IEEE Standards

802.15.1™

**IEEE Standard for Information technology—
Telecommunications and information exchange between systems—
Local and metropolitan area networks—
Specific requirements**

Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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Approved 15 April 2002

IEEE-SA Standards Board

Abstract: The lower transport layers [(Logical Link Control and Adaptation Protocol (L2CAP), Link Manager Protocol (LMP), baseband, and radio] of the Bluetooth™ wireless technology are defined. Bluetooth is an industry specification for short-range radio frequency (RF)-based connectivity for portable personal devices. The IEEE 802.15.1 Task Group has reviewed and provided a standard adaptation of the Bluetooth specifications (version 1.1) medium access control (MAC) (L2CAP, LMP, and baseband) and physical layer (PHY) (radio). Also specified is a clause on service access points (SAPs), which includes a logical link control (LLC)-MAC interface for the ISO/IEC 8802-2 LLC. A normative annex is included that provides a Protocol Implementation Conformance Statement (PICS) proforma, and an informative high-level behavioral ITU-T Z.100 specification and description language (SDL) model for an integrated Bluetooth MAC sublayer are also specified.

Keywords: ad hoc network, Bluetooth, Bluetooth wireless technology, circuit switching, FH-CDMA, frequency-hopping code division multiple access, mobile, mobility, nomadic, packet switching, piconet, radio, radio frequency, scatternet, short-range, ubiquitous computing and communications, wearables, wireless, wireless personal area network, WPAN.

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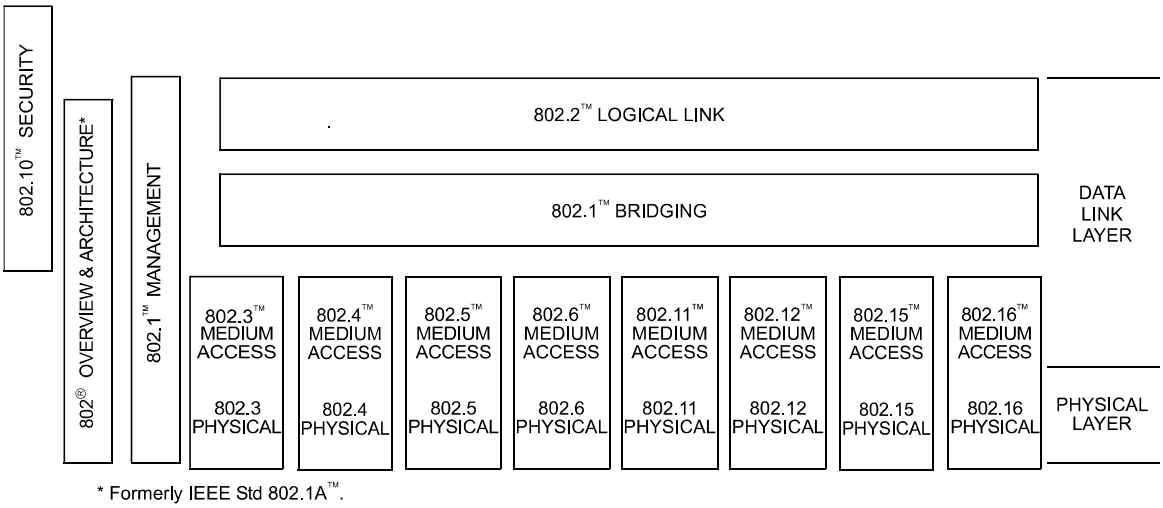
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Introduction

[This introduction is not part of IEEE Std 802.15.1-2002, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs).]

This standard is part of a family of standards for local and metropolitan area networks. The relationship between the standard and other members of the family is shown below. (The numbers in the figure refer to IEEE standards numbers.[1]) This standard focuses only on the medium access control (MAC) and physical layer (PHY) of an 802.15.1 wireless personal area network (WPAN).



This family of standards deals with the Physical and Data Link Layers as defined by the International Organization for Standardization (ISO) Open Systems Interconnection Basic Reference Model (ISO/IEC 7498-1:1994). The access standards define several types of medium access technologies and associated physical media, each appropriate for particular applications or system objectives. Other types are under investigation.

The standards defining the technologies noted above are as follows:

• IEEE Std 802:[2, 3] — *Overview and Architecture*. This standard provides an overview to the family of IEEE 802 Standards. This document forms part of the IEEE Std 802.1 scope of work.

• IEEE Std 802.1B™ and 802.1K™ [ISO/IEC 15802-2]: — *LAN/MAN Management*. Defines an Open Systems Interconnection (OSI) management-compatible architecture, and services and protocol elements for use in a LAN/MAN environment for performing remote management.

• IEEE Std 802.1D™ — *Media Access Control* (*MAC) Bridges*. Specifies an architecture and protocol for the [ISO/IEC 15802-3]: interconnection of IEEE 802 LANs below the MAC service

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[3]The IEEE 802 Architecture and Overview Specification, originally known as IEEE Std 802.1A, has been renumbered as IEEE Std 802. This has been done to accommodate recognition of the base standard in a family of standards. References to IEEE Std 802.1A should be considered as references to IEEE Std 802.

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• IEEE Std 802.1E™ [ISO/IEC 15802-4]:	*System Load Protocol*. Specifies a set of services and protocol for those aspects of management concerned with the loading of systems on IEEE 802 LANs.
• IEEE Std 802.1F™	*Common Definitions and Procedures for IEEE 802 Management Information*.
• IEEE Std 802.1G™ [ISO/IEC 15802-5]:	*Remote Media Access Control (MAC) Bridging*. Specifies extensions for the interconnection, using non-LAN systems communication technologies, of geographically separated IEEE 802 LANs below the level of the logical link control protocol.
• IEEE Std 802.1H™	*Recommended Practice for Media Access Control (MAC)*
[ISO/IEC TR 11802-5]	*Bridging of Ethernet V2.0 in IEEE 802 Local Area Networks*.
• IEEE Std 802.1Q™	*Virtual Bridged Local Area Networks*. Defines an architecture for Virtual Bridged LANs, the services provided in Virtual Bridged LANs, and the protocols and algorithms involved in the provision of those services.
• IEEE Std 802.2 [ISO/IEC 8802-2]:	*Logical Link Control*.
• IEEE Std 802.3 [ISO/IEC 8802-3]:	*CSMA/CD Access Method and Physical Layer Specifications*.
• IEEE Std 802.4 [ISO/IEC 8802-4]:	*Token Bus Access Method and Physical Layer Specifications*.
• IEEE Std 802.5 [ISO/IEC 8802-5]:	*Token Ring Access Method and Physical Layer Specifications*.
• IEEE Std 802.6 [ISO/IEC 8802-6]:	*Distributed Queue Dual Bus Access Method and Physical Layer Specifications*.
• IEEE Std 802.10:	*Interoperable LAN/MAN Security.* Currently approved: Secure Data Exchange (SDE).
• IEEE Std 802.11: [ISO/IEC 8802-11]	*Wireless LAN Medium Access Control (MAC) Sublayer and Physical Layer Specifications.*
• IEEE Std 802.12: [ISO/IEC 8802-12]	*Demand Priority Access Method, Physical Layer and Repeater Specification*.
• IEEE Std 802.15:	*Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for: Wireless Personal Area Networks.*
• IEEE Std 802.16:	*Air Interface for Fixed Broadband Wireless Access Systems*.
• IEEE Std 802.17™:	*Resilient Packet Ring Access Method and Physical Layer Specifications.*

In addition to the family of standards, the following is a recommended practice for a common physical layer technology:

• IEEE Std 802.7™:	*IEEE Recommended Practice for Broadband Local Area Networks*.

The reader of this standard is urged to become familiar with the complete family of standards.

Conformance test methodology

Products built based on this standard are considered to conform to (or be compliant with) this standard if they pass the Bluetooth™ qualification program as set forth by the Bluetooth Special Interest Group (SIG), Inc. More information can be found at http://ieee802.org/15/Bluetooth/.

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IEEE Std 802.15.1-2002 has been derived from the Bluetooth specifications (version 1.1) (see 2.4). This standard provides the reader with the lower layers of the Bluetooth specifications or MAC and PHY:

- The radio frequency (RF) layer, specifying the radio parameters.
- The baseband layer, specifying the lower level operations at the bit and packet levels, i.e., forward error correction (FEC) operations, encryption, cyclic redundancy check (CRC) calculations, and automatic repeat request (ARQ) protocol.
- The link manager (LM) layer, specifying connection establishment and release, authentication, connection and release of synchronous connection-oriented (SCO) and asynchronous connectionless (ACL) channels, traffic scheduling, link supervision, and power management tasks.
- The Logical Link Control and Adaptation Protocol (L2CAP) layer, which has been introduced to form an interface between standard data transport protocols and the Bluetooth protocol. It handles the multiplexing of higher layer protocols and the segmentation and reassembly (SAR) of large packets.

Additionally, the IEEE has conducted numerous ballots and provided all comments back to the Bluetooth SIG, Inc. as errata. These errata have in turn been reviewed and in some cases adopted into the Bluetooth specification.

This standard contains state-of-the-art material. The area covered by this standard is undergoing evolution. Revisions are anticipated to this standard within the next few years to clarify existing material, to correct possible errors, and to incorporate new related material.

There is a body of generally available industry information quantifying the level of over-the-air coexistence between 802.15.1 and 802.11. Additional information may be obtained from the anticipated IEEE 802.15.2™ Recommended Practice for Coexistence of Wireless Personal Area Networks with Other Wireless Devices Operating in Unlicensed Frequency Bands (available in draft form as P802.15.2 at the time of this publication) that deals specifically with the coexistence issue.[3]

Information on the current revision state of this and other IEEE 802 standards may be obtained from:

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[3]This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE (http://standards.ieee.org). Upon approval of IEEE P802.15.2 by the IEEE-SA Standards Board, this draft will be superceded by the approved standard and published as IEEE Std 802.15.2-2003. Approval is expected in early 2003.

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IEEE Standard for Information technology—
Telecommunications and information exchange between systems—
Local and metropolitan area networks—
Specific requirements

Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)

1. Overview

Wireless personal area networks (WPANs) are used to convey information over short distances among a private-intimate group of participant devices. Unlike a wireless local area network (WLAN), a connection made through a WPAN involves little or no infrastructure or direct connectivity to the world outside the link. This allows small, power-efficient, inexpensive solutions to be implemented for a wide range of devices.

1.1 Scope

This standard defines physical layer (PHY) and medium access control (MAC) specifications for wireless connectivity with fixed, portable, and moving devices within or entering a personal operating space (POS). A goal of the IEEE 802.15.1™ Task Group is to achieve a level of interoperability that could allow the transfer of data between a WPAN device and an IEEE 802.11™ device.

A POS is the space about a person or object that typically extends up to 10 m in all directions and envelops the person whether stationary or in motion. This standard has been developed to ensure coexistence with all IEEE 802.11 networks.

1.2 WPAN definition

The term *WPAN* in this standard refers specifically to a wireless personal area network as used in this standard.

Specifically, this standard:

- Describes the functions and services required by an IEEE 802.15.1 device to operate within ad hoc networks.
- Describes the MAC procedures to support the asynchronous connectionless (ACL) and synchronous connection-oriented (SCO) link delivery services:
  - The baseband layer, specifying the lower level operations at the bit and packet levels, e.g., forward error correction (FEC) operations, encryption, cyclic redundancy check (CRC) calculations, Automatic Repeat Request (ARQ) Protocol.
  - The link manager (LM) layer, specifying connection establishment and release, authentication, connection and release of SCO and ACL channels, traffic scheduling, link supervision, and power management tasks.

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- The link manager (LM) layer, specifying connection establishment and release, authentication, connection and release of SCO and ACL channels, traffic scheduling, link supervision, and power management tasks.
- The Logical Link Control and Adaptation Protocol (L2CAP) layer, forming an interface between standard data transport protocols and the Bluetooth™ protocol. It handles the multiplexing of higher layer protocols and the segmentation and reassembly (SAR) of large packets. The data stream crosses the LM layer, where packet scheduling on the ACL channel takes place. The audio stream is directly mapped on an SCO channel and bypasses the LM layer. The LM layer, though, is involved in the establishment of the SCO link. Between the LM layer and the application, control messages are exchanged in order to configure the Bluetooth transceiver for the considered application.

— Describes the 2.4 GHz industrial, scientific, medical (ISM) band PHY signaling techniques and interface functions that are controlled by the IEEE 802.15.1 MAC. Requirements are defined for two reasons:

- To provide compatibility between the radios used in the system.
- To define the quality of the system.

Above the L2CAP layer may reside the Serial Cable Emulation Protocol based on ETSI TS 07.10 (RFCOMM), Service Discovery Protocol (SDP), Telephone Control Protocol specification (TCS), voice-quality channels for audio and telephony, and other network protocols.

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2. References

The following standards and specifications contain provisions that, through references in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards and specifications are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the references listed below.

2.1 IEEE documents

IEEE Std 802®-2001, IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture.[3, 4]

2.2 ISO documents

ISO/IEC 3309:1993 Information technology—Telecommunications and information exchange between systems—High-level data link control (HDLC) procedures—Frame structure.[5]

ISO/IEC 7498-1:1994, Information technology—Open Systems Interconnection—Basic Reference Model: The Basic Model.

ISO/IEC 8802-2:1998, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 2: Logical link control.

ISO/IEC 10039:1991, Information technology—Open Systems Interconnection—Local Area Networks—Medium Access Control (MAC) Service Definition.

