US008085802B1

(12) **United States Patent**
Monk et al.

(10) **Patent No.: US 8,085,802 B1**
(45) **Date of Patent: Dec. 27, 2011**

(54) **MULTIMEDIA OVER COAXIAL CABLE ACCESS PROTOCOL**

(75) Inventors: **Anton Monk**, San Diego, CA (US); **Brett Bernath**, San Diego, CA (US); **Itzhak Gurantz**, San Diego, CA (US); **Ladd El Wardanj**, La Jolla, CA (US); **Ron Porat**, San Diego, CA (US); **Yusuf Ozturk**, San Diego, CA (US); **Ron Lee**, San Diego, CA (US); **Wee-Peng Goh**, Murrieta, CA (US); **Magnus Berggren**, San Diego, CA (US)

(73) Assignee: **Entropic Communications, Inc.**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 775 days.

(21) Appl. No.: **11/292,939**

(22) Filed: **Dec. 2, 2005**
(Under 37 CFR 1.47)

Related U.S. Application Data

(60) Provisional application No. 60/632,856, filed on Dec. 2, 2004.

(51) **Int. Cl.**
H04L 12/28 (2006.01)

(52) **U.S. Cl.** **370/419**; 709/203

(58) **Field of Classification Search** 370/465, 370/400, 338, 392, 419; 709/203, 208
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,761,796	A *	8/1988	Dunn et al.	375/133
6,826,195	B1 *	11/2004	Nikolich et al.	370/465
7,184,777	B2 *	2/2007	Diener et al.	455/456.1
2002/0080790	A1 *	6/2002	Beshai	370/392
2003/0012163	A1 *	1/2003	Cafarelli et al.	370/338

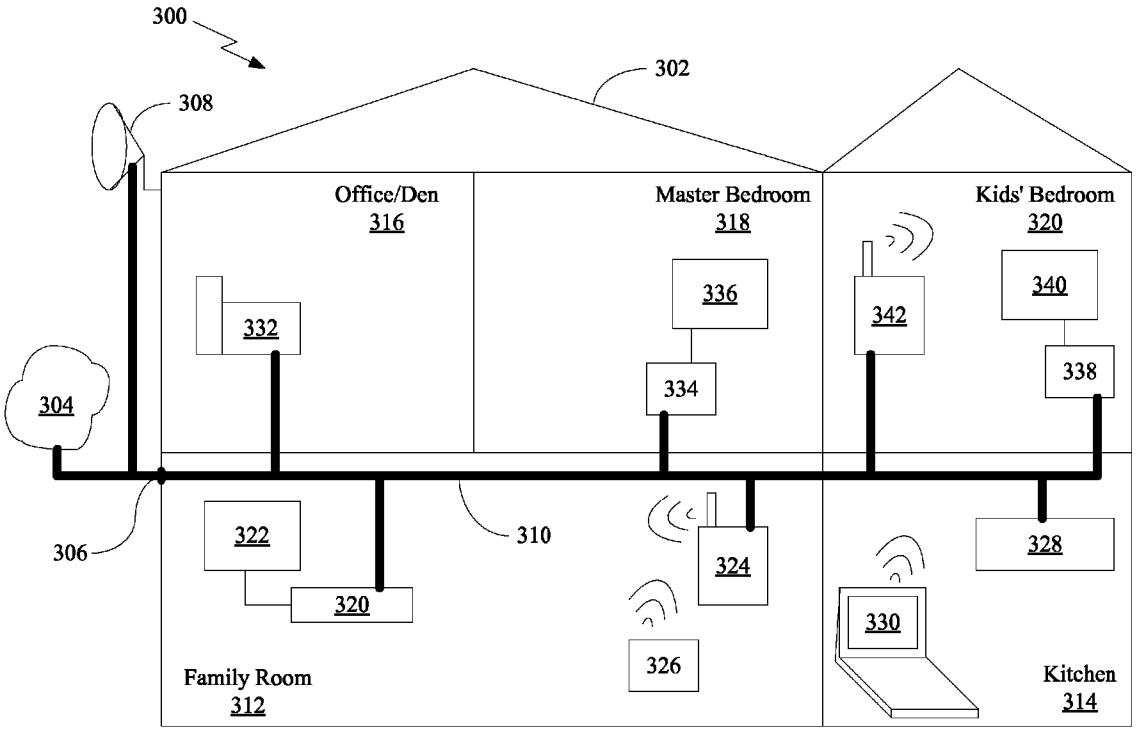
* cited by examiner

Primary Examiner — Dang Ton
Assistant Examiner — Wei Zhao
(74) *Attorney, Agent, or Firm* — Bruce W. Greenhaus; Francisco Rubio-Campos

(57) **ABSTRACT**

A BCN network with BCN modems that communicate using predefined messages to establish, optimize and facilitate data communication.

4 Claims, 33 Drawing Sheets



Comcast, Ex. 1114

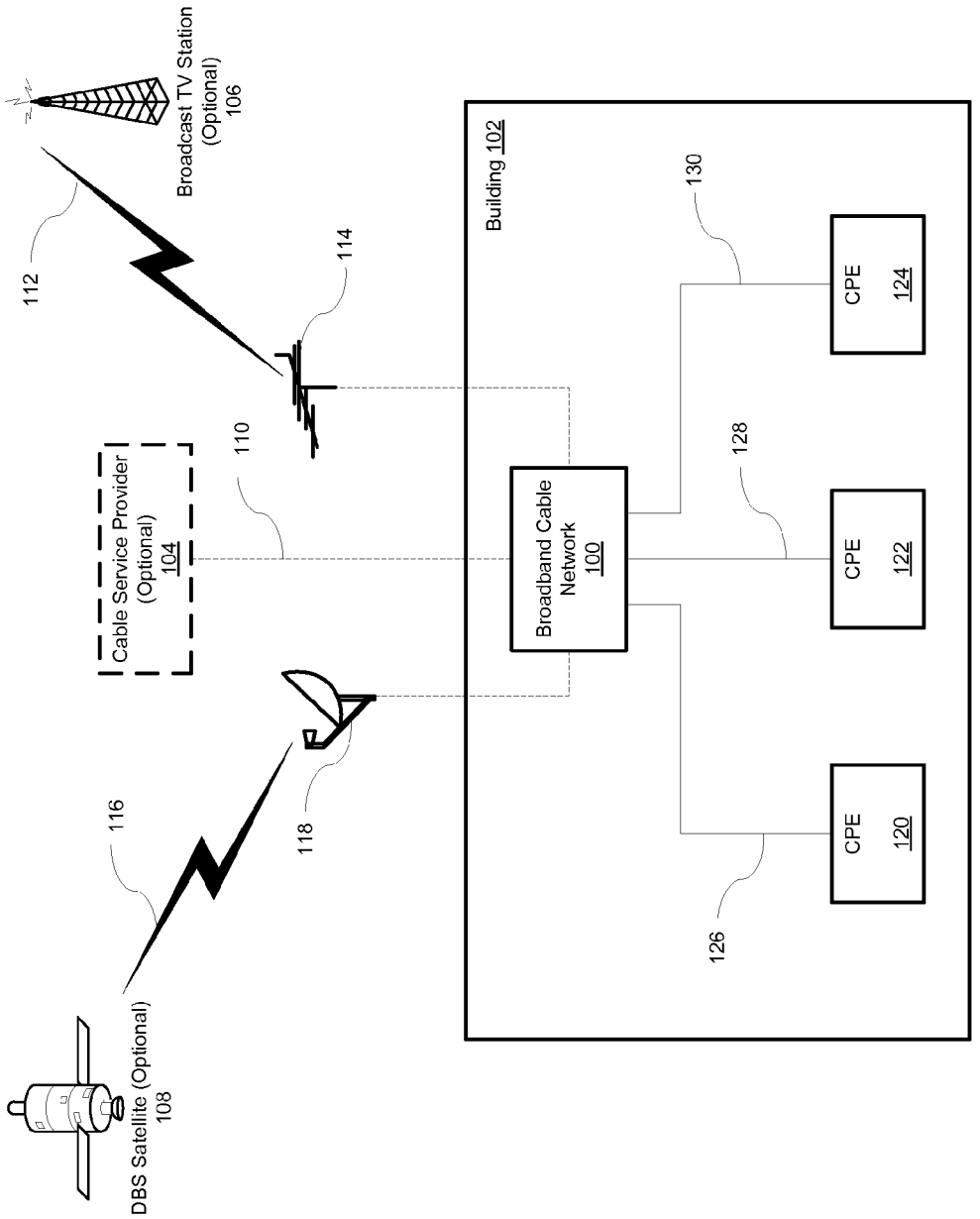


FIG. 1 (Prior Art)

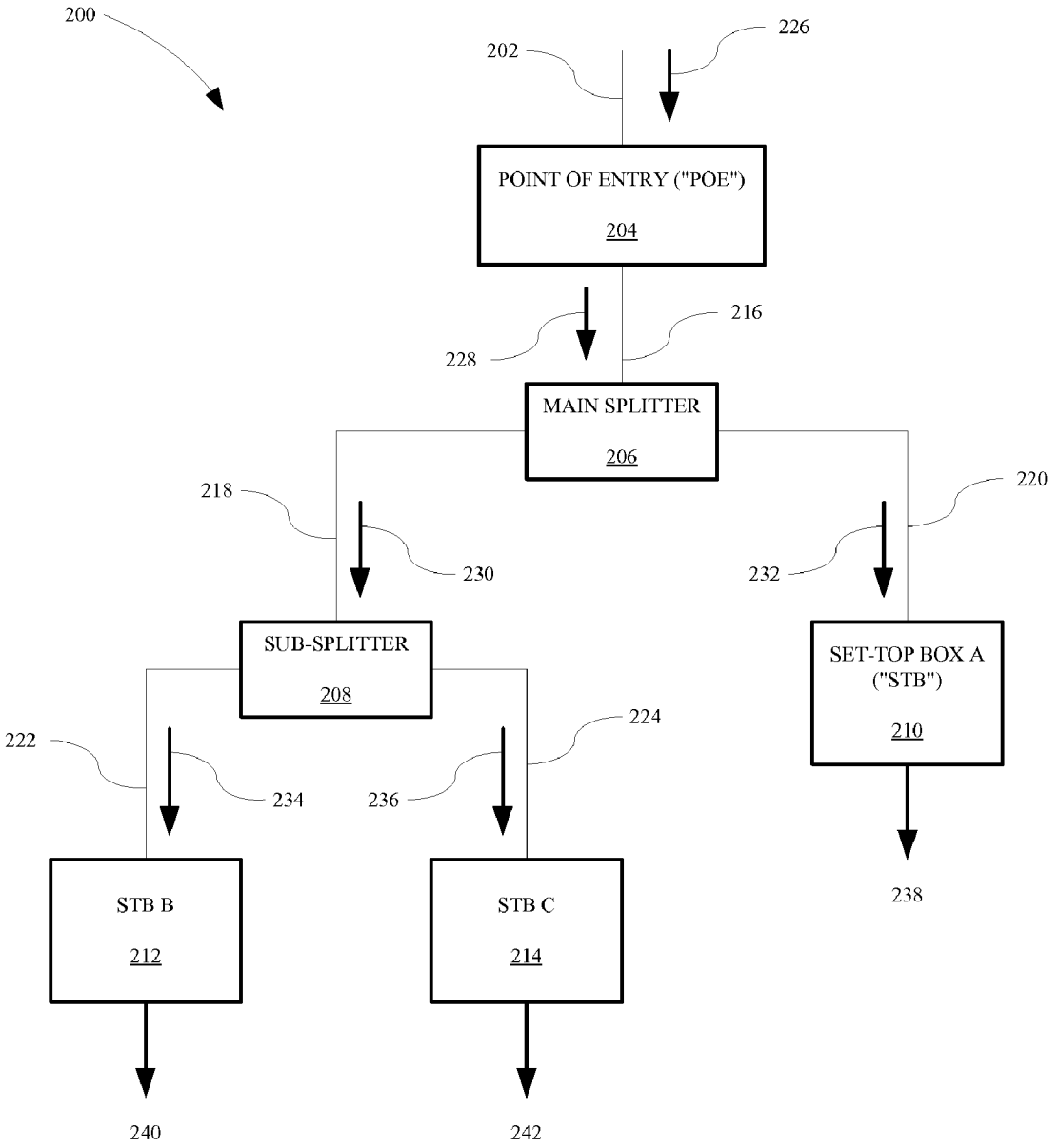


FIG. 2 (Prior Art)

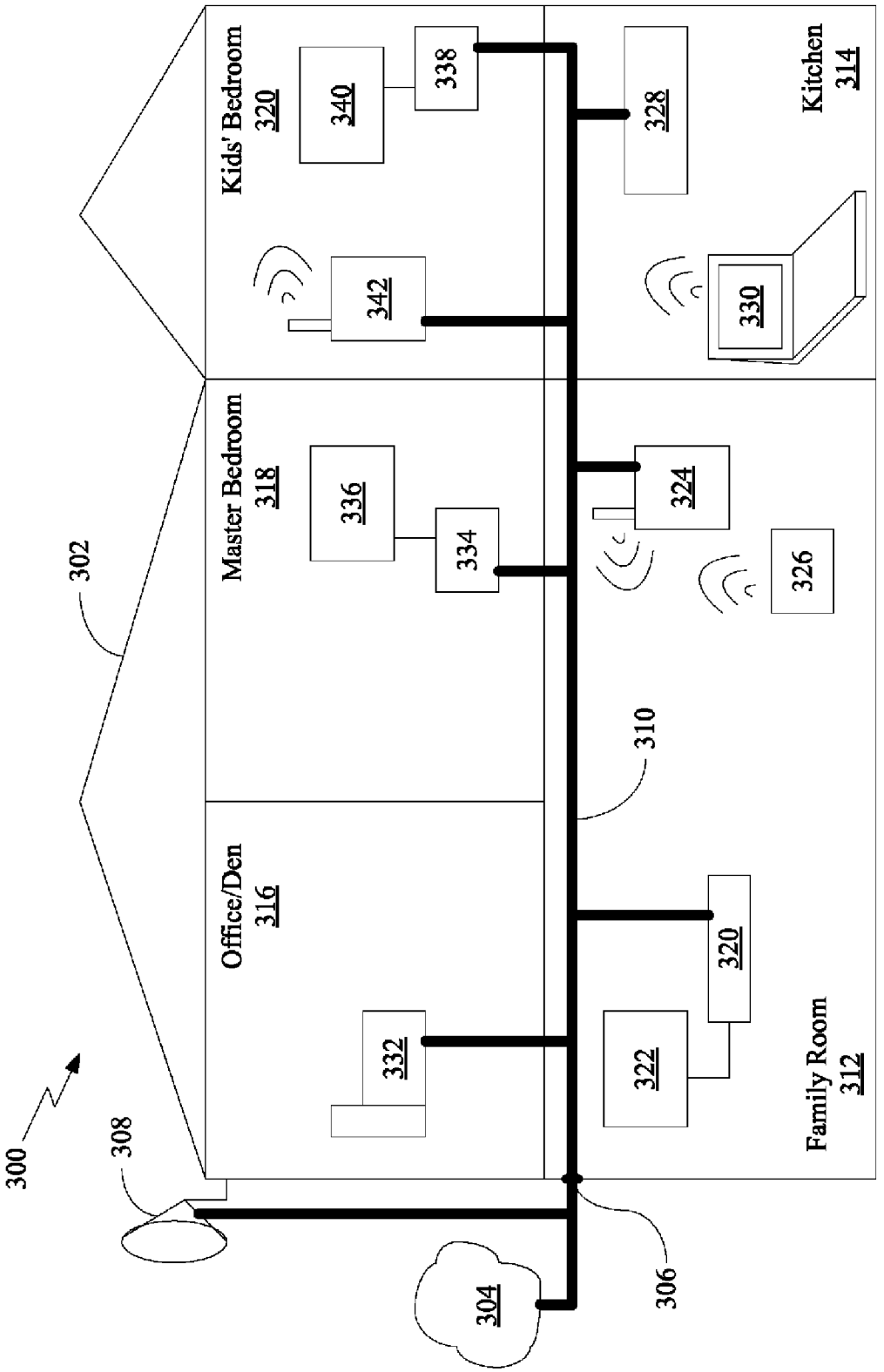

300
302
308
304
306
310
Office/Den
316
Master Bedroom
318
Kids' Bedroom
320
Family Room
312
Kitchen
314
332
336
334
340
338
342
322
320
324
326
328
330

FIG. 3

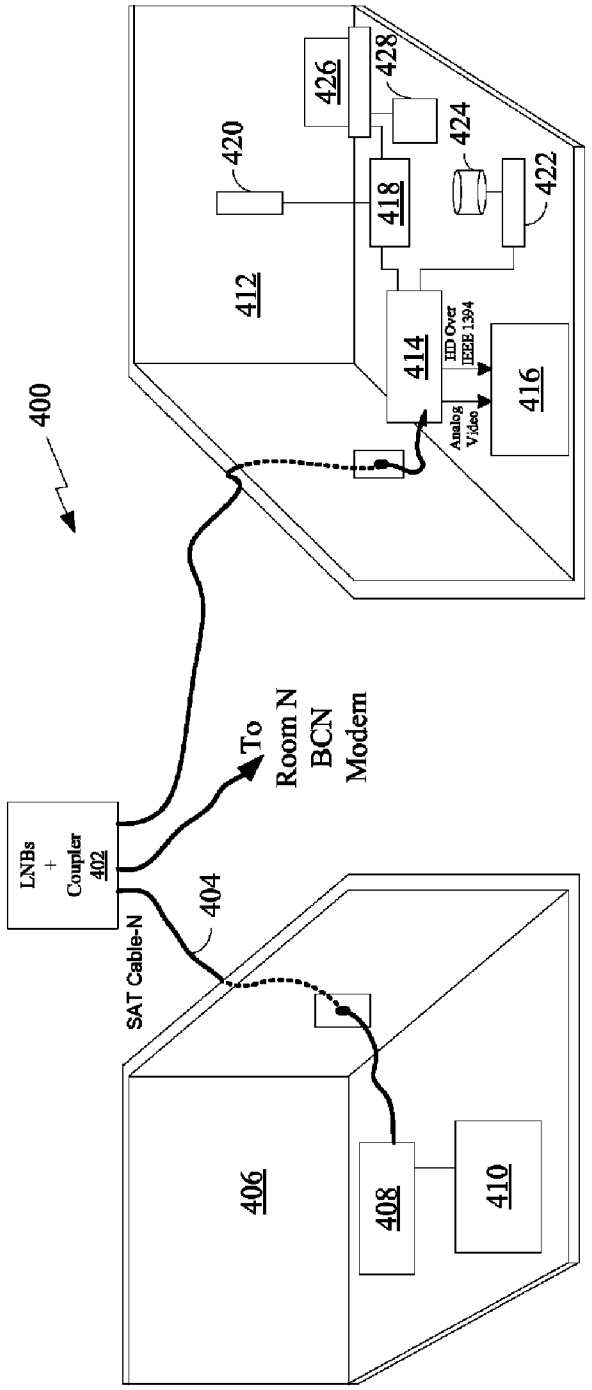

400
LNBs + Coupler 402
SAT Cable-N
404
To Room N BCN Modem
406
408
410
412
414
416
418
420
422
424
426
428
HD Over IEEE 1394
Analog Video

FIG. 4

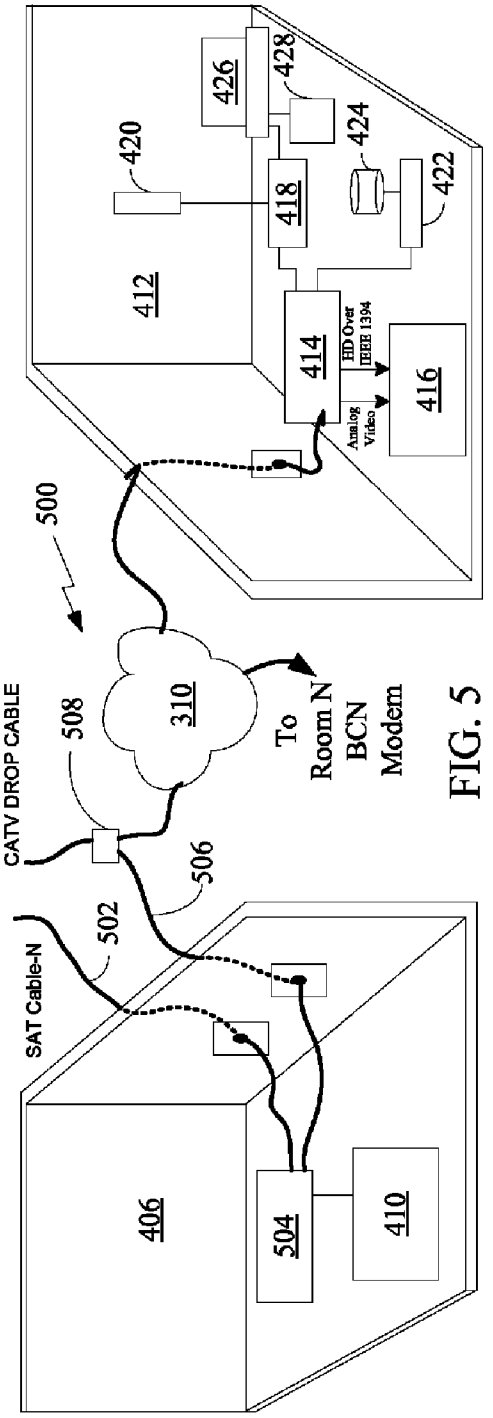

500
CATV DROP CABLE
508
310
To Room N BCN Modem
506
502
SAT Cable-N
406
504
410
412
414
416
418
420
422
424
426
428
HD Over IEEE 1394
Analog Video

