfully decode the CP beacon before being able to use the Service Slot.

The service slot starts a SIFS period after the end of the Beacon period and any retransmission slots. This means that any MPDU transmitted in the service slot will take priority over CSMA/CA transmissions that must wait at least a DIFS before transmitting.

The service slot access mechanism uses backoff within a contention window of size *ServiceSlotCW,* measured in units of dwells to reduce probability of collision.

Note that there is usually one service slot per dwell. The rate at which service slots occur is dependent upon *SubframesPresent.* Under some circumstances, there is not enough time for a service slot because there is no contention period.

The result of these procedures is that a first attempt by the CPS procedures (section 5.10 (CPS Procedures)) to transmit a management MPDU is likely to proceed without any backoff. Retransmissions of a management MPDU resulting from operation of the CPS procedures will proceed after a random backoff.

The operation of the Service Slot is defined by the *Service Slot State Machine.*

5.9.2 Service Slot Events

Table 182 defines the external events that drive the service slot procedure.

Table 182 - Events Relevant to Service Slot Procedure

Event	Definition

[135] According to implementation-defined criteria

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Service Slot Event (SSE)	This time-based event occurs at the start of the contention-period. This event shall only be generated at the start of the contention period following the reception of a valid CP beacon and if there is enough time in the contention period to fit the TDMA CPS MPDU. Note, that the event can occur at most once per dwell. The rate at which this event occurs depends on whether subframes are present. The I-node shall calculate the time in the contention period from the number of slots allocated in the main and retry slots, and assuming the maximum possible CP Beacon duration.
Tx MPDU queued	An MPDU has arrived from the MAC management entity for transmission
Tx MPDU completed	Transmission of the MPDU has completed

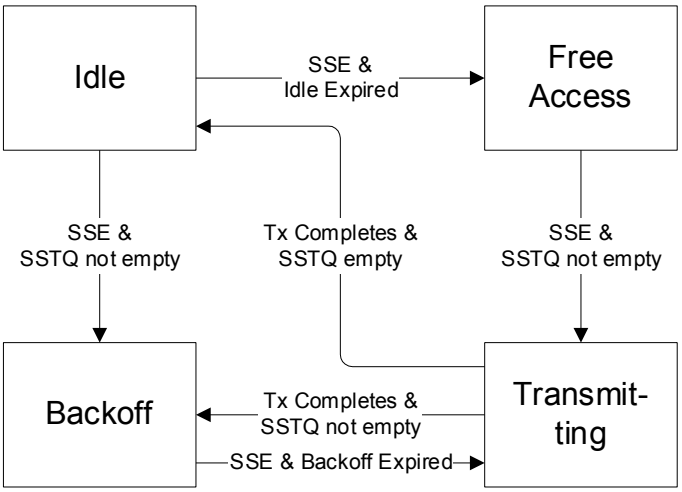
5.9.3 Service Slot State Machine Variables

The variables associated with the service slot procedure are defined in Table 183.

Table 183 - Variables Associated with the Service Slot Procedure

Variable	**Definition**
IdleCount	Number of SSE events passed in the *Idle* state
Backoff	Number of SSE events to skip in the *Backoff* state
Service Slot Tx Queue (SSTQ)	Queue of MPDUs for transmission using the service-slot access mechanism

5.9.4 Service Slot State Transition Diagram



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Figure 150 - Service Slot State Machine

5.9.5 MPDU Transmit Event

On receiving an MPDU transmit request, the service slot access mechanism shall queue it to the SSTQ.

5.9.6 Service Slot State Procedures

The operation of the state machine is defined by state in sections 5.9.6.1 (Service Slot Idle State) to 5.9.6.4 (Service Slot Transmitting State).

5.9.6.1 Service Slot Idle State

On entry to the *Idle* state, the *IdleCount* variable shall be set to zero.

Event	Action	Next State
SSE & SSTQ is not empty		Backoff
SSE & SSTQ is empty & *IdleCount* < *ServiceSlotCW*	Increment *IdleCount* by 1	
SSE & SSTQ is empty & *IdleCount* = *ServiceSlotCW*		Free Access

5.9.6.2 Service Slot Free Access State

Event	Action	Next State
SSE & SSTQ is not empty		Transmitting

5.9.6.3 Service Slot Backoff State

On entry to this state, the service slot process shall randomly select a value for *Backoff* so that numbers in the range 1 to *ServiceSlotCW* are selected with equal probability.

Event	Action	Next State
SSE & *Backoff* > 0	Decrement *Backoff* by 1	
SSE & *Backoff* = 0		Transmitting

5.9.6.4 Service Slot Transmitting State

On entry to the transmitting state, the service slot access process shall select an MPDU for transmission from the SSTQ. This MPDU shall be removed from the SSTQ and transmitted so that the first symbol of the PPDU occurs a SIFS after the start of the contention period.

Event	Action	Next State
Tx Completes & SSTQ not empty		Backoff

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Tx Completes & SSTQ empty		Idle

5.10 CPS Procedures

5.10.1 Introduction (Informative)

The CPS MPDUs are used by the nodes to communicate with the CP in order to manage TDMA and CSMA/CA services. The CPS MPDU structures and the use of these MPDUs are described elsewhere in this document (see sections 5.4.13 (CPS MPDU), 5.18 (A-node Power-Management and Power-Saving) and 5.20 (I-Node Management)).

TDMA and CSMA/CA CPS procedures are described separately. Each type of access maintains a queue of CPS MPDUs that have been queued for transmission using the CPS procedures.

5.10.2 Effect of Synchronization State

A node that is not in the *Managed* synchronization state shall ignore any requests to transmit CPS MPDUs using the CPS procedure.

A node that leaves the *Managed* synchronization state shall discard any queued CPS MPDUs. Any MPDUs thus removed are considered a transmission failure.

5.10.3 CSMA/CA CPS Procedures

5.10.3.1 CSMA/CA CPS Receive

An active CP shall be capable of receiving CPS MPDUs that are sent using the CSMA/CA access mechanism.

A node that is not the active CP shall ignore any CPS MPDUs that it receives.

5.10.3.2 CSMA/CA CPS Transmit

An A-node or passive CP that is in the *Managed* synchronization state shall perform the procedures defined in this section in order to transmit a CPS MPDU.

CPS MPDUs are placed on a CPS transmit queue. An implementation can limit the size of this queue, provided that it supports at least one entry. The MPDU is then also queued to be transmitted using the CSMA/CA access mechanism.

The node shall discard from the CPS transmit queue any CPS MPDU for which a significant response has been received. Significant responses are defined in Table 184.

Table 184 - Definition of Significant Responses to CPS Events

CPS Event	**Significant Responses**
Request Power-Management Service	A valid CP2 beacon that contains a *Power management service request accepted* or a *Power management service terminated* event with an IEEE MAC address matching the A-node's MAC address
Terminate Power-Management Service	A valid CP2 Beacon that contains a *Power management service terminated* event with an IEEE MAC address matching the A-node's MAC address
Request PS node wake-up	A valid CP2 Beacon that contains a *Wake-up Notification* or a *Wake-up Denied* event with an IEEE MAC address matching the power-saving A-node's MAC address
Acknowledge A-node wake-up notification	A valid CP2 Beacon that does not contain a *Wake-up Notification* event with an IEEE MAC address matching the A-node's MAC address
Request the CP to signal *LearnNWID*	A valid CP2 beacon that contains the *LearnNWID*

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	flag set to 1.
Request the CP to signal *DirectedLearnNWID*	A valid *Directed Learn NWID* MPDU with the IEEE MAC address of the node that the *NWID* is being directed to.

A node shall examine Incoming CP beacons for a response (acceptance or denial) to any CPS MPDUs on the CPS transmit queue that require a beacon response. [136]

A node that has requested the CP to signal *DirectedLearnNWID* shall examine each superframe for a valid *Directed Learn NWID* MPDU with the IEEE MAC address of the node that the *NWID* is being directed to.

An MPDU that requires a beacon response and that has had no response within *NumCheckCPB* beacons shall be retransmitted using the CSMA/CA access mechanism.

An MPDU that requires a valid *Directed Learn NWID* MPDU response and that has had no response within *NumCheckCPB* superframes shall be retransmitted using the CSMA/CA access mechanism.

An MPDU on the CPS queue that has been transmitted *MaxNumCPSR* times shall be removed from the CPS queue. This is considered a transmission failure of that CPS MPDU.

5.10.4 TDMA CPS Procedures

5.10.4.1 TDMA CPS Receive

An active Class-1 CP shall be capable of receiving TDMA CPS MPDUs sent using the service slot access mechanism.

A node that is not the active CP shall ignore any TDMA CPS MPDUs that it receives.

5.10.4.2 TDMA CPS Transmit

An I-node that is in the *Managed* synchronization state shall perform the procedures defined in this section in order to transmit a CPS MPDU.

TDMA CPS MPDUs are placed on a TDMA CPS transmit queue. An implementation can limit the size of this queue, provided that it supports at least one entry. The MPDU is then also queued to be transmitted by the service-slot access mechanism.

The node shall discard from the TDMA CPS transmit queue any TDMA CPS MPDU for which a significant response has been received. Significant responses are defined in Table 185.

Table 185 - Definition of Significant Responses to TDMA CPS Events

TDMA CPS Event	**Significant Responses**
Request the CP to signal *LearnNWID*	A valid TDMA beacon that contains the *LearnNWID* flag set to 1.
Request TDMA Connection	A valid TDMA beacon that contains a *Connection Established* or a *Connection Denied* event with an IEEE MAC address matching the I-node's MAC address
Request Encryption	A valid TDMA beacon is received that contains a matching *Request Encryption* event.

The node shall examine Incoming TDMA beacons for a response (acceptance or denial) to any TDMA CPS MPDUs on the CPS transmit queue. [137]

[136] This is true, even for MPDUs that have not been transmitted yet. For example, a node may observe a *Wake-up successful* event for a node for which it has a CPS *Wake-up* request in its CPS transmit queue.

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An MPDU that has had no response within *NumCheckCPB* beacons shall be retransmitted using the service-slot access mechanism.

An MPDU on the TDMA CPS queue that has been transmitted *MaxNumCPSR* times shall be removed from the TDMA CPS queue. This is considered a transmission failure of that TDMA CPS MPDU.

5.11 Capabilities

A node that supports the CSMA/CA access mechanism shall support the procedures defined in this section.

5.11.1 Introduction to Capabilities (Informative)

I-nodes communicate capabilities at a higher layer using DECT NWK-layer signaling and do not use the procedures defined in this section.

When a node wants to communicate with another node using CSMA/CA it needs to know:

- If the destination is reached through a HomeRF bridge or directly
- What *Modulation* capability and *Time Reserved Atomic MPDU Sequence Format* capability the immediate destination supports
- Whether the immediate destination supports higher-rate modulation, encryption and compression
- Whether the destination is a power-saver

When a roaming capable node wants to perform the Asynchronous Data Roaming procedures it needs to know:

- If the CP currently managing its synchronization is a roaming capable CP
- What CPs associated with the current extended network are roaming capable CPs

This information is carried in a SI MPDU, and is obtained by sending an IR MPDU. There are two forms of IR/SI MPDU exchange as described in Table 186. The IR and SI MPDUs are defined in 5.4.10).

Table 186 - Types of IR/SI Exchange

Type of IR/SI exchange	**Description**
Fast	An IR MPDU request generates an SI MPDU response immediately after a SIFS delay using the fast SI response procedure defined in 5.7.12.4 (Fast SI Response)
Slow	An IR MPDU request generates an SI MPDU response using the slow SI response procedure defined in 5.7.12.5 (Slow SI Response)

The process of determining capabilities interacts with bridging and power-saving, and can be time-consuming. For this reason, the result of a capability exchange is cached in the Capability Database.

5.11.2 Capability Service Interface

The capability service is accessed through a single primitive.

Primitive	CS_GET_CAPABILITIES			
Description	Returns the capability information about an address			
Parameters	**Req**	**Conf**		
Address	M	M		

[137] This is true, even for MPDUs that have not been transmitted yet. For example, a node may observe a *Wake-up successful* event for a node for which it has a CPS *Wake-up* request in its CPS transmit queue.

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Capability Record		M		
Notes:	M - Mandatory			

The *Address* parameter contains the MAC address of the MAC endpoint for which capabilities are to be reported.

The *Capability Record* contains the information specified in 5.11.7.1 (Capability Record) relating to the requested MAC address.

5.11.2.1.1 Effect of CS_GET_CAPABILITIES Request

A node that receives this request shall perform a lookup in the Capability Database using the specified address.

If present, the matching record shall be returned. Otherwise, the node shall perform the *Capability Request Procedure* defined in section 5.11.3 (Capability Request Procedure). On completion of this exchange, the node shall update its capability database and return the new *Capability Record*.

5.11.3 Capability Request Procedure

The capability procedure is managed by the *Capability Request State Machine*. A node shall support at least one instance of this state machine. [138]

5.11.3.1 Capability Request States

The states of the state machine are described in Table 187.

Table 187 - Capability Request States

State	Description
Idle	Ready to accept a CS_GET_CAPABILITIES request
Pending CP Response	Having transmitted a CPS *Wake-up* request, the node is waiting for a response from the CP
Pending PS Response	Having established that the desired MAC address is a power-saver, waiting for the node to wake-up
Pending Wake-Up	Having received a *Wake-up* event, the node is waiting for a *Wake-up successful* event for the desired MAC address
Pending SI Response	The node is waiting for an SI MPDU

Nodes that are power-supporters (see section 5.18.7.4 (Unicast Power-Supporting Node)) shall support all states. A node that is not a power-supporter can ignore the shaded states and associated transitions.

5.11.3.2 Capability Request Events & Conditions

The events and conditions that drive the operation of the state machine are defined in Table 188.

Table 188 - Capability Request Events and Conditions

Event / Condition	Definition
CS_GET_CAPABILITIES request	
Wake-up Denied	A CP2 Beacon is received carrying a *Wake-up Denied* event for the specified MAC address

[138] An implementation is likely to support a single instance, or an instance per record in the Capability Database.

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Event / Condition	Definition
No CPS Response	Transmission of the CPS request MPDU using the procedures specified in section 5.10.3.2 (CSMA/CA CPS Transmit) completed with failure status
Wake-up Signaled	A CP2 Beacon is received carrying a *Wake-up* event for the specified MAC address
Wake-up Succeeded	A CP2 Beacon is received carrying a *Wake-up successful* event for the specified MAC address
Wake-up Failed	A *PSinterval* after entry to the *Pending PS Response* state
SI Response	An SI MPDU is received containing the specified MAC address in its *Source Address* field
IR Tx Fails	The transmission of the IR request using the procedure defined in section 5.11.4 (Tx Capability Request) resulted in failure as defined in section 5.11.5 (IR MPDU Transmit Retry)
Try PS	The *Synchronization State* is *Managed* (see section 5.16.4 (Synchronization State Machine)) and the node is a power-supporter (see section 5.18.7.4 (Unicast Power-Supporting Node))

5.11.3.3 Capability Request State Transitions

Figure 151 shows the state transition diagram for the Capability state machine.

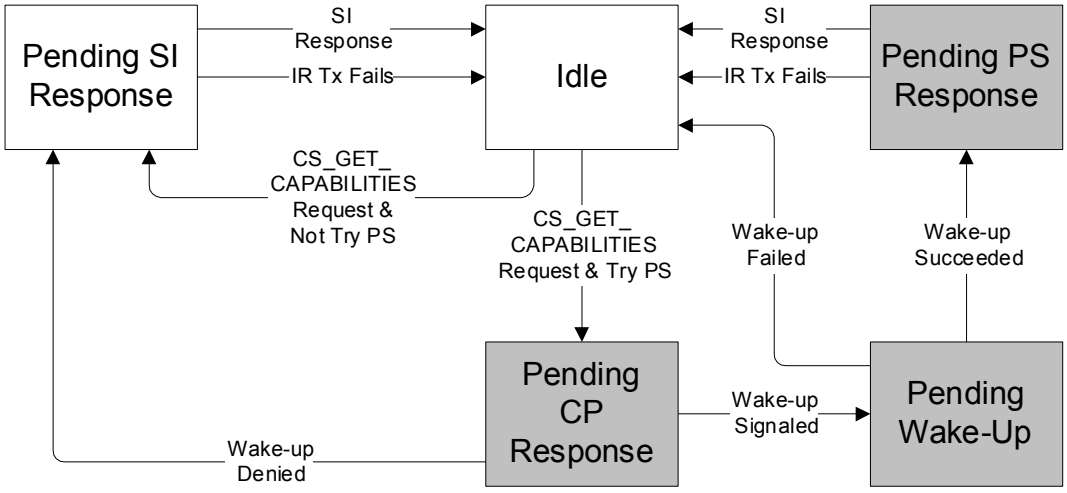


Figure 151 - Capability State Transition Diagram

The state machine for the CP is slightly modified. It does not need to perform the CPS request, but can determine the power-saving state of the destination address from its own stored data.

Sections 5.11.3.4 (Idle State) to 5.11.3.8 (Pending SI Response) contain descriptions of the actions performed in each state.

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5.11.3.4 Idle State

Event	Action	Next State
CS_GET_CAPABILITIES & Try PS	Transmit a CPS request MPDU carrying a wake-up request for the specified MAC address using the procedure specified in section 5.10.3.2 (CSMA/CA CPS Transmit)	Pending CP Response
CS_GET_CAPABILITIES & Not Try PS	Transmit a Capability request using the procedure defined in section 5.11.4 (Tx Capability Request)	Pending SI Response

5.11.3.5 Pending CP Response

Event	Action	Next State
Wake-up Signaled		Pending Wake-Up
Wake-up Denied	Transmit a Capability request using the procedure defined in section 5.11.4 (Tx Capability Request)	Pending SI Response

5.11.3.6 Pending Wake-Up

Event	Action	Next State
Wake-up Succeeded	Transmit a Capability request using the procedure defined in section 5.11.4 (Tx Capability Request)	Pending PS Response
Wake-up Failed	Create a *Capability Record* for this MAC address showing it to be non-bridged, capabilities unknown	Idle

5.11.3.7 Pending PS Response

Event	Action	Next State
SI Response	Create *Capability Record* for this MAC address showing non-bridged, and containing the capabilities in the SI MPDU	Idle
IR Tx Fail	Create a *Capability Record* for this MAC address showing it to be non-bridged, capabilities unknown	Idle

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5.11.3.8 Pending SI Response

Event	Action	Next State
SI Response	Create *Capability Record* for this MAC address showing non-bridged, and containing the capabilities in the SI MPDU	Idle
IR Tx Fails	Create *Capability Record* for this MAC address showing it to be unknown	Idle

5.11.4 Tx Capability Request

In order to transmit a capability request, the node shall format an IR MPDU and transmit it using the CSMA/CA access mechanism.

The IR MPDU shall contain the capabilities of the HomeRF node as defined in section 5.4.10.3 (Capabilities).

The address fields of the MPDU shall be as defined in Table 189.

Table 189 - IR MPDU Field Settings

Field	Contains
Destination Address	MAC Address of node from which capabilities are required
Source Address	MAC Address of local MAC entity

5.11.5 IR MPDU Transmit Retry

Successful transmission of an IR MPDU is indicated by reception of an SI MPDU from the node to which the IR MPDU is addressed.

A node that has transmitted an IR MPDU and that has not received a response within *NumCheckCPB* superframes should retransmit the IR MPDU.

The IR MPDU shall not be transmitted more than *MaxNumCPSR* times in the same Capabilities Request state. Failed transmission of an IR MPDU occurs after *MaxNumCPSR* such response timeouts.

5.11.6 IR MPDU Response

A node that supports CSMA/CA and that receives an IR MPDU shall transmit an SI MPDU containing its capabilities.

The SI MPDU shall be transmitted using the CSMA/CA access mechanism and either the slow response procedure (defined in section 5.7.12.5 (Slow SI Response)) or the fast SI response (defined in section 5.7.12.4 (Fast SI Response)).

5.11.7 Capability Database

This table holds detail about how to communicate a destination MAC address. It contains a number of *Capability Records*. A node should support at least 4 such records.

5.11.7.1 Capability Record

Table 190 defines the logical fields [139] contained within each *Capability Record.* When a capability record is created, its contents shall be set to the values defined in the *Initial Value* column of this table.

[139] There can be other implementation-dependent fields that manage the records (*e.g.* timers and Capability request state). An implementation can structure this information in any convenient way.

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Table 190 - Capability Record Fields

Field	Initial Value	Representation	Description
Destination Address	A valid value is required to created a record	IEEE MAC address (6 bytes)	MAC address of entity
Location State	*Unknown*	One of: *Local, Bridged, Unknown*	*Local* - Destination is part of the local HomeRF network *Bridged* - Destination can be reached through a HomeRF bridge *Unknown* - Nothing is known about the location of the destination
Bridge Address	Undefined	IEEE MAC address (6 bytes)	If location is *Bridged,* address of HomeRF node through which the destination MAC entity can be reached. Otherwise undefined.
Capability State	*Unknown*	One of: *Known, Unknown*	Indicates whether the *Capabilities* field is valid or not
Capabilities	zero	Includes the *Managed Capabilities* (see section 5.4.10.3.2 (Managed Capabilities Field)) and *Base Capabilities* (see section 5.4.10.3.1 (Base Capabilities)) fields	The capabilities relate to the destination address if the location is *Local*, otherwise they relate to the bridge address.
Tx CSDU Sequence Number	zero	2 bits as for the CSN (see section 5.4.4.14.3 (CSN / FragSN Field))	Contains the transmit sequence number for the next transmitted CSDU
Rx CSDU Sequence Number	zero	2 bits as for the CSN (see section 5.4.4.14.3 (CSN / FragSN Field))	Contains the receive sequence number for the last received CSDU

Support for the *Tx CSDU Sequence Number* and *Rx CSDU Sequence Number* is optional.

5.11.7.2 Updating the Capability Database

A BAN supports the capability request procedure defined in 5.11.3 (Capability Request Procedure).

It shall also support the Capability Record learning procedures defined in section 5.12.10 (Capability Record Learning Procedures).

5.11.7.3 Expiry of Capability Records

A node should remove entries from its station information database after *CapabilityRecordExpiryTime* has elapsed without successfully transmitting or receiving a unicast DATA MPDU to or from that node.

A node should reset the Location State and Bridge Address entries for all of the nodes in its station information database after it has roamed from one Connection Point to another. All Location States should return to the initial value *Unknown*, and Bridge Addresses should return to the initial value *Undefined*. This will enable the roaming capable node to determine if any nodes to which its communications were previously bridged are now accessible as peer-to-peer.

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5.12 MD-SAP Service

The MD-SAP service entity provides the asynchronous data service. A node that provides the MD-SAP service shall perform the procedures defined in this section.

5.12.1 Architecture

The MD-SAP service is the client of the CSMA/CA access mechanism. It is responsible for the following:

- MD-SAP Header Insertion / Extraction
- Compression
- Encryption
- CSDU Sequence Number Generation and Duplicate Removal (optional)
- Forwarding of Multicast MSDUs (CP only)
- Operation of Power-saving support feature

The service provides the interface to higher layers defined in section 5.2.1 (MD-SAP Data Service).

Optional parameters associated with the MD_DATA service primitives indicate whether the MSDU should be compressed or encrypted or whether it can be sent via the *Fast Unacknowledged Service Mechanism* of the CSMA/CA Access Mechanism.

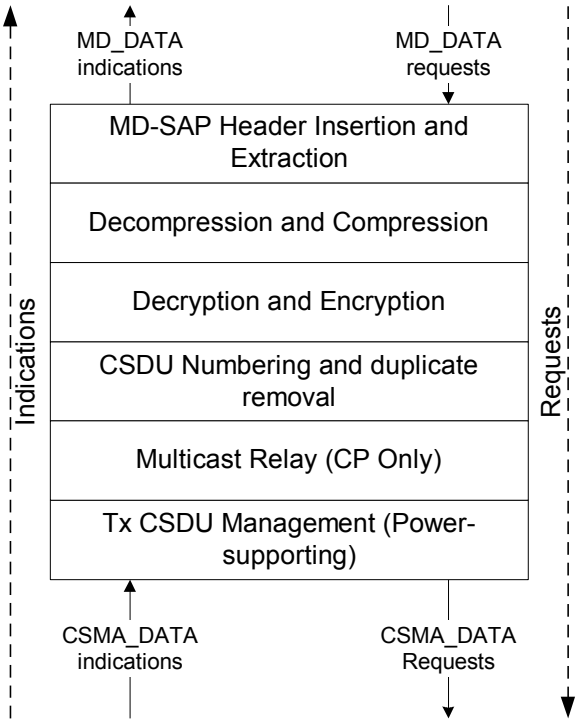


Figure 152 - MD-SAP Service Architecture

Where a feature is not supported or not selected, the primitives are passed through that feature layer unmodified.

5.12.2 Mapping Ethernet/802.3 Media to MD_DATA (Informative)

The MD_DATA primitives support the transport of Ethernet/802.3 [12] frames using the mapping defined in this section. The form of the MD_DATA primitives was chosen to provide this support because the Ethernet/802.3 media-type is supported by all likely host operating systems, whereas a native HomeRF frame format is not.

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Most networking protocols (like TCP/IP, IPX) are based on the Ethernet II/DIX frame format shown in Figure 153.

8 bits	*48 bits*	*48 bits*	*2 bytes*	*variable*	*variable*	*4 bytes*
Start Of Frame	Dest Address	Source Address	Ethernet type	Payload	Padding	CRC

Figure 153 - Ethernet II/DIX Frame Format

Another Ethernet frame format exists, the 802.3 format, which is slightly different. This is shown in Figure 154.

8 bits	*48 bits*	*48 bits*	*2 bytes*	*variable*	*variable*	*4 bytes*
Start Of Frame	Dest Address	Source Address	Ethernet size	Payload	Padding	CRC

Figure 154 - Ethernet 802.3 Frame Format

Both formats are compatible. The Ethernet type field indicates either which protocol is used (*e.g.* IP, ARP, IPX) or that the frame is in the 802.3 format. 802.3 Framing is very rarely used, but is automatically supported by supporting Ethernet II/DIX framing.

The padding used to guarantee a minimum size of the Ethernet frame for transmission on Ethernet and can be omitted from the HomeRF MSDU.

The mapping between Ethernet II/DIX frames or 802.3 frames and the MD_DATA primitive is straightforward. The Ethernet Start of Frame, padding and CRC are ignored. The destination address, source address and Ethernet type/size map directly to parameters of the MD_DATA primitive. The Ethernet payload maps to the MSDU parameter of the MD_DATA primitives.

An implementation actually is required to map between the format of the Ethernet/802.3 media-type primitives supported by the Operating System, and the MD_DATA primitives. The Operating System primitives generally do not include the fields that should be discarded.

5.12.3 CSDU structure

The CSDU is the unit of data transport provided by the CSMA/CA access mechanism. The MSDU is the unit of data transport that is provided by the MD-SAP data service to its clients. The procedures operated by the MD-SAP services map the MSDU and other parameters associated with the MD_DATA primitives into a CSDU and the other parameters associated with the CSMA_CA_DATA primitive.

The structure of the CSDU depends on the data service's *Service Control* (SC) parameters listed in Table 191.

Table 191 - CSDU Service Control Parameters

SC Parameter	**Description**
Encrypted	Indicates whether encryption is used or not
Compressed	Indicates whether compression is used or not
Bridged	Indicates whether the long (bridged) or short (not bridged) MD-SAP header is used

Figure 155 shows how the format of the CSDU relates to that of the MSDU. The MD-SAP header is defined in 5.12.4 (MD-SAP Header). The Compression PDU is defined in 5.12.6.2 (Compression PDU structure). The IV and encryption process are defined in 5.12.5 (MD-SAP Encryption Layer).

If there is no encryption and no compression, the CSDU contains the MD-SAP header field followed by the MSDU.

If there is encryption, the CSDU contains the encryption PDU. If there is compression and no encryption, the CSDU contains the compression PDU.

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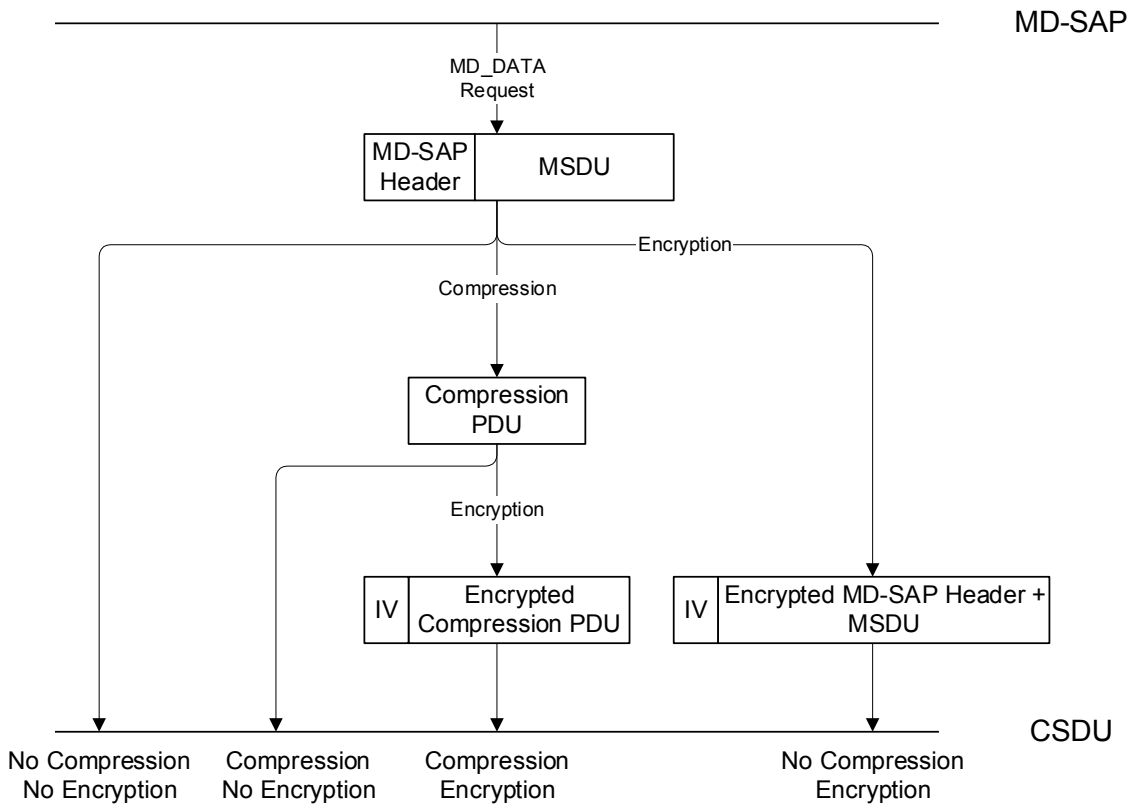


Figure 155 - CSDU Structure related to Service Attributes

5.12.4 MD-SAP Header

5.12.4.1 MD_SAP Header Structure

The MD-SAP header carries some of the MD_DATA service attributes.

There are two forms of MD-SAP: long and short. The short form (Figure 156) carries only the Ethertype attribute. The long form (Figure 157) carries the Ethertype attribute and the source and destination address field.

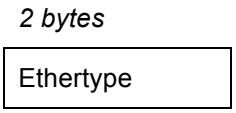


Figure 156 - Short MD-SAP Header Structure

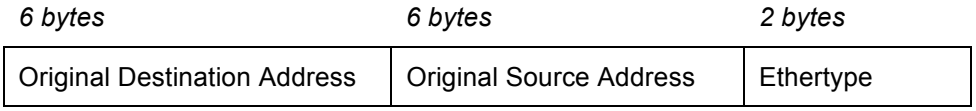


Figure 157 - Long MD-SAP Header Structure

5.12.4.1.1 Ethertype (Informative)

The Ethertype is a two-byte string passed from the higher layers of the networking stack. Its purpose is to identify the protocol encapsulated in the HomeRF frame.

The Ethertype used in HomeRF are compatible with the Ethernet Ethertype as defined in the Ethernet II/DIX specification. The list of Ethertype over Ethernet is managed by the IEEE. In most of the cases, a small number of different Ethertypes are used (like the one for IP: 0x0800).

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The use of the Ethernet type/ size field in the CSDU is an integral part of this specification. In the majority of the cases, this use is compatible with Ethernet.

5.12.4.1.2 Ethertype Field Encoding

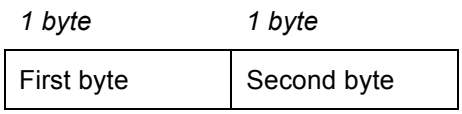


Figure 158 - Ethertype Field Structure

The *Ethertype* parameter of the MD_DATA primitive is encoded with the most significant byte transmitted first followed by the least significant byte.

5.12.4.1.3 Ethertype Field Encoding - Notes (Informative)

The byte ordering of the Ethertype is specified in the Ethernet DIX and 802.3 specification (high order byte transmitted first). For 802.3, the Ethertype might be the length of the payload.

This ordering is an exception to the little-endian byte ordering used elsewhere within HomeRF for Asynchronous data.

5.12.4.2 MD-SAP Support for Bridging (Informative)

The HomeRF architecture supports bridging just above the MAC level.

MAC-level bridging is attractive because it makes no assumptions about the higher-layer protocols, and requires no user configuration.

There are broadly two different types of bridge: transparent and source router. These types are described in Table 192.

Table 192 - Different Types of Bridging

Type of Bridging	**Characteristics of End-Node**	**Characteristics of Bridge**
Transparent	Not aware of bridging	Receives promiscuously, routes traffic between ports
Source Routing	Has to understand bridged status of intended destination	Receives multicast traffic and traffic addressed to the bridge, routes traffic between ports

Because promiscuous reception of unicast data is not reliable in a wireless network (see section 5.7.12.3.2 (Promiscuous DATA Reception (Informative))), HomeRF uses source routing for the HomeRF port. This results in placing mandatory requirements on all A-nodes and CPs, as well as requirements on a device that is a HomeRF bridge. The HomeRF source routing does not emerge above the MAC layer so that, from the perspective of MAC entities on the non-HomeRF ports, any bridging is done transparently.

There are either 2 or 4 MAC addresses associated with an MD_DATA request or indication according to the *Not Bridged / Bridged* state of the MPDU payload header.

These addresses are interpreted as described in Table 193.

Table 193 - Interpretation of Address Fields

		MPDU Header (CSMA_CA_DATA parameter)		**MD-SAP Header (MD_DATA parameter)**	
Bridging Status	**Used for**	**Destination**	**Source**	**Destination**	**Source**
Not Bridged	Traffic between HomeRF nodes	Destination HomeRF node	Originator HomeRF node	N/A	N/A

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Destination Bridged	Traffic bridged to a non-HomeRF network	Destination HomeRF bridge address	Originator HomeRF node	Destination non-HomeRF address	Originator HomeRF node
Source Bridged	Traffic bridged from a non-HomeRF network	Destination HomeRF node	Source HomeRF bridge address	Destination HomeRF node	Originator non-HomeRF address
Both Bridged	Traffic using a HomeRF segment to connect two non-HomeRF networks	Destination HomeRF bridge address	Source HomeRF bridge address	Destination non-HomeRF address	Originator non-HomeRF address

5.12.4.3 Insertion of MD-SAP Header

A node shall select between short and long MD-SAP headers and format its contents as defined in this section.

A node that receives an MD_DATA request addressed to a unicast address shall issue a CS_GET_CAPABILITIES request (see section 5.11.2 (Capability Service Interface)) to determine the destination bridged status (and possible bridge address). The attributes described in Table 194 are then evaluated.

A node that receives an MD_DATA request addressed to a multicast address shall consider the destination to be *Not Bridged*. The *Source Bridged Status* attribute described in Table 194 is then evaluated.

Table 194 - Derived Attributes of the MD_DATA Request

Request Attribute	**Description**
Destination Bridged Status	*Not Bridged* if the destination address is known to be a HomeRF node *Bridged* if the destination address can be reached through a HomeRF bridge *Unknown* if the capability exchange process cannot locate the capabilities of the destination address
Source Bridged Status	*Bridged* if the node is a HomeRF bridge, and the requested source address is not the MAC address of the node. *Not Bridged* otherwise.

If the both source and destination bridged status are *Not **Bridged***, the node shall pass down the data request with the contents defined in Table 195.

Table 195 - "Not Bridged" CSDU Request Parameters

CSMA_CA_DATA Request Parameter	**Contents**
DA	Set to the requested destination address
SA	Set to the MAC address of the node
CSDU	The short MD-SAP header containing the requested Ethertype, followed by the MSDU
Bridged Parameter	*Not Bridged*

Otherwise, the node shall pass down the data request with the contents defined in Table 196.

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Table 196 - "Bridged" CSDU Request Parameters

CSMA_CA_DATA Request Parameter	Contents
DA	If the destination is *Bridged*, set to the *Bridge Address* returned by the capability exchange process. If the destination is *Unknown*, set to the broadcast address.
SA	If the node is a HomeRF bridge, the requested source address. Otherwise, the MAC address of the node.
CSDU	The long MD-SAP header containing: · The requested destination address · The requested source address (HB) or the node's MAC address (non-HB) · The requested Ethertype Followed by the requested MSDU
Bridged Parameter	*Bridged*

5.12.4.4 Extraction of MD-SAP Header

A node that receives a CSMA_CA_DATA indication (possibly after decryption and decompression) shall (except as described below) indicate this as an MD_DATA indication, with parameters set as specified in Table 197. The CSDU is interpreted as either a short or a long MD-SAP header followed by an MSDU. The short header is used for the *Not Bridged* case. The long header is used for the *Bridged* case.

A node that is not a HomeRF bridge, and that receives a *Bridged* indication containing a unicast MD-SAP header destination address that is not the MAC address of the node shall discard the indication. [140]

Table 197 - MSDU Indication Parameters Related to CSDU Indication

Parameter	***Not Bridged***	***Bridged***
Destination Address	Destination Address attribute of the CSMA_CA_DATA indication	Destination Address field of the long MD-SAP header
Source Address	Source Address attribute of the CSMA_CA_DATA indication	Source Address field of the long MD-SAP header
Ethertype	The value of the Ethertype field of the short MD-SAP header	The value of the Ethertype field of the long MD-SAP header
MSDU	The MSDU field of the CSDU	The MSDU field of the CSDU

[140] Note that there are three classes of unicast MD_DATA indication that can be received by a BAN: unbridged unicast, bridged unicast and bridged multicast. Unbridged unicast corresponds to an originator within the HomeRF network. Bridged unicast corresponds to an originator outside the HomeRF network that has bridged through a HB that knows the existence of the destination node. Bridged multicast corresponds to an originator outside the HomeRF network that has bridged through a HB that does not know the existence of the destination node. Although a conversation between two nodes may start-up using bridged multicast, once the HB learns the destination address on the HomeRF network, it will switch to the more-reliable bridged unicast.

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5.12.5 MD-SAP Encryption Layer

5.12.5.1 Introduction (Informative)

The HomeRF MAC layer can include an encryption algorithm. The HomeRF encryption algorithm is designed for worldwide approval and exportation.

A node signals its encryption capabilities in SI MPDUs. Nodes always support communication using unencrypted MSDUs. Nodes only send encrypted MSDUs when the capabilities of the destination station are known.

All multicast traffic is sent unencrypted.

All nodes share a single common key. This is entered through the MIB, and has to be valid before the node can send or receive encrypted MSDUs.

The "core" of the encryption algorithm is common to both isochronous and asynchronous data services. All other aspects of encryption are specific to the asynchronous data service.

The encryption core algorithm takes a key, an initial-vector (IV) and unencrypted data (known as *plaintext*) and produces encrypted data (known as *ciphertext*).

5.12.5.2 Initialization Vector

The IV field has the structure defined in Figure 159.

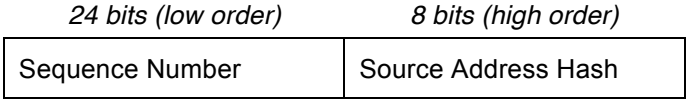


Figure 159 - Initialization Vector Structure

The *Sequence Number* field contains the MSDU transmit sequence number.

The *Source Address Hash* contains the byte-wide exclusive-or of the 6-bytes of the IEEE MAC address of the sender.

5.12.5.3 Sequence Number

A node that supports CSMA/CA encryption shall maintain a sequence number variable. This sequence number shall be incremented by 1 each time an MSDU is encrypted. Arithmetic shall be performed modulo 2^{24}.

5.12.5.4 Selection of Encryption

A node that has no *Key* value stored in the MIB shall transmit all MSDUs unencrypted.

A node shall transmit multicast MSDUs unencrypted.

A node shall only transmit an encrypted unicast MSDU to a node that it knows to support encryption. This capability can be discovered using the CS_GET_CAPABILITIES request (see section 5.11.2 (Capability Service Interface)).

A node should transmit encrypted unicast MSDUs to a node that it knows to support encryption. [141]

[141] The MD_DATA request allows the higher layers to request encryption for each MSDU. An implementation may choose to honor the encryption QoS, or modify it based on knowledge local to the MD-SAP services.

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5.12.5.5 Encryption PDU Structure

The encryption PDU structure is defined by Figure 160.

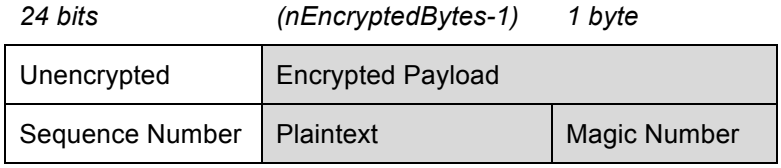


Figure 160 - Encryption PDU Structure

5.12.5.6 Magic Number (Informative)

The *Magic Number* is a single byte that contains zero. It is added to the end of a plaintext to be encrypted and transmitted as part of the encrypted payload.

The receiving node checks that, after decryption, the last byte of the encryption payload is zero. If it is not zero, it is highly likely that the two nodes must have different keys.

5.12.5.7 Encryption Process

If the node does not support encryption, or the request is not to be encrypted, then the encryption process shall pass the request and all its parameters down without modification. The plaintext to be encrypted is passed down from the compression process. [142]

To perform encryption, the node shall perform the following steps in sequence:

1. Update the *Sequence Number.* Derive an IV from it using the procedure defined in 5.12.5.2 (Initialization Vector).
2. Append a *Magic Number* byte of zero to the plaintext.
3. Perform the Encryption Core Algorithm defined in section 15.5 (Encryption Core Algorithm) on the key, IV and the output of step 2.
4. The Encryption PDU is formed from the *Sequence Number* and the output of step 3.
5. The Encryption PDU is passed down as a transmit request with the *Encrypted* SC flag set.

5.12.5.8 Decryption Process

If the indication does not have the *Encrypted* flag set, the decryption process shall pass the indication and all its parameters upward to the decompression process without modification.

If the indication does have the *Encrypted* flag set and the node does not support encryption, the indication shall be discarded.

Otherwise, to perform decryption, the node shall perform the following steps in sequence:

- Extract the source address from the MPDU header; extract the sequence number from the Encryption PDU. Derive an IV from them using the procedure defined in 5.12.5.2 (Initialization Vector).
- Perform the Encryption Core Algorithm defined in section 15.5 (Encryption Core Algorithm) on the key, IV and *Encrypted Payload*.
- Check that the *Magic Number* is a zero. If it is zero, indicate the plain-text upwards along with the other parameters of the indication. If the *Magic Number* is not zero, discard the indication.

5.12.6 Compression

5.12.6.1 Introduction (Informative)

The compression algorithm used by HomeRF is patent free and has adequate performance. It has been widely used and implemented.

The compression algorithm is described in the RFC 1951 (and RFC 1950). This is a LZ77 derivative, and has been extensively checked to be patent-free. The algorithm specified in RFC 1951 is one of the most efficient algorithms currently available and requires very little resource (memory and processor). This compression algorithm is used in gzip, Java and the PNG image format. Source code is already widely available.

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[142] Depending on whether compression has been performed, the plaintext either contains a compression PDU, or contains the Ethertype followed by the MSDU.

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5.12.6.2 Compression PDU structure

The structure of the compressed frame is the one described in the RFC 1950 document, but without the ADLER 32 CRC. [143]

4 bits	*4 bits*	*8 bits*	*32 bits (optional)*	*variable*
Compression method	Compression info	Flags	Preset dictionary	Compressed stream

Figure 161 - Compression PDU structure (based on RFC 1950)

5.12.6.3 Selection of Compression

A node shall send compressed MSDUs only to nodes that it knows to support compression. This capably can be discovered using the CS_GET_CAPABILITIES request (see section 5.11.2 (Capability Service Interface)).

A node can also decline to compress an MSDU based on any local implementation-dependent criteria.[144]

5.12.6.4 Compression Process

The input to the compression process is a request from the Ethertype insertion process (the input stream). The output is a request to the encryption process.

If compression is not supported or not to be used for this request, the compression process shall pass the request down without modification.

Otherwise, the compression process shall operate the procedures defined in RFC 1951 on the input stream. The resulting compression PDU is passed down to the encryption process along with the *Compressed* SC flag and the other parameters of the request.

5.12.6.5 Decompression Process

The input to the decompression process is an indication received from the decryption process. The output is an indication to the Ethertype extraction process.

If the indication does not have a *Compressed* flag, the indication shall be passed up to the Ethertype extraction process without modification.

If the indication does have the *Compressed* flag and the node does not support compression, the indication shall be discarded.

Otherwise, the decompression process shall operate the procedures defined in RFC 1951 on the indicated compression PDU. The resulting output stream is indicated to the Ethertype extraction process along with the other CSMA_CA_DATA indication parameters.

5.12.7 CSDU Numbering and Duplicate Removal

Support for these procedures is optional. A node should support these procedures unless its application layer is known to tolerate MSDU duplicates.

CSMA_CA_DA requests and indications that have a multicast destination address shall be passed through without modification.

5.12.7.1 CSDU Numbering and Duplicate Removal (Informative)

Duplication of MSDUs transported by the MD_DATA service should be tolerated by higher layer protocols such as TCP/IP.

An application that uses UDP can be exposed to duplication of its data packets caused by duplication within the HomeRF MAC layer. Although this behavior is expressly permitted by RFC768 for UDP, in practice many applications do not tolerate duplication because most commonly encountered MACs do not introduce duplicates.

For this reason, a node should support these procedures, unless it knows that the application tolerates duplication.

5.12.7.2 CSDU Numbering - CSDU Transmit Procedures

On receiving a CSMA_CA_DATA request that contains a unicast destination address, the node shall obtain a capability record for that destination address (using a CS_GET_CAPABILITIES request). [145]

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[143] The MAC CRC shields the MD_SAP processes from MAC channel errors, thereby providing a stream without errors.

[144] Such as available memory, or the compressibility of the MSDU.

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The node shall insert the *Tx CSDU Sequence Number* currently stored in the capability record in the CSMA_CA_DATA request's *CSN* parameter and pass it downward.

The node shall update the *Tx CSDU Sequence Number* value in the capability record as defined in Table 198.

Table 198 - Rules for Updating the Tx CSDU Sequence Number

Old Value	New Value
0 (zero) [146]	1
1	2
2	3
3	1

5.12.7.3 Duplicate Removal - CSDU Receive Procedures

On receiving a CSMA_CA_DATA indication that contains a unicast destination address, the node shall obtain a capability record for the source address (using a CS_GET_CAPABILITIES request). [147]

Depending on the value of the *CSN* parameter of the CSMA_CA_DATA indication, and the value of the *Rx CSDU Sequence Number* variable of the capability record, the node shall either pass the indication up to higher layers or discard it as defined in Table 199 [148].

Table 199 - Duplicate Removal Actions

Condition	Action
(*CSN = 0*) [149] or (*Rx CSDU Sequence Number = 0*) [150]	Indicate
CSN = Rx CSDU Sequence Number	Discard
Otherwise	Indicate

The node shall then update the capability record so that its *Rx CSDU Sequence Number* variable is set to the *CSN* parameter of the CSMA_CA_DATA indication.

5.12.8 Multicast Relay Process

This process shall pass unicast and multicast CSDU indications upwards without modification.

A node that is the active CP and that is providing multicast power-management services shall perform the procedures defined in section 5.18.8.3 (CP Multicast Power-Management Service). These procedures may result in multicast CSDUs also being queued for later re-transmission.

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[145] Note, that this record should exist as a side effect of the MD-SAP Header insertion process. If it does not, the node can create a new capability record set to the default values for this destination address.

[146] This value is only used once. In this case the capability record has just been created and sending a zero CSN value ensures that any duplicate removal process at the receiver lets the CSDU through.

[147] This is likely to exist, even if this is the first CSDU received from that source address, because of the operation of the Capability Learning Procedures. If it does not, a new capability record can be created for the source address in the CSDU. This will contain a suitable default value for the *Rx CSDU Sequence Number*.

[148] The conditions are evaluated in order down the table until one evaluates to *true*.

[149] This is the case if the transmitter has either created a new capability record or does not support CSDU numbering.

[150] This is the case if a new capability record has been created by the receiver.

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5.12.9 Tx CSDU Management Process

A node that supports transmission to power-saving A-nodes shall support the procedures defined in this section. Otherwise, requests shall be passed through without modification.

A request that specifies a Multicast CSDU shall be passed through without modification.

This process manages the transmission of CSDUs based on changes in the power-supporting state machine associated with a unicast destination address.

Two primitives are provided for use by the power-supporting state machine: *block(MAC address)* and *release(MAC address)*.

When a *block* primitive is received, this process shall ensure that any requests that subsequently arrive for the specified address are buffered internally. When a *release* primitive is received, all buffered requests are passed downward, in the order in which they were submitted to this process.

When a *block* primitive is received, the node can also remove CSDUs from the Tx Queue (regardless of whether they have started transmission or not) using the CSMA_CA_GET_TXCSDU request. When the *release* is received, this process passes these down as CSMA_CA_DATA requests ensuring that order is preserved.

A node can discard incoming CSDU requests (issuing a confirmation with failure status) for a blocked destination address if buffer resources become depleted according to implementation-dependent criteria.

5.12.10 Capability Record Learning Procedures

A BAN that receives a CSMA_CA_DATA indication containing a unicast CSDU should update the Capability Database (see section 5.11.7 (Capability Database)) according to the bridged state of the indication.

On receipt of a bridged unicast CSDU, the BAN should ensure that a *Capability Record* exists with the fields defined in Table 200.

Table 200 - Capability Record Settings for a bridged CSDU

Field	**Value**
Destination Address	MSDU Source Address
Location	Bridged
Bridge Address	CSDU Source Address

On receipt of an unbridged unicast CSDU, the BAN should ensure that a record exists with the fields defined in Table 201.

Table 201 - Capability Record Settings for an Unbridged CSDU

Field	**Value**
Destination Address	CSDU Source Address
Location	Local

5.12.10.1 Other Optional Learning Procedures (Informative)

A BAN can also update its Capability Database based on implementation-specific criteria. This section describes some possible options.

A BAN can also add or update entries in the table when it receives multicast CSDUs.

A BAN can update entries when it receives multicast non-DATA MPDUs.

A BAN can promiscuously receive unicast MPDUs and infer the MPDU source address is not bridged.

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5.13 MS-SAP Service

The MS-SAP service entity provides for access to the priority asynchronous data service. This SAP provides an interface to support the setup, tear down, and data transmissions that provide for the utilization of the priority asynchronous data service in support of streaming sessions. In essence, MS-SAP is a superset to the MD-SAP interface. It provides for the additional streaming session setup and tear down which is required to identify streaming sessions with an associated priority access to the priority asynchronous data service. See section 5.4.8 (Streaming Session Management MPDUs). Streaming session identity information (SID) is exported to the CSMA/CA access mechanism and the priority asynchronous data service that it provides. In all other respects, MS-SAP functions identical to that of the MD-SAP. See 5.12 (MD-SAP Service).

5.14 MC-SAP Services

Two services are accessed through the MC-SAP.

The C-Channel data service provides the reliable transport of its SDUs. These carry DECT DLC-layer PDUs.

The U-plane data service provides the isochronous transport of U-plane SDUs.

The procedures that provide these services are defined in these sections.

5.14.1 MC-SAP Services Connection

The C-Channel and U-plane data services are associated with a connection. The services are carried by a TDMA connection. The mechanism required to provide the MC-SAP Services on top of the TDMA connection is called an *MC-SAP Services Connection*.

The TDMA connection is managed (created and destroyed) using the procedures defined in section 5.20 (I-Node Management).

When the TDMA connection is in the *Active* state, it can carry C-Channel and U-plane SDUs in order to provide the C-Channel and U-plane data services. These services are managed by the MC-SAP services connection.

5.14.2 MC-SAP Services Connection State Machine

An MC-SAP services connection state machine instance shall exist for each TDMA connection that is in the *Active* state. This section defines the operation of this state machine.

5.14.2.1 MC-SAP Services Connection States

The states of this state machine are described in Table 202.

Table 202 - MC-SAP Services Connection States

MC-SAP Services Connection State	Description
FastC	The transmit C-Channel is operating in its *Fast* mode. The U-plane service is not enabled. This is the initial state of this state machine.
FastPendingAck	A C-Channel SDU set has been transmitted and not yet acknowledged
PendingSlowC	A request to enable the U-plane service has been received, but cannot be completed as there are C-Channel SDUs that have not been acknowledged
SlowC	The transmit C-Channel service is operating in its *Slow* mode. The U-Plane service is enabled.

5.14.2.2 MC-SAP Services Connection Events

The events that drive the MC-SAP Services Connection state machine are defined in Table 203.

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Table 203 - Events Relevant to the MC-SAP Services Connection State Machine

Event	Definition
U-plane Enable Request	An MC_UCONT(enable) request is received
U-plane Disable Request	An MC_UCONT(disable) request is received
FastTx	A C-Channel SDU set containing more than one C-channel SDU has been transmitted using the procedures defined in section 5.14.3.4.2 (Fast Mode Receive Procedures)
FastAck	An acknowledgement for a C-Channel SDU set has been received using the procedures defined in section 5.14.3.4.1 (Fast Mode Transmit Procedures)

5.14.2.3 MC-SAP Services Connection State Transition Diagram

Figure 162 shows the state-transition diagram for the MC-SAP Services Connection State machine.

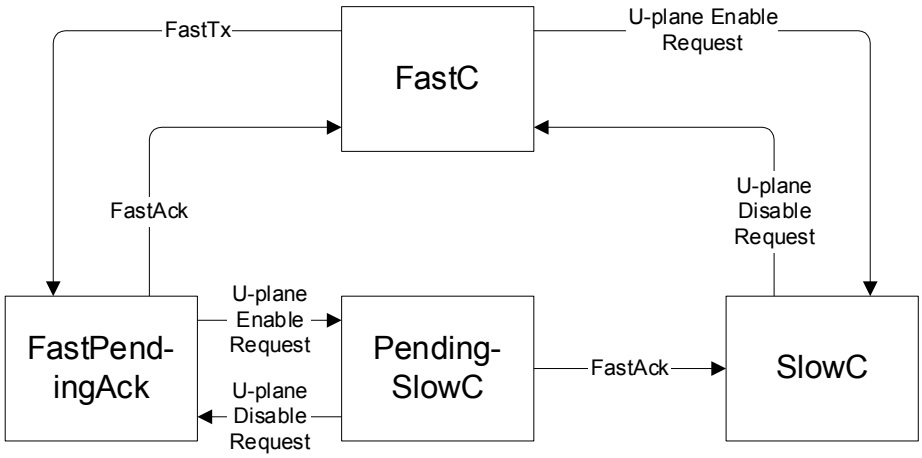


Figure 162 - MC-SAP Services Connection State Transition Diagram

5.14.2.4 MC-SAP Services State Procedures

5.14.2.4.1 FastC State

Event	Action	Next State
U-plane Enable Request		SlowC
FastTx		FastPendingAck

5.14.2.4.2 FastPendingAck State

Event	Action	Next State
U-plane Enable Request		PendingSlowC
FastAck		FastC

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5.14.2.4.3 PendingSlowC State

Event	Action	Next State
FastAck		SlowC
U-plane Disable Request		FastPendingAck

5.14.2.4.4 SlowC State

Event	Action	Next State
U-plane Disable Request		FastC

5.14.3 C-Channel Data Service

5.14.3.1 Introduction to C-Channel Data Service (Informative)

These procedures describe how the C-channel connection-oriented data service is provided on top of the raw TDMA frame exchange.

Each direction of the C-channel is considered separately. The Class-1 CP and I-node operate identical procedures.

The C-channel operates in one of two modes: fast or slow. In fast mode, the TDMA MPDU can contain more than one C-channel SDU. In slow mode, it contains at most one C-channel SDU. Switching between the two modes is controlled by the transmitting node's MC-SAP Services Connection state machine.