ISO/IEC 15802-1:1995, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 1: Medium Access Control (MAC) service definition.

2.3 ITU documents

ITU-T Recommendation G.711 (11/88), Pulse code modulation (PCM) of voice frequencies.[6]

ITU-T Recommendation O.150 (05/96), Digital test patterns for performance measurements on digital transmission equipment.

ITU-T Recommendation O.153 (10/92), Basic parameters for the measurement of error performance at bit rates below the primary rate.

ITU-T Recommendation X.200 (07/94), Information technology—Open systems interconnection—Basic reference model: The basic model.

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[5]ISO/IEC publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iso.ch/). ISO/IEC publications are also available in the United States from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/). Electronic copies are available in the United States from the American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[6]ITU-T publications are available from the International Telecommunications Union, Place des Nations, CH-1211, Geneva 20, Switzerland/Suisse (http://www.itu.int/).

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ITU-T Recommendation Z.100 (11/99), Programming languages—Specification and description language (SDL).

2.4 Bluetooth documents[7]

2.4.1 Bluetooth Core Specification Volume 1

Bluetooth Special Interest Group, "Core Specification Version 1.1," Specification of the Bluetooth System, February 22, 2001. [Bluetooth_11_Specifications_Book.pdf]

2.4.2 Bluetooth Profiles Specification Volume 2

Bluetooth Special Interest Group, "Profiles Specification Version 1.1," Specification of the Bluetooth System, February 22, 2001. [Bluetooth_11_Profiles_Book.pdf]

2.4.3 Bluetooth Assigned Numbers

Bluetooth Special Interest Group, "Bluetooth Assigned Numbers Version 1.1," Specification of the Bluetooth System, February 22, 2001. [Bluetooth_11_Assigned_Numbers.pdf]

2.4.4 Bluetooth continuous variable slope delta (CVSD) encoded test signal

Bluetooth Special Interest Group, "Bluetooth CVSD encoded test signal Version 2.1," A test signal file providing the digital CVSD encoded test signal as referred to in the Bluetooth Specification, February 22, 2001. [BluetoothSpecFiles_new_tar.gz]

2.4.5 Bluetooth Personal Area Networking Profile

Bluetooth Special Interest Group, "Bluetooth Personal Area Networking Profile Revision 0.95a," June 26, 2001. [PAN-Profile.pdf]

2.4.6 Bluetooth Network Encapsulation Protocol (BNEP) Specification

Bluetooth Special Interest Group, "Bluetooth Network Encapsulation Protocol (BNEP) Specification Revision 0.95a," June 12, 2001. [BNEP.pdf]

2.5 Other documents

Infrared Data Association, IrDA Object Exchange Protocol (IrOBEX), Version 1.2, April 1999.[8]

Internet Engineering Task Force, "A Proposed Flow Specification," RFC 1363, September 1992.[9]

Internet Engineering Task Force, "The Point-to-Point Protocol (PPP)," RFC 1661, July 1994.

[7]Bluetooth documents are available from: http://www.bluetooth.com/dev/specifications.asp or via the IEEE website: http://ieee802.org/15/Bluetooth/.

[8]IrDA documents are available from http://www.irda.org/.

[9]Internet Engineering Task Force documents are available from http://www.ietf.org/.

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3. Definitions

For the purposes of this standard, the following terms and definitions apply. *IEEE 100™*, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B4][9], should be referenced for terms not defined in this clause.

3.1 ad hoc network: A network typically created in a spontaneous manner. The principal characteristic of an ad hoc network is its limited temporal and spatial extent.

3.2 asynchronous connectionless (ACL) link: A point-to-multipoint link between the master and all the slaves participating on the piconet. In the slots not reserved for the synchronous connection-oriented (SCO) links, the master can establish an ACL link on a per-slot basis to any slave, including the slaves already engaged in an SCO link.

3.3 attachment gateway (AG): A communications node with at least two communication interfaces, one of which is a Bluetooth interface and one of which is an interface to another network. An AG is used to attach a Bluetooth wireless personal area network (WPAN) to the other network. In particular, an 802 local area network (LAN) AG attaches a Bluetooth WPAN to an 802 LAN, while a public switched telephone network (PSTN) AG attaches a Bluetooth WPAN to the PSTN.

3.4 authenticated device: A Bluetooth device whose identity has been verified during the lifetime of the current link, based on the authentication procedure.

3.5 authentication: A generic procedure based on Link Manager Protocol (LMP) authentication if a link key exists or on LMP-pairing if no link key exists.

3.6 authorization: A procedure where a user of a Bluetooth device grants a specific (remote) Bluetooth device access to a specific service. Authorization implies that the identity of the remote device can be verified through authentication.

3.7 authorize: The act of granting a specific Bluetooth device access to a specific service. It may be based on user confirmation or on the existence of a trusted relationship.

3.8 Bluetooth baseband: The layer that specifies the medium access control and physical layer procedures to support the exchange of real-time voice, data information streams, and ad hoc networking between Bluetooth units.

3.9 Bluetooth channel: A channel that is divided into time slots in which each slot corresponds to a radio frequency (RF) hop frequency. Consecutive hops correspond to different RF hop frequencies and occur at a nominal hop rate of 1600 hops/s. These consecutive hops follow a pseudo-random hopping sequence, hopping through either a 79 or 23 RF channel set.

3.10 Bluetooth host controller interface (HCI): A command interface to the baseband controller and link manager and access to hardware status and control registers. This interface provides a uniform method of accessing the Bluetooth baseband capabilities.

3.11 Bluetooth host: A computing device, peripheral, cellular telephone, 802 local area network attachment gateway (AG), public switched telephone network AG, etc. A Bluetooth host attached to a Bluetooth unit may also communicate with other Bluetooth hosts attached to their Bluetooth units.

[9]The numbers in brackets correspond to the numbers in the bibliography in Annex H.

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3.12 Bluetooth unit: A voice and data circuit equipment for a short-range wireless communication link. It allows voice and data communications between Bluetooth hosts.

3.13 Bluetooth: A wireless communication link, operating in the unlicensed industrial, scientific, medical band at 2.4 GHz using a frequency-hopping transceiver. It allows real-time voice and data communications between Bluetooth hosts. The link protocol is based on time slots.

3.14 bond: A relation between two Bluetooth devices defined by creating, exchanging, and storing a common link key. The bond is created through the bonding or Link Manager Protocol-pairing procedures.

3.15 bonding: A dedicated procedure for performing the first authentication, where a common link key is created and stored for future use.

3.16 channel establishment: A procedure for establishing a channel on the Logical Link Control and Adaptation Protocol level.

3.17 channel: A logical connection on the Logical Link Control and Adaptation Protocol level between two devices serving a single application or higher layer protocol.

3.18 connect (to service): To establish a connection to a service. If not already done, this procedure includes the establishment of a physical link, link, and channel.

3.19 connectable device: A Bluetooth device in range that will respond to a page.

3.20 connecting: A phase in the communication between devices when a connection between them is being established. (Connecting phase follows after the link establishment phase is completed.)

3.21 connection establishment: A procedure for creating a connection mapped onto a channel.

3.22 connection: A connection between two peer applications or higher layer protocols mapped onto a channel.

3.23 coverage area: The area where two Bluetooth units can exchange messages with acceptable quality and performance.

3.24 creation of a secure connection: A procedure of establishing a connection, including authentication and encryption.

3.25 creation of a trusted relationship: A procedure where the remote device is marked as a trusted device. This procedure includes storing a common link key for future authentication and pairing (if the link key is not available).

3.26 device discovery: A procedure for retrieving the Bluetooth device address, clock, class-of-device field, and used paging scheme from discoverable devices.

3.27 discoverable device: A Bluetooth device in range that will respond to an inquiry (normally in addition to responding to a page).

3.28 idle (or in idle mode): As seen from a remote device, the condition of a Bluetooth device when no link is established between the remote device and the Bluetooth device.

3.29 inquiry: A message sent by a Bluetooth unit to discover the other Bluetooth units that are within the coverage area. The Bluetooth units that capture inquiry messages may send a response to the inquiring Bluetooth unit. The response contains information about the Bluetooth unit itself and its Bluetooth host.

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3.30 isochronous user (UI) channel: A channel used for time-bounded information, e.g., compressed audio (asynchronous connectionless link).

3.31 known device: A Bluetooth device for which at least the Bluetooth device address is stored.

3.32 link establishment: A procedure for establishing a link on the Link Manager Protocol (LMP) level. A link is established when both devices have agreed that LMP setup is completed.

3.33 link: An asynchronous connectionless link.

3.34 Link-Manager-Protocol (LMP) authentication: A LMP-level procedure for verifying the identity of a remote device. The procedure is based on a challenge-response mechanism using a random number, a secret key, and the Bluetooth device address of the noninitiating device. The secret key can be a previously exchanged link key.

3.35 Link-Manager-Protocol (LMP) pairing: A procedure that authenticates two devices, based on a personal identification number (PIN), and subsequently creates a common link key that can be used as a basis for a trusted relationship or a (single) secure connection. The procedure consists of the following steps: creation of an initialization key (based on a random number and a PIN), creation and exchange of a common link key, and LMP-authentication based on the common link key.

3.36 logical channel: The different types of channels on a physical link.

3.37 mode: A set of directives that define how a device responds to certain events.

3.38 name discovery: A procedure for retrieving the user-friendly name (i.e., the Bluetooth device name) of a connectable device.

3.39 packet: Format of aggregated bits that can be transmitted in one, three, or five time slots.

3.40 page: A baseband substate where a device transmits page trains and processes any eventual responses to the page trains. Also, the transmission by a device of page trains containing the device access code of the device to which the physical link is requested.

3.41 page scan: A baseband substate where a device listens for page trains. Also, the listening by a device for page trains containing its own device access code.

3.42 paging: Messages sent out by a Bluetooth unit to set up a communication link to another Bluetooth unit that is active within the coverage area.

3.43 paired device: A Bluetooth device with which a link key has been exchanged (either before connection establishment was requested or during connecting phase).

3.44 physical channel: Synchronized radio frequency hopping sequence in a piconet.

3.45 physical link: A baseband-level connection between two devices. The connection is established using paging. A physical link comprises a sequence of transmission slots on a physical channel alternating between master and slave transmission slots.

3.46 piconet: The Bluetooth units sharing a common channel.

3.47 pre-paired device: A Bluetooth device with which a link key was exchanged and stored before link establishment.

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3.48 RFCOMM client: An application that requests a connection to another application (i.e., RFCOMM server).

3.49 RFCOMM initiator: The device initiating the RFCOMM session, i.e., setting up RFCOMM channel on Logical Link Control and Adaptation Protocol and starting RFCOMM multiplexing with the set asynchronous balanced mode command on data link connection identifier set to 0.

3.50 RFCOMM server: An application that waits for a connection from an RFCOMM client on another device. What happens after such a connection is established is out of the scope of this definition.

3.51 RFCOMM server channel: A subfield of the TS 07.10 data link connection identifier number. This abstraction is used to allow both server and client applications to reside on both sides of an RFCOMM session.

3.52 scatternet: Two or more piconets co-located in the same area with interpiconet communication.

3.53 specification and description language (SDL): A modern, high-level programming language. It is object-oriented, formal, textual, and graphical. SDL is intended for the description of complex, event-driven, real-time, and communication systems.

3.54 service discovery: Procedures for querying and browsing for services offered by or through another Bluetooth device.

3.55 silent: As seen from a remote device, the condition of a Bluetooth device if it does not respond to inquiries made by the remote device. A device may be silent due to being nondiscoverable or due to baseband congestion while being discovered.

3.56 synchronous connection-oriented (SCO) link: A point-to-point link between a master and a single slave in the piconet. The master maintains the SCO link by using reserved slots at regular intervals.

3.57 time slot: A part of the physical channel. Each time slot is 625 μs long.

3.58 trusted device: A paired device that is explicitly marked as trusted.

3.59 trusting: The marking of a paired device as trusted. Trust marking can be done by the user or done by the device automatically after a successful pairing.

3.60 unknown device: A Bluetooth device for which no information (e.g., Bluetooth device address, link key) is stored.

3.61 unpaired device: A Bluetooth device for which no exchanged link key was available before connection establishment was requested.