FIG. 5

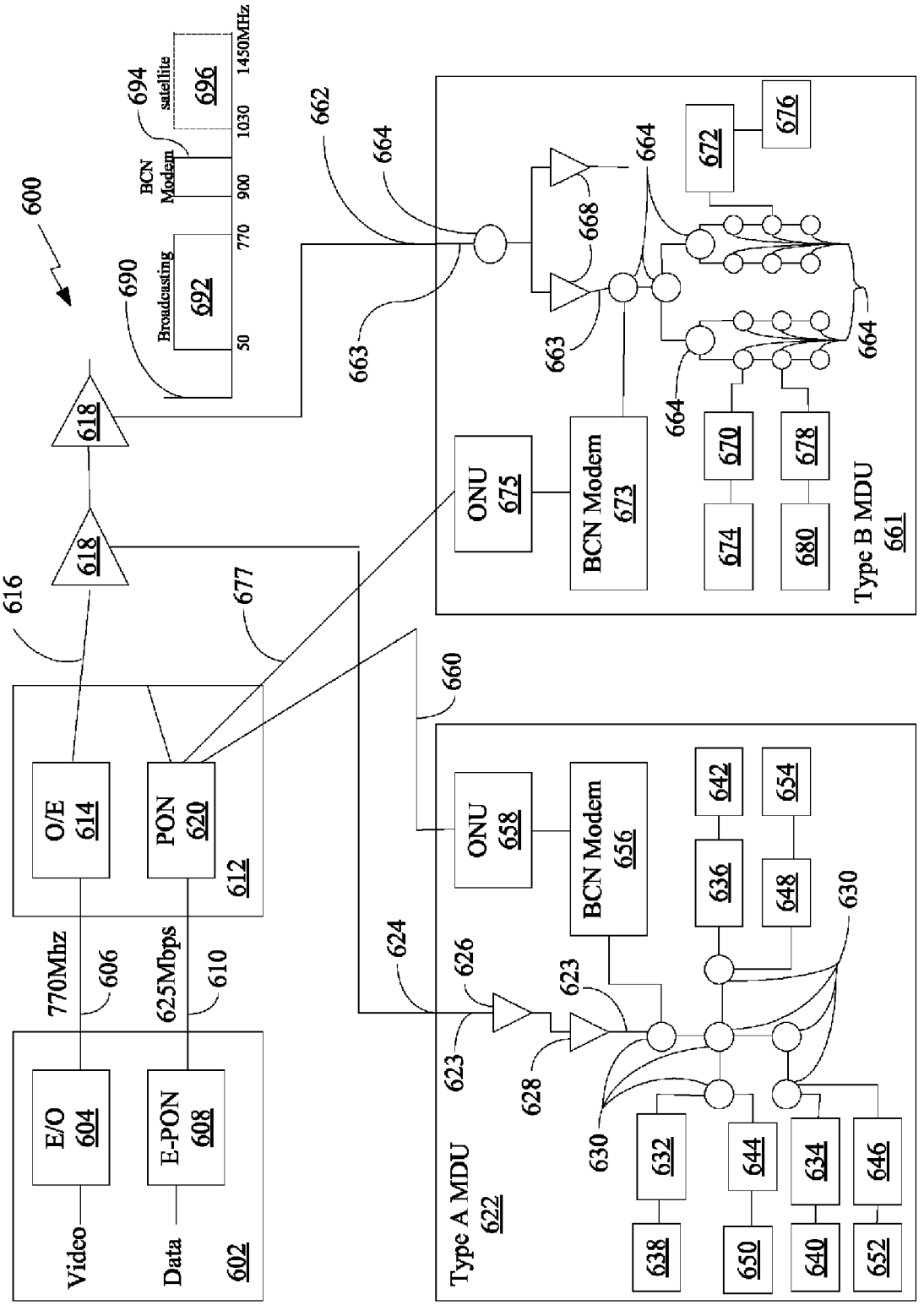

600
Broadcasting
692
BCN Modem
694
satellite
696
50
770
900
1030
1450MHz
690
618
618
616
677
660
662
664
663
668
672
676
ONU 675
BCN Modem 673
670
678
674
680
Type B MDU 661
O/E 614
PON 620
612
770Mhz
606
625Mbps
610
E/O 604
E-PON 608
Video
Data
602
624
626
623
628
630
ONU 658
BCN Modem 656
642
654
636
648
632
644
634
646
638
650
640
652
Type A MDU 622

FIG. 6

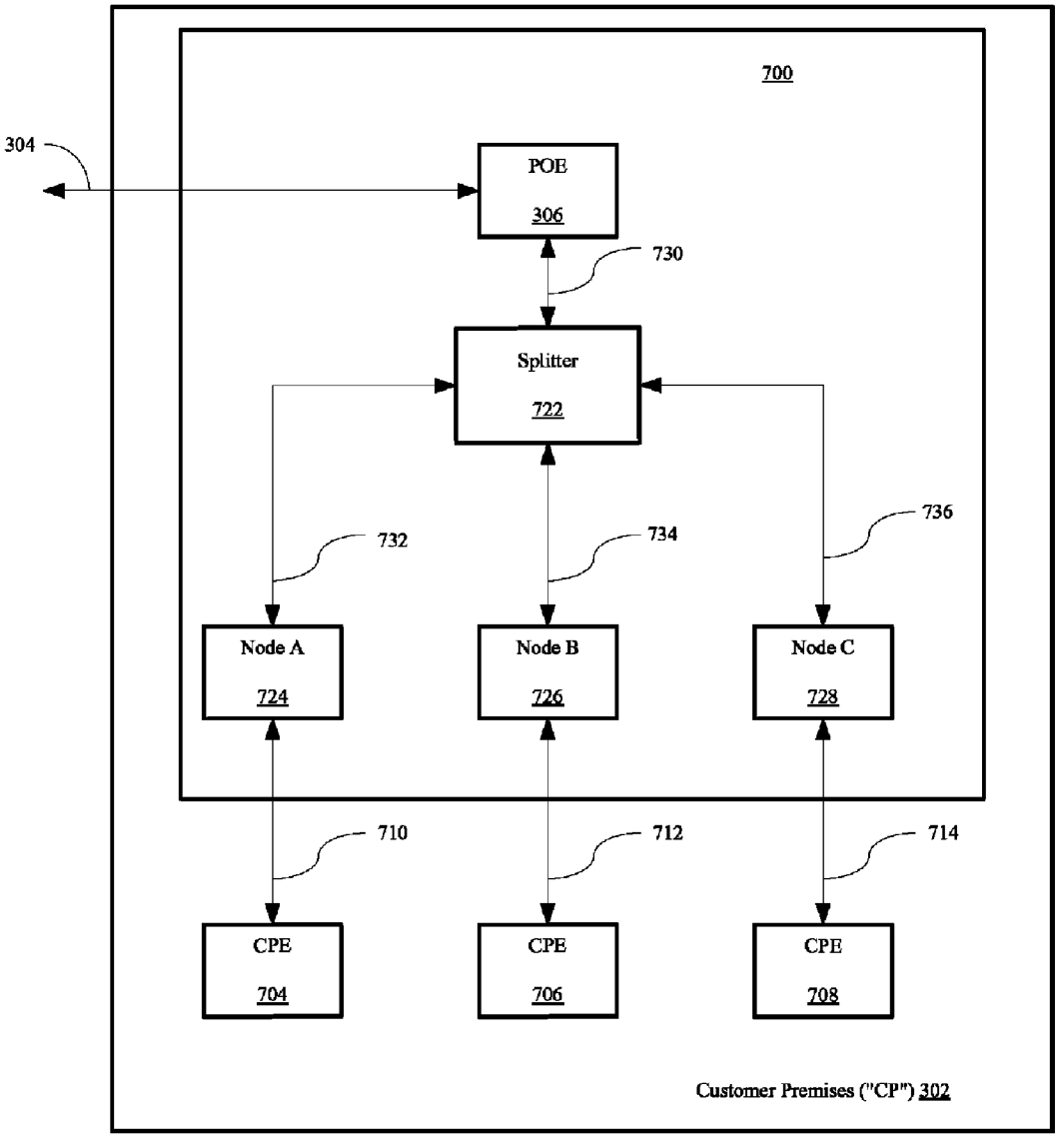

700
304
POE
306
730
Splitter
722
732
734
736
Node A
724
Node B
726
Node C
728
710
712
714
CPE
704
CPE
706
CPE
708
Customer Premises ("CP") 302

FIG. 7

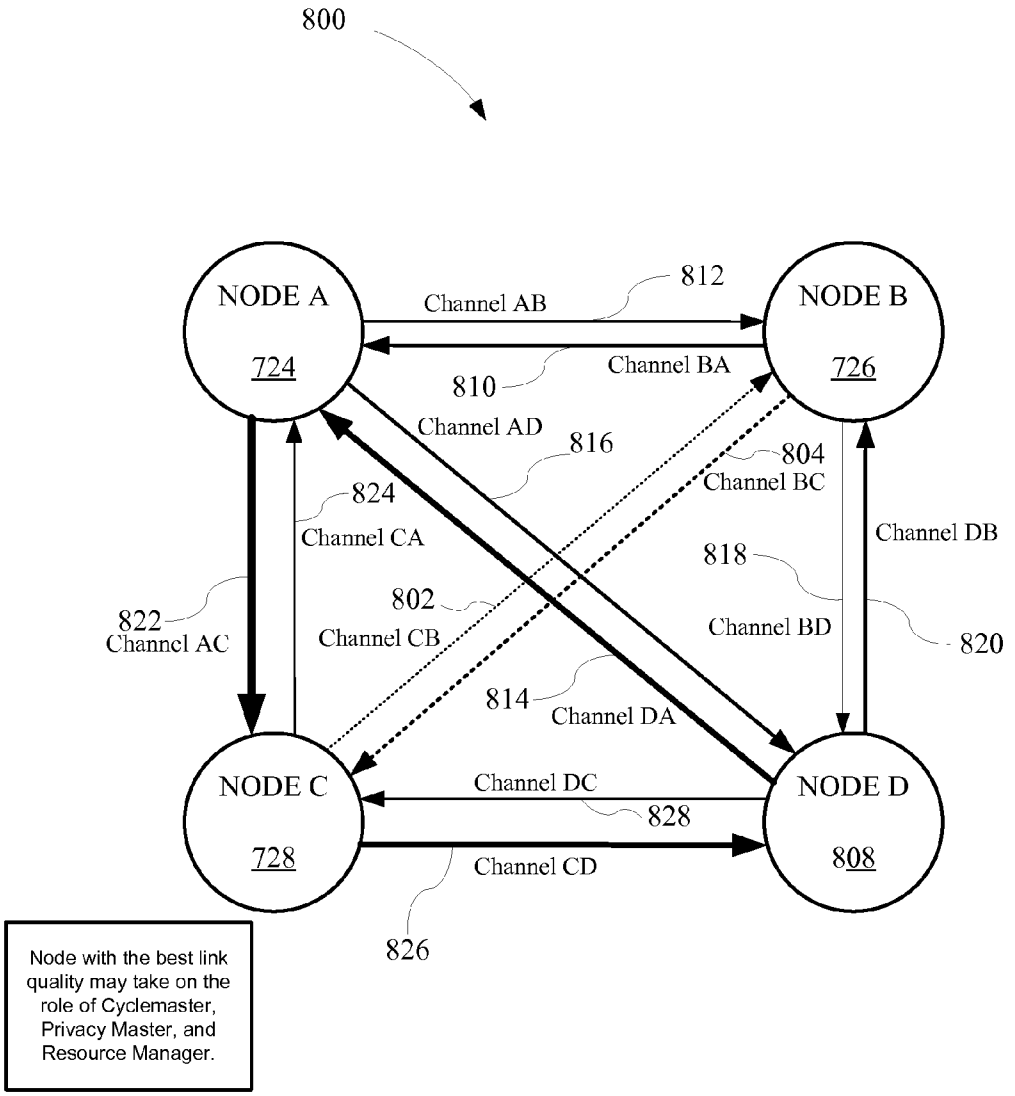

800
NODE A
724
NODE B
726
NODE C
728
NODE D
808
Channel AB
812
Channel BA
810
Channel AD
816
804
Channel BC
824
Channel CA
Channel DB
818
822
Channel AC
802
Channel CB
Channel BD
820
814
Channel DA
Channel DC
828
Channel CD
826
Node with the best link quality may take on the role of Cyclemaster, Privacy Master, and Resource Manager.

FIG. 8

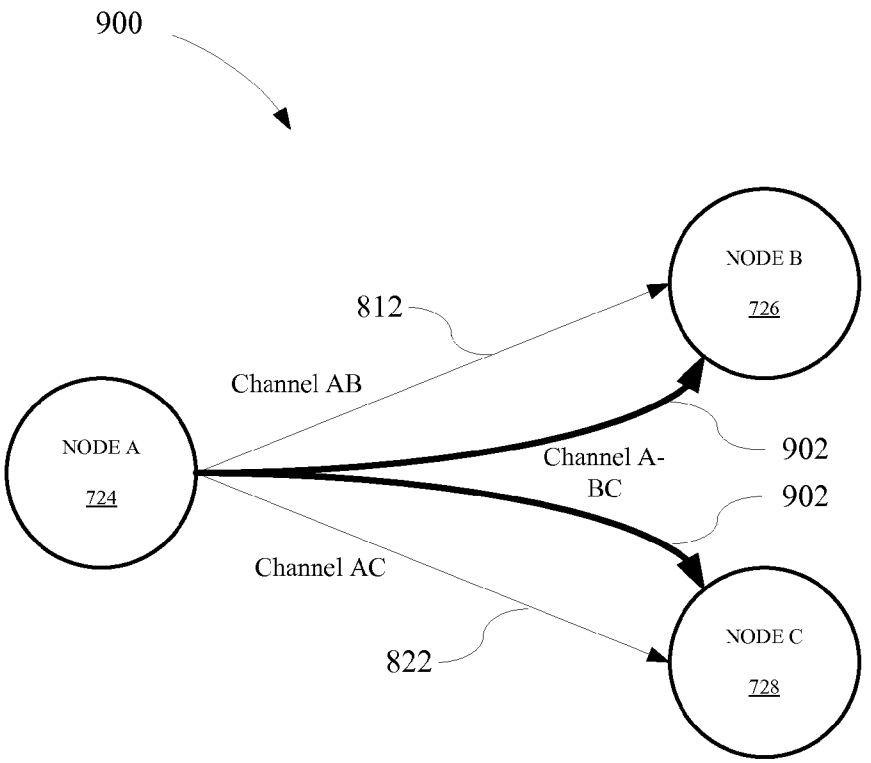

900
NODE B
726
812
Channel AB
NODE A
724
Channel A-
BC
902
902
Channel AC
822
NODE C
728

FIG. 9

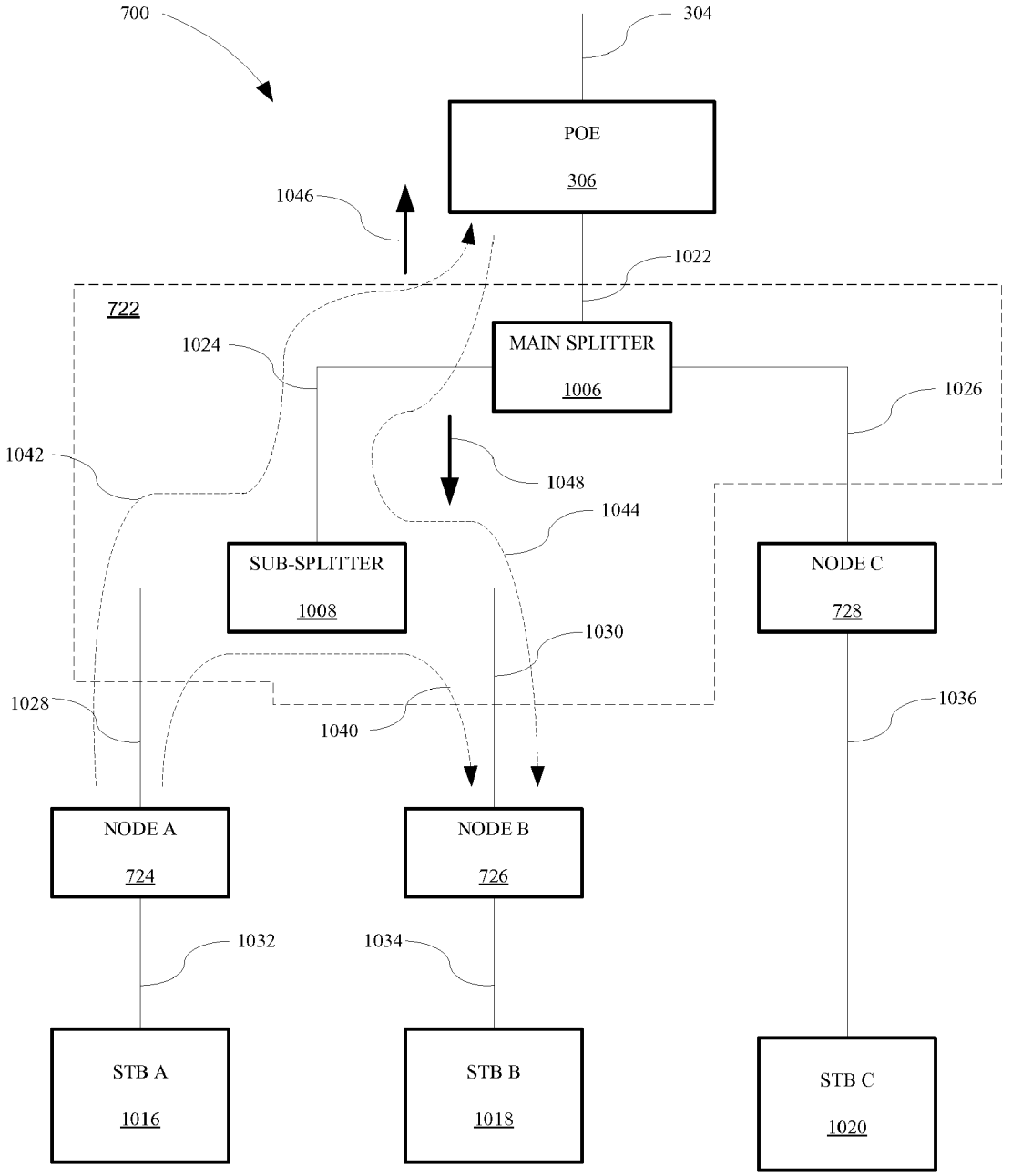

700
304
POE
306
1046
1022
722
1024
MAIN SPLITTER
1006
1026
1042
1048
1044
SUB-SPLITTER
1008
NODE C
728
1030
1028
1040
1036
NODE A
724
NODE B
726
1032
1034
STB A
1016
STB B
1018
STB C
1020

FIG. 10

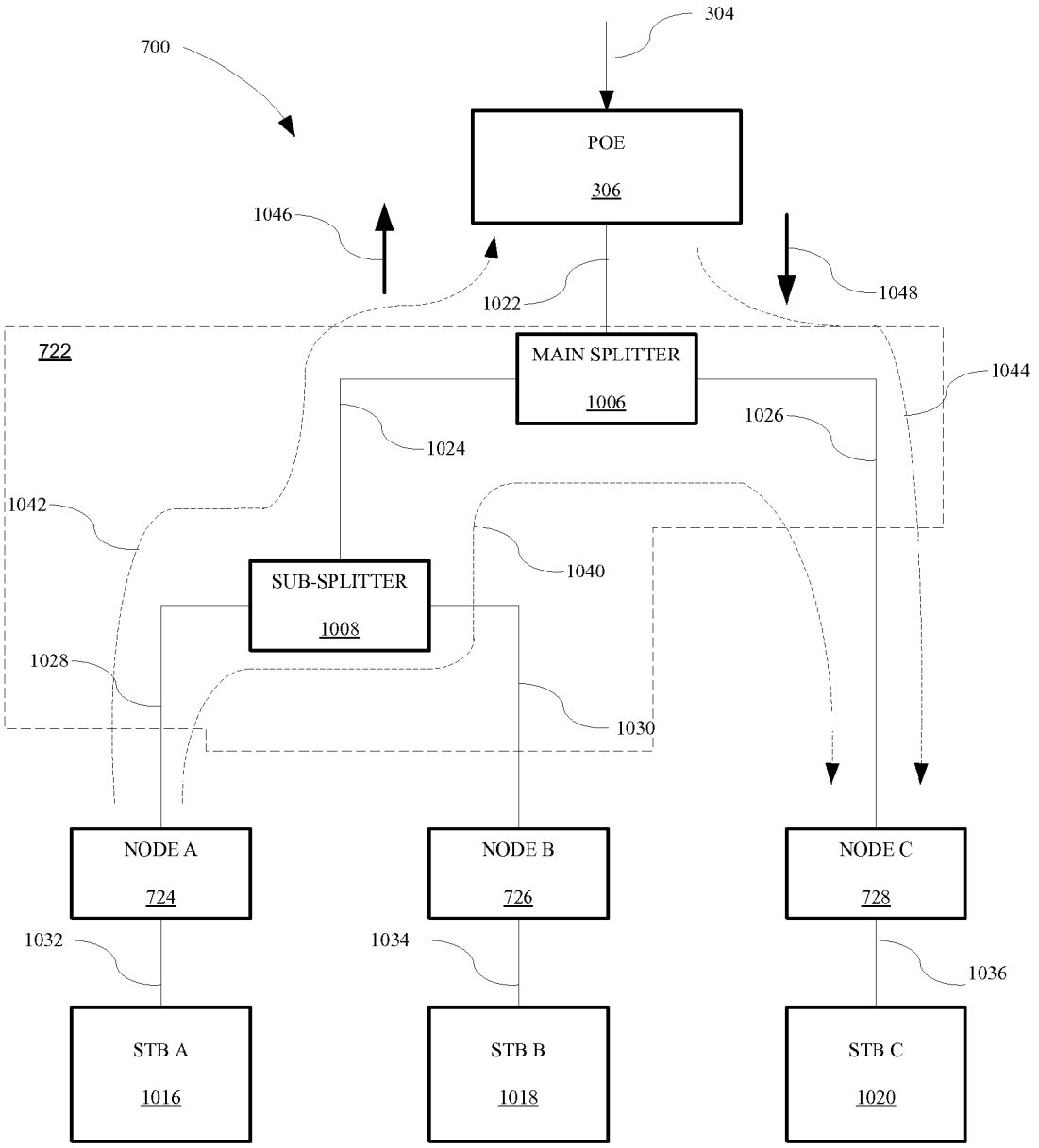

700
304
POE
306
1046
1048
1022
722
MAIN SPLITTER
1006
1044
1026
1024
1042
1040
SUB-SPLITTER
1008
1028
1030
NODE A
724
NODE B
726
NODE C
728
1032
1034
1036
STB A
1016
STB B
1018
STB C
1020