Every CP and I-node is required to support both fast and slow C-channel operation.

5.14.3.2 C-Channel Data Service Variables

A node that has a TDMA connection in the *Active* state shall keep two sequence-numbers associated with the connection: one for transmit and one for receive. Arithmetic on the sequence-numbers is performed modulo 2. Both sequence numbers are initialized to the value 1 when MC-SAP services connection is created. [151]

5.14.3.3 Slow Mode

5.14.3.3.1 Slow Mode Transmit

A node shall follow the procedures defined in this section in order to send a C-Channel SDU on an MC-SAP connection that is in the *SlowC* state.

The sender shall increment the transmit sequence number.[152]

The sender shall transmit a TDMA MPDU in successive TDMA frames until a matching C-channel ACK sequence number is seen in the TDMA MPDUs received on this connection. This TDMA MPDU shall have the following contents:

- *FastC* flag set to zero
- *C-channel SDU* flag set to one
- Sequence number set to the transmit sequence number
- C-channel SDU copied into the C-channel SDU field

A node that has no C-channel SDU to transmit shall transmit a TDMA MPDU with the following contents:

- *FastC* flag set to zero
- *C-channel SDU* flag set to zero
- Sequence number is undefined

[151] Which causes the first transmitted C-Channel SDU or SDU set to have the sequence number 0.

[152] Add 1 modulo 2.

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- C-channel SDU field is undefined

5.14.3.3.2 Slow Mode Receive

A node that has a TDMA connection in the *Active* state, and that receives a TDMA MPDU with the *fastC* field set to zero shall follow the procedures defined in this section

A node that receives a valid TDMA frame with the *C-channel SDU* field showing a single SDU and with a sequence number different from the last received sequence number has received a new C-channel SDU.

A node that receives a new C-channel SDU shall insert an acknowledgement for the received C-Channel sequence number by inserting this sequence number in the C-Channel ACK sequence number field of any TDMA MPDUs it transmits on this connection. The node may defer this acknowledgement until there is room to buffer the C-channel SDU in order to indicate it to its higher layers.

The node shall indicate this received C-channel SDU by emitting an MC_CDATA indication.

5.14.3.4 Fast Mode

5.14.3.4.1 Fast Mode Transmit Procedures

A node shall follow the procedures defined in this section in order to send C-Channel SDUs on an MC-SAP connection that is not in the *SlowC* state.

A node that has C-channel SDUs that have not been transmitted, and that has no unacknowledged C-channel SDUs can choose a number of SDUs to transmit. [153] These SDUs form its *SDU set.*

The node shall increment the transmit sequence number [154]. The sequence number applies to the whole SDU set.

A node that has transmitted an SDU set shall not modify the contents of the SDU set in any way. [155]

A node that has transmitted an SDU set and received an acknowledgement shall discard all the SDUs in the SDU set. [156]

A node that has an unacknowledged SDU set shall transmit this SDU set in successive TDMA MPDUs until a matching C-channel ACK sequence number is seen in a TDMA MPDU received on this connection. The transmitted TDMA MPDU shall have the following contents:

- *FastC* flag set to one
- NC field set to the number of C-Channel SDUs in the SDU set
- Sequence number set to the transmit sequence number
- C-channel SDUs copied into the C-channel SDU fields in the order that they were received through MC_CDATA requests. Unused C-channel SDU fields are undefined.

A node that has no C-channel SDU set to transmit shall transmit a TDMA MPDU with the following contents:

- *FastC* flag set to one
- NC field set to zero
- Sequence number is undefined
- C-channel SDU fields are undefined

5.14.3.4.2 Fast Mode Receive Procedures

A node that has a TDMA connection in the *Active* state, and that receives a TDMA MPDU with the *fastC* field set to one shall follow the procedures defined in this section

A node that receives a valid TDMA frame with the NC field showing number of SDUs greater than zero and with a sequence number different from the last received sequence number has received a new C-channel SDU set.

---

[153] There is no specification of how and when the sender makes this choice.

[154] Add 1 modulo 2.

[155] For example, to change the number of SDUs in the SDU set.

[156] This means that the receiver should not acknowledge the SDU set until it has indicated all the SDUs to its higher layers.

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A node that receives a new C-channel SDU set shall insert an acknowledgement for the received C-Channel sequence number by inserting this sequence number in the C-Channel ACK sequence number field of any TDMA MPDUs it transmits on this connection. The node may defer this acknowledgement until there is room to buffer the C-channel SDU set in order to indicate it to its higher layers.

The node shall indicate all received C-channel SDUs in the order they were received by emitting an MC_CDATA indication for each C-channel SDU.

5.14.4 U-Plane Services

An I-node or Class-1 CP that has a TDMA connection that is not in the *Idle* state shall perform the procedures defined in this section.

5.14.4.1 U-Plane Transmit

When the TDMA connection enters either the *Setup* state for the CP or the *Active* state for the I-node, the node shall define a *transmit reference point* relative to its *DwCount* (defined in section 5.5.2.1 (Hop Management)) for the MC-SAP connection.

The *transmit reference point* for the CP shall be no later than the first B-field bit of the main downlink slot assigned for the first TDMA MPDU transmitted when the *Setup* state was entered (defined in section 5.18.3.6) plus the time for the maximum number of uplink slots. See Table 204- Calculation of the Transmit Reference Point at the CP.

Table 204- Calculation of the Transmit Reference Point at the CP

n = Main slot # of first TDMA MPDU transmitted
DwCount at transmit reference point = (n+MaxMCconnections) x MainDuration + ((n+ MaxMCconnections - 2) x TIFS) + SIFS

The *transmit reference point* for the I-node shall be no later than the first B-field bit of the main uplink slot assigned for the first TDMA MPDU transmitted when the *Active* state was entered (defined in section 5.18.4.7). In every TDMA epoch in which the MC-SAP connection is in the *SlowC* state, at precisely the *transmit reference point*, the node shall issue an MC_UDTR indication to its higher layers. The higher layers will respond with an MC_UDATA request. The U-plane SDU contained in this request shall be transmitted in the B-field of all TDMA MPDUs (*i.e.- main* and *retry*) transmitted during the current TDMA epoch.

If main TDMA MPDU B-field data is invalid for any reason [157], the TDMA MPDU shall be transmitted with the *B-Field Present* field set to zero.

The *transmit reference point* shall remain constant regardless of any main slot position re-ordering for this connection.

5.14.4.2 U-Plane Receive

When a TDMA connection enters either the *Setup* state for the CP or the *Active* state for the I-node, the node shall define a *receive reference point* relative to its *DwCount* (see section 5.5.2.1 (Hop Management)) for the MC-SAP connection.

An I-node shall define the *receive reference point* so that it is no earlier than the last bit of the TDMA downlink retry slot calculated as 5 minus the main slot assigned when the *Active* state was entered (defined in section 5.18.4.7) plus the maximum CFP1 Offset. See Table 205 - Calculation of the Receive Reference Point at the I-node.[158]

Table 205 - Calculation of the Receive Reference Point at the I-node

n = 5 - Main slot # of first TDMA MPDU transmitted when the Active state was entered

[157] Such as failure by the higher layers to generate a MC_UDATA request.

[158] The I-node knows that the CP will assign retry slots in the same temporal order within the frame as the corresponding main slots.

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MaxCFP1Offset = HopDuration + MaxBeaconPeriodDuration

DwCount at receive reference point = (SubframeDuration / BasicModulationSymbolDuration) – MaxCFP1Offset – SIFS - (n x RetryDuration) – ((n-1) x TIFS)

A Class-1 CP shall define the *receive reference point* so that it is no earlier than the last bit of the TDMA uplink retry slot calculated as 5 minus the main slot assigned when the *Setup* state was entered (defined in section 5.18.3.6) plus the maximum CFP1 Offset plus the maximum number of downlink slots See Table 206 - Calculation of the Receive Reference Point at the CP.

Table 206 - Calculation of the Receive Reference Point at the CP

n = 5 - Main slot # of first TDMA MPDU transmitted when the Setup state was entered

MaxCFP1Offset = HopDuration + MaxBeaconPeriodDuration

DwCount at receive reference point = (SubframeDuration / BasicModulationSymbolDuration) –- MaxCFP1Offset – (2 x SIFS) – ((n+MaxMCconnections) x RetryDuration) - ((n+ MaxMCconnections -2) x TIFS)

For every TDMA epoch in which the TDMA connection is in the *Active* state and in which a TDMA MPDU has been correctly received on this connection carrying a B-Field, at precisely the *receive reference point*, the node shall issue an MC_UDATA indication to its higher layers that contains the received B-Field in the SDU parameter.

The *receive reference point* shall remain constant regardless of any main slot position re-ordering for this connection.

5.14.4.3 Other Constraints on the U-plane Service

The combined operation of the U-plane service and higher layers shall meet the delay constraints defined in section 7.6 (Combined Properties of Voice Stack and ADPCM Transcoder).

5.15 MB-SAP (ICBS) Services

This section defines procedures that shall be supported by a Class-1 CP or an I-node in order to provide the Isochronous Connectionless Broadcast services. These services are accessed by the higher layers through the MB-SAP.

Throughout this section, the terms C-Plane and U-plane are used to refer to the ICBS C-Plane and ICBS U-plane.

5.15.1 MB-SAP Procedures at the CP

A Class-1 CP shall operate the procedures defined in this section.

5.15.1.1 Introduction (Informative)

A Class-1 CP supports the procedures defined in this section in order to provide the Isochronous Connectionless Broadcast Services.

The CP keeps a queue of C-Plane SDUs for transmission across the ICBS-channel and a state machine to manage the timing of these transmissions and the isochronous transmission of U-plane SDUs. U-plane SDUs are not queued.

C-Plane SDUs and U-plane SDUs are carried by the ICBS-channel provided by the TDMA access mechanism. The operation of the ICBS-channel is defined in 5.8.7 (ICBS-channel Procedures). The MB-SAP Tx State Machine (defined in 5.15.1.4 (MB-SAP Tx State Machine)) is responsible for enabling and disabling the ICBS-channel.

5.15.1.1.1 MB-SAP Tx State Machine and ICBS-channel (Informative)

The ICBS-channel is activated by first heralding its activation to (potentially sleeping) I-nodes over a number of frame dwells that exceeds the maximum I-node sleep time (*ICBSHeraldingDuration* > *IPSinterval*). While performing this heralding, no SDUs are carried by the ICBS-channel. After the heralding has completed, the ICBS-channel can be used to transport C-Plane and U-plane SDUs.

If the U-plane is enabled, the ICBS-channel can carry at most one C-Plane SDU and one U-plane SDU. If the U-plane is disabled, the ICBS-channel can carry at most 9 C-Plane SDUs.

The C-Plane SDU(s) carried in a TDMA MPDU are called a C-Plane SDU set. The C-Plane SDU set is transmitted a fixed number (*ICBStransmitCount*) of times in order to increase reliability. The C-Plane SDU set is assigned a sequence number that is signaled in

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the TDMA MPDU. The number is incremented (modulo 2) for successive C-Plane SDU sets. The sequence number is used by the I-node to discard duplicate C-Plane SDU sets.

The ICBS-channel is released when there has been no traffic on the ICBS-channel for a timeout period.

5.15.1.1.2 Effect of MB-SAP Requests (Informative)

A CP that receives a MB_CDATA request adds the indicated C-Plane SDU to its Tx Queue or ignores the request if its Tx Queue is full.

The mandatory *QoS* parameter determines the delivery priority of SDUs. This parameter is only significant [159] when the Tx Queue holds more C-Plane SDUs than can be transported in the next C-Plane SDU set.

The optional *GroupID* parameter identifies a C-Plane SDU that is a state value update. A request with a *GroupID* that matches one that is already on queue is a more current state value and replaces any outdated entry that is on the queue. The *GroupID* mechanism is intended to support features such as cadence ringing where the current state should supercede the delivery of an outdated state that is still on the Tx Queue.

The optional *ConfirmationID* parameter causes a feedback confirmation to the higher layers when the associated SDU has been delivered. It is intended to provide a means of synchronizing the delivery of one type of SDU that is dependent on the completed delivery of another SDU. Take, for example, a voice announcement. The user may send an ICBS C-Plane SDU to page the I-nodes that are to be addressed with a voice announcement. Upon receipt of the confirmation for the page SDU, the CP can assume that the addressed I-nodes are ready for U-plane SDUs and can proceed with delivery of the U-plane SDUs containing the voice announcement.

The MB_UCONT primitive can be used to enable and disable the U-plane in any state of the MB-SAP Tx State Machine. However, only an MB_CDATA request can cause the MB-SAP Tx State Machine to leave the *Idle* state. MB_UDTR indications are generated only in the *Active* and *Empty* states (provided that the U-plane has been enabled). The MB-SAP Tx State Machine will only enter the *Idle* state when the U-plane has been disabled and no C-plane SDUs have been received for *ICBSemptyDuration* subframes. MB_UDATA requests are only valid when the ICBS U-plane is enabled and are accepted one per subframe.

[159] *i.e.* has an effect that can be seen above the MB-SAP

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5.15.1.2 Architecture

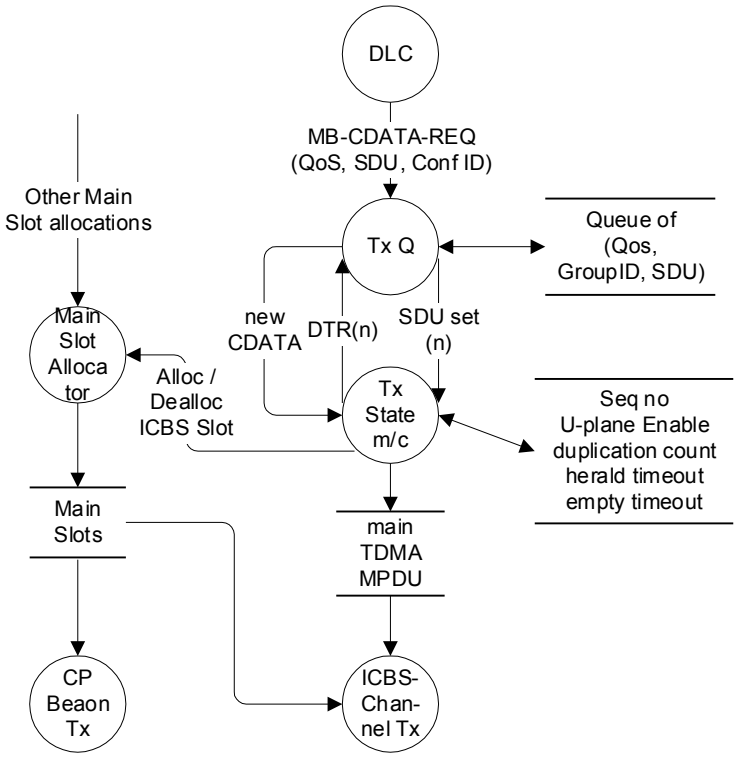


Figure 163 - MB-SAP Architecture at the CP

Figure 163 shows the (simplified) architecture of the MB-SAP services at the CP. The diagram does not show data-flows for the U-plane primitives or any mechanism to support MB_CDATA confirmations.

The higher layers pass MB_CDATA requests to the MB-SAP Tx Queue process. It is responsible for:

- Providing QoS and GroupID behavior
- Notifying the MB-SAP Tx State machine when new C-Plane SDUs arrive
- Returning a set of C-Plane SDUs, when requested by the MB-SAP Tx State machine
- Keeping a queue of pending MB_CDATA confirmations, which it emits as confirmations when requested by the MB-SAP Tx State machine

The MB-SAP Tx State Machine responds to new CDATA requests and MB_UCONT requests by allocating a main slot for the ICBS channel, and formatting a main TDMA MPDU for transmission by the ICBS-channel Transmit process (see section 5.8.7.2 (ICBS-channel procedures at the CP)). It generates MB_UDTR indications when it is ready to transmit U-plane SDUs. It generates timing for the duplication of C-Plane SDU sets and to set up and tear down the ICBS main slot.

5.15.1.3 MB-SAP Tx Queue Process

The Tx Queue process shall keep a queue of C-Plane SDUs, along with the QoS and any GroupID parameters. It shall also keep a queue of pending *ConfirmationID* values. This document does not define a size for these queues.

5.15.1.3.1 MB_CDATA Request

On receiving an MB_CDATA request, the Tx Queue process shall:

- If a *GroupID* is specified, remove any SDU with a matching *GroupID* from the Tx Queue [160]

[160] There should be at most one matching SDU

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- Either queue the specified C-Plane SDU, *QoS* and any associated *GroupID* and *ConfirmationID* in the Tx Queue or discard it[161].
- If the SDU was queued, generate a *New CDATA* signal to the MB-SAP Tx State Machine

5.15.1.3.2 Selecting a C-Plane SDU set for Transmission

The MB-SAP Tx State Machine generates requests to the Tx Queue process to return a C-Plane SDU set containing at most *n* SDUs. It generates this request when the Tx Queue is known to be non-empty.

In response, the Tx Queue process shall select at least one and at most *n* C-Plane SDUs from the Tx Queue such that:

- C-Plane SDUs with the highest QoS are selected first
- For any SDUs with the same QoS, the order in which they were presented to the MB-SAP is preserved in the order with which they are presented to the MB-SAP Tx State Machine

The Tx Queue process shall pass these SDUs to the MB-SAP Tx State machine for transmission and remove them from its Tx Queue. If any of the SDUs have an associated *ConfirmationID*, an entry containing this value is created in its Confirmation Queue.

5.15.1.3.3 Issuing C-Plane Confirmations

The MB-SAP Tx State Machine generates requests to the Tx Queue process to emit queued confirmations to the MB-SAP higher layers.

In response, the Tx Queue process shall emit an MB_CDATA confirmation for each entry in its Confirmation Queue containing the associated *ConfirmationID* value.

The Tx Queue shall emit these confirmations in the order that they were submitted to the MB-SAP Tx State Machine for transmission. It shall then remove all entries from the Confirmation Queue.

5.15.1.4 MB-SAP Tx State Machine

5.15.1.4.1 MB-SAP Tx State Machine States

The MB-SAP Tx State Machine states represent the state of the C-plane service provided by the ICBS channel. The U-plane service is controlled by the *U-plane Enable State* variable (see section 5.15.1.4.2 (Other State Variables)).

Table 207 enumerates the states operated by the MB-SAP Tx State Machine. It also shows whether the ICBS-channel is present and whether C-Plane and U-plane SDUs can be transported.

[161] The Tx Queue process can discard MB_CDATA requests according to implementation-defined criteria (*e.g.* if the Tx Queue is full).

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Table 207 - MB-SAP Tx States

State	Description	C-Plane	U-plane	ICBS-channel
Idle	The initial state of the state machine.	Disabled	Disabled	Disabled
Heralding	Waiting for I-nodes to all be awake and ready to receive the ICBS-channel	Disabled	Disabled	Enabled
Pending Data	In this state, the Tx Queue process has been asked to supply data but it has not yet responded. It is a transient state.	N/A	N/A	
Active	Transmitting the same C-Plane SDU set a fixed number of times, plus the current U-plane SDU if enabled	A C-Plane SDU set is being transmitted	Depends on U-plane Enable state	
Active Pending Enable	An MB_UCONT enable request has been received. Waiting to complete transmission of the current C-Plane SDU set before enabling the U-plane.	A C-Plane SDU set is being transmitted	Disabled.	
Empty	*No C-Plane SDUs are available for transmission.* Keeps in this state as long as the U-plane is enabled or for a fixed number of subframes without C-plane SDUs before returning to *Idle*.	Empty	Depends on U-plane Enable state	

Notes	N/A - Not applicable as this is a transient state

5.15.1.4.2 Other State Variables

In addition to its state variable, the variables defined in Table 208 are maintained by the MB-SAP Tx State machine.

Table 208 - MB-SAP Tx State Machine Variables

Variable	Definition
Heralding Count	The number of successive subframe dwells that the state machine has been in the *Heralding* state
Empty Count	The number of successive subframe dwells that the state machine has been in the *Empty* state with the U-plane disabled
Transmit Count	The number of successive subframe dwells that the current set of C-Plane SDUs has been transmitted
U-plane Enable State	One of: *disabled, enabled*
U-plane SDU valid	Indicates whether the *U-plane SDU* variable contains a valid U-plane SDU. One of: *true, false*.

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U-plane SDU	Holds the last U-plane SDU requested by the higher layers
C-Plane SDU set	Holds the last set of C-Plane SDUs returned by the MB-SAP Tx Queue process
C-Plane sequence number	Holds the sequence number for the *C-Plane SDU set*

5.15.1.4.3 MB-SAP Tx State Machine Events

Table 209 defines the events and conditions that drive the operation of the MB-SAP Tx state machine at the CP.

Table 209 - MB-SAP Tx State Machine Events & Conditions

Event / Condition	**Definition**
New CDATA	A signal from the MB-SAP Tx Queue process indicating that an MB_CDATA request has been received
Tick	The tick event occurs at the start of each subframe
Heralding Completed	*Heralding Count = ICBSheraldingDuration*
SDU set	The MB-SAP Tx Queue process has returned a set of C-Plane SDUs
UCONT	An MB_UCONT request has been received from higher layers
Empty Expired	*Empty Count = ICBSemptyDuration*
Done	*Transmit Count = ICBStransmitCount*
Queued Data	The transmit queue within the MB-SAP Tx Queue process is not empty
No Queued Data	! Queued Data
Notes: ! = logical negation	

The events defined in Table 210 are handled by the state machine without causing state transitions

Table 210 - MB-SAP Tx State Machine - Additional Events

Event	**Definitions**
UDTR Tick	Occurs once per subframe at the *UDTR Reference Point* (defined in section 5.15.1.6 (UDTR Reference Point)).
UDATA	An MB_UDATA request has been received from higher layers

5.15.1.4.4 MB-SAP Tx State Transition Diagram

Figure 164 shows the state transitions of the MB-SAP Tx State machine. Events that do not cause transitions are not shown.

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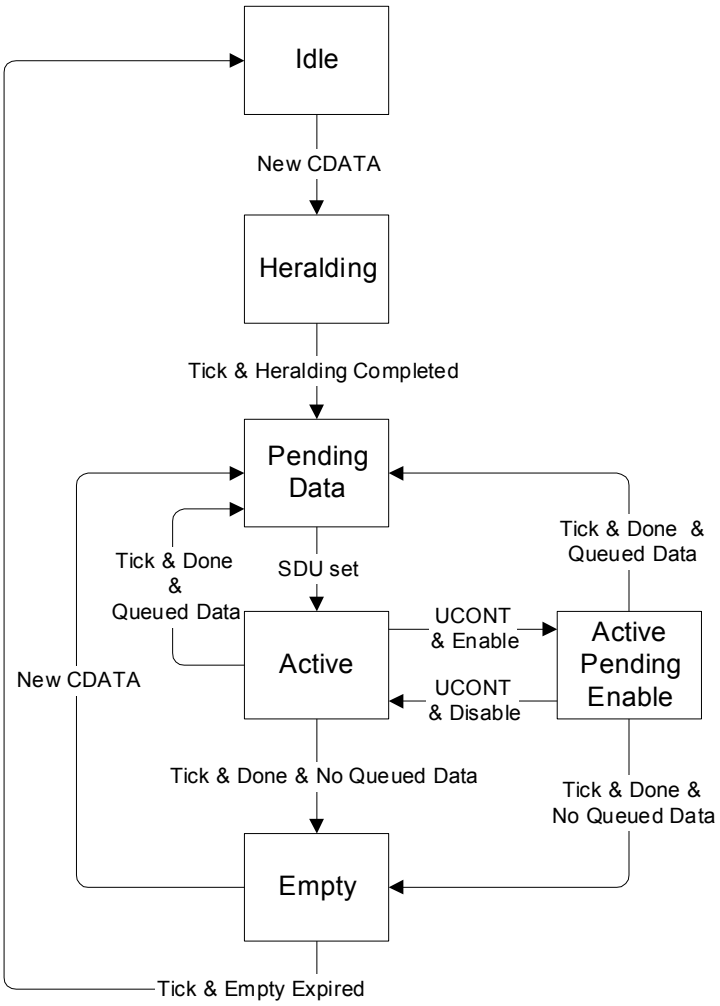


Figure 164 - MB-SAP Tx State Transition Diagram

5.15.1.4.5 Idle State

Event	Action	Next State
New CDATA	Allocate the ICBS-channel using the procedures defined in section 5.20.3.12.3 (Allocating a Main Slot to the ICBS-channel) Set the *Heralding Count* variable to zero. Set the *C-Plane Sequence Number* variable to zero.	Heralding
UCONT	Set *U-plane Enable State* to the requested state	

5.15.1.4.6 Heralding State

Event	Action	Next State
Tick &	Increment *ICBSheraldingDuration*	

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(*Heralding Count* < *ICBSheraldingDuration*)		
Tick & (*Heralding Count* = *ICBSheraldingDuration*)	Set the *U-plane SDU valid* variable to *false*	Pending Data
UCONT	Set *U-plane Enable State* to the requested state	

5.15.1.4.7 Pending Data State

The *Pending Data* state is transient.

On entry to the *Pending Data* state obtain an SDU set from the Tx Queue process using the procedures defined in section 5.15.1.3.2 (Selecting a C-Plane SDU set for Transmission). The *SDU set* event occurs when these procedures complete.

Event	**Action**	**Next State**
SDU set	Copy SDU set to *C-Plane SDU set* Set the *Transmit Count* variable to zero Increment the *C-Plane sequence number* variable modulo 2	Active

5.15.1.4.8 Active State

Event	**Action**	**Next State**
UDTR Tick and (*U-plane Enable State = Enabled)*	Set *U-plane SDU valid* to *false*. Generate an MB_UDTR indication to the higher layers	
UDATA	Copy the U-plane SDU to the *U-plane SDU* variable and set *U-plane SDU valid* to *true*	
UCONT(Enabled) and *U-plane Enable State = Disabled*		Active Pending Enable
UCONT(Disabled) and *U-plane Enable State = Enabled*	Set *U-plane Enable State* to *Disabled*	
Tick & (*Transmit Count* < *ICBStransmitCount*)	Increment *Transmit Count*	
Tick & (*Transmit Count* = *ICBStransmitCount*) & Queued Data	Issue any C-Plane Confirmations using the procedure defined in section 5.15.1.3.3 (Issuing C-Plane Confirmations)	Pending Data
Tick & (*Transmit Count* = *ICBStransmitCount)* & No Queued Data	Issue any C-Plane Confirmations using the procedure defined in section 5.15.1.3.3 (Issuing C-Plane Confirmations)	Empty

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5.15.1.4.9 Active Pending Enable State

Event	Action	Next State
UDATA	Copy the U-plane SDU to the *U-plane SDU* variable and set *U-plane SDU valid* to *true*	
MB_UCONT(Disabled) and *U-plane Enable State = Enabled*	Set *U-plane Enable State* to *Disabled*	Active
Tick & (*Transmit Count < ICBStransmitCount)*	Increment *Transmit Count*	
Tick & (*Transmit Count = ICBStransmitCount)* & Queued Data	Issue any C-Plane Confirmations using the procedure defined in section 5.15.1.3.3 (Issuing C-Plane Confirmations) Set *U-plane Enable State* to *Enabled*	Pending Data
Tick & (*Transmit Count = ICBStransmitCount)* & No Queued Data	Issue any C-Plane Confirmations using the procedure defined in section 5.15.1.3.3 (Issuing C-Plane Confirmations) Set *U-plane Enable State* to *Enabled*	Empty

5.15.1.4.10 Empty State

On entry to the *Empty* state, the MB-SAP Tx State machine shall set its *Empty Count* variable to zero.

Event	Action	Next State
UDTR Tick and (*U-plane Enable State = Enabled)*	Set *U-plane SDU valid* to *false*. Generate an MB_UDTR indication to the higher layers	
UDATA and (*U-plane Enable State = Enabled)*	Copy the U-plane SDU to the *U-plane SDU* variable and set *U-plane SDU valid* to *true*	
MB_UCONT(Enabled)	Set *U-plane Enable State* to *Enabled* Set *Empty Count* to zero	
MB_UCONT(Disabled)	Set *U-plane Enable State* to the requested state.	
Tick & (*U-plane Enable State = Disabled)* & (*Empty Count < ICBSemptyDuration*)	Increment *Empty Count*	
Tick & (*U-plane Enable State = Disabled)* & (*Empty Count =*	De-allocate the ICBS-channel main slot using the procedures defined in section 5.20.3.12.5 (De-Allocating a Main Slot from the ICBS-	Idle

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ICBSemptyDuration)	channel).	

5.15.1.5 Formatting the main TDMA MPDU

Table 211 defines values for fields of the main TDMA MPDU that are independent of the MB-SAP state. Table 212 defines rules for creating the contents of the main TDMA MPDU for transmission, according to the state and internal variables of the MB-SAP Tx State machine.

Table 211 - TDMA MPDU Field Values (Independent of MB-SAP Tx State Machine)

Field	**Value**
MPDU Type	*Main TDMA MPDU*
Connection ID	*ICBS_CID (defined in 16.2 (*MAC Constants*))*
TDMA Ack	*0*
Encrypted	*0*
C-channel sequence number	*C-Plane sequence number*
C-channel Ack Sequence number	*0*

Table 212 - TDMA MPDU Field Values

Condition	**Contents of TDMA MPDU**
State = *Heralding*	*fastC*=1, *Number of C-channel SDUs* =0
State = *Empty* and *U-plane Enable State = disabled*	*fastC*=1, *Number of C-channel SDUs* =0
(State = *Active* or *Active Pending Enable*) and *U-plane Enable State = disabled*	*fastC*=1, *Number of C-channel SDUs* = number of C-Plane SDUs in the *C-Plane SDU set* *C-SDU* = first SDU in the *C-Plane SDU set* *C-SDUs* = remaining SDUs in the *C-Plane SDU set*
State = *Empty* and *U-plane Enable State = enabled*	*fastC*=0, *C-channel SDU flag*=0 If *U-plane SDU valid*: *B-field present* = 1, *B-field = U-plane SDU* Otherwise: *B-field present* = 0
State = *Active* and *U-plane Enable State = enabled*	*fastC*=0, *C-channel SDU flag*=1 *C-SDU = C-Plane SDU set* [162] If *U-plane SDU valid*: *B-field present* = 1, *B-field = U-plane SDU* Otherwise: *B-field present* = 0

5.15.1.6 UDTR Reference Point

The CP defines a *UDTR Reference Point* that is a constant offset from the start of the subframe.

162 There is only one C-channel SDU in the SDU set

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The *UDTR Reference Point* shall occur after the beacon interval but before the earliest possible transmission of a TDMA MPDU on the ICBS-channel.

5.15.2 MB-SAP Procedures at the I-node

An I-node shall support the procedures defined in this section to provide the Isochronous Connectionless Broadcast Service (ICBS).

5.15.2.1 Introduction (Informative)

On receipt of a TDMA beacon, the TDMA Beacon Rx process (see section 5.8.5 (TDMA Beacon Receive)) identifies if the Isochronous Connectionless Broadcast Service channel connection ID is being signaled in the Main Slot Pair section of the TDMA Beacon and arranges for the TDMA ICBS-channel Rx process (see section 5.8.7.3.2 (ICBS-channel Rx Process)) to be enabled to receive in the main downlink slot allocated to the ICBS-channel.

The ICBS-channel activation is heralded by the CP for a defined number of consecutive subframes. These appear as ICBS-channel TDMA MPDUS that do not carry any C-Plane or U-plane SDUs. Once the MB-SAP Rx State Machine sees any ICBS-channel TDMA MPDUs, it stays out of the *Idle* state (forcing the I-node power-saving state machine to keep the I-node awake) until it sees a CP Beacon that is not in the emergency case (defined in section 5.5.3.5 (Permitted CFP Sizes)) [163] and that carries no ICBS-channel allocation.

The I-node decodes the received MPDU based on the settings in the *C-Channel Control* field (defined in section 5.4.12.2 (C-Channel Control)). The *fastC=1* condition designates a C-plane SDU set containing the number of 5 byte SDUs indicated in the *Number of C-channel SDUs* field. Each 5 byte C-plane SDU that is part of the received set will be indicated individually by the MB-SAP Rx Process using the MB_CDATA indication to the higher layers.

Each C-plane SDU set that is transmitted by the CP is identified by the *C-channel Sequence Number* field. The I-node initializes its C-plane SDU set sequence number from the first C-plane SDU set sequence number that it accepts. On subsequent non-empty C-plane SDU sets, the *C-channel sequence number* field is compared to the current sequence number and matching SDU sets are discarded. Since C-plane SDU transmissions are repeated by the CP, this sequence check provides the means for the I-node to discard duplicates.

The (*fastC=0* and *B-field present* = 1) condition indicates that a U-plane SDU has been received. The U-plane SDU is passed to higher layers using the MB_UDATA indication. When *fastC=0,* there is bandwidth available for only one C-plane SDU. Its presence is indicated by the *C-channel SDU* flag in the *C-Channel Control* field. Any C-plane SDU is considered a SDU set of size one and has sequence number validation and indication to higher layers as for the *fastC=1* case.

When the TDMA Beacon Rx process receives a TDMA Beacon that does not signal the Isochronous Connectionless Broadcast Service channel connection ID in any main slot position, unless the slot usage is in the emergency case (defined in 5.5.3.5 (Permitted CFP Sizes)), it signals to the MB-SAP Rx State machine that the ICBS-channel is no longer active. The MB-SAP Rx State machine then enters its *Idle* state. In the emergency TDMA slot usage case, the ICBS-channel is temporally not present. This has no effect on the MB-SAP Rx State machine state.

The I-node power-saving state machine (defined in section 5.20.5 (I-node Power-Saving)) observes the state of the MB-SAP Rx State Machine. When the MB-SAP Rx State Machine is *Idle*, the I-node can save power. When it is *Active*, the I-node power-saving state machine is forced into the *Awake* state, ensuring that TDMA beacons and any ICBS-channel can be received.

5.15.2.2 Architecture

Figure 165 defines the MB-SAP Receive architecture. The TDMA Beacon receive process (see section 5.8.5 (TDMA Beacon Receive)) decodes the beacon and indicates when the ICBS-channel has disappeared from the beacon. The ICBS-channel Rx process (see section 5.8.7.3.2 (ICBS-channel Rx Process)) receives in any ICBS-channel slot and indicates good ICBS-channel TDMA MPDUs to the Rx State Machine.

The MB-SAP Rx State Machine performs duplicate rejection of C-Plane SDU sets, and indicates received C-Plane SDU sets to the MB-SAP Rx Process. The MB-SAP Rx State is observed by the I-node power-saving state machine (defined in section 5.20.5 (I-node Power-Saving)).

The MB-SAP Rx Processes unpackages a C-Plane SDU set and generates one or more MB_CDATA indications.

[163] In the emergency case, all available contention free bandwidth has been allocated to active connections, and so none is available for the ICBS-channel.

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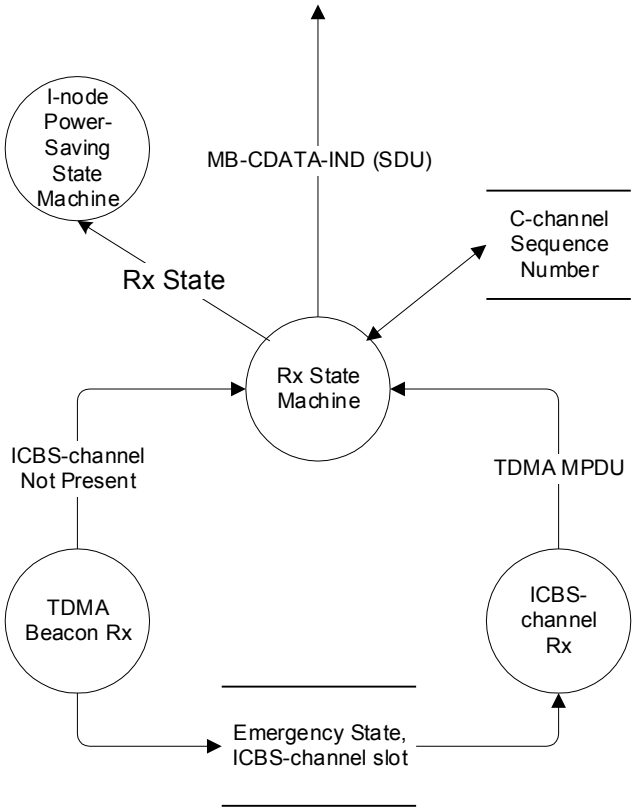


Figure 165 - MB-SAP Rx Architecture

5.15.2.3 MB-SAP Rx State Machine

5.15.2.3.1 MB-SAP Rx States & Variable

Table 213 defines the states that the state machine supports.

Table 213 - MB-SAP Rx States

State	Description
Idle	The initial state of the state machine. No ICBS-channel is allocated.
Active	An ICBS-channel is allocated and C-Plane SDUs have been received

In addition to its state variable, the MB-SAP Rx State Machine shall maintain a *C-Plane Sequence Number* variable. The permitted values of this variable are 0 and 1.

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5.15.2.4 MB-SAP Rx Events

Table 214 defines the events and conditions that drive the operation of the MB-SAP Rx State Machine at the I-node.

Table 214 - MB-SAP Rx Events

Event / Condition	Definition
TDMA MPDU	TDMA MPDU has been received by the ICBS-channel MPDU Rx Process and signaled to this state machine.
C-SDU	The TDMA MPDU received includes a C-Plane SDU set. (*fastC*=1 and *nc*>0) or (*fastC*=0 and *C-channel SDU flag* = 1)
ICBS Channel Not Present	The TDMA Beacon Rx process signals that the ICBS-channel has been deallocated and an emergency case does not apply.

5.15.2.5 MB-SAP Rx State Transition Diagram

Figure 169 shows the state transitions of the MB-SAP Rx State Machine.

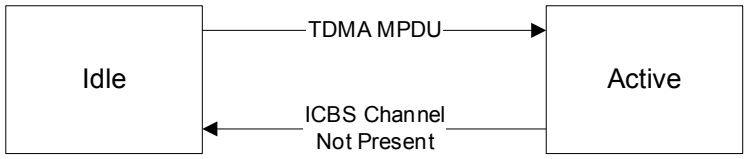


Figure 166 - MB-SAP Rx State Transition Diagram

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5.15.2.6 Idle State

Event	Action	Next State
TDMA MPDU	Set the *C-Plane Sequence Number* variable to the value in the TDMA MPDU *C-channel Sequence Number* field, less 1 modulo 2. [164] Indicate any U-plane SDU using the procedure defined in section 5.15.2.8 (MB-SAP U-plane Rx Process). Indicate any C-Plane SDUs using the procedure defined in section 5.15.2.9 (MB-SAP C-Plane Rx Process).	Active

5.15.2.7 Active State

Event	Action	Next State
TDMA MPDU	Indicate any U-plane SDU using the procedure defined in section 5.15.2.8 (MB-SAP U-plane Rx Process). Indicate any C-Plane SDUs using the procedure defined in section 5.15.2.9 (MB-SAP C-Plane Rx Process).	
ICBS Channel Not Present		Idle

5.15.2.8 MB-SAP U-plane Rx Process

Support for this process is optional.

An I-node that receives a TDMA MPDU from the ICBS-channel Rx Process that contains a U-plane SDU (*fastC*=0 and *B-field present*=1) shall emit an MB_UDATA indication whose SDU parameter contains the *B-field* that was received.

5.15.2.9 MB-SAP C-Plane Rx Process

This section defines how the MB-SAP Rx State Machine shall respond to a TDMA MPDU indication from the ICBS-channel Rx process in order to provide support for the C-Plane.

It shall either ignore the TDMA MPDU or generate one or more MB_CDATA indications as defined in Table 215.

Table 215 - MB-SAP C-Plane Rx actions

Condition (Informative)	Condition (Normative)	Action
No C-Plane SDUs	(*fastC*=1 and *nc*=0) or (*fastC*=0 and *C-channel SDU flag*= 0)	Ignore

[164] This ensures that the first C-channel SDU set received is not rejected as a duplicate.

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Duplicate	TDMA MPDU *C-channel Sequence Number* field = *C-Plane Sequence Number* variable	Ignore
Slow C-channel	*fastC*=0	Emit an MB_CDATA indication whose SDU parameter contains the SDU in the TDMA MPDU C-SDU field. Set the *C-Plane Sequence Number* variable to the value in the TDMA MPDU *C-channel Sequence Number* field.
Fast C-channel	*fastC=1*	Emit an MB_CDATA indication whose SDU parameter contains the SDU in the TDMA MPDU C-SDU field. For each of the (*nc*-1) C-Plane SDUs in the C-SDUs field, emit an MB_CDATA indication containing that SDU. Set the *C-Plane Sequence Number* variable to the value in the TDMA MPDU *C-channel Sequence Number* field.

5.16 Synchronization Management

This section defines procedures that enable all nodes within a network to operate with the same network ID (NWID) and with synchronized *DwCount* values.

5.16.1 Co-location of Networks (Informative)

HomeRF radio signals are not restricted to a well defined area, as it is the case for wired technologies. A radio device can hear any other device within range transmitting on the same frequency.

Different users may want to set up independent networks, but the range of those networks may overlap. The users do not want those networks to interact with each other and do not want to suffer too much performance degradation due to the presence of the other network.

The NWID is an identifier that is used to separate the different virtual networks located in the same area. Devices having the same NWID are part of the same logical network; devices having different NWIDs may not interact with each other.

Different networks are not synchronized - so they are very likely to use a different hopping pattern and index. This means that most of the time they are not on the same frequency and so will not be required to share the channel.

There can also be islands of connectivity, networks that use the same NWID but are not in range. These networks will have different synchronization parameters.

5.16.2 Scanning Overview (Informative)

In order for HomeRF devices to communicate, they must have the same NWID. The NWID is present in all MPDUs. HomeRF devices synchronize to the same frequency hopping sequence using a process called *passive scanning*. It involves listening for an MPDU with the required NWID that also contains synchronization information. The outcomes of the scanning process are:

- If no such MPDU is received, the device can start a network or give up
- If a suitable MPDU is received, the device synchronizes to the hop pattern signaled by it.

The scanning process described here can take a few seconds to perform in the North American locale when the network does not already exist and the scanning node concludes by starting a network. The maximum scanning time in this case is given by:

Worst case scanning time without network = *MaxNumScanChannels* * *ScanDurationPerChannel*.

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5.16.3 Network ID (Informative)

A HomeRF device requires a Network ID (NWID) before it can scan for and join a network. Network IDs can be allocated to a device by the following means:

- By direct entry into the device.
- By learning the NWID from another node.

Learning the NWID is the preferred mechanism for I-nodes. These are likely to be portable devices, and so it will be convenient to press a user-interface button to teach/learn the NWID.

An A-node is less likely to be portable, and so simultaneous operation of a user-interface button is probably not convenient. In this case, the user is likely to need direct entry.

Note that the creation of an NWID is performed by management layers above the MAC layer. The MAC places no constraint on the form of the NWID.

5.16.4 Synchronization State Machine

A HomeRF MAC entity has a synchronization state that is affected by higher layers through MM-SAP requests and by receiving MPDUs containing Synchronization Information.

5.16.4.1 Synchronization States

The synchronization states are described in Table 216.

Table 216 - Synchronization States

Synchronization State	**Description**
Idle	Not associated with any network. NWID unknown.
Scanning	Looking for a network.
Managed	Synchronized with a network. NWID and all the channel management variables (see section 5.5.2.1 (Hop Management)) are known. A CP is present.
Ad-hoc (*A-node only*)	Synchronized with a network. No CP is present. The node is operating the ad-hoc network synchronization procedures.
Roaming	Resynchronizing to a particular roamed to CP

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5.16.4.2 Synchronization Events

The events that affect the synchronization state defined in Table 217.

Table 217 - Events Affecting the Synchronization State

Event	Definition
Scan Request	An MM_START, MM_JOIN or MM_LEARN request has been received
Find Request	A MM_FIND request has been received
RoamToCP	A MM_ROAMTOCP request has been received
Started	A node has joined or started a managed network
Started (ad-hoc)	An A-node has joined or started an ad-hoc network
Not Started	An MM_START, MM_JOIN or MM_LEARN completes without joining or starting a network
Find Complete	The Finding Roaming Connection Points procedure initiated via the MM_FIND request has completed
Resynchronized	The Roaming To A Particular Connection Point procedure has completed with successful synchronization to the new CP
CP Beacon Timeout	The node has not received any CP beacons within the last *NumToAdhoc* superframes
CP Beacon Received	A CP beacon has been received

5.16.4.3 Synchronization State Transitions

Figure 167 shows the state transition diagram.

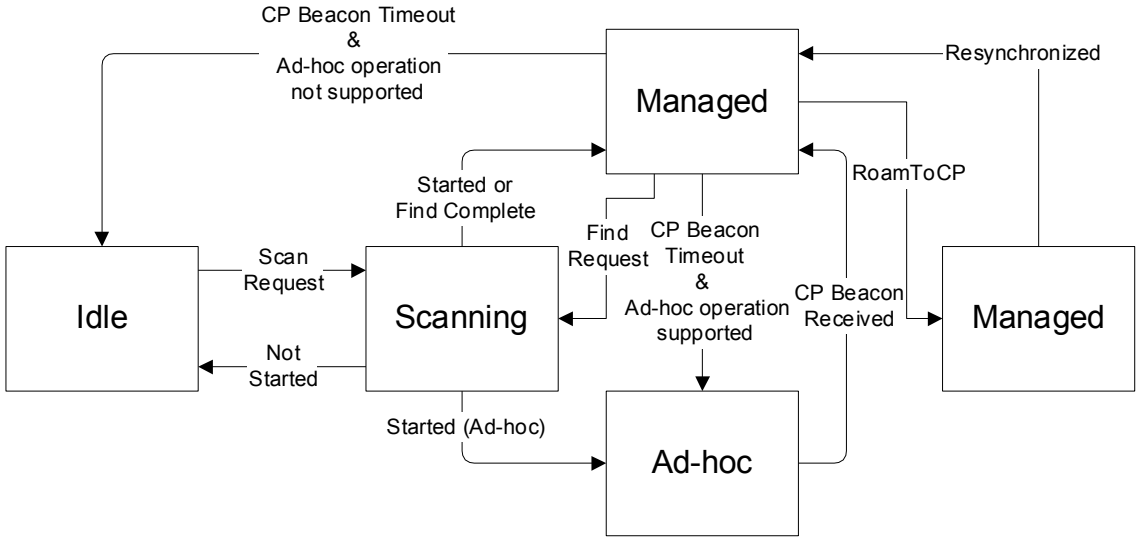


Figure 167 - Synchronization State Transition Diagram

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5.16.4.4 Effect of Synchronization State

Depending on its Synchronization State, the MAC shall follow the rules defined in the subsections of this section.

5.16.4.4.1 Idle

The MAC entity shall not transmit any MPDUs.

The MAC entity shall not receive any MPDUs.

5.16.4.4.2 Scanning

The MAC entity shall not transmit any MPDUs.

The MAC entity shall receive all MPDUs for the exclusive use of the MAC management entity scanning procedures. All received MPDUs shall have no effect except on the operation of these procedures.

The procedures required to perform the scan are defined in section 5.16.6 (Generic Scanning Procedure)

5.16.4.4.3 Managed

The MAC entity can transmit and receive MPDUs.

The node shall operate the managed network synchronization procedures defined in section 5.16.16 (Synchronization in a Managed Network).

5.16.4.4.4 Ad-hoc

The MAC entity can transmit and receive MPDUs. The MAC entity shall operate the ad-hoc synchronization procedures defined in section 5.16.17 (Maintaining Synchronization in an Ad-Hoc Network)

5.16.5 Transitions from the Managed Synchronization State

A node that is in the *Managed* synchronization state and that has not received a CP beacon for (*NumToAdhoc*) superframe periods shall enter either the *Ad-hoc* or *Idle* states of the synchronization state machine[165]. An I-node that has an active connection need not operate this timeout.

The selection between these states is based on node type and capability as defined in Table 218.

Table 218 - Selection of Ad-hoc or Idle State based on Node Type / Capability

Node Type/Capability	New State
I-node	Idle
A-node that supports ad-hoc operation	Ad-hoc
Otherwise	Idle

On entering the *Idle* state, the MAC entity shall issue an MM_LOST indication to the higher layers.

5.16.6 Generic Scanning Procedure

The procedures defined in this section are used by the MAC entity to find a HomeRF network. This section defines common scanning procedures used by the specific scanning procedures: scanning for a known network, and learning a NWID.

During a scan, the MAC entity shall receive MPDUs regardless of NWID or destination address. These are analyzed by the MAC management entity in order to determine the result of the scanning procedure. They shall have no other effect within the MAC entity.

To start the scan, the node shall set its Hop Pattern to *ScanHopPattern* and Hop Index to *ScanHopIndex*[166]. These select the PHY channel. The scanning process involves listening on different PHY channels, for up to *MaxNumScanChannels* channels, and listening on each channel for *ScanDurationPerChannel*. [167]

[165] A passive CP will have become active before this timeout occurs, and so never observes this event.

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The scan can be terminated if the specific scanning procedure so determines. If the scan has not been terminated, at the end of *ScanDurationPerChannel* on one channel, the MAC shall hop to the next channel defined by incrementing its *HopIndex*.

The scan procedure shall terminate after scanning *MaxNumScanChannels,* in which case, the PHY channel will be *FinalScanChannel* [168].

5.16.7 Scanning for a New Network

The MAC entity shall perform these procedures on receipt of an MM_LEARN request primitive.

The MAC entity shall perform the generic scan procedure defined in section 5.16.6 (Generic Scanning Procedure). If the *Completion Type* is *fast join,* the scan is terminated as soon as the first network is discovered. The MAC entity set its *DwCount*, *HopPattern* and *HopIndex* to that contained in the MPDU header. [169] The node is then synchronized to the network.

At the end of the procedure, the MAC entity shall emit an MM_LEARN confirmation containing any NWIDs discovered.

5.16.7.1 I-node

While scanning, the I-node shall record the NWID of any TDMA beacons received with the *LearnNWID* bit set. All other MPDU types are ignored.

5.16.7.2 Other nodes

While scanning, the node shall record the NWID of any MPDUs received with the *LearnNWID* bit set (see 5.4.4.8 (Learn NWID Field).

If the *Completion Type* is *fast join*, only MPDUs containing the *LearnNWID* flag bit set and with an MPDU header of type 3, 4 or 5 are recorded. [170]

5.16.8 Scanning for a New Network with a *NWID signaled by the Directed Learn NWID (Directed Learn NWID)*

The MAC entity shall perform these procedures on receipt of a MM_DIRECTEDLEARN request primitive.

The MAC entity shall perform the generic scan procedure defined in section 5.16.6 (Generic Scanning Procedure). If the *Completion Type* is *fast join,* the scan is terminated as soon as the network indicated in the *Directed Learn NWID* MPDU is discovered. The MAC entity set its *DwCount*, *HopPattern* and *HopIndex* to that contained in the MPDU header. [171] The node is then synchronized to the network.

At the end of the procedure, the MAC entity shall emit an MM_DIRECTEDLEARN confirmation containing any *NWIDs* discovered.

5.16.9 Scanning for a Known Network

The MAC entity shall perform these procedures on receipt of an MM_START request.

The MAC shall perform the generic scanning procedure defined in section 5.16.6 (Generic Scanning Procedure).

While scanning, the node device listens for MPDUs that contain a NWID that matches the *DesiredNWID* and that have a type 3 or 4 MPDU header.[172]

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166 These values have been chosen to give a good spread of the scanned channel within the frequency band. Using a common HP and HI ensures that nodes started simultaneously will end up scanning on the same channel and will see each other at network creation.

167 The maximum number of channels scanned is less than the number of channels available, and the length of time spent on each channel is much longer than the usual *SuperframeDuration.*

168 This value is dependent on the localization.

169 The value of *DwCount* will need to be adjusted to include the effect of any delay between the end of the MPDU header and the update of the *DwCount* variable.

170 *i.e.* those containing synchronization information.

171 The value of *DwCount* will need to be adjusted to include the effect of any delay between the end of the MPDU header and the update of the *DwCount* variable.

172 *i.e.* those containing synchronization information.

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If the node receives a suitable MPDU, the node shall terminate the generic scanning procedure, acquire synchronization (Hop Index, Hop Pattern, *DwCount*) from this MPDU and join the network. The MAC entity issues an MM_START confirmation with *Joined* status.

At the end of the generic scanning process, if the node has not found any CP in its list, the node shall do one of the following:

- Create a network using the *DesiredNWID* as the NWID by operating the procedures defined in section 5.16.13 (Creating a Network). At completion of these procedures, the MAC entity shall issue an MM_START confirmation with *Started* status.
- Issue an MM_START confirmation with *Cannot Join* status. [173]

The choice shall be constrained by node type as defined in Table 219.

Table 219 - Selection of MM_START Behavior on Failing to Find a Network Based on Node Type

Node Type	**Choice**
CP	Create a network.
I-node	Issue an MM_START *Cannot Join*.
A-node	Either choice. An A-node that is capable of operating within an ad-hoc network should create a network. An A-node that wishes to keep power-consumption very low should issue an MM_START *Cannot Join* confirmation.

5.16.10 Finding Roaming Connection Points

The MAC entity shall perform these procedures on receipt of an MM_FIND request.

The MAC shall perform the generic scanning procedure defined in section 5.16.6 but may terminate the scan if *MaxFindInterval* is less than *ScanDurationPerChannel*. An implementation that invokes the power saving procedures to avoid disruption of ongoing data connections will select a *MaxFindInterval* that minimizes the power supporting requirements of nodes and the store and forward requirements of the CP. See 5.19 (Asynchronous Data Roaming). If a scan is terminated before the end of the *ScanDurationPerChannel*, the node should record how long it has spent scanning the current channel. The node should then wait for some multiple of *ScanDurationPerChannel* durations before resuming the find operation with the next scan procedure for the same *ScanHopPattern* and *ScanHopIndex* as were in use by the scan that was terminated. Scan procedures will continue to be performed for the in-progress find operation until the current channel has been scanned for *ScanDurationPerChannel* duration.

While scanning, the node listens for MPDUs that contain a NWID that matches the *DesiredNWID* and that have type 3 MPDU headers.[174]

If the node receives a suitable MPDU, the node shall store the discovered synchronization parameters (*DwCount*, *HopPattern*, and *HopIndex*) associated with the indicated CP's MAC address in a database for future use.

5.16.11 Roaming to a Particular Connection Point

The MAC entity shall perform these procedures on receipt of an MM_ROAMTOCP request.

A roaming capable node undergoing this roaming procedure shall store in memory the address of the Connection Point to which it was originally synchronized.

The MAC shall use the synchronization parameters contained in its database associated with the particular connection point to acquire immediate synchronization to that CP. If immediate synchronization is not acquired, the node shall acquire synchronization according to the CP Beacon Timeout procedure. See 5.16.15.

---

[173] An I-node that is not an AI-node does not have a NWID, and so cannot start its own network.

[174] i.e. those headers coming from CPs with synchronization information. The ability to roam between managed and ad-hoc networks is not defined, so there is no reason for the node to scan for type 4 MPDU headers.

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If synchronization is acquired with the roaming particular CP, the MAC shall send a *Roam Notify* MPDU to the Connection Point that was originally providing it with synchronization information. This message shall be sent with the address of the current Connection Point in the Bridge Header. The MAC address of the original Connection Point shall be the destination address in the MD_SAP header (5.12.4 MD-SAP Header.)

5.16.12 Scanning for a set of Known Networks (I-node only)

The MAC entity shall perform these procedures on receipt of an MM_JOIN request.

An I-node shall record in its DECT subscription database the NWIDs of all Class-1 CPs with which it has performed the DECT NWK subscription procedure.

The MAC shall perform the generic scanning procedure defined in section 5.16.6 (Generic Scanning Procedure).

While scanning, the I-node shall receive only TDMA beacons that contain a NWID that matches one of the addresses in the desired NWIDs. All other MPDUs shall be ignored.

An I-node that receives a TDMA beacon containing a matching NWID shall terminate the generic scanning procedure, acquire synchronization (Hop Index, Subframe Index, Hop Pattern, *DwCount*) and the NWID from this TDMA beacon and shall join the network. The MAC entity shall issue an MM_JOIN confirmation with *Joined status* indicating the NWID found.

At the end of the generic scanning process, if no matching CP beacon has been heard, the node shall issue an MM_JOIN confirmation with *Cannot Join* status [175]. In this case, if the node is an AI-node, it can change its mode of operation so that it is effectively just an A-node and then repeat the scanning process using the procedures defined for an A-node.