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4. Acronyms and abbreviations

ac	alternating current
ACK	acknowledgment
ACL	asynchronous connectionless (link)
ACO	authenticated ciphering offset
AES	advanced encryption standard
AG	attachment gateway
AM_ADDR	active member address
AR_ADDR	access request address
ARIB	Association of Radio Industries and Businesses
ARQ	automatic repeat request
ARQN	automatic repeat request negative
ASN.1	abstract syntax notation one
BB	baseband
BCH	Bose-Chaudhuri-Hocquenghem
BD_ADDR	Bluetooth device address
BER	bit error rate
BNEP	Bluetooth Network Encapsulation Protocol
BQA	Bluetooth qualification administrator
BSIG	Bluetooth Special Interest Group, Inc.
BT	bandwidth time product (i.e., B*T)
CAC	channel access code
CC	call control
CDMA	code divison multiple access
CID	channel identifier
CL	connectionless
COD	class of device
CODEC	coder decoder
COF	ciphering offset number
CRC	cyclic redundancy check
CSMA/CD	carrier sense multiple access with collision detection
CVSD	continuous variable slope delta (modulation)
DAC	device access code
dc	direct current
DCE	data communication equipment
DCI	default check initialization
DCID	destination channel identifier
DH	data-high rate
DIAC	dedicated inquiry access code
DLC	data link control
DLCI	data link connection identifier
DLL	data link layer
DM	data-medium rate
DQPSK	differential quadrature phase shift keying
DSAP	destination address field
DTE	data terminal equipment
DTMF	dual tone multiple frequency

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DUT	device under test
DV	data - voice
ED	energy detection
EIFS	extended interframe space
ERTX	expanded response timeout expired
ETC	extreme test conditions
ETSI	European Telecommunications Standards Institute
FC	frame control
FCC	Federal Communications Commission
FCS	frame check sequence
FEC	forward error correction
FER	frame error rate
FH	frequency hopping
FHS	frequency hop synchronization
FHSS	frequency hopping spread spectrum
FIFO	first in first out
FSK	frequency shift keying
FW	firmware
GAP	generic access profile
GEOP	generic object exchange profile
GFSK	Gaussian frequency shift keying
GIAC	general inquiry access code
GM	group management
HA	host application software using Bluetooth
HC	host controller
HCI	host controller interface
HEC	header error check
HID	human interface device
HPC	hand-held personal computer
HV	high-quality voice
HW	hardware
IAC	inquiry access code
ICS	implementation conformance statement
ICV	integrity check value
ID	identity or identifier
IDU	interface data unit
IETF	Internet Engineering Task Force
IP	Internet Protocol
IrDA	Infrared Data Association
IrMC	infrared mobile communications
ISDN	integrated services digital networks
ISM	industrial, scientific, medical
IUT	implementation under test
IV	initialization vector
L_CH	logical channel
L2CA	logical link control and adaptation
L2CAP	Logical Link Control and Adaptation Protocol
LAN	local area network

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LAP	lower address part
LC	link controller
LCID	local channel identifier
LCP	Link Control Protocol
LCSS	link controller service signalling
LFSR	linear feedback shift register
LIAC	limited inquiry access code
LLC	logical link control
LM	link manager
LME	layer management entity
LMP	Link Manager Protocol
Log PCM	logarithimic pulse coded modulation
LP	Lower Layer Protocol
LPO	low-power oscillator
LSB	least significant bit
M	master or mandatory
MAC	medium access control
MAPI	messaging application procedure interface
MDF	management-defined field
MIB	management information base
MLME	MAC sublayer management entity
MMI	man-machine interface
MPDU	MAC protocol data unit
MPT	Ministry of Post and Telecommunications
MSB	most significant bit
MSC	message sequence chart
MSDU	MAC service data unit
MTU	maximum transmission unit
MUX	multiplexing sublayer a sublayer of the L2CAP layer
NAK	negative acknowledgment
NAP	nonsignificant address part
NOP	no operation
NTC	nominal test condition
O	optional
OBEX	Object Exchange Protocol
OCF	opcode command field
OGF	opcode group field
OSI	open systems interconnection
PAN	personal area network
PAR	project authorization request
PC	personal computer
PCM	pulse coded modulation
PCMCIA	Personal Computer Memory Card International Association
PCS	personal communications service
PDA	personal digital assistant
PDU	protocol data unit
PHT	pseudo-Hadamard transform
PHY	physical layer

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PICS	Protocol Implementation Conformance Statement
PIN	personal identification number
PLCP	physical layer convergence procedure
PLME	physical layer management entity
PM_ADDR	parked member address
PMD	physical medium dependent
PN	pseudo-random noise
PnP	plug and play
POS	personal operating space
POTS	plain old telephone service
PPDU	PHY protocol data unit
PPP	Point-to-Point Protocol
PRBS	pseudo-random bit sequence
PRD	program reference document
PRNG	pseudo-random number generator
PS	power save
PSM	protocol/service multiplexer
PSTN	public switched telephone network
QoS	quality of service
RA	receiver address
RAND	random number
RF	radio frequency
RFC	request for comments
RFCOMM	Serial Cable Emulation Protocol based on ETSI TS 07.10
RSSI	receiver signal strength indication
RTS	request to send
RTX	response timeout expired
RX	receive or receiver
S	slave
SA	source address
SABM	set asynchronous balanced mode
SAP	service access point
SAR	segmentation and reassembly
SC	scan period
SCID	source channel identifier
SCO	synchronous connection-oriented (link)
SD	service discovery
SDDB	service discovery database
SDL	specification and description language
SDP	Service Discovery Protocol
SDU	service data unit
SEQN	sequential numbering scheme
SFD	start frame delimiter
SIFS	short inter-frame space
SIG	special interest group
SLRC	station long retry count
SME	station management entity
SQ	signal quality

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SR	scan repetition
SRC	short retry count
SRES	signed response
SS	supplementary services
SSAP	source address field
SSI	signal strength indication
SSRC	station short retry count
SUT	system under test
SW	software
TA	transmitter address
TAE	terminal adapter equipment
TBD	to be defined
TBTT	target beacon transmission time
TC	test control layer for the test interface
TCI	test control interface
TCP	Transmission Control Protocol
TCP/IP	Transport Control Protocol/Internet Protocol
TCS	Telephony Control Protocol specification
TDD	time division duplex
TDMA	time division multiple access
TS	technical specification
TSF	timing synchronization function
TTP	Tiny Transport Protocol
TX	transmit or transmitter
TXE	transmit enable
UA	user asynchronous
UAP	upper address part
UART	universal asynchronous receiver transmitter
UC	user control
UDP	User Datagram Protocol
UDP/IP	User Datagram Protocol/Internet Protocol
UI	user isochronous or user interface, depending on context
URL	uniform resource locator
US	user synchronous
USB	universal serial bus
UT	upper tester
UUID	universally unique identifier
WAN	wide area network
WAP	Wireless Application Protocol
WLAN	wireless local area network
WPAN	wireless personal area network
WUG	wireless user group

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5. General description

This standard is derived from the Bluetooth core, profiles, and test specifications (version 1.1) (see Siep [B13]). Portions of this standard consist of unaltered or minimally altered text of the Bluetooth specifications (see 2.4). This clause provides the general description of this standard and identifies the source of each of the subsequent clauses. The Bluetooth wireless technology is an industry specification for small form factor, low-cost wireless communication and networking between personal computers (PCs), mobile phones, and other portable devices.

5.1 IEEE and Bluetooth Special Interest Group (SIG), Inc., license agreement

The Bluetooth SIG wanted to have the IEEE adopt the Bluetooth specifications and make them a formal IEEE 802 standard. The IEEE requested and was granted a limited, nonexclusive, nontransferable license from the Bluetooth SIG to adopt or adapt and copy a portion of the Bluetooth specifications to be used as base material in IEEE Std 802.15.1-2002. An agreement in principle was struck in mid-1999, and final agreement was achieved in 2000.

Specifically, the license allows IEEE to create, publish, and distribute the standard as a stand-alone publication or as part of a collection together with other IEEE standards. The area covered by this standard is undergoing evolution. Revisions are anticipated within the next few years to clarify existing material, correct possible errors, and incorporate new related or supplement material. Information on the license or current revision state of this standard may be obtained from the Secretary, IEEE Standards Board. Information on the license or the current Bluetooth specifications should be directed to the Bluetooth SIG.

5.2 The origin of the document and layout

The first five clauses are standard IEEE introductory information. The overview, reference citation, unique definition, and acronym and abbreviation clauses are common to all IEEE 802 base standards. This clause, Clause 5, is generally used in these standards to provide guidance to the reader about the form and content of the standard. In this standard, Clause 5 is devoted to the specific relationship between this document and the original Bluetooth specifications. Clause 6 describes the interworkings and architecture of this standard. It also relates those attributes to the original Bluetooth constructs.

For the next five clauses, Clause 7 through Clause 11, the standard is derived from the Bluetooth core (Volume 1) specification (see 2.4.1). Clause 11 about host controller interface (HCI) is the only Bluetooth-derived section that has undergone significant editorial modification. These edits were applied to delete implementation-specific text as well as unrelated text. Clause 12 was added by IEEE to define the service access points (SAPs). IEEE 802-specific interfaces are documented in Clause 12. These interfaces describe how the lower layers of a Bluetooth implementation would interface with the traditional IEEE 802.2™[9] logical link control (LLC) entity.

Annex A is also a derived text and corresponds to the Bluetooth Protocol Implementation Conformance Statement (PICS) proforma, which is a separate document from the Bluetooth specifications. Annex B was added by IEEE to define the high-level behavioral specification and description language (SDL) model for an integrated WPAN Bluetooth MAC sublayer (e.g., L2CAP, LM, and baseband) based on ITU-T Recommendation Z.100 (11/99)[10]. For the next five annexes, Annex C through Annex G, the standard uses additional derivation materials from the Bluetooth core (Volume 1) and profiles (Volume 2) specifications (see 2.4.1 and 2.3) to assist the reader: Part K:1, Generic Access Profile, from Volume 2, and Appendix VII, Optional Paging Scheme; Part I:1, Bluetooth Test Mode; Appendix VI, Baseband Timers; and Appendix IX, Message Sequence Charts, from Volume 1, respectively. The last annex is the bibliography.

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[10]For information on references, see Clause 2.

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Figure 1 maps the IEEE Std 802.15.1-2002 clauses to the applicable portion of the Bluetooth protocol stack.

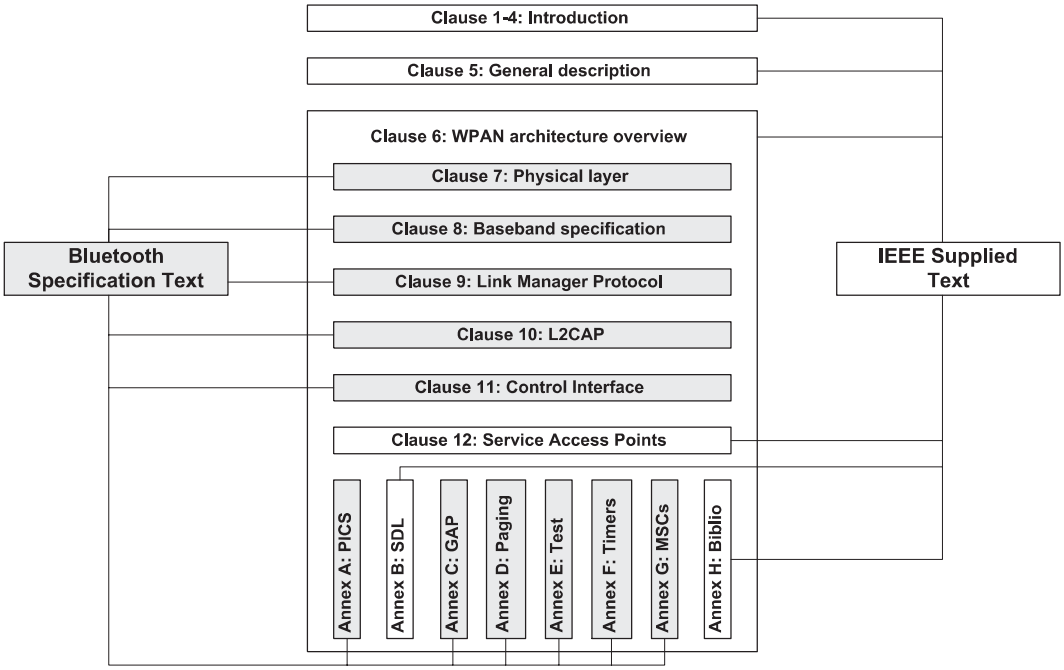


Figure 1—IEEE Std 802.15.1-2002 derived text

In Figure 1 the lines from the left-hand graphic clearly identify the shaded portions of this IEEE standard that consist of the text of the Bluetooth specifications. In most cases the shaded portions of this IEEE standard consist of unaltered or minimally altered text from the Bluetooth specifications.

Table 1 provides a detailed description of each of the clauses and annexes.

Table 1—Clause and annex descriptions

IEEE clause or annex (Bluetooth specification part)	Title	Description
Front matter	Front matter	The front matter includes mutually agreed-to copyright statement from the Bluetooth SIG and IEEE-SA.
Clause 1	Overview	Overview
Clause 2	References	The references include the derivative documents from the the Bluetooth SIG.
Clause 3	Definitions	Definitions
Clause 4	Acronyms and abbreviations	Acronyms and abbreviations
Clause 5	General description	This clause describes the source, contents, and format of the standard. The purpose is to identify the Bluetooth specification source material and make the standard easier to read for readers familiar with the Bluetooth specifications.