FIG. 11

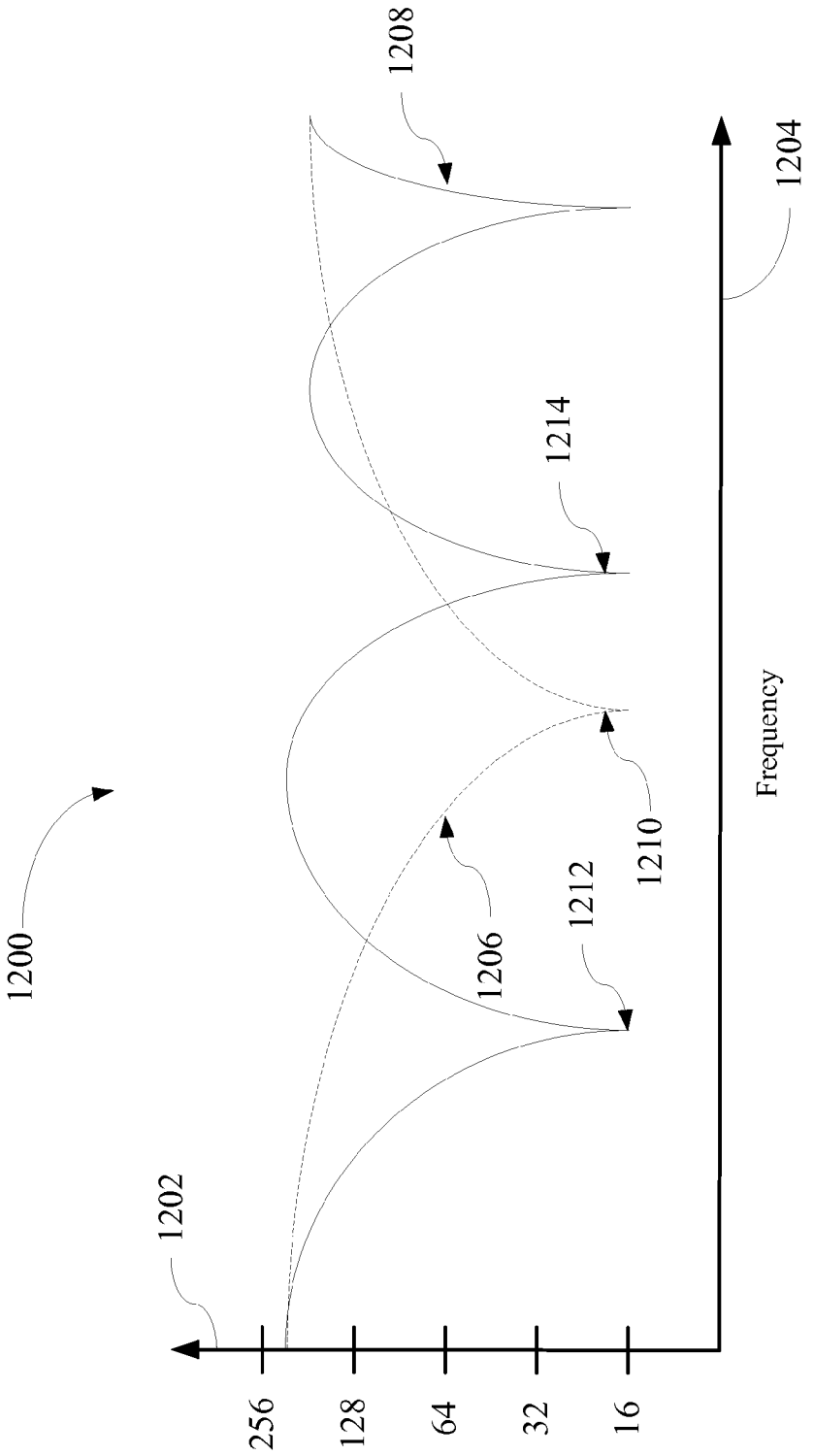

1200
1202
256
128
64
32
16
1206
1208
1210
1212
1214
1204
Frequency

FIG. 12

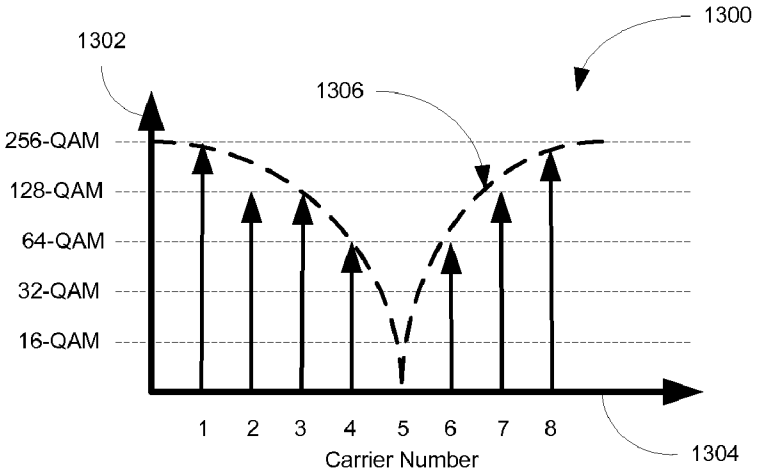


FIG. 13A

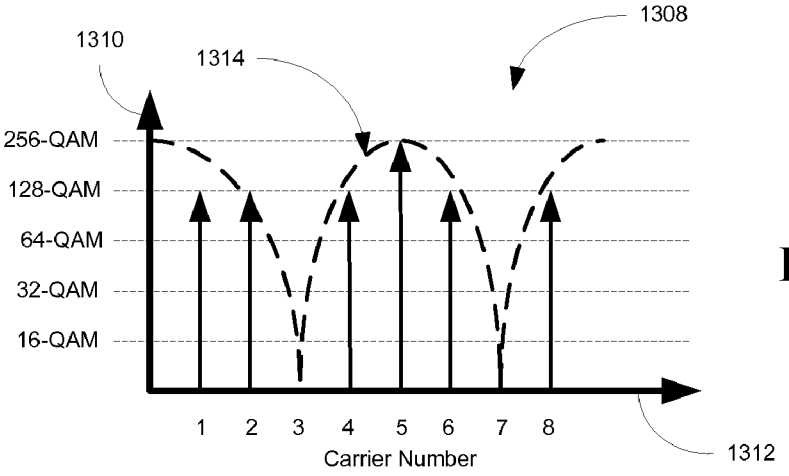


FIG. 13B

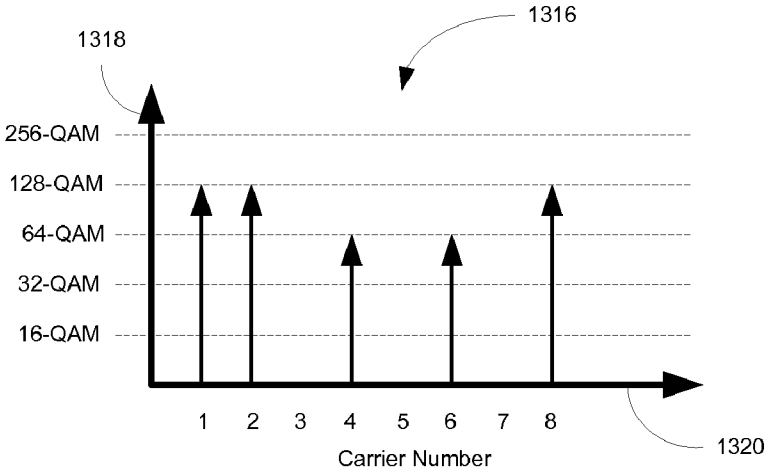


FIG. 13C

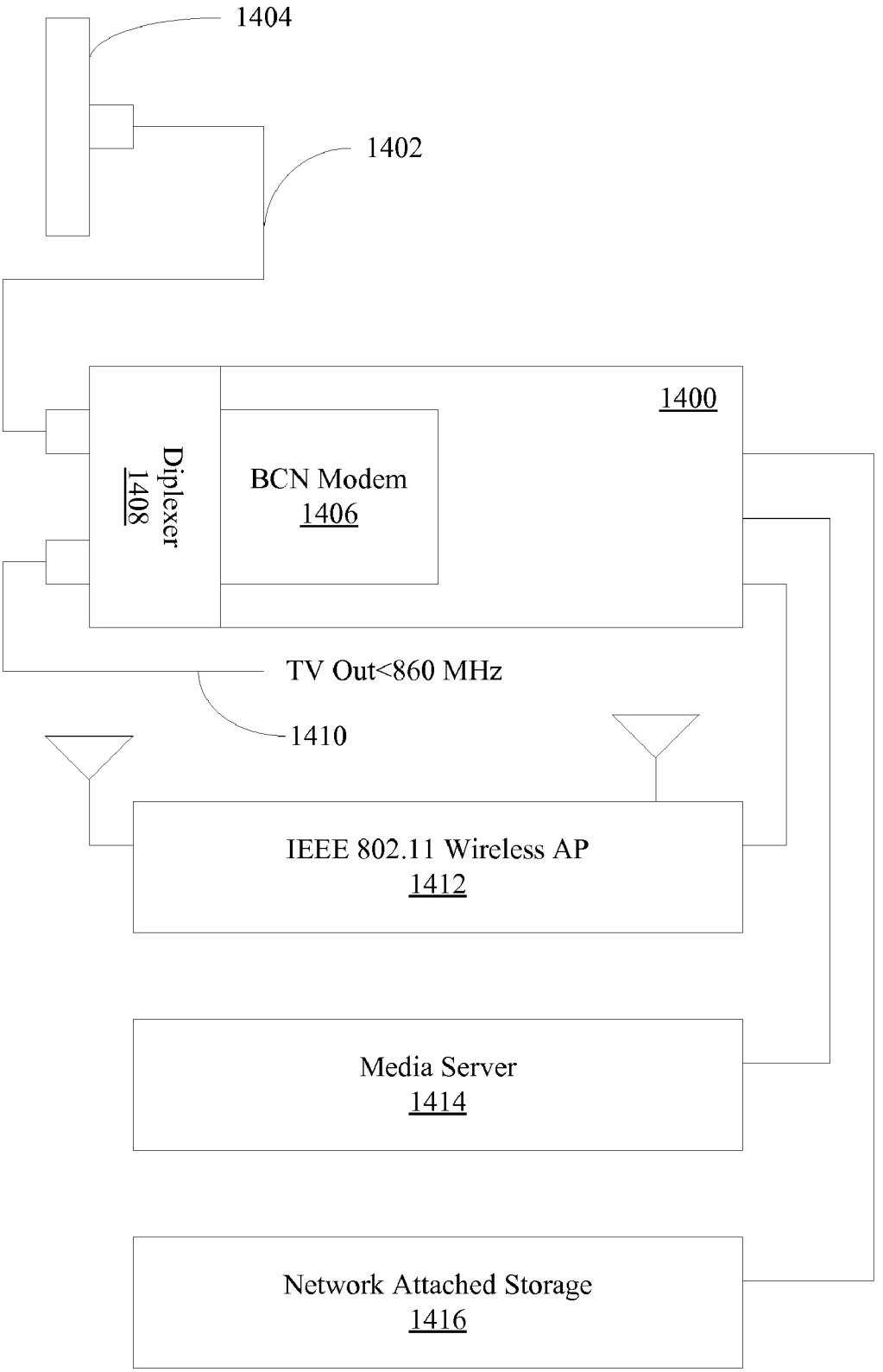

1404
1402
1400
Diplexer
1408
BCN Modem
1406
TV Out<860 MHz
1410
IEEE 802.11 Wireless AP
1412
Media Server
1414
Network Attached Storage
1416

FIG. 14

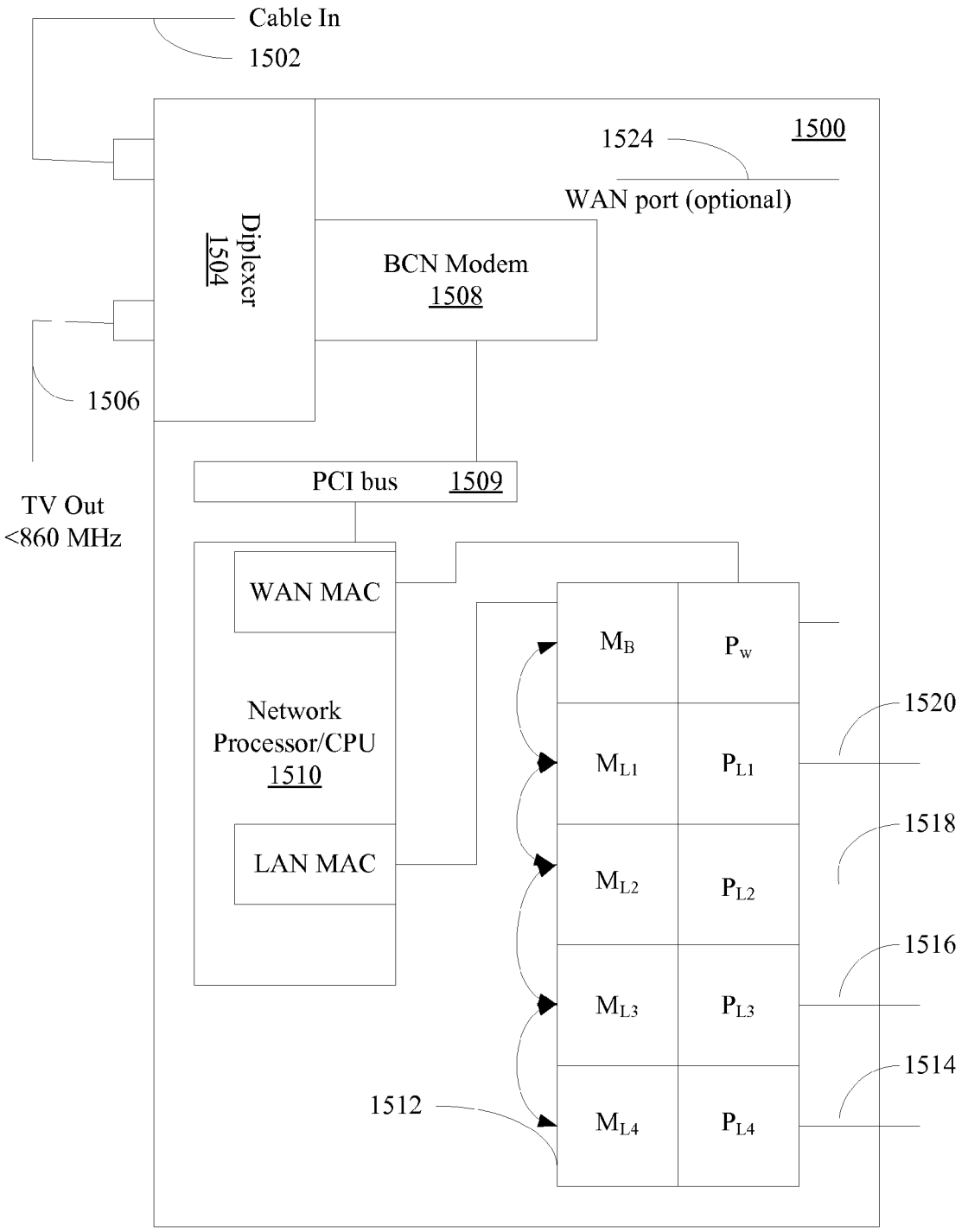

Cable In
1502
1500
1524
WAN port (optional)
Diplexer
1504
BCN Modem
1508
1506
TV Out
<860 MHz
PCI bus
1509
WAN MAC
Network
Processor/CPU
1510
LAN MAC
M_B
P_w
M_{L1}
P_{L1}
M_{L2}
P_{L2}
M_{L3}
P_{L3}
M_{L4}
P_{L4}
1520
1518
1516
1514
1512

FIG. 15

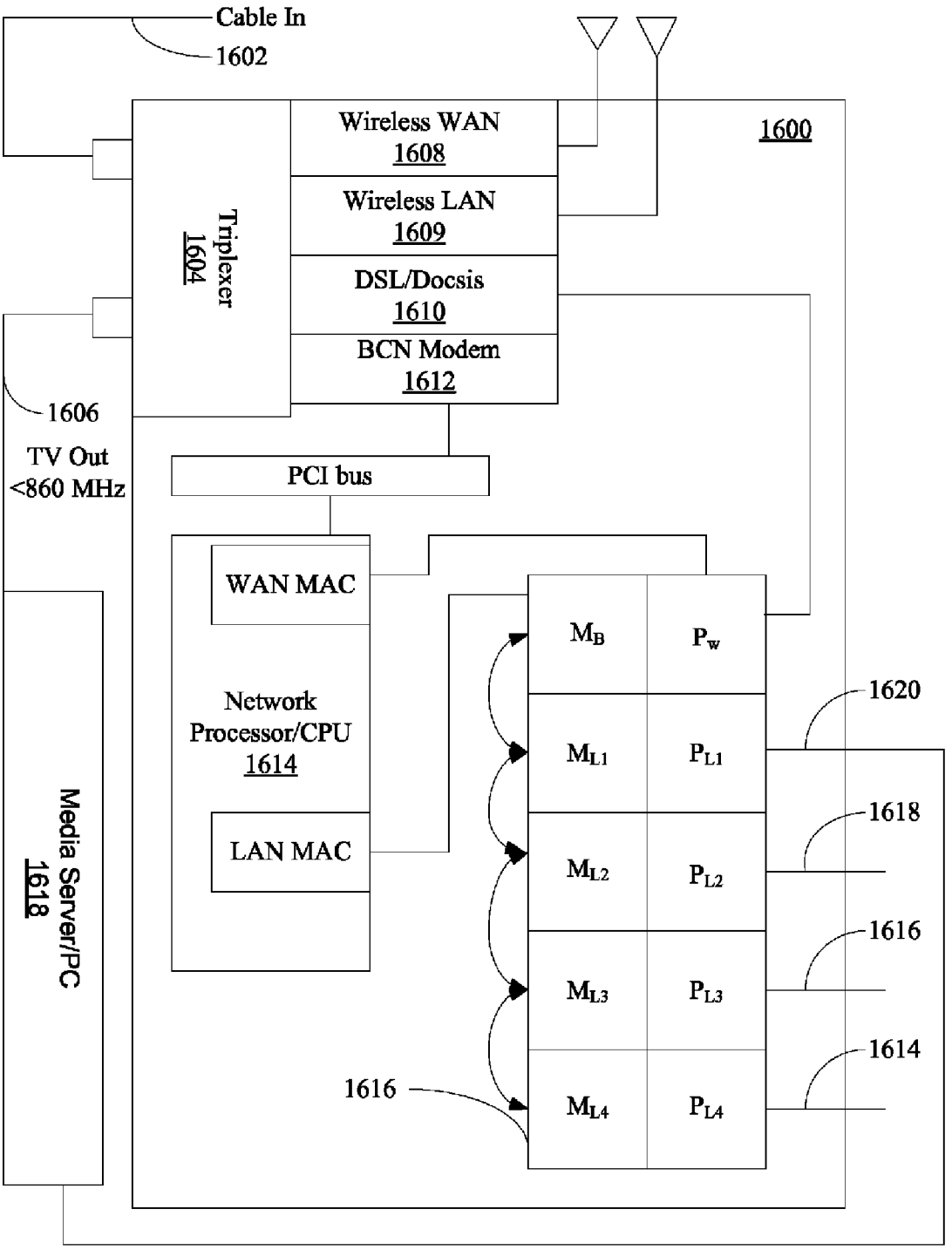

Cable In
1602
1600
Wireless WAN
1608
Wireless LAN
1609
DSL/Docsis
1610
BCN Modem
1612
Triplexer
1604
1606
TV Out
<860 MHz
PCI bus
WAN MAC
Network
Processor/CPU
1614
LAN MAC
Media Server/PC
1618
M_B
P_w
M_{L1}
P_{L1}
M_{L2}
P_{L2}
M_{L3}
P_{L3}
M_{L4}
P_{L4}
1620
1618
1616
1614
1616

FIG. 16

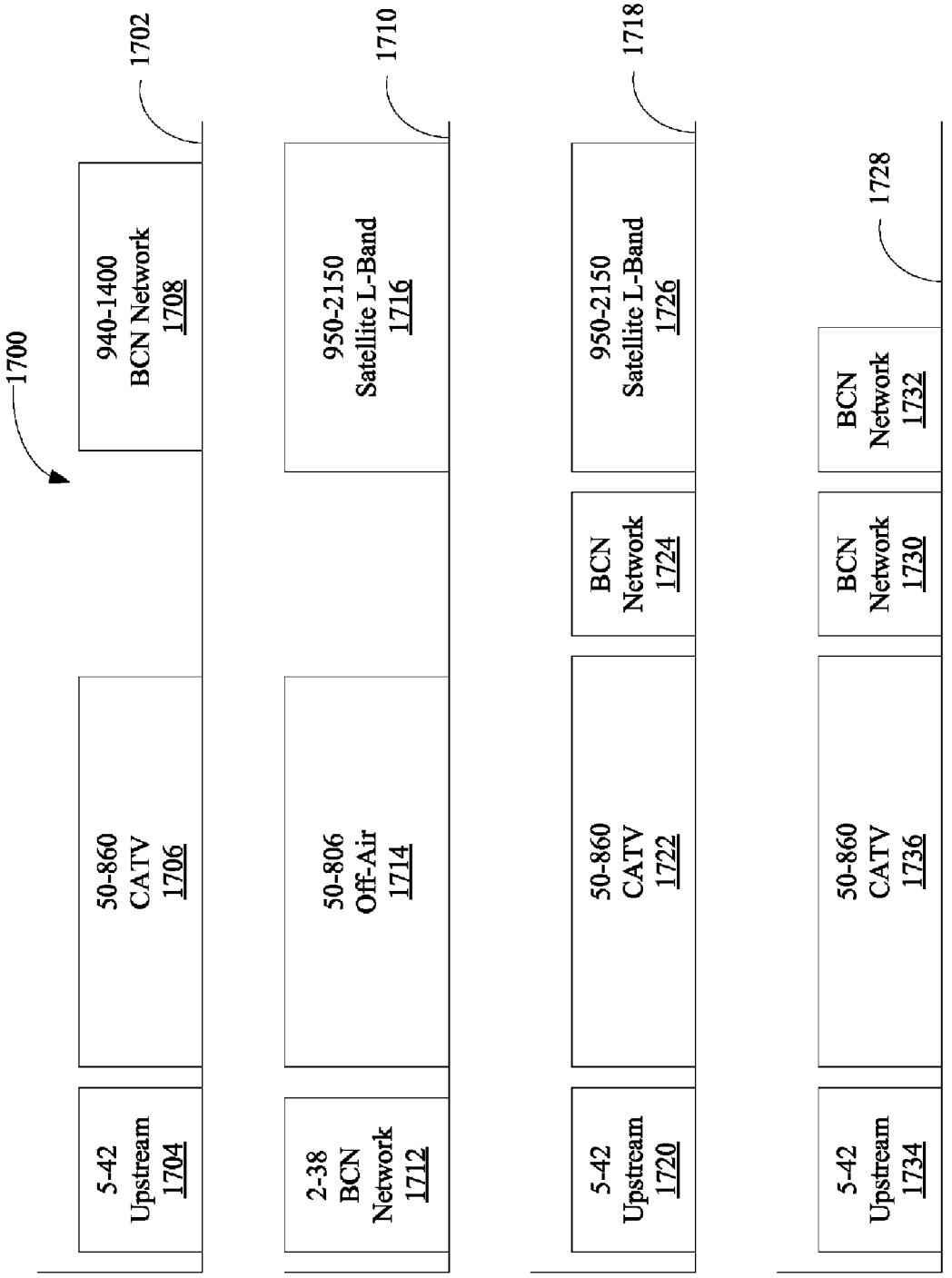

1700
1702
940-1400
BCN Network
1708
50-860
CATV
1706
5-42
Upstream
1704
1710
950-2150
Satellite L-Band
1716
50-806
Off-Air
1714
2-38
BCN
Network
1712
1718
950-2150
Satellite L-Band
1726
BCN
Network
1724
50-860
CATV
1722
5-42
Upstream
1720
1728
BCN
Network
1732
BCN
Network
1730
50-860
CATV
1736
5-42
Upstream
1734

