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(54) SYSTEM AND METHOD FOR TRANSMITTING DATA

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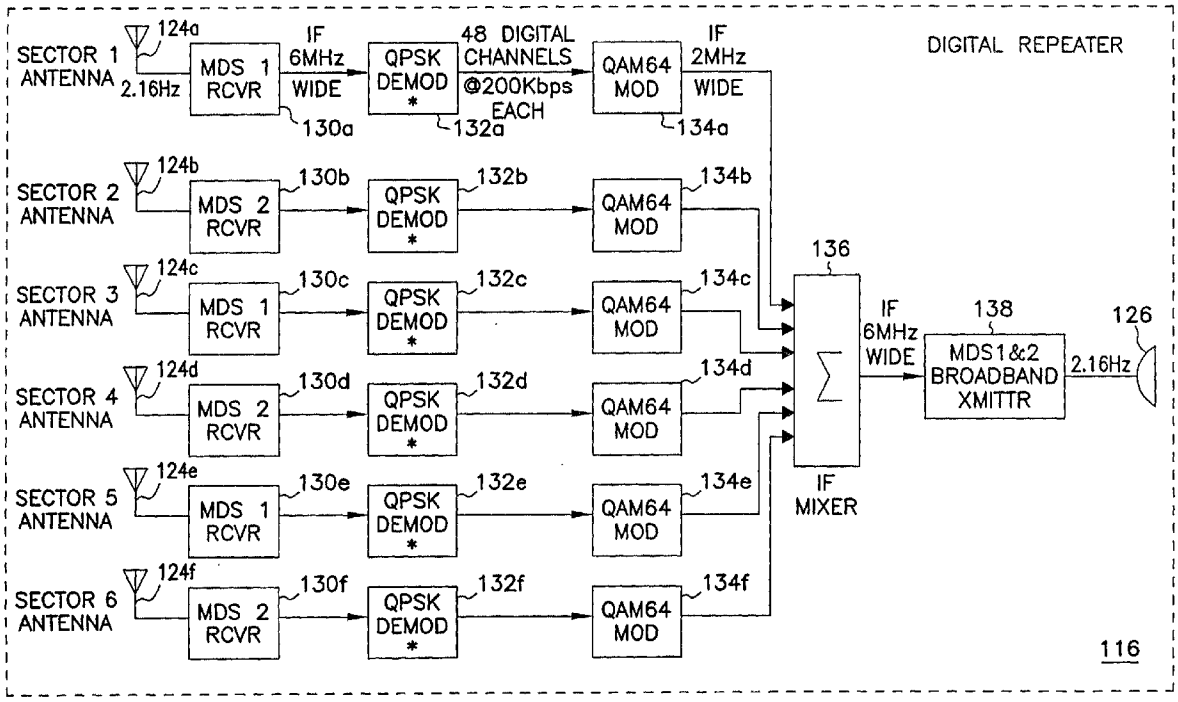
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(52) **U.S. Cl.** **455/3.01**; 455/562

(57) **ABSTRACT**

A transmission system (**10**). The transmission system communicates data to a number of subscribers (**14***a*, **14***b*). The transmission system includes a transceiver (**12**) that has a number of highly directional antennas (**28**). A number of digital repeaters (**16***a*,**16***b*,**16***c*) are disposed in a geographic region serviced by the transceiver. The repeaters include a sectorized antenna that communicates with subscribers in a number of sectors of the geographic region of the repeater. The repeater also includes an upstream demodulator/modulator circuit (**19**). The upstream demodulator/modulator circuit demodulates data from signals from subscribers that were modulated with a first modulation technique, and generates a re-modulated signal with the data using a second modulation technique. The second modulation technique is different from the first modulation technique such that the signals from the subscribers from the number of sectors are combined in the re-modulated signal so as to increase the capacity of the transmission system. The digital repeaters also include a highly directional antenna, that is coupled to the demodulator/modulator circuit and that communicates the re-modulated signal to the transceiver.