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Table 1—Clause and annex descriptions *(continued)*

IEEE clause or annex (Bluetooth specification part)	Title	Description
Clause 6	WPAN architecture overview	The architectural clause emphasizes the large-scale separation of the system into two parts: the IEEE 802.15.1 PHY and the MAC sublayer of the data link layer (DLL).
Clause 7 (Part A)	Physical layer (PHY)	The radio clause defines the requirements for a Bluetooth transceiver operating in the unlicensed ISM band.
Clause 8 (Part B)	Baseband specification	The baseband clause describes the specifications of the Bluetooth link controller (LC) that carries out the baseband protocols and other low-level link routines.
Clause 9 (Part C)	Link Manager Protocol (LMP)	The LMP is used for link setup and control. The signals are interpreted and filtered out by the LM on the receiving side and are not propagated to higher layers.
Clause 10 (Part D)	Logical link control and adaptation protocol (L2CAP)	The Bluetooth L2CAP supports higher level protocol multiplexing, packet SAR, and the conveying of quality-of-service information. This clause also describes the protocol state machine, the packet format and composition, and a test interface required for the Bluetooth test and certification program.
Clause 11 (Part H:1)	Control interface	Control information from upper layers flows through this interface. The text of this clause was taken from the host controller interface section of the Bluetooth specification and modified to eliminate references to specific physical interfaces and their control parameters.
Clause 12	Service access point interfaces and primitives	Various entities within this standard interact in various ways. Some of these interactions are defined explicitly within this standard, via a SAP across which defined primitives are exchanged.
Annex A (Bluetooth ICS & IXIT pro forma)	Protocol implementation conformance statement (PICS proforma)	The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.15.1-2002 shall complete the PICS proforma.
Annex B	Formal description of IEEE Std 802.15.1-2002 operation	SDL is the formal, object-oriented language that defines the IEEE Std 802.15.1-2002 MAC sublayer.
Annex C (V2, Part K:1)	Generic access profile	This annex defines the generic procedures related to discovery of Bluetooth devices (idle mode procedures) and link management aspects of connecting to Bluetooth devices (connecting mode procedures). It also defines procedures related to the use of different security levels. In addition, this profile includes common format requirements for parameters accessible on the user interface level.
Annex D (Appendix VII)	Optional paging schemes	For the access procedure, several paging schemes may be used. One mandatory paging scheme shall be supported by all Bluetooth devices. (This scheme is described in Clause 8.) In addition to the mandatory scheme, a Bluetooth unit may support one or more optional paging schemes. This annex contains these optional schemes.
Annex E (Part I:1)	Bluetooth test mode	This annex describes the test mode for hardware and low-level functionality tests of Bluetooth devices. The test mode includes transmitter tests (packets with constant bit patterns) and loopback tests.

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Table 1—Clause and annex descriptions *(continued)*

IEEE clause or annex (Bluetooth specification part)	Title	Description
Annex F (Appendix VI)	Baseband timers	This annex contains a list of all timers defined in the baseband specification. Definitions and default values of the timers are listed. All timer values are given in slots.
Annex G (Appendix IX)	Message sequence charts (MSCs)	This annex shows examples of interworking between HCI commands and LM protocol data units (PDUs) in the form of MSCs. It helps the reader understand and correctly use the HCI commands.
Annex H	Bibliography	Bibliography

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6. WPAN architecture overview

The essential components of the IEEE Std 802.15.1-2002 WPAN architecture are based on the Bluetooth specifications (see 2.4). The terms *Bluetooth WPAN* and *IEEE 802.15.1 WPAN* refer to the specific, single example of a WPAN presented in this standard.

This clause presents the IEEE 802.15.1 WPAN technology and its architecture. It also presents an overview of the major components of the Bluetooth WPAN protocol stack including a high-level summary of this standard and its relation with the Bluetooth Foundation Specification.

6.1 The WPAN communications technology

Personal electronic devices are becoming more intelligent and interactive. Many devices [e.g., notebook computers, cellular phones, personal digital assistants (PDAs), personal solid-state music players, digital cameras] have increased data capabilities. This capability allows them to retain, use, process, and communicate various amounts of information. For example, several of these personal devices have a personal information management (PIM) database maintaining personal calendars, address books, and to-do lists. PIM databases in one personal device should remain synchronized with PIM databases in other personal devices. The obvious solution for keeping these PIM databases synchronized is to interconnect and synchronize them.

Traditionally, proprietary special-purpose cables have been used to interconnect personal devices. However, many users find using these cables to be quite a frustrating and unproductive chore. Cables may get lost or damaged and they add unnecessary bulk and weight when carried around. It thus becomes quite desirable to develop connectivity solutions for interconnecting personal devices that do not require the use of cables. Because the desired solution will not involve interconnection cables, a wireless solution must be employed.

6.1.1 General requirements

The demands of the consumer market require connectivity solutions that respect the primary functionality of the personal device. For example, a communications-enabled PDA must still look and function as a PDA. Its wireless connectivity solution must not impact the PDA's form factor, weight, power requirements, cost, ease of use, or other traits in a significant way.

Personal devices used as a part of an individual's productivity management and entertainment tool set may also be needed to interact with a corporate information technology (IT) infrastructure. Further, these devices will likely be used in several of many different environments (e.g., offices, homes, in the middle of a park, industrial plants). The wireless solution for these devices should, therefore, accommodate the design and marketing requirements dictated not only by the consumer market but also by the business market.

Interconnecting personal devices is different from connecting computing devices. Typical connectivity solutions for computing devices (e.g., a WLAN connectivity solution for a notebook computer) associates the user of the device with data services available on, for instance, a corporate Ethernet-based intranet. This situation contrasts with the intimate, personal nature of a wireless connectivity solution for the personal devices associated with a particular user. The user is concerned with electronic devices in his or her possession, or in his or her vicinity, rather than to any particular geographic or network location. The term *personal area network* (PAN) was coined to describe this different kind of network connection. The untethered version of this concept is a WPAN. A WPAN can be viewed as a personal communications bubble around a person. Within this bubble, which moves as a person moves around, personal devices can connect with one another. These devices may be under the control of a single individual or several people's devices may interact with each other.

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Communicating devices may not be within line of sight of each other. For this reason WPANs may employ radio frequency (RF) technologies to provide the added flexibility to communicate to hidden devices. This standard presents a WPAN using RF technology based on the Bluetooth wireless technology.

6.1.2 How WPANs differ from WLANs

At first glance the operation and objectives of a WPAN may appear to resemble the operation and objectives of a WLAN, e.g., IEEE 802.11. Both the WLAN and WPAN technologies allow a device to connect to its surrounding environment and exchange data with it over an unlicensed, wireless link. However, WLANs have been designed and are optimized for usage of transportable, computing (client) devices (e.g., notebook computers). WPAN devices are even more mobile.

The two technologies differ in three fundamental ways:

— Power levels and coverage

— Control of the media

— Lifespan of the network

6.1.2.1 Power levels and coverage

To extend the WLAN as much as possible, while minimizing the burden of multihop networks, a WLAN installation is often optimized for coverage. Typical coverage distances are about 100 m and are implemented at the expense of power consumption (typically 100 mW or more of transmit power). The added power consumption for covering larger distances has an impact on the devices participating in a WLAN: They tend to be connected to a power plug on the wall or utilize the wireless link for a relatively short time while unplugged.

A WLAN enables ease of deployment, where the much more desirable (with respect to reliability and bandwidth) cables are hard or costly to deploy. WLAN links have been designed to serve as a substitute for the physical cables of a LAN cabling infrastructure. While wireless connectivity allows for portability of the client devices, the WLAN itself is quasi-static. A client device in a WLAN is typically connected to a fixed base station, and on occasion it may roam between fixed base stations. While WLANs are much easier to deploy as compared with their wire line counterparts, they still need to be deployed and set up. Their primary orientation is reaching outward from portable devices to connect to an established infrastructure—wired or not.

WPANs are oriented to interconnect multiple mobile, personal devices. The distinction between “mobile” and “portable” devices in this discussion is that mobile devices typically operate on batteries and have a fleeting interconnection with other devices; portable devices are moved less frequently, have longer time periods of connections, and usually run from power supplied by wall sockets. A personal device may not necessarily have the need to access LAN-level data services, but access to data services on a LAN is not excluded.

In contrast to a WLAN, a WPAN trades coverage for power consumption. Through small coverage area (about 10 m), reduced power consumption (typically 1 mW of transmit power), and low power modes of operation, a WPAN can achieve sufficiently small power-consumption rates to enable portability. Several simple, power-conscious personal devices can, therefore, utilize a WPAN technology, share data, and be truly mobile.

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6.1.2.2 Control of the medium

WLANs are typically wireless extensions of wire-line LANs. Like its wired counterpart, IEEE 802.3™[11] LAN (Ethernet), a WLAN's primary objective is to provide the type of infrastructure data services typically available through a LAN to the client devices. Once a client device joins a WLAN, the device typically stays connected to the LAN until the device moves away from the LAN's boundaries. These devices typically operate in an office or an industrial warehouse, a home, or similar infrastructure.

Given the high variety of personal devices that may participate in a WPAN, the WPAN technology should support applications with stringent (i.e., reserved) bandwidth requirements as well as applications with more flexible bandwidth requirements. To provide the necessary bandwidth guarantees for the various connections, the WPAN employs a controlling mechanism that regulates the transmissions of the devices in the WPAN.

WLANs employ similar coordination functions as an option, recognizing that over the large distances covered by them, it may not always be desirable to have a strict and absolute control of the media. When they do have this level of control, it is described as a "contention-free period," but it does not mean an interference-free environment. Other independently operating networks (of various technologies) may occasionally interfere with transmissions during a contention-free period. However, no contention resolution mechanisms are employed to recover from disturbed transmissions during a contention-free period. With this in mind, in IEEE 802.15.1 WPANs, all the time is contention free. This level of control is achieved by creating a relationship (in IEEE 802.15.1 WPANs, a master-slave relationship) between the devices and operating on a single, time-multiplexed, slotted system. The IEEE 802.15.1 WPAN master polls its collection of IEEE 802.15.1 WPAN slaves for transmissions, thus regulating the bandwidth assigned to them based on quality-of-service requirements that it enforces. Using small slots efficiently controls the jitter in transmissions experienced by the high-quality traffic. In addition, employing a frequency-hopping scheme with the small slots provides noise resilience from interference that may occur from other networks, including other independently operating IEEE 802.15.1 WPANs, operating over unlicensed bands.

The ad hoc nature of connectivity in a WPAN implies that devices may need to act as either a master or a slave at different times. As a result, the design objectives for the IEEE 802.15.1 WPAN technology (e.g., low cost, low power) still apply no matter whether a device implements the typical master-or-slave capability or only one of them. In all cases a master must be present for communications to occur.

Personal devices that participate in a WPAN are designed for their personal appeal and functionality. They are not designed to be members of an established networking infrastructure, even if they may connect to it when necessary. A typical WPAN device does not need to maintain a network-observable and network-controllable state. WLANs are required, for example, to maintain a management information base (MIB). As bona fide members of a larger infrastructure, this requirement is appropriate. However, with a WPAN technology, it may be inappropriate—if not impossible—for an end-to-end networking solution to be employed that is observed and controlled remotely over a network. Such end-to-end solutions can be built on top of the WPAN technology, are outside the scope of this standard, and will likely be application-specific.

6.1.2.3 Lifespan of the network

WLANs do not have an inherent or implied lifespan. They have "existence" independent of their constituent devices. If all the devices migrated out of a WLAN's coverage area and replacement units arrived, the WLAN would be said to have uninterrupted existence. This concept is not true for IEEE 802.15.1 WPANs. If the master does not participate, the network no longer exists.

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In a WPAN a device creates a connection that lasts only for as long as needed and has a finite lifespan. For example, a file transfer application may cause a connection to be created only long enough to accomplish its goal. When the application terminates, the connection between the two devices may also be severed. The connections that a mobile client device creates in a WPAN are ad hoc and temporary in nature. The devices to which a personal device is connected in a WPAN at one moment may bear no resemblance to the devices to which it was previously connected or will connect in the future. For example, a notebook computer may connect with a PDA at one moment, a digital camera at another moment, and a cellular phone at yet another moment. At times, the notebook computer may be connected with any or all of these other devices. The WPAN technology must be able to support fast (i.e., in a few seconds) ad hoc connectivity with no need of predeployment of any type.

6.2 High-level view

This standard presents a WPAN that utilizes the Bluetooth wireless technology. In the text of this standard, unless otherwise stated, the term *Bluetooth WPAN* or simply *IEEE 802.15.1 WPAN* refers to a WPAN that utilizes the Bluetooth wireless technology. The term *Bluetooth wireless technology* and other similar terms are also used to further emphasize the use of this technology in the Bluetooth WPAN defined and described in this standard.

6.2.1 Open systems interconnection (OSI)

Two important ways exist to view any communications system design: architectural and functional. The architectural approach emphasizes the logical divisions of the system and how they fit together. The functional approach emphasizes the actual components, their packaging, and their interconnections.

This subclause presents the architectural view of a WPAN. It emphasizes the traditional large-scale separation of the system into two parts: the IEEE 802.15.1 PHY and the MAC sublayer of the DLL. These layers are intended to correspond closely to the lowest layers of the ITU-T Recommendation X.200 (07/94) or ISO-7498-1:1994.

Figure 2 shows the protocol stacks in the OSI seven-layer model and in the Bluetooth wireless technology and their relation as it pertains to this standard. As shown in Figure 2, the LLC and MAC sublayers together encompass the functions intended for the DLL of the OSI model. The definition of MAC-to-LLC service is specified in ISO/IEC 15802-1:1995.

6.2.2 Overview of the Bluetooth WPAN

The Bluetooth wireless technology uses a short-range radio link that has been optimized for power-conscious, battery-operated, small size, lightweight personal devices. A Bluetooth WPAN supports both synchronous communication channels for telephony-grade voice communication and asynchronous communications channels for data communications. These facilities enable a rich set of devices and applications to participate in the Bluetooth WPAN. For example, a cellular phone may use the circuit-switched channels to carry audio to and from a headset while concurrently using a packet-switched channel to exchange data with a notebook computer.

A Bluetooth WPAN is not created *a priori* and has a limited life span. It is created in an ad hoc manner whenever an application in a device desires to exchange data with matching applications in other devices. The Bluetooth WPAN may cease to exist when the applications involved have completed their tasks and no longer need to continue exchanging data.