FIG. 17

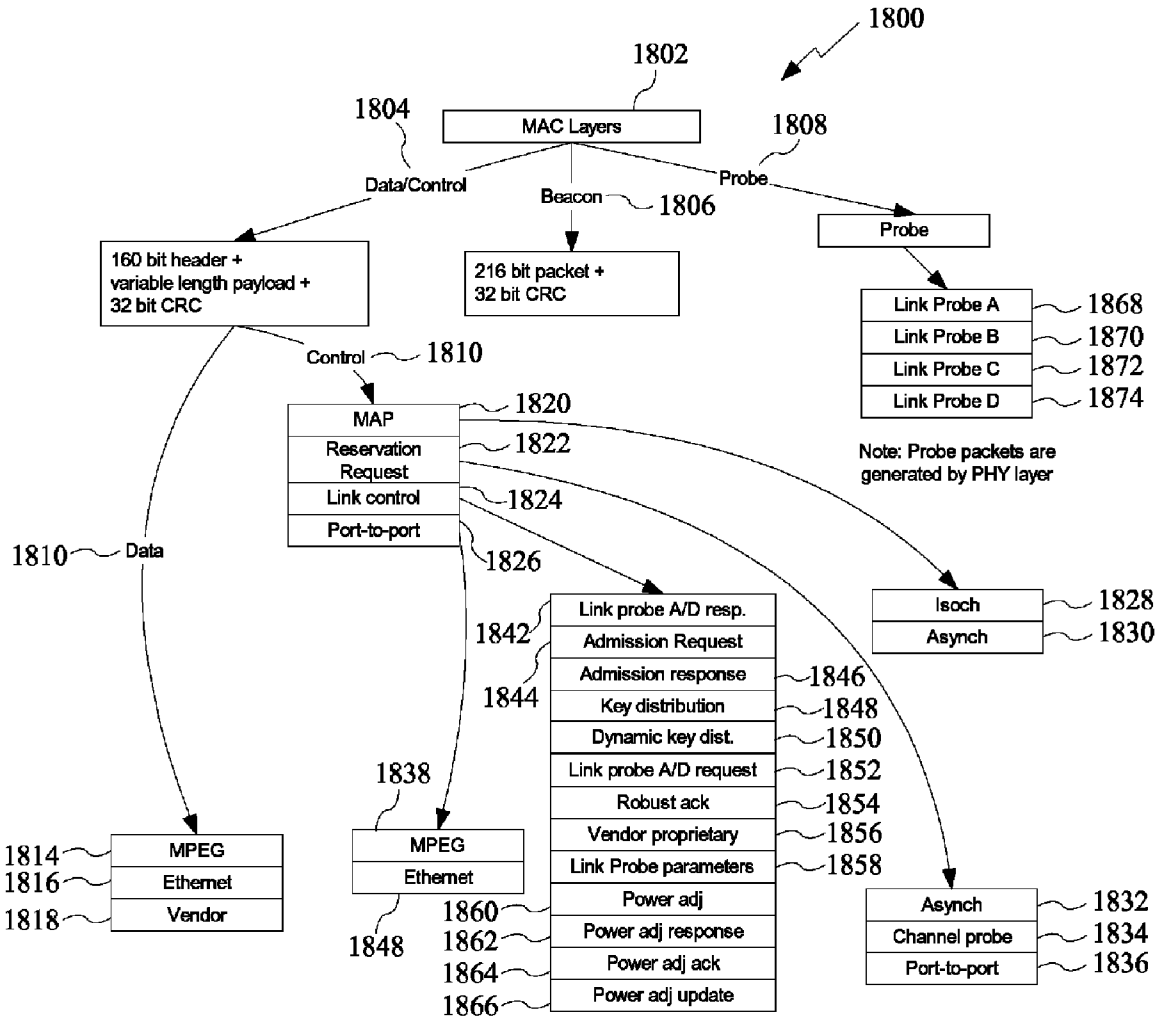

1800
1802
MAC Layers
1804
Data/Control
Beacon
1806
Probe
1808
160 bit header +
variable length payload +
32 bit CRC
216 bit packet +
32 bit CRC
Probe
Link Probe A
Link Probe B
Link Probe C
Link Probe D
1868
1870
1872
1874
Note: Probe packets are generated by PHY layer
Control
1810
MAP
Reservation Request
Link control
Port-to-port
1820
1822
1824
1826
1810
Data
Isoch
Asynch
1828
1830
Link probe A/D resp.
Admission Request
Admission response
Key distribution
Dynamic key dist.
Link probe A/D request
Robust ack
Vendor proprietary
Link Probe parameters
Power adj
Power adj response
Power adj ack
Power adj update
1842
1844
1846
1848
1850
1852
1854
1856
1858
1860
1862
1864
1866
1838
MPEG
Ethernet
1848
1814
1816
1818
MPEG
Ethernet
Vendor
Asynch
Channel probe
Port-to-port
1832
1834
1836

FIG. 18

1900

	Field	Length	Usage
1902	Transmit clock	32 bits	System time when the first bit is transmitted over the medium
	Packet type 1904	4 bits	Indicates the type of MAC packet being transmitted 0x0 – MAP 0x1 – Reservation Request 0x2 – Link control 0x3 – Ethernet unicast/broadcast 0x4 – Port-to-port 0x5 – MPEG/DSS 0x6 – Vendor proprietary 0x7 - 0xF – Reserved
	Packet subtype 1906	4 bits	If packet type == MAP 0x0 = Asynch MAP If packet_type == Reservation Request 0x0 = Asynchronous data reservation request If packet_type == Link control 0x0 – Probe A/D Reply 0x1 – Self ID/ Admission Request 0x2 – Admission response 0x3 – Key distribution 0x4 – Dynamic Key distribution 0x5 – Probe A/D reply request 0x6 – General link acknowledgement 0x7 – Link Probe C parameters 0x8 – Vendor Proprietary 0x9 – Tx_power_adj 0xA – Tx_power_adj response 0xB – Tx_power_adj ack 0xC – Tx_power_adj update 0xD – Topology update 0xE – 0xF – reserved If packet_type == port-to-port 0x0 - Ethernet 0x1 – MPEG All other values reserved
	version 1908	8 bits	Indicates the MAC specification version implemented by a node. 0x00 – node complies with this specification All other values Reserved.
1910	Source node ID	16 bits	As defined in xxx
1912	Destination node ID	16 bits	As defined in xxx
1914	Packet Length	16 bits	Length of this MAC packet in bytes, inclusive of the packet header, payload and CRC at the end
1916	Reserved	32 bits	
	Header Check Sequence	16 bits	Header CRC

1918

FIG. 19

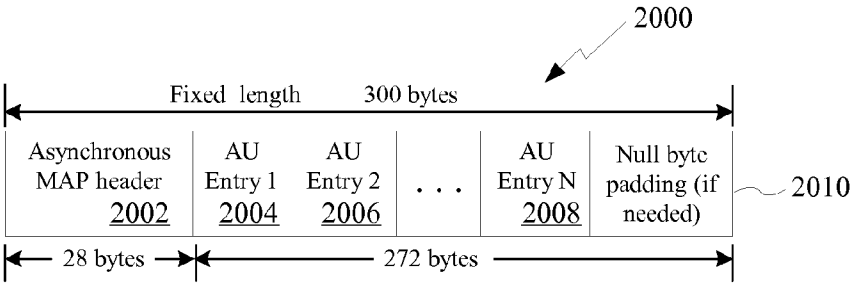


FIG. 20

2100

Field	Length	Usage	
Valid_from	32 bits	System time from which the MAP is valid	2102
Valid_to	32 bits	System time to which the MAP is valid	2104
Parameters	32 bits	Bits used as follows: Bit 31-reserved Bit 30- reserved Bit 29- reserved Bit 28- reserved Bit 27- Encryption_on flag 1 = Encryption on 0 = Reserved Bit 26- TEK_encryption_key_flag 1 = Odd TEK encryption key is in use 0 = Even TEK encryption key is in use Bit 25- PMK_encryption_key_flag 1 = Odd PMK encryption key is in use 0 = Even PMK encryption key is in use Bits 24:0 - reserved	2106
State	32 bits	Informs nodes of the state of the network	2108
Node_bitmask	32 bits	In each bit position, the bit is set to "1" if the corresponding node is present in the network (implies only 32 nodes in the network)	2110
Probe source node	32 bits	Node ID for the node that is up next for sending a Link type A probe.	2112
Miscellaneous	32 bits	Miscellaneous data	2114

FIG. 21

2200

Field	Length	Usage	
Type	4 bits	Indicates the type of transmission for which the time is being allocated. 0x0 = MAP 0x1 = Reservation request 0x2 = Link control packet 0x3 = Ethernet unicast Probe allocation 0x4 = Port-to-port message 0x5 = MPEG/DSS transmission 0x6 = Vendor proprietary format 0x7 – 0x9 = reserved 0xA = silent allocation 0xB = Probe 0xC = Beacon 0xD – 0xF = reserved	2202
Subtype	4 bits	If packet type == MAP 0x0 = Asynch MAP If packet_type == Reservation Request 0x0 = asynchronous If packet_type == Link control 0x0 – Probe A/D Reply 0x1 – Self ID/ Admission Request 0x2 – Admission response 0x3 – Key distribution 0x4 – Dynamic Key distribution 0x5 – Probe A/D reply request 0x6 – General link Ack 0x7 – Link Probe C parameters 0x8 – Vendor Proprietary 0x9 – Tx_power_adj 0xA – Tx_power_adj response 0xB – Tx_power_adj ack 0xC- Tx_power_adj update 0xD – Topology update 0xE – 0xF – reserved If packet_type == port-to-port 0x0 - Ethernet All other values reserved	2204
SRC	8 bits	ID of source node for the transmission	2206
Destination	8 bits	ID of destination node for the transmission	2208
PHY Profile	8 bits	Indicates the type of modulation scheme used for this transmission bits 7:6 00 = profile sequence 0 01 = profile sequence 1 bits 5:0 11111 = Beacon profile 11110 = Diversity mode profile 11101 = Link probe A profile 11100 = Link probe C profile	2210

FIG. 22A

Field	Length	Usage	
Code	8 bits	Indicates type of probe transmission	2212
source	8 bits	Node ID of the source node	2214
Destination	8 bits	Node ID of the destination node	2216
Training	8 bits		2218
Miscellaneous	32 bits	Miscellaneous data	2220
Sc1	8 bits	I believe this probe format is only intended for Type C probes (mandatory transmission capability and optional reception capability)	
Sc2	8 bits		
Sc3	8 bits		
Sc4	8 bits		
offset	32 bits		2222

FIG. 22B

2300

Field	Length	Usage	
Code	8 bits	Reason for Non-allocation 0x00 = Unspecified reason 0x01 = incorrect state of node 0x02 = Bandwidth unavailable 0x03 – 0xFF = Reserved	2302
SRC	8 bits	Node ID of original requester	2304
Sequence ID	8 bits	Sequence number of the original request	2306
Type	4 bits	Type of the original request being NACK-ed 0x0 = reserved 0x1 = reserved 0x2 = Link control packet 0x3 = Ethernet unicast 0x4 = Port-to-port message 0x5 = MPEG/DSS transmission 0x6 = Vendor proprietary format 0x7 – 0x9 = reserved 0xA = silent allocation 0xB = Probe 0xC – 0xF = reserved	2308
Subtype	4 bits	If type == Link control 0x0 – Probe A/D Reply 0x1 – Self ID/ Admission Request 0x2 – Admission response 0x3 – Key distribution 0x4 – Dynamic Key distribution 0x5 – Probe A/D reply request 0x6 – General link Ack 0x7 – Link Probe C parameters 0x8 – Vendor Proprietary 0x9 – Tx_power_adj 0xA – Tx_power_adj response 0xB – Tx_power_adj ack 0xC – Tx_power_adj update 0xD – Topology update 0xE – 0xF – reserved If type == port-to-port 0x0 - Ethernet All other values reserved	2310

FIG. 23

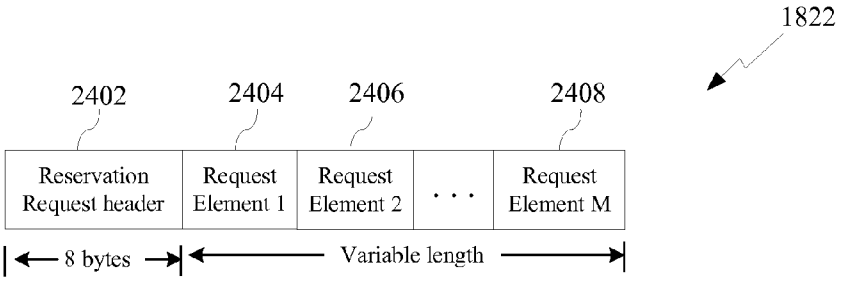


FIG. 24

2500

Field	Length	Usage	
Num elements	16 bits	Total number of request elements in the subsequent iteration	2502
Miscellaneous	8 bits	Miscellaneous data	2504
Reserved	8 bits		2506
state	32 bits	8 LSBs used to indicate the state of the requesting node 0x00 – Network Empty 0x01 – Network Admission 0x02 – Network TX channel estimate state 0x03 – Network RX channel estimate state 0x04 – Network Broadcast Bitloading TX state 0x05 – Broadcast bitloading update state 0x06 – Steady state (Active state) 0x07 – Link probe D state 0x08 – Link probe A state 0x09 – Broadcast bitload TX state 0x0A –Broadcast bitload update state	2508
for i=0,i<Num_elements,i ++{			
Request element ()	Variable bits	Request element can be one of – Isochronous data – future version Asynchronous data – 8 bytes long Link probe – variable length Link control – 8 bytes long Port-to-port message – future version	2510
}			

FIG. 25

2600

Field	Length	Usage	
Type	8 bits	Bits used as follows: 0x0D = Ethernet unicast/ broadcast All other values reserved	2602
Destination	8 bits	Node ID of destination node	2604
PHY Profile	8 bits	PHY profile that will be used for the requested transmission bits 7:6 00 = profile sequence 0 01 = profile sequence 1 bits 5:0 11111 = Beacon profile 11110 = Diversity mode profile 11101 = Link probe A profile 11100 = Link probe C profile 11011 = Link probe D profile 11010 = unicast profile to the destination node	2606
Request ID	8 bits	A sequence number associated with the request. This number will be incremented by one every time bandwidth allocation is received for a pending request for transmission using the same PHY profile to the same destination.	2608
Parameters	16 bits	Set to 0x0000	
Bandwidth	16 bits	Bandwidth requested in integer multiples of 20 nanoseconds	2610
			2612

FIG. 26

2700

Field	Length	Usage	
Type	8 bits	Bits used as follows:	2702
Reserved	8 bits		2704
Destination	8 bits	Node ID of destination node	2706
Probe index	8 bits	Index of the probe requested	2708
Request ID	32 bits	ID of this request. Incremented by one everytime a link probe reservation request is granted by the NC	2710
PHY profile	8 bits	PHY profile used for the transmission bits 7:6 00 = profile sequence 0 01 = profile sequence 1 bits 5:0 11111 = Beacon profile 11110 = Diversity mode profile 11101 = Link probe A profile 11100 = Link probe C profile 11011 = Link probe D profile 11010 = unicast profile to destination node (proposed)	2712
Reserved	8 bits		2714
Bandwidth	16 bits	Transmission time required in multiples of 20 nanoseconds	2716

FIG. 27

2800

Field	Length	Usage	
Type	4 bits	0x2	2802
Subtype	4 bits	0x0 – Probe A/D Reply 0x1 – Self ID/ Admission Request 0x2 – Admission response 0x3 – Key distribution 0x4 – Dynamic Key distribution 0x5 – Probe A/D reply request 0x6 – Robust Ack 0x7 – Link Probe C parameters 0x8 – Vendor Proprietary 0x9 – Tx_power_adj 0xA – Tx_power_adj response 0xB – Tx_power_adj ack 0xC- Tx_power_adj update 0xD – 0xF – reserved	2804
Destination	8 bits	ID of destination node	2806
PHY Profile	8 bits	PHY profile used for the transmission bits 7:6 00 = profile sequence 0 01 = profile sequence 1 bits 5:0 11111 = Beacon profile 11110 = Diversity mode profile 11101 = Link probe A profile 11100 = Link probe C profile 11011 = Link probe D profile	2808
Request ID	8 bits	A sequence number associated with the request	2810
Reserved	16 bits		2812
Bandwidth	16 bits	Transmission time required in multiples of 20 nanoseconds	2814

FIG. 28

2900

Field	Length	Usage	
Num_elements	32 bits	Number of source-destination pairs in the next iteration	2902
Src	8 bit	Source of the report	2904
Dst	8 bits	Destination node of the report	2906
Relay	8 bits	Whether NC relays the report to other nodes.	2908
Miscellaneous	8 bits	Miscellaneous data	2910
For i=0;i<Num_elemnts;i++{			
Src	8 bits	Source node ID	2912
Dst	8 bits	Destination node ID	2914
profile	8 bits	PHY profile to be used for transmission	2916
Preamble Type	8 bits		
Num_of_syms	8 bits		
Num_of_bins	8 bits		
Bits_per_ACMT_symbol	16 bits		
Channel_usable	8 bits		
Reserved	24 bits		
Broadcast Bitloading Bitmask	32 bits		
CP length	32 bits		
Tx_power_adjustment	16 bits		
E_ratio_adjustment	16 bits		
for j=0;j<N; j++ {		Total length of this loop not to exceed 128 bytes	
Subcarrier_modulation	32 bits		
}			
}			

FIG. 29

1844

Field	Length	Usage	
Node Protocol support	16 bits	Bit positions defined as: Bit 0 : 0 = Ethernet not supported 1 = Ethernet supported Bits 1:15 – Reserved	3002
Reserved	16 bits		3004
GUID	64 bits	64 bit MAC address of the device	3006
Tx power adjustment	32 bits	This is a decimal number between 0 and 63, indicating the power adjustment value in DB to be used by the NC for subsequent transmissions to the node	3008

FIG. 30

1846

Field	Length	Usage	
Number_of_Nodes	8 bits	Total number of nodes (including the NC and the newly admitted node) in the network	3102
Network reset flag	8 bits	Set to value 0x00	3104
Reserved	16 bits		3106
Max Tx power	32 bits	An integer indicating the maximum value of transmit power adjustment in DB that can be used by the receiving node.	3108
for (i=0; i<Number_of_nodes; i++) {		This iteration enumerates all nodes in the network	3110
Node_ID	16 bits	ID of a node within the network. New node is listed first in the loop.	3112
Reserved	16 bits		3114
Node_protocol_support	16 bits	Protocols supported by the node, as reported by the node during its admission	3116
Reserved	16 bits	This field will reflect any changes in a similar reserved field that follows the Node_protocol_support field of an Admission Request PDU.	3118
Node GUID	64 bits	64-bit device ID of the node	3120
}			

FIG. 31

1848

Syntax	Length	Usage
Transaction_Type	8 bits	Type of transaction in the descriptor 0x01 = request 0x0F = response 0xF0 = acknowledgement All other reserved
Transaction_ID	8 bits	Identification number of the descriptor
if (transaction_type == response){		
Number Of Key Blocks	2 bits	Number of key blocks in this descriptor 00 = one key block 01 = two key blocks 10 = three key blocks 11 = four key blocks
Reserved	6 bits	
for(i=0;i<Number of key blocks;i++) {		
Key ID	4 bits	Type of key as follows 0xx0 = PMK even 0xx1 = PMK odd 1xx0 = TEK even 1xx1 = TEK odd
Reserved	4 bits	
Key Data	64 bits	Key used for encryption
}		
}		
if (transaction_type == request) {		
Requested Key	4 bits	Type of key as follows 0xx0 = PMK even 0xx1 = PMK odd 1xx0 = TEK even 1xx1 = TEK odd
Reserved	4 bits	
}		
if(transaction_type ==Acknowledge) {		
Key ID being acknowledged	8 bits	
}		

FIG. 32

3300

Field	Length	Usage	
Src	8 bits	Source node of the report	3302
Dst	8 bits	Destination node of the report	3304
Reserved	8 bits		3306
Relay flag	8 bits	Used to indicate whether the report is to be relayed to the NC 0x00 = relayed to the NC 0x01 = relayed to the requesting node All other values reserved	3308
Reserved	32 bits		3310

FIG. 33

3400

Field	Length	Usage
Src	8 bits	Source node of the report
Dst	8 bits	Destination node of the report
Reserved	8 bits	
Relay flag	8 bits	Used to indicate whether the report is to be relayed to the NC 0x00 = relayed to the NC 0x01 = relayed to the requesting node All other values reserved
Reserved	32 bits	

FIG. 34

3500

Field	Length	Usage
cp_length	8 bits	Length of cyclic prefix to be used
Num_of_symbols	8 bits	Number of symbols to be used for probe transmission
Num_of_packets	8 bits	Number of packets
Most_negative_bin	8 bits	
Center_negative_bin	8 bits	
status	8 bits	
reserved	16 bits	

FIG. 35

Field	Length	Usage
Source Node ID	16 bits	
Destination node ID	16 bits	
TX power adjustment	32 bits	Decimal value between 0 and 63, represents power gain in DB.

FIG. 36

Field	Length	Usage
Destination node ID	16 bits	
Reserved	16 bits	
TX power adjustment	32 bits	Decimal value between 0 and 63, represent power adjustment to be used

FIG. 37

Field	Length	Usage
Destination node ID	16 bits	
Max Tx Power	32 bits	Decimal value between 0 and 63, represent maximum power adjustment permitted for a node

FIG. 38

Field	Length	Usage
Destination node ID	16 bits	
Delta Power adjustment	8 bits	Decimal value between 0 and 63, represent difference from the previous value

FIG. 39

1840

Fields	Length	Usage
for (i=0; i<N; i++) {		Length of payload field is the length of the MAC packet as indicated in packet header minus packet CRC and optional timestamps, if present.
Data bytes	8	
}		

FIG. 40

1806

Field	Length	Explanation	
IE Type	5 bits		4102
IE length	3 bits		
Channel Number	8 bits		
Change Field	2 bits		
Sequence Number	6 bits		
Reserved	8 bits	Added for future use.	4104
Network information	8 bits	Added for future use. This field may be used to convey information regarding star/ mesh topology.	4106
Reserved	10 bits		4108
NCID	6 bits	Node ID of the Network Coordinator	4110
Next beacon index	8 bits	Number of SUs to the next Beacon transmission	4112
Reserved	8 bits		4114
Admission Frame Length	16 bits	Duration in units of 20 nsec clock ticks of the following admission request/contention window	4116
Async MAP length	16 bits	Duration in 20 nanoseconds.	4118
Isoch MAP length	16 bits	Length in bytes or in nanoseconds.	4120
Admission/robust window PHY profile	8 bits	PHY profile used for the next admission window	4122
Admission/ Robust contention Index	24 bits	Duration in units of 20 nsec to the beginning of the next admission window from the end of this Beacon transmission	4124
Asynch MAP profile	8 bits		4126
Asynch MAP index	24 bits		4128
Isoch MAP profile	8 bits		4130
Isoch MAP Index	24 bits	Index of Isoch MAP transmission time in units of 20 nanoseconds	4132
Beacon CRC	32 bit	CRC over all bit	4134

FIG. 41

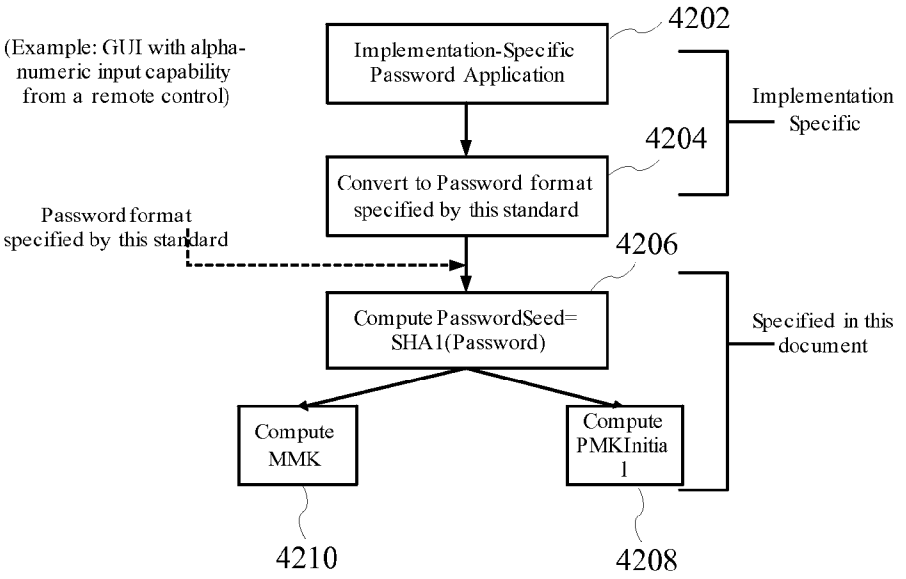

(Example: GUI with alpha-numeric input capability from a remote control)
Implementation-Specific Password Application
4202
Implementation Specific
4204
Convert to Password format specified by this standard
Password format specified by this standard
4206
Compute PasswordSeed= SHA1(Password)
Specified in this document
Compute MMK
Compute PMKInitial
4210
4208

FIG. 42

MULTIMEDIA OVER COAXIAL CABLE ACCESS PROTOCOL

REFERENCE TO EARLIER-FILED APPLICATIONS

This application claims priority under Section 119(e) to U.S. Provisional Application Ser. No. 60/632,856 titled "Interface for a Broadband Coaxial Network," filed Dec. 2, 2004, which is incorporated herein, in its entirety, by this reference.