5.16.13 Creating a Network

The MAC entity performs these procedures in order to create a network, given a NWID.

The node shall set its *SubframesPresent, SubframeIndex* and *HopsetAdapted* variables to the value zero.

The node shall select values for *HopPattern* and the initial *HopIndex* so that:

- *HopPattern* is in the range 0 to (*NumberOfChannels-1).* Numbers within this range are selected with equal probability and appear to be random.
- The first channel selected using the algorithm defined in section 5.5.2 (Frequency Hopping) is equal to *FinalScanChannel.* See section 16.2 (MAC Constants).

The node then starts to send Beacons. The process for sending Beacon MPDUs is described in sections 5.16.17 (Maintaining Synchronization in an Ad-Hoc Network) and 5.17.3 (CP Beacon).

5.16.14 Signaling *LearnNWID*

The MAC performs these procedures on receipt of an MM_TEACH request primitive.

The MAC shall either signal *LearnNWID* locally using the procedure defined in section 5.16.14.1 (Signaling LearnNWID Locally), it shall request the CP to signal *LearnNWID* using the procedure defined in section 5.16.14.2 (Signaling LearnNWID using the CP), or it shall ignore the request. Table 220 defines the conditions that select between these behaviors.

Table 220 - Conditions for Signaling LearnNWID Behaviors

Condition	Behavior
The node in the *Idle* or *Scanning* synchronization states	Ignore the request
The node is an active CP in the *Managed* synchronization state	Signal locally
The node is in the *Ad-hoc* synchronization state	Signal locally
Otherwise	Signal through the CP

[175] An I-node that is not an AI-node does not have a NWID, and so cannot start its own network. An AI-node can subsequently operate as just an A-node and perform a scan procedure to find its NWID. This may result in it starting an ad-hoc network.

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5.16.14.1 Signaling LearnNWID Locally

A node shall perform the procedures defined in this section to signal LearnNWID locally.

The node shall enter a *SignalNWID* state and stay in this state for *LearnNWIDtimeout* seconds.

A node that is in the *SignalNWID* state shall transmit all MPDUs with the *LearnNWID* bit set to one.

A node that is not in the *SignalNWID* state shall transmit all MPDUs with the *LearnNWID* bit reset to zero.

The operation of ad-hoc beacon transmission is also affected by this state. See section 5.16.17 (Maintaining Synchronization in an Ad-Hoc Network).

5.16.14.2 Signaling LearnNWID using the CP

A node shall perform the procedures defined in this section to request the CP to generate LearnNWID signaling.

The node shall transmit a CPS request for the CP to signal LearnNWID using the procedures defined in section 5.10.3.2 (CSMA/CA CPS Transmit).

5.16.15 Signaling *DirectedLearnNWID*

The MAC performs these procedures on receipt of a MM_DIRECTEDTEACH request primitive.

The MAC shall either signal *DirectedLearnNWID* locally using the procedure defined in section 5.16.15.1 (Signaling *DirectedLearnNWID* Locally), it shall request the CP to signal *DirectedLearnNWID* using the procedure defined in section 5.16.15.2 (Signaling *DirectedLearnNWID* using the CP), or it shall ignore the request. Table 220 defines the conditions that select between these behaviors.

Table 221 - Conditions for Signaling DirectedLearnNWID Behaviors

Condition	**Behavior**
The node in the *Idle* or *Scanning* synchronization states	Ignore the request
The node is an active CP in the *Managed* synchronization state	Signal locally
The node is in the *Ad-hoc* synchronization state	Signal locally
Otherwise	Signal through the CP

5.16.15.1 Signaling *DirectedLearnNWID* Locally

A node shall perform the procedures defined in this section to signal *DirectedLearnNWID* locally.

The node shall enter a *DirectedSignalNWID* state and stay in this state for *DirectedLearnNWIDtimeout* seconds.

A node that is in the *DirectedSignalNWID* state shall once every superframe transmit a *Directed Learn NWID* MPDU with the IEEE MAC address of the node that the NWID is being directed to.

5.16.15.2 Signaling *DirectedLearnNWID* using the CP

A node shall perform the procedures defined in this section to request the CP to generate *DirectedLearnNWID* signaling.

The node shall transmit a CPS request for the CP to signal *DirectedLearnNWID* using the procedures defined in section 5.10.3.2 (CSMA/CA CPS Transmit).

5.16.16 Synchronization in a Managed Network

5.16.16.1 Overview (Informative)

In a managed network, the CP is the sole source of the synchronization information.

Through the CP beacon (in the Synchronization Information field of the header), the CP distributes the current hop management variables. See section 5.5.2.1 (Hop Management).

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Nodes are required to update their dwell counter based on the value received in the CP beacon. Nodes that are in a power-saving state will not receive all CP beacons, and will therefore perform this update less frequently.

The CP never updates its Synchronization Information based on the MPDUs heard on the network.

5.16.16.2 Synchronization Update

The procedure defined in this section shall be performed by a node that is part of a managed network. The CP shall not perform this procedure.

When a node receives a CP beacon with matching NWID containing synchronization information, it shall update its local hop management variables as defined in this section. A node may defer this update process, but should not defer it longer than a dwell period.

5.16.16.2.1 DwCount Update

The node shall update its *DwCount* variable from the *DwCount* field in the CP beacon.

After the update process, the local *DwCount* variable shall contain the value in the CP beacon less any time elapsed between the end of the MPDU header and the update process. The tolerance permitted in this value is *DwCountUpdateTolerance.*

5.16.16.3 SubframesPresent and SubframeIndex Update

The node shall update its *SubframesPresent* variable from the *SubframesPresent* field of the CP beacon.

The node can update its *SubframeIndex* variable from the *SubframeIndex* field of the CP beacon. It shall perform this update whenever *SubframesPresent* changes value.

5.16.16.4 Hopset Adaption Update

The node shall update its *HopsetAdapted* variable from the *HopsetAdapted* field in the CP beacon.

If *HopsetAdapted* equals one, it shall update its *InterferenceStart* and *InterferenceWidth* from the fields in the CP beacon.

If there is any change in these values, the node shall re-calculate its *HopPatternArray* using the procedures defined in 5.5.2.4 (HopPatternArray Calculation). The node should complete this calculation in time for the next hop.

5.16.16.5 Beacon Transmission in a Managed Network

In a Managed Network the Connection Point shall transmit a CP beacon every beacon period.

A Class-1 CP shall transmit a CP1 Beacon. A Class-2 or Class-3 CP shall transmit a CP2 Beacon.

The timing of this transmission shall be as defined in section 5.5.3.2.

5.16.16.6 Selection of SuperframesPresent in a Managed Network

A CP shall set its *SuperframesPresent* variable to zero whenever it becomes active.

A Class-1 CP shall set its *SuperframesPresent* to one whenever there is a TDMA connection that is not in the *Idle* state. Otherwise it should set its *SuperframesPresent* to zero.

5.16.16.7 Conflicting Hop Patterns in a Managed Network

The procedure in this section applies to a node that receives a CP beacon with the correct NWID, but with a different hop pattern or index.

An active CP shall ignore the CP beacon.

A node that is not the active CP shall adopt the new synchronization parameters immediately.

5.16.16.8 Effect of other MPDUs received with type 4 header

A node in the *Managed* synchronization state that receives a MPDU with a type 4 header shall ignore the synchronization parameters that it contains.

5.16.17 Maintaining Synchronization in an Ad-Hoc Network

An A-node that is part of an ad-hoc network shall perform the procedures defined in this section.

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5.16.17.1 Overview (Informative)

The management of synchronization is distributed - all A-nodes participate in the process.

In an ad-hoc network, there is no Connection Point. When operating in an ad-hoc network, these procedures ensure that an MPDU containing synchronization information is sent in each dwell. If there are other A-nodes in the network, each node hears at least one such MPDU on the network.

Synchronization information (*Hop Pattern, Hop Index* and *DwCount*) is transmitted in the header of at least one MPDU per dwell. In the absence of data MPDUs, ad-hoc beacons are generated to carry this information. Sub-frame structure information (*SubframesPresent, SubframeIndex*) is defined to be zero during ad-hoc operation both in internal variables, and in any sub-frame structure signaled in an ad-hoc beacon.

When a node receives an MPDU carrying synchronization information, it updates its *DwCount*. Under some circumstances it may also update the Hop Pattern and Hop Index.

The procedures are modified for low transmit power nodes in two ways. Firstly, they never send synchronization information in DATA MPDUs. Secondly, they send ad-hoc beacons later than other nodes, thereby giving priority to ad-hoc beacons from normal transmit power nodes.

A node that is in the *SignalNWID* state disregards incoming synchronization information during this state for the purposes of deciding whether to transmit synchronization information. This increases the probability that a node attempting to learn the NWID sees an MPDU with the *LearnNWID* flag set.

5.16.17.2 Transmission of Synchronization Information in an Ad-hoc Network

An A-node that is part of a managed network shall transmit no MPDUs with header type 4 and no ad-hoc beacon MPDUs.

A node that transmits using low power shall not transmit any MPDUs with header type 4.

An A-node that is in the *Ad-hoc* synchronization state has a state machine that controls the transmission of Synchronization Information.

Table 222 describes the states of the *Ad-hoc Synchronization Tx* state machine.

Table 222 - Ad-hoc Synchronization Transmit States

Ad-hoc Synchronization Tx State	Description
Idle	No Synchronization Information Transmission is required this dwell
Pending Tx	Synchronization information transmission is required this dwell

The events defined in Table 223 drive this state machine.

Table 223 - Events that Affect the Ad-hoc Synchronization Tx State

Ad-hoc Synchronization Event	Description
Start of Contention	The hop has completed and the CSMA/CA access mechanism is enabled
End of Contention	The CSMA/CA access mechanism is disabled to perform a frequency hop
Synchronization Information Transmitted	A MPDU with header type 3, or header type 4 has been transmitted
Synchronization Information Received	A MPDU with header type 3, or header type 4 has been received and the node is not in the *SignalNWID* state (see section 5.16.14 (Signaling *LearnNWID*))
Time To Transmit Ad-hoc Beacon	It is time to transmit an ad-hoc beacon. This is defined in section 5.16.17.2.3 (Time To Transmit Ad-hoc Beacon)

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Figure 168 shows the state transition diagram of the *Ad-hoc Synchronization Tx* state machine.

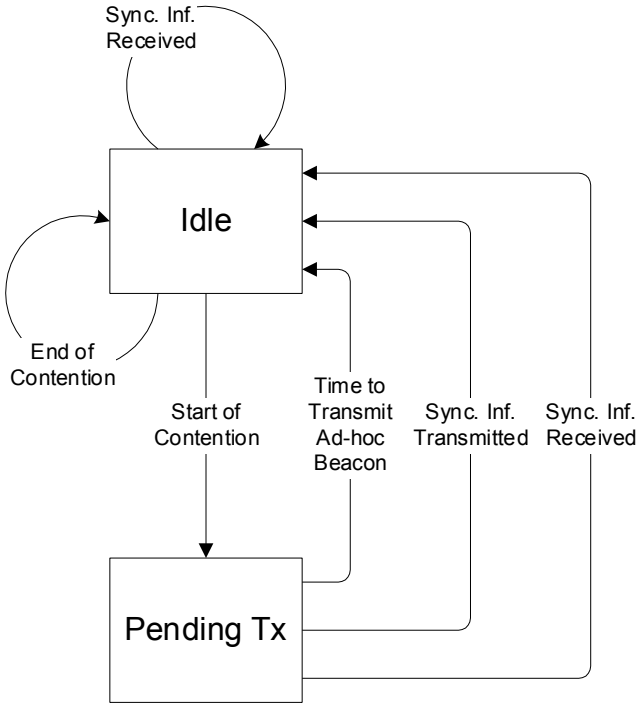


Figure 168 - Ad-hoc Synchronization Tx State Transition Diagram

The actions by state are defined in the following sections.

5.16.17.2.1 Idle

In the *Idle* state, an A-node that is not a low transmit power node can transmit MPDUs with either header type 4, or header type 2.

Event	Action	Next State
Start of Contention		Pending Tx
Synchronization Information Received	Discard any ad-hoc beacons that are on the Tx Queue	Idle
End of Contention	Discard any ad-hoc beacons that are on the Tx Queue	Idle

5.16.17.2.2 Pending Tx

In the pending Tx state, an A-node that is not a low transmit power node shall transmit any DATA or Time Reservation Establish MPDUs with an MPDU header type 4. [176]

Event	Action	Next State
Time to Transmit Ad-hoc Beacon	Transmit an ad-hoc beacon as defined in section 5.7.10.8 (Ad-hoc Beacon)	Idle
Synchronization		Idle

[176] On completion of this transmission, the state machine will enter the *Idle* state, thereby ensuring that at least one MPDU is seen by this node on the network for each entry into the *Pending Tx* state.

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Information Transmitted		
Synchronization Information Received		Idle

5.16.17.2.3 Time To Transmit Ad-hoc Beacon

This event is generated at a specific time in each superframe, based upon the A-node's *DwCount*. The specific time is dependent upon the A-node's transmit power.

Table 224 - Transmission Times for Ad-hoc Beacon Based on Node Type

Condition	Time To Transmit Ad-hoc Beacon
The node is operating with Transmit power Class 1 (see section 4.5.3 (Permitted Transmit Power according to HomeRF Node Type)	*DwCount* = *SuperframeDuration* / 2
The node is operating with Transmit power Class 2 (low power - see section 4.5.3 (Permitted Transmit Power according to HomeRF Node Type)	*DwCount* = *floor*(*SuperframeDuration* / 3) [177]

5.16.17.3 Updating Local Synchronization Information

A node that receives an MPDU that has header type 3, or header type 4 shall perform these update procedures.

5.16.17.3.1 Transition to Managed Network

A node that receives a CP beacon shall behave as described in (section 5.16.16.7 (Conflicting Hop Patterns in a Managed Network).

It shall consider itself part of a managed network, and cease operating the procedures defined in section 5.16.17 (Maintaining Synchronization in an Ad-Hoc Network).

5.16.17.3.2 Conflicting Hop Patterns in an Ad-hoc Network

A node that receives an MPDU with a matching NWID but with a different Hop Pattern shall operate the procedures defined in this section.

The least significant bit (LSB) of its current pattern and the LSB of the other hop pattern shall be used to select the numerically higher or lower hop pattern. The chosen hop pattern shall be the upper value if the LSBs are the same, and the lower value if the LSBs differ. This is summarized in the Table 225.

Table 225 - Resolving Hop Pattern Conflicts

LSB of Current Hop Pattern	LSB of Different Hop Pattern	Chosen Hop Pattern
0	0	The higher hop pattern.
0	1	The lower hop pattern.
1	0	The lower hop pattern.

[177] In an ad-hoc network of mixed Class 1 and Class 2 Transmit power A-nodes, these rules result in the Class-1 A-nodes sharing responsibility for transmitting the beacon. In an ad-hoc network of only Class-2 transmit power A-nodes, these nodes will share responsibility for transmitting the beacon.

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1	1	The higher hop pattern.
Notes:	*Higher* means the numerically higher pattern *Lower* means the numerically lower pattern	

If a different hop pattern is detected, a node that changes hop pattern shall transmit an ad-hoc Beacon MPDU using the new Hop Pattern and Hop Index (provided there is enough time remaining in its former dwell period, and the node can get access to the wireless medium).[178]

5.16.17.3.3 DwCount Update

When an A-node receives an MPDU with matching NWID containing synchronization information, it shall update its local *DwCount* variable. A node may defer this update process, but shall not defer it longer than a dwell. A node is not required to perform the update process more than once per dwell.

After update process, the local *DwCount* variable shall contain the value in the MPDU less any time elapsed between the end of the MPDU header and the update process. The tolerance permitted in this value is *DwCountUpdateTolerance.*

5.17 CP Management

5.17.1 Overview (Informative)

The most basic HomeRF network is an ad-hoc network in which all the nodes participating are equal. This means that network control is completely distributed among the participating nodes of the network. An A-node supports ad-hoc operation at its option.

In a HomeRF Managed Network a Connection Point provides:

- power management services;
- isochronous TDMA services;

Only one Active CP is allowed in a HomeRF network.

A *passive* CP is a Connection Point that is not providing CP services to the network because there is already an active CP on the network. A passive CP has in fact most of its functionality inhibited (depending on the implementation, even TDMA and CSMA access as a node might be inhibited), and some of the higher layer functionality may also be inhibited. A passive CP can take over as the active CP under certain circumstances: confirmation that the present network is ad-hoc; occupied by a CP of a lower functionality or priority or the previous active CP has failed.

The CP responds to CPS MPDUs from A-nodes and to TDMA CPS MPDUs from I-nodes to provide its services. The CP periodically sends the CP beacon that carries its response to these requests.

5.17.2 Addresses and identifiers

This section of the document list the different identifiers used in the CP services. The CP services also use the Headers and identifiers defined in section 5.4 (MPDU).

5.17.2.1 Connection ID

A CP may have up to *MaxMCconnections* connections active simultaneously. Each connection is identified by a connection ID. Section 5.8.3 (Connection ID) defines the connection ID.

5.17.2.2 PS service ID

The PS service ID is a 4-bit field that defines a combination of power saving services. Table 226 defines the representation of this field.

[178] The reason for this requirement is that it provides a mechanism by which hop pattern changes can be propagated throughout the network. All stations that are out of range of the station that transmitted the original message should receive a message transmitted by a station that has chosen a new hop pattern.

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Table 226 - PS Services

Bit Position	PS service bit description
0 (LSB)	Multicast power management services (store and forward CP service)
1	Unicast power management services (wake-up notification CP service)
2-3	Reserved for future use - set to 0

For most PS nodes, the PS service ID corresponding to the level of services that they require will be 0x3, but the other values are possible. The CP can ignore this field provided it allocates full PM services to every request.

5.17.3 CP Beacon Transmit

This section describes behavior that shall be supported by a CP in order to create the variable parts of a CP Beacon.

The CP shall transmit a CP beacon once per dwell according to the timing defined in section 5.5.3.2 (Connection Point Beacon Timing).

When subframes are present, the mandatory presence or absence of certain fields within the CP beacon varies by subframe number. This variability is defined in 5.17.3.4 (Event Priorities). The CP shall include in the CP beacon all mandatory CP fields. The CP shall not include any fields that are not permitted.

5.17.3.1 Architecture

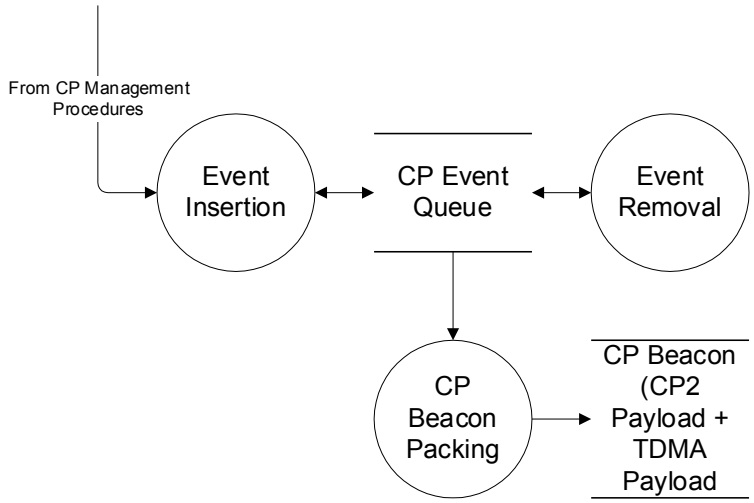


Figure 169 - CP Beacon Transmission Procedures Architecture

Events to be signaled in the CP beacon are placed in the CP Event Queue by the event insertion process. Events stay in the queue until removed by the Event Removal process, which has rules for removing events from the Queue based on event type.

The CP beacon packing procedure operates priority rules to format the payload content of the CP beacon according to event priority. Events are inserted into either the TDMA payload or the CP2 payload.

5.17.3.2 Event Insertion

When an event is to be inserted into the CP Event Queue, the event is inserted so as to replace any matching occurrence of the same event. The match includes any parameters associated with the event. When the event is replaced, it is considered that the old event has been deleted and a new event inserted, for the purposes of operating the Event removal procedures.

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5.17.3.3 CP Beacon Packing Rules

The CP beacon packer shall select events from the CP beacon queue, highest priority first, and insert them in the TDMA or CP beacon Payload according to event type, formatted according to the CP beacon MPDU structure defined in section 5.4.16 (CP Beacon). Event priorities are defined in section 5.17.3.4 (Event Priorities).

The CP beacon packer shall stop inserting events in the CP2 payload before it exceeds the limit on CP beacon length defined in section 5.4.16.3.1 (CP2 Beacon Payload Structure).

The CP beacon packet shall stop inserting events in the TDMA Beacon before it exceeds the limit on TDMA beacon length defined in section 5.4.16.4 (TDMA Beacon Structure).

The CP beacon packer can stop at an earlier point, provided it has included any mandatory events.

The CP beacon packet shall stop inserting events in the CP Beacon before the *ContentionDuration* becomes negative. *ContentionDuration* is defined to be:

Dwell Duration - HopDuration - CP Beacon Duration - CFP1 Duration - CFP2 Duration

Where:

- *CP Beacon Duration* is the actual on-air duration of the CP Beacon,
- *CFP1 Duration* is the duration of CFP1 calculated from the downlink retry and uplink retry signaling in the CP Beacon as defined in 5.5.3.4 (CFP1 Structure).
- *CFP2 Duration* is the duration of CFP2 calculated from the main slot signaling in the CP Beacon as defined in 5.5.3.3 (CFP2 Structure).

5.17.3.4 Event Priorities and Constraints

The CP beacon can carry only a limited number of events. This section defines a relative priority between events to be signaled in a CP beacon field that shall be used to select events for transmission. [179]

Certain events are constrained by subframe index. [180]

Table 227 defines the event priority and subframe constraint.

Table 227 - CP Event Priority and Subframe Constraint

Priority	**Subframe Constraint**	**CP events**
Mandatory if there are any TDMA connections that are not in the *Idle* state	none	Main slots, Retry Downlink slots, Retry uplink slots Channel Management (short or long forms)
1 (*High*)	subframe index zero only	PS wake-up notification and PS wake-up successful events
2	none	TDMA connection established and TDMA Request Encryption events.
3	subframe index zero only	PM services accepted and terminated, PS wake-up denied and, CW signaling
3	none	TDMA Channel Management
4 *(Low)*	none	TDMA connection denied events

[179] The highest priority events are those defining the structure of the superframe, then come those concerning node waking-up only occasionally, and then the remaining ones.

[180] Constraining an event to subframe index zero improves robustness when signaling in the presence of transitions in *SubframesPresent* and power-saving nodes.

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5.17.3.5 Event Removal

This section defines under what circumstances events that have been inserted into the CP beacon Event Queue are removed. The rules depend on event type as defined in Table 228.

Table 228 - CP Beacon Event Removal Conditions

CP Beacon Event	Removal Condition
TDMA main slots, TDMA retry downlink slots, TDMA retry uplink slots	Immediately after transmission [181]
CFP Duration Signaling	Immediately after transmission [182]
PM service request accepted PM service terminated PS wake-up denied PS wake-up successful Connection denied	After the event has been transmitted in *CPBEpersistence* CP beacons
Connection established	*NumMissedCPB* superframes after event insertion or having received a TDMA MPDU with a matching connection ID.
Terminate connection	*NumMissedCPB* superframes after event insertion or having received a CPS MPDU containing a *Release TDMA connection* request from the node addressed by this event and with a matching connection ID.
TDMA Request Encryption	*NumMissedCPB* superframes after event insertion or having received a TDMA CPS MPDU with a matching connection ID and containing a *Request Encryption* event.
PS wake-up notification	A *PSinterval* after event insertion or having received a CPS MPDU containing a *wake-up acknowledge* request from the node addressed by this event.
CW Signaling	A *PSinterval* after event insertion

5.17.4 Proxy Signaling of LearnNWID

A CP that receives a valid CPS MPDU or TDMA CPS MPDU containing a request to signal LearnNWID shall perform the *Signaling LearnNWID Locally* procedure defined in section 5.16.14.1 (Signaling LearnNWID Locally).

To be considered valid, this MPDU shall have:

- TDMA CPS or CPS MPDU type
- Correct CRC

5.17.5 Proxy Signaling of *DirectedLearnNWID*

A CP that receives a valid CPS MPDU containing a request to signal *DirectedLearnNWID* shall perform the *Signaling DirectedLearnNWID Locally* procedure defined in section 5.16.15.1 (Signaling *DirectedLearnNWID* Locally).

[181] The T DMA slot signaling events are inserted once a subframe by an entity above the CP Beacon packer.

[182] The CFP Duration signaling event is inserted once a subframe by an entity above the CP Beacon packer.

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To be considered valid, this MPDU shall have:

- CPS MPDU type
- Valid *NWID*
- Correct CRC

5.17.6 CW Signaling

A CP can select a new value for CWmin and CWstart based upon implementation-specific criteria.

Support for the priority asynchronous data service requires a CP to adjust the value for CWstart to insure that the non-priority access to the medium does not occur until after the priority streams have gained access to the medium.

While the current value of CWmin is different from the *CWminDefault* value, or the value of CWstart is different from the *CWstartDefault* value, the CP shall periodically insert CW signaling events into the CP beacon using the procedure defined in section 5.17.3 (CP Beacon Transmit). The interval between these insertions should be no longer than *CWtxInterval.*

The *CWmin* value selected shall meet the following constraints:

- It must be a power of 2
- It must be no less than 2
- It must be no greater than *CWmax*

When the *CWstart* value is selected by the CP according to implementation-specific criteria, the signaled value shall meet the following constraints:

- It shall be no greater than *CWstartMax*
- It shall be greater than or equal to 'n' where is n is the number of active priority streams

When a CP grants priority access to a stream, then the CP will also be responsible for transmitting the CWPriority[n] within the beacon. This field must be resent periodically within the beacon at an interval no less than CWTxinterval. The CP will be required to send this field with the corresponding CWstart and CWmin values whenever a new priority stream is granted access, or when other conditions cause the network to drop a stream.

The CWPriority[n] array values selected shall meet the following constraints:

- *CWstartPriorityDefault* ≥ n ≤ CWstart
- For each n, CWPriority[n] shall equal the corresponding stream ID

5.17.6.1 Updated CWmin values (Informative)

This specification does not define the criteria the CP uses to select a new *CWmin* value.

The CP could use an updated *CWmin* value to maximize network performance based upon observations of the number of contentions, the number of contending nodes, the number of active nodes.

5.17.6.2 Updated CWPriority[n] values (informative)

The values in this array will dictate what unique backoff number will be used by each active priority stream to insure its priority access. Interference, TDMA voice calls, large time reservations by nodes with streams of higher priority, could all be factors in causing a lower priority stream not to gain access to the medium during a specific superframe period. Accordingly, priority streams that request a session with stricter QoS variables should get the lower (higher priority) backoff numbers. In the case that the setup of more than one stream with identical QoS parameters is requested, then backoff numbers should be assigned on a first come first serve basis. When new streams are granted access, the CP shall supply a backoff number appropriate for the level of QoS. The CP then must send out the CW Signaling information including the CWPrioirity[n] array in the next beacon to update all nodes to any changes in the priority access.

5.17.7 Hopset Adaption

This section defines behavior that shall be supported by a CP in order to select values for and signal its hopset adaption variables. Hopset adaption is intended to provide interference mitigation for 1 MHz channels. The time sensitive nature of voice communications (which exclusively use 1 MHz hopping channels) gets the most advantage from the removal of bad-bad hop pairs.

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However, even for wider channels a significant reduction in bad-bad hop pairs is obtained through the use of this algorithm. This provides for more robust transmission of streaming data, in which the packets are also time-sensitive.

5.17.7.1 Hopset Adaption by a Class-2 and Class-3 CP

A Class-2 or Class-3 CP shall set its *HopsetAdapted* variable to zero. [183]

5.17.7.2 Hopset Adaption by a Class-1 CP

A Class-1 CP can determine values for its *HopsetAdapted, InterferenceWidth* and *InterferenceStart* variables according to implementation-defined criteria with the following constraints:

- Either *HopsetAdapted* shall be zero, or
- The interference band shall lie entirely in the range 0 to (*NumberOfChannels*-1) and the *InterferenceWidth* shall lie in the range *MinInterferenceWidth* to *MaxInterferenceWidth*.

The CP shall signal in the CP Beacon the same values of the hopset adaption variables for duration of at least *HopsetAdaptionPersistence*.

The values of the hopset adaption signaling fields signaled in the *TDMA Channel Management* and *Channel Management* fields shall be consistent. A *TDMA Channel Management* field shall be transmitted if, and only if, a CP2 *Channel Management* field is transmitted.

When *HopsetAdaption* is non-zero, the CP should signal the hopset adaption signaling fields in every CP Beacon. The CP can choose not to signal them in order to limit CP Beacon length.

5.17.8 Connection Point Negotiation

The procedures defined in this section ensure that there is only one active CP in a network. Through a negotiation process, one CP survives in the active state, and any other CPs operate in the passive state.

5.17.8.1 Overview (Informative)

A HomeRF network is managed by a single CP, the *active* CP.

In a passive CP, the procedures that the active CP performs to provide services to I-nodes and A-nodes are not operational. For example, a network may contain a Class-1 CP, and one or more Class-2 or Class-3 CPs. These operate as passive CPs until the Class-1 CP is removed from the network. Then one of them takes over as the active CP. If a Class-2 CP takes over as the active CP, it continues to provide power-management services to the nodes on the network.

The only procedures that are performed by a passive CP are those that permit the connection-points within a network to negotiate which CP is to be active. These are based on the CP assertion procedures and CP assertion MPDU.

The passive CP can act as an A-node or I-node by performing the procedures specific to those HomeRF node types. It is unlikely that a passive CP will operate as an I-node, but is reasonable for it to act as an A-node providing asynchronous data-transport. On the other hand, the passive CP need do nothing more than perform the passive CP procedures. When a passive CP become active, the MAC entity does not inform its higher layers. Whether a CP is active or not is not visible above the MAC layer.

The CP can also perform power-saving procedures. These do not interfere with the procedures it is required to operate as a passive CP.

The passive CP regularly checks that the CP beacon is being sent by the active CP on the network. If the active CP disappears, the passive CP takes over the network management. If more than one passive CP detects the loss of the active CP, the CP assertion mechanism ensures that only one of them remains active.

The CP assertion mechanism also permits a CP to resume control of a network after loss of control, for whatever reason.

The total time for a passive CP to take over after a removal of the active CP is between *NumMissedCPB* and *NumMissedCPB* * 2 (=*NumToAdhoc*) superframes.

When a CP ceases operation as the active CP, it immediately stops supporting any CP services (such as power-management, streaming session management, and TDMA connections). Any state associated with any active services is lost. A HomeRF network supports only a single Class-1 CP on a network, so it is anomalous for a Class-1 CP to switch from active to passive operation.

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[183] The *HopsetAdaption* field will be transmitted in all CP beacons. No *InterferenceStart* and *InterferenceWidth* values will be signaled.

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A node that was provided services by the active CP that has become inactive has to request services of the new CP. Power-saving nodes are not aware of the transition of control. A power-saving node regularly re-requests power-saving services, and so the new CP learns of the node's requirement after a bounded period of time.

5.17.8.2 CP Terminology Convention

In this specification the term *CP* without any qualification refers solely to the *active* CP.

5.17.8.3 CPA Assertion MPDU Transmit

The CP Assertion MPDU shall be transmitted using the CSMA/CA mechanism. The MPDU destination address field shall be the broadcast address. The Connection Point type and Connection Point priority fields shall be set with the type and priority of the sender.

A passive CP shall transmit the CP assertion MPDU with the ACP superframe counter set to 0. An active CP shall set the ACP superframe counter with the number of superframes elapsed since its first transmission of a CP beacon. If this value is larger than 0xFFFFFFFF, 0xFFFFFFFF shall be used instead (the counter saturates and does not wrap around).

5.17.8.4 CP Startup

When a CP finds and joins an existing network, it does so as a passive CP.

The CP shall only become active following the operation of these procedures.

When a CP has joined an existing network, it can optionally send several CP assertion MPDUs.[184] The CP should send three CP assertion MPDUs in different superframes. This can result in faster detection of contention.

When a CP has failed to find a network and has started one of its own, it can start operating immediately as an active CP. Alternatively, it can wait for the operation of the passive CP procedures to cause it to become active.

5.17.8.5 Passive CP operation

A *passive* Connection Point is a node that can potentially act as an active Connection Point, but which is not currently acting as an active Connection Point.

A passive CP shall perform the procedures defined in this section.

A passive CP shall not use any of the procedures defined for the active CP in this specification.

A passive CP shall ignore any received CPS MPDUs. A passive CP shall perform the managed network synchronization procedures defined in section 5.16.16 (Synchronization in a Managed Network).[185]

The passive CP shall regularly listen for the presence of a CP beacon. The interval between these shall be no greater than *NumMissedCPB* superframes.

A passive CP that fails to hear a CP beacon for *NumMissedCPB* consecutive superframes shall do the following in order:

- Transmit three CP Assertion MPDUs in different superframes,
- Wait until the next superframe dwell,
- Start operation as the active CP

5.17.8.5.1 Transition from Passive to Active Operation

A passive CP that has started operation, and has determined that it is of higher priority than the active CP (following the operation of the procedures in section 5.17.8.6.4 (CP Assertion) shall perform the procedures in this section.

The passive CP shall stop operating any power-saving procedures.

The passive CP shall transmit CPA MPDUs once a superframe until it has received no CP beacons for two successive superframes, or until 5 CPA MPDUs have been transmitted.

The node then becomes the active CP and starts operating the active CP procedures.

[184] Thereby forcing a CP contention.

[185] Thereby obtaining synchronization from the active CP.

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5.17.8.5.2 Passive CP Power-Saving

After starting synchronized operation, a passive CP shall perform the following steps before it can start power-saving:

- Receive a CP beacon
- Receive a CP assertion MPDU from the active CP (as indicated by a matching MPDU source address field).
- Verify that it need not start operation as the active CP based on the CP assertion MPDU CP type and priority fields.

A passive CP that is power-saving is required to wake to listen for CP beacons, as defined in section 5.17.8.5 (Passive CP operation).

A passive CP that is performing a power-saving procedure and that fails to receive a CP beacon shall continue to listen for CP beacons in subsequent CP beacon intervals until one is received, or the operation of these procedures cause it to start operation as the active CP.

5.17.8.6 Active CP operation

An active CP shall perform the procedures defined in this section. The active CP shall not perform any power-saving procedures.

5.17.8.6.1 CP Beacon Transmit

The active CP shall send a CP beacon at the beginning of each dwell using the timing defined in 5.5.3.2 (Connection Point Beacon Timing).

If the CP is a Class-1 CP, it shall transmit a CP1 Beacon using the *Dual Beacon* format. If it is a Class-2 or Class-3 CP, it shall transmit a CP2 Beacon using the *Basic Rate Single PSDU* format.

5.17.8.6.2 CPS MPDU Receive

The active CP shall provide power-management services and can provide I-node management services by receiving CPS and TDMA CPS MPDUs using the procedures defined in 5.10.3.1 (CSMA/CA CPS Receive), 5.18 (A-node Power-Management and Power-Saving) and 5.20.1 (Introduction to I-node Management (Informative)).

5.17.8.6.3 CP Assertion MPDU Transmit

The active CP shall send regular CP Assertion MPDUs.[186] The active CP shall send the CP Assertion MPDU using the CSMA/CA mechanism. The interval between two CP Assertion MPDU transmissions shall be no greater than *CPAtimeout* (defined in section 16.2 (MAC Constants)).

5.17.8.6.4 CP Assertion Receive

An active CP that receives a CP assertion MPDU determines from that MPDU whether it is from a CP of *higher priority*. A received CP assertion MPDU indicates that its sender is higher priority than the receiver CP if any of the following apply:

- the CP Assertion MPDU has a higher functionality than the receiver CP,
- the CP Assertion MPDU has the same functionality and a higher priority than the receiver CP,
- the CP Assertion MPDU has the same functionality, the same priority and a higher superframe counter,

If the received CP assertion is of higher priority, the active CP shall immediately start operation as a passive CP.

If the received CP assertion is of lower priority, the active CP shall send a CP Assertion MPDU. It continues to operate as the active CP.

5.17.8.6.5 CP Contention Optimization

A CP can perform the procedures defined in this section to provide faster resolution of active CP conflicts. These procedures are optional. They provide increased performance if there are multiple CPs with marginal radio connectivity.

A CP that:

- Receives a CP beacon, [187]
- Receives an ad-hoc beacon in two consecutive superframes, [188] or

[186] This may create contention with a new passive CP added to the network and resolve contention between active CPs.

[187] Which means that some other CP thinks it is also the active CP.

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- Looses all feedback from active I-nodes for 5 consecutive subframes (nodes losing connection, or no use of any retry slots at all, no answer to events).[189]

shall transmit a CP assertion MPDU in the current dwell.

5.18 A-node Power-Management and Power-Saving

This section defines power-management procedures operated by the A-node and CP MAC entities that shall be used to manage power-saving within the A-node.

5.18.1 Introduction (Informative)

An A-node that saves power is called a PS node. An A-node saves power by operating the power-management (PM) and power-saving (PS) procedures. The PM procedures enable it to request power-management services from the CP. The PS procedures define when it must be enabled to receive. This A-node is called a *Power-Saving* A-node.

An A-node that transmits MSDUs to another A-node is either a *Power-Supporting* A-node or a *non-Power-Supporting* A-node. The *Power-Supporting A-node* operates all relevant procedures defined here. The *non-Power-Supporting* A-node operates without regard to any of these procedures.

Power-management signaling in the CP Beacon is only present when the *SubframeIndex* is zero, *i.e.* on a Superframe boundary. All timing of these procedures is defined in terms of superframes, not dwells. This enables a power-saving A-node to wake only for these CP beacons, and to be insensitive to changes in the *SubframesPresent* variable

The procedures required to support the transport of unicast and multicast MSDUs are defined in separate following sections.

5.18.2 Relation Between Unicast and Multicast Power-Saving (Informative)

The procedures required to support unicast power-saving are independent of multicast power-saving at the CP, the power-saving A-node and the power-supporting A-node.

A power-saving A-node can operate unicast, multicast or both types of power-saving procedures.

At the Power-Saving A-node, its unicast and multicast PS state machines are independent. A PS node that enters UPS-awake state is likely to be in the MPS-asleep state. A PS node that enters MPS-awake state will probably stay in the UPS-asleep mode. An A-node that does not care about multicast MSDUs can be in the MPS Idle state and in the UPS-asleep state. (See sections 5.18.7.2.1.1 (Unicast PS States) and 5.18.8.5.1 (Multicast PS states) for a definition of these states).

An A-node can request unicast and multicast power-management services from the CP in one CPS MPDU.

5.18.3 Effect of non-Power-Supporting Originating Nodes (Informative)

An A-node can ignore totally all the power-supporting procedures and treat PS nodes as though they were non-PS nodes.

The multicast PM service is already totally transparent to the originator (see section 5.18.8 (Multicast Power-Saving)): the CP automatically re-sends all multicast MSDUs regardless of their source.

The transparent transmission of unicast MSDUs to a PS node does work as well in most cases, even if the node does not support sending data to a PS node (see section 5.18.7.4 (Unicast Power-Supporting Node)). A TCP connection starts with an ARP request, in order to discover the MAC address of the destination. The ARP request is a broadcast MSDU, so the CP ensures its delivery to the PS nodes. The PS node receives the ARP broadcast and replies to it with an ARP response (a unicast MSDU). By sending this unicast MSDU, it exits *UPS Asleep* state and enters the *UPS Awake* state (see section 5.18.7.2.1 (Unicast PS state)), allowing the other node to send data to it.

5.18.4 Power-Management Services

5.18.4.1 Power Management Service Request

A PS node that requires PM services from the Connection Point shall transmit a CPS MPDU to the CP, as defined in section 5.10 (CPS Procedures). Successful transmission of the MPDU is indicated by receiving a CPB containing a *PM service request accepted* or *PM service request terminated* event addressed to this node.

The payload of the CPS request shall contain the values defined in Table 229.

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188 Which means that one or more CSMA/CA nodes cannot receive the CP Beacon.

189 Which means that I-nodes cannot receive the CP beacon

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Table 229 - CPS MPDU Field Settings for a Power-Management Service Request

CPS MPDU Field	Contents
CPS Request ID	Power-management service request
Connection ID	0
PS Service ID	The level of service required (unicast PM service, multicast PM service or both)

A CP that receives a PM service request, and that can provide the requested service shall:

- store the address of the PS node (source address of the CPS MPDU) in the list of nodes for which it provides power management services
- start providing PM services for the PS node. The CP need not decode the requested *Service ID* field of the CPS request. It can simply start both unicast and multicast PM services regardless of the requested *Service ID*. [190]

Queue a CP beacon *PM service request accepted* event for the PS node containing the address of the PS node. See section 5.17.3 (CP Beacon).

A CP that receives a PM service request, and that cannot provide the requested service shall:

- Queue a CP beacon *PM service request terminated* event for the PS node containing the address of the PS node. See section 5.17.3 (CP Beacon).

5.18.4.2 Power Management Service Termination

A PS node that no longer requires PM services from the Connection Point shall transmit a CPS MPDU to the CP, as defined in section 5.10 (CPS Procedures). Successful transmission of the MPDU is indicated by receiving a CPB containing a *PM service request terminated* event addressed to this node.

The CPS MPDU shall contain the field settings defined in Table 230.

Table 230 - CPS MPDU Field Settings for Power-Management Service Termination

CPS MPDU Field	Contents
CPS Request ID	Terminate power management service request
Connection ID	0
PS Service ID	0

A CP that receives a PM service termination shall:

- Remove the address of the node from the list of nodes for which it provides power-management services
- Stop providing PM services for that node.
- Queue a CP beacon *PM service request terminated* event for the PS node containing the address of the PS node. See section 5.17.3 (CP Beacon).

5.18.4.3 CP Response to Power-Management Requests (Informative)

Note that the CP responds to all power-management requests (by denying or accepting the request) regardless of whether it is already providing power-management services for the node sending the request.

[190] The correct interpretation of this field permits the CP to optimize its operation.

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This behavior provides an acknowledgement of the CPS MPDU.

5.18.4.4 Maintaining Power-management Services

5.18.4.4.1 Introduction (Informative)

The CP may need to release the resources associated with power managing a specific PS node. This is usually done when the node terminates PM services. But, because HomeRF is a dynamic radio network, nodes may disappear without warning. The CP cannot rely on the correct PM service termination by the node.

The CP may disappear from the network (if it is stopped, or a higher functionality CP takes over), and so a PS node has no guarantee that it is still power managed.

To overcome these difficulties, the PS node is required to periodically re-request PM services from the CP.

5.18.4.4.2 CP Procedure

The CP shall provide power-management services for a PS node for a period of up to *PMinterval* after accepting a power management service request from it.

After expiry of this timeout, the power management of this node by the CP is up to the implementation.

5.18.4.4.3 PS Node Procedure (Informative)

A PS node that requires power-management services from the CP periodically requests power-management services from the CP using the procedure defined in 5.18.4.1 (Power Management Service Request). The interval between these requests is no longer than *PMinterval*.

Its power-management state machine ensures this behavior.

5.18.5 PS Node Power-Management State Machine

The PS node has an overall PM state machine that defines its operation.

The events that control this state machine are defined in Table 231.

Table 231 - Events Relevant to the Power-Management State Machine

Event	Definition
Enters Managed	The Node's Network Synchronization State has entered the Managed state
Leaves Managed	The Node's Network Synchronization State has left the Managed state
PM accepted	The PS node has received a CP beacon containing a *PM service request accepted* event for it
PM terminated	The PS node has received a CP beacon containing a *PM service request terminated* event for it
CPS timeout	The transmission of a CP MPDU using the Connection Point Service (CPS) Procedures failed with timeout status

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The states of the state machine are defined in Table 232.

Table 232 - Power-Management States

PM State	Definition
PM Idle	The station is not in the *Managed* network synchronization state
PM Disabled	The station is enabled to receive at all times.
PM Enabled	The station can save power by operating the power-management procedures.

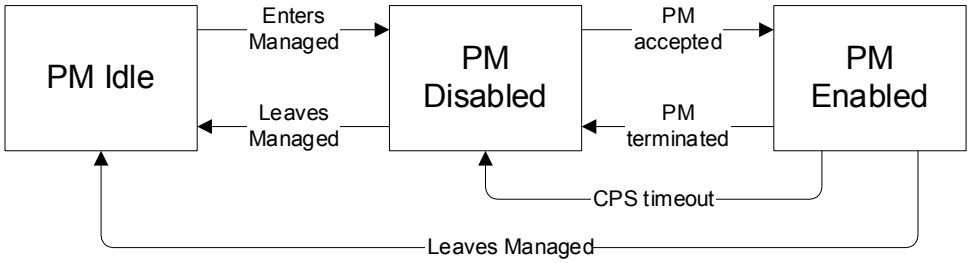


Figure 170 - Power Management State Transition Diagram

The transitions of the state machine are defined by the following sections.

5.18.5.1 PM Idle

In this state, the node shall not operate any of the power-management procedures.

Event	Action	Next State
Enters Managed		PM Disabled

5.18.5.2 PM Disabled

In this state:

- The node shall be capable of receiving during the beacon period and contention period
- The node can send a *power management service request* at any time using the procedures defined in 5.18.4.1 (Power Management Service Request). The criteria used to decide when to send this request are specific to the implementation.

Event	Action	Next State
Leaves Managed		PM Idle
PM accepted		PM Enabled

5.18.5.3 PM Enabled

A node that is in the *PM Enabled* state shall operate the procedures defined in this section.

The node shall repeat the PM service request procedure (see section5.18.4.1 (Power Management Service Request)) periodically. The interval between successive requests shall be no longer than *PMinterval* (which is defined in section 16.2 (MAC Constants)).

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A node that has requested multicast PM services shall operate the multicast power-management procedures defined in section 5.18.8 (Multicast Power-Saving).

A node that has requested unicast PM services shall operate the unicast power-management procedures defined in section 5.18.7 (Unicast Power-Saving).

The node shall be capable of receiving when required so to do by either the multicast power-management procedures or the unicast power-management procedures.

The node can initiate a *power management service termination* request at any time. How it decides to do this is up to the implementation.

Event	Action	Next State
Leaves Managed		PM Idle
PM terminated		PM Disabled
CPS timeout		PM Disabled

5.18.6 PS Mode Enabled Capability

The *PS mode enabled capability* transmitted in any SI MPDUs shall be set according to the PM state as defined in Table 233.

Table 233 - Transmitted PS Mode Enabled Capability Based on PM State

PM State	PS mode enabled capability
PM idle	0
PM disabled	0
PM enabled	1

5.18.7 Unicast Power-Saving

5.18.7.1 Introduction to Unicast Power-Saving (Informative)

5.18.7.1.1 Unicast Power-Saving Procedures (Informative)

The unicast power saving procedures ensure that a PS node is able to receive unicast data CSDUs addressed to it by an originating node that supports these procedures. These are received with the same reliability as a non-PS node. They can be delayed by the operation of these procedures.

These procedures rely on the CP to wake PS nodes on demand.

5.18.7.1.2 Unicast Power-Saving Entities (Informative)

Table 234 describes the three entities involved in operating the unicast power-saving procedures.

Table 234 - Entities involved in the Unicast Power-Saving Procedures

Entity	Description
Unicast PS node	A HomeRF A-node that wants to save power. It enters a power-saving state when permitted so to do by the procedures defined in section 5.18.7.2 (Unicast PS Node Procedures)
CP	The CP provides power-management services defined by the procedures in section 5.18.7.3 (CP Unicast Power-Management Service). It wakes the destination PS node on request from the originating node.
Unicast Power-Supporting	A Node that wants to transmit to a power-saving node and that operates

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Node	the procedures defined in section 5.18.7.4 (Unicast Power-Supporting Node).

There is also another possible entity: an originating node that does not support the procedures defined in section 5.18.7.4 (Unicast Power-Supporting Node). The operation of the network under these conditions is considered in section 5.18.3 (Effect of non-Power-Supporting Originating Nodes (Informative)).

5.18.7.1.3 Unicast Power-saving Protocol (Informative)

A PS node that wants to save power requests power-management services from the CP. It does so by sending a CPS MPDU containing a power-management service request (see 5.18.4.1 (Power Management Service Request)). The CP acknowledges and grants the request by inserting an event in the CP beacon. When the PS node has received this, it enters a low-power state after a *PStimeout* delay. The PS node then wakes periodically to check for *wake-up* requests in the CP beacon.

If a Power-Supporting node wants to send data to a destination node, the destination might or might not be a PS node. If it is a PS node, it might or might not be awake.

The power-supporting node first asks the CP to wake the destination by sending a CPS *wake-up* request. If the destination is a power-saver, the CP will respond by transmitting a *wake-up notification* in a CP beacon. Otherwise it responds with a *wake-up denied*.

So the originating node can determine whether the station is an enabled power-saver based on the contents of the CP beacon. If the destination is not an enabled power-saver, the node can transmit data to it without further protocol.

If the station is an enabled power-saver, it responds to the *wake-up notification* with a CPS MPDU carrying a *wake-up acknowledge* event after a maximum delay of *PSinterval*. The CP receives this and transmits a *wake-up successful* event in a CP beacon. The originating node receives this and knows that the destination is awake.

The destination stays awake for a *PStimout* after receiving the wake-up notification, transmitting any DATA MPDU or receiving any unicast DATA MPDU - so the originating node also keeps a timer, which is reset to *PStimeout* whenever it receives a *wake-up successful* event, or transmits to or receives from the destination node.

As long as this timer is active, the originator can assume that the destination node is awake, and can send DATA MPDUs to it.

When the timer is not active, the node has to assume that the destination node is not awake. In this case it will not send any DATA MPDUs to it. Incoming DATA CSDUs are buffered within the MAC until the station is known to be awake.

5.18.7.1.4 Summary of Unicast PS Procedures (Informative)

Figure 171 illustrates the operation of the unicast PS procedures showing the sequence of messages exchanged between an originating A-node (power-supporter), the CP and the recipient A-node (power-saver).

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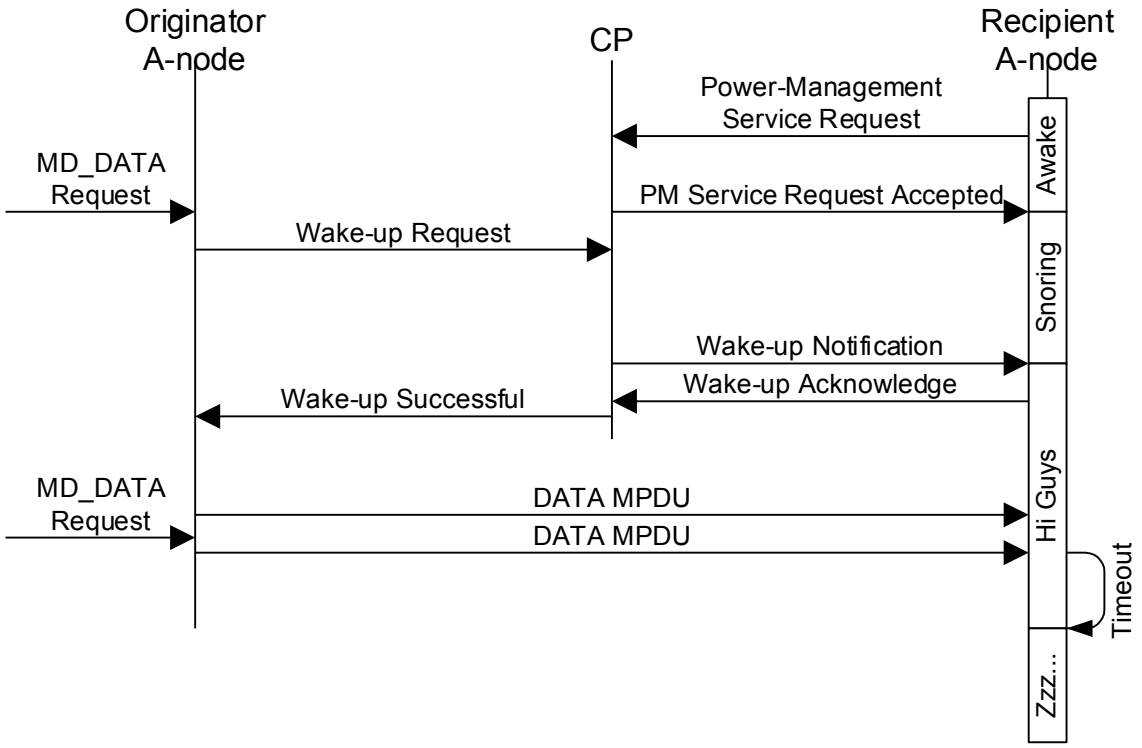


Figure 171 - Summary of Unicast PS Procedures

5.18.7.2 Unicast PS Node Procedures

An A-node that is in the *PM Enabled* state of its Power Management State machine and that has requested unicast power-management services from the CP shall operate the procedures defined in sections 5.18.7.2.1 (Unicast PS state) to 5.18.7.2.2 (Transmitting a Wake-Up Acknowledgement).

5.18.7.2.1 Unicast PS state

The Unicast PS procedures are defined in the following sections by a state machine. A single instance of this state machine exists only when the A-node's Power Management State is in the *PM Enabled* state.

5.18.7.2.1.1 Unicast PS States

Table 235 describes the Unicast Power-Saving states that control the behavior of a PS node.

Table 235 - Unicast Power Saving states

UPS state	Description
UPS Awake	The node is able to receive all CP beacons and Unicast MPDUs. This is the initial state of this state machine.
UPS Asleep	The node is only able to receive some CP beacons

5.18.7.2.1.2 Unicast PS Events

The following events drive the operation of the UPS state machine

Table 236 - Unicast Power-Saving Events

Event	Definition

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Keep Awake Expires	The keep-awake timer expires. See section 5.18.7.2.1.4 (UPS Awake State)
Wake Notification	The CP beacon contains a *wake-up notification* event containing the MAC address of this node
Unicast DATA Received	A unicast DATA MPDU addressed to this node has been received
DATA Transmitted	A DATA MPDU has been transmitted by this node regardless of completion status

5.18.7.2.1.3 UPS State Transition Diagram

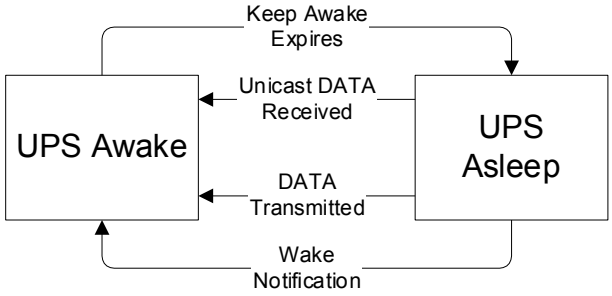


Figure 172 - Unicast Power-Saving State Transition Diagram

The procedures to be followed in the UPS states are defined in the following sections.

5.18.7.2.1.4 UPS Awake State

A node in this state shall be capable of receiving during the beacon period and during the contention period.

The node shall support a *Keep Awake* timer. The timer shall be reset to *PStimeout* on entry to the UPS Awake state, and on other events as defined in the following state transition table.

On expiry of the *Keep Awake* timer, a *Keep Awake Expiry* event is signaled to the Unicast Power-saving state machine.[191]

Event	**Action**	**Next State**
Keep Awake Expires		UPS Asleep
Wake Notification	Transmit *a wake-up acknowledge* using the procedure defined in section 5.18.7.2.2 (Transmitting a Wake-Up Acknowledgement). Reset *Keep Awake* timer to *PStimeout*	
Unicast DATA Received	Reset *Keep Awake* timer to *PStimeout*	
DATA Transmitted	Reset *Keep Awake* timer to *PStimeout*	

[191] This may result in the node being permitted to go to sleep.

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5.18.7.2.1.5 UPS Asleep State

A node that is in the UPS Asleep state shall periodically power-up to ensure that it is capable of receiving during the beacon period. The interval between these power-up events shall be no greater than *PSinterval*. [192]

A node that has powered-up to receive a beacon shall remain powered-up until a beacon is received or the operation of the CP beacon Timeout procedures (see section 5.16.16 (Synchronization in a Managed Network)) cause it to leave the UPS asleep state.[193]

Event	Action	Next State
Wake Notification	Transmit *a wake-up acknowledge* using the procedure defined in section 5.18.7.2.2 (Transmitting a Wake-Up Acknowledgement).	UPS Awake
Unicast DATA Received		UPS Awake
DATA Transmitted		UPS Awake

5.18.7.2.2 Transmitting a Wake-Up Acknowledgement

A PS node that has received a *wake-up notification* event in a CP beacon shall transmit a CPS MPDU containing *a wake-up acknowledge* request using the CPS procedures defined in section 5.10 (CPS Procedures).