The Bluetooth WPAN operates in the unlicensed 2.4 GHz ISM band. A fast frequency-hop (1600 hops/s) transceiver is used to combat interference and fading in this band (i.e., reduce the probability that all transmission is destroyed by interference). A Gaussian-shaped, binary frequency shift keying (FSK) with a

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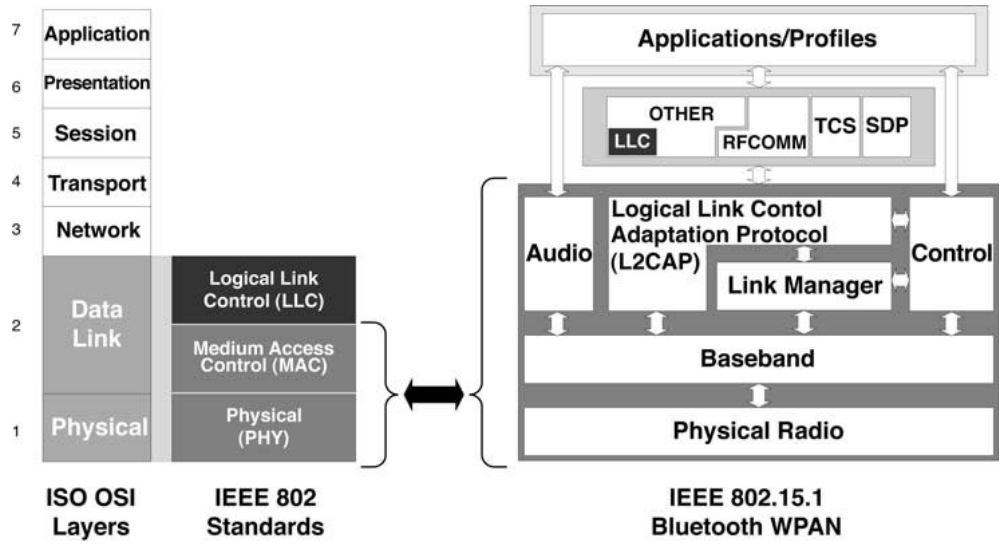


Figure 2—Mapping of ISO OSI to scope of IEEE 802.15.1 WPAN standard

symbol rate of 1 Msymbols/s minimizes transceiver complexity. A slotted channel is used, which has a slot duration of 625 µs. A fast time division duplex (TDD) scheme is used that enables full duplex communications at higher layers. On the channel, information is exchanged through packets. Each packet is transmitted on a different frequency in the hopping sequence. A packet nominally covers a single slot, but can be extended up to either three or five slots. For data traffic, a unidirectional (i.e., asymmetric) maximum of 723.2 kb/s is possible between two devices. A bidirectional 64 kb/s channel supports voice traffic between two devices. The jitter for the voice traffic is kept low by using small transmission slots.

Figure 3 shows the general format of a single-slot, payload-bearing packet transmitted over the air in a Bluetooth WPAN. The packet comprises a fixed-size access code, which is used, among other things, to distinguish one Bluetooth WPAN from another; a fixed-size packet header, which is used for managing the transmission of the packet in a Bluetooth WPAN; and a variable-size payload, which carries upper layer data. Due to the small size of these packets, large upper-layer packets need to be segmented prior to transmission over the air. Detailed information about this packet format can be found in 8.4.

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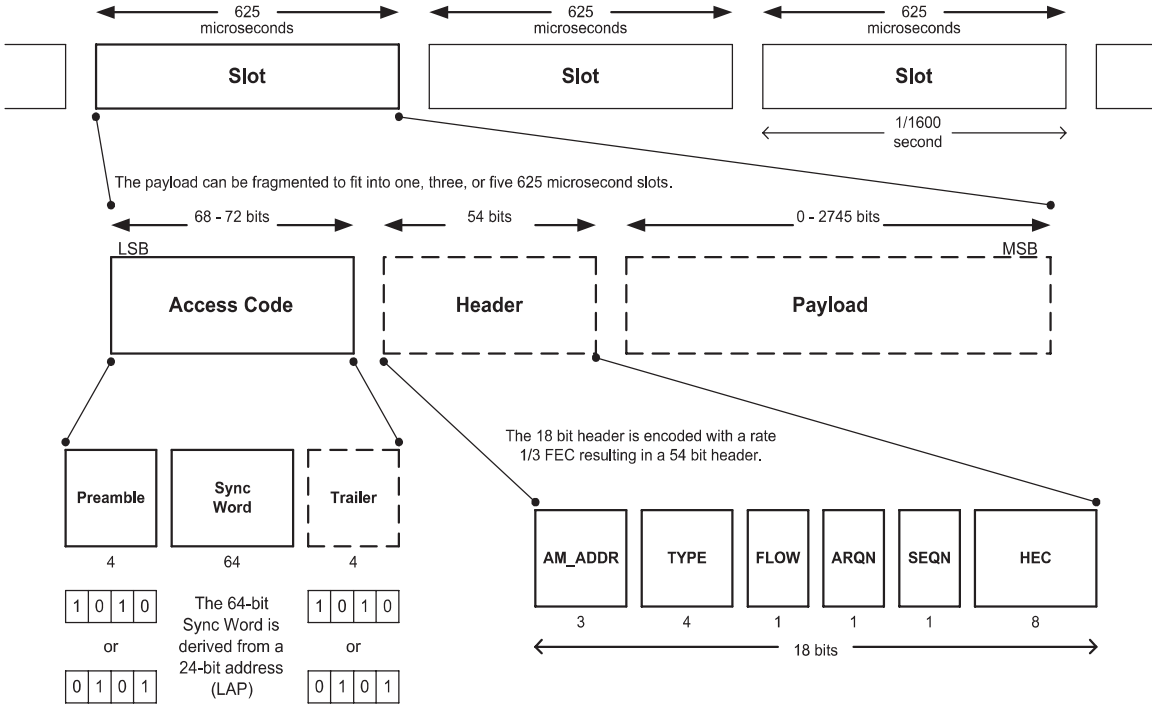


Figure 3—Format of an over-the-air payload bearing Bluetooth WPAN packet

6.2.3 The Bluetooth WPAN connectivity topologies

6.2.3.1 The Bluetooth WPAN piconet

A piconet is a WPAN formed by a Bluetooth device serving as a master in the piconet and one or more Bluetooth devices serving as slaves. A frequency-hopping channel based on the address of the master defines each piconet. All devices participating in communications in a given piconet are synchronized to the frequency-hopping channel for the piconet, using the clock of the master of the piconet. Slaves communicate only with their master in a point-to-point fashion under the control of the master. The master's transmissions may be either point-to-point or point-to-multipoint. Usage scenarios may dictate that certain devices act always as masters or slaves. However, this standard does not distinguish between devices with permanent master and slave designations. A slave device during one communications session could be a master in another and vice versa.

6.2.3.2 The Bluetooth WPAN scatternet

A scatternet is a collection of operational Bluetooth piconets overlapping in time and space. A Bluetooth device may participate in several piconets at the same time, thus allowing for the possibility that information could flow beyond the coverage area of the single piconet. A device in a scatternet could be a slave in several piconets, but master in only one of them. Figure 4 shows the various ways Bluetooth devices interconnect to form communicating systems.

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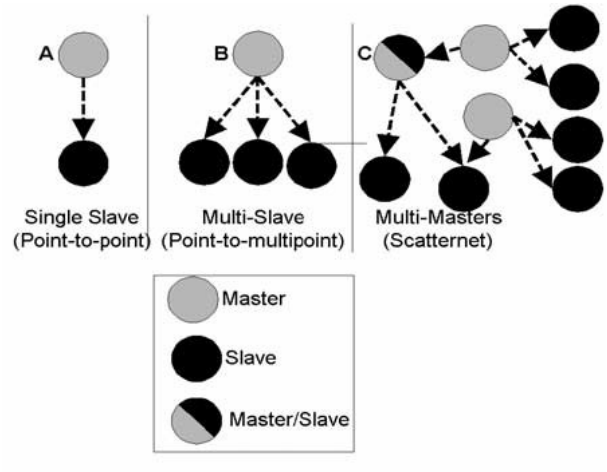


Figure 4—Various piconet formations: (a) single-slave operation; (b) multislave operation; and (c) scatternet operation

6.2.3.3 Integration with LANs

A Bluetooth WPAN may attach to and participate in communications with other LANs in the IEEE 802 family (e.g., IEEE 802.3, IEEE 802.11) through the use of an IEEE 802 LAN attachment gateway (AG) (see Figure 5). An IEEE 802 LAN AG is a logical architectural component that may or may not be implemented directly on a Bluetooth device. Through an IEEE 802 LAN AG, MAC service data units (MSDUs) from or to other LANs can be conditioned for transport over a Bluetooth WPAN.

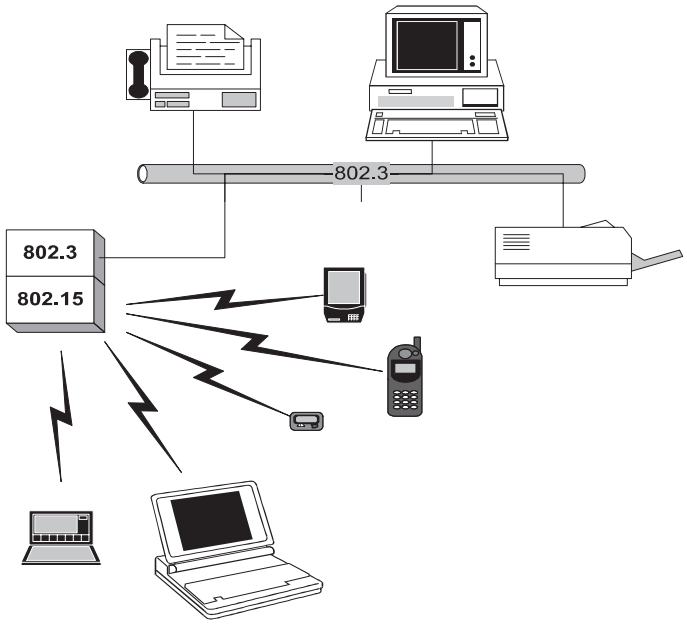


Figure 5—IEEE 802 LAN AG

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6.3 Components of the Bluetooth WPAN architecture

The ultimate objective of communication protocols is to enable applications in different devices to interact with each other. To achieve this interactivity, compatible communication stacks need to run on the devices. This implies that not only the communication protocol stacks that run in each device are functionally compatible, but also the applications that run on top of these stacks match.

To enable the creation of interoperable, interactive applications the Bluetooth specifications (see 2.4) comprise both a set of communication protocols, including transport protocols for carrying data between devices over Bluetooth links, and a set of interoperable applications used to instantiate the collection of usage scenarios addressed in the specification. This standard pertains only to a subset of the communication protocols in the Bluetooth specifications related to PHY and MAC protocols as identified in Figure 2.

However, for completeness, the rest of this subclause contains a high-level description of the Bluetooth WPAN PHY and MAC communication protocols and their relation with the rest of the protocols in the Bluetooth specifications.

6.3.1 The Bluetooth protocol stack

Figure 6 shows the Bluetooth protocol stack. It includes both Bluetooth-specific protocols (e.g., LMP, L2CAP) and non-Bluetooth-specific protocols (grouped in the "Other" box). These other protocols include the Object Exchange Protocol (OBEX), the Point-to-Point Protocol (PPP), the Wireless Application Protocol (WAP), and so on. In designing the protocols and the whole protocol stack, the main principle has been to maximize the reuse of existing protocols for different purposes at the higher layers instead of "reinventing the wheel." Protocol reuse also helps to adapt existing (i.e., legacy) applications to work with the Bluetooth wireless technology and ensure the smooth operation and interoperability of these applications. Thus, many applications already developed by vendors can take immediate advantage of hardware and software systems that are compliant to the Bluetooth specifications (see 2.4). The specifications are publicly available and permit the development of a large number of new applications that take full advantage of the capabilities of the Bluetooth wireless technology.

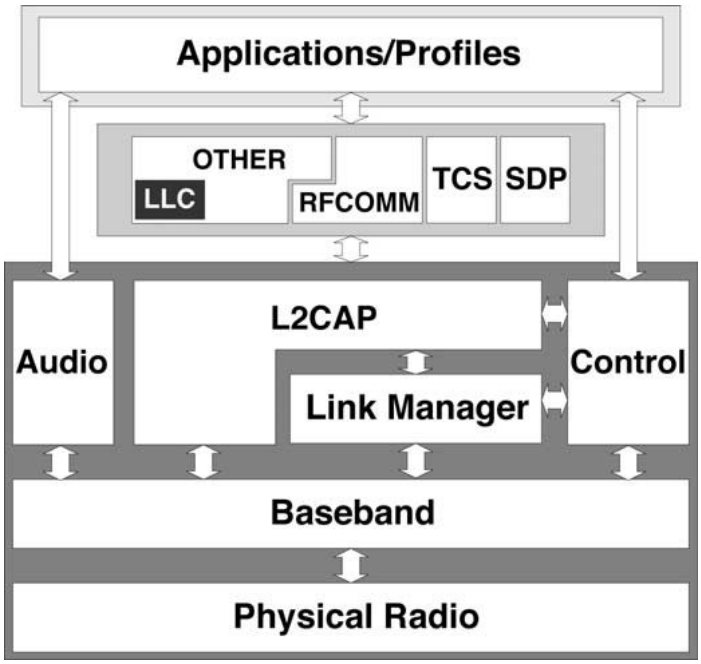


Figure 6—Bluetooth protocol stack

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For this standard, an LLC layer has been explicitly added within the “Other” box. The LLC layer is not part of the Bluetooth specifications. It is shown here to demonstrate where it shall be placed in relation to the rest of the Bluetooth protocol layers. LLC traffic may be encapsulated within the BNEP packets prior to entering the lower Bluetooth protocol layers that map to the IEEE 802.15.1 MAC sublayer and PHY (see 2.4.6).