BACKGROUND OF THE INVENTION

1. Field of Invention

The invention relates to broadband communication networks, and in particular to access protocols used in a local area broadband communication networks.

2. Related Art

The worldwide utilization of external television ("TV") antennas for receiving broadcast TV, cable television (CATV), and satellite TV is growing at a rapid pace. These TV signals received via an external TV antenna, cable TV and satellite TV, such as a direct broadcast satellite ("DBS") system, are usually located on the exterior of a building (such as a home or an office) and enter the building at a point-of-entry ("POE"). Multiple TV receivers, audio video receivers, and/or video monitor devices may be located within the building and these multiple devices may be in signal communication with the POE via a broadband cable network that may include a plurality of cables and cable splitters. Generally, these cable splitters are passive devices and distribute downstream signals from the POE to various terminals (also known as "nodes") in the building. The nodes may be various types of customer premise equipment ("CPE") such as cable converter boxes, televisions, video monitors, cable modems, cable phones, audio video receivers, set-top boxes (STBs) and video game consoles.

Within a typical building or home, there may be a mixture of coaxial cables of varying types and quality, such as RG-59, RG-6, and RG-6 quad shield, thus creating a less than optimal RF environment within the cable. Further, typical homes do little or no termination of cable outlets enabling the introduction of RF interference into the coaxial cables. Another problem often encountered with a typical home or building coaxial cable configuration is the use of multiple splitters of varying quality and frequency ranges. This also creates a problem for known approaches to local area networking over coaxial cable. Such networking often requires a more controlled RF environment or higher quality cabling to support higher frequency ranges.

Typically, an STB connects to a coaxial cable at a wall outlet terminal and receives cable TV and/or satellite TV signals. A device, such as the STB, connected to the coaxial cable may be called a node. Usually, the STB receives the cable TV and/or satellite TV signals and converts them into tuned RF TV signals that may be received by the TV receiver and/or video signals that may be received by a video monitor.

In FIG. **1**, an example of a known broadband cable network **100** (also known as a "cable system" and/or "cable wiring") is shown within a building **102** (also known as customer premises) such as a typical home or office. The broadband cable system **100** may be in signal communication with an optional cable service provider **104**, optional broadcast TV station **106**, and/or optional DBS satellite **108**, via signal path **110**, signal path **112** and external antenna **114**, and signal path **116** and DBS antenna **118**, respectively. The broadband cable system **100** also may be in signal communication with optional CPEs **120**, **122** and **124**, via signal paths **126**, **128** and **130**, respectively.

In FIG. **2**, another example of a known broadband cable system is shown within a building (not shown) such as a typical home. The cable system **200** may be in signal communication with a cable provider (not shown), satellite TV dish (not shown), and/or external antenna (not shown) via a signal path **202** such as a main coaxial cable from the building to a cable connection switch (not shown) outside of the building. The cable system **200** may include a multi-tap device (not shown) that allows communication to neighboring homes, a POE to the home **204**, N:1 Splitter **206**, which in this system may also be considered a Root Node, sub-splitter **208**, and node devices **210**, **212** and **214**.

Within the cable system **200**, the Multi-Tap (not shown) may be in signal communication with the Root Node/main splitter **206** via signal path **228**. The Root Node/main splitter **206** may be the connection point from the cable provider that is located externally to the building of the cable system **200**. The Root Node/main splitter **206** may be implemented as a coaxial cable splitter that may include passive devices and packages including connectors, transformer and/or filters.

The N:1 splitter **206** (a 2:1 splitter in FIG. **2**) acts as the main splitter and may be in signal communication with N:1 sub-splitter **208** (a 2:1 splitter in FIG. **2**), and node device **210**, via signal paths **230** and **232**, respectively. The N:1 sub-splitter **208** may be in signal communication with node devices **212** and **214** via signal paths **234** and **236**, respectively. The node devices may be comprised of numerous known STB coaxial units such as cable television STBs and/or satellite television STBs, as well as various video and multimedia devices typically found in the home or office. Typically, the signal paths **228**, **230**, **232**, **234**, and **236** may be implemented utilizing coaxial cables **216**, **218**, **220**, **222** and **224**, respectively.

In an example operation, the cable system **200** would receive CATV, cable and/or satellite radio frequency ("RF") TV signals **226** from the Multi-Tap (not shown) via signal path **216** into the Root Node/main splitter **206**. The Root Node/main splitter **206** may pass, transform and/or filter the received RF signals to a second RF signal **230** that may be passed to N:1 sub-splitter **208** via signal path **218**. Sub-splitter **208** may then split the second RF signal **230** into split RF signals **234** and **236** that are passed to node devices **212** and **214** via signal paths **222** and **224**, respectively. If the node device is an STB, the node device may convert the received split RF signal into a baseband signal (not shown) that may be passed to a video monitor (not shown) in signal communication with the STB. Similarly, the Root Node/Main Splitter passes a second signal **232** via signal path **220** to another node device **210**.

In recent years, numerous consumer electronics appliances and software applications have been developed and continue to be developed that are able to receive, store, process and transmit programming information to multiple devices in the home at the time and manner as determined by the viewer. The main drawback to the ability of users to view multimedia information stored on multiple storage devices at the home and view it (or listen to it) on any capable home appliance at the time and manner of his choosing is the lack of a viable home networking solution. There are large numbers and types of CPEs that can be utilized and shared in such a fashion including televisions, video monitors, cable modems, cable phones, video game consoles, and, audio components, as well as various storage devices. There is a growing need for different CPEs to communicate between themselves in a net-

work type of environment within the building. As an example, users in a home may want to share other types of digital data (such as video and/or computer information) between different devices in different rooms of a building.

The present invention is focused on utilizing the home coaxial cable as a medium for high speed home networking by utilizing frequencies above the ones currently used by the Cable Operators for their cable service. The home coaxial cable is a natural medium for connecting multimedia devices since it has an enormous amount of available bandwidth required for the high data rates that are needed for such applications and also, all the multimedia devices and appliances are most likely to be already connected to the coaxial cable. Unfortunately, most broadband cable networks (such as the examples shown in both FIG. **1** and FIG. **2**) presently utilized within most existing buildings are not configured to allow for networking between CPEs. Most broadband cable networks utilize broadband cable splitters that are designed to split an incoming signal from the POE into numerous split signals that are passed downstream to the different nodes in different rooms, or equivalently, combine signals from multiple sources (on the "output" ports) to an aggregate on the "input" port. The existing conventional wisdom is that the use of splitters in the existing broadband cable networks make these networks able to communicate only between the "point of entry" **204** and node devices **210**, **212**, and **214**, and prevents direct networking between node devices in the network because signals returning from the node devices cannot be routed back through the splitters, i.e., cannot "jump" a splitter. The present invention describes a system that allows node devices ("CPEs") to communicate directly over the existing coaxial cable with its current architecture without the need to modify the home cable infrastructure.

As an example, in a typical home the signal splitters are commonly coaxial cable splitters that have an input port and multiple output ports. Generally, the input port is known as a common port and the output ports are known as tap ports. These types of splitters are generally passive devices and may be constructed using lumped element circuits with discrete transformers, inductors, capacitors, and resistors and/or using strip-line or microstrip circuits.

Presently many CPEs utilized in modern cable and DBS systems, however, have the ability to transmit as well as receive. If a CPE is capable of transmitting an upstream signal, the transmitted upstream signal from that CPE typically flows through the signal splitters back to the POE and to the cable and/or DBS provider. In this reverse flow direction, the signal splitters function as signal combiners for upstream signals from the CPEs to the POE. Usually, most of the energy from the upstream signals is passed from the CPEs to the POE because the splitters typically have a high level of isolation between the different connected terminals resulting in significant isolation between the various CPEs.

The isolation creates a difficult environment in which to network between the different CPEs because the isolation results in difficulty for transmitting two-way communication data between the different CPEs. However, CPEs are becoming increasingly more capable and a growing number of users desire to network multiple CPEs to share storage and capabilities across the network. As CPEs are networked together in this difficult environment, the problem of coordinating network resources, accesses and optimizing communications between CPEs becomes a necessity.

Therefore, there is a need for a system and method to connect a variety of CPEs into a local data network, such as a local area network ("LAN"), within a building such as a home or office, while utilizing an existing coaxial cable network within the building. Additionally, there is a need for coordinating network resources, access to the network, and to optimize the communication between CPEs.

SUMMARY

A Broadband Coaxial Network (BCN) network formed by a plurality of common coaxial network elements that may include passive splitters and coaxial network nodes where a signal is transmitted from a first BCN modem to one or more other BCN modems with the signal having multiple paths caused by reflected signals from the splitters and coaxial network elements. A Network Controller (NC) BCN modem is established by the activation of the first BCN modem or when there are multiple devices through a selection process. The other BCN modems in the network then communicate with the NC to be admitted to the network and when attempting to access the network and request transmission opportunities to any other node in the network. Each BCN modem communicates with the other BCN modems in the network and establishes the best modulation and other transmission parameters that is optimized and periodically adapted to the channel between each pair of BCN modems. Further, a bridge may be created between a first type of network and a second type of network, such as an Ethernet wiring to a coaxial network wiring.

Other systems, methods, features and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be better understood with reference to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. In the figures, like reference numerals designate corresponding parts throughout the different views.

FIG. **1** shows a block diagram of an example implementation of a known broadband cable system within a building.

FIG. **2** shows a block diagram of another example implementation of a known broadband cable system within the building shown in FIG. **1**.

FIG. **3** shows an example of a BCN network within a home or building and its utilization.

FIG. **4** illustrates two examples of two different architectures for a satellite television system utilizing networking between devices, in this case, utilizing the Satellite cable to form a network between the devices.

FIG. **5** illustrates another satellite television bridging approach that employs the BCN network of FIG. **3**.

FIG. **6** shows a block diagram of a multiple dwelling implementation that employs another configuration and utilization of a BCN network.

FIG. **7** shows a block diagram of the BCN network of FIG. **3**.

FIG. **8** is an illustration of a functional diagram showing the communication between various nodes of a network similar to the one shown in FIG. **3**.

FIG. **9** is another functional diagram showing the interfaces and functional relationships between the Nodes of a network similar to the one shown in FIG. **3**.

FIG. **10** shows a block diagram of another example implementation and signal flows of a BCN network

FIG. **11** illustrates another block diagram of another example implementation and signal flows of a BCN network.

FIG. **12** shows a plot of an example bit-loading constellation versus frequency.

FIG. **13**A shows a plot of the bit-loading constellation versus carrier number for the channel path between node A and node B of FIG. **7**.

FIG. **13**B shows a plot of the bit-loading constellation versus carrier number for the channel path between node A and node C shown in FIG. **7**.

FIG. **13**C shows a plot of the bit-loading constellation versus carrier number for the resulting broadcast channel path between node A and node B and node A and node C based on the constellations shown in FIGS. **13**A and **13**B.

FIG. **14** shows an example block diagram of an Ethernet to Coax bridge node in a BCN network.

FIG. **15** shows a block diagram of one implementation of a multi-port Ethernet to coax bridge/router.

FIG. **16** shows a block diagram of an Ethernet bridge/router with additional WAN and LAN ports including DSL/Cable Modem and wireless.

FIG. **17** is an illustration of various frequency plans for use of the BCN network in different home environments that may include satellite, cable, telco or other services.

FIG. **18** is an illustration of the multimedia access control (MAC) frame types.

FIG. **19** shows a general format of an example header portion of the MAC control/data packet of FIG. **18**.

FIG. **20** shows an asynchronous MAP PDU of FIG. **18** with a fixed-length PDU.

FIG. **21** is an illustration of an asynchronous MAP PDU header **2100** of the asynchronous MAP PDU of FIG. **18**.

FIGS. **22**A&B is an illustration asynchronous MAP allocation unit format.

FIG. **23** is an illustration of a NACK allocation unit.

FIG. **24** is an illustration of a reservation request PDU of FIG. **18**.

FIG. **25** is an illustration of the format of the request PDU of FIG. **24**.

FIG. **26** shows an asynchronous data reservation request element used in the format of FIG. **25**

FIG. **27** is a link probe reservation request element used in the format of FIG. **25**.

FIG. **28** is a link control reservation request element used in the format of FIG. **25**.

FIG. **29** is an illustration of a link probe report PDU of FIG. **18**.

FIG. **30** is an illustration of an admission request PDU of FIG. **18**.

FIG. **31** is an illustration of an admission response PDU of FIG. **18**.

FIG. **32** is an illustration of the format of a key distribution PDU of FIG. **18**.

FIG. **33** is an illustration of the format of the link probe report request PDU of FIG. **18**.

FIG. **34** is an illustration of the format of a general link acknowledgement PDU.

FIG. **35** is an illustration of the link probe C parameters PDU.

FIG. **36** is an illustration of the power adjustment control PDU.

FIG. **37** is an illustration of the power adjustment response PDU.

FIG. **38** is an illustration of the power adjustment acknowledgement PDU.

FIG. **39** is an illustration of the power adjustment update PDU

FIG. **40** is an illustration of an Ethernet data payload of FIG. **18**.

FIG. **41** is an illustration of a beacon packet of FIG. **18**.

FIG. **42** is a flow diagram of password generation in a BCN network.

DETAILED DESCRIPTION

In the following description of the exemplar embodiments, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Turning to FIG. **3**, a diagram **300** of a BCN network within a home or building **302** is shown. A cable/terrestrial network connection **304** is made at a POE **306** in home **302**. The home **302** has a satellite dish **308** that may also enter at the POE **306**. The satellite dish **308** and cable/terrestrial network **304** may carry data, video, and audio signals that may be encoded as analog signals and/or digital signals.

A BCN network **310** within the home **302** connects with the satellite dish **308** and cable/terrestrial network **304** at POE **306**. The BCN network **310** may have connections in different rooms of the home **302**, for example, a family room **312**, kitchen **314**, office/den **316**, master bedroom **318**, and kids' bedroom **320**. In the family room **312**, there may be electrical/electronics devices such as a home media server **320** (also denoted as DVRs such as a personal computer, REPLAYTV or TWO) that may be connected to a television (i.e., normal television or high definition) or video monitor **322**. Another type of device in the family room **312** connected to the BCN network **310** may be a wireless access point (AP) **324** that communicates with wireless devices such as WebPad **326** using a communication standard such as IEEE 802.11 (a, b, and/or g), or BlueTooth, to name but a few communication standards. In the kitchen **314**, a network audio appliance **328**, such as a WMA/MP3 Audio Client, may be connected to the BCN network **310**. Further, a laptop personal computer **330** having wireless access ability may communicate with the wireless AP **324** located in the family room **312**.

The upstairs of home **302** is shown with a media center personal computer **332** connected to the BCN network **310** in the office/den **316**. The master bedroom **318** may have a STB **334** that may demodulate an analog or digital signal from a cable headend or a satellite receiver connected to television or video monitor **336**. In the kids' bedroom **320**, another STB **338** and television or video monitor **340** is shown along with another wireless access point **342** connected to the BCN network **310**.

The different types of devices connected to the BCN network **310** are provided as examples of some of the different types of video, data, multimedia, and audio devices that may be typically coupled to the BCN network **310**. The BCN network **310** enables two-way communication between network entities such as the media center personal computer **332** and laptop personal computer **330** via the wireless AP **324** or **342**. The BCN network **310** may also provide streaming multimedia support to transport audio and video, for example, from the media center PC **332** to the Set-top boxes **334** and/or **338** or any other device connected on the BCN home network **310**.

The BCN network **310** may also connect BCN modems that may be present in the different devices shown in FIG. **3** in

a peer-to-peer mesh network, such that every BCN modem enabled device can communicate directly with any other BCN modem enabled device on the network. Also, in addition to the peer-to-peer communications, the system can also offer capabilities that may be point-to-multipoint optimized. The BCN modem may be a device that communicates across one or more of multiple RF channels where the communications over each RF channel by the various devices is divided by time, where each device transmits in a different time slot, typically referred to as a time division multiple access (TDMA) communication, and each device transmits or receive at a time denoted as time division duplex (TDD), thus enabling one node to transmit at a time into an assigned TDMA frequency channel.

The BCN modem devices may be classified as Intermediate Devices, Terminal Devices, or both, and Operator Service Provider (OSP) Devices or Non-OSP devices. An intermediate devices device is a device that has as one of its primary functions bridging of user content between the BCN network **300** and an external device over an industry standard interface such as Ethernet or USB. A Terminal Device is a device whose primary function is to source or sink user content over the BCN network **300**. Because an intermediate device functions as a bridge between two interfaces, and does not know what data services are being bridged, intermediate devices may have throughput requirements while terminal devices may not. A device may be both an intermediate device and a terminal device.

An Operator-Service Provider (OSP) is an entity that fulfills all of the following requirements of maintaining a WAN infrastructure for delivery of content directly to consumer's homes such as DBS, HFC, FTTH, xDSL, and wireless, delivers or enables delivery of services (video, audio, voice or data) directly to the consumer's home over such WAN infrastructure, provides significant installation and technical support to consumers, including live support and maintenance directly to homes, and significantly advertises such installation and technical support.

Some OSPs may choose to use BCN modems to deliver their WAN and/or LAN services into a customer's home. Because the OSP is responsible for the network, an OSP may be permitted to limit BCN modem functionality in their BCN modems. In particular, the OSP rules ay be:

OSPs may limit his WAN devices to a single channel and is

OSPs are not required to allow sharing of the BCN modem WAN network with other services or BCN modem devices. However, the OSP

OSPs must enable sharing of the OSPs LAN network with non-OSP devices.

OSPs may limit privacy options as long as non-OSP devices may be configured to share the LAN network.

Furthermore, OSPs may have different factory default values from non-OSP devices as long as the non-OSP devices may be configured to share the LAN network.

In the preferred implementation, the BCN network is a multichannel TDMA/TDD system. Even though there is nothing prohibiting a simultaneous use of multiple frequencies on the same logical network, most of the description that follows assumes that the devices that form the network are operating on a single frequency channel. Network operation over multiple frequency channels can be accomplished in several ways. One method can perform transmission opportunities allocations based on both time and frequency. In this case, a given BCN node or modem receives its transmission opportunities on a given frequency channel at a specific time slot. Similarly, it expects to receive designated packets from other stations on a given frequency channel at a given time slot. Another method for multiple frequency channels operations is through the utilization of BCN modem bridges that can bridge single frequency channel networks (or multiple frequency channels networks). It is appreciated by those skilled in the art that the extension of a single frequency channel operation to multiple frequency channels operation is known; therefore this disclosure focuses primarily on a single frequency channel operation. Due to the unique transmission characteristics of the in-home coaxial network, which may include a highly dispersive environment with very large multipath reflections and a potentially different channel response between each pair of BCN modems in either direction, the lower network layer of the BCN network **310**, denoted as the physical layer (or PHY layer) may be implemented with a modulation pre-coding (where the modulating waveform is modified to adapt to the channel in a format that is known to the demodulator in most cases) approach such as adaptive (also denoted as bit-loaded) orthogonal frequency division multiplexing (OFDM). OFDM is a modulation technique that splits the modulated waveform into multiple RF sub-channels, each of which is modulated by a portion of the data stream and is sent over a different subcarrier frequency. With the precoded OFDM technique, the system will modulate each of the subcarriers according to the signal-to-noise ratio of each of the subcarriers.

The physical layer may use a modulation technique such as Adaptive Constellation Multi-tone (ACMT). ACMT is a form of orthogonal frequency domain multiplexing (OFDM) where knowledge of the channel is used to select and optimize the modulation. The modulation automatically adapts to the channel characteristics to provide the maximum data rate possible while maintaining low Packet Error Rates (PER). The ACMT modulation can vary from 1 to 8 bits per symbol (i.e. BPSK through 256-QAM) depending on the channel and the capabilities of the node. The term used to describe the modulation of an ACMT transmission is "modulation profile". Other precoding methods besides adaptive OFDM may be used in the BCN network **310** with single broadband carrier systems such as Tomlinson pre-coding or others.

In a typical application, each frequency channel of operation may constitute a separate network of communicating devices. It is also possible to include a network of multiple frequencies, but the operation of such a network requires rapid frequency changes by BCN modems on a packet-by-packet basis. In a single frequency of operation, one of the BCN modems is assigned as the Network Controller (NC) and provides all the necessary information allowing other BCN modems to be admitted to the network, adapt to the network characteristics, synchronize to the network timing and framing, make transmission requests and be able to communicate with some or all of the other BCN modems in the network. In the current approach, the first BCN modem in the BCN network **310** becomes the NC by default and the other BCN modems may be referred to as slave BCN modems. The NC provides network timing synchronization including the timing of admission area for slave BCN modems. When a BCN modem is activated, it attempts to locate the network timing by receiving a beacon identifying network timing and essential network control information including network admission area and other information identifying the time location and characteristics of other important and valid information, such as future beacon locations, future channel assignment information, etc. Any BCN modem that wishes to be admitted to the network then transmits an admission request signal to the NC using the identified admission area. If collision occurs in the admission area between slave BCN modems, then an appropriate back-off algorithm may be used to resolve the

collision and enable the colliding slave BCN modems to access the admission area at different times. The back-off algorithm may have the BCN modem wait a predetermined number of beacons. The predetermined number of beacons the BCN modem waits may be a random number between 0 and (2^n−1), inclusive, where n is the number of admission requests sent since receiving the first good beacon, up to maximum value of n=5. Otherwise admission to the BCN network **310** may be achieved.

Once a new BCN modem establishes its identity and its communications with the NC, it may start a network admission process that may include several steps, including the optimization of its communications with the NC based on the channel response characteristics between the BCN modem and the NC in either communications direction, the optimization of the transmission characteristics between the BCN modem and any of the other BCN modems already in the network, any calibration requirements to ensure adequate communications, etc. Once admitted to the BCN network **310**, the slave BCN modem can communicate efficiently with every other node in the network. The NC BCN modem assigns timeslots to the BCN modem to make requests for transmission opportunities to enable the communication between the slave BCN modem and each of the other nodes in the BCN network **310**. Once the slave BCN modem contacts another node, the data path or link between the slave BCN modems and the other nodes may be optimized. By the end of the admission process, the slave BCN modem knows how to transmit efficiently to every other node in the BCN network **310** and subsets of nodes.