Successful transmission of this MPDU is indicated by receiving a CP beacon containing a *wake-up successful* event addressed to this node.

5.18.7.3 CP Unicast Power-Management Service

A CP that receives a PS wake-up request shall queue a *wake-up notification* event or a *wake-up denied* event to be transmitted in the CP beacon as defined in section 5.17.3 (CP Beacon). The event shall contain the MAC address of the node contained in the IEEE address field of the CPS MPDU.

The *wake-up notification* event shall be selected if the CP is providing unicast power-management services for the requested node. Otherwise, the *wake-up denied* event shall be selected.

The *wake-up notification* event shall be cancelled if the CP receives a CPS MPDU containing a *wake-up acknowledge* request from the node addressed by this event.

A CP that receives a CPS MPDU containing a *wake-up acknowledge* request shall:

- Cancel any pending *wake-up notification* events associated with the source address of the CPS MPDU
- Queue a *wake-up successful* event containing a MAC address set to the source address of the CPS MPDU to be transmitted in the CP beacon as defined in section 5.17.3 (CP Beacon).

5.18.7.4 Unicast Power-Supporting Node

A node that supports Unicast DATA MPDU transmission to PS nodes shall operate the procedures defined in this section. A node that does not operate these procedures shall transmit Unicast DATA MPDUs to the destination node without regard to its power-saving status.

The operation of these procedures is defined by a state machine. The power-supporting node shall support at least one instance of this state machine.[194] The instance of the state machine is identified by the destination node MAC address.

---

[192] The implementer is advised to wake after a slightly shorter interval to allow for a few missed CP Beacons. The implementer is also advised to allow for worst-case synchronization drift between this node and the CP in locating the beacon period.

[193] In case of a CP Beacon timeout, the Synchronization state machine leaves the *Managed* state. The PM state machine leaves the *PM Enabled* state and the Unicast Power-Saving state machine ceases to exist.

[194] A single instance requires the originating node to re-discover the destination's power-saving status each time the destination address changes.

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5.18.7.4.1 PS Supporter Capability

A node that operates the procedures defined in section 5.18.7.4 (Unicast Power-Supporting Node) shall transmit all IR/SI MPDUs with the *PS Supporter Capability* bit set to a one. All other nodes shall transmit this bit set to a zero. [195]

5.18.7.4.2 Power-Supporting States

Table 237 - Unicast Power-Supporting States

Power-Supporting State	Description
Idle	The local MAC entity has no DATA to transmit to the destination node
Pending Wake-up	The local MAC entity has sent a *wake-up* request to the CP and is waiting for a response
PS Disabled	The local MAC entity knows that the PS enabled capability of the destination node is a 0
Awake Unknown	The local MAC entity knows that the PS enabled capability of the destination node is a 1, but does not know that it is awake
Awake Known	The local MAC entity knows that the PS enabled capability of the destination node is a 1 and knows that it is awake

[195] Note that this capability is not linked in any way to the ability of the node to perform its own power-saving procedures. Many non-PS nodes might have this capability, and a few PS nodes might not have this capability.

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5.18.7.4.3 Power-Supporting Events

Table 238 - Events Relevant to the Power-Supporting State Machine

Power-Supporting Event	Definition
DATA queued	A DATA CSDU request for the destination address has arrived for transmission
Wake-up Succeeded	A *wake-up successful* event for the destination node has been received in the CP beacon
Wake-up Failed	No wake-up successful or wake-up denied event has been received in the CP beacon for a *PSinterval* after transmitting a CPS MPDU carrying a wake-up request
Wake-up Denied	A *wake-up denied* event for the destination node has been received in the CP beacon
DATA transmitted	A Unicast DATA MPDU has been successfully transmitted to the destination node
DATA received	A DATA MPDU has been received with source address matching that of the destination node. An A-node shall only consider unicast MPDUs for this event.[196] A CP shall consider both unicast and multicast MPDUs.
Keep Awake Expires	The Keep Awake Timer expires
PS Disabled	A SI MPDU is received that contains the *PS Enabled* capability set to zero

[196] Because a multicast MPDU may have been relayed by the CP and subject to considerable delay. Its arrival indicates nothing about the PS state of the originating node.

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5.18.7.4.4 Power-Supporting State Transition Diagram

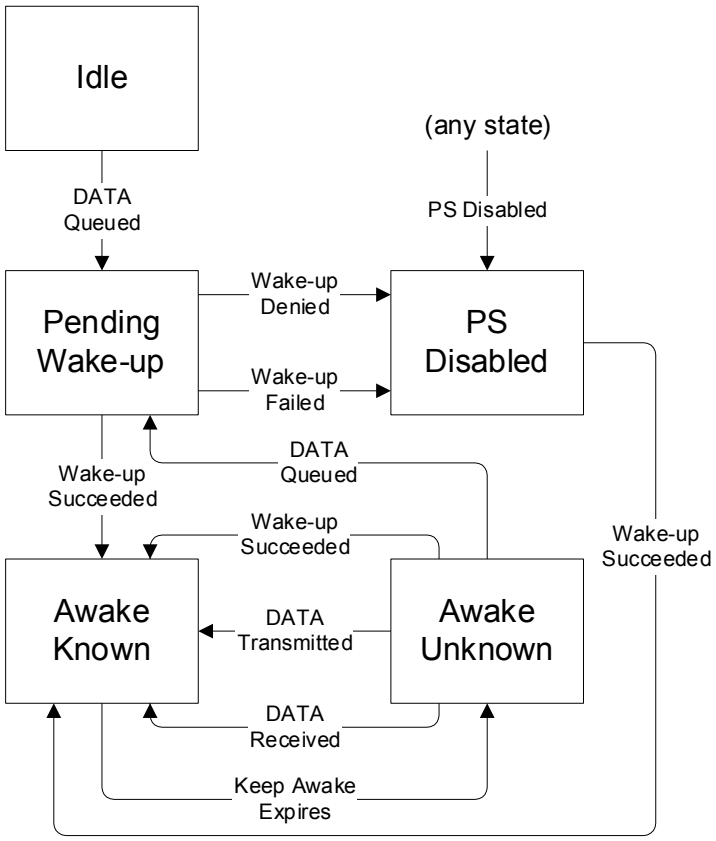


Figure 173 - Power Supporting State Transition Diagram

The operation of the state machine by state is defined in the following sections.

5.18.7.4.5 Idle

Event	Action	Next State
DATA queued	Optionally issue a *block* request to the MD-SAP services specifying this destination address.	Pending Wake-up
PS Disabled		PS Disabled

5.18.7.4.6 Pending Wake-Up

On entry to this state, the node shall transmit a CPS MPDU carrying a *Wake-up* request using the procedures defined in section 5.10 (CPS Procedures). The request shall contain the destination node address. Successful transmission of this MPDU is indicated by receiving a CP beacon containing a *Wake-up notification* or *Wake-up denied* event with an address matching that of the destination node.

If transmission of the CPS request MPDU fails, a *Wake-up Failed e*vent shall be signaled to the state machine.

If a CP beacon containing a *Wake-up notification* event is received, the node shall start a *wake-up failure* timer with a value of *PSinterval*. On expiry of this timer, a *Wake-up Failed* event shall be signaled to the state machine.

On exit from this state, the node shall:

- Optionally cancel any queued Wake-up request MPDUs
- Cancel the wake-up failure timer

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Event	Action	Next State
Wake-up Succeeded		Awake Known
Wake-up Denied, Wake-up Failed or PS Disabled	Issue a *release* request to the MD-SAP services specifying this destination address.	PS Disabled

5.18.7.4.7 PS Disabled

A node in this state is permitted to send a *Wake-up request* in a CPS MPDU using the procedures defined in section 5.10 (CPS Procedures) in order to confirm the *PS Enable* state of the destination node. [197]

A node can also leave this state if it receives a SI MPDU from the destination node containing *PS Enabled* set to 1, or if it observes a CP beacon containing a *Power Management Accepted* event for the destination node.

Event	Action	Next State
Wake-up Succeeded		Awake Known

[197] It might, for example, do this if a CSDU transmission to this address completes with failure status.

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5.18.7.4.8 Awake Unknown

Event	Action	Next State
DATA queued or there is DATA already buffered for this destination		Pending Wake-up
Wake-up Succeeded, DATA Transmitted, or DATA Received		Awake Known

5.18.7.4.9 Awake Known

In this state, the node shall support a timer: the *Keep Awake* timer. On entry to the state, the timer is set to *PStimeout.* If the timer expires, a *Keep Awake Expires* event is signaled to the state machine.

On entry to this state, a *release* primitive shall be issued to the MD-SAP services specifying the destination address associated with this state machine.

Event	Action	Next State
Wake-up Succeeded, DATA transmitted, DATA received	Reset the *Keep Awake* timer to *PStimeout*.	
Keep Awake Expires	Issue a *block* request to the MD-SAP services specifying this destination address.	Awake Unknown

5.18.7.5 CP Unicast Power-Supporting

A CP shall operate the procedures defined in this section in order to transmit unicast CSDUs.

The CP shall operate all the procedures defined in section 5.18.7.4 (Unicast Power-Supporting Node) (unicast power-supporting) with the following exceptions:

- The *Wake-up Succeeded* event is signaled when the CP receives a CPS MPDU carrying a *Wake-up acknowledgement* request from the destination node.
- The *Wake-up Denied* event occurs without exchange of any MPDUs based on the list of nodes for which the CP is providing unicast power-management services.

The operation of its *Pending Wake-Up* state is defined in section 5.18.7.5.1 (CP Pending Wake-Up State).

5.18.7.5.1 CP Pending Wake-Up State

On entry to this state, the CP shall queue a *Wake-up notification* event to be transmitted in the CP beacon using the procedures defined in section 5.17.3 (CP Beacon).

If the *Wake-up notification* event is discarded following the operation of the *PSinterval* timer, a *Wake-up failed* event shall be signaled to the state machine.

Event	Action	Next State
Wake-up Succeeded		Awake Known
Wake-up Denied or Wake-up Failed	Issue a *release* request to the MD-SAP services specifying this destination address.	PS Disabled

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5.18.8 Multicast Power-Saving

This section defines procedures that enable a power-saving A-node to receive multicast DATA MSDUs.

An A-node can transmit a multicast DATA MPDU at any time. It has no special procedures to support A-node multicast power-saving.

A CP shall operate the procedures defined in section 5.18.8.3 (CP Multicast Power-Management Service).

An A-node can operate the procedures defined in section 5.18.8.5 (A-node Multicast Power-Saving) to receive multicast MSDUs.[198]

All A-nodes shall operate the procedures defined in section 5.18.8.6 (A-node Multicast MSDU) to filter received multicast MSDUs.

5.18.8.1 Overview of Multicast Power-Saving (Informative)

The CP receives and stores multicast MSDUs. The CP defines a time, the *Multicast Period*, at which all A-nodes that operate these procedures will be awake. At that time, the CP re-transmits all stored MSDUs. The *Multicast Period* is signaled in the CP beacon. Signaling is in terms of superframes, and so is not dependent on *SubframesPresent*.

An A-node that wants to save power and also wants to receive multicast MSDUs ensures that it is able to receive during the *Multicast Period*. It does this by decoding a single CP beacon and then arranging to wake at the right time.

Not all nodes receives multicast MSDUs at the same time, PS nodes receive them later than other nodes. The original transmission and the retransmission are distinguished by the setting of the MPDU's *MPS Relay Field*. All nodes select whether to keep only the original or retransmission. Because of the re-transmission by the CP, an A-node also has to discard any MSDUs that it originally sent. These two rules ensure that multicast MSDUs are not duplicated.

An A-node that transmits a multicast MSDU does so without regard to any multicast power-saving state.

A broadcast MSDU is an MSDU addressed to the broadcast MAC address (all ones). Note that a broadcast MSDU is a special case of multicast MSDUs, and support for broadcast MSDUs is provided transparently by these procedures.

5.18.8.2 Example of Multicast PS (Informative)

This section presents the message sequence that results from the transport of a single multicast MSDU using the procedures defined in these sections. The terminology used here is defined in sections 5.18.8.3 (CP Multicast Power-Management Service) to 5.18.8.5 (A-node Multicast Power-Saving).

Figure 174 illustrates the transport of a multicast MSDU and the operation of these procedures. The originating A-node sends a multicast MSDU request during the non-Multicast Period. The node contends for the medium and transmits the multicast MSDU within a DATA MPDU.

The CP receives the multicast MSDU and stores it. Although not shown on the figure, this MSDU will be indicated to the MAC user of the CP at this point.

The CP transmits two CP beacons with countdown values of 2 and 1 and with the MPS *active* flag set to 0. At the next hop time, the Multicast Power-Saving A-node leaves the MPS-asleep state, based on the value of its *MPS downcounter* variable.

The CP, having stored multicast MSDUs to retransmit, transmits a CP beacon with the *active* flag set to 1. It then transmits the stored multicast MSDU.

On receiving the re-transmitted multicast MSDU that it originally sent, the originating A-node discards it. The Multicast PS A-node is awake and receives the multicast MSDU, which is then indicated to its MAC user.

On transmitting the next CP beacon, the CP multicast re-transmission store is empty, and the CP transmits a CP beacon with the *active* flag set to 0.

On receiving this CP beacon, the multicast PS A-node leaves the MPS-awake state and enters the MPS-asleep state.

[198] A power-saving A-node that does not operate these procedures will receive multicast MSDUs with significantly reduced reliability.

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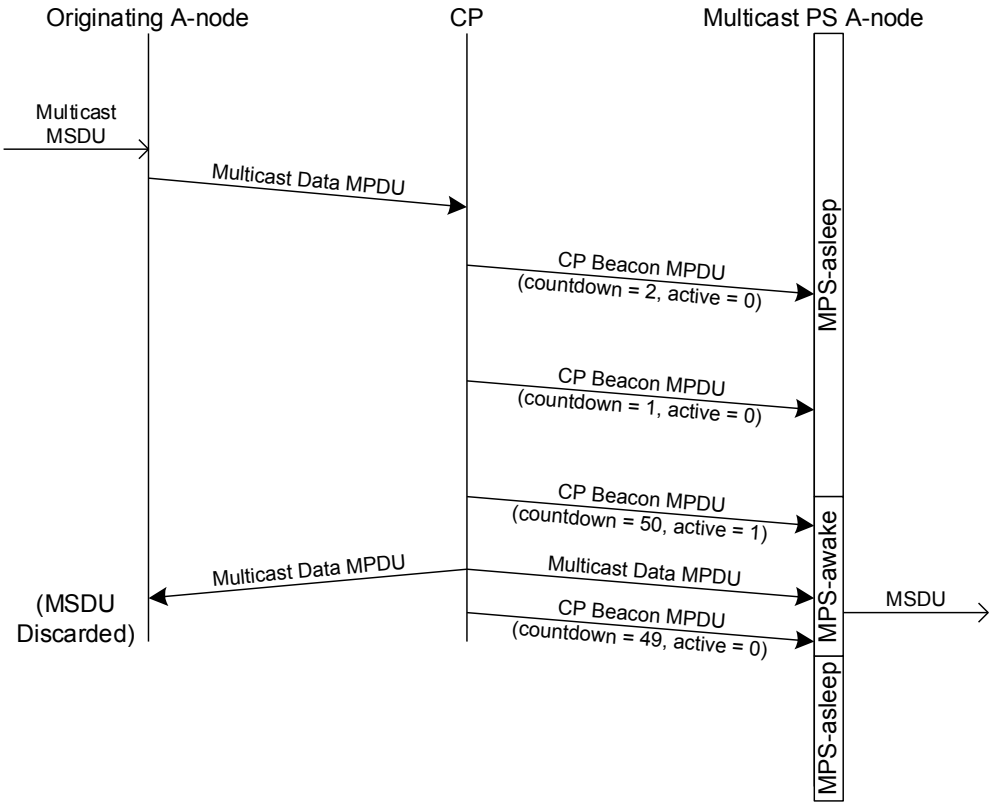


Figure 174 - Power Saving and Multicast MSDUs

5.18.8.3 CP Multicast Power-Management Service

A CP that has one or more A-nodes from which a multicast PM service request has been accepted shall operate the procedures defined in sections 5.18.8.3.1 (Multicast Period) to 5.18.8.3.5 (Multicast MSDU).

A CP that has no A-nodes from which a multicast PM service request has been accepted shall either operate the procedures defined in sections 5.18.8.3.1 (Multicast Period) to 5.18.8.3.5 (Multicast MSDU) or the procedure defined in section 5.18.8.4 (Inactive Multicast Period).

5.18.8.3.1 Multicast Period

A Multicast Period is a whole number of successive superframes. Outside this period is called the *non-Multicast Period*.

The CP selects the interval between multicast periods and the duration of the multicast period, and can adjust those numbers depending on the needs of the multicast PM service. The interval between the start of multicast periods shall be less than *PMinterval* (see section 16.2 (MAC Constants)) (recommended values are around *PSinterval*). The duration shall include at least one superframe.

The CP shall only modify the value of the multicast period interval at the start of the multicast period.[199]

The CP can extend the duration of the multicast PS period[200] by signaling a continuation of the multicast period in the CP beacon.

Figure 175 illustrates these multicast period definitions.

[199] Thereby ensuring that a node can determine the start of the next multicast period from any CP Beacon.

[200] For example, while its multicast MSDU retransmission store is not empty.

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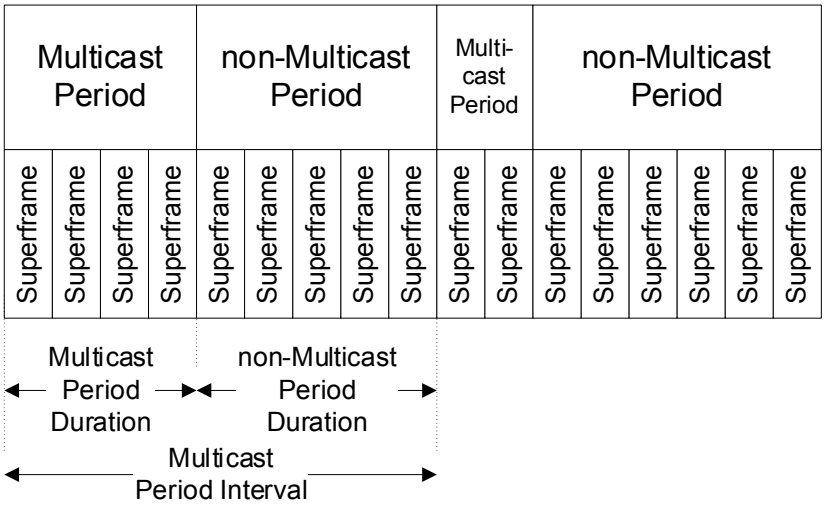


Figure 175 - Example of Multicast Period Timing

5.18.8.3.2 Signaling the Multicast Period

The CP shall signal the multicast period duration and interval in *the A-node Power Management Field* of every CP beacon as defined in Table 239.

Table 239 - Signaling the Multicast Period

Field	Contains
Multicast PS period countdown	The number of superframes to the start of the next multicast period. A value of 1 indicates that the following superframe is the first superframe of a multicast PS period. In the first superframe of the multicast PS period, the countdown resets to the number of superframes to the following multicast PS period[201] [202].
Multicast PS period active	1 during the multicast period 0 otherwise

5.18.8.3.3 Example of Multicast Period Signaling (Informative)

Figure 176 shows an example of the contents of the *countdown* and *active* sub-fields in CP beacons transmitted by a CP that is operating these procedures.

[201] So, the counter never goes to 0.

[202] This is the only time when the CP may adjust the countdown and thereby change the interval between multicast PS periods, all other times the countdown must only be reduced by one.

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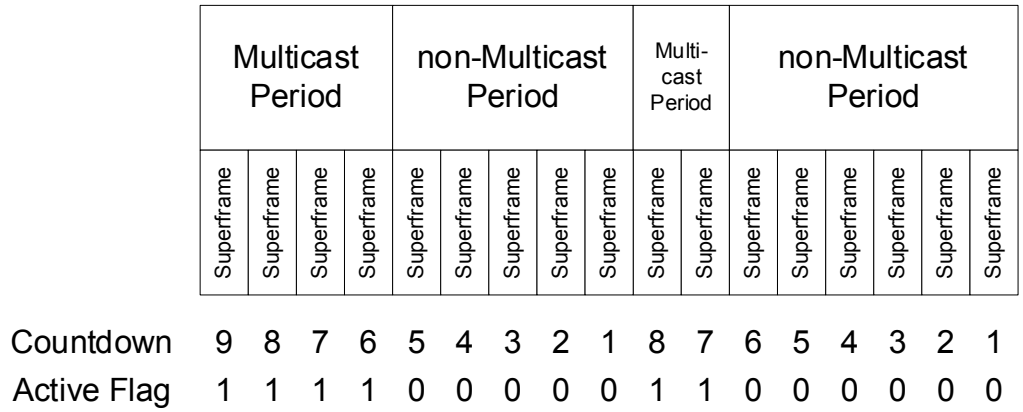


Figure 176 - Example of Multicast Period Signaling

5.18.8.3.4 Multicast MSDU Storage

The CP shall provide a store to hold multicast MSDUs for re-transmission.

During the non-Multicast Period, the CP shall receive all multicast MSDUs and shall store them internally. It shall also store a copy of any multicast MSDUs that it transmits as a result of a MD_DATA request from its MAC user.

A CP can discard multicast MSDUs in an implementation dependent way when it runs out of storage for multicast MSDUs.

During the Multicast Period, the CP does not store multicast MSDUs (transmitted or received).[203]

5.18.8.3.5 Multicast MSDU Re-Transmission

During the *Multicast Period,* the CP can re-transmit stored multicast MSDUs. The DATA MPDUs shall be re-transmitted with the MPDU header source address set to the source address of the original sender of the MSDU.[204]

The DATA MPDUs shall be transmitted using the CSMA/CA access mechanism. Stored multicast MSDUs shall be transmitted with the *MPS Relay* flag set to 1.

During the non-Multicast Period, the CP shall not transmit any stored multicast MSDUs.

Each stored multicast MSDU should be transmitted only once.

Stored multicast MSDUs should be transmitted in the same order that they were received.

5.18.8.4 Inactive Multicast Period

A CP that is not providing multicast PM services and that does not need to signal any other A-node PM events can transmit a CP beacon with an empty *A-node Power Management Field*.

If the CP needs to transmit a non-empty *A-node Power Management Field*, it shall do so with *the Multicast PS Management* sub-fields set to all zeroes.

5.18.8.5 A-node Multicast Power-Saving

An A-node that is in the *PM enabled* power-management state, and that has requested multicast power-management services from the CP shall operate the procedures defined in this section.

[203] These will already have been received by multicast PS nodes.

[204] This is an exception to the rule that the transmitting node's address goes in the MPDU source address field.

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5.18.8.5.1 Multicast PS states

A PS node may be in one of the three Multicast Power Saving states define in Table 240.

Table 240 - Multicast Power Saving states

MPS state	Description
MPS Idle	The PS node is managed by the CP, the timing of the next multicast period is not yet known. This is the initial state of this state machine that becomes active once the power-management state machine enters the *PM Enabled* state.
MPS Awake	The PS node is managed by the CP, and is listening to a multicast period
MPS Asleep	The PS node is managed by the CP, and waiting for the next multicast period

5.18.8.5.2 Multicast PS Variable

An A-node that supports multicast power-saving shall provide the variable defined in Table 241.

Table 241 - MPS Variable

MPS variable	Definition
MPS Countdown	The number of *Hop* events until the start of the multicast period

5.18.8.5.3 Multicast PS Events

The events and conditions that operate the state machine are defined in Table 242.

Table 242 - Multicast PS Events and Conditions

MPS event / Condition	Definition
CP Beacon	A CP2 beacon has been received
Period Known	The CP2 beacon contains a valid (non-zero) *multicast period countdown* field
Active	The CP2 beacon contains a *multicast period active* flag set to 1
Hop	Time to perform a frequency hop

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5.18.8.5.4 Multicast PS State Transition Diagram

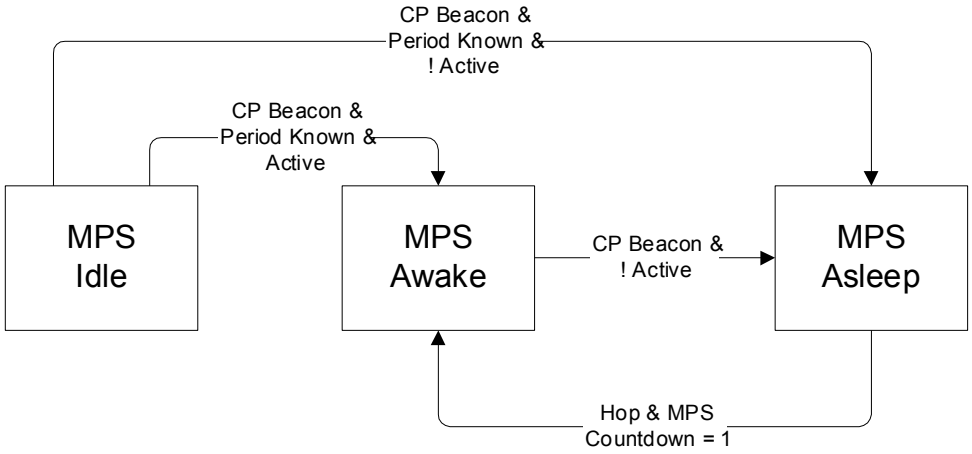


Figure 177 - Multicast Power-Saving State Transition Diagram

5.18.8.5.5 MPS Idle State

In the MPS Idle state, the A-node shall be capable of receiving during all beacon and contention periods.

Event	Action	Next State
CP Beacon & Period Known & Active	Copy the *multicast period countdown* field to the MPS countdown variable	MPS Awake
CP Beacon & Period Known & ! Active	Copy the *multicast period countdown* field to the MPS countdown variable	MPS Asleep

5.18.8.5.6 MPS Awake State

In the MPS Awake state, the A-node shall be capable of receiving during all beacon and contention periods.

Event	Action	Next State
CP Beacon & ! Active	Copy the *multicast period countdown* field to the MPS countdown variable	MPS Asleep

5.18.8.5.7 MPS Asleep State

Event	Action	Next State
Hop & MPS Countdown > 1	Decrement the MPS Countdown variable	
Hop & MPS Countdown = 1		MPS Awake

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5.18.8.6 A-node Multicast MSDU Receive

An A-node shall discard any multicast MSDUs it receives that have an MPDU Header *source address* equal to its own MAC address. [205]

5.19 Asynchronous Data Roaming

This section defines roaming procedures operated by roaming capable nodes and CP MAC entities that shall or may be used to manage roaming within a managed network.

5.19.1 Introduction to Roaming (Informative)

A node that can roam from one CP to another is called a roaming capable node. Nodes that roam will or may perform certain roaming procedures, described below. In addition, nodes can only roam between CPs that support roaming procedures. For the CP, these procedures include both the unicast and multicast power saving management procedures.

5.19.2 Detailed Description of Asynchronous Data Roaming (Informative)

The Asynchronous Data Roaming mechanism supports a node's ability to access the wireless LAN while the node is moving between associated networks within an extended network. An extended network is an aggregate of individual networks associated with the same network ID (*NWID*). When a node initially synchronized with one associated network moves into the area served by another associated network of the same extended network, it will re-associate itself with the new network. Additionally, an implementation may support the power saving management procedures that enable the roaming operation to be performed in as transparent a manner as possible so that any asynchronous data process will not be interrupted.

5.19.2.1 Asynchronous Data Roaming Procedures for Roaming Capable nodes (Informative)

A node that is capable of roaming will or may have the capabilities described in the following paragraphs.

A roaming capable node may begin its roaming procedure by invoking both the Unicast and Multicast Power Saving Management procedures in order to insure that packets for the node are not lost while the node is performing a Finding Roaming Connection Points procedure. In this case, the Finding Roaming Connection Points procedure will operate within the bounds of a Multicast PS period countdown. If a Multicast PS period countdown is in progress and the Finding Roaming Connection Points procedure cannot be performed within the bounds of this countdown, the node will defer the procedure and the invocation of the PS management until the next period, otherwise it will immediately invoke the PS management and initiate the Finding Roaming Connection Points procedure.

Roaming capable nodes will have the ability to monitor different Connection Points that are associated with an extended network. This monitor function is performed by the Finding Roaming Connection Points procedure.

Roaming capable nodes in the presence of more than one associated CP within an extended network will have the ability to determine the CP to which it would prefer to be synchronized. A likely implementation would be to do this based on the signal strength it perceives from each CP, though the details of this assessment are beyond the scope of this specification. Various methods including raw signal strength (RSSI), a signal-to-noise measurement, or a measurement of bit errors are among the possible solutions. It is recommended that this determination contain some sort of hysteresis effect to avoid fast re-associations in regions where the signal strength from two associated CPs is nearly equal. For example,

```
if(NewCPSignal>CurrentCPSignal)then synchronize to new CP
```

would cause the node to undergo rapid re-synchronizations in areas of nearly equal, but fluctuating signal strength. On the other hand,

```
if(NewCPSignal>CurrentCPSignal+5dB)then synchronize to new CP
```

would stabilize this process and would only allow for re-synchronizations when a CP signal which was better by 5 dB became available.

After choosing to synchronize to a new CP, the roaming capable node will have the ability to inform the old CP of its new affiliation. This is accomplished by the sending of a *Roam Notify* MPDU through the new CP back to the old CP. The new and old CPs, as well as any intermediate switching devices, will automatically have their bridging tables adjusted to reflect the new location of the roaming capable node. In addition, HomeRF nodes maintain their own internal source routing tables. Once a node synchronizes with a new CP, it should reset the Location State and Bridge Address variables for all nodes in its internal routing table. See 5.11.7.3.

[205] These arise from the retransmission of its own MSDUs by a CP.

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5.19.2.2 Asynchronous Data Roaming Procedures for Roaming Capable CPs (Informative)

A CP that supports roaming will have the capabilities described in the following paragraphs.

A CP that supports roaming must support manual entry of the NWID.

A CP that supports roaming must operate both the Unicast and Multicast Power Saving Management procedures.

A CP that supports roaming must be able to distinguish between transmissions intended for it, and those intended for other CPs within the same extended network. It will do this by maintaining a list of nodes that it is managing and by using the 48-bit IEEE MAC source address in the MPDU header to filter these packets.

5.20 I-Node Management

This section defines procedures that are followed by a Class-1 CP and an I-node to set-up, maintain and destroy TDMA connections. It also includes procedures that support the MB-SAP data service.

5.20.1 Introduction to I-node Management (Informative)

The MB-SAP data service is used by the DECT higher layers to carry I-node paging, cadence ringing, caller ID, and voice announcement requests via the Isochronous Connectionless Broadcast Service from the CP to I-nodes. MAC-layer connection setup is always originated at the I-node (perhaps as a higher-layer response to a paging request).

To create a connection, an I-node sends a TDMA CPS MPDU carrying a connection request. On receiving this, the CP allocates a main slot position for the I-node and transmits a *Connection Established* event in the TDMA beacon. The I-node decodes the TDMA beacon and sees this event and associated connection ID.

If the CP cannot allocate a main slot position, it sends a *Connection Denied* event in the TDMA beacon. An I-node decoding this event informs its higher layers that a connection cannot be established.

Once a connection is established, the CP and I-node isochronously exchange TDMA MPDUs using the TDMA access mechanism.

The connection starts operating with the U-plane service disabled. This allows the C-channel data service to use the full bandwidth of the TDMA MPDU exchange. Some time after a connection has been established, the DECT higher layers will enable the U-plane service. When the U-plane is enabled, the U-plane DATA service transports its SDUs isochronously.

A connection is usually destroyed as a result of a request from the higher layers at both the I-node and the CP. A connection may also be destroyed because a certain number of successive TDMA MPDUs have been missed.

When a connection is destroyed, the CP may need to re-order existing main slot allocations to avoid introducing a gap in the contention-free period. See also section 5.20.1.1.1 (Connection Reordering (Informative)).

Both the Class-1 CP and an I-node with an active connection keep a TDMA epoch number, incremented at the start of the TDMA epoch. Its current value is signaled in a CP beacon carrying a *Connection Established* event.

The TDMA Epoch Number is used by the TDMA encryption process.

5.20.1.1.1 Connection Reordering (Informative)

When an existing connection is destroyed, the CP might need to adjust the main slot allocation in order to minimize the duration of the CFP and avoid holes in the TDMA frame. Only one main slot allocation can be changed at a time. CP does not delay this re-ordering, because until it has, CFP2 has a “hole” in it that may allow CSMA devices in other networks to jump in.

To limit the number of nodes that have to move slots, the node allocated the earliest (highest-numbered) slot position in CFP2 is moved to the vacant position. If a connection to the highest-numbered main slot position is closed, no reallocation of main slots allocated to TDMA connections needs to be performed.

The ICBS-channel is always allocated the highest-numbered main slot. Its position is adjusted when TDMA connections are created and destroyed.

The Connection Point notifies the node of its new slots using the *Main Slots* field of the TDMA Beacon. On receipt of the Beacon the node starts using the new slot and will transmit up-link data in the new slot.

As all I-nodes are required to respond to any change in main slot allocation by the following CFP2, there is no need to handshake the change of slot allocation with the modified I-node. All I-nodes are affected by the change in number of uplink slots.

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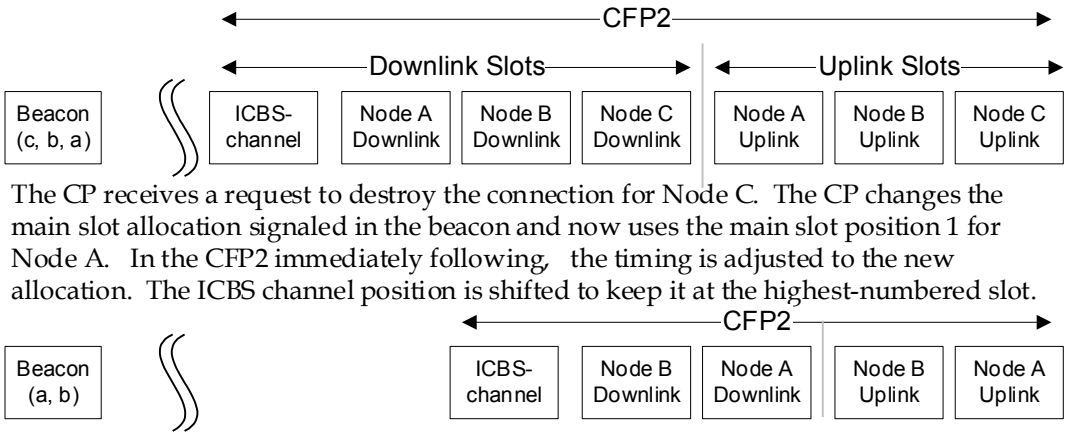


Figure 178 - Example of Re-ordering Main Slot Positions

5.20.2 TDMA Service ID

The procedures defined in section 5.20.1 (Introduction to I-node Management (Informative)) support the management of a TDMA connection between a CP and an I-node.

The services offered by this connection are defined by a TDMA Service ID. This is present in the connection setup request. Once a TDMA connection is established, the TDMA service associated with that connection cannot be modified.

Table 243 defines the values for the TDMA Service ID.

Table 243 - TDMA Service ID Values

TDMA Service ID	Definition
0	32-kbps full duplex U-plane service carried using the main TDMA and retry TDMA MPDUs.

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5.20.3 Connection Management (at the CP)

A Class-1 CP shall operate the procedures defined in these subsections.

The procedure is defined in the form of a state machine. An instance of this state machine exists for each possible connection ID that can be used for a TDMA connection. This range of connection IDs is specified in 5.8.3 (Connection ID).

5.20.3.1 Connection States

Table 244 enumerates the states that the state machine supports.

Table 244 - TDMA Connection States at the CP

State	Description
Idle	The initial state of the state machine. The connection ID is available for use.
Setup	Waiting for the first TDMA MPDU uplink
Active	A connection has been established

5.20.3.2 Connection Events

Table 245 defines the events and conditions that drive the operation of the connection state machine at the CP.

Table 245 - TDMA Connection Events at the CP

Event / Condition	Definition
Connection Allocated	Defined in section 5.20.3.8 (Connection Request)
TDMA MPDU received	A valid TDMA MPDU has been received on this connection
Connection Established Timeout	The *Connection Established* event has been removed from the CP beacon queue without having received a valid TDMA MPDU with matching connection ID. See section 5.17.3.5 (Event Removal)
Missing TDMA Limit	Defined in sections 5.20.3.10 (TDMA MPDU Missed Counter) and 5.20.4.8 (TDMA MPDU Missed Counter)
Terminate Connection Timeout	The *Terminate Connection* event has been removed from the CP beacon queue without having received a matching *Release TDMA connection* request contained in a CPS MPDU. See section 5.17.3.5 (Event Removal)

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Event / Condition	Definition
MC_DIS Request	An MC_DIS request primitive is received from higher layers
Notes: A *valid TDMA MPDU* is a TDMA MPDU with a correct A-field CRC and with a matching connection ID. A *valid CPS MPDU* is a TDMA CPS MPDU with correct header and payload CRCs, containing a connection ID field that matches the connection's ID and a NWID field that matches the CP's NWID.	

5.20.3.3 Connection State Transition Diagram

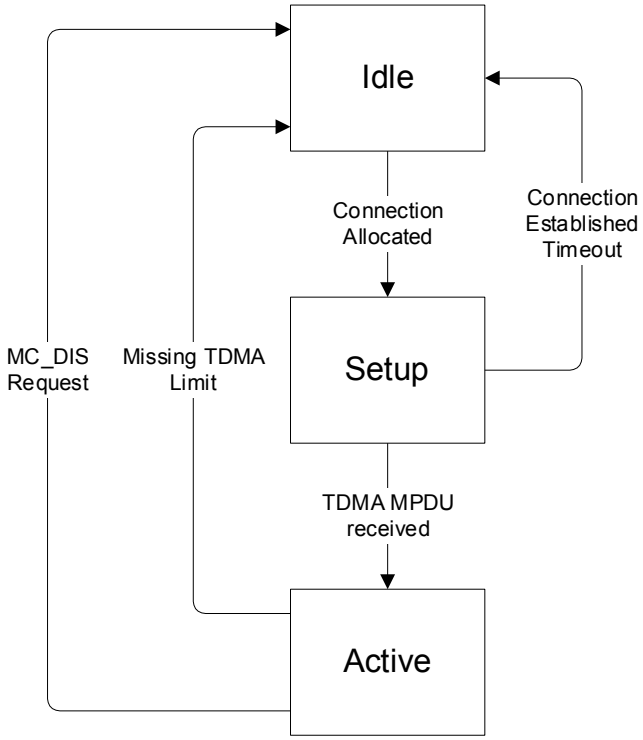


Figure 179 - TDMA Connection State Transition Diagram - at the CP

5.20.3.4 Other State Variables

In addition to the connection state, associated with each connection that is not in the *Idle* state are the variables defined in Table 246.

Table 246 - TDMA Connection State Variables - at the CP

Variable	Definition
Missing TDMA Count	The number of successive missing TDMA MPDUs
U-plane Enable State	One of: *disabled, enabled*
I-node MAC address	MAC address of the I-node that created the connection

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5.20.3.5 Idle State

On entry to the *Idle* state, the CP shall De-allocate the main slot assignment using the procedure defined in section 5.20.3.12.4 (De-allocating a Main Slot) [206]

In the *Idle* state the CP shall discard any TDMA MPDUs received with this connection ID.

Event	Action	Next State
Connection Allocated	Set *Missing TDMA Count* to zero. Set *U-plane enable state* to *disabled.* Set the *I-node MAC address* to the TDMA CPS MPDU source address field of the CPS MPDU that created the connection.	*Setup*

5.20.3.6 Setup State

On entry to the *Setup* state, the CP shall queue for transmission using the procedures defined in section 5.17.3 (CP Beacon) a *Connection Established* event carrying the MAC address of the I-node associated with this connection and this connection ID.

In the *Setup* state, the CP shall isochronously transmit TDMA MPDUs with this connection ID using the procedures defined in section 5.8 (TDMA Access Mechanism). These TDMA MPDUs shall use the *fastC=1* format, and contain no C-Channel SDUs.

Event	Action	Next State
TDMA MPDU received	Issue an MC_CON Indication primitive to higher layers as defined in section5.2.3.2 (MC_CON Primitive)	Active
Connection Established Timeout		Idle

5.20.3.7 Active State

In the *Active* state, the CP shall isochronously transmit TDMA MPDUs with this connection ID using the procedures defined in section 5.8 (TDMA Access Mechanism).

The CP shall operate the procedures defined in section 5.14 (MC-SAP Services) to provide MC-SAP services.

Event	Action	Next State
Missing TDMA Limit	Issue an MC_DIS Indication with reason *abnormal*	Idle
MC_DIS Request	Issue an MC_DIS Confirmation	Idle

5.20.3.8 Connection Request

5.20.3.8.1 Connection Request Definition

A *valid connection request* is a CPS MPDU in which the following apply:

- Has a correct CRC
- Contains a TDMA connection request
- Contains a zero connection ID

[206] This action is taken on transition from some other state into the *Idle* state, not initially.

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5.20.3.8.2 Connection Request Procedures

This section defines how a Class-1 CP responds to valid connection requests.

The CP shall respond using either the successful or unsuccessful outcome behavior defined in Table 248.

If any of the conditions defined in Table 247 apply, the request shall result in the unsuccessful outcome behavior. Otherwise the request shall result in the successful outcome behavior.

Table 247 - Conditions that cause a Connection Request to be Unsuccessful

Condition	Description
Unsupported TDMA Service ID	The requested TDMA Service ID is not supported by the CP
Existing Connection	A TDMA connection already exists for that I-node
No available main slot	A main slot cannot be allocated to the connection
Elective	An implementation can choose to reject a connection according to additional implementation-defined criteria provided that the mandatory requirements of section 12.7 (CP Requirements) and 12.7.1 (Class 1 CP Requirements) are met.

Table 248 - Connection Request Outcomes

Successful Outcome	Unsuccessful Outcome
· Allocate a new main slot number using the procedure defined in 5.20.3.12.2 (Allocating a Main Slot to a TDMA connection). · Select a valid connection ID that is in the *Idle* state. See also section 5.20.3.9 (Connection ID) · Queue a *connection established* event to be transmitted in the CP beacon using the procedures defined in section 5.17.3 (CP Beacon). The event shall include the MAC address of the I-node from which the CPS MPDU was received and the connection ID that is allocated to it. · Signal a *Connection Allocated* event to the connection state machine associated with this connection ID	· queue a *connection denied* event to be transmitted in the CP beacon using the procedures defined in section 5.17.3 (CP Beacon). The event shall include the MAC address of the I-node from which the CPS MPDU was received.

5.20.3.9 Connection ID use

5.20.3.9.1 Introduction (Informative)

When a connection is set to the *Idle* state, the procedures defined here do not guarantee that the I-node to which the connection had been assigned has also closed the connection. One such possible scenario is a disconnect to an I-node that has just gone out of radio contact. The I-node will keep the connection alive for *NumNoData* subframes, which is much longer than *CBEpersistence*.

In the worst case, an I-node that can receive the TDMA MPDUs, but not the TDMA Beacon will not stop using the connection until *NumNoData* subframes after the connection has entered the *Idle* state at the CP.

Therefore, it is important to avoid re-using a connection ID for a connection that has just been terminated.

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There is no difficulty in avoiding connection ID re-use because there is more connection IDs than possible simultaneous connections.

5.20.3.9.2 Procedure

The Class-1 CP should allocate a valid connection ID from among *Idle* connections so that the connection ID that was set to the *Idle* state the longest time ago is considered first for re-use.

For the purposes of this section, a *valid* connection ID shall be one in the range defined in 5.8.3 (Connection ID) for TDMA connections.

5.20.3.10 TDMA MPDU Missed Counter

For each connection in the *Setup* and *Active* states, the CP shall operate the procedures defined in this section.

At the end of CFP1, if no valid TDMA MPDU has been received for this connection during CFP2 or CFP1:

- If the connection's *Missing TDMA Count* is less than *NumNoData* (see section 16.2 (MAC Constants)), increment *Missing TDMA Count,*
- Otherwise, signal a *Missing TDMA Limit* event to the connection's state machine

At the end of CFP1, if a valid TDMA MPDU has been received for this connection during CFP2 or CFP1, set the *Missing TDMA Count* to zero.

5.20.3.11 TDMA Epoch

The Class-1 CP shall maintain a *TDMA epoch number* variable.

A Class-1 CP shall initialize its *TDMA epoch number* to an implementation-defined value when it starts operating as the Active CP.

A Class-1 (active) CP shall increment the TDMA epoch number (modulo 2^{24}) at the start of each actual or possible TDMA epoch. It should do this regardless of whether subframes are present or not.

A Class-1 CP that transmits a CP beacon with a non-empty *Connection Management* field shall insert the current *TDMA epoch number* into the *TDMA epoch number* sub-field of the *Connection Management* field within the TDMA part of the CP1 beacon MPDU.

5.20.3.12 Main Slot Management

A Class-1 CP shall perform the procedures defined in this section to allocate, de-allocate, use and signal main slot positions to connections.

5.20.3.12.1 Variables

Main slots are numbered 1 up to the *MaxMain*.

MaxMain is defined to be (*MaxMCconnections* + 1). This includes the maximum number of TDMA connections plus one for a possible ICBS-channel allocation.

The CP shall maintain, for each of the *MaxMain* slot positions, the variables defined in Table 249. This record is called *MS* in the sections that follow.

Table 249 - Main Slot Variables

Variable	Definition
State	One of: *Idle* or *Active*
ConnectionID	Connection ID of connection using this main slot

5.20.3.12.2 Allocating a Main Slot to a TDMA connection

In order to allocate a main slot position to a TDMA connection, the CP shall perform this procedure:

```
For I = 1 to (MaxMain-1)
{
    if MS(I).State = Idle
    {
```

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```
        MS(I).State = Active
        MS(I).ConnectionID = Allocate a Connection ID using the
                             procedure defined in section
                             5.20.3.9 (Connection ID use)

        return I and an allocation success status
    }
    else if MS(I).ConnectionID = ICBS_CID
    {
        /* Have found an ICBS-channel. Move it up and re-use its old position */
        MS(I).State = Active
        MS(I).ConnectionID = Allocate a Connection ID using the
                             procedure defined in section
                             5.20.3.9 (Connection ID use)

        MS(I+1).State = Active
        MS(I+1).ConnectionID = ICBS_CID

        return I and an allocation success status
   }
}
return an allocation failure status
```

The CP can also fail an allocation request according to implementation-dependent criteria, provided that it meet the mandatory CP requirements defined in section 12.7 (CP Requirements).

5.20.3.12.3 Allocating a Main Slot to the ICBS-channel

In order to allocate a main slot position to the ICBS-channel, the CP shall perform this procedure:

```
For I = 1 to MaxMain
{
    /* Ensure there is no existing ICBS channel allocated */
    if MS (I).ConnectionID = ICBS_CID
    {
        return an allocation failure status
    }

    if MS(I).State = Idle
    {
        MS(I).State = Active
        MS(I).ConnectionID = ICBS_CID

        return I and an allocation success status
    }
}
return an allocation failure status
```

The CP can also fail an allocation request according to implementation-dependent criteria provided that it meet the mandatory CP requirements defined in section 12.7 (CP Requirements).

5.20.3.12.4 De-allocating a Main Slot from a TDMA connection

In order to de-allocate a main slot position, the CP shall perform this procedure:

```
On entry:  deallocatePosition is the number of the slot to be de-allocated.

integer highestTDMAposition = 0  /* The highest TDMA connection slot position */
integer ICBSChannel = 0          /* The location of any active ICBS-channel */

/* find the highest active main-slot pair and any ICBS channel */
For I = 1 to MaxMain
{
    if MS(I).State = Active
    {
        if MS(I).ConnectionID <> ICBS_CID
        {
```

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```
            highestTDMAposition = I
        }
        else
        {
            ICBSChannel = I
        }
    }
}


/* If the slot to be deallocated is less than the maximum, a hole has opened
   up. Swap the highest-numbered active connection into this hole */

if (deallocatePosition < highestTDMAposition)
{
    MS(deallocatePosition).State = Active

    MS(deallocatePosition).ConnectionID = MS(highestTDMAposition).ConnectionID

    /* Mark old position as Idle */
    MS(highestTDMAposition).State = Idle
    MS(highestTDMAposition).ConnectionID = 0

}
else
{
    /* Otherwise just mark this slot as not in use */
    MS(deallocatePosition).State = Idle
    MS(deallocatePosition).ConnectionID = 0
}

/* If there is an ICBS-channel, it replaces the old highest TDMA position */
if (ICBSChannel <> 0)
{
    MS(highestTDMAposition).State = Active
    MS(highestTDMAposition).ConnectionID = ICBS_CID
    MS(ICBSChannel).State = Idle
    MS(ICBSChannel).ConnectionID = 0
}
```

5.20.3.12.5 De-Allocating a Main Slot from the ICBS-channel

In order to de-allocate a main slot position from the ICBS-channel, the CP shall perform this procedure:

```
For I = 1 to MaxMain
{
    if MS (I).ConnectionID = ICBS_CID
    {
          MS(I).State = Idle
          MS(I).ConnectionID = 0
    }
}
```

5.20.4 Connection Management (at the I-node)

An I-node shall operate the procedures defined in these subsections.

The procedure is defined in the form of a state machine. A single instance of this state machine exists.

5.20.4.1 Connection States

Table 250 enumerates the states that the state machine supports.

Table 250 - TDMA Connection States at the I-node

State	Description

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Idle	The initial state of the state machine. There is no connection to the CP.
Setup	Waiting for a response to the connection request
Active	A connection has been established

5.20.4.2 Connection Events

Table 251 defines the events and conditions that drive the operation of the connection state machine at the CP.

Table 251 - TDMA Connection Events at the I-node

Event / Condition	**Definition**
MC_CON Request	Connection Request received from higher layers
Connection Established	A valid TDMA Beacon has been received containing a *Connection Established* event within the *Connection Management* field with an IEEE address matching the I-node's MAC address
Connection Request Failed	The transmission of the CPS MPDU carrying the connection request has failed - the MPDU was discarded without any response. See section 5.10 (CPS Procedures).
Connection Denied	A valid TDMA Beacon has been received containing a *Connection Denied* event within the *Connection Management* field with an IEEE address matching the I-node's MAC address
Allocation Dropped	A valid TDMA Beacon has been received that does not contain a main slot allocation for the I-node's current connection
Missing TDMA Limit	Defined in section 5.20.4.8 (TDMA MPDU Missed Counter)
MC_DIS Request	An MC_DIS request primitive is received from higher layers
Notes: A valid TDMA beacon is a TDMA beacon MPDU with correct CRC, with an MPDU header NWID field matching the I-node's current NWID.	

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5.20.4.3 Connection State Transition Diagram - at the I-node

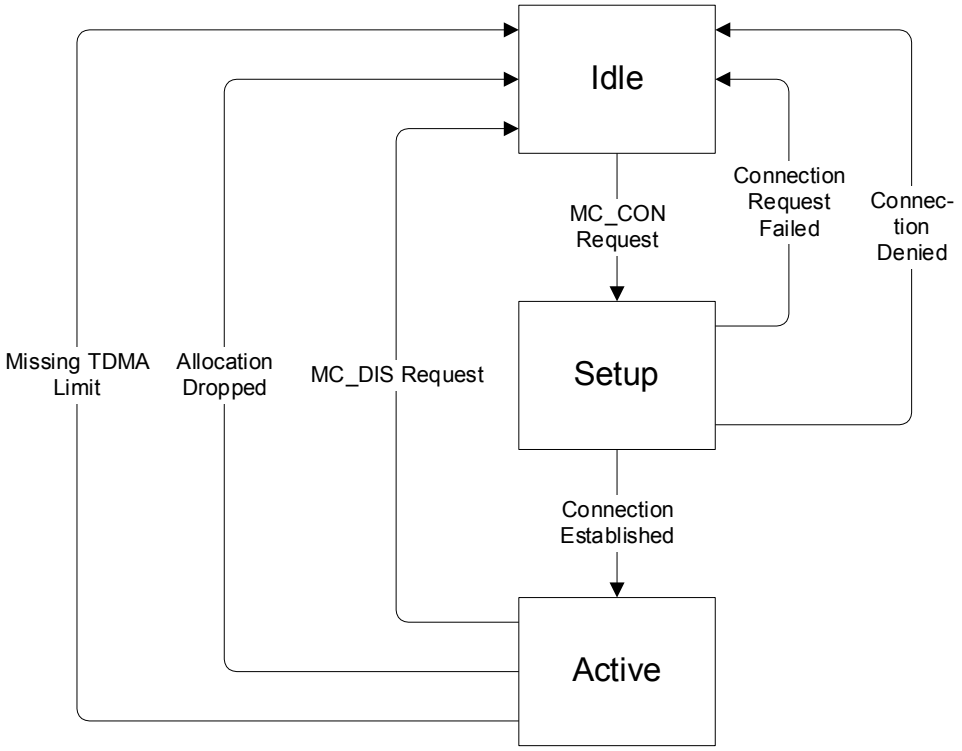


Figure 180 - TDMA Connection State Transition Diagram - at the I-node

5.20.4.4 Other State Variables

In addition to the connection state, associated with a connection that is not in the *Idle* state are the variables defined in Table 252.

Table 252 - TDMA Connection State Variables - at the I-node

Variable	Definition
Missing TDMA Count	The number of successive missing TDMA MPDUs
U-plane Enable State	One of: *disabled, enabled*
Connection ID	Connection ID assigned to the connection by the CP

5.20.4.5 Idle State

In the *Idle* state, the node shall discard any TDMA MPDUs received.

Event	Action	Next State
MC_CON Request	Queue a CPS MPDU carrying a *Request TDMA connection* request using the procedures of section 5.10 (CPS Procedures)	Setup

5.20.4.6 Setup State

In the *Setup* state, the node shall discard any TDMA MPDUs received.

Event	Action	Next State

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Connection Established	Record allocated connection ID from the *Connection Established* event in the TDMA Beacon Issue an MC_CON Confirmation with success status (If the I-node supports encryption) Initialize the TDMA epoch number (see section 5.20.4.9 (TDMA Epoch Number)).	Active
Connection Denied	Issue an MC_CON Confirmation with failure status	Idle
Connection Request Failed	Issue an MC_CON Confirmation with failure status	Idle

5.20.4.7 Active State

In the *Active* state, the I-node shall isochronously transmit TDMA MPDUs with this connection ID using the procedures defined in section 5.8 (TDMA Access Mechanism).

The I-node shall operate the procedures defined in section 5.14 (MC-SAP Services) to provide MC-SAP services.

The I-node can also update its TDMA epoch number based on any valid TDMA Beacons received that carry a *Connection Management* field. See section 5.20.4.9 (TDMA Epoch Number).

Event	**Action**	**Next State**
MC_DIS Request	Issue an MC_DIS Confirmation	Idle
Missing TDMA Limit	Issue an MC_DIS Indication with reason *abnormal*	Idle
Allocation Dropped	Issue an MC_DIS Indication with reason *normal*	Idle

5.20.4.8 TDMA MPDU Missed Counter

For each connection in the *Active* state, the I-node shall operate the procedures defined in this section.

At the end of CFP1, if no valid TDMA MPDU has been received for this connection during CFP2 or CFP1:

- If the connection's *Missing TDMA Count* is less than *NumNoData* (see section 16.2 (MAC Constants)), increment *Missing TDMA Count,*
- Otherwise, signal a *Missing TDMA Limit* event to the connection's state machine

At the end of CFP1, if a valid TDMA MPDU has been received for this connection during CFP2 or CFP1, set the *Missing TDMA Count* to zero.

5.20.4.9 TDMA Epoch Number

An I-node that supports encryption shall support the procedures defined in this section.

It shall maintain a *TDMA epoch number* variable.

An I-node that receives a *Connection Established* event in a TDMA Beacon shall initialize its TDMA epoch number to the value contained in the *Connection Management* field of the TDMA Beacon.

An I-node that has a connection in the *Active* state shall increment its TDMA epoch number (modulo 2^{24}) at the start of each TDMA epoch.