The RFCOMM layer is a serial port emulation layer for enabling legacy applications over Bluetooth links. The TCS is a telephony control and signaling layer for advanced telephony applications. The SDP is a service discovery layer allowing Bluetooth devices to ask other devices for the services that they can provide. Details on these layers can be found in the Bluetooth specifications.

The layers from L2CAP and below are what this standard discusses.

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7. Physical layer (PHY)

Figure 7 indicates the relationship of the Bluetooth protocol stack to the PHY. The PHY is the first layer of the seven-layer OSI model and is responsible for transporting bits between adjacent systems over the air. The description of this layer, the radio portion, is limited to the following:

— Receiving a bit stream from the MAC subayer and transmitting the bitstream via radio waves to an associated station

— Receiving radio waves from an associated station and converting them to a bitstream that is passed to the MAC

This reflects the limited scope of the physical radio portion of the IEEE 802.15.1 architecture. Bits and radio waves are transmuted, but this layer does not do any interpretation.

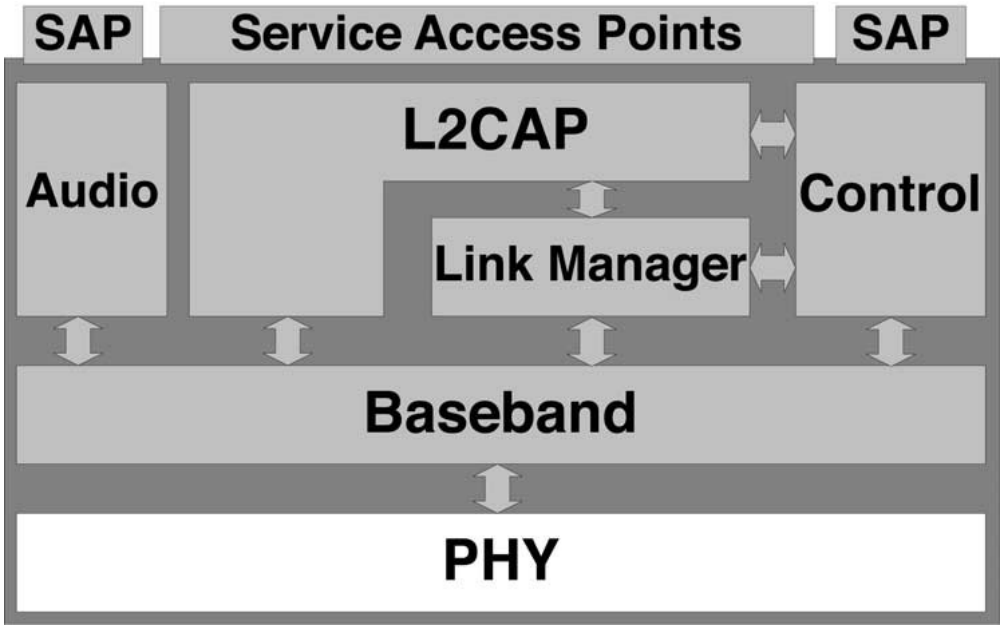


Figure 7—PHY interface relationships

7.1 Regulatory requirements

The Bluetooth transceiver operates in the 2.4 GHz ISM (Industrial, Scientific, Medical) band. This clause defines the requirements for a Bluetooth transceiver operating in this unlicensed band.

Requirements are defined for the following two reasons:

— To provide compatibility between the radios used in the system

— To define the quality of the system

The Bluetooth transceiver shall fulfill the stated requirements under the operating conditions specified in 7.5 and 7.6.

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This clause is based on the established regulations for Europe, Japan, and North America. The regulatory documents listed below are for information only and are subject to change or revision at any time.

- **Europe** (except France and Spain)**:**
  - Approval standards: European Telecommunications Standards Institute (ETSI)
  - Documents: ETS 300-328, ETS 300-826 [B2]
  - Approval authority: National type approval authorities
- **France**:
  - Approval standards: La Reglementation en France pour les Equipements fonctionnant dans la bande de frequences 2.4 GHz “RLAN-Radio Local Area Network”
  - Documents: SP/DGPT/ATAS/23, ETS 300-328, ETS 300-826 [B11]
  - Approval authority: Direction Generale des Postes et Telecommunications
- **Spain**:
  - Approval standards: Supplemento Del Numero 164 Del Boletin Oficial Del Estado (Published 10 July 1991, Revised 25 June 1993)
  - Documents: ETS 300-328, ETS 300-826 [B14]
  - Approval authority: Cuadro Nacional de Atribucion de Frecuesias
- **Japan**:
  - Approval standards: Association of Radio Industries and Businesses (ARIB)
  - Documents: RCR STD-33A, ARIB STD-T66 [B1]
  - Approval authority: Ministry of Post and Telecommunications (MPT)
- **North America**:
  - Approval standards: Federal Communications Commission (FCC), United States
  - Documents: CFR 47, Part 15, Sections 15.205, 15.209, 15.247, 15.249 [B3]
  - Approval standards: Industry Canada, Canada
  - Document: GL36 [B5]
  - Approval Authority: FCC (United States), Industry Canada (Canada)

7.2 Frequency bands and channel arrangement

The Bluetooth system operates in the 2.4 GHz ISM band. In a majority of countries around the world, the range of this frequency band is 2400 MHz to 2483.5 MHz. Some countries, however, have national limitations in the frequency range. To comply with these national limitations, special frequency-hopping algorithms have been specified for these countries. It should be noted that products implementing the reduced frequency band *will not* work with products that implement the full band. The products implementing the reduced frequency band shall, therefore, be considered as local versions for a single market (see Table 2).

Channel spacing is 1 MHz. In order to comply with out-of-band regulations in each country, a guard band is used at the lower and upper band edge (see Table 3).

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Table 2—Operating frequency bands

Geography	Regulatory range (GHz)	RF channels
United States, Europe, and most other countries	2.400–2.4835	$f = 2402 + k$ MHz, $k = 0, \ldots, 78$
France	2.4465–2.4835	$f = 2454 + k$ MHz, $k = 0, \ldots, 22$

Table 3—Guard bands

Geography	Lower guard band (MHz)	Upper guard band (MHz)
United States, Europe, and most other countries	2	3.5

7.3 Transmitter characteristics

The requirements stated in this clause are given as power levels at the antenna connector of the equipment. If the equipment does not have a connector, a reference antenna with 0 dBi gain is assumed.

As a result of difficulty in measurement accuracy in radiated measurements, it is preferred that systems with an integral antenna provide a temporary antenna connector during type approval.

If transmitting antennas of directional gain greater than 0 dBi are used, the transmission power shall be compensated according to the applicable paragraphs in ETSI ETS 300-328 or the FCC's CFR 47, Part 15.

The equipment is divided into three power classes, as shown in Table 4.

Table 4—Power classes

Power class	Maximum output power (P_{max})	Nominal output power	Minimum output power[a]	Power control
1	100 mW (20 dBm)	N/A	1 mW (0 dBm)	P_{min}< +4 dBm to P_{max} Optional: P_{min}[b] to P_{max}
2	2.5 mW (4 dBm)	1 mW (0 dBm)	0.25 mW (–6 dBm)	Optional: P_{min}[b] to P_{max}
3	1 mW (0 dBm)	N/A	N/A	Optional: P_{min}[b] to P_{max}

[a]Minimum output power at maximum power setting.
[b]The lower power limit P_{min} < –30dBm is suggested, but is not mandatory, and may be chosen according to application needs.

Power control is required for power class 1 equipment. The power control is used for limiting the transmitted power over 0 dBm. Power control capability under 0 dBm is optional and could be used for optimizing the power consumption and overall interference level. The power steps shall form a monotonic sequence with a maximum step size of 8 dB and a minimum step size of 2 dB. Class 1 equipment with a maximum transmit power of +20 dBm shall be able to control its transmit power down to 4 dBm or less.

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Equipment with power control capability optimizes the output power in a link with LMP commands (see Clause 9). This is done by measuring receiver signal strength indication (RSSI) and reporting back if the power should be increased or decreased.

Power class 1 shall not be used for sending packets from one device to another if the receiving side of a connection does not support the necessary messaging for power control of the sending side (i.e., RSSI measurements and related messages). In this case, the transmitter should comply with the rules of a class 2 or class 3 transmitter. Additionally, if a class 1 device is paging or inquiring in close proximity to another device, the input power could be larger than the stated requirement (see 7.4.5). This can cause the listening device to fail to respond. A device performing page or inquiry should do so according to power class 2 or class 3.

7.3.1 Modulation characteristics

The modulation is Gaussian frequency shift keying (GFSK) with a bandwidth time (BT) = 0.5. The modulation index shall be between 0.28 and 0.35. A binary 1 is represented by a positive frequency deviation, and a binary 0 is represented by a negative frequency deviation. The symbol timing shall be better than ± 20 ppm (see Figure 8).

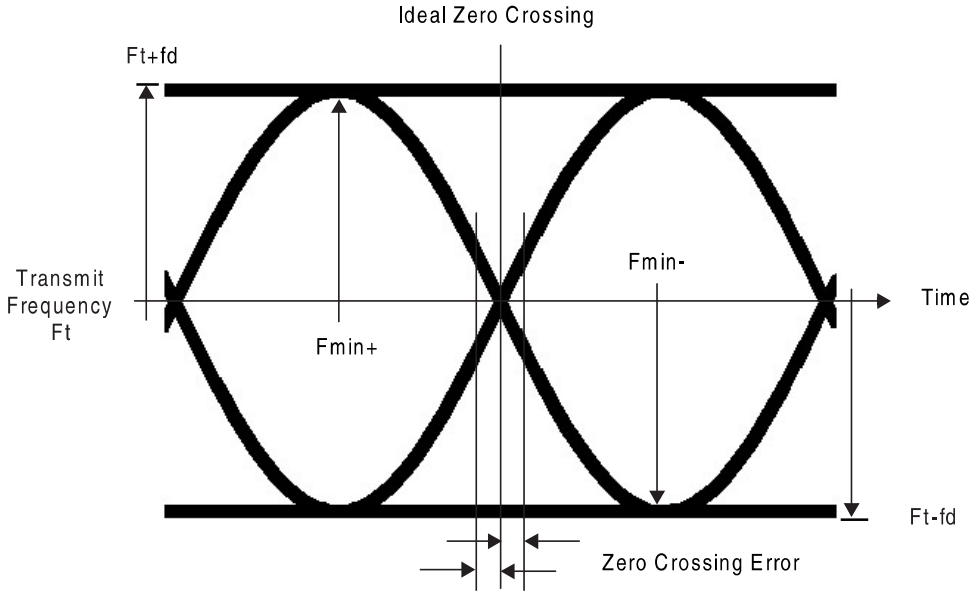


Figure 8—Actual transmit modulation

For each transmit channel, the minimum frequency deviation (F_{min} = the lesser of $\{F_{min+}, F_{min-}\}$) that corresponds to 1010 sequence shall be no smaller than ± 80% of the frequency deviation (*fd*) that corresponds to a 00001111 sequence. Additionally, the minimum deviation shall never be smaller than 115 kHz. Transmitted data have a symbol rate of 1 Msymbol/s.

The zero crossing error is the time difference between the ideal symbol period and the measured crossing time. This shall be less than ± 0.125 of a symbol period. The maximum frequency deviation shall be between 140 kHz and 175 kHz.

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7.3.2 Spurious emissions

The spurious emission, in band and out of band, is measured with a frequency-hopping transmitter hopping on a single frequency. In other words, the synthesizer must change frequency between the receive slot and the transmit slot, but always returns to the same transmit frequency.

For the United States, FCC Parts 15.247, 15.249, 15.205, and 15.209 are applicable regulations. For Japan, RCR STD-33 and ARIB STD-T66 apply, and for Europe, ETS 300-328 and ETS 300-826 apply.

7.3.2.1 In-band spurious emission

Within the ISM band, the transmitter shall pass a spectrum mask, given in Table 5. The spectrum shall comply with the FCC's 20 dB bandwidth definition stated below and should be measured accordingly. In addition to the FCC requirement, an adjacent channel power is defined for channels with a difference in channel number of two or greater. This adjacent channel power is defined as the sum of the measured power in a 1 MHz channel. The transmitted power shall be measured in a 100 kHz bandwidth using maximum hold. The transmitter is transmitting on channel M, and the adjacent channel power is measured on channel number N. The transmitter sends a pseudo-random data pattern throughout the test.

Table 5—Transmit spectrum mask

Frequency offset	Transmit power
± 500 kHz	–20 dBc
$\lvert M-N \rvert = 2$	–20 dBm
$\lvert M-N \rvert \geq 3$	–40 dBm
NOTE—If the output power is less than 0 dBm, then, wherever appropriate, the FCC's 20 dB relative requirement overrules the absolute adjacent channel power requirement stated in this table.	

Exceptions are allowed in up to three bands of 1 MHz width centered on a frequency that is an integer multiple of 1 MHz. They shall, however, comply with an absolute value of –20 dBm.