In order to manage the BCN network, and control and optimize its operation and enable efficient data transmission in the network, several types of data packets may be used to transmit information. The three most prevalent packet types, for example, are robust packets, probe packets and data transfer packets. The robust packet's main characteristics are that it can be received by any BCN modem in the network even before channels are optimized. The robust packets contain significant redundancy and are transmitted using lower order modulation. The robust packet type is used mainly to broadcast information to all nodes in the BCN network **310** and to enable communications between them before the network is optimized, or to communicate most important control and timing information. One of the robust packets may be called a beacon that may be sent at anytime, no matter the quality of the link, to provide the basic timing and control information that may be required for robust network operation. The robust packets may also transfer original contention and admission information. Another type of robust packet may be used for influencing hardware, i.e., a global reset of all BCN modems in the BCN network **310**.

The probe packet type may be used for at least three functions in a BCN network **310**. The first use for the probe packet is link optimization. An echo profile probe is sent to determine the distance between significant echoes in the network. The determined distances between the echoes are used to calculate the cyclic prefix that is used in messages to accommodate for the echo and multipath profile of the specific link.

Another probe function may be for hardware calibration. The probe may be used for calibrating the I/Q amplitude and phase Quadrature balance of the up and down conversion process. Typical causes for I/Q imbalance are well known. For example, the phase between the I and Q upconverter and/or downconverter may be off from the optimal **90** degrees, causing an I/Q phase imbalance. Other reasons are unequal signal attenuation and/or delay between the I and the Q signal paths. One can accommodate less stringent I/Q hardware requirements by using probe packets for adaptive calibrations. The probe packet may also be used by requesting a timeslot to be allocated by a NC that may be used by a BCN modem to send packets to itself or other nodes in order to calibrate parameters and circuits, such as power level, filters, in addition to the I/Q transmission signal.

The third type of packet is the data transport packet. The data transport packet is used to transfer data between nodes in the BCN network **310**. These packets are denoted as a MAC packet unit (MPU) and are generally adaptively optimized for each transmission link in order to achieve the optimal network throughput.

From a communications services point of view, the BCN network provides both best effort and reserved communications capabilities. It can also support asynchronous and isochronous communications services. In the best effort services, any packet received by a BCN modem for communications over the network requires the BCN modem to make a request to the NC and receive a time allocation grant to transmit the packet. The BCN modem can make requests for data transmission opportunities for more than one packet but the key characteristics of this operation mode is that transmission requests and grants are made based on a packet or multiple packet transmission requirements basis and is of a temporary nature; i.e., no long term data transmission allocations commitments are provided to a BCN modem.

In the reserved mode, certain long-term data transmission requests and grants are made. In this case, the requests and grants may take several forms. A common method may be implemented where a BCN modem node makes a request and is granted a specific allocation for a certain data rate; for example, a BCN modem node may request 10 Mbps channel for a definite or indefinite duration. In this case, the NC controller (or the network, if the allocation is done in a different manner) may allocate certain packet transmission opportunities for this node that will amount to the allocated data rate based on the requested data rate. This allocation may provide for significant time duration until the requested duration expires, no data being transmitted for a predetermined duration, higher priority traffic obtaining the required allocation, or any other network policy that may be implemented according to the nature of the allocations and priorities.

Another method for a reserved channel allocation may include a base allocation (that may be of any size) and additional allocations that may be based on a flow control method that allows the NC to monitor a transmit buffer at the transmitting node (or other traffic requirement indication) and provide variable transmit opportunities according to the transmit buffer load or other indicators. In this case, the fixed reserved allocation can support the effective "average" data rate, while the additional allocations are able to accommodate temporary data rate "peaks." That allows a more efficient utilization of the channel, compared to a case where the reserved allocation is required to accommodate the peak data rate of a given link. Also, even though such reserved bandwidth is allocated on a "long term" basis, it may be readjusted very quickly to accommodate potential changes in the traffic profile.

The NC BCN modem (or the network, in cases where the allocations are performed in a different manner) may also provide asynchronous and isochronous functionality. Its characteristics are similar to those of the best effort and reserved channel communications capability and at times, the terms are used interchangeably. However, with asynchronous and isochronous functionality, the focus is on the timeliness of the services. Asynchronous functionality is similar to the best effort capability discussed above, but the focus is on the

indeterminate nature of the timing of delivery. Since this service is in response mostly to a packet delivery that is of random nature, the BCN network does not provide a tight timing control on the latency of packet delivery through the BCN network. Priorities may also be assigned to packets within the BCN network **310** to ensure a priority delivery to certain packets based on IEEE 802.1p priority tags. Packets of higher priority may have preference traversing the network as established by a NC policy. Yet another example of asynchronous functionality may be flow-controlled reservation of timeslots and/or bandwidth for BCN modems. Flow-controlled reservation may include every node being able to communicate the status of its transmission buffer status to the NC BCN modem. The NC BCN modem may give opportunities to transmit even if the other nodes have not requested opportunities for transmission. An isochronous service is similar to the reserved service but the focus is on a tight control on the delivery time and time variation through the network. Certain communications services, such as MPEG Transport Stream (MPEG-TS) may have tight jitter requirements. In order for the BCN network to support such services, its own communications services needs to be able to limit the delay and delay jitter through the BCN network. This can be done through the assignment of a tightly controlled reserved bandwidth allocation.

As discussed in the above sections, the BCN network may offer both asynchronous best effort communications services and isochronous, reserved data transport services. An adaptation layer between other communications services and the BCN network allows it to provide a wide range of communications services over the BCN network and may be implemented in the protocol above a MAC layer for transport. The adaptation layer provides the specific protocol interface to the outside network and adapts it to BCN network transport. It provides all the necessary functions to adapt the specific protocol to be transported over the BCN network. This adaptation may include the same protocol on both sides of the network or may include protocol conversion functionality where one node that may be adapted to one protocol is able to communicate with another node that may be adapted to another protocol. A simple example may include a device with an Ethernet interface to a BCN node communicating with a device with a USB interface to a BCN node. The adaptation layer may transport other protocols, such as Ethernet, MPEG Transport Streams, IEEE 1394, and universal serial bus (USB), data over the BCN network. For example, a native MPEG packet from a MPEG transport stream is 188 bytes long and is transmitted with a defined clocking system, so the packets arrive in a predicted fashion. The 188-byte MPEG2 TS packet or multiple MPEG2 TS packets are placed (or encapsulated) in a BCN packet for transmission between BCN modems. Because a MPEG2 TS packet is always 188 bytes, and its timing of arrival is very well predicted, the bandwidth required in the BCN network **310** may be reserved to match the predicted arrival time and thus, such a packet can be transported over the BCN network very efficiently. Additional data, such as timestamps, may be added to the encapsulated packets without an impact on that data in order to assure a proper timing transfer resulting in an extremely low jitter. Also, the MPEG2-TS adaptation layer can provide Program ID filtering to select just the desired programs for delivery over the BCN network.

Another possible adaptation layer is for Ethernet packets. In this case, the adaptation layer may utilize the BCN network asynchronous protocol to transport Ethernet packets over the BCN network. This adaptation layer may also include the utilization of IEEE 802.1p priorities to provide a preferential transport to higher priority packets.

A third adaptation layer may include IEEE 1394 transport through the BCN network. In this case, the adaptation layer may utilize both the isochronous, reserved allocations of the BCN network protocol to transport the 1394 isochronous packets and the asynchronous service to transport the asynchronous 1394 packets. Also, it can transport the whole 1394 transport through the isochronous, reserved allocations. In a similar fashion, a USB adaptation layer can transport USB packets through the network.

One of the key features of the BCN network is its ability to co-exist with other services over the existing coaxial cable. Such services may include both analog and digital Cable TV services, satellite services and/or terrestrial TV services. In order to minimize the potential for interference by the BCN transmission on the existing services, the BCN modems in the BCN network **310** may use power control in order to manage the interference generated by and to each of the BCN modems by other BCN modems and other devices on the network. Nodes or BCN modems that are close to each other may be subject to a lower attenuation and thus require less power to communicate at a given data rate than nodes that are further apart. The nodes have the ability to adjust transmit power as communication needs dictate in order to achieve the required throughput with potentially lower transmit power. Thus, the interference created by transmitting nodes is minimized in the BCN network **310** without much impact on the total network throughput.

Other power control strategies are also possible. If the network is subject to a significant ingress or other interference from devices in the BCN network, transmitting to an interfered-with node at maximum power may overcome the interference. In this case, the network may deem it necessary to slightly increase the probability of interfering with other devices in the network in order to enable more effective communications with interfered-with nodes. Other nodes that may not suffer the interference may be communicated with only at the nominal or controlled power level.

The BCN network is dynamic and allows the occasional additions and removals of nodes without disruptions of network communications. Each node in the network contains a BCN modem. One of the BCN modems usually assumes the role of a Network Controller ("NC") (which may also be referred to as the Network Coordinator). The NC can be associated with a specific BCN modem (for example, it can be associated with a network gateway or a router) or is dynamically assigned according to certain network rules. In a typical application, the NC BCN modem is established when the first BCN modem is activated in the cable network. In the current implementation, if the NC BCN modem dies or becomes unavailable, a successor takes it place. The successor may be the second BCN modem activated in the cable network and may monitor a signal from the NC BCN modem. Or in other implementations, the successor may be predetermined by a current NC BCN modem based on facts such as link quality with the other BCN modem clients. If the signal is not received for a predetermined amount of time, then the successor becomes an NC for the BCN network **310**. If both the first and second BCN modems are unavailable, then either a third designated node (if one exists) may take over or a hunt for an NC occurs between the slave BCN modems based on a defined strategy or in a random fashion with the appropriate back-off strategy to resolve conflicts. In other implementations, the slave BCN modem to take over as an NC may be based on random numbers selection, back-off timers, or simi-

lar approaches that vary slave BCN modems determining that an NC is unavailable. This feature may be referred to as NC mobility.

The NC BCN modem is responsible for managing the BCN network **310**. The NC BCN modem manages the other clients' BCN access to the BCN network **310** and coordinates assignment of time slots for all BCN modems within a BCN network **310**. Additionally, the NC BCN provides synchronization and timing to the other BCN modems in the BCN network **310**.

In another implementation, each new BCN modem wishing to join the network listens to the network on a selected frequency channel to see whether there is an NC node on the channel. If there is, the new BCN modem receives the Beacon messages from the NC BCN. The Beacon messages are very robust and can be received even in a very poor channel environment. The Beacon also has information about the admission time slot for the new node and other network control information. If the new BCN modem is authorized to join the network, the transmit admission request in the admission slot announces its presence to the NC. If more than one new BCN modem is trying to access the admission time slot, the request may be unsuccessful and a backup algorithm (a well-known technique) is used for resolution. Once admitted to the network, the new BCN modem continues through the admission process, under the direction of the NC, and communicates with each of the other BCN modems, characterizing each of the possible communication paths to the other BCN modems. Once the paths to the other BCN modems are characterized, then the BCN modem optimizes the communication on each link to maximize transmission/reception efficiency and quality. Further, each BCN modem (including the NC) may periodically probe all the links to the other BCN modems and continually make adjustments to maintain the efficiency and quality. Thus, each path or channel between all BCN modems is individually characterized and optimized, both on admission and periodically thereafter. Also, if a severe communication interruption occurs, the affected node may repeat a process similar to the admission process.

The BCN network may also span across several channel frequencies, where a single NC may control several frequencies, or each frequency may have its own NC. In the first case, the NC may control the access to multiple channel frequencies by controlling not only the time slot allocations of BCN modems in the network but also their operating frequencies. An example of this network may include a NC that controls more than one frequency channel and may assign communications resources to all the BCN modems in the frequencies under its control. Such network may include the assignment of other BCN modems to a given frequency for a certain duration or assign communications resources such as transmission slots and frequencies on a packet-by-packet basis. All other descriptions above are relevant to such an operation as well.

Turning to FIG. **4**, a satellite television bridging approach that employs the BCN network of FIG. **3** is illustrated in cut-away diagram **400**. A satellite LNB+coupler **402** (this may be two or more separate devices that are connected to each other by signal communication, but is shown here as a single entity for convenience) receives and down converts a satellite signal from the frequencies transmitted from the satellite to the antenna (not shown) to frequencies that can be carried over the coaxial cable **404**. The signal is carried by a coaxial cable **404** to a room **406** having a STB **408** that tunes, demodulates and decodes the satellite signal into a signal for display on television **410**. The STB **408** may be equipped to stream a digitally-encoded video show via a BCN modem located in the STB to another BCN modem in another room. The streamed video may be transmitted from the STB **408** to another room **412** via the LNB+coupler **402**. The streamed video may be received at the slave BCN modem **414** that is attached to television **416**. The slave BCN modem **414** communicates with other networking devices, such as a router **418**, DSL/Cable Modem **420**, and an A/V jukebox **422**, using a communication standard such as TCP/IP over Ethernet or IEEE 1394 standard. The A/V jukebox **422** may have a network-attached storage (NAS) **424**. The router **418** may be connected to a personal computer **426** that communicates via a USB connection with a printer **428**.

The satellite signal is received at the LNB+coupler **402** and is then transmitted via the coaxial cable **404** to the STB **408**. The STB **408** has 1+N tuners/receivers used to select desired channels. The channel received by the first tuner is demodulated, decoded and is shown on the connected TV (or monitor) **410**. The other N tuners may each select a channel and demodulate and decode the signal received at the selected channel as a digital video data stream. The data stream is carried by the BCN network back through the LNB+coupler **402** to the device having the slave BCN modem located in another room **412** for display on television **406** or through the router **418** to be displayed on the personal computer **426**. Such transmission of data between devices and rooms may occur to any number of rooms, provided another BCN modem is present on the BCN network in the other rooms. Transmission may be point-to-point or point-to-multipoint. The LNB+coupler **402** provides the means of communication between the various cables **404** connected to it at a certain frequency band or several frequency bands that do not interfere with other signals on these cables. Such frequencies may include both baseband frequencies and RF frequencies.

In FIG. **5**, another satellite television bridging approach that employs the BCN network of FIG. **3** is illustrated in cut-away diagram **500**. A cable **502** from a satellite antenna is coupled to a STB **504** having 1+N tuners/receivers. The STB **504** may have a second connection via a BCN modem to the BCN network **310** via cable **506** and cable television (CATV) drop **508**. The BCN network **310** has outlets in other rooms, such as **412**.

In this implementation, the satellite signal is received at the STB via cable **502**. At least one of the 1+N tuners converts the signal into a video signal for display on a local television **410**. The other N tuner/receivers tune and demodulate other possible channels where any, some or all demodulated data are then encoded into one or more digital streams and transmitted across the BCN network **310** by the BCN modem enabled device. The digital stream is then received in another room **412** at a device having another BCN modem. The digital stream is then converted and/or RF modulated for display on a television **416** or directly streamed to a personal computer **426**. Even though digital streaming of video is used here to demonstrate data transmission across a BCN network, other types of data may be exchanged to transmit and/or receive.

Turning to FIG. **6**, a block diagram **600** of a multiple dwelling unit ("MDU") application that employs the BCN network is shown. It is often desirable to provide office buildings and apartment/condominium developments with cost effective data and video services. Such a system may be referred to as an "access type" implementation and is described with a cable television (CATV) headend **602** being a source for reception of video transmission from a provider of video services and connection to other two-way networks for data and video. The CATV headend **602** may have a fiber optical encoder **604** that encodes a single or multiple analog or digital video signals onto an optical physical transport

medium, such as multimode fiber-optic cable **606**. The headend **602** may also have an Ethernet to passive optical network ("E-PON") transceiver **608** that converts Ethernet data for transmission over a fiber-optic cable **610**. The fiber-optic cables **606** and **610** may be terminated at a hybrid fiber-optic cable ("HFC") node **612**.

The HFC node **612** may have an Optical to Electrical converter **614** to decode the received video signal for transmission over a coaxial cable **616**. The coaxial cable **616** may have one or more amplifiers **618** to maintain the necessary transmitted signal strength range along the coaxial distribution. A passive optical network ("PON") splitter **620** may split the optical signal to multiple location terminations, e.g., **16** terminations.

At least two different access implementation examples in a MDU are shown where data may be supplied by fiber-optic cable to the MDU and distributed to the different units on the coaxial cable typically used for video services, such as cable television distribution. The first example, referred to as "Type A MDU" dwelling **622**, has a POE **624** to the dwelling **622**. The coaxial cable within the dwelling **622** forms the BCN network **623**. Often within the dwelling **622**, one or more amplifiers **626**, **628** are installed along with one or more passive splitters **630** to form the BCN network **623**. The BCN network **623** is connected to BCN modems **632**, **634**, and **636** that enable Ethernet traffic to be carried over the BCN network **623**. The BCN modem **632** may be connected to a personal computer (PC) **638**, as BCN modem **634** is connected to PC **640**, and BCN modem **636** to PC **642**. The BCN network may also carry analog or digital video signals to set-top boxes **644**, **646**, and **648** that may be connected to televisions **650**, **652**, and **654**, respectively.

The BCN network **623** is connected to the Internet via a BCN modem enabled Ethernet hub **656** that is shown connected to an optical network unit (ONU) **658** that functions as a transceiver on the fiber-optic cable **660** connected to PON **620**. Thus downstream video and audio signals are transmitted via the HFC node **612** to the dwelling **622**. A two-way data path exists from the ONU **658** to the E-PON **608** located at the headend **602**.

The "Type A" MDU implementation enables multiple units, e.g., **32** units in the example embodiment, to share the BCN modem enabled Ethernet hub **656** and ONU **658**. The communication between devices, such as PCs **638** and **640** in the "Type A" implementation, flows through the PON **620** and headend **602**. This is in contrast to the single home BCN network, shown in FIG. **3**, where devices within the home communicate directly with each other.

In the other implementation example, "Type B" MDU **661** has a coaxial cable POE **662** connected to the internal coaxial network **663**. The internal coaxial network **663** may have passive elements such as splitters **664**. The coaxial network **663** may have BCN modems **670** and **672** connected to PCs **674** and **676**, respectively, or other Ethernet enabled devices. The BCN modems **670** and **672** communicate with the BCN modem enabled hub **673** that is coupled to the ONU **675** for bi-directional communication with the PON **620** via a fiber optical cable **677**. One or more STBs, such as **678**, may be connected to televisions, such as **680**, and the coaxial network **663**. Unlike the "Type A" MDU **622** implementation, the "Type B" MDU **661** implementation has some units with access to the BCN Modem enabled hub **673** while others only receive the traditional features provided by a cable company.

Within either the "Type A" or Type B" MDU implementations, the coaxial cable may employ a frequency plan **690** that uses 50-770 MHz **692** for broadcasting of video and audio signals. Another area of the frequency plan **690** employs a 50 MHz bandwidth **694** at approximately 900 MHz for use by the BCN modems. The upper end of the frequency band 1030 MHz-1450 MHz **696** may be used by satellite television systems, such as DIRECTV.

The BCN modems are able to create a BCN network while supporting features such as high definition television, Dolby 5.1 digital audio, parental control systems, return channels (remote or interactive television), and Internet data. They enable CPE devices that are TCP/IP enabled, or utilize other protocols, to communicate across the BCN network by communicating with a BCN modem that receives the data via a communication protocol, such as TCP/IP, and converts the TCP/IP signal into a signal for transmission across the BCN network.

The BCN modems may also use encryption algorithms to encrypt data to be transmitted across the BCN network. The transmitted data is then decrypted at the receiving BCN modem for delivery to another CPE. The encryption may be DES based or use other encryption algorithms such as IP-SEC, etc. Various keying systems can be used and the various keying methods are well established in various standards, such as IEEE 802.11, Docsis, and others, and need not be detailed herein.

In FIG. **7**, a block diagram **700** of a BCN network similar to that of FIG. **3** is shown. The coaxial cable **304** enters the premises at the POE **306**. One or more passive splitters, such as passive splitter **722** may be in the BCN network **310**, FIG. **3**. The splitter **722** splits the signals in coaxial cable **730** into multiple coaxial cable lines **732**, **734**, and **736**. The coaxial cable line **732** is coupled to Node A **724**, coaxial cable line **734** is coupled to Node B **726**, and coaxial cable line **736** is coupled to Node C **728**. Each Node may have a BCN modem that transmits and receives TCP/IP (or other protocols) data over their respective coaxial cable lines **732**, **734**, or **736**. The BCN modem also converts the data from/to a physical layer and link layers transmitted on the twisted pair Ethernet cable lines **710**, **712**, and **714**, to the BCN network. The cable lines **710**, **712** and **714** may also be USB cables, IEEE 1394 cables or any other communication connections, including printed circuit board communication lines or even communication wires inside integrated circuits. These cable lines represent any communications methods, including all layers of the communications protocol, which are then translated at Nodes A **724**, B **726**, and C **728**, prior to transmission over the BCN network. Each CPE **704**, **706**, and **708** may be connected to an Ethernet cable **710**, **712**, and **714**, respectively (or other communications methods). The different CPEs **704**, **706** and **708** may communicate over the BCN network across the splitter **722**.

In FIG. **8**, a functional diagram **800** showing the logical communication between various nodes, Node A **724**, Node B **726**, Node C **728**, and Node D **808**, in the form of a virtual logical mesh network is shown. The nodes **724**, **726**, **728**, and **808** may be interconnected between node pairs utilizing corresponding inter-node channels between the node pairs. It is appreciated by those skilled in the art that even if the nodes are individually connected with one another via a single inter-node channel between the node pairs, each inter-node channel between node pairs may be asymmetric. Therefore, inter-node channels between Node A **724**, Node B **726**, Node C **728** and Node D **808** may be asymmetric and may require different modulation schemes for optimizing the specific link. Such optimization may be a different bit-loading scheme in an OFDM-based communications system or some other optimized method that optimizes the communications based on the specific channel available, which may be different on one physical link, depending on the direction of the signals

between the nodes. As a result, the typically asymmetric inter-node channels between Node A **724**, Node B **726**, Node C **728**, and Node D **808** may be described by the corresponding direction-dependent node channels AB, BA, AC, CA, BC, CB, AD, DA, BD, DB, CD, and DC.

As an example, Node A **724** is in signal communication with Node B **726** via signal paths **810** and **812**. Signal path **812** corresponds to the AB channel and signal path **810** corresponds to the BA channel. Additionally, Node A **724** is also in signal communication with Node C **728** via signal paths **822** and **824**. Signal path **822** corresponds to the AC channel and signal path **824** corresponds to the CA channel. Similarly, Node B **726** is also in signal communication with Node C **728** via signal paths **802** and **804**. Signal path **804** corresponds to the BC channel and signal path **802** corresponds to the CB channel.

In this example, the AB channel corresponds to the channel utilized by Node A **724** transmitting to Node B **726** along signal path **812**. The BA channel corresponds to the reverse channel utilized by Node B **726** transmitting to Node A **724** along signal path **810**. Similarly, the AC channel corresponds to the channel utilized by Node A **724** transmitting to Node C **728** along signal path **822**. The CA channel corresponds to the reverse channel utilized by Node C **728** transmitting to Node A **724** along signal path **824**.

Because all links are individually optimized to maximize the throughput on each link, a multicast or a broadcast transmission is problematic. In an example of operation, in order for Node A **724** to transmit the same message to both Node B **726** and Node C **728** using the AB channel along signal path **812** and the AC channel along signal path **822**, Node A **724** may need to transmit (i.e., "unicast") the same message twice, once to Node B **726** and a second time to Node C **728** if the channel pre-coding makes the optimized signal waveform on the AC channel quite different from that of the AB channel. Since the nature of communicating on the network may include a significant percentage of multicast/broadcast communications, this may have a significant impact on network efficiency if similar messages need to be repeated on each optimized link.