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5.20.5 I-node Power-Saving

This section defines procedures that shall be performed by an I-node that is in the *Managed* synchronization state.

An I-node that receives a TDMA Beacon in which the NWID field does not match its current CP Address shall discard the TDMA Beacon without any other effect.

5.20.5.1 I-node Power-Saving while not in a call

An I-node can support the I-node sleep state machine. An I-node that does not support the I-node sleep state machine shall remain able to receive and transmit as defined in section 5.8 (TDMA Access Mechanism).

An I-node that supports the sleep state machine can reduce power during the *ISS Asleep* state.

The I-node Sleep States are defined in Table 253.

Table 253 - I-node Sleep States

State	Description
ISS Idle	No connection active, enabled to transmit and receive. This is the initial state of the state machine.
ISS Awake	There is a TDMA-connection or ICBS-channel active
ISS Pending Beacon	Waiting to receive a TDMA Beacon. Enabled to receive during all Beacon Periods
ISS Asleep	Not able to transmit or receive

The events defined in Table 254 drive the I-node sleep state machine.

Table 254 - I-node Sleep State Machine Events

Event / Condition	Definition
Connection Present	The I-node's connection is not in the *Idle* state
ICBS-channel Present	The MB-SAP Rx State Machine is not in the *Idle* state (see section 5.15.2.3 (MB-SAP Rx State Machine))
Must be Awake	(Connection Present) or (ICBS-channel Present)
Can Sleep	not (Must be awake)
Time To Check Beacon	This event shall occur no longer than *IPSinterval* superframes since the last valid TDMA Beacon was received. [207]
CP Beacon	A valid TDMA Beacon was received
Any Time	At any time, as defined by the implementation

Figure 181 Shows the state transitions for the I-node sleep state machine.

[207] The implementer is advised to allow for a worst case clock drift when waking-up to receive a CP Beacon, and also to allow for a few CP Beacon losses.

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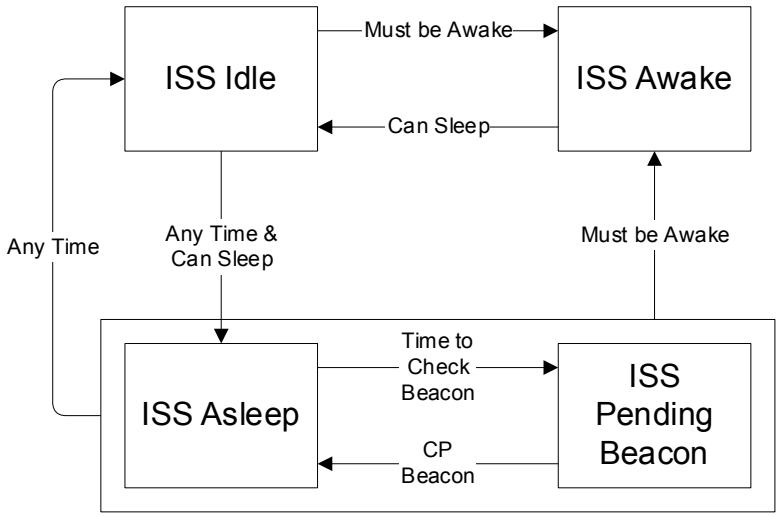


Figure 181 - I-node Sleep State Transition Diagram

5.20.5.1.1 ISS Idle State

In the *ISS Idle* state, the I-node shall be enabled to receive during all Beacon Intervals.

Event	Action	Next State
Any Time & Can Sleep		ISS Asleep
Must be Awake		ISS Awake

5.20.5.1.2 ISS Awake State

In the *ISS Awake* state, the I-node shall be enabled to receive:

- During the beacon period to receive the TDMA Beacon
- During any main slot downlink allocated to the I-node
- During any retry slot downlink allocated to the I-node
- If the TDMA main slot indicates that a connectionless main downlink slot has been allocated during this main downlink slot

At other times the I-node can save power by not being able to receive. [208]

Event	Action	Next State
Can Sleep		ISS Idle

5.20.5.1.3 ISS Pending Beacon State

In the *ISS Pending Beacon* state, the I-node shall be enabled to receive during all Beacon Periods.

Event	Action	Next State
CP Beacon		ISS Asleep

[208] Clearly it also has to be able to transmit in its uplink slots, and if it has a TDMA CPS MPDU to transmit.

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Must be Awake		ISS Awake
Any Time		ISS Idle

5.20.5.1.4 ISS Asleep State

In the *ISS Asleep* state, the I-node need not be enabled to receive or transmit.

Event	**Action**	**Next State**
Time to Check Beacon		ISS Pending Beacon
Must be Awake		ISS Awake
Any Time		ISS Idle

5.20.6 TDMA Encryption

5.20.6.1 Introduction (Informative)

One objective of the implementation of encryption of TDMA connections in HomeRF is to provide as nearly as possible the services offered by the DECT MAC. This permits the reuse of the DECT higher layers largely unchanged and all the procedures defined in GAP (authentication, key management and encryption negotiation).

Some of the DECT security procedures (authentication and derived cipher key generation) together with DECT NWK identifiers are modified to support HomeRF TDMA encryption.

In the TDMA transmission process, the encryption is performed just before transmission and on a per MPDU basis. The encryption of each TDMA connection is done independent of other connections, using a different key and IV.

The encryption process applies to the TDMA payload of the TDMA MPDU. The MPDU header, TDMA header and any CRCs are not encrypted.

Note that, unlike DECT, no unused bits are generated. The encryption engine is started with the first bit to encrypt and stopped with the last bit to encrypt.

The encryption process uses a derived cipher key shared by the TDMA device and the CP, specific to the link and derived from the DECT authentication process (there is one derived cipher key per TDMA connection). The MAC entity is supplied with this derived cipher key by higher layers.

The Initialization Vector is not transmitted with the packet but calculated from the address of the sender of the packet (either the CP or the node) and the TDMA epoch number shared by all TDMA devices on the network.

5.20.6.2 Encryption Negotiation

A TDMA connection shall only be encrypted only if both ends support encryption.

The DECT signaling offers both ends of the link the ability to discover the encryption capabilities of the other end, to negotiate the level of encryption used and to decide to start the encryption of the connection.

When the CP creates a connection between two TDMA devices (intercom mode), the CP should use the same level of security for the two connections (each TDMA node to the CP). Each connection is encrypted independently with its own derived cipher key and IV.

5.20.6.3 Storing the KEY

An I-node shall provide storage for a single key. On receipt of an MC_KEY request, it shall update the stored key.

A CP shall provide storage for multiple keys. The number of keys stored is defined by the maximum number of simultaneous connections that the CP supports. On receipt of an MC_KEY request, the CP shall update the stored key associated with a specific connection ID.

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5.20.6.4 Starting Encryption

The MAC entity shall perform the procedures defined in this section on receipt of a MC_ENC request.

These procedures are defined in terms of a state machine. There is one instance of this state machine in an I-node. There is one instance of this state machine per active connection in the CP.

5.20.6.4.1 Introduction to Starting Encryption (Informative)

The start of encryption is managed using the MPDU fields defined in Table 255.

Table 255 - MPDU Fields Used in Managing Encryption

Field	Present in
Encrypted	TDMA MPDU, TDMA Header field
CPS Request ID	TDMA CPS MPDU
Connection Management Event	TDMA Beacon

Note that the start of encryption of the two directions of the TDMA connection is independent, and there might be some rare cases when only one direction is encrypted for a few subframes, due to frame losses. This behavior causes no problems.

5.20.6.4.2 Events

The events that drive this process are defined in Table 256.

Table 256 - Events Relevant to the Start Encryption Procedures

Event	Definition
Good MC_ENC request	An MC_ENC request has been received from higher layer and a key is known
Bad MC_ENC request	An MC_ENC request has been received from higher layer and no key is known
Request Encryption Received	A CP has received a valid matching TDMA CPS MPDU containing a *Request Encryption* event. An I-node has received a valid TDMA Beacon containing a *Request Encryption* event.

5.20.6.4.3 States

Table 257 - TDMA Connection Encryption States

State	Description
Unencrypted	Transmitted TDMA frames are not encrypted.
Pending Local Request	Waiting for MC_ENC request from higher layers
Pending Remote Request	Waiting for *Request Encryption*
Encrypted	Transmitted TDMA frames are encrypted.

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5.20.6.4.4 State Transition Diagram

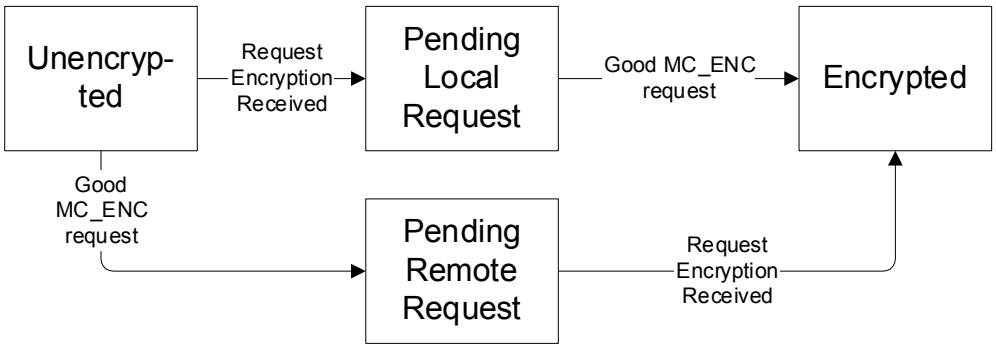


Figure 182 - TDMA Starting Encryption State Transition Diagram

5.20.6.4.5 Actions by State

5.20.6.4.5.1 Unencrypted

In this state all TDMA MPDUs shall be transmitted unencrypted with the MPDU TDMA header *Encrypted* field set to zero.

Event	Action	Next State
Good MC_ENC request	I-node: format a TDMA CPS MPDU containing a *Request Encryption* event and transmit it using the procedures defined in 5.10.4.2 (TDMA CPS Transmit). CP: Queue a *Request Encryption* event to be transmitted using the procedures defined in 5.17.3 (CP Beacon Transmit).	Pending Remote Request
Bad MC_ENC request	Issue an MC_ENC confirmation to higher layers containing a status value of *no key*	
Request Encryption Received	Issue an MC_ENC indication to higher layers	Pending Local Request

5.20.6.4.5.2 Pending Local Request

In this state all TDMA MPDUs shall be transmitted unencrypted with the MPDU TDMA header *Encrypted* field set to zero.

Event	Action	Next State
Good MC_ENC request	Issue an MC_ENC confirmation to higher layers containing status *Successful*.	Encrypted
Bad MC_ENC request	Issue an MC_ENC confirmation to higher layers containing a status value of *no key*	

5.20.6.4.5.3 Pending Remote Request

In this state all TDMA MPDUs shall be transmitted unencrypted with the MPDU TDMA header *Encrypted* field set to zero.

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Event	Action	Next State
Request Encryption Received	Issue an MC_ENC indication to higher layers Issue an MC_ENC confirmation to higher layers containing status *Successful*.	Encrypted

5.20.6.4.5.4 Encrypted

In this state all TDMA MPDUs shall be transmitted unencrypted with the MPDU TDMA header *Encrypted* field set to zero.

The connection stays in this state until destroyed.

5.20.6.5 Deriving the TDMA IV

The 32 bit IV used by encryption algorithm is constructed using a 24 bit sequence number and a 8 bit hash derived from the IEEE address of the sender of the packet as defined by Figure 183.

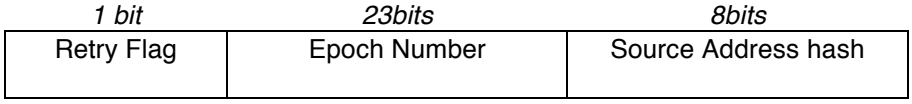


Figure 183 - TDMA IV Structure

The *Retry Flag* has a value of zero for the encrypted content of a main TDMA MPDU. It has a value of one for the encrypted content of a retry TDMA MPDU.

The *Epoch Number* is given by the least significant 23 bits of the current Epoch number in which the TDMA frame is transmitted. See section 5.20.4.9 (TDMA Epoch Number).

The Source Address Hash is formed by the byte-wide exclusive-OR of the 6 bytes in the IEEE MAC address of the source of the TDMA frame.

5.20.6.6 Encrypted Data Structure

Figure 90 defines the TDMA Payload for main TDMA MPDUs. Figure 91 defines the TDMA Payload for retry TDMA MPDUs.

The TDMA Payload is encrypted. The TDMA MPDU Header, TDMA Header and any CRCs are not encrypted. In the case of the Main TDMA MPDU, the TDMA payload is split into two parts separated by a CRC. However, for the purpose of encryption, the two parts of the TDMA payload are considered to be contiguous.

Any TDMA CRCs are calculated based on the contents of the encrypted payload.

Every encrypted TDMA MPDU shall have the *Encrypted* field of the TDMA header set to 1.

5.20.6.7 Encrypted Data Structure (Informative)

The encrypted TDMA MPDU does not carry the IV and a Magic Number like its CSMA/CA counterpart. The IV is calculated based on values known to all members of the network.

The length of the TDMA payload differs between main and retry TDMA MPDUs.

5.20.6.8 Encryption Performance (Informative)

The performance of the encryption process should not significantly increase the latency of the TDMA transmission process. As the latency constraints are quite tight, an implementation is likely to require hardware support for TDMA encryption.

5.21 S-Node Management

This section defines procedures that are followed by a CP and a S-node to setup, maintain, and tear down streaming sessions that utilize the Priority Asynchronous Data Service.

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5.21.1 Introduction to S-node Management (Informative)

A S-node can facilitate the transport of a streaming session by utilizing the Priority Asynchronous Data Service. The parameters governing this service are setup and maintained by the Streaming Session Management process at the CP.

To create a streaming session, a S-node sends a Streaming Session Management Setup request to the CP with requested QoS Time Reservation, jitter, latency, and Priority parameters. Upon receiving this, the CP will determine the level of QoS closest to that which was requested and that can be facilitated. The CP will either send to the S-node a Streaming Session Management Access Granted response indicating resultant QoS and an associated Stream ID (SID) or will send a Streaming Session Management Access Denied response. In the case of an Access Granted response, the CP will also indicate, on the next CP2 Beacon, the Priority Access value associated with the SID. The S-node will use the Priority Access value to perform the CSMA/CA access for sending its streaming data. See section 5.7.7.3.

5.21.2 Streaming Session Reprioritization (Informative)

Existing streaming sessions can be reprioritized based on whether a higher priority access value has become available or due to a new streaming session management setup request that requires a higher priority access value.

A higher priority access value may become available due to an existing session tear down. The tear down may be the result of an explicit request or due to the session timing out. In either case, the CP can decide to reprioritze the other exisiting streaming sessions to reutilize the priority access that was released.

A new streaming session management setup request may require a priority that is higher than existing streaming sessions. In this case, the CP may want to repriortize the existing sessions in order to grant the higher priority access to the new session.Table 258 proposes the decision matrix for repriortization of streaming sessions.

Table 258 - Priority Access Value Reprioritization Decision Matrix

Condition	Result
Existing session tears down	All exisiting sessions with lower priority access values are promoted to backfill the value vacated by the session tear down
Existing session times out	All exisiting sessions with lower priority access values are promoted to backfill the value vacated by the session tear down
New session	Demote all exisiting sessions with lower Priorities by one priority access level to make room for the new session priority access value

5.21.3 Streaming Session Management (at the CP)

All Class-1, Class-2, and Class-3 CPs shall operate the procedures defined in these subsections.

The procedure for managing streaming sessions at the CP is given in the form of a state machine. There is one instance of this state machine for each possible priority stream allowed.

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5.21.3.1 Streaming Session States

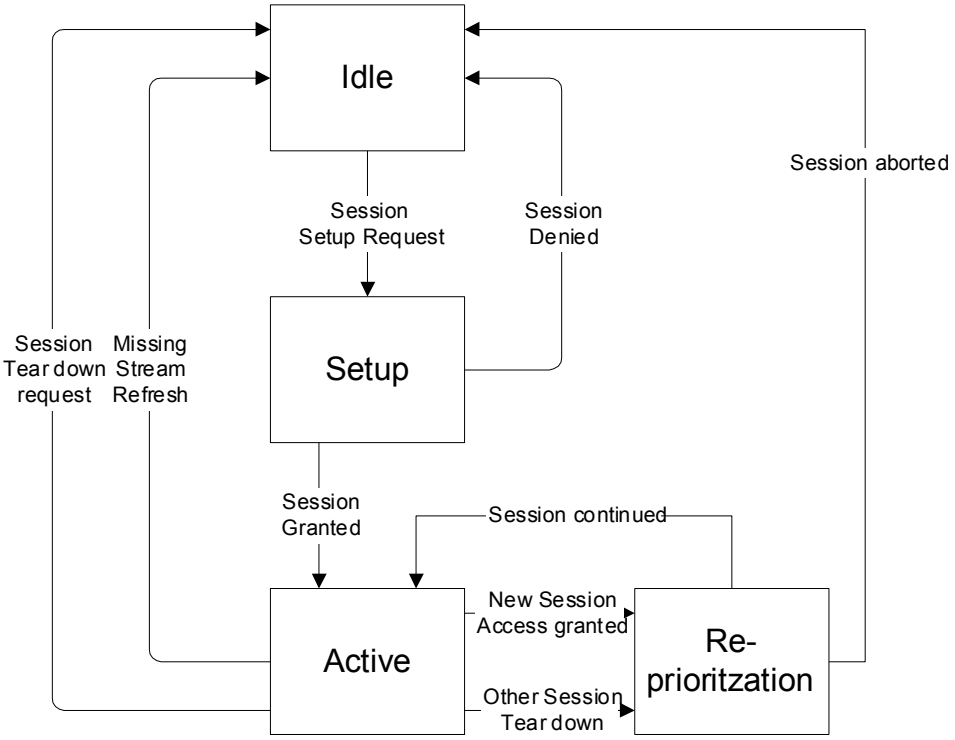
State	Description
Idle	The initial state of the state machine.
Setup	A streaming session has been requested. Determine priority access by QoS parameters
Active	A streaming session has been established.
Re-prioritization	A streaming session is being re-prioritized

5.21.3.2 Streaming Session Events

Event / Condition	Definition
Session Setup request	A Streaming session setup request was received
Session Granted	The CP determined according to available bandwith and QoS parameters to grant priority access to the medium
Session Denied	No more available bandwidth for streaming sessions is present
New Session Access granted	Access for another stream has been granted and hence priority access must be re-evaluated for the stream represented by this state machine
Missing Stream Refresh	The S-node did not send a stream refresh and a timeout occured
Session Tear down request	A Streaming session tear down request was received
Other Session Tear down	Another active streaming session has been torn down
Session continued	The streaming session continues after a re-prioritization
Session aborted	The streaming session is aborted after a re-prioritization

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5.21.3.3 Streaming Session State Transition Diagram



5.21.3.4 Idle State

Upon entering the Idle state, the CP shall free both the associated Stream ID and priority access value (Backoff).

Event	Action	Next State
Session Setup request	Enter into setup mode so the CP can calculate bandwidth availability and priority access	Setup

5.21.3.5 Setup State

On entry to the Setup state, the CP will analyze the QoS parameters in the Streaming Session Management - Setup Request MPDU. If the CP determines that a priority is deserved and the bandwidth is available on the network, then access will be granted, a Streaming Session Management – Access Granted MPDU will be sent to the requesting S-node, and the state machine will transition into the Active state. If a priority assigned by the CP is lower then all other streams, and the NTR requested with this stream would cause *MaxPriorityBandwidth* to be exceeded, then access will be denied, a Streaming Session Management – Access Denied MPDU will be sent to the requesting S-node, and the state machine will transition back to Idle.

Event	Action	Next State
Session Granted	Calculate priority access value. Send Streaming Session Management – Access Granted MPDU to the S-node with the stream ID that will be associated with this stream. The CP must also update its CWPriority[n] array.	Active

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Session Denied	Send a Streaming Session Management – Access Denied MPDU to the S-node	Idle

5.21.3.5.1 Calculating Priority Access (Backoff) Value (Informative)

While in the Setup state, the CP will be responsible for calculating a backoff value that is in sync with the requested QoS parameters. Requested priority values, jitter and latency variables are ideal for calculating backoff numbers. Because only one stream can occupy a given slot time, the lowest backoff numbers are given out first based on highest QoS needs, and then on a first come first serve basis for streams of equal QoS needs.

If two streams request a session witht the same priority, then the jitter and latency parameters should be used to dicate priority access values. A lower backoff number will suffer less jitter and latency delay. If jitter or latency were not requested QoS parameters, and two streams with the same priority are requested, then backoff numbers shall be assigned on a first come first serve basis.

It should be noted that there is an inverse mapping from the priority value requested to the priority access value (Backoff value) given by the CP. In other words, a S-node that requests a streaming session with a priority of 7 (highest), would desire the CP to return a priority access value (backoff) of 0 (lowest backoff value and best performance).

5.21.3.6 Active State

In the Active state, the CP will repeatedly signal the StreamIDs and their associated priority values. If, while in the Active state, a new streaming session is requested, or an existing session is torn down, then all the state machines in the CP for the other existing streams must enter the Re-prioritization state to redeterime ther eligibility for priority access.

Event	**Action**	**Next State**
New Session Access Granted	Recalculate priority access value.	Re-prioritization
Other Session Tear down	Recalculate priority access value.	Re-prioritization
Session Tear down request		Idle
Missing Stream Refresh		Idle

5.21.3.7 Re-prioritization State

In the Re-prioritization state, the CP will determine whether the session is to be reprioritized or aborted based on whether a higher priority access value has become available or due to a new streaming session management setup request that requires a higher priority access value. The session may continue with a higher, lower, or the same priority access value. Or the CP may determine that the session must be aborted to make access available for a new higher priority session.

Event	**Action**	**Next State**
Session continued		Active
Session aborted		Idle

5.21.4 Streaming Session Management (at the S-node)

Streaming session management at the S-node is defined in the following subsections.

The procedures are described in the form of a state machine. There should be one instance of the state machine for each active priority stream within a S-node.

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5.21.4.1 Streaming Session States

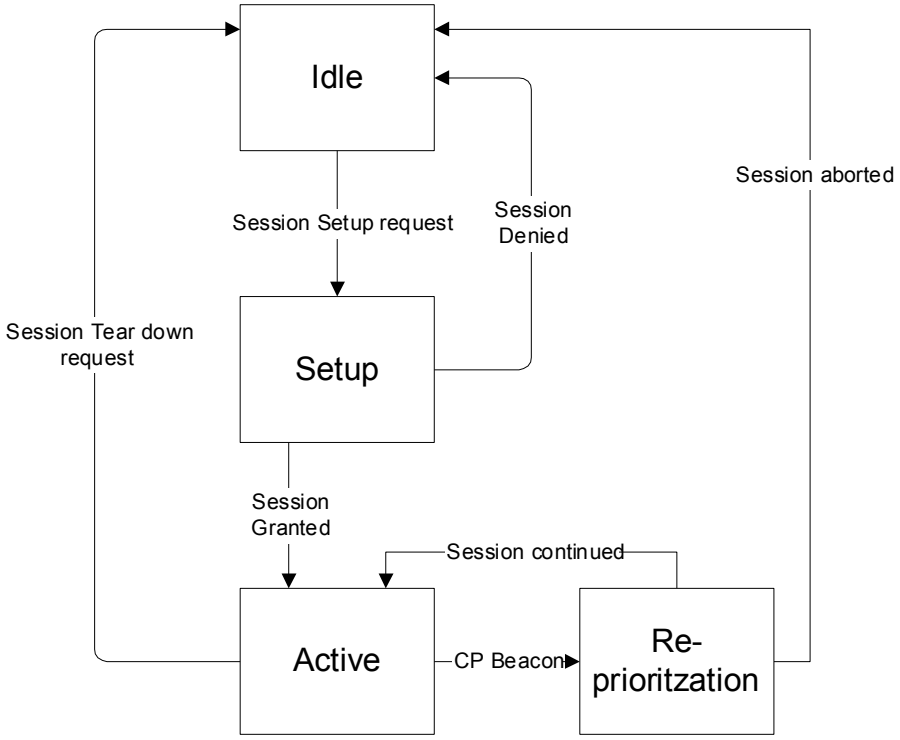
State	Description
Idle	Initial state of the state machine
Setup	Calculate MAC level QoS parameters
Active	Stream is active
Re-prioritization	Stream is being re-prioritized

5.21.4.2 Streaming Session Events

Event / Condition	Definition
Session Setup request	MS-SAP has received a MS_SETUP request from a higher layer
Session granted	The CP returned a Streaming Session Management response - Access Granted MPDU
Session denied	The CP returned a Streaming Session Management response - Access Denied MPDU
Session Tear down request	MS-SAP has received a MS_TEARDOWN request from a higher layer
CP Beacon	CP has sent a beacon indicating the CWPriority[n] array
Session continued	The streaming session continues after a re-prioritization
Session aborted	The streaming session is aborted after a re-prioritization

5.21.4.3 Streaming Session State Transition Diagram

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5.21.4.4 Idle State

Upon entering this state, the S-node will free any resources associated with this stream including the Stream ID and the backoff value that was given by the CP.

Event	Action	Next State
Session Setup request	Queue a Streaming session request MPDU.	Setup

5.21.4.5 Setup State

When an S-node receives a Session Setup request, it will enter the setup state. In the the setup state, the S-node will take the QoS parameters passed down as parameters in the MS_SETUP primitive and will convert them to MAC layer QoS values. Once these values are calculated, a Streaming Session Management - Setup request MPDU can be generated and sent to the CP.

Event	Action	Next State
Session Granted	Save the stream ID assigned by the CP. This SID will be used to apply the associated CWPriority value indicated in the CP Beacon	Active
Session Denied		Idle

5.21.4.6 Active State

Upon entering the active state the S-node will begin transmitting MPDUs using the CSMA/CA access mechanism Priority Aysnchronous Data service with the CP assigned backoff (CWPriority value).

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Event	Action	Next State
CP Beacon	Refresh local CW variables as indicated in the beacon	Re-prioritization
Session Tear down request	Free any resources associated with this stream including the stream ID and backoff value.	Idle

5.21.4.7 Re-prioritization State

Upon entering the Re-prioritization state, the S-node will refresh the local CW variables as indicated in the beacon.

Event	Action	Next State
Session continued		Active
Session aborted		Idle

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6 DECT DLC AND NWK LAYERS

6.1 Introduction (Informative)

This section defines the Class-1 CP and I-node DECT-GAP profiles. It provides a number of tables, similar to those in section 6 (Inter-operability requirements) of the DECT-GAP spec [11]. In these tables, the status of each of the NWK features and DLC, MAC and PHY services is defined for both the Class-1 CP (DECT: FT) and I-node (DECT: PT). Each feature or service can be mandatory (M), optional (O), conditional (C; explained under table), or not applicable (N/A). The definitions of features and services as listed in chapters 4 and 5 of [11] have been maintained (see references in tables), although some of the DECT features and services are not applicable for HomeRF. DECT GAP numbering of the features and services has been maintained. For Class-1 CP interoperability requirements, the DECT Residential / Business (R/B) environment served as a reference.

The mapping of features and services to procedures within each particular protocol layer is as defined for DECT-GAP [11].

HomeRF Application (IWU) features and their status are defined in section 8 (HomeRF IWU).

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6.2 NWK Features

Table 259 defines the DECT NWK features that a HomeRF node supports.

Table 259 - DECT NWK Layer Features Supported

DECT NWK Feature supported			**Status**	
Item no.	**Name of feature**	**Ref. (GAP)**	**I-node (PT)**	**Class-1 CP (FT)**
N.1	Outgoing call	4.1	M	M
N.2	Off hook	4.1	M	M
N.3	On hook (full release)	4.1	M	M
N.4	Dialed digits (basic)	4.1	M	M
N.5	Register recall (note 4 and note 5)	4.1	M	O
N.6	Go to DTMF signaling (defined tone length) (note 1)	4.1	M	O
N.7	Pause (dialing pause) (note 3)	4.1	M	O
N.8	Incoming call (note 2)	4.1	M	M
N.9	Authentication of I-node	4.1	C1	C1
N.10	Authentication of user	4.1	O	O
N.11	Location registration	4.1	M	M
N.12	On air key allocation	4.1	C1	C1
N.13	Identification of I-node	4.1	M	O
N.14	Service class indication/assignment	4.1	M	O
N.15	Alerting (note 2)	4.1	M	M
N.16	ZAP	4.1	O	O
N.17	Encryption activation CP initiated	4.1	O	C2
N.18	Subscription registration procedure on-air	4.1	M	M
N.19	Link control	4.1	M	M
N.20	Terminate access rights CP initiated	4.1	M	M
N.21	Partial release	4.1	O	O
N.22	Go to DTMF (infinite tone length)	4.1	O	O
N.23	Go to Pulse	4.1	O	O
N.24	Signaling of display characters	4.1	O	O
N.25	Display control characters	4.1	O	O

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DECT NWK Feature supported			Status	
Item no.	**Name of feature**	**Ref. (GAP)**	**I-node (PT)**	**Class-1 CP (FT)**
N.26	Authentication of CP	4.1	O	O
N.27	Encryption activation I-node initiated	4.1	O	O
N.28	Encryption deactivation CP initiated	4.1	N/A	N/A
N.29	Encryption deactivation I-node initiated	4.1	N/A	N/A
N.30	Calling Line Identification Presentation (CLIP)	4.1	O	O
N.31	Internal call	4.1	C3	C4
N.32	Service call	4.1	O	O

Notes

M - Mandatory
O - Optional
C1 - This feature is mandatory if TDMA encryption is supported, optional otherwise.
C2 - Mandatory in the U.S.
C3 - Mandatory for a node that supports DECT voice. This specification does allow for a Non-Voice I-node (see section 10.6).
C4 - Mandatory for a CP operating autonomous or slave mode, optional for standalone mode.
N/A – Not Applicable.

1. The I-node is only required to be able to send the <<MULTI-KEYPAD>> information element containing the DECT standard 8-bit character [refer to 6, annex D] codes "Go to DTMF", defined tone length and the CP is required to be able to understand it.
2. These features require the Class-1 CP to support the Group ringing feature and to optionally support the connection oriented incoming call feature. The I-node is required to support both the Group ringing feature and the connection oriented incoming call feature.
3. The I-node is required to be able to send the <<MULTI-KEYPAD>> information element containing the DECT standard 8-bit character [refer to 6, annex D] codes "Dialing Pause". This guarantees automatic access to secondary or alternative networks.
4. This feature uses keypad code 15 hex.
5. The CP is not mandated to receive and understand the register recall DECT character. However, if a CP supports it, there may be no corresponding action that the CP can take with the local network as a result of this function.

6.2.1 Additional NWK Behavior

This section defines additional behavior that shall be supported by a HomeRF NWK layer.

6.2.1.1 Call Release

Following release of a call in the network layer, both CP and I-node shall perform a downward disconnect. [209]

[209] This requirement arises because there is no signaling in the HomeRF MAC layer that supports an upward connection release. In the normal case, both I-node and CP MACs will see an MC_DIS request (in no defined order).

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6.2.1.2 CLMS Procedures

6.2.1.2.1 CLMS Procedures (Informative)

The DECT NWK-layer CLMS entity provides the MNCL_UNITDATA service to transport connectionless data. The request primitive supports optional *Alphanumeric*, *IWU-TO-IWU* and *IWU-packet* parameters.

In the standard DECT case, the CLMS service is provided on top of two transport mechanisms: the *fixed* and *variable*. The fixed mechanism transports 5-byte segments using the DLC's *Lb* broadcast service. The *variable* mechanism transports variable-length SDUs using the DLC's unacknowledged service addressed at the MAC'c connectionless S-SAP (SAPI=3). The *fixed* service exchanges {CLMS-FIXED} PDUs, and the *variable* service exchanges {CLMS-VARIABLE} PDUs between peer CLMS entities.

The DECT {CLMS-FIXED} PDU supports a limited maximum length, and cannot transport the *IWU-TO-IWU* and *IWU-packet* parameters of the MNCL_UNITDATA service.

For this reason, this section defines a means of transporting {CLMS-VARIABLE} PDUs thereby providing support for the full MNCL_UNITDATA service.

The DECT NWK layer limits the length of the {CLMS-FIXED} PDU to 20 bytes of data [5, section 6.4.3 and 8.3].[210] The limit is increased in the HomeRF case to support the maximum possible size that can be signaled using the DECT PDU formats.

Support for the {CLMS-VARIABLE} PDU is provided by embedding a {CLMS-VARIABLE} PDU as the payload of a {CLMS-FIXED} PDU and defining a value of the {CLMS-FIXED} *Protocol Discriminator* field to signal this use.

Support for long (*i.e.* longer than the {CLMS-FIXED} payload size) MNCL_UNIDATA parameters is provided through the DECT <<SEGMENTED-INFO>> element. Using this, the CLMS entity can transport about 18 bytes of MNCL_UNITDATA SDU per {CLMS-FIXED}[211].

6.2.1.2.2 CLMS Procedures (Normative)

Support for CLMS is optional.

The HomeRF {CLMS-FIXED} PDU shall support between 1-32 bytes of data[212].

In addition to the DECT definitions special value (*CLMS-VARIABLE*) is defined for the *Protocol Discriminator* field of the {CLMS-FIXED} address section. Table 260 defines this value [213].

Table 260 - Definition of CLMS-VARIABLE Protocol Discriminator Value

Bit	8 (msb)	7	6	5	4	3	2	1 (lsb)
DECT Field Name	Not Used	Character Type			Odd / Even	Character Set		
HomeRF *CLMS-VARIABLE* Value	1	1	1	1	1	1	1	1

A protocol discriminator field (the Protocol Discriminator field of the CLMS-FIXED address section [6, section 8.3.1]) equal to CLMS-VARIABLE indicates that the data field of the {CLMS –FIXED} PDU contains a {CLMS-VARIABLE} PDU. In this case, the permitted lengths for the data field are 7-32 bytes.[214]

If the entire CLMS-Variable PDU cannot fit within 32 bytes, one or more of the information elements (IEs) must be segmented via the *Segmented info* IE. The *Segmented info* IE adds 2 bytes of overhead per each segmented IE.

---

[210] 6 frames of CLMS: 1 frame is address frame, 5 data frames each carry 4 bytes of payload data yielding 20 net bytes of payload data.

[211] There are two bytes of overhead for the Segmented Info element reducing the max 20 bytes of data per CLMS message to 18 bytes.

[212] 9 PDUs at 5 bytes each: 1 PDU is address SDU, 8 PDUs carry 4 byte SDUs yielding 32 bytes of payload data.

[213] DECT terminology and numbering conventions apply to this section.

[214] The CLMS-VARIABLE PDU contains a minimum 7 bytes of required fields.

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The format of the {CLMS-VARIABLE} PDU shall be as defined in [5, section 6.3.5.1].

An I-node that receives a {CLMS-FIXED} PDU that contains an embedded {CLMS-VARIABLE} PDU can ignore it.

6.2.1.3 LCE Procedures

6.2.1.3.1 B-FORMAT PDU Structure

The LCE shall interpret the 5-byte PDU as defined in Table 261. [215]

Table 261 - LCE B-FORMAT PDU Structure

Bit:	8 (msb)	7	6	5	4	3	2	1 (lsb)	
Protocol Discriminator				X	X	X	X	Octet: 1
X	X	X	X	X	X	X	X	2
X	X	X	X	X	X	X	X	3
X	X	X	X	X	X	X	X	4
X	X	X	X	X	X	X	X	5

The LCE shall use the same values for the B-FORMAT *Protocol Discriminator* field as it does for the S-FORMAT *Protocol Discriminator* field. These values are defined in [5, 7.2]. The bit value "1000" which is currently classified as an 'Unknown protocol entity' will be used as the *Protocol Discriminator* when indicating a proprietary entity. Accordingly, the remainder of the B-FIXED message shall contain proprietary information that is dictated by the Class-1 CP of the managed network.[216]

The CP's LCE shall insert a 4-bit protocol discriminator field in outgoing B-FIXED message PDUs.

The I-node's LCE shall interpret the 4-bit protocol discriminator field of incoming B-FIXED message PDUs and route to NWK-layer entities according to its value.

6.2.1.3.2 {LCE-REQUEST-PAGE} Structure

The LCE shall use the 3-byte (short) {LCE-REQUEST-PAGE} for all paging. [217]

The 3-byte PDU is transported at the front of a 5-byte B-FORMAT PDU such that the last two bytes of the 5-byte B-FORMAT PDU are transmitted as zeroes and shall be ignored by an I-node on receive.

6.2.1.4 Voice Announcement

6.2.1.4.1 Voice Announcement (Informative)

The MB-SAP U-plane data service supports the isochronous connectionless transport of U-plane SDUs. These, when present, carry a voice announcement.

The MB-SAP C-channel is used to address the announcement to one or more I-nodes by reserving the alerting pattern 7 to indicate a voice announcement.

A CP sends an {LCE- REQUEST-PAGE} containing the reserved pattern and addressing one or more I-nodes using a group mask or collective ringing.

An I-node only responds to U-plane data once it has received an {LCE-REQUEST-PAGE} that indicates this pattern. Once it has responded, it continues to accept U-plane data until either an {LCE-REQUEST-PAGE} that turns "alerting" off, or a timeout.

---

[215] DECT terminology and numbering conventions apply to this section.

[216] An implementation dependant method (i.e. IWU-IWU) that identifies the Class-1 CP to the I-node is used by the I-node to determine if it can decode any proprietary entities sent by this Class-1 CP.

[217] This is because the 3-byte format supports group alerting, whereas the 5-byte format does not.

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6.2.1.4.2 Voice Announcement - CP

This section defines procedures that can be supported by a CP to provide voice announcement.

The CP shall send an initial {LCE-REQUEST-PAGE} that contains alerting pattern 7. When the MB-SAP indicates that this has been transmitted, the CP shall enable the MB-SAP U-plane and respond to MB_UDTR indications with MB_UDATA requests containing successive segments of the voice announcement.

During the voice announcement, the LCE shall repeat the original {LCE-REQUEST-PAGE} at an interval no longer than *VoiceAnnouncementRepeatInterval* (defined in 16.4 (NWK Constants)).

At the end of the voice announcement, the LCE shall transmit an {LCE-REQUEST-PAGE} addressed to the same I-nodes that contains the "alerting off" pattern. The LCE shall then disable the MB-SAP U-plane.

6.2.1.4.3 Voice Announcement - I-node

This section defines procedures that can be supported by an I-node to provide voice announcement.

On receipt of an {LCE-REQUEST-PAGE} that addresses this I-node and that contains alerting pattern 7, enter an *Enabled for voice announcement* state. In this state, any U-plane SDUs received through the MB-SAP are accepted and copied to the top of the voice stack, thereby becoming audible to the I-node user.

On entry to this state, and on receipt of subsequent identical {LCE-REQUEST-PAGE} PDUs, the I-node shall set/reset a timer to value *VoiceAnnouncementRepeatInterval,* defined in section 16.4 (NWK Constants).

On receipt of an {LCE-REQUEST-PAGE} that addresses this I-node and that contains alerting pattern "alerting off" [218] or on expiry of the *VoiceAnnouncementRepeatInterval* timer [219], the I-node shall leave the *Enabled for voice announcement* state and discard any MB-SAP U-plane SDUs it subsequently receives.

6.3 DLC Services

Table 262 defines the DECT DLC Layer services that a HomeRF node supports.

Table 262 - DECT DLC Layer Services Supported

DECT DLC Service supported			**Status**	
Item no.	**Name of service**	**Ref. (GAP)**	**I-node (PT)**	**CP (FT)**
D.1	LAPC class A service and Lc	5.1	M	M
D.2	Cs channel fragmentation and recombination	5.1	M	M
D.3	Broadcast Lb service	5.1	M	M
D.4	Intra-cell voluntary connection handover	5.1	N/A	N/A
D.5	Intercell voluntary connection handover	5.1	N/A	N/A
D.6	Encryption activation	5.1	C1	C1
D.7	LU1 TRUP Class 0/min_delay	5.1	M	M
D.8	FU1	5.1	M	M
D.9	Encryption deactivation	5.1	N/A	N/A
Notes: M – Mandatory				

[218] *i.e.* explicit termination of the Voice Announcement.

[219] Abnormal/Implicit termination of the Voice Announcement.

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O – Optional N/A - Not applicable C1: IF feature N.17 OR N.27 THEN M ELSE N/A

6.3.1 Additional DLC Broadcast Service (Lb) Requirements

The DLC shall support the 5-byte Lb SDU.

The DLC shall provide a means of propagating the full HomeRF MB-SAP functionality to the DECT NWK layer. The full set of primitives is defined in 5.2.4 (MB-SAP Data Service (ICBS)).

6.4 General Requirements

Except as defined in this section, the HomeRF node shall conform to all the general requirements of the DECT GAP (section 6.9).

6.4.1 HomeRF Default Attributes

The <<IWU-ATTRIBUTES>> and <<CALL-ATTRIBUTES>> information elements are not required to be understood by a *GAP* equipment. The values, as stated in [6, annex E] shall be considered as default. The value 1 of the field <Network layer attributes> in <<CALL-ATTRIBUTES>> shall be interpreted as indicating *HomeRF*.

6.5 Mapping HomeRF Identities to DECT Identities

This section defines the following DECT Identities in terms of HomeRF identities.

Table 263 - DECT Identities Related to HomeRF Identities

DECT Identifier	**Description**
IPUI *Individual Portable Unit Identifier*	Derived from an I-node's MAC address
PARK *Portable Access Rights Key*	Derived from the NWID

6.5.1 Mapping MAC Address to IPUI

The HomeRF IPUI is derived from the I-node's MAC address as defined in Figure 184.

Bits	4	4	48
HomeRF IPUI	PUT	*reserved*	PUN
Contains	"1111"	*zeroes*	I-node MAC address

Figure 184 - HomeRF IPUI Structure

The *PUT* encoding uses a value reserved in the DECT standard.

6.5.2 Mapping CP Address to PARK

The HomeRF PARK is derived from the NWID of the Class-1 CP that started the network as defined in Figure 185.

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Bits	3	24
HomeRF PARK	ARC	ARD
Contains	“111”	NWID

Figure 185 - HomeRF PARK Structure

The *ARC* encoding uses a value reserved in the DECT standard.

6.6 CC-SAP Primitives (Informative)

This section describes primitives that are exported by the top of the DECT NWK layer by the call-control entity, and accessed through the Call-Control SAP (CC-SAP).

The purpose of this section is to define the primitives used in the description of the IWU-TAPI interface in section 14.5 (Isochronous Data Interface of a Class-1 CP). See also [6, section 16.3].

6.6.1 MNCC_SETUP Primitive

Primitive	MNCC_SETUP			
Description	Call setup. The Req primitive establishes an I-node call. The Ind primitive indicates that an I-node call has been established.			
Parameters	**Req**	**Conf**	**Ind**	
I-node call ID		M	M	
I-node ID	M		M	
Service Type			M	
Signal	M			
Status		M		
Notes:	M - Mandatory			

The request primitive can fail only if an I-node call ID cannot be allocated. Other DECT-related failure cases result in an MNCC_RELEASE Indication primitive being issued. The I-node call ID is valid after a MNCC_SETUP confirmation or indication until a MNCC_RELEASE or MNCC_REJECT primitive.

The *I-node call ID* addresses a call-control instance. While a call exists, this identifier provides a means to address the call.

The *I-node ID* addresses an individual I-node. The form of representation is not specified here. [220]The service type has one of the values: *basic* or *internal*. The I-node uses it to distinguish between an external call and an internal call.

The *Signal* controls the generation of alerting patterns at the I-node and values defined in Table 264.

The *Status* confirms the success or failure to allocate an I-node call ID.

Table 264 - MNCC_SETUP Signal Values

Signal Value
Pattern Number 0 - 7

[220] It could be a TPUI, or a MAC address.

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Continuous
None

6.6.2 MNCC_SETUP_ACK Primitive

Primitive	MNCC_SETUP_ACK			
Description	This primitive is used to place the CP on the Overlap Sending state after receipt of an MNCC_SETUP Indication In the Overlap Sending state, the I-node can send MNCC_INFO indications containing keypad codes. The CP can send MNCC_INFO indications containing display codes and signal values.			
Parameters	**Req**		**Ind**	
I-node Call ID	M		M	
Progress Indicator	M		M	
Notes:	M - Mandatory			

The *Progress Indicator* is one of: *no further information* or *in band information now available*. The latter shall only be sent if the I-node voice stream has been connected by the IWU-TAPI interface. See section 14.5 (Isochronous Data Interface of a Class-1 CP).

6.6.3 MNCC_REJECT Primitive

Primitive	MNCC_REJECT			
Description	This primitive is used to reject a call.			
Parameters	**Req (I-node)**		**Ind (CP only)**	
I-node Call ID	M		M	
Cause			M	
Notes:	M - Mandatory			

Cause is one of: *peer request* or *timeout*. A *peer request* indicates that the other end of a call setup has requested an MNCC_REJECT. A *timeout* indicates that the local CC entity has aborted the setup attempt due to a protocol timeout.

6.6.4 MNCC_CALL_PROC Primitive

Primitive	MNCC_CALL_PROC			
Description	This primitive causes the CP to enter the call proceeding state. It is used to support overlap sending (see [11, section 8.3]).			
Parameters	**Req**		**Ind**	
I-node Call ID	M		M	
Progress Indicator	M		M	

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Notes:	M - Mandatory

Progress indicator takes one of: *no further information* or *in band information now available*. The latter setting shall only be used once the CP has established a voice connection.

6.6.5 MNCC_ALERT Primitive

Primitive	MNCC_ALERT			
Description	The Ind primitive indicates that the I-node is generating an alerting pattern.			
Parameters	**Req**		**Ind**	
I-node Call ID	M		M	
Notes:	M - Mandatory			

6.6.6 MNCC_CONNECT Primitive

Primitive	MNCC_CONNECT			
Description	This primitive is used by the CP to indicate completion of the connection of an incoming call from the I-node. It is also used to request the completion of the connection of an outgoing call.			
Parameters	**Req**	**Conf**	**Ind**	**Resp**
I-node Call ID	M		M	
Notes:	M - Mandatory			

6.6.7 MNCC_RELEASE Primitive

Primitive	MNCC_RELEASE			
Description	This primitive is used to destroy a call or to request that a call to an I-node be destroyed.			
Parameters	**Req**	**Conf**	**Ind**	**Resp**
I-node Call ID	M	M	M	M
Notes:	M - Mandatory			

6.6.8 MNCC_INFO Primitive

Primitive	MNCC_INFO			
Description	This primitive is used to pass information to the I-node for display (or to generate an altering signal), and indicates keypad codes sent by the I-node.			
Parameters	**Req**		**Ind**	
I-node Call ID	M		M	

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Keypad Codes			M	
Signal	O1			
Multi Display	O1			
Notes:	M - Mandatory O1 - At least one of *Signal* or *Multi Display* must be present.			

Note that when issuing the MNCC_INFO request, it is the responsibility of the IWU to ensure that there is either a signal or multi display information (or both), i.e. the request should not have 'no signal' and a multi display length of 0.

The *Keypad Codes* is a sequence of bytes coded as defined in Table 265.

Table 265 - Keypad Code Values

Keypad Code	**Value**
Dialed Digits: 0 - 9	0x30 - 0x39
#	0x23
*	0x2a
interdigit pause	0x05
go to pulse	0x12
go to DTMF	0x14
register recall	0x15
internal call	0x17

Multi Display is a sequence of bytes encoded as defined by DECT [6].

Signal is defined in section 6.6.1 (MNCC_SETUP Primitive).

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6.6.9 MNIWU_INFO Primitive

This primitive is included for completeness only. The IWU-TAPI interface does not provide access to this primitive.

Primitive	MNIWU_INFO			
Description	Transports a message to and from the I-node IWU. The *User Specific Contents* should only contain Information Elements as described in [6, section 6.3.2.14]. The construction and interpretation of these elements is the responsibility of the PC application. This data should contain information elements as described in [6, section 6.3.2.14]. The format of each information element should be as described in the relevant subsection. Failure to adhere to the correct information element formats will result in a non-HomeRF application			
Parameters	**Req**		**Ind**	
I-node Call ID	M		M	
User Specific Contents	M		M	
Notes:	M - Mandatory			

The *User Specific Contents* is a sequence of bytes of length up to 56.

6.7 MNMM-SAP Primitives (Informative)

According to the DECT architecture, control of encryption is a mobility management function, even though it is associated with a particular call control entity.

This section describes the subset of the MNMM-SAP [221] primitives that are required to understand the operation of the IWU-TAPI interface in section 14.4 (Support for Priority Asynchronous Data in Microsoft Windows).

6.7.1 MNMM_ENCRYPT Primitive

Primitive	MNMM_ENCRYPT			
Description	The request primitive is used to activate encryption initiated by the CP. The indication primitive notifies the IWU that encryption has been enabled, initiated by the I-node.			
Parameters	**Req**	**Conf**	**Ind**	
I-node Call ID	M	M	M	
Status		M		
Notes:	De-activation of encryption is not supported. The confirm primitive indicates encryption status after a request has been made.			

The request primitive is used to activate ciphering initiated by the CP. De-activation of encryption is not supported in this specification. The confirm primitive indicates the encryption status after a request has been made and completed. The indication primitive notifies the IWU of a change in encryption status.

Possible *Status* values are listed in Table 266.

[221] Note this have been renamed MNMM-SAP (Network layer Mobility Management) from MM-SAP to distinguish it from the HomeRF MM-SAP (MAC layer Management).

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Table 266 - MM_ENCRYPT Status Values

Status	**Reason**
Successful	
Timeout	No reply from I-node
Link Failure	
No Key known by CP for this I-node	
I-node rejects the request	

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7 VOICE STACK AND ON-AIR VOICE PROCESSOR

7.1 Introduction (Informative)

The *Voice Stack* provides the IWU with access to one or more isochronous voice connections to an external voice signal. The Voice Stack also includes any required echo cancellation.

In the case of an I-node external voice signal is likely to be a microphone and speaker. In the case of a Class-1 CP, it is a connection to the PSTN (for example, ISDN or POTS).

The IWU is given control of the voice stack through the management service access point.

The I-node supports only a single connection. The Class-1 CP can support any number of external PSTN lines, although only *MaxMCconnections* (see section 16.2 (MAC Constants)) of them can be routed by the IWU to I-nodes at any time.

This section also includes a description of the on-air voice processor, and of the combined operation of the Voice Stack and on-air voice processor.

A HomeRF Class-1 CP is required to support conferencing (refer to Table 279 for the types of conferencing supported). The *Conference Mixing* function is logically performed within the IWU, although an implementation will usually make this a function of a hardware voice processor.

7.2 Voice Stack Services

There are two SAPs - one for voice data and one for management of voice connections.

The voice data service is accessed through the voice data service access point (VD-SAP). The management service is accessed through the voice management service access point (VM-SAP).

7.2.1 VD-SAP Data Service

The VD-SAP supports only a single primitive: VD_DATA.

7.2.1.1 VD_DATA

Primitive	VD_DATA			
Description	This service transports voice data isochronously			
Parameters	**Req**		**Ind**	
Line ID	CP		CP	
Voice SDU	M		M	
Notes:	CP - only at CP M - Mandatory			

The *Line ID* distinguishes between external PSTN lines at a Class-1 connection-point.

The *Voice SDU* contains voice data encoded as specified in section 7.3 (Voice Encoding) (Voice Encoding).

7.2.2 VM-SAP Management Service

The service primitives supported are described in Table 267.

Table 267 - Voice Stack Management Service Primitives

VM-SAP Service Primitive	**Description**
VM_CONTROL_HOOK	Goes offhook and onhook.
VM_DIAL	Dials a number

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VM_CONTROL_DATA	Connects and disconnects voice data path
VM_INCOMING_CALL	Indicates incoming call
VM_ALERT	Generate alert pattern
VM_SET_SIDETONE	Generate a side-tone in I-node

7.2.2.1 VM_CONTROL_HOOK

Primitive	VM_CONTROL_HOOK (CP only)			
Description	Causes an external line to go offhook or onhook.			
Parameters	**Req**			
Line ID	M			
Hook State	M			
Notes:	M - Mandatory			

The *Hook State* parameter takes one of the two values: *offhook* or *onhook*.

7.2.2.2 VM_DIAL

Primitive	VM_DIAL (CP only)			
Description	Dials a number. The line must be offhook. The Conf is issued when the dialing has completed.			
Parameters	**Req**	**Conf**		
Line ID	M	M		
Number	M	O		
Method	M	O		
Notes:	M - Mandatory O - Optional			

The *Number* is a sequence of digits to dial. The *Method* includes pulse generation and DTMF tone generation.

7.2.2.3 VM_CONTROL_DATA

Primitive	VM_CONTROL_DATA			
Description	Enables or disables the isochronous data flow to the external voice interface. When enabled, VD_DATA SDUs will be accepted and indicated isochronously through the VD-SAP.			
Parameters	**Req**			
Line ID	CP			
Control State	M			

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Notes:	CP - CP only M - Mandatory

The *Control State* takes values: *enabled* and *disabled.*

7.2.2.4 VM_INCOMING_CALL

Primitive	VM_INCOMING_CALL (CP only)			
Description	Indicates that an external line is receiving an incoming call.			
Parameters			**Ind**	
Line ID			M	
Caller ID			O	
Called Line ID			O	
Notes:	M - Mandatory O - Optional			

7.2.2.5 VM_ALERT

Primitive	VM_ALERT (I-node only)			
Description	Generates an alert at the I-node. This is used to alert the user to a call incoming at the I-node.			
Parameters	**Req**			
Alert Pattern	O			
Notes:	O - Optional			

The *Alert Pattern* distinguishes between different possible ringing cadences, and includes the value *none* which stops the alert pattern generation.

7.2.2.6 VM_SET_SIDETONE

Primitive	VM_SET_SIDETONE (I-node only)			
Description	Generates a side-tone at the I-node. This is heard at the I-node speaker, but does not appear on-air.			
Parameters	**Req**			
Tone	M			
Notes:	M - Mandatory			

The *Tone* includes values for DTMF digits, dial and busy tones, and a value to stop tone generation.

7.3 Voice Encoding

A *Voice SDU* contains a 10ms segment of 14-bit linear PCM audio sampled at 8kHz.

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7.4 Echo Cancellation Generally (Informative)

An echo, or delayed sidetone, can distract the talker. The distraction gets worse with increasing sidetone amplitude and delay.

There are three sources of echo that require cancellation in a system such as HomeRF:

- *Handset Echo* arises mainly from acoustic coupling between an I-node's speaker and microphone, although electromagnetic coupling may also contribute.
- *Network Interface Echo* arises from the interface between the CP and the PSTN. The amount of echo introduced depends significantly on the form of interface (2-wire, 4-wire or digital).
- *Network Echo* is generated within the PSTN. The network operator provides echo cancellation to achieve subjectively acceptable levels of echo. Because the I-node–CP link introduces additional echo, additional suppression of the network echo is required.

Handset echo is specified in terms of the *Terminal Coupling Loss* (TCL) between the linear PCM signal to the speaker and the linear PCM signal from the microphone.

The two network echoes are lumped together and specified in terms of *Talker's Echo Loudness Rating* (TELR) between the signal to the network and the echo from the network.

Handset Echo causes a problem for the remote user. Network Echo causes a problem for the HomeRF user.

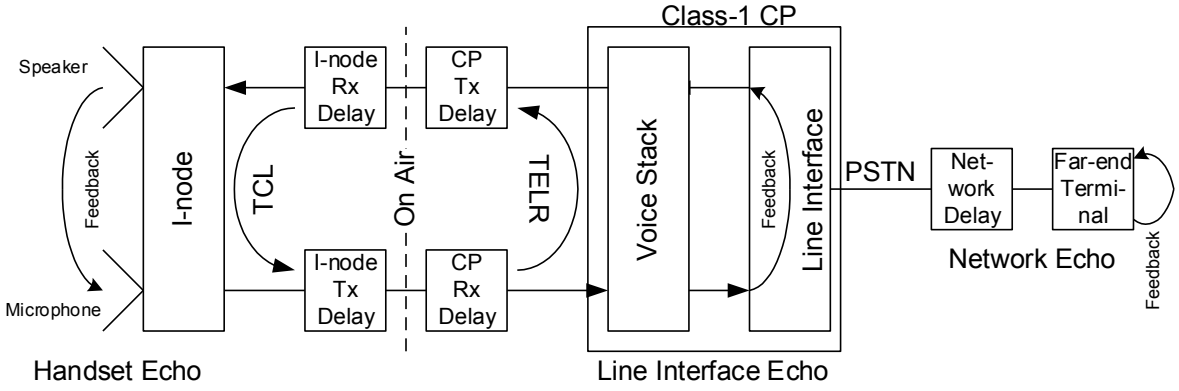


Figure 186 - Sources of Echo

HomeRF guarantees a required level of TCL at the I-node, and a maximum TELR at the CP. This differs from the DECT model in which the handset provides one of two classes of TCL, and the DECT base-station provides additional handset echo cancellation if the handset does not provide the higher class of TCL.