7.3.2.2 Out-of-band spurious emission

The power should be measured in a 100 kHz bandwidth. The out-of-band emission shall conform to the requirements found in Table 6.

Table 6—Out-of-band spurious emission requirement

Frequency band (GHz)	Operation mode (dBm)	Idle mode (dBm)
0.030–1.000	–36	–57
1.000–12.750	–30	–47
1.800–1.900	–47	–47
5.150–5.300	–47	–47

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7.3.3 RF tolerance

The transmitter initial center frequency (F_c) accuracy shall be ±75 kHz maximum from F_c. The initial frequency accuracy is defined as the frequency accuracy before any information is transmitted. Note that the frequency drift requirement is not included in the ±75 kHz.

The transmitter center frequency drift in a packet is specified in Table 7. The different packets are defined in 8.4.4.

Table 7—Frequency drift in a packet

Type of packet	Frequency drift
One-slot packet	±25 kHz
Three-slot packet	±40 kHz
Five-slot packet	±40 kHz
Maximum drift rate[a]	400 Hz/µs

[a]The maximum drift rate is allowed anywhere in a packet.

7.4 Receiver characteristics

To measure the bit error rate performance, the equipment shall have a loopback facility. The equipment sends back the decoded information. This facility is specified in the test mode specification (see Annex E).

The reference sensitivity level referred to in this clause equals –70 dBm.

7.4.1 Actual sensitivity level

The actual sensitivity level is defined as the input level for which a raw bit error rate (BER) of 0.1% is met. The requirement for a Bluetooth receiver is an actual sensitivity level of –70 dBm or better. The receiver shall achieve the –70 dBm sensitivity level with any Bluetooth transmitter compliant to the transmitter specification specified in 7.3.

7.4.2 Interference performance

The interference performance on co-channel and adjacent 1 MHz and 2 MHz is measured with the desired signal 10 dB over the reference sensitivity level. On all other frequencies, the desired signal shall be 3 dB over the reference sensitivity level. If the frequency of an interfering signal lies outside the band of 2400 MHz to 2497 MHz, the out-of-band blocking specification (see 7.4.3) shall apply. The interfering signal shall be Bluetooth-modulated (see 7.4.8). The BER shall be ≤ 0.1%. The signal-to-interference ratio shall be as shown in Table 8.

These specifications are to be tested only at nominal temperature conditions with a receiver hopping on one frequency. In other words, the synthesizer must change frequency between the receive slot and the transmit slot, but always return to the same receive frequency.

Frequencies where the requirements are not met are called spurious response frequencies. Five spurious response frequencies are allowed at frequencies with a distance ≥ 2 MHz from the wanted signal. On these spurious response frequencies, a relaxed interference requirement of C/I = –17 dB shall be met.

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Table 8—Interference performance

Requirement	Ratio (dB)
Co-channel interference, $C/I_{co\text{-}channel}$	11[a]
Adjacent (1 MHz) interference, C/I_{1MHz}	0[a]
Adjacent (2 MHz) interference, C/I_{2MHz}	–30
Adjacent (≥3 MHz) interference, $C/I_{\geq 3MHz}$	–40
Image frequency interference,[b,c] C/I_{Image}	–9[a]
Adjacent (1 MHz) interference to in-band image frequency, $C/I_{Image\pm 1MHz}$	–20[a]
Note that if two adjacent channel specifications above are applicable to the same channel, the more relaxed specification applies.	

[a]During the period July 1999 to July 2002, Bluetooth devices need to achieve a co-channel interference resistance of +14 dB, an ACI (@1 MHz) resistance of +4 dB, image frequency interference resistance of –6 dB, and an adjacent interference to in-band image frequency resistance of –16 dB to meet Bluetooth qualification requirements.
[b]In-band image frequency.
[c]If the image frequency ≠ n*1 MHz, the image reference frequency is defined as the closest n*1 MHz frequency.

7.4.3 Out-of-band blocking

The out-of-band blocking is measured with the desired signal 3 dB over the reference sensitivity level. The interfering signal shall be a continuous wave signal. The BER shall be ≤ 0.1%. The out-of-band blocking shall fulfill the requirements in Table 9.

Table 9—Out-of-band blocking requirements

Interfering signal frequency (GHz)	Interfering signal power level (dBm)
0.030–2.000	–10
2.000–2.399	–27
2.498–3.000	–27
3.000–12.750	–10

Twenty-four exceptions are permitted that are dependent on the given receive channel frequency and are centered at a frequency that is an integer multiple of 1 MHz. At nineteen of these spurious response frequencies, a relaxed power level –50 dBm of the interferer may be used to achieve a BER of 0.1%. At the remaining five spurious response frequencies, the power level is arbitrary.

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7.4.4 Intermodulation characteristics

The reference sensitivity performance of BER = 0.1% shall be met under the following conditions:

— The desired signal at frequency f_0 with a power level 6 dB over the reference sensitivity level

— A static sine wave signal at f_1 with a power level of –39 dBm

— A Bluetooth modulated signal (see 7.4.8) at f_2 with a power level of –39 dBm

such that $f_0 = 2f_1 - f_2$ and $|f_2 - f_1| = n*1$ MHz, where n can be 3, 4, or 5. The system shall fulfill one of the three alternatives.

7.4.5 Maximum usable level

The maximum usable input level the receiver shall operate at shall be better than –20 dBm. The BER shall be less than or equal to 0.1% at –20 dBm input power.

7.4.6 Spurious emissions

The spurious emission for a Bluetooth receiver shall not be more than the value shown in Table 10.

Table 10—Out-of-band spurious emission

Frequency band (GHz)	Requirement (dBm)
0.030–1.000	–57
1.000–12.750	–47

The power should be measured in a 100 kHz bandwidth.

7.4.7 Receiver signal strength indicator (optional)

A transceiver that wishes to take part in a power-controlled link shall be able to measure its own receiver signal strength and determine whether the transmitter on the other side of the link should increase or decrease its output power level. A receiver signal strength indicator (RSSI) makes this possible.

The RSSI measurement compares the received signal power with two threshold levels, which define the ideal receive power range. The lower threshold level corresponds to a received power between –56 dBm and 6 dB above the actual sensitivity of the receiver. The upper threshold level is 20 dB above the lower threshold level to an accuracy of ± 6 dB (see Figure 9).

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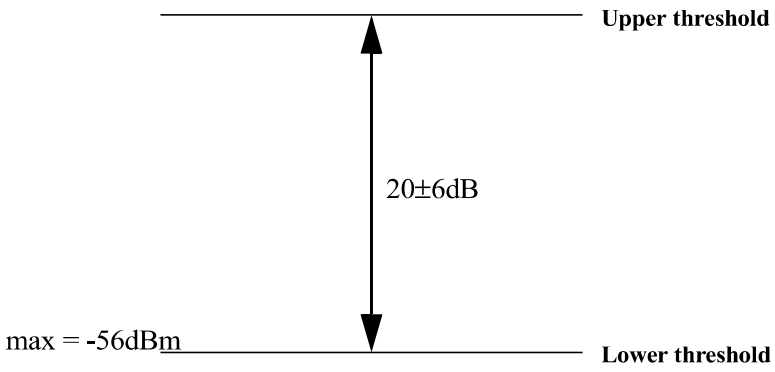


Figure 9—RSSI dynamic range and accuracy

7.4.8 Reference interference-signal definition

A Bluetooth modulated interfering signal is defined as follows:

- Modulation = GFSK
- Modulation index = 0.32 ± 1%
- Bandwidth time (BT) = 0.5 ± 1%
- Bit rate = 1 Mb/s ± 1 ppm
- Modulating data = PRBS-9 (see Annex E.2.1.2)
- Modulating data for interfering signal = PRBS-15 [see ITU-T Recommendation O.150 (05/96)]
- Frequency accuracy better than ± 1 ppm

7.5 Test conditions

7.5.1 Nominal test conditions (NTC)

7.5.1.1 Nominal temperature

The nominal temperature conditions for tests shall be +15 °C to +35 °C. When it is impractical to carry out the test under this condition, a note to this effect, stating the ambient temperature, shall be recorded.

Note that the actual value during the test shall be recorded in the test report.

7.5.1.2 Nominal power source

7.5.1.2.1 Mains voltage

The nominal test voltage for equipment to be connected to the mains shall be the nominal mains voltage. The nominal voltage shall be the declared voltage or any of the declared voltages for which the equipment was designed. The frequency of the test power source corresponding to the ac mains shall be within 2% of the nominal frequency.

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7.5.1.2.2 Lead-acid battery power sources used in vehicles

When radio equipment is intended for operation from the alternator-fed lead-acid battery power sources that are standard in vehicles, the nominal test voltage shall be 1.1 times the nominal voltage of the battery (e.g., 6 V, 12 V, etc.).

7.5.1.2.3 Other power sources

For operation from other power sources or types of battery (primary or secondary), the nominal test voltage shall be as declared by the equipment manufacturer.

7.5.2 Extreme test conditions (ETC)

7.5.2.1 Extreme temperatures

The extreme temperature range is defined as the largest temperature range given by the combination of

— The minimum temperature range 0 °C to +35 °C
— The product operating temperature range declared by the manufacturer

7.5.2.2 Extreme power source voltages

Tests at the extreme power source voltages specified below (7.5.2.2.1 through 7.5.2.2.4) are not required when the equipment under test is designed for operation as part of and is powered by another system or piece of equipment. In such cases, the limit values of the host system or host equipment shall apply.

7.5.2.2.1 Mains voltage

The extreme test voltage for equipment to be connected to an ac mains source shall be the nominal mains voltage ± 10%.

7.5.2.2.2 Lead-acid battery power source used on vehicles

When radio equipment is intended for operation from the alternator-fed lead-acid battery power sources that are standard in vehicles, the extreme test voltage shall be 1.3 and 0.9 times the nominal voltage of the battery (e.g., 6 V, 12 V, etc.).

7.5.2.2.3 Power sources using other types of batteries

The lower extreme test voltage for equipment with power sources using the following types of batteries shall be:

— For Leclanché, alkaline, or lithium type batteries: 0.85 times the nominal voltage of the battery
— For mercury or nickel-cadmium type batteries: 0.9 times the nominal voltage of the battery

In both cases, the upper extreme test voltage shall be 1.15 times the nominal voltage of the battery.

7.5.2.2.4 Other power sources

For equipment using other power sources or capable of being operated from a variety of power sources (primary or secondary), the extreme test voltages shall be those declared by the manufacturer.

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7.6 Radio parameters

The radio parameters shall be tested as shown in Table 11:

Table 11—Radio parameter test conditions

Parameter	Temperature	Power source
Output power	ETC[a]	ETC
Power control	NTC[b]	NTC
Modulation index	ETC	ETC
Initial carrier frequency accuracy	ETC	ETC
Carrier frequency drift	ETC	ETC
In-band spurious emissions	ETC	ETC
Out-of-band spurious emissions	ETC	ETC
Sensitivity	ETC	ETC
Interference performance	NTC	NTC
Intermodulation characteristics	NTC	NTC
Out-of-band blocking	NTC	NTC
Maximum usable level	NTC	NTC
Receiver signal strength indicator	NTC	NTC

[a]Extreme test conditions
[b]Nominal test conditions

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8. Baseband specification

Figure 10 indicates the relationship of the Bluetooth protocol stack to this clause. This clause describes the specifications of the Bluetooth link controller which carries out the baseband protocols and other low-level link routines.

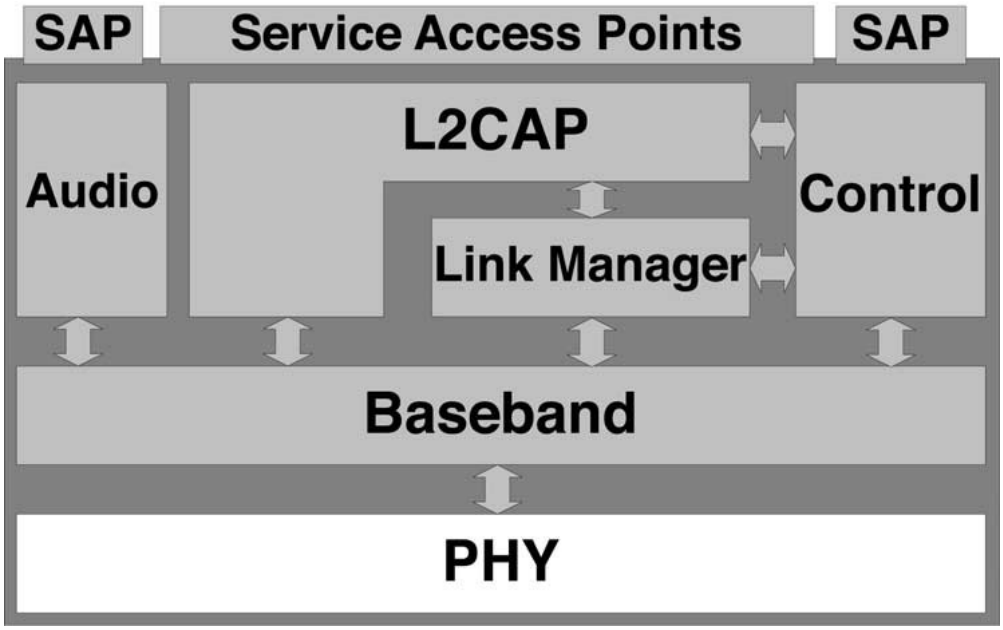


Figure 10—BB interface relationships

8.1 General description

Bluetooth is a short-range radio link intended to replace the cable(s) connecting portable and/or fixed electronic devices. Key features are robustness, low complexity, low power, and low cost.