To maximize the network efficiency even for multicast and broadcast traffic profiles, each of the nodes utilizes the individual link optimization into a combined link optimization as follows; when a node, such as Node A, joins the network, it optimizes its transmission to each of the other nodes in the network. This optimized link is stored in the node's storage. Once a node wishes to transmit a certain message to multiple other nodes, it may do it by repeating the message multiple times or computing an optimal "multicast" transmission profile from the individual profiles in its memory. The node may also utilize a hybrid scheme if a better throughput can be achieved. In such a hybrid scheme, the node may decide to break the nodes it wishes to send the same message to into subsets of nodes that may share largely similar channel characteristics. Each of these subsets will utilize a specifically optimized channel transmission and the same message will be transmitted to all such subset groups. In actual operation, it may be that most messaging will be unicast or broadcast, so that in addition to the individually optimized transmission to each of the other nodes in the network, only a broadcast optimized transmission may be necessary. The preferred implementation of the optimized multicast or broadcast scheme in the proposed network takes advantage of the preferred bit-loaded OFDM scheme and utilizes a combined bit-loading for the subset of the channels to which a node wants to send the common message. This method is described further in the following sections.

The network topology shown in FIG. **8** is a full-mesh peer-to-peer network. The BCN modem may utilize other forms of network topology, which may include a partial-mesh network, a star network, or a combination thereof. Because in a star network, communications are always between a central node and the network nodes only, the optimized transmission is performed between the central node and the other network nodes only, and in the preferred optimization, the bit-loading scheme is established between the central node device acting as the NC and each of the remaining nodes in the network.

The BCN modems may automatically be configured as either a NC or a slave during startup. Each BCN modem is capable of transmitting and receiving on a selected control and/or broadcast channel using what is commonly referred to as precoding. The selected broadcast channel is selected as a channel having sufficient quality to enable all BCN modems to communicate with the NC.

If a BCN modem is started and it does not detect a control channel with a NC BCN modem, then it assumes the role of a NC. Otherwise a NC BCN modem is detected and the BCN modem starting up is configured as a slave BCN modem. For example, when Node A **724** starts up first and assumes the role of NC, the other Nodes B **726** and Node C **728** start up later as slave BCN modems. If two or more BCN modem start up at the same time, a random back-off timer may be used to stagger the establishment of a NC BCN modem. Further, if the network is divided, a BCN modem slave will determine that no NC is present and assume the role of the NC.

Once a NC, such as Node A, is established, the quality of the data paths to and between the other nodes is determined. There may be multiple communications paths between Node A and the other nodes due to the signal reflections that may occur at splitters and other network connections. The data paths for communication between selected nodes are determined and the paths between one node to multiple nodes commonly called multicast are determined. It may not be true that the best signal quality path for a pair of nodes will be the best quality for a multicast to the pair of nodes and one or more other nodes. Often there may be a common channel that has an acceptable quality for all the nodes involved in the multicast.

The multicasting is typically setup at the link layer of the protocol with a multicast group and members join and leave the group as required. A multicast address translation protocol may map up to **64** multicast channels to unique BCN modem channels. Further, either the NC or slave BCN modem may initiate a multicast session.

In FIG. **9**, another functional diagram **900** showing the interfaces and functional relationships between the Nodes of FIG. **3** is shown. In this diagram, Node A **724** may transmit a message in broadcast or multicast mode simultaneously to Node B **726** and Node C **728** channel via signal paths **812** and **822**, respectively. When the network was established, Node A **724** had optimized its communications with Node B **726** as channel AB. Also, Node A **724** optimized its communications with Node C **728** as channel AC. If Node A **724** needs to transmit a message to Node B **726** or Node C **728**, it utilizes the optimized transmission for channel AB or channel AC, respectively. However, once Node A **724** wishes to transmit a message to both Node B **726** and Node C **728** simultaneously, it may not be able to do it effectively if the optimized transmissions for channel AB and channel AC are different. Node A **724** may transmit the message twice, once to Node B **726** with an optimized transmission to channel AB, and once to Node C **728**, with an optimized transmission to channel AC. However, analysis has shown that there is a better and more efficient way to transmit the same message to both Nodes B

726 and C 728. Node A 724 can optimize the transmission to a new channel denoted as channel A-BC. This optimized transmission may be the best transmission for messages destined to both Nodes B 726 and C 728. Extensive analysis on models of real cable systems have shown that in most cases, such method is preferred and yields a better throughput compared to repeating the message for optimized channels AB and AC. In the implementation discussed herein, the optimization for channel A-BC is relatively straightforward. Because each of the optimizations for channel AB and channel AC are done by bit-loading according to the frequency responses of paths 812 and 822, channel A-BC optimized transmission is the one that optimizes the bit-loading for the combined response of paths 812 and 813.

It is appreciated by those skilled in the art that the different channels typically utilize different bit-loading modulation schemes, because the channels typically are physically and electrically different in the BCN network. Physically the channels often vary in length between nodes and electrically vary because of the paths through and the reflections from the various cables, switches, terminals, connections, and other electrical components in the BCN network. A bit-loading scheme is described in U.S. Utility application Ser. No. 10/322,834 titled "Broadband Network for Coaxial Cable Using Multi-carrier Modulation," filed Dec. 18, 2002, which is incorporated herein, in its entirety, by this reference.

In another implementation, the BCN network may operate with waveforms that utilize bit-loaded orthogonal frequency division multiplexing (OFDM). Therefore, the BCN network may transmit multiple carrier signals with different QAM constellations on each carrier. As an example, over a bandwidth of about 50 MHz, the BCN network may have 256 different carriers that in the best circumstances would utilize up to 256 QAM modulations. However, the modulation of each carrier may be adjusted according to the specific channel response. If at certain frequencies, the response is poor, the BCN network may utilize BPSK or a low order QAM for carriers in those frequencies. If the channel is good in some other frequencies, then a high order QAM can be utilized on those frequencies, which is the essence of bit-loading optimization.

The application of bit-loading in a BCN network is demonstrated in FIG. 10. As an example, in FIG. 10, a block diagram of the BCN network 700 of FIG. 7 is shown. The BCN network 700 may be in signal communication with a cable provider (not shown), satellite TV dish (not shown), and/or external antenna (not shown) via a signal path 304, such as a main coaxial cable from the customer premises to a cable connection switch (not shown) outside of the customer premises.

The BCN network 700 may include the POE 306 and splitter network 722 that has a main splitter 1006, a sub-splitter 1008, Nodes A 724, B 726 and C 728, and STBs A 1016, B 1018 and C 1020. Within the BCN network 700, the POE 306 may be in signal communication with the main splitter 1006 via signal path 1022. The POE 306 may be implemented as a coaxial cable connector, transformer and/or filter.

The main splitter 1006 may be in signal communication with sub-splitter 1008 and Node C 728 via signal paths 1024 and 1026, respectively. The sub-splitter 1008 may be in signal communication with Node A 724 and Node B 726 via signal paths 1028 and 1030, respectively. The main splitter 1006 and sub-splitter 1008 may be implemented as coaxial cable splitters. Node A 724 may be in signal communication with STB A 1016 via signal path 1028. Similarly, Node B 726 may be in signal communication with STB B 1018 via signal path 1030. Moreover, Node C 728 may be in signal communication with STB C 1020 via signal path 1026. STBs A 1016, B 1018 and C 1020 may be implemented by numerous well known STB coaxial units, such as cable television set-top boxes and/or satellite television set-top boxes. Typically, the signal paths 304, 1022, 1024, 1026, 1028, 1030, 1032, 1034, and 1036 may be implemented utilizing coaxial cables.

As an example of operation, if STB A 1016 transmits a message to STB B 1018, the message will propagate through at least two transmission paths from Node A 724 to Node B 726. The first transmission path 1040 travels from Node A 724 through signal path 1028, leakage between output ports in sub-splitter 1008, and signal path 1030 to Node B 726. The second transmission path includes transmission sub-paths 1042 and 1044. The first sub-path 1042 travels from Node A 724 through signal path 1028, sub-splitter 1008, signal path 1024, main splitter 1006, and signal path 1022 to POE 306. The message may reflect due to less than ideal termination at the input or output of the POE 306 and go back through the second sub-path 1044. The second sub-path 1044 travels from POE 306, through signal path 1022, main splitter 1006, signal path 1024, sub-splitter 1008, and signal path 1030.

The first transmission path 1040 typically tends to experience a certain attenuation because of the isolation between the output ports of sub-splitter 1008. The second transmission path 1042 attenuation results mostly from the reflection at the POE 306 due primarily to impedance mismatches between the input or output of POE 306 and the rest of the BCN network 700. Of course, there may be additional paths the signal can travel through due to other reflections in the various paths of the BCN network 700. The result of all these multiple transmission paths is a potentially extensive dispersive channel between STB A 1016 and STB B 1018. This channel, however, is fairly static and does not change rapidly.

As another example, in FIG. 11, the communications between STB A 1016 and STB C 1020 is described for the BCN network of FIG. 10. In this example of operation, if STB A 1016 transmits a message to STB C 1020, the message will propagate through two or more transmission paths from Node A 724 to Node C 728. Two transmission paths of this example are shown in FIG. 11. The first transmission path 1040 travels from Node A 724 through signal path 1028, sub-splitter 1008, signal path 1024, and signal path 1026 to Node C 728, with leakage between the output ports of the main splitter 1006. A second transmission path includes transmission sub-paths 1042 and 1044 and the reflection at the input and/or the output of the POE 306.

In the example of FIG. 11, it is to be expected that the dispersal may be of a different nature than that of FIG. 10 because the leakage through the main splitter 1006 output ports is likely to be different compared to the leakage between the output ports of the sub-splitter 1008, and the difference in path lengths between the two transmission paths in the example of FIG. 11 is likely to be smaller because it includes only the traversing of the path 1022 twice, once on the way to the POE 306 and once on the way back. In contrast, in the example of FIG. 10, the difference in the paths includes the traversing twice of both the 1022 and 1024 paths.

In FIG. 12, a plot 1200 of the frequency response of the Node A to Node B 1208 two transmission path and the Node A to Node C 1206 two transmission path is shown. In both channels, the two transmission paths have similar attenuation, resulting in a frequency response with deep notches. This occurs at frequencies where the phase difference through the two paths is 180 degrees, resulting in the cancellation of the signal because their amplitude is identical. It may be noted that the frequency response of the Node A to Node B 1208

transmission path contains more notches per unit frequency than the Node A to Node C **1306** transmission path because its path time difference is larger. Similarly, because the time difference between the two paths of the Node A to Node C channel is smaller, the frequency difference between the notches in its frequency response is larger, as should be expected. Thus, FIG. **12** illustrates that in order to communicate between Node A and Node B, or between Node A and Node C, a special waveform may be required in order to deal effectively with the respective channels. Moreover, these channel responses are likely to be different in different cable systems and also are likely to change in time due to a change in configuration, such as when a user may add new devices to his cable system or change its topology, or due to slowly occurring changes caused by aging or changes in temperature or humidity that can change the leakage through the devices. Hence, the transmission system needs to constantly adapt to changing channel conditions.

In the example implementation, such adaptation is performed through a technique of OFDM modulation combined with an optimized bit-loading. In an OFDM optimized bit-loading, the modulation for each carrier is adapted to the channel response and noise (and interference) at the carrier frequency. FIG. **12** shows an example of bit-loading constellation **1202** versus frequency **1204** for the channel path utilized by Node A to transmit to Node B **1208** and the channel path utilized by node A to transmit to Node C **1206**. Line **1208** represents the AB channel and line **1206** represents the AC channel. As can be seen from FIG. **12**, at frequencies where the frequency response provides good transmission path and depending on the noise level, the BCN network may utilize high order modulation to permit better throughput at these frequencies. The modulation axis **1202** shows the QAM level (16, 32, 64 . . . 256) corresponding to a given frequency response level **1206** and **1208** at a given frequency **1204**. Around the notch frequencies **1212** and **1214** of the response **1208** and **1210** of the response **1206**, nothing at all may be transmitted because the notch is very deep. Sufficient margin may be provided to ensure that the selected modulation provides the necessary Bit Error Rate ("BER") and allows for small changes in the response. Additional QAM levels such as 2-QAM, also known as BPSK, and 4-QAM, also known as QPSK, can be used but are not shown in FIG. **12**.

Returning to FIG. **9**, the BCN network **900**, in order to ensure that both Node B **726** and Node C **728** are able to receive a broadcast signal transmitted from Node A **724**, utilizes a bit-loading modulation scheme that is known as the common bit-loaded modulation scheme. The common bit-loaded modulation scheme transmitted via the A-BC channel, along signal path **902**, is a combination of the bit-loading modulation scheme transmitted via the AB channel, along signal path **812**, and the AC channel, along signal path **822**.

FIGS. **13**A, **13**B and **13**C provide examples of common bit-loading. In FIG. **13**A, a plot **1300** of carrier frequency signals of various bit-loading constellations **1302** versus carrier number **1304** for the AB channel path such as that of FIG. **9** between Node A and Node B is shown. Line **1306** represents the AB channel frequency response and a corresponding envelope of the constellation sizes of 8 different carrier signals numbered 1-8 within the transmission signal for the AB channel. In the example, within the AB channel the transmitted OFDM signal includes the individual carriers with different modulation constellations, such as carrier number signals **1** and **8** that may transmit at a constellation size of 256 QAM, carrier number signals **2**, **3** and **7** that may transmit at a constellation size of 128 QAM, carrier number signals **4** and **6** that may transmit at a constellation size of 64 QAM, and carrier number signal **5** that may be OFF (i.e., no carrier signal may be transmitted because of the null in the channel response).

Similarly in FIG. **13**B, a plot **1308** of a frequency response **1314** and the corresponding bit loading scheme **1310** vs. frequency **1312** for the OFDM carrier frequency signals for the AC channel such as that of FIG. **9** is shown. Again, line **1314** represents the AC channel response and there is a corresponding envelope of the constellation sizes of the **8** different carrier number signals within the AC channel. As an example, within the AC channel, carrier number signals **1**, **2**, **4**, **6** and **8** may transmit at a constellation size of 128 QAM, carrier number signal **5** may transmit at a constellation size of 256 QAM, and carrier number signals **3** and **7** may be OFF (again, no carrier signals may be transmitted because of nulls in the channel response).

In FIG. **13**C, a plot **1316** shows the common bit-loading scheme of the OFDM carrier constellations **1318** versus carrier number **1320** for broadcasting messages over the A-BC channel path between Node A and Nodes B and C. In this example, plot **1316** shows that within the A-BC channel, an OFDM signal consisting of carrier number signals **1**, **2**, and **8** may transmit at a constellation size of 128 QAM, carrier number signals **4** and **6** may transmit at a constellation size of 64 QAM, and carrier number signals **3**, **5**, and **7** are OFF. These carrier number signal values are the result of comparing the carrier number signals from the AB channel in FIG. **13**A and the corresponding carrier number signals from the AC channel in FIG. **13**B and choosing the lowest corresponding modulation value for each carrier number. The resulting common carrier frequency signals in FIG. **13**C graphically represent signals utilizing the common bit-loaded modulation scheme. These signals would be able to transmit information from Node A to Node B and Node C simultaneously.

Turning to FIG. **14**, a block diagram of an Ethernet bridge node of the BCN network **700** for FIG. **7** or FIG. **3** is shown. The BCN network cable **1402** may be connected to a standard coaxial cable wall plate **1404**, such as those made by LEVITON. The coaxial wall plate **1404** may secure to the cable **1402** via a connector, such as a F-type or BNC connector. Typically the cable may be 75-ohm RG-59, some type of RG-6, or a combination of such 75-ohm cables. The Ethernet to Coax Bridge Device **1400** may have a diplexer **1408** that passes the RF frequencies below 860 MHz to a cable **1410** that may be connected to a video type device (not shown), such as a television, VCR, Audio/Visual Receiver, or television tuner PC card.

The Ethernet to Coax Bridge Device **1400** may have a BCN modem **1406** that connects to a BCN network such as that shown in FIG. **3** and FIG. **7**, and that enables it to code and decode messages between connected devices such as a wireless access point **1412**, media server **1414** or a network attached storage **1416** for transport across the BCN network through the cable **1402**. The various devices wishing to communicate over the BCN Network to other devices in other bedrooms communicate by using standard Ethernet packets. The Ethernet to Coax Bridge (ECB) provides Ethernet bridging, switching and/or routing functions for all connected devices to other devices connected over the BCN network. Hence, a laptop (not shown) may be connected wirelessly to the Wireless AP **1412**. The Wireless AP **1412** may route the Laptop packets to other devices connected to the ECB or through the BCN Network, to other devices in other rooms that are connected to the BCN Network through other ECBs, or directly to STBs, PCs, TVs, gateway and any other device that is capable of communications over the BCN network through a BCN modem. Similarly, the Media Server **1414**

may communicate through the ECB to TV sets, other Media Servers or Media Extenders connected to the BCN Network in any room. The ECB may operate a bridge, switch and or router over an Ethernet network. However, its functionality spans not only any Ethernet segment it is connected to but also across the full BCN Network, providing a full Layer 2 and upper layers functionality across the whole BCN network and other networks through gateways. Due to the capabilities of the BCN Network, the ECBs may provide high levels of Quality of Service ("QOS"), including network wide priorities such as IEEE 802.1p, and even higher level of QOS services including prioritized flow control for selected flow across the network. These capabilities are inherent in the BCN Network and may be utilized by all the devices connected to the BCN Network including ECBs.

In FIG. **15**, a cable home gateway/router node **1500** is shown. The cable home gateway/router node **1500** is connected to BCN network by a cable **1502**. The cable home gateway/router node **1500** may have a diplexer **1504** that passes RF frequencies below 860 MHz to another cable **1506** that may be connected to a video type device or any other cable device that utilizes frequencies below 860 MHz, such as a STB, TV set, cable modem, etc. A BCN modem **1508** may be connected to BCN network cable **1502** via the diplexer **1504**. The BCN modem **1508** may also be connected to a network processor/CPU **1510**, such as a host microprocessor, digital signal processor, or other known digital controllers by an electrical bus, such as a PCI bus **1509** or any other internal or external parallel or serial high speed bus.

The Network Processor/CPU **1510** may be configured to support WAN connectivity, such as the Docsis cable modem communication standard for data communication with a cable head end or DSL, dial-up connection, or Wireless Access through a WAN port. This port may or may not support MAC functions, but may transmit and receive WAN Packet Data Units to the WAN port **1524**. Further, the Network Processor/CPU may support other connections, such as USB 1.0, USB2.0, or other networking technologies. A N-port switch (4-port shown) **1512** may also be incorporated into the cable home gateway node/router **1500**. The ports **1514**, **1516**, **1518**, and **1520** (typically called local area network ports) may be coupled to Ethernet network devices (not shown). The cable home gateway/router node **1500** may also provide multiple networking functions, including gateway functions, e.g., WAN to/from LAN packet transmission and protocol conversions, LAN switching and/or routing functions and protocol conversions between the multiple LAN and WAN functions, which may include one or more BCN networks.

Turning to FIG. **16**, an integrated Ethernet bridge/router with integrated WAN modems ("IEBR") **1600** is shown. In this example implementation, the functionality and options of the bridge/router of FIG. **15** are integrated with the functionality of cable modem and/or DSL and/or wireless access, and also with wireless LAN connectivity as additional local ports. A BCN network cable **1602** is connected to a triplexer **1604** that may pass RF frequencies less than 860 MHz on another cable **1606** to a video device (not shown). The triplexer **1604** may also be coupled to a Docsis cable modem **1610** and a BCN modem **1612**. The IEBR **1600** also may have a DSL modem that interfaces to a telephone line (not shown) and also to a wireless WAN access modem **1608**. The IEBR **1600** may also be connected to a network processor **1614** and support an N-port switch (4-port switch shown) **1616** and a wireless LAN **1609**. Each of the ports of the N-port switch may be connected to an Ethernet enabled device, such as a media server/PC **1622**. The media server/PC **1622** may also be connected to the other cable **1606**. The functionality of the integrated router/WAN modem is similar to that of FIG. **15** but is integrated with the WAN modems and a wireless LAN.

In FIG. **17**, a diagram **1700** of frequency plans is illustrated. In most two-way cable systems **1702**, an upstream frequency band is located in the 5-42 MHz frequency band **1704**. Analog and digital cable television signals and cable modem downstream carriers are found in the 50-860 MHz frequency band **1706** and the BCN network **1708** is located between 940-1400 MHz. In theory, the BCN network can be located above 860 MHz, but in order to allow diplexers in systems that may require it, it may be prudent to allow a certain frequency band for the filters roll-off. A different implementation, such as the network shown in FIG. **4** or one where the BCN network is not connected to cable at all and is available exclusively for satellite use, is shown in FIG. **17**, **1710**. In this implementation, the BCN network **1712** may be located between 2-38 MHz and off-air signals **1714** between 50-806 MHz. The Satellite L-Band **1716** may be located between 950-2150 MHz. In yet another implementation **1718**, the system operates on a BCN Cable Network that is capable of providing both satellite and cable services. In this case, the cable upstream frequency band **1720** may be present between 5-42 MHz, the cable TV signals between 50-860 MHz **1722**, the BCN network **1724** in a frequency band found between 880 and 940 MHz, and satellite L-band **1726** located between 950-2150 MHz. The final implementation **1728** demonstrates the application over cable systems where two or more distinct BCN networks **1730** and **1732** located above the 5-42 upstream frequency band **1734** and cable TV 50-860 frequency band **1736** are utilized. In this frequency plan, although only two BCN Networks, **1730** and **1732**, are shown, many more may be placed above the ones shown in this frequency plan. Thus, it is shown that BCN networks may be located above or below traditional services in addition to being multiple BCN networks.

Turning to FIG. **18**, multimedia access control (MAC) frame types **1800** are described. A multiple layer protocol model may be employed with a transport layer encapsulating the MAC layer and carried in a physical (PHY) layer. The MAC layers **1802** may be made up of predefined packets or formats. The three top-level types of MAC transmission packets that may occur within the BCN Network **300** are; Data/control packet transmissions **1804** (performed by both the Network Coordinator (NC) node and client nodes), Beacon transmissions packet **1806** (performed by NC node) and Probe transmissions packet **1808** (scheduled by the MAC layer but transmitted by another layer).

The data/control packet **1804** may have a hundred and sixty bit header followed by a variable length payload and then a thirty-two bit cyclic redundancy checking (CRC). The payloads, for example, may be either control payload **1810** or data payload **1812**. The data payload **1812** may be MPEG type data **1814** (MPEG, MPEG-2, MPEG-4, etc. . . .), data protocols **1816**, such as Ethernet, or vendor defined data messaging **1818** that supports audio, video, data, or a combination of audio, video and data.

The control payload **1810** may be made up of MAP data **1820**, reservation request **1822**, link control **1824**, and port-to-port control data **1826**. Examples of MAP data **1820** that may be included as control payload **1810** include isochroous MAP data **1828** or asynchronous MAP data **1830**. Examples of reservation request control payloads **1810** include messages to reserve bandwidth for asynchronous communication **1832**, channel probes **1834**, and reserved bandwidth for port-to-port communication **1836**. The port-to-port control data

1826 may contain control information for the transmission of MPEG type data 1838 and Ethernet 1840.