The reason for the difference between the HomeRF model of echo cancellation and the DECT model is that the transit delay (between the PSTN interface and the I-node audio interface) is significantly longer than in DECT. To follow the DECT model of additional handset echo cancellation would require echo cancellation with a control range up to 40ms. Additional echo cancellation at the I-node requires a much shorter control range.

7.4.1 I-node Echo Cancellation

An I-node shall provide a terminal coupling loss between downlink TDMA frames to uplink TDMA frames of at least 33dB at default volume. Note that this is a minimum value, and will not guarantee user acceptance for all combinations of CP and I-node implementations and CP network connections (e.g. VoIP networks with additional delays). For best performance, it is recommended that I-nodes provide at least 35 dB of TCL at all volume settings, and at least 45 dB at default volume.

TCL shall be measured as weighted TCL, TCLw, as defined in [16, Annex B.4], "trapezoidal rule".

The I-node need not, but can signal "Full TCL" as described in [6, section 7.7.4.1].

The CP shall assume that all I-nodes provide this value of terminal coupling loss.

The CP need not provide any artificial echo as described in [9, section 7.4.1.2].

7.4.2 Line Interface and Network Echo Cancellation

The CP shall implement the procedures defined in [9, section 7.10].

These provide suppression of the line interface echo and additional suppression of network echo.

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7.4.3 Synchronous Coding Adjustment

If the CP voice stack interfaces to the network an 8-bit compressed PCM (μ-Law or A-Law) form, the receiving end shall perform the synchronous coding adjustment as described in G.726 [2].

The purpose of the adjustment is to ensure that an 8-bit PCM – ADPCM – 8-bit PCM link through the on-air interface does not additionally degrade the voice signal if there have been one or more tandem PCM/ADPCM conversions on the network route to the end voice terminal.

This adjustment is only required if the IWU routes the received I-node U-plane connection through without modification.

The adjustment requires a refinement of the HomeRF U-plane architecture to allow the On-air voice interface to provide an 8-bit PCM connection, which is then routed by the IWU to the voice stack. For simplicity, this refinement is not shown in the HomeRF architecture diagrams. A practical implementation would lump together all voice-data processing, such as Compander, ADPCM Transcoder, Echo-Cancellation into one functional block where such architectural niceties no longer apply.

7.4.4 Echo Cancellation Algorithm (Informative)

This document only specifies the requirements of echo cancellation in terms of level and control range (delay over which the level must be achieved). Any algorithm that meets these requirements can be used.

7.5 On-Air Voice Processor

The *On-air voice processor* is responsible for two processes: companding and ADPCM transcoding.

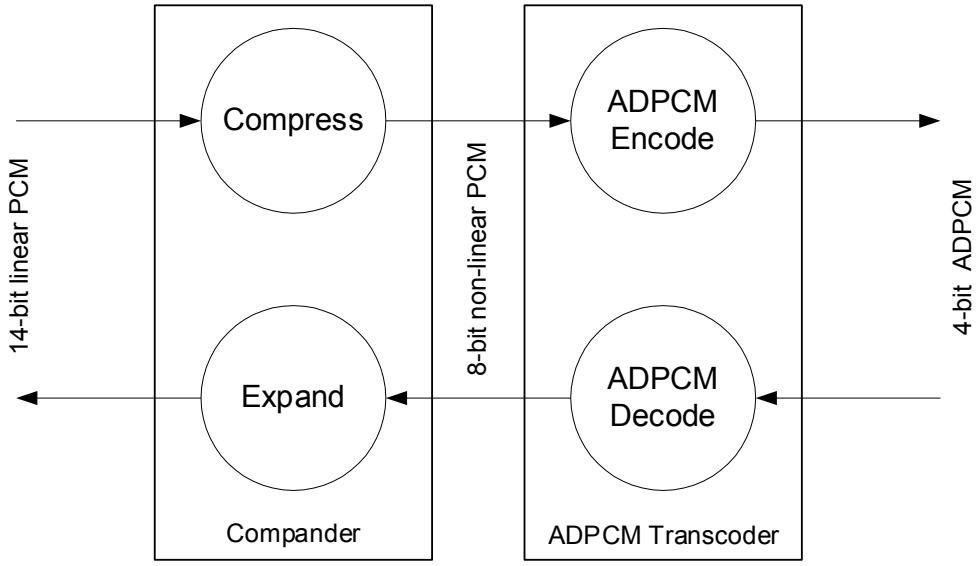


Figure 187 - On-Air Voice Processor

Companding converts between 14-bit linear PCM samples and 8-bit compressed samples.

ADPCM converts between a sequence of 8-bit compressed samples and a sequence of 4-bit ADPCM code-words.

7.5.1 Speech Encoding

DECT U-plane SDUs that are carried in a call with a NWK layer attribute of *Basic Speech* [6, section 7.7.5] shall be encoded using 32kbps ADPCM defined by CCITT Recommendation G.726 [2].

7.5.2 On-Air Transmission Order

ADPCM words shall be transmitted in chronological order.

Bits in ADPCM words shall be transmitted most significant bit first. [222]

[222] Note, this is contrary to HomeRF's conventional little-endian ordering, but is consistent with the requirements of G.726.

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7.5.3 Effect of Loss of Voice SDUs (Informative)

This document does not specify what happens in the voice stack or On-Air U-plane stack if an SDU containing voice data is lost.

The response to the loss of voice SDUs is defined by the manufacturer. Such responses could include muting the speaker, repeating a previous segment of voice data or injecting a noise signal.

7.6 Combined Properties of Voice Stack and ADPCM Transcoder

Except where modified in this specification, the combined properties of the Voice Stack and ADPCM transcoder shall be as specified in the DECT GAP specification [11].

7.6.1 I-node Delay

The sum of the delays from the microphone to the air interface, and from the air interface to the speaker shall not exceed 48 ms.

7.6.2 CP Delay

The sum of the delays from the line interface to the air interface and from the air interface to the line interface shall not exceed 49 ms.

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7.7 Voice-Stack DECT Profile

The following table defines which procedures standardized in the DECT part 8 - (Speech Coding and Transmission) [9] shall be followed by a HomeRF device. The values and procedures referenced from DECT are specified as defaults. Local variations, requirements, and recommendations may superceede these procedures and values.

Reference in [9]	Description	Class-1 CP	I-node	Default value
5.1.1	Encoding - Algorithm	M	M	-
5.1.2	Bit Sequence	M	M	-
7.1.1	PP Frequency Response Sending	N/A	M	Table
7.1.2	PP Frequency Response Receiving	N/A	M	Table
7.2.1	PP sending loudness ratings	N/A	M	7dB+-3.5
7.2.1	PP receive loudness ratings	N/A	M	3dB+-3.5
7.3.1	Talker Sidetone (STMR)	N/A	M	13dB –3/+5
7.4.1	Weighted Terminal Coupling Loss	N/A	S	
7.4.2	Stability loss	N/A	M	6dB
7.5.1	Distortion - Sending	N/A	M	>= 35 dB at line interface
7.5.2	Distortion - Receive	N/A	M	>= 33 dB at ERP
7.5.4	Distortion - Sidetone	N/A	M	<= 10% third harmonic
7.6.1	Out of band signals - Sending	N/A	M	Table
7.6.2	Out of band signals - Receiving	N/A	M	Table
7.7.1	Noise - Sending	N/A	M	-64 dBm0p
7.7.2	Noise – Narrow Band in any 10 Hz Band 300-3400 Hz	N/A	M	-73 dBm0
7.7.3	Noise - Receiving	N/A	M	-54 dBPa(A)
7.8.1	Acoustic Shock - Continuous	N/A	M	24 dBPa Unweighted
7.8.2	Acoustic Shock - Peak	N/A	M	36 dBPa Unweighted
7.9	Delay	S	S	
7.10	Network Echo Control	M	N/A	

Notes:
M - Mandatory
S – Superseded by this specification
N/A – Not Applicable

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8 HOMERF IWU

8.1 Use of DECT NWK messages to support IWU features

8.1.1 The *Internal* Keypad Code

The <*internal*> keypad code (value 0x17) is used to introduce all HomeRF IWU feature signaling. The generic syntax of the signaling is:

<*internal*>*<*keypad codes*>#

Where: <*keypad codes*> is a sequence of keypad codes that does not include a "#" code.

8.1.2 Unsupported Features

A node that does not interpret a particular HomeRF sequence shall use the generic syntax to locate the end of the HomeRF sequence.

The entire HomeRF sequence shall then be discarded.[223]

8.1.3 Intercom Call

Definition: An intercom call is a call originated at an I-node intended for another I-node.

An intercom call shall be signaled within the {CC-SETUP} message by including a <<BASIC-SERVICE>> information element that indicates *internal call set-up.*

8.1.4 Call hold

Definition: The ability to hold calls while other services are accessed. The call hold supplementary service allows a user to interrupt communications on an existing call (hold call) and then subsequently, if desired, re-establish communications (retrieve call).

Call hold shall be signaled by the sequence: <*internal*> * *1* #

Effect:

- Press during a call terminates the call within the CP and I-node. Appears to be “on-hook” at the I-node.

User may then:

- Press “hold” again - reconnects to call.
- Press “off-hook” - connects to the original call or external line
- Press “intercom” - connects an internal call
- User can toggle between intercom and external call by pressing “hold”.

8.1.5 Call transfer

Definition: The call transfer supplementary service enables a user who has two calls, each of which can be an incoming call or an outgoing call, to connect together the other two calls into one call.

This feature assumes the user to have one active call and another call on hold. At least one of the calls is an internal call (no more than one network connection involved). Using the call hold procedures the user can alternate between the calls. The call transfer feature allows the user to connect the two calls within the CP, while releasing both calls between the CP and I-node.

The I-node uses the <<”KEYPAD”>> information element to indicate to the CP IWU layer (DECT: F-IWU) its intention to transfer a call. A single {CC-INFO} message shall be used, transferring a <<MULTI-KEYPAD>> element.

The call transfer shall be signaled by the sequence*:* <*internal*> * *2* #

8.1.6 Call forward

Definition: The call forward supplementary service enables a user to redirect all incoming calls from the *own* I-node to another *new* internal extension. The user’s ability to initiate outgoing call is unaffected by the service. After the call forward supplementary service has been activated, calls are forwarded independent of the status of the user initiating the service. [224]

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[223] Note this also requires a node to ignore any manufacturer-specific extensions it does not understand.

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The user should be able to activate (only from own I-node), cancel (from own and new I-node) and change the call forward service.

The I-node uses a single <<MULTI-KEYPAD>> information element to transfer each of the call forward related messages to the CP IWU layer (IWU). The information element shall be transferred using a {CC-INFO} message.

The sequences associated with this feature are defined in Table 268.

Table 268 - Call Forward Sequences

Sequence	Description
<*internal*> * 3 * <*new extension number*> #	To activate call forwarding
<*internal*> * 3 #	To cancel call forwarding from *own* I-node
<*internal*> * 3 * <*own extension number*> #	To cancel call forwarding from *new* I-node
<*internal*> * 3 * <*own extension number*> * <*new extension number*> #	To change call forwarding

8.1.7 Remote off-hook (babycom)

Definition: The ability for a user to force the called I-node to go off-hook (applies to internal calls only).

It is a mode of the I-node in which it auto-answers individual pages without ringing.

No additional signaling is defined to support this feature.

8.1.8 Pickup conferencing

Definition: If a user initiates an outgoing normal call while the PSTN line is busy, and the number of I-nodes conferenced in the call is less than the maximum number supported by the CP, the user is conferenced with the existing call. See section 12.7.1 (Class 1 CP Requirements) for the mandatory requirements on the minimum number of I-nodes that are conferenced together.

If an I-node goes offhook and it is connected to a CP that has multiple PSTN lines, the CP can behave in an implementation-dependent fashion. This could include using the I-node display to select between alternatives such as conferencing an existing call or placing a new call.

8.1.9 Intercom conferencing

Definition: The intercom conferencing service enables a user who has two calls, each of which can be an intercom call, to connect together all three users into a single conference call.

This feature assumes the user to have one active call and another call on hold. At least one of the calls is an internal call (no more than one network connection involved). Using the call hold procedures the user can alternate between the calls. The intercom conferencing feature allows the user to conference all three users in a single call. For the user initiating the conference call, the active call becomes the conference call, and the call on hold is released.

The I-node uses the <<"KEYPAD">> information element to indicate to the CP IWU layer (F-IWU) its intention to conference calls. A single {CC-INFO} message shall be used, transferring a <<MULTI-KEYPAD>> element.

Intercom conferencing shall be signaled by the sequence: <*internal*> * *4* #

8.1.10 Computer Call

Definition: A speech link is set up between I-node and PC. This link can be used by a HomeRF-aware application to support voice commands, voice mail, etc.

In order to setup a voice connection with the PC, the I-node initiates an internal call. A specific <<"KEYPAD"">> element is used to access the voice connection between CP and PC. A single {CC-INFO} message shall be used, transferring a <<MULTI-KEYPAD>> element.

The voice connection shall be signaled by the sequence: <*internal*> * *5* #

---

224 Conditional call forwarding (e.g. on busy / no reply) is not specified.

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8.1.11 Silent polling

Definition: The ability of a CP to establish whether a specific I-node is within range without alerting the user of that I-node.

This feature shall be implemented by the minimum set of DECT generic access protocol elements plus the CP and I-node shall support the MM identification procedures as defined in the DECT NWK layer specification. A number of specific DECT NWK messages are defined to support these procedures ({IDENTITY-REQUEST}, {IDENTITY-REPLY}).

8.1.12 Communicating manufacturer name and product ID

Definition: Manufacturer name and product ID is exchanged between CP and I-node IWU.

The manufacturer name and product ID shall each be limited to a maximum of 20 characters. An I-node may announce its manufacturer and product IDs using the following KEYPAD sequence:

*<internal> * M * <manufacturer's name> * <product id> #*

The sequence of keypad codes within *<manufacturer's name>* shall not include the * or # keypad codes. The sequence of keypad codes within *<product id>* shall not include the * or # keypad codes.

8.1.13 Manufacturer-specific Extensions

A manufacturer may define any extensions to HomeRF keypad code sequences that satisfy the following syntax.

Sequence: *<internal> * X * <manufacturer's name> * <product id> * <manufacturer-specific> #*

The sequence of keypad codes within *<manufacturer's name>* shall not include the * or # keypad codes. The sequence of keypad codes within *<product id>* shall not include the * or # keypad codes. The sequence of keypad codes within *< manufacturer-specific>* shall not include the # keypad code.

8.2 Switching between external calls

In a CP that supports multiple PSTN lines, it is recommended that the *Call Hold* supplementary service be used to switch between multiple external calls routed to a single I-node.

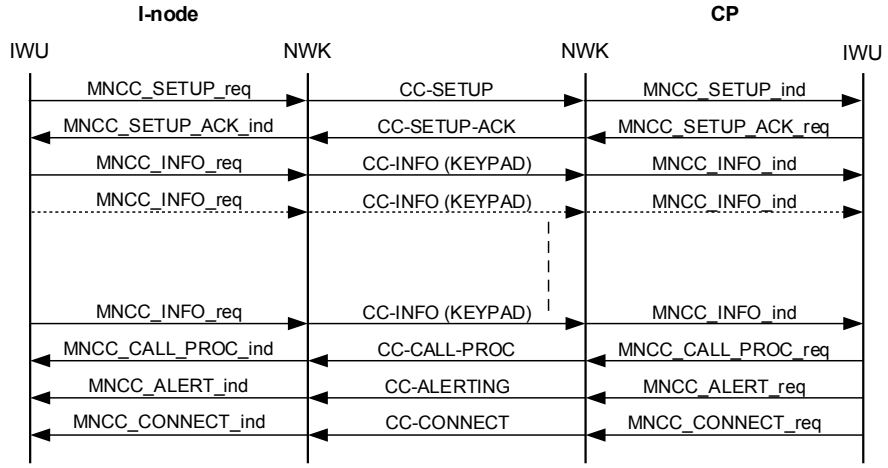
8.3 HomeRF IWU Procedures

8.3.1 Outgoing call

Definition: An outgoing call is a call initiated by the I-node. This can be any type of call as defined by DECT, including normal, internal and service calls.

The outgoing call establishment procedures are as defined in [6, section 9.3.1]

Figure 188 to Figure 191 show all the possible sequences of outgoing call related messages. Note that several more messages may be exchanged between the NWK peers, such as authentication messages. Definitions of messages, states and associated timers can be found in [6].



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Figure 188 - Connection Setup (1)

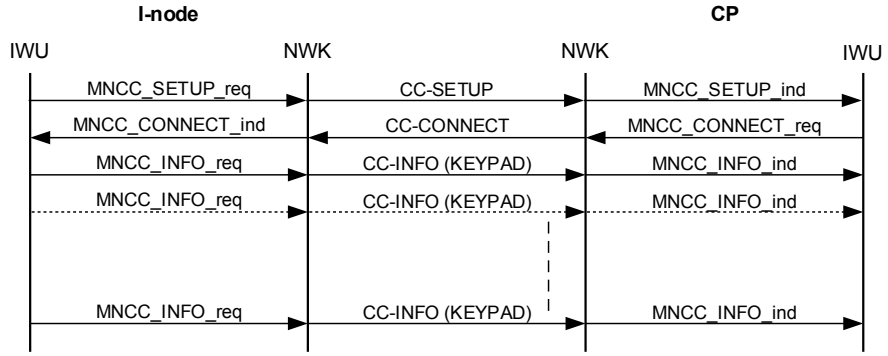


Figure 189 - Connection Setup (2)

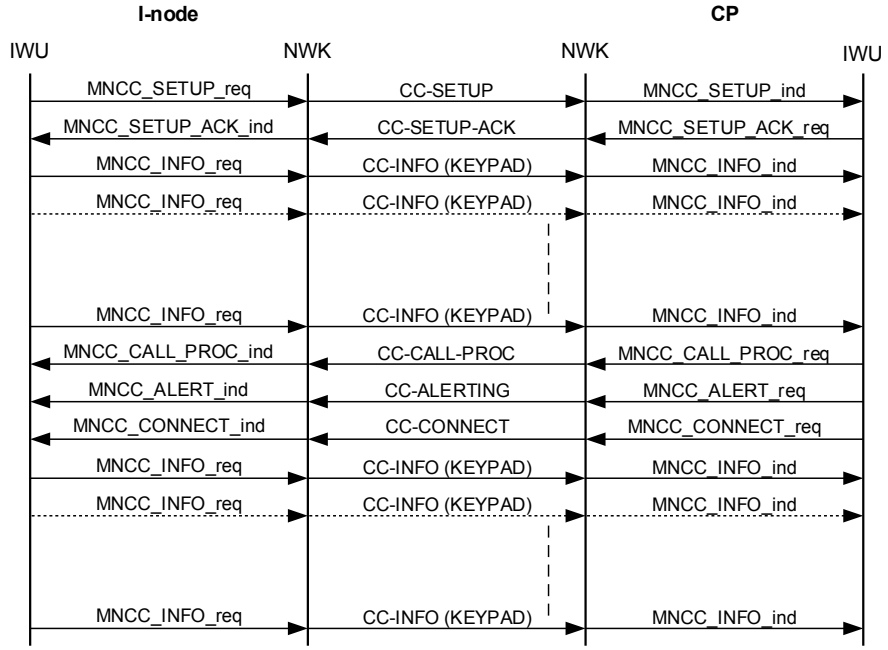
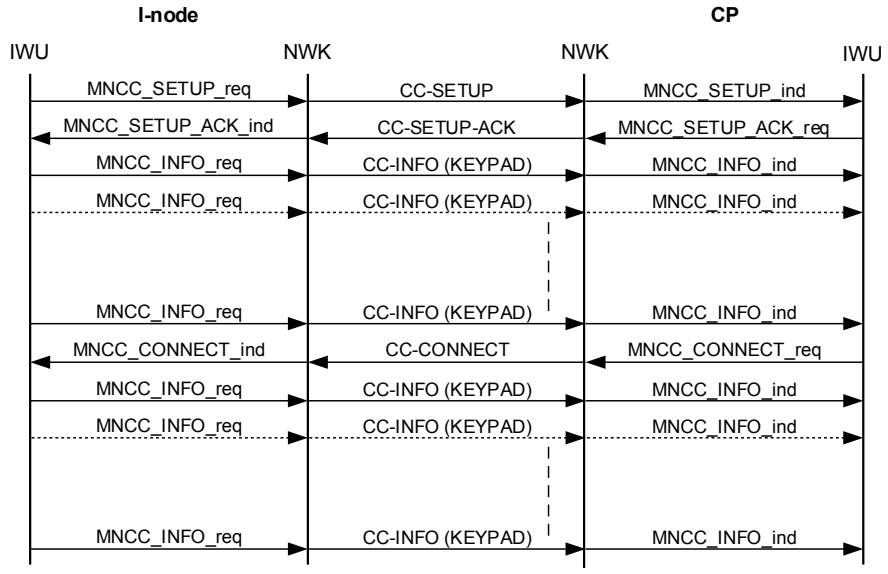


Figure 190 - Connection Setup (3)



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Figure 191 - Connection Setup (4)

8.3.2 Incoming call

Definition: An incoming call is a call initiated by the CP. The type of call is "normal call" as defined by DECT.

The incoming call establishment procedures are as defined in [6, section 9.3.2].

Figure 192 and Figure 193 show all the possible sequences of incoming call related messages. Note that several more messages may be exchanged between the NWK peers, such as authentication messages. Definitions of messages, states and associated timers can be found in [6].

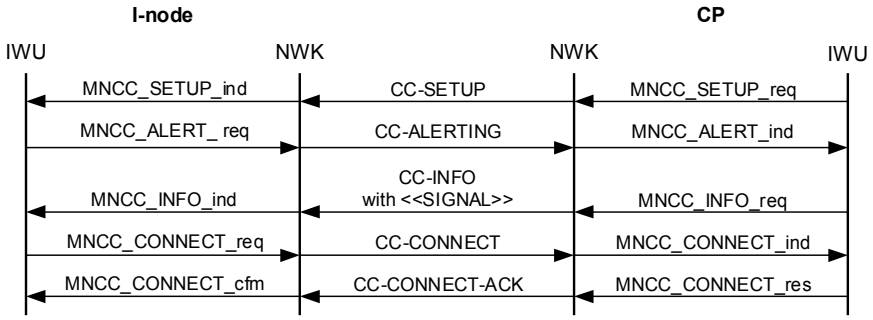


Figure 192 - Incoming Call Setup (1)

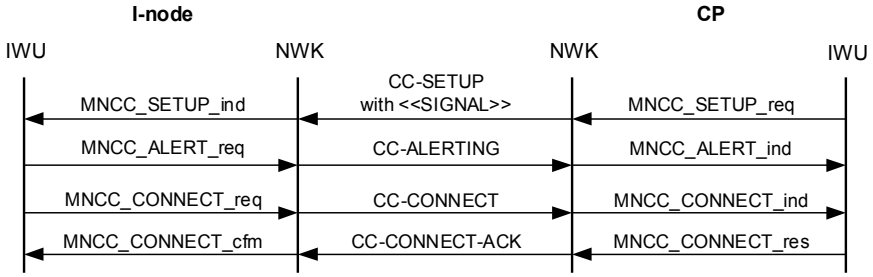


Figure 193 - Incoming Call Setup (2)

8.3.3 Group ringing

Definition: An incoming call results in a defined set (group) or all of the I-nodes in the HomeRF network to ring.

The procedure for collective and group ringing is as described in the DECT NWK specification [6, section 14.4]. The message structure and contents are as defined in section 8.2.1 of that same document ({LCE-REQUEST-PAGE} message), indicating MAC service type 001 (unknown & ringing). The 24-bit page message is carried by the HomeRF ICBS C-plane SDU.

If an implementation desires that defined sets of I-nodes ring, then a connectionless group TPUI must be obtained via the DECT Temporary Identity Assignment procedure [6, section 13.2.2].

8.3.4 Intercom call

Definition: A call between 2 users in the HomeRF network that does not make use of the (public) network.

The procedures for an internal call result from the combination of an outgoing (section 8.3.1) and incoming (section 8.3.2) call. Some restrictions apply to the call setup and keypad messages, see DECT-GAP [11], sections 8.18 and 8.19.

8.3.5 PC Call ("call Mom")

Definition: A call is set up using voice commands.

This call consists of the following four steps:

- A voice connection to the PC is set up from the I-node (see section 8.1.10 (Computer Call));
- Using a (set of) voice command(s), the PC is instructed to initiate an outgoing (normal or internal) call;
- The CP-IWU sets up the call as instructed by the PC;

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- The CP-IWU connects the I-node voice connection (previously connected to PC) to the new call.

8.4 Presentation of Call-related information

There are two choices when presenting call-related information to the user: to use DECT-defined specific elements such as <<CALLING-PARTY-NUMBER>>, or to use generic elements such as <<"DISPLAY">> and <<ALPHANUMERIC>>.

In the first case, the CP IWU and the I-node IWU both need to know that a <<CALLING-PARTY-NUMBER>> needs to be transferred and displayed. In the latter case, the CP IWU just treats the I-node as a "dumb" display.

In HomeRF the technique that is strongly recommended is to put the intelligence into the CP IWU, and to use the I-node as a display using either <<MULTI-DISPLAY>> or <<ALPHANUMERIC>> elements to convey call-related information.

The CP IWU should use a CLMS message to transport <<ALPHANUMERIC>> information relating to an incoming call during group/collective ringing.

The CP IWU should use a CC message to transport <<"DISPLAY">> information relating to a call once it is established.

8.5 IWU-IWU Signaling

A CP IWU and I-node IWU can exchange information using the MNCL_UNITDATA, MNCC_INFO and MNCC_IWU_INFO services.

In order to exchange Manufacturer-specific information, the manufacturer shall first obtain an *Equipment Manufacturer's Code*. Contact the HomeRF Technical Committee for EMC assignment requests.

Manufacturer-specific information should be encoded in <<IWU-TO-IWU>> elements using a *Protocol Discriminator* set to *User Specific*, a *Discriminator Type* set to *EMC*. Octets 5 and 6 shall contain the EMC.

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9 USER-INTERFACE PROCEDURES

9.1 Introduction (Informative)

The HomeRF specification has been designed for products that will operate in the home. This has resulted in procedures that maximize ease of use.

The most important simplifying concept used in adding nodes to a network is the Teach/Learn procedure. From the user's point-of-view, these will be initiated by two obvious buttons pressed simultaneously on the CP and I-node. [225]

To support network configuration where it is not convenient to press two buttons simultaneously, such as in a fixed installation of an A-node, these procedures allow for manual entry of the network ID (NWID). Because this is also an optional procedure for an I-node user, the limitations of the I-node user-interface place constraints on the presentation format for the NWID.

Table 269 summarizes the methods of NWID entry.

Table 269 - Methods for Obtaining an NWID

Method	At a CP	At an I-node	An A-node or S-node
NWID Signaling	The user issues the “Teach Network” or “Directed Teach Network” command.	The user issues the “Learn Network” command.	The user issues the “Learn Network” or “Directed Learn Network” command.
NWID manual entry	The user enters the NWID in presentation format at an installation program on the connected PC, or local user-interface The NWID is displayed in presentation format	The user enters the NWID in presentation format on a numeric keypad	The user enters the NWID in presentation format at an installation program on the connected PC, or local user-interface

If authentication or privacy are to be used, the I-node needs to acquire an AC from the user-interface of the CP.

The implementer is strongly encouraged to provide at the CP and A-node a *Setup Wizard* that guides the user through the installation and setup process.

9.2 User-Interface Requirements for each Node Type

Table 270 defines the required level of support that shall be provided by the different node types.

Table 270 - User Interface Requirements for each node type

Procedure	Reference	Class-1 CP	I-node	Class-2 CP	Class-3 CP	A-node	S-node
Teach HomeRF	9.3 (Teach Network Procedure)	M	X	M	M	C1	X
Learn HomeRF	9.4 (Learn Network Procedure)	X	M	O	O	O	O

[225] During development of this specification, this was described as the *Big Red Button*.

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Directed Teach HomeRF	9.5 (Directed Teach Network Procedure)	O	X	O	O	O	X
Directed Learn HomeRF	9.6 (Directed Learn Network Procedure)	X	X	O	O	O	O
Display NWID	9.7 (Presentation of the NWID)	M	O	M	M	O	O
Manual Entry of NWID	9.8 (Manual Entry of the NWID)	C6	C8	C6	C6	C7	C7
Display IEEE MAC Address	9.10 (Presentation of an IEEE MAC Address)	C4	X	C4, C5	C4, C5	C4, C5	C5
Manual Entry of IEEE MAC Address	9.11 (Manual Entry of an IEEE MAC Address)	C4	X	C4	C4	C4	X
Presentation of an AC	9.14 (Presentation of an AC)	C2	X	X	X	X	X
Manual Entry of the AC	9.15 (Manual Entry of the AC)	O	C2	X	X	X	X
Presentation of the Key	9.12 (Presentation of the Key)	C2	X	C2	C2	O	O
Manual entry of the Key	9.13 (Manual Entry of the Key)	C2	X	C2	C2	C2	C2
Presentation of the Extension Number	9.16 (Presentation of the Extension Number)	M	O	X	X	X	X
Removal of I-node	9.17 (Removal of I-node)	M	X	X	X	X	X
Notes	X - Not Permitted C1 - Mandatory if node is capable of operating in an ad-hoc network, otherwise optional. C2 - Mandatory if the node supports Encryption, otherwise not permitted C4 – Mandatory if the node supports Directed Teach HomeRF C5 – Mandatory if the node supports Directed Learn HomeRF C6 – Mandatory if the node supports Roaming C7 – Mandatory if the Learn HomeRF or Directed Learn HomeRF procedures are not supported C8 – Mandatory if the Learn HomeRF procedure is not supported						

9.3 Teach Network Procedure

A node that supports the *Teach Network* procedure shall provide on its user-interface a button or command labeled: "*Teach HomeRF*". This button should be prominent on the user-interface.

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When the *Teach Network* feature is operated, the node shall issue an MM_TEACH request to the MAC.[226] The MAC layer signals the *LearnNWID* state for a *LearnNWIDtimeout.* The user-interface entity can lengthen the effective duration of this state without limit by repeatedly generating MM_TEACH requests.

9.4 Learn Network Procedure

A node that supports the *Learn Network* procedure shall provide on its user-interface a button or command labeled: "*Learn HomeRF*". This button should be prominent on the user-interface. Some non-manual way of initiating this procedure is also permissible.

When the *Learn Network* feature is operated, the node shall issue an MM_LEARN request to the MAC.[227]

9.5 Directed Teach Network Procedure

A node that supports the *Directed Teach Network* procedure shall provide on its user-interface a button or command labeled: "*Directed Teach HomeRF*". This button should be prominent on the user-interface.

When the *Directed Teach Network* feature is operated, the node shall perform the manual entry of an IEEE MAC address to acquire the address of the node that the NWID is being directed to. See 9.11. The node will then issue an MM_DIRECTEDTEACH request to the MAC with the acquired address. The user-interface entity can lengthen the effective duration of this state without limit by repeatedly generating MM_DIRECTEDTEACH requests.

9.6 Directed Learn Network Procedure

A node that supports the *Directed Learn Network* procedure provides on its user-interface a button or command labeled: "*Directed Learn HomeRF*". This button should be prominent on the user-interface. Some non-manual way of initiating this procedure is also permissible.

When the *Directed Learn Network* feature is operated, the node shall issue an MM_DIRECTEDLEARN request to the MAC.[228]

9.7 Presentation of the NWID

This NWID presentation format shall be used whenever a NWID value is to be viewed or manually entered by the user. Some non-electronic form of presentation, such as a visible sticker, also meets the intent of this section when only viewing is required.

The 24-bit NWID is divided into 8 3-bit fields. These fields are represented as 2 groups of 4 BCD digits, separated by a space. Digit d0 is presented on the right and contains the least-significant bit of the NWID in its least significant position. Leading zeroes are not suppressed.

Figure 194 shows the mapping from NWID bits to displayed digits.

NWID bits	b0 (lsb)	b1	b2	b3	b4	b5	…	b21	b22	b23 (msb)
Displayed Digits	d0 (displayed rightmost)			d1			…	d7 (displayed leftmost)		

Figure 194 - NWID Presentation Format

[226] Causing it to transmit CP Beacons with the *Learn NWID* flag bit set.

[227] Causing it to look for CP Beacons with the *Learn NWID* flag bit set.

[228] Causing it to look for Directed Learn NWID MPDUs with its MAC address as the destination.

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Table 271 gives the mapping from BCD digits to the displayed character.

Table 271 - Mapping from BCD digits to Displayed Character

BCD digit bits (b0, b1, b2)	Displayed Character
0 0 0	0
1 0 0	1
0 1 0	2
1 1 0	3
0 0 1	4
1 0 1	5
0 1 1	6
1 1 1	7

In an I-node or Class-1 CP, the DECT PARK is derived from a NWID and so the DECT GAP procedures for entry of the PARK are superseded by this procedure.

9.7.1 Example of NWID Presentation Format (Informative)

The NWID represented by the hexadecimal number 0x123456 will be presented as "0443 2126".

9.8 Manual Entry of the NWID

A node that supports manual entry of the NWID shall permit the user to enter the NWID in the presentation format defined in 9.6 (Presentation of the NWID). A node may also meet the requirements of this section by supporting a way for the NWID to be downloaded to it.

9.9 Deriving the NWID from a MAC address

A node that derives a NWID from a MAC address shall do so using these procedures.

The 48-bit MAC address is split into two halves, and the two resulting 24-bit numbers are bitwise exclusive-ORed together to form the 24-bit NWID. Figure 195 illustrates this process.

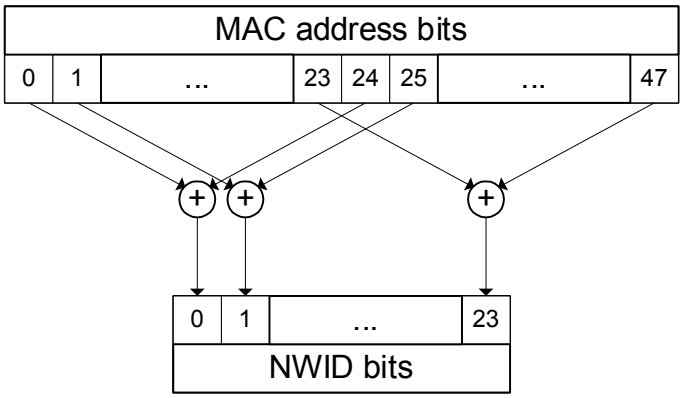


Figure 195 - Converting a MAC address to an NWID

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9.10 Presentation of an IEEE MAC Address

This IEEE MAC Address presentation format shall be used whenever an IEEE MAC Address value is to be viewed or manually entered by the user. Some non-electronic form of presentation, such as a visible sticker, also meets the intent of this section when only viewing is required.

The 48-bit IEEE MAC Address is divided into 16 3-bit fields. These fields are represented as 4 groups of 4 BCD digits, separated by a space. Digit d0 is presented on the right and contains the least-significant bit of the IEEE MAC Address in its least significant position. Leading zeroes are not suppressed.

Figure 194 shows the mapping from IEEE MAC Address bits to displayed digits.

IEEE MAC Address bits	b0 (lsb)	b1	b2	b3	b4	b5	…	B45	B46	B47 (msb)
Displayed Digits	d0 (displayed rightmost)			d1			…	d15 (displayed leftmost)		

Figure 196 - IEEE MAC Address Presentation Format

Table 271 gives the mapping from BCD digits to the displayed character.

9.10.1 Example of IEEE MAC Address Presentation Format (Informative)

The IEEE MAC Address represented by the hexadecimal number 0x123456789ABC will be presented as "0443 2126 3611 5274".

9.11 Manual Entry of an IEEE MAC Address

A node that supports manual entry of the IEEE MAC Address shall permit the user to enter the IEEE MAC Address in the presentation format defined in 9.10 (Presentation of an IEEE MAC Address).

9.12 Presentation of the Key

This section defines the format that a node shall use whenever a Key value is to be viewed or manually entered by the user. Some non-electronic form of presentation, such as a visible sticker, also meets the intent of this section when only viewing is required.

The n-bit key is divided into 3-bit fields. These fields are represented in groups of 4 BCD digits, separated by spaces. Digit d0 is presented on the right and contains the least significant bit of the key in its least significant position. Leading zeroes are suppressed.

Key bits	b0 (lsb)	b1	b2	b3	b4	b5	…
Displayed Digits	d0 (displayed rightmost)			d1			…

Figure 197 - Presentation Format for the Key

9.13 Manual Entry of the Key

A node that supports manual entry of the key shall allow entry of the key in the presentation format defined in 9.12 (Presentation of the Key).

The key shall be stored within the *Node Parameters* of the MIB.

9.14 Presentation of an AC

The procedure defined in the DECT GAP [11] section 14.2 shall be followed. Some non-electronic form of presentation, such as a visible sticker, also meets the intent of this section when only viewing is required.

9.15 Manual Entry of the AC

A node that supports manual entry of the AC shall permit the user to enter the AC in the format defined in 9.14 (Presentation of an AC).

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9.16 Presentation of the Extension Number

A node that supports presentation of the extension number and that has performed a location registration shall display the TPUI thus obtained for the I-node using the format defined in this section.

The TPUI shall be interpreted as an unsigned number and displayed as a decimal number, with leading zeroes suppressed.

9.17 Removal of I-node

A Class-1 CP shall support a user command that removes either a selected I-node, or all I-nodes from its subscription database.

9.18 Node Installation Support

A node that is connected to or is part of a PC should provide an interactive program [229] running on the PC that guides the user through the procedures defined in Table 272, depending on node type.

Table 272 - Node Installation Procedures

Node Type	Procedures Supported
Class-1 CP	Adding an I-node (Signaling *LearnNWID*, presentation and entry of the AC, display of extension number) Removing an I-node Adding an A-node (Signaling *LearnNWID* and presentation of NWID, presentation and entry of the key)
Class-2 CP	Adding Class-2 CP to an existing network (LearnNWID and manual entry of NWID. Manual entry of key) Adding an A-node (Signaling *LearnNWID* and presentation of NWID, presentation and entry of the key)
Class-3 CP	Adding Class-3 CP to an existing network (LearnNWID and manual entry of NWID. Manual entry of key) Adding an A-node (Signaling *LearnNWID* and presentation of NWID, presentation and entry of the key)
A-node	Adding an A-node to an existing network (LearnNWID and manual entry of NWID. Manual entry of key, support for ad-hoc operation) Adding another A-node (Signaling *LearnNWID* and presentation of NWID, presentation and entry of the key)

[229] Under the Windows operating systems, this is generally called a *Wizard*.

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10 ISOCHRONOUS NODES (I-NODES)

This section defines the procedures that are specific to an I-node.

10.1 Introduction to I-nodes (Informative)

An *Isochronous Node* (I-node) is a HomeRF device that uses the isochronous connection-oriented services of the On-Air stack to communicate with a Connection-Point.

The isochronous data-stream usually contains full-duplex 32-kbps ADPCM encoded speech. The most likely I-node product is a HomeRF cordless handset although combined AI-nodes are also possible.

10.2 I-node User-interface

The I-node shall provide a user-interface through which the mandatory user-interface procedures (defined in section 9.2 (User-Interface Requirements for each Node Type)) are supported. [230]

10.3 Moving an I-node Between Networks

The DECT GAP requires a handset to maintain two subscription records.

An I-node shall store at least one subscription record. An I-node should store at least two subscription records. [231]

When scanning for a network, an I-node can scan for any network in its subscription database. The network is identified by the PARK that is derived from the CP NWID. Refer to section 6.5 (Mapping HomeRF Identities to DECT Identities).

10.4 Management Procedures

10.4.1 I-node Learn HomeRF Management

When the user issues a “Learn HomeRF” command, the I-node shall operate the MAC-level procedures described in section 5.16.7 (Scanning for a New Network). This builds a list NWIDs of Class-1 CPs that are currently signaling “Teach Network”.

If the I-node encounters a single network signaling “Teach Network”, it shall then perform the procedures defined in section 5.16.12 (Scanning for a set of Known Networks (I-node only)) to synchronize with the network.

If the I-node encounters multiple networks signaling “Teach Network”, it shall select between these in an implementation-dependant way. [232]

If an I-node learns no NWIDs, it can behave in an implementation-dependent way. [233]

10.4.2 Joining a Known Network

In order to join a known network, an I-node shall scan for and synchronize to the network using the MAC-level procedures described in section 5.16.12 (Scanning for a set of Known Networks (I-node only)), based on the CP address of the required network.

If the I-node does not have a DECT subscription record for the known network, it shall perform the DECT GAP subscription registration procedures.

If the I-node supports authentication, this may require the entry of an authentication code (AC) through the I-node’s user-interface. This AC can be viewed at the Class-1 CP’s user-interface.

The I-node should use this AC to obtain a user access key (UAK) which it stores in the subscription record, and which will be used for subsequent authentication responses. The I-node shall not store the AC within its subscription record.

When the I-node has subscribed, it shall perform the DECT location registration procedure to obtain a TPUI. If the I-node is capable, the TPUI shall be displayed on its user-interface as the I-node “extension number”. [234]

---

[230] This can be a keypad and LCD display (handsets), but can be much less in the case of very low cost HomeRF devices.

[231] In order to avoid repeated user entry of the AC when moving an I-node between HomeRF networks.

[232] For example, based on its subscription database.

[233] Typical response may be to prompt the user to enter a specific network ID, to inform the user that no network can be found, to prompt the user to press “Teach Network” at the CP.

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Additionally, one or more group TPUIs can be assigned to an I-node at the CP by the DECT Temporary Identity Assignment procedure [6, section 13.2.2].

10.4.3 Loss of Network Connectivity (Informative)

The MAC layer can indicate that it has lost connectivity with the network by issuing an MM_LOST indication (see section 5.2.5.7 (MM_LOST Primitive)).

The effect of this on the I-node is specific to the implementation. For example, the I-node may scan from time to time for known networks for a fixed period, and then to switch off.

10.4.4 Power Management

Depending on the state of association of the I-node to the network, an I-node can save power as defined in Table 273.

An I-node is not required to perform any power-saving management procedures.

Table 273 - I-node Power Management

State	Power-Management
Switched Off	Nothing need be powered-on, except the user-interface to leave the *Off* state.
In the *Idle* Synchronization State	Implementation dependent
In the *Scanning* Synchronization State	Fully-powered on
In the *Managed* Synchronization State	Refer to section 5.20.5 (I-node Power-Saving)

If an I-node is also an AI-node, then it is required to be awake at times defined by the A-node power-saving procedures described in section 5.18 (A-node Power-Management and Power-Saving).

10.5 DECT Identities at the I-node

The following table describes what DECT identities are held within the I-node, and how they are obtained.

Refer to DECT Part 6: Identities and Addressing [7] for a definition of the DECT identities.

DECT Identifier	Description
IPUI *Individual Portable Unit Identifier*	Derived from the I-node's MAC address. See section 6.5.1 (Mapping MAC Address to IPUI). Globally unique and constant.
TPUI *Temporary Portable Unit Identifier*	Assigned by the CP during location registration. Shall only be retained while the I-node is in the *Managed* synchronization state.
PARK *Portable Access Rights Key*	Derived from the CP NWID. (See section 6.5.2 (Mapping CP Address to PARK)) There will be one PARK for each record in the subscription database.
AC *Authentication Code*	Entered by the user during subscription. Shall not be retained beyond the subscription procedure.
UAK	Derived during subscription from the AC.

234 The CP will keep the mapping of TPUI to I-node constant.

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User Access Key	There can be one UAK for each record in the subscription database.

10.6 Non-Voice I-node

It is permitted for an I-node to use the isochronous 32-kbps U-plane service to carry payloads that are not ADPCM-encoded speech.

All I-nodes shall provide the DECT DLC, NWK and IWU functionality, as profiled by the DECT GAP [11] and modified here. An I-node can implement additional DECT procedures and signaling (such as defined in another DECT profile), provided that they can be supported on a single full-duplex 32-kbps MAC-level connection of DECT U-plane Class 0.

This specification does not describe any other uses of the isochronous data service. [235]

10.7 I-node Mandatory and Optional Features

Table 274 defines the HomeRF features that are required by an I-node.

Refer to section 9.2 (User-Interface Requirements for each Node Type) for the requirements on the I-node user-interface.

Table 274 - I-node Mandatory and Optional Features

Item	**Reference**	**I-node Requirement**
MB-SAP service	5.15.2 (MB-SAP Procedures at the I-node)	M
MC-SAP service	5.14 (MC-SAP Services)	M
Learn HomeRF Management	10.4.1 (I-node Learn HomeRF)	M
Authentication	15.4 (HomeRF Authentication)	C1
Encryption	5.20.6 (TDMA Encryption)	O
Multiple Subscription Records	10.3 (Moving an I-node Between Networks)	O
Power Saving	10.4.4 (Power Management)	O
Voice Stack	7 (Voice Stack and On-Air Voice Processor)	C2
DECT GAP	[11]	G
Intercom Call	8.1.3 (Intercom Call)	C2
Call Hold	8.1.4 (Call hold)	O
Call Transfer	8.1.5 (Call transfer)	O
Call Forward	8.1.6 (Call forward)	O
Remote Off-Hook	8.1.7 (Remote off-hook (babycom))	O
Voice Connection to PC	8.1.10 (Computer Call)	C2
Silent Polling	8.1.11 (Silent polling)	O
Communicating Manufacturer name and Product ID	8.1.12 (Communicating manufacturer name and product ID)	O
Manufacturer-specific Extensions	8.1.13 (Manufacturer-specific Extensions)	O
CLMS Procedures	6.2.1.2 (CLMS Procedures)	O

[235] Companies interested in standardizing other isochronous services should propose them to the HomeRF Working Group, Inc. for consideration.

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Item	Reference	I-node Requirement
Voice Announcement	6.2.1.4 (Voice Announcement)	O
Notes:	M - Mandatory O - Optional C1 - Mandatory if I-node supports encryption C2 - Mandatory if the I-node supports voice G - As defined by the DECT GAP and profiled in this specification	

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11 ASYNCHRONOUS NODES (A-NODES) AND BRIDGING

11.1 Introduction (Informative)

An A-node is defined in this specification to mean a HomeRF node that implements the asynchronous data service (MD_DATA) provided through the MD-SAP. An A-node is likely to be a data-networking client in the traditional networking sense of such devices.

The underlying HomeRF MAC and PHY layers, by using packets formats related to Ethernet provide the asynchronous data service in a form that can be mapped straightforwardly to an Ethernet frame.

Today, most manufactures supply networking drivers for an operating system specific to their hardware, such as NDIS drivers for the Windows environment. The HomeRF MAC and PHY continue to support this model. A HomeRF networking driver can register as an Ethernet driver thereby permitting existing protocol stack to attach to the HomeRF driver.

The attributes of the asynchronous data service have been designed to support conventional networking protocols such as TCP/IP and IPX. This does not imply that other protocols are not supported. In fact the HomeRF MAC and PHY layers are not constrained to any specific protocol. This was done to provide implementers the utmost flexibility in their designs.

A HomeRF bridge is an A-node or CP that supports the procedures defined in section 11.6 (Bridging Layer Procedures). It provides bridging of asynchronous data between networking protocol stacks just about the MAC (or link) layer.

11.2 MD-SAP Services

An A-node shall support the MD-SAP services defined in 5.12 (MD-SAP Service).

11.3 A-Node Management

An A-Node shall be able to configure the following managed objects within the HomeRF MIB (defined in section 16 (The HomeRF MIB)):

- The network ID (NWID)
- The encryption key (if supported)
- Compression settings (if supported)
- Power management settings (if supported)

Capabilities of the specific hardware, such as supported data rates, should be available.

The A-node should provide its driver access to the Management Information Base, defined in section 16 (The HomeRF MIB).

The initialization of an A-node that is acting as a network client, given a Network ID, should cause the MAC to either join or start a HomeRF network. A-nodes that are acting as other kinds of device can save power by declining to start an ad-hoc HomeRF network.

11.4 A-node User-interface

The A-node shall provide a user-interface through which the mandatory user-interface procedures are supported.

Refer to section 9.2 (User-Interface Requirements for each Node Type) for the requirements on the A-node user-interface.

11.5 Application Layer (Informative)

A wide variety of networking applications will be implemented using the HomeRF data-networking services. These applications could include traditional server functions such as file and printer sharing or a simple data acquisition.

The specification of the operation any application that is a client of the asynchronous data service is outside the scope of this specification. The HomeRF MAC and PHY layers do not make any assumptions concerning the operation of higher-layer protocols.

However, it is recommended that such applications are *well behaved*. A well-behaved application must not interfere with other applications using the asynchronous data service - such as traditional network stacks. This can be accomplished by adopting a well-known protocol, such as TCP/IP or IPX. By the use of a well known-port (TCP/IP) or an assigned socket (IPX) the possibility that a data packet might be incorrectly interpreted by another application is removed.

11.6 Bridging Layer Procedures

An A-node or CP that supports bridging is called a HomeRF bridge (HB). A HB shall support the procedures defined in this section.

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11.6.1 Introduction to Bridging (Informative)

The MD-SAP provides a data service that hides the details of HomeRF source-routing within the MAC layer. To the bridge above the HomeRF port, it appears to like the other ports as regards the characteristics of its DATA service.

A HomeRF bridge (HB) receives at the top of each protocol stack. In the case of the non-HomeRF ports, it receives promiscuously. The behavior defined in these sections refers to the *Bridging Layer* that sits above the multiple ports and below the higher networking protocol layers.

11.6.2 Bridging Table

A HB maintains a *Bridging Table* that contains a number of bridging records. The fields of this record are described in Table 275. The number of these records should be no less than 4.

Table 275 - Bridging Record Fields

Field	Description
Address	IEEE MAC address
Port	Port through which that MAC entity may be reached

When the Bridging Layer receives a DATA indication from any of its ports, it shall ensure that there is an entry in the *Bridging Table* for the source address and port from which the MSDU was received.

11.6.3 Avoiding Bridging Loops

The HB shall avoid bridging loops[236]. The HB should run the 802.1D spanning-tree algorithm [15]. [237]

Each port has a *Port Control* state that takes values: *Enabled* and *Disabled*. In the absence of any bridging loops, all ports will be in the *Enabled* state. In the presence of a bridging loop, the spanning-tree algorithm selects ports to disable to remove the bridging loop.

11.6.4 Bridging Unicast MSDUs

The HB shall act as defined in Table 276 on receipt of a MD_DATA indication from a port (the originating port) that carries a unicast destination address.

Table 276 - Bridging Unicast MSDU Actions

Condition	Action
The destination address addresses the local MAC entity	Pass the indication up to higher layers
The destination address is not associated with a port in the *BridgeDatabase*	Pass the indication on as an MD_DATA request to each *Enabled* port
The destination address is associated with a port in the *Bridge Database* and the indication was received from some other port	If the associated port is *Enabled*, pass the indication on to it as an MD_DATA request. Otherwise, discard the indication.
The destination address is associated with a port in the *Bridge Database* and the indication was received from that port	Discard the indication

[236] These would otherwise bring down the network.

[237] This algorithm avoids bridging loops by disabling ports. If this algorithm is not used, an alternative manufacturer-specific mechanism for avoiding bridging loops will be necessary.

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11.6.5 Bridging Multicast MSDUs

A multicast MD_DATA indication should be passed to higher layers and passed to each enabled port (except the originator) as an MD_DATA request.

The bridging layer can choose not to pass the request on to a HomeRF port according to implementation-defined criteria. [238]

[238] The reason for this statement is that a HomeRF bridge that is bridging between a wired technology and HomeRF might receive multicast traffic from the wired port at a rate higher than the capability of the HomeRF network. Note that HomeRF multicast bandwidth can be reduced (halved) by the operation of the CP multicast power-supporting procedures. A HB product could distinguish between multicast TCP/IP protocol packets (such as ARP), which it would transmit, and (for example) multicast streaming multimedia packets that it could selectively discard according to network load and local buffer space.

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12 CONNECTION POINT DEVICES

12.1 Introduction (Informative)

A Connection Point (CP) is a HomeRF device that provides management of a HomeRF network, and can provide (depending on its class) a connection between the On-Air interface, the public telephone network and a personal computer.

When a Connection Point is present, the network operates as a managed network. The Connection Point can also (depending on its class) manage the allocation of TDMA time slots thereby providing contention free access to the medium for isochronous data.

If there is more than one CP in a network then one CP is automatically designated the Active Connection Point and all other CPs operate as Passive Connection Points. The MAC-layer CP negotiation procedures (section 5.17.8 (Connection Point Negotiation)) ensure this behavior.

A Connection Point is also required to support Power Management services. A-nodes and passive Control Points can use Power Management services. An active Connection Point cannot itself use the Power Management services.

Note that there can only ever be one Class-1 CP in a network. A Class-1 CP is always the active CP.

For further details of the CP architecture, refer to section 3.5.5 (CP Architecture).

12.2 CP User-Interface

A CP shall support the operation of all mandatory User Procedures defined in section 9.2 (User-Interface Requirements for each Node Type).

A separate CP may divide its mandatory user-interface between a local user-interface (such as a keypad and LCD display) and a Management user-interface application running on the Host PC.

A separate CP, while disconnected from its Host PC, need not provide any user-interface. Refer to section 12.7 (CP Requirements).

12.3 CP Configuration

Table 277 defined procedures that shall be followed to configure the CP.

Table 277 - CP Configuration Procedures

Parameter	Configuration Procedure
IEEE MAC address	Shall be configured by the manufacturer prior to distribution. Manufacturers shall use a globally unique identifier based on a manufacturer's ID allocated to them by the IEEE.
NWID (Network ID)	A CP shall allow the user to specify a NWID. The default value for the NWID shall be the NWID derived from its IEEE MAC address as defined in section 9.9 (Deriving the NWID from a MAC address)

12.3.1 Retained CP Configuration

The CP configuration parameters shall be retained by the CP that is disconnected from the power supply or switched off.

12.4 DECT Subscription Database

A Class-1 CP shall keep a DECT subscription database holding a subscription record[239] for each subscribed I-node. The CP shall support at least *NumMinSubscriptions* records in the database.

A CP that supports I-node authentication and encryption shall support one or more ACs. There is typically either a single global AC, or one AC per subscription.

[239] The contents of the subscription record are defined by the requirements of the DECT protocol and are not described here.

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12.5 Extension Numbers

This section defines the use of *Extension Numbers* within a Class-1 CP. An *Extension Number* is an individual TPUI interpreted as an unsigned number.

When a record is added to the DECT subscription database, the CP shall allocate a TPUI. The CP should allocate TPUIs that correspond to small numbers (preferably single-digit).

When an I-node performs location registration, the CP shall provide it the TPUI that it has allocated to it in the subscription database.[240]

12.6 CP-PC Interface

The PC interface connects the software (firmware) components that are part of the CP equipment to software components within the PC.

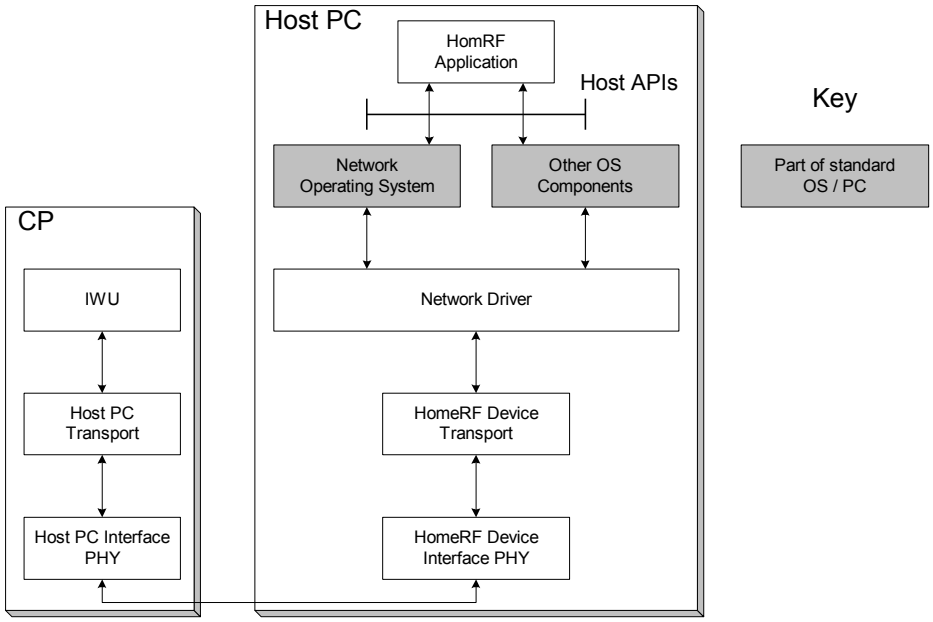


Figure 198 - CP-PC Architecture

The exported boundary of the CP is considered to be the standard functionality exported through standard Host APIs. Note that the details of the architecture of the OS layers depend on the OS supported.