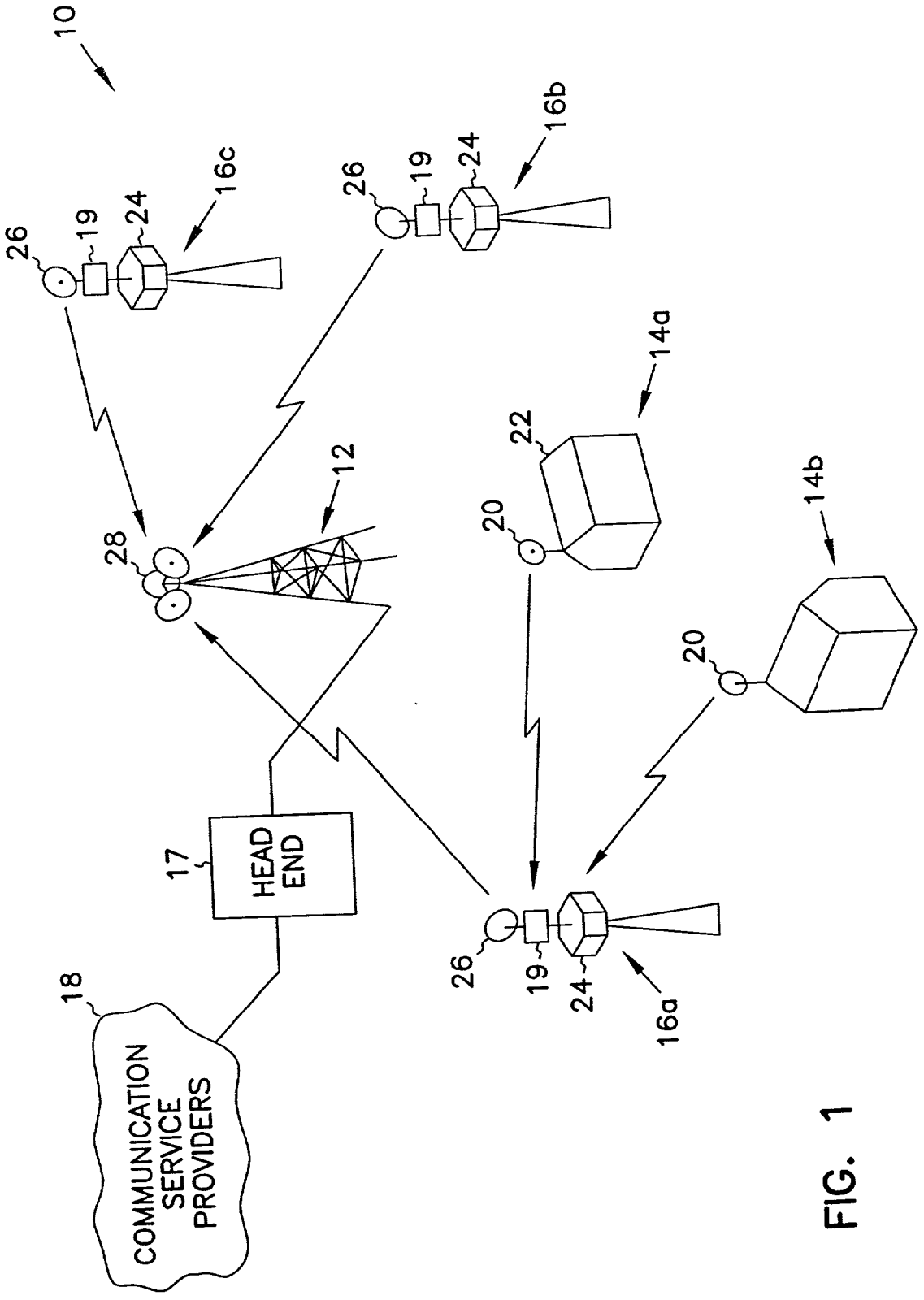

10
16c
26
19
24
16b
26
19
24
14a
22
20
12
28
14b
20
17
HEAD END
18
COMMUNICATION SERVICE PROVIDERS
26
19
24
16a

FIG. 1

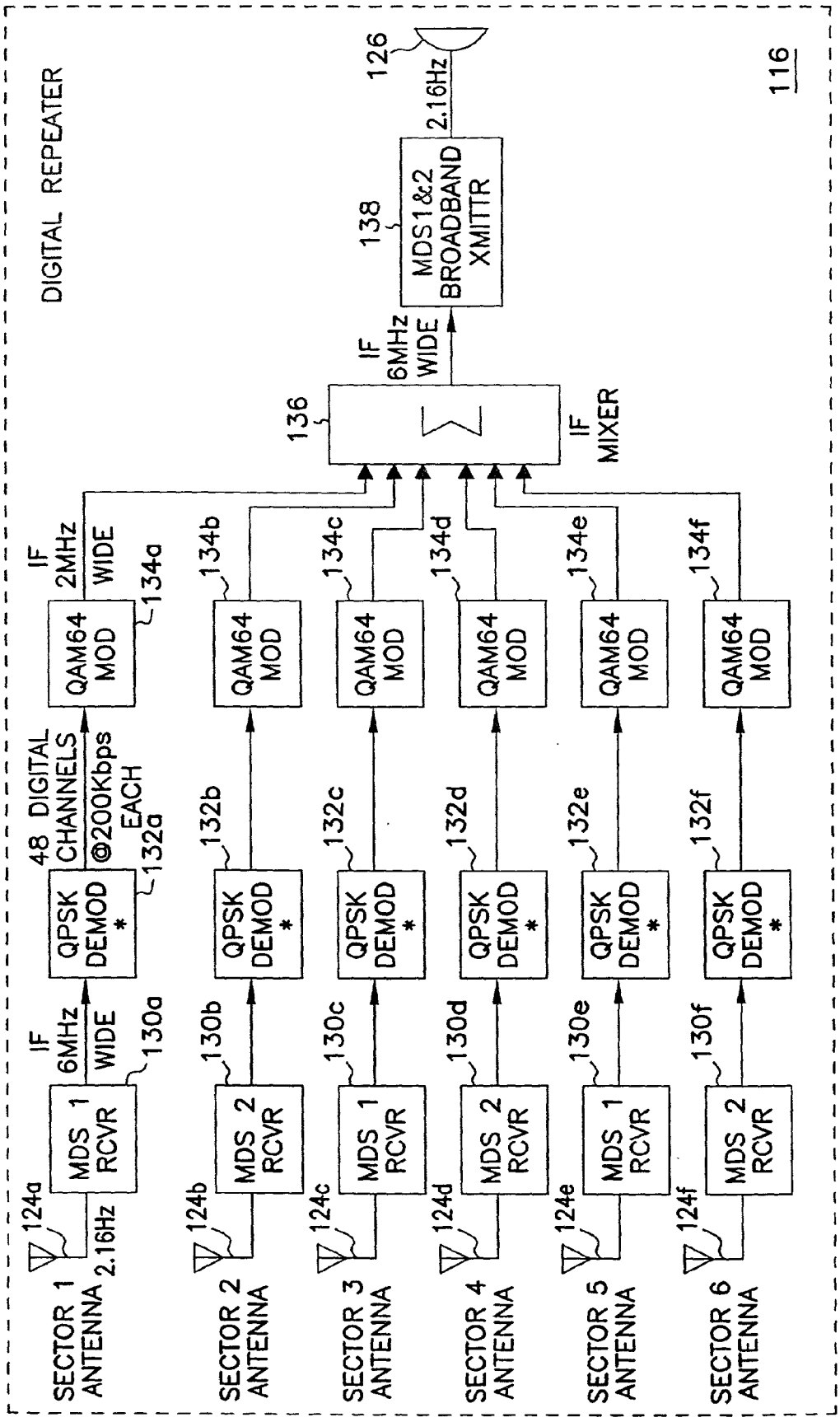

DIGITAL REPEATER
116
126
2.16Hz
138
MDS1&2 BROADBAND XMITTR
IF 6MHz WIDE
136
IF MIXER