Bluetooth operates in the unlicensed ISM band at 2.4 GHz. A frequency hop transceiver is applied to combat interference and fading. A shaped, binary FM modulation is applied to minimize transceiver complexity. The symbol rate is 1 Msymbol/s. A slotted channel is applied with a nominal slot length of 625 µs. To emulate full duplex transmission, a Time-Division Duplex (TDD) scheme is used. On the channel, information is exchanged through packets. Each packet is transmitted on a different hop frequency. A packet nominally covers a single slot, but can be extended to cover up to five slots.

The Bluetooth protocol uses a combination of circuit and packet switching. Slots can be reserved for synchronous packets. Bluetooth can support an asynchronous data channel, up to three simultaneous synchronous voice channels, or a channel which simultaneously supports asynchronous data and synchronous voice. Each voice channel supports a 64 kb/s synchronous (voice) channel in each direction. The asynchronous channel can support maximal 723.2 kb/s asymmetric (and still up to 57.6 kb/s in the return direction), or 433.9 kb/s symmetric.

The Bluetooth system consists of a radio unit (see Clause 7), a link control unit, and a support unit for link management and host terminal interface functions (see Figure 11). This clause describes the specifications of the Bluetooth link controller, which carries out the baseband protocols and other low-level link routines. Link layer messages for link set-up and control are defined in Clause 9.

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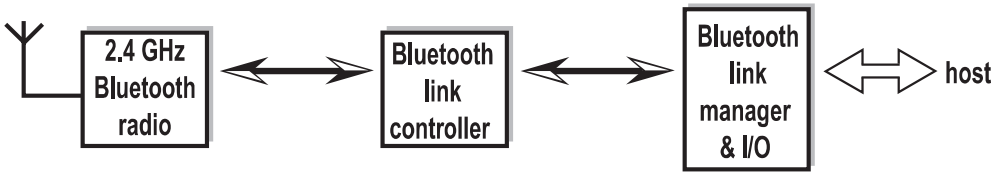


Figure 11—Different functional blocks in the Bluetooth system

The Bluetooth system provides a point-to-point connection (only two Bluetooth units involved), or a point-to-multipoint connection (see Figure 12). In the point-to-multipoint connection, the channel is shared among several Bluetooth units. Two or more units sharing the same channel form a *piconet*. One Bluetooth unit acts as the master of the piconet, whereas the other unit(s) acts as slave(s). Up to seven slaves can be active in the piconet. In addition, many more slaves can remain locked to the master in a so-called parked state. These parked slaves cannot be active on the channel, but remain synchronized to the master. Both for active and parked slaves, the channel access is controlled by the master.

Multiple piconets with overlapping coverage areas form a *scatternet*. Each piconet can only have a single master. However, slaves can participate in different piconets on a time-division multiplex basis. In addition, a master in one piconet can be a slave in another piconet. The piconets shall not be frequency-synchronized. Each piconet has its own hopping channel.

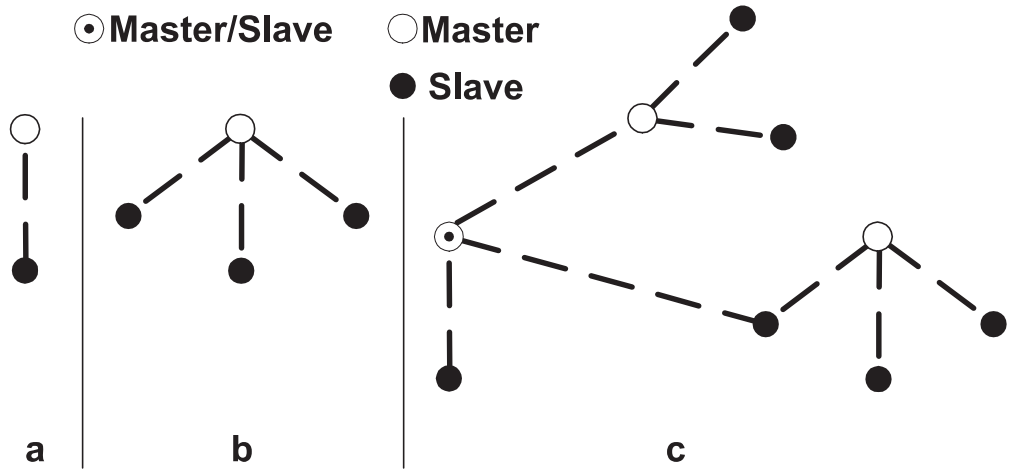


Figure 12—Various piconet formations: (a) single slave operation; (b) multislave operation; and (c) scatternet operation (Master with dot is Master/Slave)

8.2 Physical channel

8.2.1 Channel definition

The channel is represented by a pseudo-random hopping sequence hopping through the 79 or 23 RF channels. The hopping sequence is unique for the piconet and is determined by the Bluetooth device address of the master. The phase in the hopping sequence is determined by the Bluetooth clock of the master. The channel is divided into time slots where each slot corresponds to an RF hop frequency. Consecutive hops

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correspond to different RF hop frequencies. The nominal hop rate is 1600 hops/s. All Bluetooth units participating in the piconet are time- and hop-synchronized to the channel.

8.2.2 Time slots

The channel is divided into time slots, each 625 µs in length. The time slots are numbered according to the Bluetooth clock of the piconet master. The slot numbering ranges from 0 to 2^{27}-1 and is cyclic with a cycle length of 2^{27}.

A TDD scheme is used where master and slave alternatively transmit (see Figure 13). The master shall start its transmission in even-numbered time slots only, and the slave shall start its transmission in odd-numbered time slots only. The packet start shall be aligned with the slot start. Packets transmitted by the master or the slave may extend over up to five time slots.

The RF hop frequency shall remain fixed for the duration of the packet. For a single packet, the RF hop frequency to be used is derived from the current Bluetooth clock value. For a multislot packet, the RF hop frequency to be used for the entire packet is derived from the Bluetooth clock value in the first slot of the packet. The RF hop frequency in the first slot after a multislot packet shall use the frequency as determined by the current Bluetooth clock value. Figure 14 illustrates the hop definition on single-slot and multislot packets. If a packet occupies more than one time slot, the hop frequency applied shall be the hop frequency as applied in the time slot where the packet transmission was started.

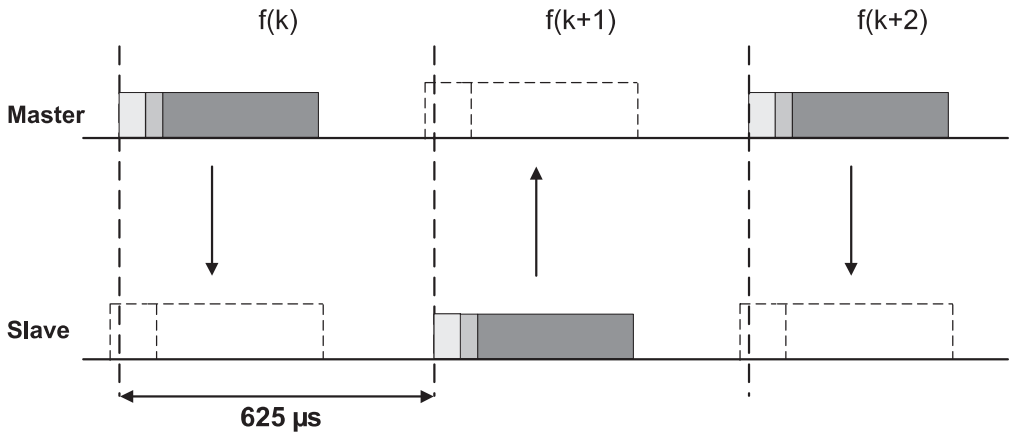


Figure 13—TDD and timing

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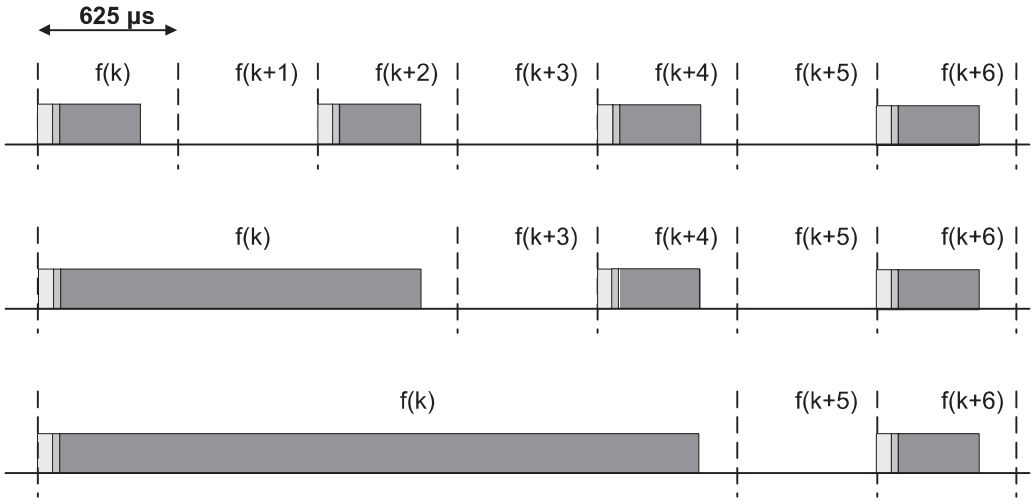


Figure 14—Multislot packets

8.3 Physical links

8.3.1 General

Between master and slave(s), different types of links can be established. Two link types have been defined:

— Synchronous Connection-Oriented (SCO) link

— Asynchronous Connection-Less (ACL) link

The SCO link is a point-to-point link between a master and a single slave in the piconet. The master maintains the SCO link by using reserved slots at regular intervals. The ACL link is a point-to-multipoint link between the master and all the slaves participating on the piconet. In the slots not reserved for the SCO link(s), the master can establish an ACL link on a per-slot basis to any slave, including the slave(s) already engaged in an SCO link.

8.3.2 SCO link

The SCO link is a symmetric, point-to-point link between the master and a specific slave. The SCO link reserves slots and can therefore be considered as a circuit-switched connection between the master and the slave. The SCO link typically supports time-bounded information like voice. The master can support up to three SCO links to the same slave or to different slaves. A slave can support up to three SCO links from the same master, or two SCO links if the links originate from different masters. SCO packets are never retransmitted.

The master will send SCO packets at regular intervals, the so-called SCO interval T_{SCO} (counted in slots) to the slave in the reserved master-to-slave slots. The SCO slave is always allowed to respond with an SCO packet in the following slave-to-master slot unless a different slave was addressed in the previous master-to-slave slot. If the SCO slave fails to decode the slave address in the packet header, it is still allowed to return an SCO packet in the reserved SCO slot.

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The SCO link is established by the master sending an SCO setup message via the LM protocol. This message will contain timing parameters such as the SCO interval T_{SCO} and the offset D_{SCO} to specify the reserved slots.

In order to prevent clock wrap-around problems, an initialization flag in the LMP setup message indicates whether initialization procedure 1 or 2 is being used. The slave shall apply the initialization method as indicated by the initialization flag. The master uses initialization 1 when the MSB of the current master clock (CLK_{27}) is 0; it uses initialization 2 when the MSB of the current master clock (CLK_{27}) is 1. The master-to-slave SCO slots reserved by the master and the slave shall be initialized on the slots for which the clock satisfies the following equation:

$CLK_{27-1} \bmod T_{SCO} = D_{SCO}$ for initialization 1

$(\overline{CLK}_{27}, CLK_{26-1}) \bmod T_{SCO} = D_{SCO}$ for initialization 2

The slave-to-master SCO slots shall directly follow the reserved master-to-slave SCO slots. After initialization, the clock value CLK(k + 1) for the next master-to-slave SCO slot is found by adding the fixed interval T_{SCO} to the clock value of the current master-to-slave SCO slot:

$CLK(k + 1) = CLK(k) + T_{SCO}$

8.3.3 ACL link

In the slots not reserved for SCO links, the master can exchange packets with any slave on a per-slot basis. The ACL link provides a packet-switched connection between the master and all active slaves participating in the piconet. Both asynchronous and isochronous services are supported. Between a master and a slave only a single ACL link can exist. For most ACL packets, packet retransmission is applied to assure data integrity.

A slave is permitted to return an ACL packet in the slave-to-master slot if and only if it has been addressed in the preceding master-to-slave slot. If the slave fails to decode the slave address in the packet header, it is not allowed to transmit.

ACL packets not addressed to a specific slave are considered as broadcast packets and are read by every slave. If there is no data to be sent on the ACL link and no polling is required, no transmission shall take place.

8.4 Packets

8.4.1 General format

The bit ordering when defining packets and messages in this clause, follows the Little Endian format, i.e., the following rules apply:

— The least significant bit (LSB) corresponds to b_0.

— The LSB is the first bit sent over the air.

— In illustrations, the LSB is shown on the left side.

The link controller interprets the first bit arriving from a higher software layer as b_0; i.e. this is the first bit to be sent over the air. Furthermore, data fields generated internally at baseband level, such as the packet header fields and payload header length, are transmitted with the LSB first. For instance, a 3-bit parameter X = 3 is sent as $b_0 b_1 b_2 = 110$ over the air where 1 is sent first and 0 is sent last.

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