The software interface at the top of the network driver is whatever is required by the operating system to provide the required level of functionality through the Host APIs. Refer to 14.5 (Isochronous Data Interface of a Class-1 CP).

12.6.1 Class-1 CP IWU Operating Modes

A Class-1 CP IWU operates in one of three modes defined in Table 278.

Table 278 - CP Operating Modes

Mode	Description
Standalone	The CP is not connected to a PC.[241]
Autonomous	The CP is connected to a PC. The CP responds to incoming call-setup indications. The CP permits a HomeRF application to make call-setup

[240] This ensures that the mapping of I-node identity to extension number remains constant as long as the I-node exists in the subscription database at the CP.

[241] For example, in a *Separate* CP, a PC is not configured, or the PC is switched-off, or the connection between the CP and PC has been removed.

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	requests.
Slave	The CP is connected to a PC. All incoming call-setup indications are routed to the HomeRF application.

12.6.2 Functionality exported through Host APIs (Informative)

In *Standalone* mode, clearly the Class-1 CP is responsible for operating all required procedures.

In *Autonomous* mode, the Class-1 CP continues to be responsible for operating required procedures, such as incoming and outgoing calls. However, the Class-1 CP also permits a host application, through the Host APIs to access resources within the Class-1 CP and to originate calls.

In *Slave* mode, the Class-1 CP relies on one or more applications running on the Host PC to provide required HomeRF behavior relating to call-setup, such as answering and then routing incoming calls.

12.6.3 Role of CP-PC Physical Interface (Informative)

The form of the physical interface is irrelevant. The drivers in the PC and the IWU in the CP can communicate over the physical interface using any suitable encoding.

On the host PC, access to the physical device is likely to go through a standard OS driver.

There is no requirement for any particular physical interface, provided that the required functionality is available at the Host APIs.

12.7 CP Requirements

12.7.1 Class 1 CP Requirements

Class-1 CP shall support all mandatory items defined in Table 279, depending upon its current operating mode.

Table 279 - Class-1 CP Requirements

Item	**Reference**	**CP Operating Mode**		
		Standalone	**Autonomous**	**Slave**
Call pickup conferencing	8.1.8 (Pickup conferencing)	M, 2	M, 2	MA, 2
Intercom conferencing	8.1.9 (Intercom conferencing)	O	O	O
Intercom call	8.1.3 (Intercom Call)	O	M	MA
Outgoing call	8.3.1 (Outgoing call)	M	M	MA
Incoming call	8.3.2 (Incoming call)	M	M	MA
MB-SAP services	5.15 (MB-SAP (ICBS) Service)	M	M	M
MC-SAP services	5.14 (MC-SAP Services)	M	M	M
MD-SAP services	5.12 (MD-SAP Service)	M	M	M
MS-SAP services	5.13 (MS-SAP Service)	O	O	O
I-node Authentication	15.4 (HomeRF Authentication)	MU	MU	MU
TDMA Encryption	5.20.6 (TDMA Encryption)	MU	MU	MU
MD-SAP Encryption	5.12.5 (MD-SAP Encryption Layer)	MU	MU	MU

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Item	Reference	CP Operating Mode		
		Standalone	Autonomous	Slave
Unicast Power-Management support	5.18.7.3 (CP Unicast Power-Management Service) and 5.18.7.5 (CP Unicast Power-Supporting)	M	M	M
Multicast Power-Management support	5.18.8 (Multicast Power-Saving)	M	M	M
Number of PSTN lines		> 0	> 0	> 0
Voice Stack	7 (Voice Stack and On-Air Voice Processor)	M	M	M
CP Assertion	5.17.8 (Connection Point Negotiation)	M	M	M
Hold	8.1.4 (Call hold)	O	O	O
Call Transfer	8.1.5 (Call transfer)	O	O	O
Call Forward	8.1.6 (Call forward)	O	O	O
Remote Off-hook	8.1.7 (Remote off-hook (babycom))	O	O	O
Voice connection to PC ("Computer call")	8.1.10 (Computer Call)	X	M	M
Silent Polling	8.1.11 (Silent polling)	O	O	O
Manufacturer Extensions	8.1.13 (Manufacturer-specific Extensions)	O	O	O
Product ID	8.1.12 (Communicating manufacturer name and product ID)	O	O	O
CLMS Procedures	6.2.1.2 (CLMS Procedures)	O	O	O
Voice Announcement	6.2.1.4 (Voice Announcement)	O	O	O
Notes:	M - Mandatory MU - Support for encryption is mandatory if the CP is intended for use in USA MA - Mandatory support is required within a HomeRF application that places the CP into *Slave* mode O - Optional 2 - The CP shall support at least 2 I-nodes conferenced onto a single external PSTN line X - not possible			

Refer to section 9.2 (User-Interface Requirements for each Node Type) for the requirements on the Class-1 CP user-interface.

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12.7.1.1 Mandatory Requirement of a HomeRF Application

A HomeRF -aware application that leaves the CP IWU in its *Autonomous* mode can place outgoing PSTN and I-node calls, can connect them together in any fashion supported by the CP hardware. There are no mandatory requirements on the operation of this application.

A HomeRF application that switches the CP IWU to its *Slave* mode shall provide all the mandatory requirements of the CP *Slave* mode defined in 12.7.1 (Class 1 CP Requirements).

12.7.1.2 Requirements for continued service based on PC power transitions

A Class-1 CP shall provide all the mandatory features of the *Standalone* operating mode, without any additional user intervention in all the following cases:

- When a host PC is not part of the configuration
- While the host PC is powered-down
- After a host PC power-up transition
- After a host PC power-down transition

12.7.2 Class-2 CP

The following table defines the features that a Class-2 CP shall provide or the procedures that it shall operate.

Table 280 - Class-2 CP Requirements

Item	Reference	Class-2 CP Requirement
MD-SAP services	5.12 (MD-SAP Service)	M
MS-SAP services	5.13 (MS-SAP Service)	O
Unicast Power-Management support	5.18.7.3 (CP Unicast Power-Management Service) and 5.18.7.5 (CP Unicast Power-Supporting)	A
Multicast Power-Management support	5.18.8 (Multicast Power-Saving)	A
CP Assertion	5.17.8 (Connection Point Negotiation)	M
MD-SAP Encryption	5.12.5 (MD-SAP Encryption Layer)	MU
Notes:	M - Mandatory when switched on MU - Support for encryption is mandatory if the CP is intended for use in USA A - Mandatory when acting as an Active CP, not allowed otherwise.	

Refer to section 9.2 (User-Interface Requirements for each Node Type) for the requirements on the Class-2 CP user-interface.

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12.7.3 Class-3 CP

The following table defines the features that a Class-3 CP shall provide or the procedures that it shall operate.

Table 281 – Class-3 CP Requirements

Item	Reference	Class-3 CP Requirement
MD-SAP services	5.12 (MD-SAP Service)	M
MS-SAP services	5.13 (MS-SAP Service)	M
CP Assertion	5.17.8 (Connection Point Negotiation)	M
MD-SAP Encryption	5.12.5 (MD-SAP Encryption Layer)	MU
Notes:	M - Mandatory when switched on MU - Support for encryption is mandatory if the CP is intended for use in USA A - Mandatory when acting as an Active CP, not allowed otherwise.	

Refer to section 9.2 (User-Interface Requirements for each Node Type) for the requirements on the Class-3 CP user-interface.

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13 STREAMING NODES (S-NODES)

13.1 Introduction (informative)

S-nodes in the HomeRF specification refer to any node that implements the Priority Asynchronous Data Service through the MS_SAP. S-nodes will generally be devices capable of streaming various forms of media (i.e. audio and video).

13.2 MS-SAP

An S-node shall support the MS-SAP services defined in section 5.13 (MS-SAP Service).

13.3 S-Node Management

A S-node shall function as an A-node and must be able to configure the following managed objects within the HomeRF MIB (defined in section 16):

- The network ID (NWID)
- The encryption key (if supported)
- Compression settings (if supported)
- Power management settings (if supported)

Capabilities of the specific hardware, such as, supported data rates should be available.

The S-node should provide its driver access to the Management Information Base, defined in section 16.

The initialization of an S-node that is acting as a network client, given a Network ID, should cause the MAC to either join or start a HomeRF network.

13.4 S-Node User Interface

The S-node shall provide a user-interface through which the mandatory user-interface procedures are supported.

Refer to section 9.2 (User-Interface Requirements for each Node Type) for the requirements on the S-node user interface.

13.5 Application Layer (Informative)

It is pressuemd that the application layer used in conjunction with the S-node data services, will either be a client or server device involved in the streaming or reception of streaming media (i.e. Audio and Video).

The specification of the operation of any application that is a client of the priority asynchronous data service is outside the scope of this specification. The HomeRF MAC and PHY layers make no assumptions regarding the operation of higer layer protocols. An exception to this is in regards to the priority of the stream. The application layer of any given streaming node will most likely require the ability to give a priority label to a given stream, as well as have the ability to separate this traffic from other non-priority traffic.

It is recommended that applications be well behaved. This can easily be accompilished by using existing protocol stacks that support streaming media, such as RTP/UDP/IP. In certain operating systems, priorities will need to be mapped into HomeRF using IEEE 802.1D. This is further discussed in section 5.4.8.1.1.2 (Priority field.)

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14 MICROSOFT ® WINDOWS ® INTERFACES

14.1 Note (Informative)

This section of the specification is not intended as a comprehensive guide to implementing HomeRF software. A working knowledge of NDIS, TAPI, and DirectShow™ is assumed. For more information on these subjects, please consult the Microsoft Platform Software Development Kit. [242]

This section defines requirements on HomeRF driver developers using the Microsoft Platform Software Development Kit.

14.2 Architecture

A HomeRF node connected to a PC exposes three distinct types of interfaces: *Asynchronous Data*, *Isochronous Data* and *Management*.

The properties of the asynchronous data interface corresponds closely to a network interface card. The MAC MD-SAP services can be exposed through a conventional network driver. This is described in section 14.3 (HomeRF Support for Asynchronous Data in Microsoft Windows).

A driver interface for isochronous data is only defined for the case of the Class-1 CP. The properties of the *Class-1 CP IWU* interface are unlike any existing device, but closest to the functionality supported by telephony devices. Section 14.5 (Isochronous Data Interface of a Class-1 CP) describes support for the Class-1 CP IWU. A CP that is physically distinct from a PC is required to support a basic level of functionality if disconnected from the PC (see section 12.7 (CP Requirements)).

This specification does not define the isochronous data interface for an I-node connected directly to a PC. An I-node is normally a stand-alone product (such as a cordless handset). A manufacturer may choose to connect an I-node to a PC and export the I-node end-user functionality through any applicable APIs. A manufacturer can implement an I-node interfaced to a host device in any suitable way. This document does not specify any aspects of that interface. Neither does it specify the operating system on the host device.

An A-node or CP driver will also support a private management interface that permits access to the MIB defined in section 16 (The HomeRF MIB). Because there is no requirement for support through a standard OS API, this is not described further in this section.

Table 282 - Status of Exported Driver Interface by HomeRF Node Type

HomeRF Node Type	**Exported Driver Interface**		
	Asynchronous Data	**Isochronous Data**	**Private Management**
A-node	S		P
Class-3 CP	S		P
Class-2 CP	S		P
Class-1 CP	S	S	P
I-node		U [243]	U
Notes:	S - Present as defined in this document P - Will exist, but the form of the interface is private to the implementation, and is not specified in this document U - Unlikely to exist, not specified in this document		

Figure 199 illustrates these three types of interface.

[242] The Microsoft Platform Software Development Kit, TAPI, and DirectShow are not incorporated by reference into this specification, and no license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted thereto.

[243] An I-node can be interfaced to a PC. This specification does not require any particular interfaces to be supported. Any applications interfacing to an I-node directly do so using application-specific interfaces.

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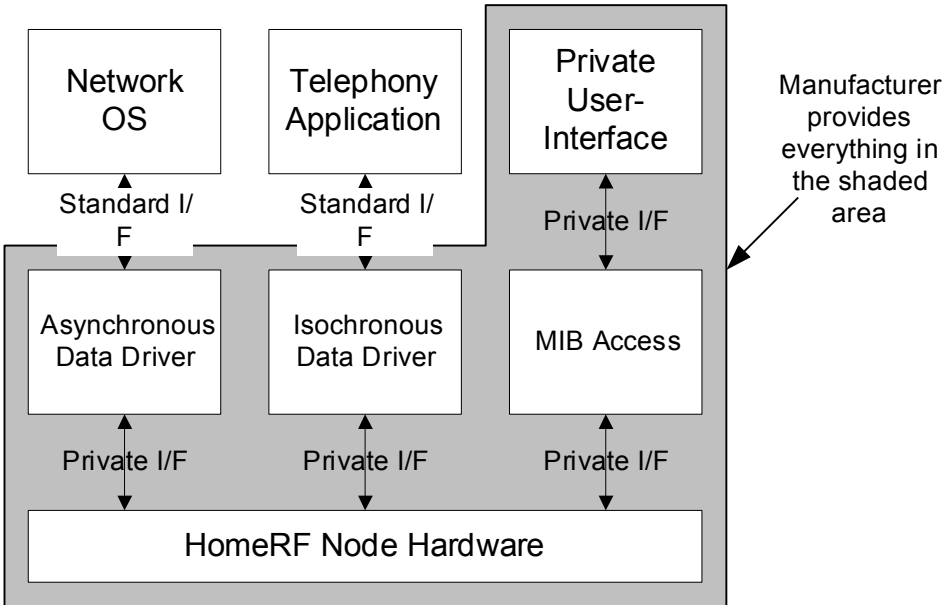


Figure 199 - HomeRF OS Interface Components

14.3 HomeRF Support for Asynchronous Data in Microsoft Windows

HomeRF nodes that support the MD-SAP services should interface with Microsoft Windows operating systems through the NDIS library. [244] This device-specific code is exposed to NDIS as a *miniport* driver.

HomeRF asynchronous data miniport drivers should expose a connectionless NDIS interface and should declare themselves as members of the Ethernet (IEEE 802.3) media type. This will allow these nodes to appear as Ethernet adapters to higher level protocols, and thus enable applications designed to function over Ethernet to operate over the HomeRF network without further changes.

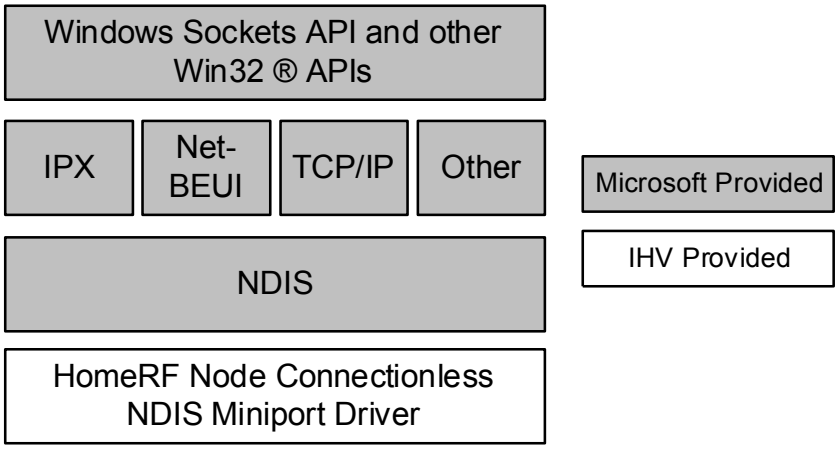


Figure 200 - HomeRF MD-SAP Services OS Architecture

Windows 2000, Windows NT 4.0, Windows 98, Windows 95, and Windows CE (version 2.0 and subsequent) all incorporate NDIS. It is possible to write a single connectionless miniport driver that is binary compatible with Windows 2000, Windows NT 4.0, Windows 98, and Windows 95 OEM Service Release 2, with only changes to the associated INF file required to allow operation on each operating system. Furthermore, the same driver will be source code compatible with Windows CE (version 2.0 and subsequent), and will function on Windows CE after being recompiled. It is strongly recommended that hardware manufacturers write a single driver for all platforms.

[244] NDIS simplifies the task of implementing network drivers by providing the most common network driver functions. Since these functions are provided by NDIS, hardware manufacturers are freed from writing any software save that required for functions specific to their particular devices.

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For more information on how to implement NDIS miniport drivers, refer to [13].

14.4 Support for Priority Asynchronous Data in Microsoft Windows

Windows supports QoS for Ethernet type networks via 802.1D priorities. These are passed down through the NDIS_PACKET structure. HomeRF drivers should use this strucuture to acquire the higher level priority that was requested.

14.5 Isochronous Data Interface of a Class-1 CP

This section defines the interface that shall be provided by the IWU of a Class-1 CP so that HomeRF-aware applications running under the Microsoft Windows operating systems can control the IWU and access isochronous data.

A Class-1 CP shall provide a TAPI Service Provider (TSP), a Media Service Provider (MSP), and DirectShow filters as defined in these sections. The HomeRF-aware application operates the IWU using the TUBA interface.

This section does not describe the interface to the MD-SAP that the CP also exports. This is described in section 14.3 (HomeRF Support for Asynchronous Data in Microsoft Windows).

14.5.1 TAPI Overview (Informative)

TAPI was developed in 1993 to be a standard interface for application programs to talk to telephony hardware such as telephones and modems. Its development was part of a drive towards greater Computer Telephony Integration (CTI).

Traditionally, a specific modem had to be specified to an application before the application could operate with the modem. TAPI provides telephony applications with a generic hardware interface analogous to those available to other hardware devices, such as printers. Printers are accessed through a generic API built into the operating system; after the printer driver is installed, any application can access it through the standard interface, without knowing what type of printer it is. TAPI provides the same isolation between application and hardware for telephony devices.

14.5.1.1 TSPI (Informative)

TAPI is the interface between telephony applications and a telephony dynamic linked library (DLL) that contains routines which implement the TAPI functionality.

Device-specific functions are performed by a device-specific driver that provides routines that are called by the telephony DLL. This driver is a TAPI service provider (TSP). The interface between the TAPI DLL and the service providers is the Telephony Service Providers Interface (TSPI).

14.5.1.2 MSP Interface (Informative)

A TAPI 3.0 TSP also provides a Media Service Provider (MSP) that allows TAPI 3.0 applications to access the media streams associated with a TAPI call.

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14.5.2 Architecture

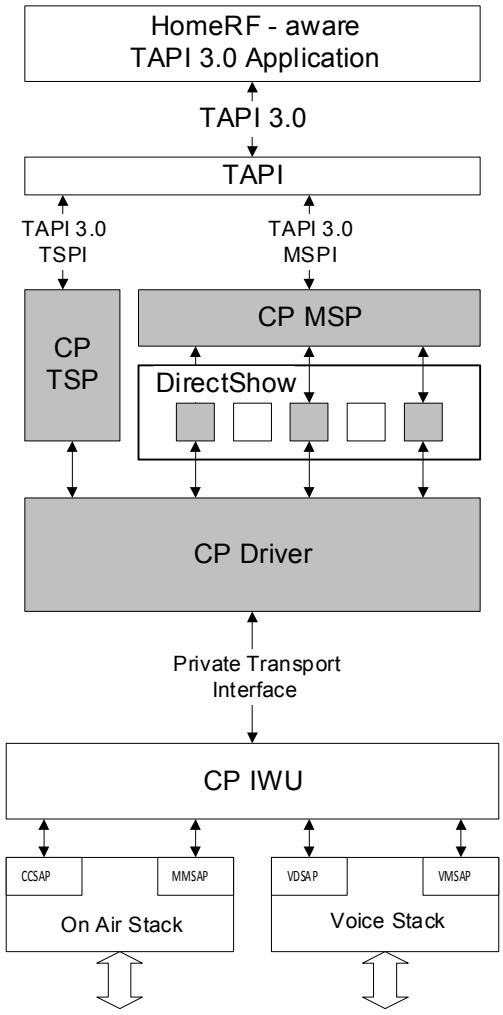


Figure 201 - Class-1 CP PC Interfaces

In Figure 201, The CP provides the host-side drivers that are shown shaded.

The CP exports a *TAPI Service Provider* and *a Media Service Provider* interface to TAPI.

The CP provides a number of TAPI 3.0 terminals. These terminals both provide access to the isochronous data stream and provide control of CP conferencing hardware. The isochronous data stream interface is implemented in this architecture as a DirectShow filter component.

The CP also has (in this model) a host-side driver that exports private interfaces to its other drivers.

An application that is not HomeRF aware can only use a limited subset of the CP functionality. It can make calls on both the On-Air and PSTN lines. It cannot receive incoming call notification on these lines. It cannot receive the I-node keypad code stream; neither can it send characters for display.

The CP IWU shall support the operating modes defined in 12.6.1 (Class-1 CP IWU Operating Modes). These affect the behavior of the IWU.

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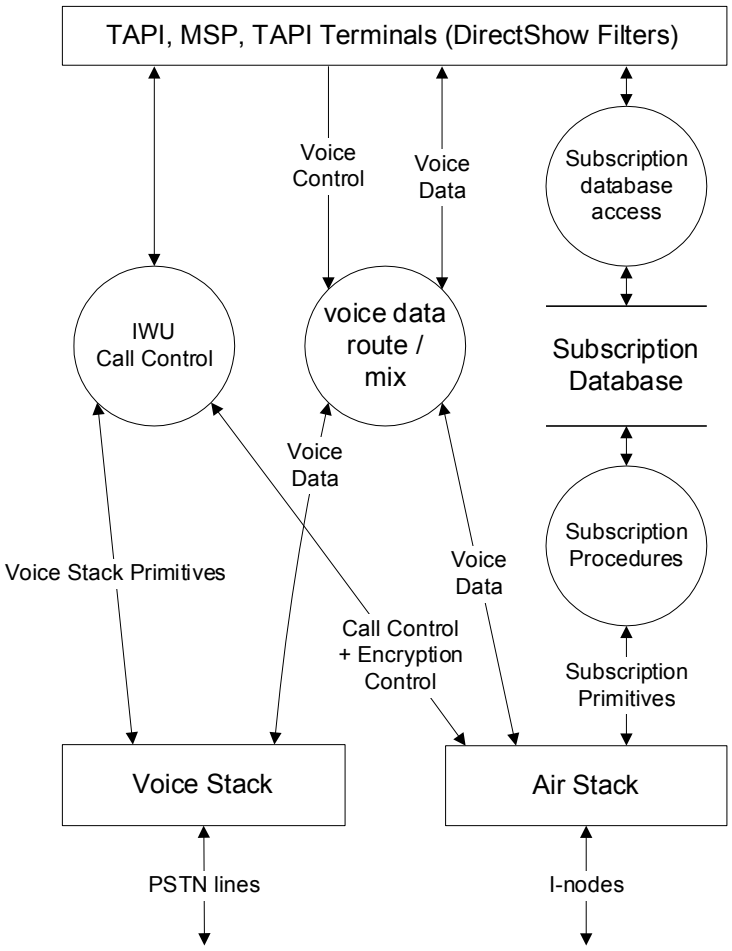


Figure 202 - Class-1 CP IWU Dataflow

Figure 202 shows the dataflow within the CP IWU that relates to control across the IWU-TAPI interface.

The IWU call control contains a state machine that provides the TAPI application a simplified view of the DECT call setup states.

The *voice data route/mix* process represents moving isochronous data between the Voice Stack, Air Stack and PC. This process probably includes hardware support for voice stream conferencing, controlled through TAPI terminal objects exposed by the MSP.

Hardware manufacturers may wish to stream isochronous data from the HomeRF device hardware to another peripheral in the PC. For example, connecting an I-node call maintained by a HomeRF adapter to a PSTN connection residing on a separate adapter would require isochronous data streaming within the PC. Manufacturers can also stream isochronous data through the PC in order to make use of sound processing filters provided with the operating system (Windows 2000 and Windows 98 with TAPI 3.0 only). [245]

Windows NT 4.0, Windows 95, and Windows CE do not include TAPI 3.0 or the DirectShow architecture. Isochronous data streaming for these operating systems must therefore be implemented in a proprietary fashion by the hardware manufacturer. This document does not specify how this should be done.

14.5.3 TSP Interface

The CP shall export a TAPI service provider interface as defined in this section.

14.5.3.1 Service Provider Information

This section relates to how the CP describes its capabilities in response to TAPI requests across the TSP interface.

The CP shall provide a response to *TSPI_providerEnumDevices()* that indicates the total number of all lines supported.

[245] TAPI 3.0 will be available for Windows 98

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14.5.3.2 Line Types

The TSPI permits a device-specific extension (including structures and events) to be associated with a particular line. This extension mechanism is used in this specification to provide HomeRF-specific communication between the HomeRF application and the TSP interface of the CP. Table 283 defines the different line types provided by the IWU of a Class-1 CP.

Table 283 - IWU Line Types

Line Type	Description
PSTN line	Provides basic telephony (using the HomeRF voice stack). No device-specific extension is required for this line type. There are as many TSP line devices as there are PSTN lines.
On-Air line	This line type is used to place calls to I-nodes. A device-specific extension is used to identify this line type, and to provide support for out-of-band signaling (carried in DECT <<KEYPAD>> and <<DISPLAY>> information elements). This line type also provides an interface that supports control of the overall IWU operating mode, and access to the subscription database. The number of these lines should be the maximum number of TDMA connections that are supported by the CP.

The operating mode of the IWU can be controlled by device-specific calls to the On-Air line and affects the operation of all lines. It is described in 12.6.1 (Class-1 CP IWU Operating Modes).

14.5.4 TSPI for On-Air Line

The On-Air line supports calls to I-nodes.

14.5.4.1 Entities associated with the On-Air Line

For each possible simultaneous call through the on-air protocol stack, the IWU provides an instance of a TAPI line, called an *On-Air* line.

Calls are made on this line to *I-nodes*. The call is called an *I-node call*. The I-node supports the states defined in section 14.5.4.10.1 (Call States).

While an I-node call is not in the *Idle* state, there are two additional entities associated with the I-node call:

- An instance of a TAPI call, associated by TAPI with a particular instance of a TAPI line.
- An instance of a DECT NWK-layer call-control entity, accessed through the DECT NWK-layer Call-Control SAP (CCSAP). All call-control messages are directed to or received from this entity.

The IWU shall maintain a one-to-one association between any DECT NWK-layer call-control entity, the On-air line and any TAPI call.

14.5.4.2 TSPI Line Behavior

The TSPI shall provide a line device for each On-Air line. Associated with all of these lines shall be a single device extension.

This extension shall have the device ID as defined in Table 284 and shall report version 1.0.

Table 284 - Device Extension Identifier

Line Type	Identifier

On-Air line	`// {880B6C30-9337-11d2-AA02-00C04F843A90}`
	
	`static const GUID sGUID_OnAirLine =`
	`{ 0x880b6c30, 0x9337, 0x11d2,`
	`  { 0xaa, 0x2, 0x0, 0xc0, 0x4f, 0x84, 0x3a, 0x90 } };`

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The On-Air Line shall provide the behavior defined in Table 285.

Table 285 - On-Air Line TSPI Calls

TSPI Call	On-Air Line Behavior
TSPI_lineGetExtensionID	Return the On-Air Extension ID
TSPI_lineNegotiateExtVersion	Return the On-Air Extension Version number
TSPI_lineDevSpecific	See section 14.5.4.11 (On-Air Line Device Specific Extension).

14.5.4.3 Control of IWU Operating Mode

Three device-specific functions are provided that provide control over the IWU and status information.

The IWU has a single operational mode that takes one of the following state: *Standalone, Autonomous* and *Slave*.

The IWU starts in the *Standalone* mode, and then transitions to the *Autonomous* operating mode once connection between the IWU and the TSP is established. This specification does not define how this occurs.

Once the IWU is in the *Autonomous* state it may be placed in the *Slave* state by an IWU_STATE device-specific function performed on any On-Air line. This call affects the IWU operational mode for all lines. A subsequent IWU_METRICS device-specific call on any On-Air line will indicate that the IWU is in the *Slave* mode.

The device-specific IWU_SUBSCRIPTION function is used to read the subscription information relating to subscripted I-nodes. Identical results will be returned regardless of the On-Air line to which this is addressed. These device-specific functions are described in 14.5.4.11 (On-Air Line Device Specific Extension).

14.5.4.4 Effect of IWU Operating Mode

The CP shall provide control of the On-Air stack in order to allow a HomeRF application to make calls to I-nodes. Depending on its operating mode, the IWU shall behave as defined in Table 286.

Table 286 - On-Air Line Behavior Based on IWU Operating Mode

IWU Operating Mode	On-Air Line Behavior
Standalone	All On-air calls shall be handled entirely within the IWU according the requirements of the DECT GAP profile [11], as modified in section 6 (DECT DLC and NWK Layers), meeting the requirements of 12.7.1 (Class 1 CP Requirements) for *Standalone* mode.
Autonomous	On-air *Computer Calls* shall be handled as defined in section 14.5.4.8 (Computer Calls). On-air calls that are originated by an I-node shall be handled entirely within the IWU according the requirements of the DECT GAP profile [11], as modified in section 6 (DECT DLC and NWK Layers), meeting the requirements of 12.7.1 (Class 1 CP Requirements) for *Autonomous* mode. The TAPI line associated with an active On-air call shall appear to be temporarily unavailable for use by TAPI for the duration of that call. [246] The TAPI line associated with an idle On-air line shall be available for PC-to-I-node calls using the procedures defined in section 14.5.4.10 (I-node Call State Machine).
Slave	The TAPI line associated with an On-air line shall operate the procedures defined in section 14.5.4.10 (I-node Call State Machine). The IWU shall perform no autonomous control of the On-Air line. The IWU shall continue to support subscription and location registration procedures as defined in the DECT GAP profile [11] and modified in section 6 (DECT DLC and NWK Layers), meeting the requirements of 12.7.1 (Class 1 CP Requirements) for

[246] Such as appearing to be busy.

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	Slave mode.

14.5.4.5 Transitions Between Operating Modes

On entry into the *Standalone* state, the CP shall send a LINEDEVSTATE_OUTOFSERVICE message to all On-air and PSTN TAPI lines.

On exit from the *Standalone* state, the CP shall send a LINEDEVSTATE_INSERVICE message to all On-air and PSTN TAPI lines.

This specification does not define how the CP drivers determine that the CP is in the *Standalone* state.

14.5.4.6 I-node Call Ownership

An I-node call is owned either by the IWU or by TAPI. This ownership affects the operation of the I-node call state machine defined in section 14.5.4.10 (I-node Call State Machine).

Table 287 defines the conditions that define call ownership based on CP operating mode.

Table 287 - Effect of IWU Operating Mode on I-node call Ownership

Operating Mode	**Rules for Ownership**
Standalone	All I-node calls are owned by the IWU
Autonomous	Any I-node calls originated across the TAPI interface are owned by TAPI. An I-node call that has detected the *computer call* sequence is owned by TAPI. See section 14.5.4.8 (Computer Calls). All others are owned by the IWU
Slave	All I-node calls are owned by TAPI

The CP's view as to whether a call is owned by the IWU or TAPI is not affected by the mode (*monitor* or *open*) that a TAPI application uses when it opens an On-air line.

14.5.4.7 Effect of I-node Call Ownership

An I-node call that is owned by the IWU operates as specified by the DECT GAP and as profiled and modified in section 6 (DECT DLC and NWK Layers).

The On-Air line associated with a non-Idle I-node call shall be unavailable for making calls. All incoming events on the call shall be handled by the IWU. A HomeRF application can open the line in order to monitor for incoming *Computer Calls*. Any other TAPI call that attempts to control the state of the I-node call shall be ignored. [247]

The HomeRF application has no visibility of an I-node call owned by the IWU.

If the I-node signals a *Computer Call*, the ownership is passed to TAPI, which sees this as a new incoming call.

14.5.4.8 Computer Calls

A Class-1 CP IWU that is in *Autonomous* mode shall meet the requirements of this section.

If the *Computer Call* (defined in section 8.1.10 (Computer Call)) sequence of <<KEYPAD>> codes is signaled by an I-node, the IWU shall consider this an instruction to connect the call to the PC.

The IWU shall consume the <<KEYPAD>> code sequence, and then indicate an incoming I-node call as defined in 14.5.4.10 (I-node Call State Machine). Ownership of the I-node call passes to the TAPI interface.

14.5.4.9 Addressing I-nodes

The individual TPUIs of I-nodes present can be obtained from the subscription database using the procedure defined in 14.5.4.11.6 (Return Subscription Record).

[247] With a suitable error return.

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The HomeRF application shall address a particular I-node in a call by forming a dial string from the TPUI. The TPUI is considered to be an unsigned integer. The dial string is the decimal representation of this number (most significant digit first).

If a zero-length dial string is supplied, the IWU shall interpret this as a call to any I-node using group ringing.

14.5.4.10 I-node Call State Machine

This section defines a state machine that defines the operation of the I-node call. The purpose of this state machine is to present to the DECT NWK layer a form of behavior consistent with the DECT GAP IWU (as profiled and modified by this specification), and to present to a TAPI client a call-control model that is consistent with the TAPI call-control model.

This state machine defines behavior of a call that is owned by TAPI. There is no description of behavior for a call that is owned by the IWU, as this is adequately specified by the DECT GAP as profiled and modified in this specification.

14.5.4.10.1 Call States

The I-node call states are described in Table 288. Some states are specific to particular IWU modes. This is also described in this table.

Table 288 - I-node Call States in the IWU-TAPI Interface

I-node Call State	Reported TAPI Call state	Possible in IWU modes	Description
Idle	Idle	All	No Call exists
Call Present	Proceeding (outgoing)	All	A PC-originated call-setup has been received
Call Received	Ringback (outgoing)	All	A PC-originated call-setup has reached the destination I-node
Offering	Offering	Slave	An I-node originated call-setup has been received
Overlap Sending	Accepted	Slave	An I-node initiated call has been established, and the HomeRF application wants to gather keypad information prior to connecting the call
CCall Overlap Offering	Offering	Autonomous	An I-node call, owned by the IWU, that is not connected[248] has issued a *Computer Call* sequence
Active	Connected	All	The call is connected
CCall Active Offering	Connected	Autonomous	An I-node call, owned by the IWU, that is connected has issued a *Computer Call* sequence
Release Pending	Connected	All	The PC has released the call and is waiting confirmation from the I-node.
Release Pending (Closed)	Disconnected	All	The PC has closed the call and is waiting for confirmation from the I-node
Disconnected	Disconnected	All	The call has been disconnected

[248] *i.e.* has not issued or received an MNCC_CONNECT primitive

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The *Active* and *Overlap Sending* states are collectively called *Info-enabled* states, because MNCC_INFO primitives may be exchanged in these states. All other states are called *Info-disabled* states.

14.5.4.10.2 Call Events

The I-node call-control state machine receives events from two sources:

- TAPI through the TSP interface routines that the CP's driver exports
- DECT NWK-layer call-control entity

Table 289 defines the events that drive the operation of this state machine. Some events are specific to particular IWU modes. This is also described in the table.

Table 289 - I-node Call Events

I-node Call Event	Description	Possible in IWU modes	Source
SETUP Indication	MNCC_SETUP Indication	Slave	CC
REJECT Indication	MNCC_REJECT Indication	All	CC
PROC Indication	MNCC_CALL_PROC Indication	All	CC
ALERT Indication	MNCC_ALERT Indication	All	CC
CONNECT Indication	MNCC_CONNECT Indication	All	CC
RELEASE Indication	MNCC_RELEASE Indication	All	CC
RELEASE Confirmation	MNCC_RELEASE Confirmation	All	CC
INFO Indication	MNCC_INFO Indication	All	CC
ENCRYPT Indication	MM_ENCRYPT Indication	All	CC
LineMakeCall	TSPI_lineMakeCall() call as defined in section14.5.4.10.15 (TSPI_lineMakeCall Event)	All	TSPI
LineAccept	TSPI_lineAccept() call	All	TSPI
LineAnswer	TSPI_lineAnswer() call	All	TSPI
LineDrop	TSPI_lineDrop() call	All	TSPI
LineCloseCall	TSPI_lineCloseCall() call	All	TSPI
CallProceding	A CallProceding request has been received from the HomeRF application for this call using the procedure defined in section 14.5.4.11.7 (Call Proceeding Request)	All	DEV
DisplayRequest	An DisplayRequest has been received from the HomeRF application for this call using the procedure defined in section 14.5.4.11.8 (DisplayRequest)	All	DEV

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I-node Call Event	Description	Possible in IWU modes	Source
EncryptRequest	An EncryptRequest has been received from the HomeRF application for this call using the procedure defined in section 14.5.4.11.10 (INODE_ENCRYPT Request)	All	DEV
CCall Overlap	A Computer Call sequence has been signaled by an I-node that has a call setup owned by the IWU that is in a state in which an MNCC_CONNECT has not occurred	Autonomous	INFO
CCall Active	A Computer Call sequence has been signaled by an I-node that has a call setup owned by the IWU that is in a state in which an MNCC_CONNECT has occurred	Autonomous	INFO
Notes:	CC - DECT NWK-layer call control entity associated with this I-node call TSPI - HomeRF application or TAPI through the TSPI DEV - HomeRF application through device-specific TSPI calls INFO - I-node through one or more MNCC_INFO requests		

14.5.4.10.3 Call State Transition Diagram

Figure 203 defines the state transition diagram for the I-node call.

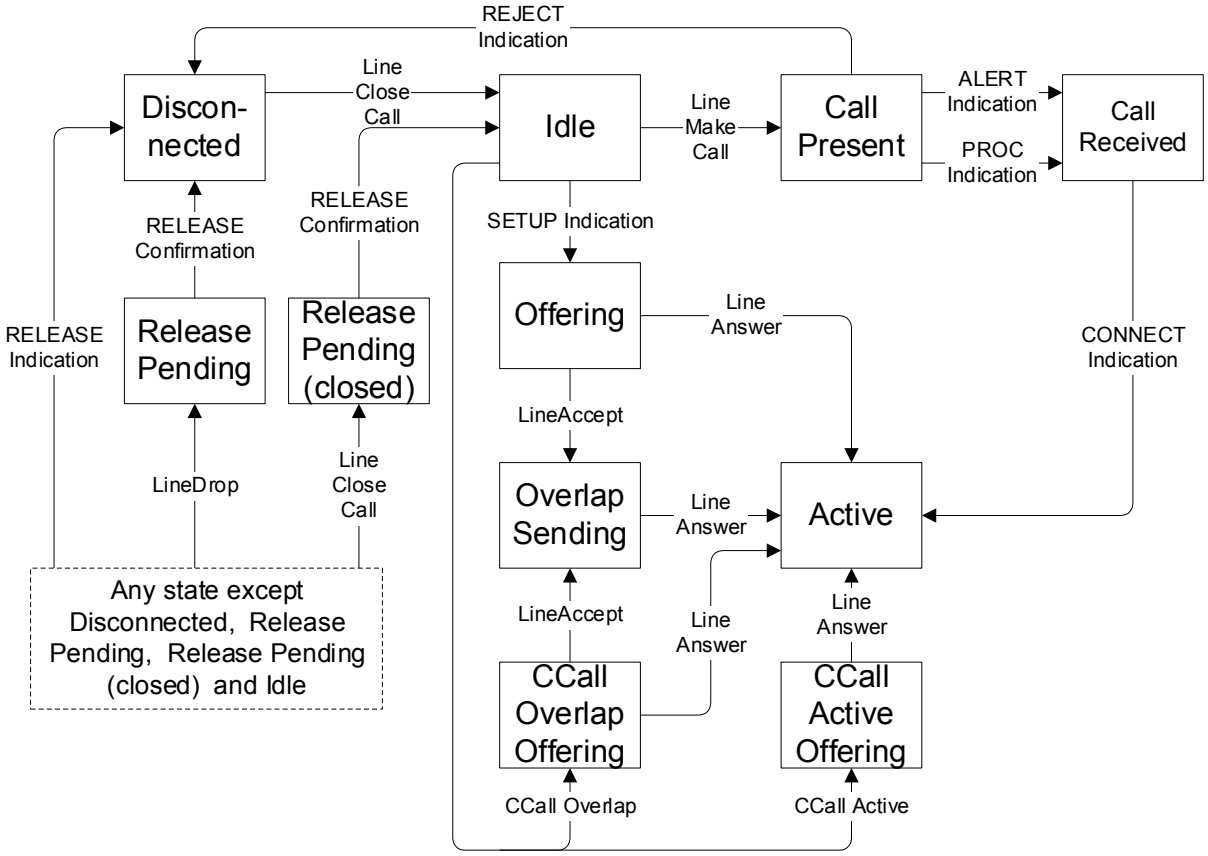


Figure 203 - I-node Call State Transitions

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14.5.4.10.4 Idle

Condition	Action	Next State
SETUP Indication	Create a TAPI call for this I-node call by sending a LINE_NEWCALL to the LINEEVENT callback	Offering
LineMakeCall	Issue an MNCC_SETUP request for this call [249]	Call Present
CCall Overlap	Create a TAPI call for this I-node call by sending a LINE_NEWCALL to the LINEEVENT callback	CCall Overlap Offering
CCall Active	Create a TAPI call for this I-node call by sending a LINE_NEWCALL to the LINEEVENT callback	CCall Active Offering

14.5.4.10.5 Call Present

Condition	Action	Next State
ALERT Indication		Call Received
PROC Indication		Call Received
REJECT Indication		Disconnected

14.5.4.10.6 Call Received

Condition	Action	Next State
CONNECT Indication		Active

14.5.4.10.7 Offering

Condition	Action	Next State
LineAccept	Issue an MNCC_SETUP_ACK request	Overlap Sending
LineAnswer	Issue an MNCC_CONNECT request	Active

14.5.4.10.8 Overlap Sending

Condition	Action	Next State
LineAnswer	Issue an MNCC_CONNECT	Active

[249] This is a simplification. The MNCC_SETUP request will usually succeed because if the intended I-node does not answer the call, an MNCC_RELEASE will be issued.

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	request	
CallProceding	Issue an MNCC_CALL_PROC request with the specified parameters	
INFO Indication	Issue an INFO Indication using the procedures defined in 14.5.4.11.2 (INFO Indication)	
DisplayRequest	Issue an MNCC_INFO request carrying the parameters specified in the DisplayRequest	

14.5.4.10.9 Active

Condition	Action	Next State
INFO Indication	Issue an INFO Indication using the procedures defined in 14.5.4.11.2 (INFO Indication)	
EncryptRequest	Issue an MM_ENCRYPT request	
DisplayRequest	Issue an MNCC_INFO request carrying the parameters specified in the DisplayRequest	

Call release is described in section 14.5.4.10.17 (RELEASE Indication Event).

14.5.4.10.10 CCall Overlap Offering

Condition	Action	Next State
LineAccept	If there are any queued INFO indications, issue an INFO indication using the procedures defined in 14.5.4.11.2 (INFO Indication)	Overlap Sending
LineAnswer	Issue an MNCC_CONNECT request If there are any queued INFO indications, issue an INFO indication using the procedures defined in 14.5.4.11.2 (INFO Indication)	Active
INFO Indication	Queue the INFO indication using the procedures defined in 14.5.4.11.2 (INFO Indication)	

14.5.4.10.11 CCall Active Offering

Condition	Action	Next State
LineAnswer	Issue any queued INFO Indications	Active

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	as separate InfoIndications, preserving the order using the procedures defined in 14.5.4.11.2 (INFO Indication)	
INFO Indication	Queue the INFO indication	

14.5.4.10.12 Release Pending

Condition	Action	Next State
RELEASE Confirmation		Disconnected

14.5.4.10.13 Release Pending (Closed)

Condition	Action	Next State
RELEASE Confirmation		Idle

14.5.4.10.14 Disconnected

Condition	Action	Next State
LineCloseCall		Idle

14.5.4.10.15 TSPI_lineMakeCall Event

The LINECALLPARAMS may include a Device-specific structure as defined below, or it may be absent. This indicates the *Signal* value to use in the MNCC_SETUP request. If the structure is absent, the value IS_0 defined in section 14.5.4.11.8 (DisplayRequest) shall be used.

```
struct INODE_CALLPARAMS {
    DWORD  dwSignal;     // One of the permitted Signal Value
                         // values defined in 14.5.4.11.8 (DisplayRequest)
}
```

14.5.4.10.16 LineDrop Event

An I-node call that receives a LineDrop event, in any state except the *Idle, Release Pending, Release Pending (Closed) and Disconnected* states, shall issue an MNCC_RELEASE request and enter the *Release Pending* state.

14.5.4.10.17 RELEASE Indication Event

An I-node call that receives a RELEASE indication event, in state any except the *Idle, Release Pending, Release Pending (Closed) and Disconnected* states, shall issue an MNCC_RELEASE response and enter the *Disconnected* state.

14.5.4.10.18 LineCloseCall Event

An I-node call that receives a LineCloseCall event in any state, except the *Idle, Release Pending, Release Pending (Closed)* and *Disconnected* states shall send a MNCC_RELEASE request to this call, and enter the *Release Pending (Closed) state.*

14.5.4.10.19 ENCRYPT Indication Event

An I-node call that receives an ENCRYPT Indication event in any state except *Idle* and *Disconnected* shall set the *dwEncrypted* field of its device-specific call-state to 1, and shall generate a LINE_CALLINFO message that indicates that the device-specific call information has changed.

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14.5.4.10.20 Reporting TAPI Call State Changes

Whenever the I-node call state machine makes a state transition that changes the *Reported TAPI Call State* (defined in 14.5.4.10.1 (Call States)), it shall send a LINE_CALLSTATE message to its LINEVENT callback function that indicates the change of TAPI call state.

14.5.4.10.21 Keypad Code Queue

Associated with an I-node call that is not in the *Idle* state is a queue of Keypad Codes that have been received from the I-node (through MNCC_INFO indications), but not yet passed to the HomeRF application.

Items are added to the queue by the INFO indication procedure, as described in section 14.5.4.11.2 (INFO Indication).

Items are removed from the queue by the INODE_GETKEYPAD procedure, as described in section 14.5.4.11.9 (INODE_GETKEYPAD Request).

14.5.4.11 On-Air Line Device Specific Extension

14.5.4.11.1 Device-Specific Call State

In response to both *TSPI_lineGetCallInfo()* and *TSPI_lineGetCallStatus()* the TSPI shall return in the device-specific field an *INODE_CALLSTATE* structure.

```
struct INODE_CALLSTATE {
    DWORD  dwServiceType;             // 0 = basic, 1 = internal
    DWORD  dwTPUI;                    // TPUI of I-node connected
    DWORD  dwEncrypted;               // 0 if not encrypted, 1 if encrypted
    DWORD  dwProgressIndicator;       // 0 = No further information
                                      // 1 = In-band information now available
    DWORD  dwKeypadPending;           // Number of Keypad codes pending
}
```

The *dwKeypadPending* field shall be set according to the number of keypad codes queued on the I-node call's keypad code queue (see section 14.5.4.11.2 (INFO Indication)).

14.5.4.11.2 INFO Indication

When an MNCC_INFO indication is received, the contents of its *Keypad* parameter shall be placed on the I-node call's keypad code queue and the *dwKeypadPending* field of the *INODE_CALLSTATE* shall be updated. [250]

If the I-node call is in an *Info-enabled* state, it shall also generate a TAPI *LINE_CALLINFO* message to the LINEEVENT callback associated with the TAPI line that indicates that the device-specific call information has changed.

An I-node call that transitions from an *Info-disabled* to an *Info-enabled* state and that has a non-empty INFO indication queue shall generate a *LINE_CALLINFO* message that indicates that the device-specific call information has changed.

14.5.4.11.3 I-node Device-Specific Structure and Calls

The *TSPI_lineDevSpecific()* call is used to perform all device-specific requests. For each of these, the *lpParams* parameter of this call shall point to an I-node call device-specific control block.

The first DWORD[251] of this control block shall contain a function code. It identifies the format and length of the control block. The device extension shall support the functions defined in Table 290.

Table 290 - On-Air Line Device-Specific Behaviors

On-Air Line Function ID	Structure	On-Air Line Behavior
1	IWU_GET_METRICS	Get IWU Metrics and operational state

[250] The TAPI application can read the keypad code queue using a device-specific INODE_GETKEYPAD request.

[251] 32-bit quantity

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2	IWU_SET_STATE	Set IWU operational state
3	IWU_ GET_SUBSCRIPTION	Return a subscription record
10 (decimal)	INODE_CPROCREQ	Issue an MNCC_CALL_PROC request
11	INODE_DISPLAYREQ	Issue an MNCC_INFO request
12	INODE_GETKEYPAD	Get keypad codes from the keypad code queue. See section 14.5.4.11.9 (INODE_GETKEYPAD Request).
13	INODE_ENCRYPT	Issue an MM_ENCRYPT request

14.5.4.11.4 Get IWU Metrics

The IWU shall return fields within the IWU_GET_METRICS structure.

```
struct IWU_GET_METRICS {
    DWORD  dwFunction;          // (in) 1
    DWORD  dwState;             // (out) Current IWU state one of IWU_STATE
    DWORD  dwPSTNlines;         // (out) Number of PSTN lines supported
    DWORD  dwOnAirLines;        // (out) Number of on-air lines supported
    DWORD  dwConnectionLines;   // (out) Number of Connection lines
    DWORD  dwSubscriptions;     // (out) Number of subscriptions present
}
```

The IWU_STATE value is one of the following:

```
enum IWU_STATE {
    IWUS_Standalone             = 0,   // IWU Is in Standalone mode
    IWUS_Autonomous     = 1,   // IWU Is in Autonomous mode
    IWUS_Slave          = 2    // IWU Is in Slave mode
}
```

14.5.4.11.5 Set IWU Operational State

The IWU shall set its state to the value specified in the IWU_SET_STATE structure.

```
struct IWU_SET_STATE {
    DWORD  dwFunction;          // (in) 2
    DWORD  dwState;             // (in) New Operational state one of IWU_STATE
}
```

14.5.4.11.6 Return Subscription Record

This call requests subscription information for subscription *dwSubscriptionIndex*. The IWU shall return the requested subscription record, numbering valid subscriptions from 0. The IWU shall return an error code if the requested subscription index is not valid.

```
struct IWU_GET_SUBSCRIPTION {
    DWORD  dwFunction;          // 3
    DWORD  dwSubscriptionIndex; // (in) Runs from 0 to dwSubscriptions-1
    DWORD  dwTPUI;              // (out) Individual TPUI of node
    BYTE   abMACaddress[6];     // (out) IEEE address (IG bit in byte 0)
    BYTE    abCapabilities[12]; // (out) Terminal capabilities as specified
                                //     in [11, Annex C.]
    DWORD dwEncryption;         // (out)
                                // 1 if a call to the I-node can be encrypted,
                                // 0 otherwise
}
```

14.5.4.11.7 Call Proceeding Request

This device-specific function requests the transmission of an MNCC_CALL_PROC request.

```
struct INODE_CPROCREQ {
    DWORD  dwFunction;                // (in) 10
```

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```
    DWORD  dwProgressIndicator;              // (in)
                                    // 0 = No further information
                                    // 1 = In-band information now available
}
```

14.5.4.11.8 DisplayRequest

This device-specific function requests the transmission of an MNCC_INFO request from the CP to the I-node.

```
struct INODE_DISPLAYREQ {
    DWORD  dwFunction;              // (in) 11
    DWORD  dwSignal;                // (in) One of the INODE_SIGNAL codes
    DWORD  dwDisplayLength;         // (in) Number of display codes
    BYTE   abDisplay[0];            // (in) Codes to display,
                                    // Actually of length dwDisplayLength
}
```

The *dwSignal* field selects an alert signal as defined by the following enumeration:

```
enum INODE_SIGNAL {
    IS_NONE = 0,                // No alert tone
    IS_0 = 1,                   // Alerting pattern 0
    IS_1 = 2,                   // Alerting pattern 1
    IS_2 = 3,                   // Alerting pattern 2
    IS_3 = 4,                   // Alerting pattern 3
    IS_4 = 5,                   // Alerting pattern 4
    IS_5 = 6,                   // Alerting pattern 5
    IS_6 = 7,                   // Alerting pattern 6
    IS_7 = 8,                   // Alerting pattern 7
    IS_CONTINUOUS = 9           // Continuous alert tone
}
```

The *abDisplay[]* member contains the <<DISPLAY>> codes to be displayed at the I-node. These codes are defined in [6].

14.5.4.11.9 INODE_GETKEYPAD Request

This device-specific function shall remove and return keypad codes from the I-node call's keypad code queue. Keypad codes are returned in the order that they were received. The number of keypad codes returned is the smaller of the number requested, and the number in the keypad code queue.