The link control 1824 payload may contain link probe A/D response 1842, admission request 1844, admission response 1846, key distribution 1848, dynamic key distribution 1850, link probe A/D request 1852, robust acknowledgement 1854, vendor proprietary link control payload 1856, link probe parameters 1858, power adjustment 1860, power adjustment response 1862, power adjustment acknowledgement 1864, and power adjustment update 1866. In other implementations, other types of link control payload data may be defined and used in control packets 1810.

The beacon packet 1806 may be a packet that is 216 bits in length with an additional 32 bits of CRC data. When a BCN modem is activated, it attempts to locate the network timing by receiving a beacon packet 1806 which identifies network timing and essential network control information including network admission area, and other information identifying the time location and characteristics of other important and valid information such as future beacon locations, future channel assignment information, etc. Any BCN modem that wishes to be admitted to the network then transmits an admission request 1844 in a data/control packet 1804 to the NC using the identified admission area.

A probe packet 1808 may be generated by the physical layer and be used to optimize and to verify each link in the network, such as link probe A 1868, link probe B 1870, link probe C 1872, and link probe D 1874. More specifically, the probe packet 1808 may be used for at least three functions in a BCN network 310: link optimization, hardware calibration, and requesting a time slot to be allocated by a NC that may be used by a BCN modem to send packets to itself. In other implementations, additional probe packet payloads may be defined for the additional link configuration and optimization.

In FIG. 19, a general format of an example header portion 1900 of the MAC control/data packet 1804 of FIG. 18 is shown. The header 1900 may be of a fixed length and consists of a transmit clock time stamp 1902, type 1904 and subtype 1906 of the packet, a version identifier for MAC format 1908, identification of the source BCN modem 1910 and the destination BCN modems 1912, length of the packet 1914, a reserved area 1916 and a header check sequence 1918 such as a CRC. In other implementations, the header portion of the MAC control/data packet may contain additional fields or few fields (i.e., no reserved area 1916). Further, the size of the fields may vary in different implementations.

The payload of a MAC packet 1804 may vary in length from 0 to 16 KB. The specific size is dependent on the packet type 1904 and packet subtype fields in the MAC packet header 1900. In the current implementation, if the payload length is zero, then there is no payload or CRC following the MAC Packet Header 1900. If the payload length is between 4B to 16 KB, the last 4 bytes of the payload will contain the 32-bit CRC. The 32-bit CRC covers the entire payload, but the 32-bit CRC does not cover the MAC Packet Header. Also in the current implementation, payload lengths of 1, 2 and 3 bytes may not be allowed.

In some implementations, multiple payloads may be nested inside a primary payload. This is commonly referred to as Concatenation and may be indicated by a flag in the MAC Packet Header (not shown). Concatenation is useful to gather multiple smaller payloads (e.g., Ethernet packets) into a single transmission, which greatly increases efficiency within the network.

Turning to FIG. 20, a media access plan (MAP) protocol data unit (PDU) that is continued in the payload part of a MAC control packet 1804 of FIG. 18 is shown. The MAP PDU 1820 is one of four possible control PDUs (MAP PDU 1820, Reservation request PDU 1822, link control PDU 1824, and port-to-port message PDU 1826). The MAP PDU 1820 may be used to convey information between BCN modems regarding upcoming transmissions. The reservation request PDU 1822 may be used to obtain transmission bandwidth. The link control PDU 1824 may be used to ensure efficient operation of the BCN network. The port-to-port message PDU 1826 may be used to compliment data flows by exchanging information associated with providing quality of service within the network. The packet type field 1904 of the MAC header 1900 indicates the presence of one of the control PDUs 1810.

Two types of MAP PDUs 1820 are possible in the BCN: isochronous 1828 and asynchronous 1830. Isochronous MAP PDUs 1828 are used to convey information regarding transmission times of isochronous data flow. Asynchronous MAP PDUs 1830 are used to convey information about scheduled transmissions on the medium.

In FIG. 20, an asynchronous MAP PDU 1830 of FIG. 18 with a fixed-length PDU 2000 is shown. The fixed-length PDU 1830 consist of the following fields: asynchronous MAP header 2002, followed by one or more allocation units (AUs) 2004, 2006, 2008, belonging to one of the following types—Asynchronous MAP AUs, Probe AUs, and NACK AUs. Each of the AUs may have null bytes that may be used to pad the MAP PDU 2000 to a fixed length. In other implementations, the asynchronous MAP PDU 1830 may be of variable length, but additional processing would be required for formatting and decoding the PDU. Further, the probe AUs are used to allocate transmission opportunities to probe transmissions and the asynchronous MAP AUs 2004; 2006, 2008 may be used to allocate transmission bandwidth to MAC control/data packet 1804 transmissions.

Turning to FIG. 21, an asynchronous MAP PDU header 2100 of the asynchronous MAP PDU of FIG. 18 is illustrated. The asynchronous MAP PDU header 2100 may be a fixed-length header with a length of 224 bits. The MAP PDU header 2100 may include a system time from which the MAP is valid 2102, system time to which the MAP is valid 2104, parameters such as encryption flags 2106, state information 2108, bit masks 2110, Node identification for probe messages 2112, and miscellaneous data 2114.

In FIGS. 22A&B, the format 2200 of an asynchronous MAP allocation unit 1830 is illustrated. Each allocation unit 1830 provides information about the start time and type of transmission scheduled along with the modulation scheme to be used and the source and destination BCN modems for the transmission. The format 2200 may include a type field 2202, subtype field 2204, source node identification 2206, destination node identification 2208, modulation identification 2210, type of probe transmission 2212, identification of source node 2214, destination node identification 2216, training bits 2218, miscellaneous bits 2220, and probe data and offsets 2222.

Turning to FIG. 23, an illustration of the format of a NACK allocation unit 2300 is shown. These NACK allocation entries are used to provide information to requesting BCN modems and include reasons why the NC BCN modem did not allocate bandwidth to their pending requests. The use of the NACK allocation units 2300 may be optional in some implementations. The NACK allocation unit 2300 may include reason code 2302, identification of original requesting BCN modem 2304, sequence number 2306, type of original request being NACKed 2308, and subtype 2310.

Turning to FIG. **24**, an illustration of a reservation request PDU **1822** is shown. BCN modem devices in a BCN network to request transmission times use the reservation request PDU **1822**. An example of a reservation request PDU may include a reservation header **2402** and request elements **2404**, **2406**, **2408**. The request element portion of the request PDU **1822** may be of variable length. In other implementations, the request element portion may have a predetermined fixed length which is maintained with padding bits. The following types of reservation request PDUs **1822** may be used in a BCN network to make a reservation for isochronous data, asynchronous data, link probe, link control, and port-to-port messages.

In FIG. **25**, an illustration of the format **2500** of the request PDU **1822** of FIG. **24** is shown. The format **2500** may include an identifier **2502** of the number of request elements in the payload, miscellaneous data **2504**, reserved bits **2506**, state data **2508**, and type of request elements **2510**. In other implementations, fewer or additional fields may be used in a request PDU.

In FIG. **26**, an asynchronous data reservation request element **2600** used in the format **2500** of FIG. **25** is illustrated. The asynchronous reservation requests may be sent by a requesting BCN modem to the NC BCN modem to reserve bandwidth for transmission of asynchronous data. The asynchronous data reservation request element **2600** may include a type field **2602**, destination field **2604**, profile field **2606**, sequence number associated with the request **2608**, other parameters **2610**, and a bandwidth request field **2612**.

Turning to FIG. **27**, a link probe reservation request element **2700** used in the format **2500** of FIG. **25** is illustrated. The link probe reservation requests are sent by a requesting BCN modem the NC BCN modem in order to reserve bandwidth for a probe transmission. The link probe reservation request element **2700** may include a type field **2702**, reserved bits **2704**, destination field **2706**, index of the probe request **2708**, identification of the request **2710**, profile field **2712**, additional reserved bit field **2714**, and transmission time required **2716**. The identification of the request **2710** may be incremented every time a link probe reservation request is granted by the NC BCN modem. Further, the transmission time required **2716** may be a representation of predefined units, such as **20** nanoseconds in the current implementation.

In FIG. **28**, a link control reservation request element **2800** used in the format **2500** of FIG. **25** is shown. The link control reservation requests are used to reserve bandwidth for transmitting link control packets **1824**. The link control reservation request element **2800** may have a type field **2802**, subtype field **2804**, destination BCN modem identification **2806**, profile for transmission **2808**, sequence number associated with the request **2810**, reserved bits **2812**, and required transmission time **2814**. The required transmission time **2814** may be a representation of predetermined units, such as 20 nanoseconds used in the current implementation.

In FIG. **29**, an illustration of the format **2900** of the link probe report PDU of FIG. **18** is shown. Link control PDUs are used to maintain connectivity among all BCN modems in a BCN modem network to ensure an acceptable quality of service (QOS) operation of the BCN network. A link probe report may be sent in a MAC packet of Packet type link-control **1824** and Packet_subtype Link probe A/D report. This descriptor includes information regarding source and destination nodes, various settings used for unicast transmission on the channel, transmit power control parameters and reports usable constellation for each subcarrier of the signal transmission. The fields of the format **2900** may include an identifier of the number of source-destination pairs in the next iteration **2902**, source identifier **2904**, destination BCN modem identifier **2906**, BCN NC relay data **2908**, miscellaneous data **2910**, Source BCN modem **2912**, destination BCN modem **2914**, profile data **2916**, along with other data.

Turning to FIG. **30**, an illustration of an admission request PDU **1844** of FIG. **18** is shown. A new BCN modem wishing to join the BCN network sends an admission request PDU **1844** to the NC BCN modem. This request may be sent using diversity mode transmission. The admission request may contain data fields for node protocol support **3002**, reserved bits **3004**, MAC address of the BCN modem **3006**, and transmit power adjustment **3008**. The transmit power adjustment **3008** may be a decimal number between zero and 63 which indicates the power adjustment value in units of dB to be used by the NC BCN modem for subsequent transmissions the BCN modem.

In FIG. **31**, an illustration of an admission response PDU **1846** of FIG. **18** is shown. The admission response PDU **1846** is sent by the NC BCN modem to a BCN modem that is being admitted to the BCN network. The fields of the admission response PDU may include data fields for the total number of BCN modems or nodes in the network **3102**, a reset flag **3104**, reserved bits **3106**, maximum value of transmit power **3108**, iteration data **3112**, additional reserved bits **3114**, protocols supported **3116**, changes to following reserved field **3118**, and device identification of the BCN modem **3120**. In FIG. **32**, an illustration of the format of a key distribution PDU1848 is shown.

Turning to FIG. **33**, an illustration of the format of the link probe report request PDU **1852** of FIG. **18** is shown. This link control payload **1824** is used by BCN modems to request from other BCN modems a response to the previous A or D type of link probe transmission. The format of the link probe report request PDU **1852** may include fields for source of the report **3302**, destination of the report **3304**, reserved bits **3306**, relay flag **3308**, and additional reserved bits **3310**.

In FIG. **34**, an illustration of the format of a general link acknowledgement PDU **3400** is shown. The general link acknowledgement PUD **3400** is a general-purpose acknowledgement payload used at the link layer to acknowledge various requests and operations.

In FIG. **35**, an illustration of the link probe C parameters PUD **3500** is shown. The link probe C parameters PDU is sent by a node wishing to receive a C type of probe. This packet is sent to the transmitter of the probe to specify the details of the probe signal to be transmitted. Further example PDUs are power adjustment control PDU FIG. **36**, power adjustment response PDU FIG. **37**, power adjustment acknowledgement PDU FIG. **38**, and power adjustment update PDU FIG. **39**.

In FIG. **40**, an illustration of an Ethernet data payload **1840** of FIG. **18** is shown. Ethernet data payloads are inserted into the MAC payload field according to an IEEE 802.3 frame without its FCS. The length of the Ethernet data payload field is the length of the MAC packet as indicated in the packet header minus the packet CRC and optional timestamps, if present. Other protocols may be transferred in a similar manner as Ethernet data, for example, MPEG data, frame-relay data . . . .

Turning to FIG. **41**, a beacon packet **1806** of FIG. **18** is shown. The Beacon packet may be a fixed length packet with a format that includes information elements **4102**, reserved bits **4104**, network information **4106**, reserved bits **4108**, BCN modem ID of the NC **4110**, next beacon index **4112**, reserved bits **4114**, admission frame length **4116**, asynchronous MAP length **4118**, isochronous MAP length **4120**, admission window **4122**, admission contention index **4124**,

asynchronous MAP profile **4126**, asynchronous MAP index **4128**, isochronous profile **4130**, isochronous index **4132**, and CRC **4134**.

Security of data transmitted in the BCN network is provided to assure privacy of transmitted data. The signals in the BCN network are transmitted on the home coax network and may be detectible in homes that share the same multi-tap or are connected to an adjacent multi-tap. Without the use of a blocking filter such as, a "goober," it is possible that neighbors could attempt to maliciously eavesdrop on another's BCN network traffic. In order to prevent this type of eavesdropping, the BCN network provides a privacy feature, which inhibits eavesdropping.

Privacy procedures encrypt all packets transmitted on a BCN network (i.e., the Home Video Network (HVN)) with a 56-bit DES encryption. A user enters a password, which is used to distinguish between different HVNs. The password is basically used to derive keys and authenticate BCN modems. Once a BCN modem is authenticated, it is admitted with no further requirements. BCN modems with the same password will form one HVN and nodes with different passwords will form separate HVNs.

In the BCN network, privacy procedures also help distinguish nodes which should locate themselves on different RF channels. Nodes with different passwords will not locate themselves on the same RF channel because they will not be able to decrypt each other's messages. Instead they will see each other's transmissions as interference on the cable and thus automatically locate themselves on different channels.

Privacy procedures may use both static and dynamic keys for encryption. The static keys are used for authentication and initial key distribution while the dynamic keys are used for subsequent key distribution and traffic. Generation and distribution of dynamic keys are controlled by a BCN modem designated as the Privacy Master, which may also be the NC BCN modem.

The password may be used to derive two static keys, which are used for encrypting MAC Management Messages and initially distributing dynamic keys. These static keys are called the MAC Management Key (MMK) and Initial Privacy Management Key (PMKInitial). BCN modems that have the correct MMK and PMKInitial will be able to communicate with the Privacy Master, receive dynamic keys, and join the HVN.

The two dynamic keys may be used for encrypting the Privacy Management messages and BCN modem traffic. These keys are the Privacy Management Key (PMK) and Traffic Encryption Key (TEK) respectively. PMKs and TEKs are generated and distributed to all other nodes by the Privacy Master. PMKs and TEKs are changed periodically.

There are five levels of attack that BCN modem privacy must consider: Simple Manipulation, Casual Hacking, Sophisticated Hacking, University Challenge, and Criminal Enterprise. The same attack levels may be generalized to the BCN network, which provides protection against Simple Manipulation, Casual Hacking, and Casual Hacking with help from Sophisticated Hacking, by link security in the BCN network for transmitted data.

All encrypted BCN modem messages may be encrypted using DES Cipher Block Chaining (CBC) mode. In other implementations, 128-bit strong encryption may be employed. Encryption blocks must be aligned so that the beginning of the first 64-bit DES block is aligned to the first byte of the BCN modem packet. Chaining is reinitialized on each BCN modem packet. Fragments of less than 64 bits at the end of a packet are encrypted using residual termination block processing. Note that all BCN modem packets must contain an integer number of bytes and because of the 144 bit BCN modem header will contain at least two DES encryption blocks. Given a final block having n bits, where n is less than 64, the next-to-last ciphertext block is DES-encrypted a second time, using the ECB mode, and the least-significant n bits of the result are exclusive OR-ed with the final n bits of the payload to generate the short final cipher block.

An alternative description of this procedure is that given a final block having n bits, where n is less than 64, the n bits are padded up to a block of 64 bits by appending 64-n bits of arbitrary value to the right of the n payload bits. The resulting block is DES-encrypted using the CFB64 mode, with the next-to-last ciphertext block serving as an initialization vector for the CFB64 operation. The leftmost n bits of the resulting ciphertext are used as the short cipher block.

The alternative description produces the same ciphertext. In the alternative description, however, no mention is made of combining ECB encryption with exclusive-OR-ing. These operations are internal to CFB64, just as they are internal to CBC. The alternative description is convenient here because it allows residual block processing to be illustrated using CFB64 examples in [FIPS-81]. CBC mode provides more protection against attacks but can introduce error propagation. However, since a BCN modem provides a high availability network, the impact of error propagation would be small.

A 64 bit Initialization Vector (IV) used with all encrypted packets is fixed and must be; IV=0×AA-AA-AA-AA-AA-AA-AA-AA. The IV may not be transmitted and is known a priori by both the encryption and decryption BCN modem or other network devices. This is not a security risk because all BCN modem messages include a 32 bit transmit time at the beginning of the message which changes with every message. This creates the same effect as a dynamic IV.

A user-entered password may be used to control access of BCN modems to a HVN. BCN modems that have the same password will form one HVN while BCN modems with different passwords will form separate HVNs. Passwords may be manually entered by the user and typically will be the same for all devices, which the user wants to be part of the same HVN. Therefore, it is expected that the user will go around his home and enter the same password into every BCN device in the current implementation. In other implementations, different HVN membership schemes may be employed (such as IP address, MAC address, Portions of address, etc. . . .).

Although the layout of a graphical user interface (GUI) and other details of how passwords are input to a BCN modem are not shown, each implementation preferably will be capable of accepting a number up to **17** digits long as the password for the BCN network. The GUI should encourage users to enter **17** digit random passwords for maximum protection. If a password that long cannot be entered, it should be pre-pended by numerical zero ("0") to make it into a **17** character ASCII string that is then used to produce a password seed in the current implementation. In order for devices to interoperate, passwords entered on GUI using different methods should result in the same value of for the password seed. In other implementations, other approaches to password seed generation may be used.

In FIG. **42**, a flow diagram of password generation in a BCN network is shown. The implementation specific password application, such as GUI with alphanumeric input capability, accepts the password from a user **4202**. The format of the password is converted to a predetermined standard **4204**. The formatted password is then used to compute the password seed **4206**. The password seed then results in a PMK value **4208** and a MMK value **4210**. Upon calculating the password

seed, the password must be destroyed from local memory so that reading host memory cannot discover it. The password seed should persist through power cycles to ensure that multiple BCN modems may come up and restore communication with each other through power failures.

The process and messaging shown may be performed by hardware or software. If the process is performed by software, the software may reside in software memory or memories (not shown) in the BCN network. The software in software memory may include an ordered listing of executable instructions for implementing logical functions (i.e., "logic" that may be implemented either in digital form such as digital circuitry or source code or in analog form such as analog circuitry or an analog source such as an analog electrical, sound or video signal), may selectively be embodied in any computer-readable (or signal-bearing) medium for use by or in connection with an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that may selectively fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions. In the context of this document, a "computer-readable medium" and/or "signal-bearing medium" is any means that may contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The computer readable medium may selectively be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific examples, that is "a non-exhaustive list" of the computer-readable media, would include the following: an electrical connection (electronic) having one or more wires, a portable computer diskette (magnetic), a RAM (electronic), a read-only memory "ROM" (electronic), an erasable programmable read-only memory (EPROM or Flash memory) (electronic), an optical fiber (optical), and a portable compact disc read-only memory "CDROM" (optical). Note that the computer-readable medium may even be paper or another suitable medium upon which the program is printed, as the program can be electronically captured, via for instance, optical scanning of the paper or other medium, then compiled, interpreted or otherwise processed in a suitable manner if necessary, and then stored in a computer memory.

While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible that are within the scope of this invention.

What is claimed is:

1. A Broadband Cable Network (BCN) modem having a transmitter that transmits packets to a plurality of nodes in a broadband cable network, the transmitter comprising:

a MAC subsystem that provides the packets for transmission within the broadband cable network;

a Modem subsystem in signal communication with the MAC subsystem, the Modem subsystem receiving the packets from the MAC subsystem and appending information to the packets; and

a RF subsystem in signal communication with the Modem subsystem, that receives the packets from the Modem subsystem and upconverting the packets received from the Modem subsystem;

wherein at least one of the packets is a beacon packet that has a channel number field, change field, sequence number field, network coordinator ID field, next beacon index field, admission frame length field, admission window, asynchronous MAP length field and a beacon Cyclic Redundancy Checking (CRC) field; and

wherein at least one of the packets is a data and control packet having a header and a variable length payload and wherein the header has at least five fields selected from the group consisting of a transmit clock field, packet type field, packet subtype field, version field, source node ID field, destination node ID field, and header check sequence field.

2. A Broadband Cable Network (BCN) modem having a receiver that receives packets from a plurality of nodes in a broadband cable network, the receiver comprising:

a RF subsystem that receives packets and downconverting the packets wherein at least one of the packets is a control and data packet having a header, the header having at least five fields selected from a group consisting of a transmit clock field, packet type field, packet subtype field, version field, source node ID field, destination node ID field, and header check sequence field, the control and data packet further having a variable length payload;

a Modem subsystem in signal communication with the RF subsystem, the Modem subsystem receiving the packets and removing control information from the packets; and

a MAC subsystem that receives packets within the broadband cable network and retrieving data for use by the BCN modem;

wherein at least one of the packets is a beacon packet that has a channel number field, change field, sequence number field, network coordinator ID field, next beacon index field, admission frame length field, admission window, asynchronous MAP length field and a beacon Cyclic Redundancy Checking (CRC) field.

3. A method for transmitting packets from a Broadband Cable Network (BCN) modem to a plurality of nodes in a broadband cable network, the method comprising:

formatting the packets in a MAC subsystem that transmits the packets within the broadband cable network, including formatting a data and control packet for transmission within the broadband cable network, the data and control packet having a header and a variable length payload, the header having at least five fields selected from the group consisting of a transmit clock field, packet type field, packet subtype field, version field, source node ID field, destination node ID field, and header check sequence field;

receiving the packets from the MAC subsystem at a Modem subsystem that is in signal communication with the MAC subsystem and that appends information to the packets; and

upconverting the packets with the information for transmission via the broadband cable network at a RF subsystem that is in signal communication with the Modem subsystem;

wherein at least one of the packets is a beacon packet that has a channel number field, change field, sequence number field, network coordinator ID field, next beacon index field, admission frame length field, admission window, asynchronous MAP length field and a beacon Cyclic Redundancy Checking (CRC) field.

4. A method for receiving packets at a receiver in a Broadband Cable Network (BCN) modem from at least one node in a broadband cable network, the method comprising:

receiving the packets and downconverting the packets at a RF subsystem including a control and data packet having a header that has at least five fields selected from the group consisting of a transmit clock field, packet type field, packet subtype field, version field, source node ID

field, destination node ID field, and header check sequence field and variable length payload;

removing control information from the packets in a Modem subsystem that is in signal communication with the RF subsystem; and

retrieving data for use by the BCN modem at a MAC subsystem that is in signal communication with the Modem subsystem and in receipt of the packet with the control information removed;

wherein at least one of the packets is a beacon packet that has a channel number field, change field, sequence number field, network coordinator ID field, next beacon index field, admission frame length field, admission window, asynchronous MAP length field and a beacon Cyclic Redundancy Checking (CRC) field.

* * * * *