```
struct INODE_GETKEYPAD {
    DWORD  dwFunction;              // (in) 12
    DWORD  dwRequestedLength;       // (in) Number to return
    DWORD  dwActualLength;          // (out) Number actually returned
    BYTE   abKeypad[0];             // (out) Returned keypad codes
                                    // Actually of length dwActualLength
}
```

The keypad codes are defined in [6]. Section 8 (HomeRF IWU) defines keypad code sequences that are used to access HomeRF IWU procedures.

14.5.4.11.10 INODE_ENCRYPT Request

An I-node call that is in the *Active* state that receives this device-specific request shall issue an MM_ENCRYPT request for the I-node connection. [252]

```
struct INODE_ENCRYPT {
    DWORD  dwFunction;              // (in) 13
}
```

14.5.4.11.11 PROC Indication

An I-node call in the *Call Present* state that receives a PROC indication shall update the dwProgressIndicator field of its INODE_CALLSTATE, and shall generate a LINE_CALLINFO message that indicates that the device-specific call information has changed.

---

[252] This, unlike other requests is notionally sent through the DECT NWK-layer MMSAP. This makes no practical difference. The IWU maintains a mapping that enables it to associate an MM_ENCRYPT request with an active call-control entity.

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14.5.4.12 Message-Sequence Diagrams (Informative)

This section contains message-sequence diagrams that illustrate the operation of the I-node call state machine.

14.5.4.12.1 I-node Originated Call

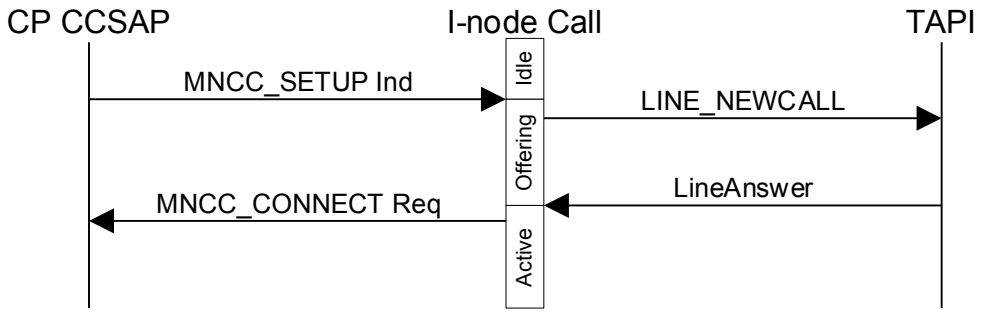


Figure 204 - I-node Originated Call Message Sequence Diagram

14.5.4.12.2 I-node Originated Call - Overlap Sending

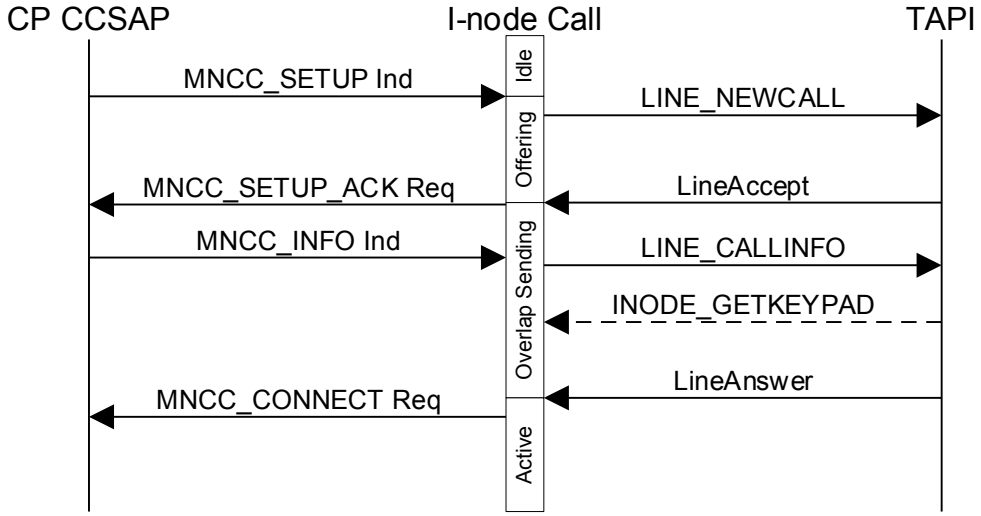


Figure 205 - I-node Originated Call - Overlap Sending

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14.5.4.12.3 PC-Originated Call

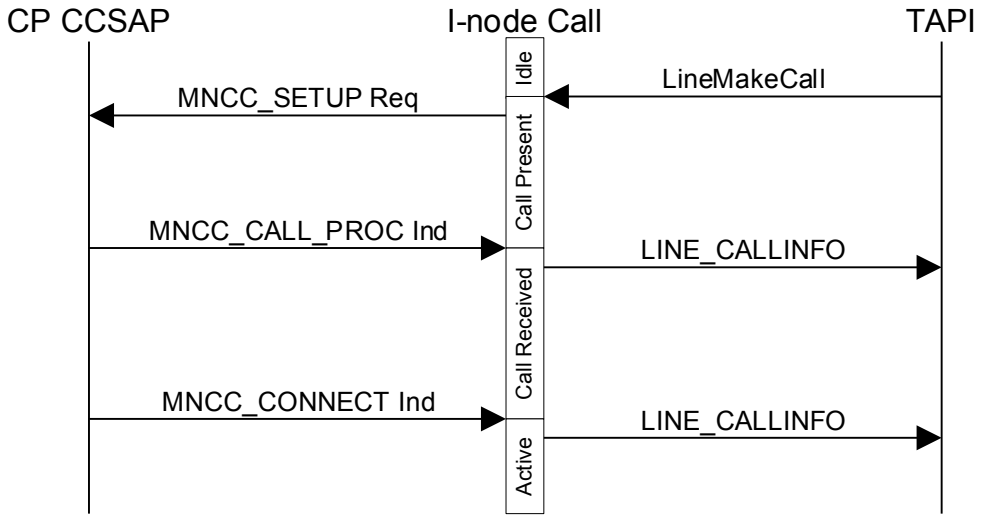


Figure 206 - PC-Originated Call Message Sequence Diagram

14.5.4.12.4 I-node Originated Call Release

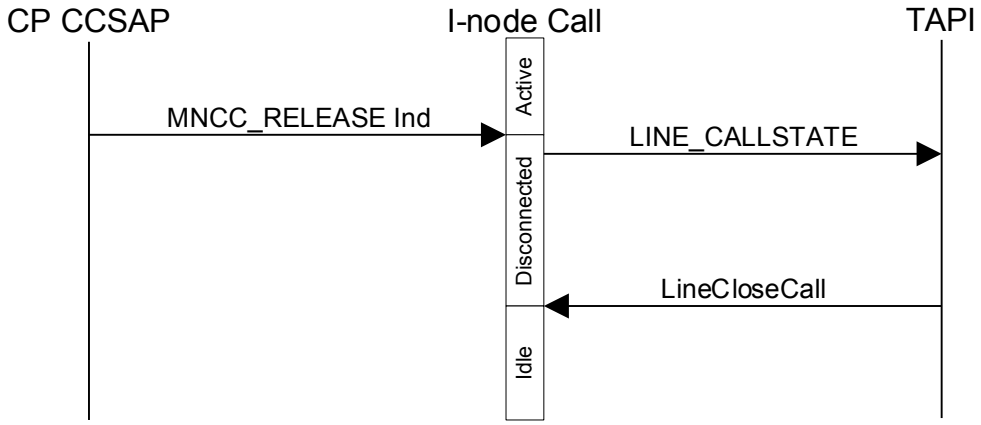


Figure 207 - I-node Originated Call Release

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14.5.4.12.5 PC-Originated Call Release

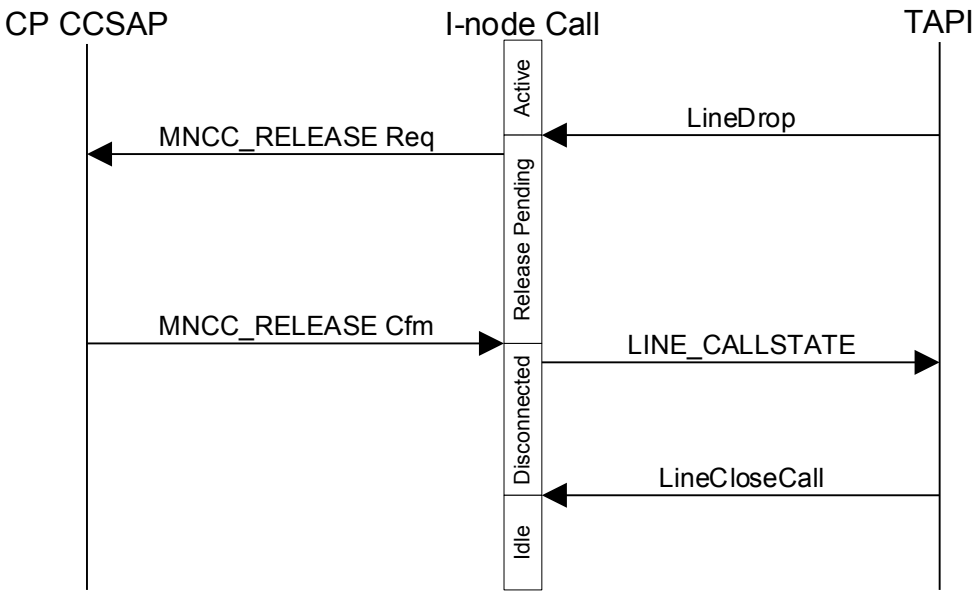


Figure 208 - PC-Originated Call Release

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14.5.5 TSPI for PSTN Line

The CP shall provide control of the voice stack as TAPI lines that support basic telephony as described in [14]. These lines are called *PSTN lines.*

Depending on its operating mode, the IWU shall behave as defined in Table 291.

Table 291 - PSTN Line Behavior Dependent on IWU Operating Mode

IWU Operating Mode	PSTN Line Behavior
Standalone	All incoming PSTN calls shall be handled entirely within the IWU according the requirements of the DECT GAP profile [11], as modified in section 6 (DECT DLC and NWK Layers), meeting the requirements of 12.7.1 (Class 1 CP Requirements) for *Standalone* mode.
Autonomous	All incoming PSTN calls shall be handled entirely within the IWU according the requirements of the DECT profile [11], as modified in section 6 (DECT DLC and NWK Layers), meeting the requirements of 12.7.1 (Class 1 CP Requirements) for "Autonomous" mode. The TAPI line associated with an incoming call shall appear to be unavailable for use by TAPI for the duration of that call. The TAPI line associated with an idle PSTN line shall be available for all supported TAPI basic telephony operations, except incoming call notification.
Slave	The PSTN line provides all supported TAPI basic telephony operations, including incoming call notification. The IWU shall perform no autonomous control of the PSTN line.

14.5.6 Media Devices

HomeRF applications will control and access HomeRF audio data streams through TAPI terminals exposed by the CP's Media Service Provider.

14.5.6.1 Media Device Architecture

The CP shall associate with each On-air and PSTN call a TAPI terminal. This terminal is called here a *voice* terminal. The MSP uses a TAPI component called the *Terminal Manager* to expose these terminals. Each voice terminal shall expose two DirectShow, one providing *capture* and the other *renderer* semantics.

Conferencing of media streams can be achieved in two ways. Firstly, by bringing the audio streams in through DirectShow interfaces, and then using a DirectShow filter to conference streams together. Secondly, by exposing multiple interfaces on the voice terminals and selecting these on a media stream.

Refer to the *Windows 2000 Platform SDK* [14] for details of these interfaces.

14.5.6.2 DirectShow Interface

Where access is provided to the isochronous data stream, this shall be through a pair of DirectShow filters - one for each half of the full-duplex stream. These are called capture (CP to PC) and renderer (PC to CP) filters. These interfaces are used only when a voice data stream needs to be brought off the CP into the PC.

A *pin* is a DirectShow term for an interface to a DirectShow object that can act as a source or sink of multimedia data. A HomeRF CP output pin generates a stream of isochronous voice data. A HomeRF CP input pin accepts a stream of isochronous voice data.

A HomeRF capture filter shall support an input pin. A HomeRF renderer filter shall support an output pin.

A Class-1 CP that contains signal processing hardware (i.e. format conversion) can also represent this functionality through separate DirectShow filters or by supporting additional DirectShow media types

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14.5.6.3 HomeRF Audio Media Type

A HomeRF DirectShow filter shall support an audio media type that corresponds to uniform PCM sampled at 8kHz. [253]

14.5.6.4 Audio Capture Filter

The HomeRF audio capture filter shall provide a DirectShow output pin that supports the HomeRF audio media type.

The stream shall only be available only when the I-node call is in the *Active* state. In other states, the stream shall generate silence.

14.5.6.5 Audio Rendering Filter

The HomeRF audio rendering filter shall provide a DirectShow input pin that supports the HomeRF audio media type.

[253] It can also support other audio media types.

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15 HOMERF SECURITY ARCHITECTURE

15.1 Introduction (Informative)

A HomeRF node either shall, can, or shall-not support encryption according to its type and intended country of use. This specification defines under what conditions a node shall or can support encryption. It does not define under what conditions a node shall not support encryption - this is likely to depend on local regulations.

A node signals its support for encryption in the Encryption Capability field of the IR and SI MPDUs. An I-node will also signal its support for encryption and authentication within the DECT NWK layer using values defined in sections 15.4.2.2 (Encoding for HomeRF Authentication Algorithm) and 15.4.2.3 (Encoding for HomeRF Encryption Algorithm) to signal the HomeRF authentication and encryption algorithms.

There is a single encryption core algorithm, defined below, that is used to provide encryption of both asynchronous and isochronous data services. The same algorithm is used by the DECT authentication and session-key generation algorithms.

A Class-1 CP or AI-node that supports encryption does so for both types of data service.

All HomeRF A-nodes and CPs in the network that support encryption share a common key. This is used as the encryption key for asynchronous data.

The DECT procedures for entry of the AC enable each I-node to have its own master key, from which derived cipher keys are derived to encrypt isochronous data.

15.2 Encryption of the MD-SAP Data Service

This is specified in section 5.12.5 (MD-SAP Encryption Layer). The node shall use the key stored in the *Node Parameters* of the MIB for all encrypted MD-SAP data.

15.3 Encryption of the MC-SAP Data Services

This is specified in section 5.20.6 (TDMA Encryption). Support for the TDMA encryption by the I-node is declared by including the <<AUTH-TYPE>> and <<CIPHER INFO>> information elements in the {ACCESS-RIGHTS-REQUEST} message as part of the I-node subscription procedure. The Class-1 CP declares its support for TDMA encryption by including the <<AUTH-TYPE>> and <<CIPHER INFO>> information elements in the {ACCESS-RIGHTS-ACCEPT} message as part of the I-node subscription procedure. The key used to encrypt a link shall be derived from the UAK using the procedures defined in section 15.4 (HomeRF Authentication) below.

15.4 HomeRF Authentication

HomeRF Authentication shall be supported by an I-node or Class-1 CP that declares support for TDMA encryption.

This section defines procedures for HomeRF authentication.

15.4.1 DECT Security Model (Informational)

With reference to the DECT security model defined in [8], DECT Authentication is defined by the operation of the processes defined in Table 292.

Table 292 - DECT Security Processes

Process Label	Description
A11	Derives Portable-part (PP) Authentication session key from a master key and a random number
A12	Derives PP Authentication check result and derived cipher key from the authentication session key and a random number
A21	Derives FP authentication session key from the a master key and a random number
A22	Derives FP authentication check result from the authentication session key and a random number

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One side effect of an authentication of the portable part is that a derived cipher key for the encryption process is derived.

The purpose of splitting the authentication into two processes is to support roaming. A DECT handset can authenticate at a "guest" base-station without the "home" base-station having to reveal the handset's master key.

The DECT NWK layer [6] defines the <<AUTH-TYPE>> and <<CIPHER-INFO>> information elements that are used during authentication and when enabling encryption to select the algorithm to be used.

This specification defines values to go in these information elements to signal the use of the HomeRF algorithms.

15.4.2 HomeRF Authentication Model

This section defines the HomeRF authentication algorithm in terms of the DECT Security Model entities.

15.4.2.1 Authentication Processes

Table 293 defines the HomeRF authentication processes in terms of the DECT security model [8].

Table 293 - Definition of HomeRF Authentication Processes

Process Label	Definition
A11	KS = K, RS is unused
A12	Operate HomeRF encryption core algorithm with the following inputs: key = lowest *KeyLength* bits of KS, IV = lowest 32 bits of RAND_F Text = 16 bytes, all zeroes The output bytes are numbered 0 to 15. The RES1 output is defined by bytes 8 to 11 of the output, interpreted as a natural number, with byte 8 being the least significant byte. The DCK output is defined by bytes 12 to 15 of the output, interpreted as a natural number, with byte 12 being the least significant byte.
A21	KS' = K, RS is unused
A22	Operate HomeRF encryption core algorithm with the following inputs: key = lowest *KeyLength* bits of KS', IV = lowest 32 bits of RAND_P Text = 12 bytes, all zeroes The output bytes are numbered 0 to 11. The RES2 output is defined by bytes 8 to 11 of the output, interpreted as a natural number, with byte 8 being the least significant byte.

15.4.2.2 Encoding for HomeRF Authentication Algorithm

A node that supports HomeRF authentication shall signal this in the <<AUTH-TYPE>> message element as defined in Table 294.

Table 294 - HomeRF Authentication Algorithm Encoding

Authentication Algorithm Identifier coding (octet 3 of <<AUTH-TYPE>>) [254] 8 7 6 5 4 3 2 1	**Meaning**
0 1 1 1 1 1 1 0	HomeRF Authentication Algorithm

[254] The DECT convention for this numbering is bit 1 is the least significant bit and is shown on the right.

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15.4.2.3 Encoding for HomeRF Encryption Algorithm

A node that supports HomeRF encryption shall signal this in the <<CIPHER-INFO>> message element as defined in Table 295.

Table 295 - HomeRF Encryption Algorithm Encoding

Cipher algorithm identifier coding (octet 3 of <<CIPHER-INFO>> [255] 8 7 6 5 4 3 2 1	**Meaning**
0 1 1 1 1 1 1 0	HomeRF Encryption Algorithm

15.5 Encryption Core Algorithm

The components of the Encryption Core Algorithm consist of the files “cipher.c”, “cipher.h”, “main.c”, “Vec40.txt”, “Vec56.txt”, and “Vec128.txt” and are described in Appendix C.

15.5.1 Interface

The inputs to the algorithm are defined in Table 296.

Table 296 - Encryption Algorithm Inputs

Encryption Core Algorithm Input	**Description**	**Size**
Key	Encryption Key	*KeyLength* bits
IV	Initialization Vector	32 bits
Text	A sequence of bytes to be encrypted	0-*nEncryptedBytes*

The output text is the same length as the input text. The encryption core algorithm is symmetric. Encryption performs the same process as decryption.

The interface to the encryption core algorithm is defined in the ANSI “C” file “cipher.h”.

15.5.2 Status of the Algorithm

At the time of writing, HomeRF does not have permission from the US government to distribute electronic copies of the encryption core algorithm. The details of the algorithm are available in Appendix C, available to HomeRF adopters. Section 1.7 (Technical Feedback and Document Updates) describes how to acquire a paper copy.

[255] The DECT convention for this numbering is bit 1 is the least significant bit and is shown on the right.

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15.5.3 Algorithm (Informative)

Figure 209 shows the structure of the pseudo-random bit-string generator of the encryption algorithm.

There are five linear-feedback shift registers (LFSRs) of differing lengths. Four of these combine to form an address. The other provides the data input for “Algorithm M”. The output of Algorithm M is combined with the outputs of all the shift registers to produce an output bit.

The Key and IV are initially distributed into the bits of the LFSR registers, and a sequence of pseudo-random bits is generated. These bits are exclusive-ORed with the bits of the input string to produce the output string.

The cryptanalysis of this algorithm is left as an exercise for the reader.

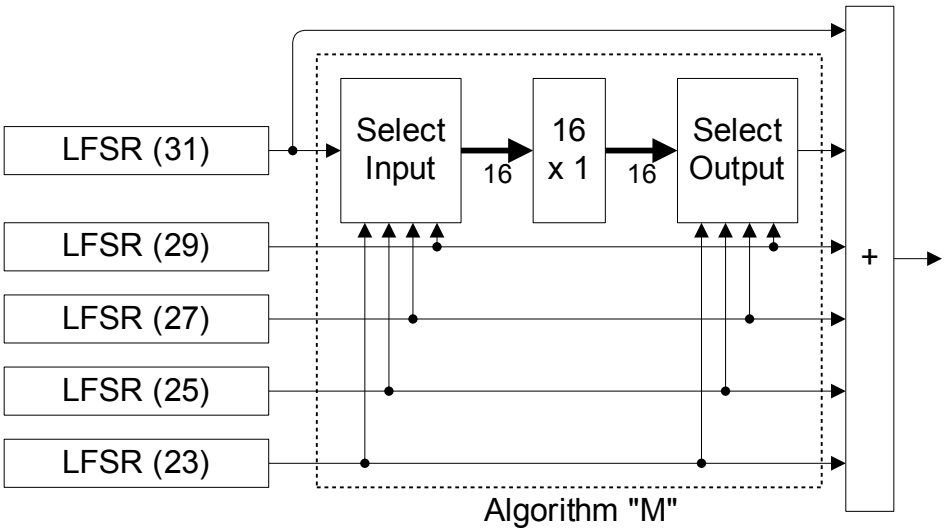


Figure 209 - Encryption Core Algorithm

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16 THE HOMERF MIB

The Management Information-Base contains information that is used by the procedures within this specification to manage the operation of a HomeRF node. It also includes information that can be used by higher layers to manage the operation of a HomeRF node.

Some of the values are constant - the values are defined by this specification. Other values are variable. These values are used to communicate management information between a HomeRF node and its higher layers.

16.1 PHY Constants

Table 297 defines constants used in the PHY layer. These constants all relate to PHY timing performance. These act as a constraint on an implementation. They are all a constant of this specification.

Table 297 - PHY Constants

Constant	Description	Derived from	Value
BasicModulationSymbolDuration	Time a single PHY symbol takes to transmit using basic modulation		1.25 μs
CCAtime	Time to sense the channel.		21 Basic Modulation symbols
HighRateModulationSymbolDuration	Time a single PHY symbol takes to transmit using high-rate modulation		200 ns.
HopDuration	Time taken to change the radio frequency and settle within the tolerance specified in section 4.5.1.1.3 (LR Modulation Transition Time and Deviation Accuracy) and be ready to transmit or receive the start of a PPDU		112 Basic Modulation symbols
RxPHYdelay	Delay between the last symbol of a PPDU being received and the PD_RX_PSDU1/2 indication		3 Basic Modulation symbols
RxTxTurnround	Time to switch the receiver from receiving to transmitting.	*TxRxTurnround*	107 Basic Modulation symbols
TIFS	Time between two adjacent uplink or downlink TDMA PPDUs		28 Basic Modulation symbols
TxRxTurnround	Time to switch the receiver from transmitting to receiving.		107 Basic Modulation symbols

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16.2 MAC Constants

Table 298 defines constants used in the MAC layer.

Table 298 - MAC Constants

Constant	Value	Description
LR2FSKfragmentationThreshold (LR 2-FSK)	512 Bytes	Max fragment payload length for transmission using LR 2-FSK modulation
LR4FSKfragmentationThreshold (LR 4-FSK)	1024 Bytes	Max fragment payload length for transmission using LR 4-FSK modulation
HR2FSKfragmentationThreshold (HR 2-FSK)	*MaxCSDUlength*	Max fragment payload length for transmission using HR 2-FSK modulation. Currently set to the maximum CSDU size
HR4FSKfragmentationThreshold (HR 4-FSK)	*MaxCSDUlength*	Max fragment payload length for transmission using HR 4-FSK modulation. Currently set to the maximum CSDU size
AckTolerance	5 μs	Tolerance [256] in the relative position of a DATA MPDU and its ACK response.
CFP1Tolerance	8 Basic Modulation symbols	The CFP1 offset signaled in a TDMA Beacon must equal the actual on-air duration of Hop + Beacon to within this tolerance either way.
CPAtimeout	10 s	Maximum time between transmitting CP Assertion MPDUs
CPBEpersistence	3	Persistence of events in the CP beacon
CSDUtimeout	100 ms	Maximum time to spend transmitting or receiving a CSDU (MSDU + MD-SAP header)
CWadhoc	4 * *CWminDefault*	Contention Window to use when calculating a backoff for the transmission of ad-hoc beacons
CWmax	64 slots	Maximum Contention Window Setting
CWminDefault	4 slots	Default value for the minimum Contention Window Setting used by the CSMA/CA access mechanism
CWstartPriorityDefault	0	Default value for the priority *CWstart*
CWstartDefault	0	Default value for *CWstart*
CWstartMax	7	Maximum value of *CWstart* that can be signaled by a CP

[256] Maximum absolute error between the actual value and the defined value.

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Constant	Value		Description
CWtxInterval	60s		Maximum period between transmitting a CP beacon containing a CW signaling field if the CW parameters are not at their default values.
CP2IFS	160 μs		Delay between end of the hop and the first symbol of a CP2 Beacon PPDU
DirectedLearnNWIDtimeout	60 s		Period for which a node signals the *DirectedLearnNWID*
DwCountUpdateTolerance	1 symbol		Maximum absolute error in the value of the *DwCount* variable following an update based on received synchronization information
FinalScanChannel	North America and Europe, Japan, Spain, France	76 95 50 81	The final channel of a MAC scanning procedure
HopsetAdaptionPersistence	*750 ms*		Period of time during which the same values of the Hopset adaption field must be signaled by a CP.
ICBS_CID	15		Connection ID reserved for the ICBS-channel
ICBSemptyDuration	10 subframes		The duration of the MB-SAP Tx State Machine *Empty* state
ICBSheraldingDuration	50 subframes		The duration of the MB-SAP Tx State Machine *Heralding* state
ICBStransmitCount	5		Number of times the same C-channel SDU set is transmitted
IPSinterval	25 superframes		Maximum time between successive checks of the CP beacon by a power-saving I-node
KeyLength	North America	56	Number of Bits in the Encryption Algorithm Key
LearnNWIDtimeout	60 s		Period for which a node signals the *LearnNWID* flag after receiving an MM_TEACH request or a Request the CP to signal *LearnNWID* CPS MPDU
MAC_CCAdelay	2.5 μs		Time permitted for MAC to respond to the result of a PM_GET_CCA request
MAC_CRCdelay	2.5 μs		Time permitted for the MAC to check the CRC(s) of a received MPDU
MaxCP2beaconPayloadLength	64 Bytes		Maximum length of a CP2 Beacon payload

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Constant	Value	Description
MaxCSDUlength	*MaxMSDUlength* + 18	Maximum length of CSDU that can be transmitted [257]
MaxFindInterval	200 superframes	This value is based on being equal to *Psinterval* duration
MaxFUSMSDUlength	64 Bytes	Maximum length of a MSDU that can be sent via the *Fast Unacknowledged Service Mechanism*
MaxInterferenceWidth	31 radio channels	Maximum value of the *InterferenceWidth*
MaxJitter	60 ms.	Maximum value for specifying jitter
MaxLatency	200 ms.	Maximum value for specifying latency
MaxMCconnections	4	The maximum number of simultaneous MC-SAP connections that can be supported by a Class-1 CP
MaxMSDUlength	1500 Bytes	Maximum MSDU length
MaxNumCPSR	5	Maximum number of times a specific CPS or IR MPDU can be transmitted
MaxNumScanChannels	3	The number of channels scanned by the generic scanning procedure, provided that it is not terminated early
MaxPriorityBandwidth	90 %	The percentage of the contention period that is made available to the Priority Asynchronous Data service
MaxTimeReservation	8191 Basic Modulation symbols	Maximum time reservation. Currently allows for 6072 (4 CSDUs @ *MaxCSDUlength*) HR 4-FSK data symbols plus overhead symbols
MaxTDMAbeaconLength	64 Bytes	Maximum length of a TDMA Beacon 64 Bytes = 11 (MPDU/TDMA header) + 5 (Main Slots Field) + 5 (Downlink Retry Slots Field) + 5 (Uplink retry Slots Field) + 32 (Connection management Field) + 3 (TDMA Channel Management) + 2 (CRC) + 1 (FILLER)
MinInterferenceWidth	10 radio channels	Minimum value of the *InterferenceWidth*
MPDUheaderLength1	7	Length of an MPDU header Type 1
MPDUheaderLength2	19	Length of an MPDU header Type 2

[257] Includes allowance for the long MD-SAP header and the Encryption PDU overhead

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Constant	Value		Description
MPDUheaderLength3	17		Length of an MPDU header Type 3
MPDUheaderLength4	23		Length of an MPDU header Type 4
MPDUinitialHeaderLength	7		Length of the MPDU header which is sufficient to delimit the PPDU fields
MulticastFragmentThreshold	512 Bytes		Max fragment payload length for transmission of a multicast CSDU
NumberOfChannels	North America and Europe, Japan, Spain, France	75 23 27 35	Number of radio channels over which the MAC hops
NumberOfSubframes	2		Number of sub-frames in a super-frame
NumCheckCPB	2		Number of CP beacons to check for confirmation following the transmission of a CPS or IR MPDU before re-transmitting the request
NumMissedCPB	50		Number of consecutive CP beacons that fail to arrive before a Passive CP becomes an Active CP
NumNoData	100		Number of consecutive TDMA Epochs in which no TDMA data has been received on a connection before the connection is destroyed
NumToAdhoc	100		Number of consecutive CP beacons that fail to arrive before an A-node starts operating the ad-hoc synchronization procedures
PMinterval	1 min		Maximum time between power management requests by a node
PSinterval	4 s		Maximum time between checking the CP beacon for wake-up events by a PS node
PStimeout	1 s		Time after which a node can go in power saving mode if it has not received any relevant DATA MPDUs
ScanDurationPerChannel	(*NumberOfChannels*+1) * *SuperframeDuration*		Time spent looking for Synchronization Information per radio channel when scanning for a network
ScanHopIndex	North America and Europe, Japan, Spain, France	2	Hop Index to use in the generic scanning procedure

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Constant	Value		Description
ScanHopPattern	North America and Europe, Japan, Spain, France	57	Hop Pattern to use in the generic scanning procedure
ServiceSlotCW	16		Maximum number of dwells an I-node should backoff using the service slot access mechanism
SubframeDuration	10 ms		Duration of a subframe
SuperframeDuration	20 ms		Duration of a superframe
TDMAtolerance	1 symbol		Tolerance permitted in the time position of a transmitted TDMA MPDU relative to the station's DwCount
TRextensionTolerance	SIFs		Tolerance permitted a time reservation to be extended to allow an ACK MPDU with a tunneled CSDU as its payload to be transmitted

16.3 MAC Derived Values (Informative)

These values are derived by calculation from the MAC and PHY constants.

Parameter	Derivation	Value (Basic Modulation symbols)	Value (μs)	Description
DIFS	*SIFS* + *SlotDuration*	245	306.25	Shortest possible delay between the last symbol on air of a PPDU and the first symbol of a PPDU that is part of a separate CSMA/CA MPDU sequence. This interval includes the time to recover from any prior transmission, perform a CCA procedure and start a transmission.
Max Beacon Period Duration	Max Beacon MPDU duration	1341	1676	Maximum duration of the CP beacon period. Calculated assuming that stuff bits are added in the ratio of 1 stuff bit to every 64 bits of PPDU payload.
Emergency Case Beacon Period Duration	Beacon MPDU Duration	556	694	Duration of the CP Beacon in the *Emergency Case* (see section 5.5.3.5 (Permitted CFP Sizes)).
SIFS	*RxPHYdelay* + *MAC_CRCdelay* + *RxTxTurnround*	112	140	Shortest time between the last symbol of one PPDU and the first symbol of the next transmitted PPDU
SlotTime	*RxPHYdelay* +	133	166.25	Time taken to perform a CCA

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	CCAtime + MAC_CCAdelay + RxTxTurnround			procedure and start a transmission
MainDuration		440	550	Duration of a Main TDMA PPDU
RetryDuration		376	470	Duration of a Retry TDMA PPDU

16.4 NWK Constants

The parameters defined in Table 299 are used to control the operation of the NWK layer.

Table 299 - NWK Constants

Parameter	Value	Description
VoiceAnnouncementRepeatInterval	0.2 s	Maximum interval between C-plane page transmissions that identify a Voice Announcement

16.5 Node Parameters

The parameters defined in Table 300 can be used to manage the operation of a HomeRF node.

Table 300 - Node Parameters

Parameter	Value		R/W	Description
CapabilityRecord-ExpiryTime	10 - 10000 (default = 300)		RW	The time (in seconds) for which a station information database entry may remain in the cache without a refresh
DesiredNetworkType	Managed Any	1 2	RW	The type of network the node shall accept when scanning for a network with which to synchronize. When set to *managed*, the node shall only synchronize with a network which is controlled by a CP. When set to *any*, the Node can synchronize to either ad-hoc or managed networks.
DesiredNWID	3 byte number		RW	Network ID of the network that the node desires to join or start
HopIndex	1 Byte number 0 - (*NumberOfChannels-1*)		RO	Current Position within the hop pattern
HopPattern	1 Byte number		RO	The Hopping Pattern used by the node
Key	*KeyLength* bits		WO	The key used to encrypt the asynchronous data service
MACaddress	48-bit IEEE address format		RO	IEEE MAC address of the node
NodeType	A-node I-node	1 2	RO	HomeRF Device Type as defined by the

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Parameter	Value		R/W	Description
	AI-node Class-2 CP Class-1 CP Class-3 CP	3 4 5 6		HomeRF architecture
PowerManagement-ControlMode	non-PS PS	0 1	RW	In the non-PS mode, the node shall not request power-management services from the CP. In the PS mode, the node can request power-management services from the CP and subsequently enter a PS state.
PowerManagementState	Idle Disabled Enabled	0 1 2	RO	In the Idle state, the node is not part of a managed network. In the Disabled state, the node is not being power-managed by a CP. In the Enabled state, the node is being provided with power-management services by a CP.
SynchronizationState	Idle Scanning Managed Ad-hoc	0 1 2 3	RO	The current state of the node's Synchronization State variable
TxPowerLevel			RO	The transmit power level in mW

16.6 MD-SAP Statistics

The variables defined in Table 301 are provided by the MAC to provide management information relating to the operation of the asynchronous data service.

Table 301 - MD-SAP Statistics

Parameter	R/W	Description
RxBufErrorCount	RO	This counter shall increment when a DATA MPDU is discarded because there are insufficient resources (buffer space or re-assembly structures)
RxCRCerrorCount	RO	This counter shall increment when a DATA MPDU is discarded due to a payload CRC error.
RxMPDUcount	RO	This counter shall be incremented for each successfully received DATA MPDU.
RxMSDUcount	RO	This counter shall increment for each successfully received MSDU
RxMSDUfailureCount	RO	This counter shall increment each time a partly-reassembled received MSDU is discarded due to expiry of a *CSDUtimeout*
TxMPDUcount	RO	Number of Transmitted DATA MPDUs (regardless of success or failure)
TxMPDUfailureCount	RO	This counter shall increment when an ACK is not received

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Parameter	R/W	Description
		when expected for an MPDU.
TxMSDUcount	RO	This counter shall increment for each successfully transmitted MSDU
TxMSDUfailureCount	RO	This counter shall increment when a MSDU is not transmitted successfully due to the expiry of a *CSDUtimeout.*

16.7 Station Information Records

Table 302 defines information that a node shall store about other nodes in the network.

Table 302 - Station Information Record

Parameter	R/W	Description
Address	RO	MAC address of the node
Capability	RO	The capabilities of the node. See section 5.4.10.3 (Capabilities)
PStimeoutLeft	RO	The time (in ms) after which a PS node can go into low power mode if it has not received any messages

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16.8 Power-Saving Parameters

Table 303 defines the parameters that control the operation of a power-saving A-node.

Table 303 - Power-Saving Parameters

Parameter	R/W	Description
CPBlistenInterval	RW	The interval (in superframes) between times when the node wakes up to listen for CP beacons
RegAttemptInterval	RW	The duration (in superframes) between registration attempts for a power saving node

16.9 CP Parameters

Table 304 defines parameters that control the operation of a CP.

Table 304 - CP Parameters

Parameter	Value	R/W	Description
CPpriority	0-15	RW	The priority given to a CP (regardless of its active/passive status) relative to other such CPs on the network. ‘0’ means the lowest and ‘15’ is the highest priority. This is used by the CP during the CP negotiation procedure.
MaxTDMAcon-nectionsSupported	2 - *MaxMCconnections*	R	The maximum number of simultaneous TDMA connections that are supported by a CP
NumMinSubscriptions	8	R	The lowest upper bound on the number of subscription records held by a Class-1 CP.

16.10 Resource Group

Parameter	Value	R/W	Description
ProductName	Maximum string length is 128 bytes	RO	A null-terminated ASCII string used to identify the manufacturer's product name of the resource.
ProductVersion	Maximum string length is 128 bytes	RO	A null-terminated ASCII string used to identify the manufacturer's product version of the resource.
HomeRFversion	Maximum string length is 32 bytes Shall contain “HomeRF 2.0” for a node that is compliant with this specification.	RO	A null-terminated ASCII string used to identify the version of the HomeRF implemented on the device.

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APPENDIX A - LOCALIZATIONS

1. Countries for which the North American hopping sequence can be used

The countries on the following list have a spectrum allocation that allows the use of the hopping pattern specified for the North American location.

Australia
Austria
Belgium
Canada
Denmark
Finland
Germany
Greece
Hong Kong
Iceland
Ireland
Italy
Japan
Korea
Liechtenstein
Luxembourg
Monaco
Netherlands
New Zealand
Norway
Portugal
South Africa
Spain
Sweden
Switzerland
Taiwan
Turkey

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United Kingdom
US

2. Localization for France, Mexico, and Singapore

Region	BaseFrequency (MHz)	ChannelSeparation (MHz)	NumberOfChannels	BaseChannel
France, Mexico, Singapore	2400	1	27	52

Base Hopping Sequence for France, Mexico, and Singapore					
I	b(I)	I	b(I)	I	b(I)
0	13	10	8	20	20
1	4	11	23	21	5
2	24	12	15	22	16
3	18	13	22	23	2
4	5	14	9	24	11
5	12	15	21	25	17
6	3	16	0	26	26
7	10	17	6		
8	25	18	14		
9	19	19	1		

3. Localization for Israel

Region	BaseFrequency (MHz)	ChannelSeparation (MHz)	NumberOfChannels	BaseChannel
Israel	2400	1	27	25

Base Hopping Sequence for Israel
Identical to France, Mexico, Singapore sequence, above.

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4. Localization for Saudi Arabia

Region	BaseFrequency (MHz)	ChannelSeparation (MHz)	NumberOfChannels	BaseChannel
Saudi Arabia	2400	1	21	16

Base Hopping Sequence for Saudi Arabia					
I	b(I)	I	b(I)	I	b(I)
0	0	10	17	20	14
1	13	11	5		
2	8	12	18		
3	19	13	9		
4	10	14	15		
5	4	15	3		
6	11	16	16		
7	6	17	1		
8	20	18	12		
9	2	19	7		

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APPENDIX B - ARCHITECTURE NOTATION (INFORMATIVE)

This section introduces the concepts and language used to describe the HomeRF architecture.

An architecture block provides one or more services to client (or higher-layer) blocks.

B.1 Service Access Point

Services are accessed through a named *service access point* (or SAP). A SAP that provides peer-peer services is drawn on top of the architectural block providing that service. Where necessary, there is also a SAP that provides access to management primitives.

B.2 Service Primitives

Associated with each service are one or more service *primitives*, each of which may take parameters. Primitives reflect a layered architecture that places layers above and below one another. Primitives generally map on to the exchange of messages between architectural entities. There are four types of primitive as described in Table 305.

Table 305 - The Four Service Primitive Types

Primitive Type	**Description**
Request (Req)	A primitive initiated by a higher layer
Confirm (Conf)	The response by the lower layer to a *Request* primitive
Indication (Ind)	A primitive initiated by a lower layer
Response (Resp)	The response by the higher layer to an *Indication* primitive

So, for example, consider a hypothetical interface between a MAC layer and its client DLC layer. DLC 1 attempts to set up a MAC connection using the MAC's connection-oriented data, accessed through its MC-SAP (MAC, Connection-oriented, Service Access Point).

The service primitive associated with connection setup is called "CON".

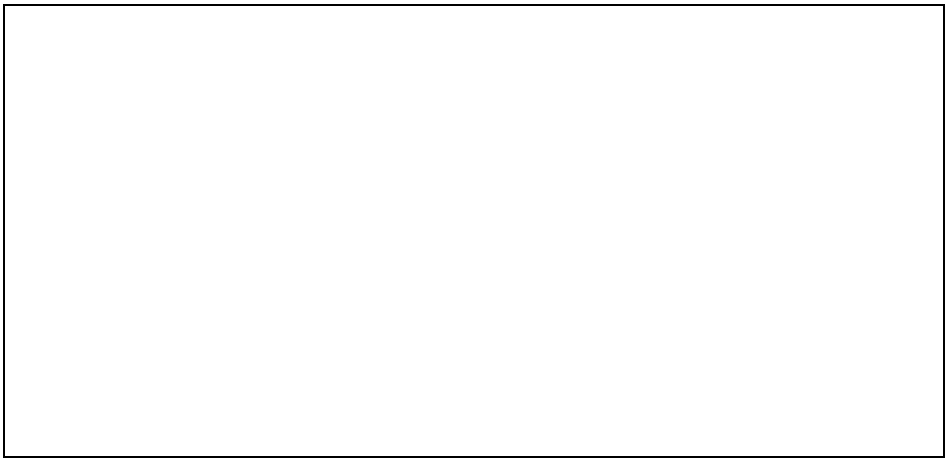


Figure 210 - Architectural Entities

In order to perform the requested primitive, the two MACs exchange one or more peer-peer messages, called MPDUs (Mac Protocol Data Units). The DLC entities are not aware of this exchange.

DLC 1 issues a connection request (CON.req) to its MAC (MAC 1). This communicates with its peer entity (MAC 2) through the exchange of one or more MPDUs. The second MAC indicates the connection setup to its DLC by sending it a CON.ind primitive. DLC 2 eventually responds with a CON.resp primitive. Some time later, MAC 1 confirms the connection establishment to DLC 1 by sending it a CON.conf primitive.

This exchange of primitives is best shown as a message sequence diagram. This shows the sequence of the exchange of these primitives.

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Figure 211 - Example Message Sequence Diagram

The individual primitives are documented in a tabular form. For this example, the following definition could apply:

Primitive	CON			
Description	MAC connection setup			
Parameters	**Req (I-node)**	**Conf (I-node)**	**Ind (CP)**	**Resp (CP)**
Connection ID			M	M
I-node MAC Address			O	
Notes:	M - Mandatory O – Optional			

This should be read to mean that the I-node supports request and confirm messages, which take no parameters. The CP supports indication and response messages. Both carry a mandatory *Connection ID* parameter. In addition, the indication carries an optional *I-node MAC Address* parameter.

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B.3 CSMA/CA Terminology (Informative)

The MAC asynchronous data service transports packets of user data from one HomeRF node to one or more other nodes.

The *MAC user* is the source of the data. The individual packet of user data is called the *MAC service data unit* (MSDU). The *MAC entity* operates the MAC procedures. These involve exchanging *MAC protocol data units* (MPDUs) both to carry the MAC user data and to manage the operation of the MAC entity. The MPDUs are organized on-air into *MPDU sequences*, the shortest of which are *atomic* MPDU sequences.

Within the MAC entity, the data service is provided by two processes: MD-SAP services and CSMA/CA. The CSMA/CA provides a CSMA/CA data service which exchanges CSMA/CA service data units (CSDUs).

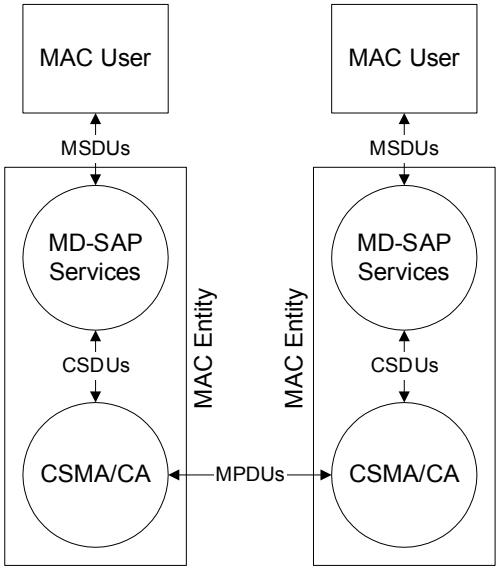


Figure 212 - CSMA/CA Terminology

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APPENDIX C (ENCRYPTION CORE ALGORITHM)

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APPENDIX D – SPECIFICATIONS

Table 306 - PHY Specifications

ITEM	REFERENCE	Class-1 CP	Class-2 CP	Class-3 CP	A-node	S-node	I-node
Channel Settling Time	4.7.3 and 16.1	*HopDuration* ± 50 ppm					
Clear Channel Assessment (CCA) @ 90% probability	Table 55 and Table 56	LR 2-FSK Idle to busy threshold >= *–75 dBm* HR 2-FSK Idle to busy threshold >= *–80 dBm* Busy to idle threshold >= *–61 dBm*					LR 2-FSK Idle to busy threshold >= *–80 dBm* Busy to idle threshold >= *–66 dBm*
Carrier Deviation to d-symbol for LR 2-FSK	Table 40	d-symbol 0: Nominal = +*Fd*/2 Accuracy = ± 20 kHz					
		d-symbol 1 Nominal = –*Fd*/2 Accuracy ± 20 kHz					
Carrier Deviation to d-symbol for LR 4-FSK	Table 42	d-symbol (b1,b0) 00: Nominal = +*Fd*/2 Accuracy = ± 15 kHz					
		d-symbol (b1,b0) 01: Nominal = +*Fd*/6 Accuracy ± 10 kHz					
		d-symbol (b1,b0) 10: Nominal = –*Fd*/6 Accuracy ± 10 kHz					
		d-symbol (b1,b0) 11: Nominal = –*Fd*/2 Accuracy = ± 15 kHz					
Carrier Deviation to d-symbol for HR 2-FSK	Table 45	d-symbol 0: Nominal = +*Fd*/2 Accuracy = ± 70 kHz					
		d-symbol 1 Nominal = –*Fd*/2 Accuracy ± 70 kHz					

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ITEM	REFERENCE	Class-1 CP	Class-2 CP	Class-3 CP	A-node	S-node	I-node
Carrier Deviation to d-symbol for HR 4-FSK	Table 47	d-symbol (b1,b0) 00: Nominal = +*Fd*/2 Accuracy = ± 60 kHz					
		d-symbol (b1,b0) 01: Nominal = +*Fd*/6 Accuracy ± 40 kHz					
		d-symbol (b1,b0) 10: Nominal = –*Fd*/6 Accuracy ± 40 kHz					
		d-symbol (b1,b0) 11: Nominal = –*Fd*/2 Accuracy = ± 60 kHz					
Frequency Deviation Constraints for LR 2-FSK	Table 39	Minimum *Fd* 200 kHz Nominal *Fd* 280 kHz Maximum *Fd* 350 kHz					
Frequency Deviation Constraints for LR 4-FSK	Table 41	Minimum *Fd* 270 kHz Nominal *Fd* 315 kHz Maximum *Fd* 380 kHz					
Frequency Deviation Constraints for HR 2-FSK	Table 44	Minimum *Fd* 1400 kHz Nominal *Fd* 1550 kHz Maximum *Fd* 1750 kHz					
Frequency Deviation Constraints for HR 4-FSK	Table 46	Minimum *Fd* 1800 kHz Nominal *Fd* 2000 kHz Maximum *Fd* 2250 kHz					
Modulation Type – LR 2-FSK	4.5.1.1.1	M	M	M	M	M	M
Modulation Type – LR 4-FSK	4.5.1.1.2	O	O	O	O	O	X
Modulation Type – HR 2-FSK	4.5.1.2.1	M	M	M	M	M	X
Modulation Type – HR 4-FSK	4.5.1.2.2	M	M	M	M	M	X

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ITEM	REFERENCE	Class-1 CP	Class-2 CP	Class-3 CP	A-node	S-node	I-node
Occupied Channel Bandwidth	4.5.4	Localization value					
Operating Temperature Range	4.7.6	+10 to +40 ^{o}C ambient temperature					
Pre-modulation Filter Bandwidth for high-rate modulation (recommended)	Table 43	3 dB Bandwidth B = 2.50 MHz Equivalent BT product = 0.50					
PPDU format: *TDMA* PPDU	Table 29	M	X	X	X	X	M
PPDU format: *Basic Rate Single PSDU* PPDU	Table 29	M	M	M	M	M	X
PPDU format: *Extended Preamble High Rate Single PSDU* PPDU	Table 29	M	M	M	M	M	X
PPDU format: *Dual PSDU* PPDU	Table 29	O	O	O	O	O	X
PPDU format: *Dual Beacon* PPDU	Table 29	[1]	[2]	[2]	[2]	[2]	[3]
Receive Error-rate Performance Limits	Table 51	3 % FER for payload PSDU of 400 bytes (pseudo-random data) (Alternate measurement of 30 % FER with 1 dB margin added)					3 % FER for a standard TDMA PSDU (pseudo-random data) (Alternate measurement of 30 % FER with 1 dB margin added)
Receive to Transmit turn around time	4.7.4 and 16.1	*RxTxTurnround*					

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ITEM	REFERENCE	Class-1 CP	Class-2 CP	Class-3 CP	A-node	S-node	I-node
Receiver Center Frquency Acceptance Range	4.6.3	± 50 ppm from nominal					
Receiver Intermodulation Test Parameters	Table 52	LR 2-FSK Δf1=9 MHz, Δf2=18 MHz, Minimum *IMp*=20 dB LR 4-FSK Δf1=9 MHz, Δf2=18 MHz, Minimum *IMp*=15 dB HR 2-FSK Δf1=12 MHz, Δf2=24 MHz, Minimum *IMp*=TBD HR 4-FSK Δf1=12 MHz, Δf2=24 MHz, Minimum *IMp*=TBD					
Receiver Sensitivity Threshold	Table 51	LR 2-FSK < –75 dBm LR 4-FSK < –65 dBm HR 2-FSK < –80 dBm HR 4-FSK < –70 dBm					LR 2-FSK < –80 dBm
Settling Time for low-rate modulation	4.5.1.1.3	Maximum 750 ns					
Settling Time for high-rate modulation	Table 48	Minimum 165 ns Nominal 200 ns Maximum 250 ns					X
Symbol Rate Tolerance	4.7.5	low-rate ± 50 ppm high-rate ± 50 ppm					low-rate ± 50 ppm
Training Sequences	4.2.2 and 4.2.3	TDMA (TTS) 16 d-symbols CSMA LR 2-FSK (L2TS) 64 d-symbols CSMA LR 4-FSK (L4TS) 64 d-symbols CSMA HR 2-FSK (H2TS) 540 d-symbols CSMA HR 4-FSK (H4TS) 540 d-symbols					
Transition Time for low-rate modulation	4.5.1.1.3	2-FSK Maximum 250 ns 4-FSK Maximum 150 ns					2-FSK Maximum 250 ns
Transition Time for high-rate modulation	Table 48	Minimum 70 ns Nominal 85 ns Maximum 105 ns					X
Transmit Center Frquency Tolerance	4.5.7	± 50 ppm measured from *Fc*					
Transmit Output Power[4]	Table 49 and Table 50	Class 1 (Normal) minimum = 16 dBm, maximum =	Class 1 (Normal) minimum = 16 dBm, maximum = 21 dBm		Class 1 (Normal) minimum = 16 dBm, maximum = 21 dBm		Class 1 (Normal) minimum = 12 dBm, maximum = 30 dBm

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ITEM	REFERENCE	Class-1 CP	Class-2 CP	Class-3 CP	A-node	S-node	I-node
		30 dBm for non-contention period transmissions, otherwise 21 dBm			Class 2 (Low) minimum = 0 dBm, maximum = 4 dBm		Class 2 (Low) minimum = 0 dBm, maximum = 4 dBm
Unwanted Emission	4.5.5	Localization value					

NOTES

M – Mandatory support of this item

O – Optional support of this item

X – Not applicable

[1] – Mandatory transmission of both the *PSDU1* (TDMA Beacon) and *PSDU2* (CP2 Beacon)

[2] – Mandatory reception of *PSDU2* (CP2 Beacon) when part of a class 1 managed network

[3] – Mandatory reception of the *PSDU1* (TDMA Beacon)

[4] – Any HomeRF device must conform to applicable local regulations such as those described in the FCC Part 15 rules or ETS 300 328

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Table 307 - HomeRF Node Differentiated Requirements of Procedures, Services, and Mechanisms

Procedure / Service / Mechanism	HomeRF Node Type							
	Class-1 CP	Class-2 CP	Class-3 CP	A-node	I-node	AI-node	S-node	SI-node
A-node power-management services	M	M	X	X	X	X	X	X
A-node power-management services	M	M	X	X	X	X	X	X
A-node Power-saving	X	1 and 5	1 and 5	5	X	5	5	5
A-node Power-supporting	M	M	M	5	X	5	5	5
Asynchronous Data Roaming	5	5	X	5	X	O	X	X
Asynchronous Data Service	M	M	M	M	X	M	M	M
Authentication Code – Manual Entry of the AC user interface procedure	O	X	X	X	12	12	X	12
Authentication Code - Presentation of an AC user interface procedure	12	X	X	X	X	X	X	X
CLMS	O	X	X	X	O	O	X	O
Compression capability	2	2	2	2	X	2	2	2
Connection management	M	X	X	X	M	X	X	M
Connection Point Negotiation Mechanism (CP Assertion)	M	M	M	X	X	X	X	X
CSMA/CA Access mechanism	M	M	M	M	X	M	M	M
DECT - GAP	14	X	X	X	14	14	X	14
DECT - Incoming call – group ringing	M	X	X	X	M	M	X	M
DECT - Incoming call normal	O	X	X	X	M	M	X	M
DECT - Intercom call	16	X	X	X	15	15	X	15
DECT – Outgoing call	M	X	X	X	M	M	X	M
DECT – Temporary Identity Assignment	20	X	X	X	M	M	X	M
DECT - Voice support	O	X	X	X	O	O	X	O
Directed Learn Network user interface procedure	X	O	O	O	X	O	O	O

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Directed Teach Network user interface procedure	O	O	O	9	X	9	X	X
Encryption capability for asynchronous data	2, 6	2, 6	2, 6	2, 6	X	2, 6	2, 6	2, 6
Encryption capability for isochronous data (TDMA encryption)	6	X	X	X	O	O	X	O
Fast Unacknowledged Service Mechanism	O	O	O	O	X	O	O	O
Hopset Adaption	M	7	7	7	M	M	7	M
I-node - Multiple Subscription Records	X	X	X	X	O	O	X	O
I-node - Authentication	12	X	X	X	12	12	X	12
I-node - Power Saving	X	X	X	X	O	O	X	O
I-node - Presentation of the Extension Number user interface procedure	M	X	X	X	O	O	X	O
I-node - Removal of I-node user interface procedure	M	X	X	X	X	X	X	X
IEEE MAC Address - Manual Entry of an IEEE MAC Address user interface procedure	10	10	10	10	X	10	X	X
IEEE MAC Address - Presentation of an IEEE MAC Address user interface procedure	10	10, 11	10, 11	10, 11	X	10, 11	11	11
Isochronous Connectionless Broadcast service	4	X	X	X	4	4	X	4
Isochronous Data Service	M	X	X	X	M	M	X	M
IWU features - Call forward	O	X	X	X	O	O	X	O
IWU features - Call hold	O	X	X	X	O	O	X	O
IWU features - Call transfer	O	X	X	X	O	O	X	O
IWU features - Communicating manufacturer name and product ID	O	X	X	X	O	O	X	O
IWU features - Computer call	3	X	X	X	15	15	X	15
IWU features - Intercom conferencing	O	X	X	X	O	O	X	O
IWU features - Manufacturer-specific Extensions	O	X	X	X	O	O	X	O

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IWU features - Pickup conferencing	M	X	X	X	X	X	X	X
IWU features - Remote Off-Hook	O	X	X	X	O	O	X	O
IWU features - Silent polling	O	X	X	X	O	O	X	O
Key - Manual Entry of the Key user interface procedure	13	13	13	13	X	13	13	13
Key - Presentation of the Key user interface procedure	13	13	13	O	X	O	O	O
Learn Network user interface procedure	X	O	O	O	M	M	O	M
Modulation capability	2	2	2	2	X	2	2	2
Multicast power-supporting	M	M	X	X	X	X	X	X
Multi-rate data service	2	2	2	2	X	2	2	2
NWID - Manual Entry of the NWID user interface procedure	17	17	17	18	19	18	18	18
NWID - Presentation of the NWID user interface procedure	M	M	M	O	O	O	O	O
PC connectivity	O	O	O	O	X	O	O	O
Priority Asynchronous Data Service	M	M	M	X	X	X	M	M
Promiscuous DATA Reception	O	O	O	O	X	O	O	O
Service Slot Access Mechanism	X	X	X	X	M	O	X	O
Session management	M	M	M	X	X	X	M	M
Synchronization within an ad-hoc network	X	X	X	O	X	O	O	X
Synchronization within a managed network	M	M	X	M	M	M	M	M
TDMA Access mechanism	M	X	X	X	M	M	X	M
TDMAack Field - full feature behavior	O	X	X	X	X	X	X	X
Teach Network user interface procedure	M	M	M	8	X	8	X	X
Time Reservation mechanism	M	M	M	M	X	M	M	M
Time Reservation w. RTS-CTS mechanism	O	O	O	O	X	O	O	O
Time Reserved Atomic MPDU Sequence format	2	2	2	2	X	2	2	2

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Transmit Output Power Capability - CSMA	Class 1	Class 1	Class 1	[2]	X	[2]	[2]	[2]
Transmit Output Power Capability - TDMA	Class 1	X	X	X	Class 1 or Class 2	Class 1 or Class 2	X	Class 1 or Class 2
Voice Stack	M	X	X	X	[15]	[15]	X	[15]

NOTES

M – Mandatory support of this item

O – Optional support of this item

X – Not applicable

[1] – Only permitted when acting as a Passive CP

[2] – Behavior as indicated in the Base Capabilities of the Station Information

[3] – Mandatory for a CP operating autonomous or slave mode, not applicable for standalone mode

[4] – Support for ICBS C-Plane data is mandatory; support for ICBS U-plane data is optional

[5] – Behavior as indicated in the Managed Capabilities of the Station Information

[6] – Mandatory in the U.S., otherwise optional

[7] – Mandatory if part of a Class-1 managed network

[8] – Mandatory if node is capable of operating in an ad-hoc network, otherwise optional

[9] – Optional if node is capable of operating in an ad-hoc network, otherwise not applicable

[10] – Mandatory if the node supports Directed Teach HomeRF

[11] – Mandatory if the node supports the "Directed Learn *NWID" procedure*

[12] – Mandatory if the node supports TDMA Encryption, otherwise not allowed

[13] – Mandatory if the node supports Encryption for asynchronous data, otherwise not allowed

[14] – As defined by the DECT GAP and profiled in this specification

[15] – Mandatory for a node that supports DECT voice. This specification does allow for a Non-Voice I-node (see section 10.6)

[16] – Mandatory for a CP operating autonomous or slave mode, optional for standalone mode

[17] – Mandatory if the node supports Roaming

[18]– Mandatory if the Learn Network or Directed Learn Network procedures are not supported

[19]– Mandatory if the Learn Network procedure is not supported

[20]– Mandatory to obtain a connectionless group TPUI if the group ringing of defined sets of I-nodes is required

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