IF 2MHz WIDE
48 DIGITAL CHANNELS @200Kbps EACH
132a
QPSK DEMOD *
QAM64 MOD
134a
IF 6MHz WIDE
130a
MDS 1 RCVR
124a
SECTOR 1 ANTENNA
2.16Hz
130b
MDS 2 RCVR
124b
SECTOR 2 ANTENNA
132b
134b
130c
MDS 1 RCVR
124c
SECTOR 3 ANTENNA
132c
134c
130d
MDS 2 RCVR
124d
SECTOR 4 ANTENNA
132d
134d
130e
MDS 1 RCVR
124e
SECTOR 5 ANTENNA
132e
134e
130f
MDS 2 RCVR
124f
SECTOR 6 ANTENNA
132f
134f

FIG. 2

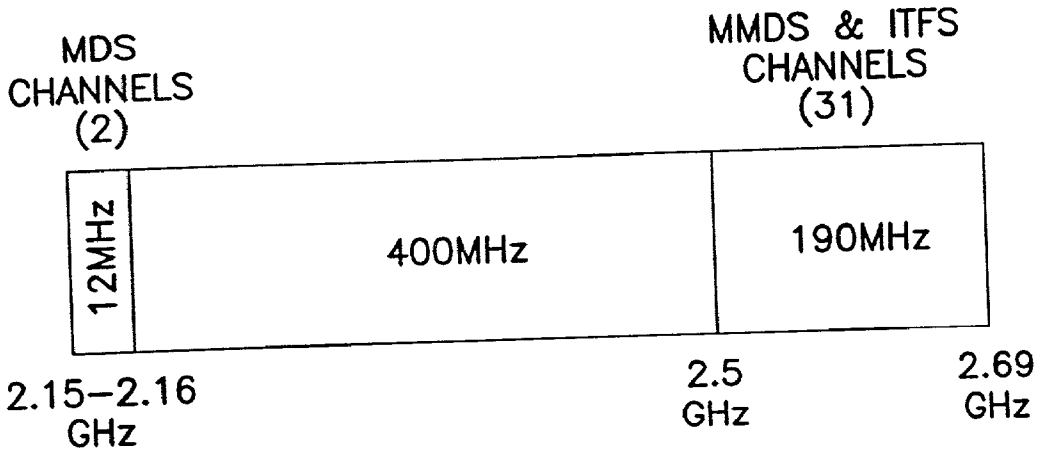

MDS
CHANNELS
(2)
MMDS & ITFS
CHANNELS
(31)
12MHz
400MHz
190MHz
2.15–2.16
GHz
2.5
GHz
2.69
GHz

FIG. 3

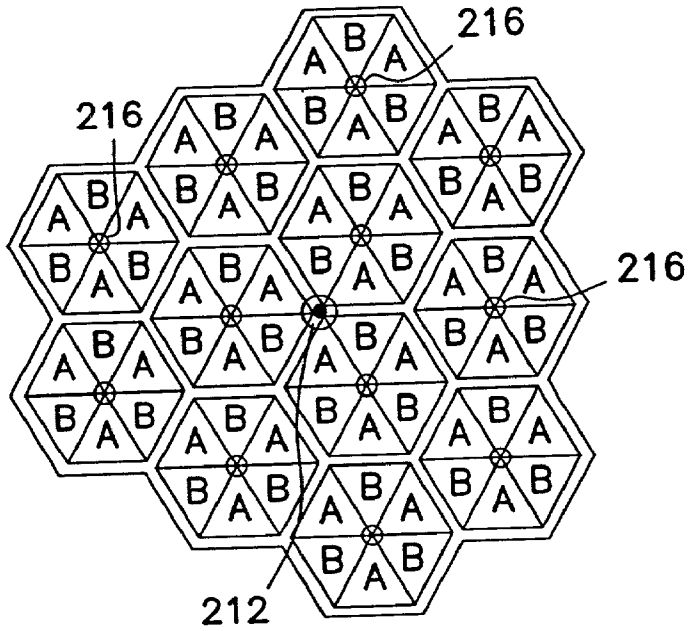

216
216
216
212

FIG. 4A

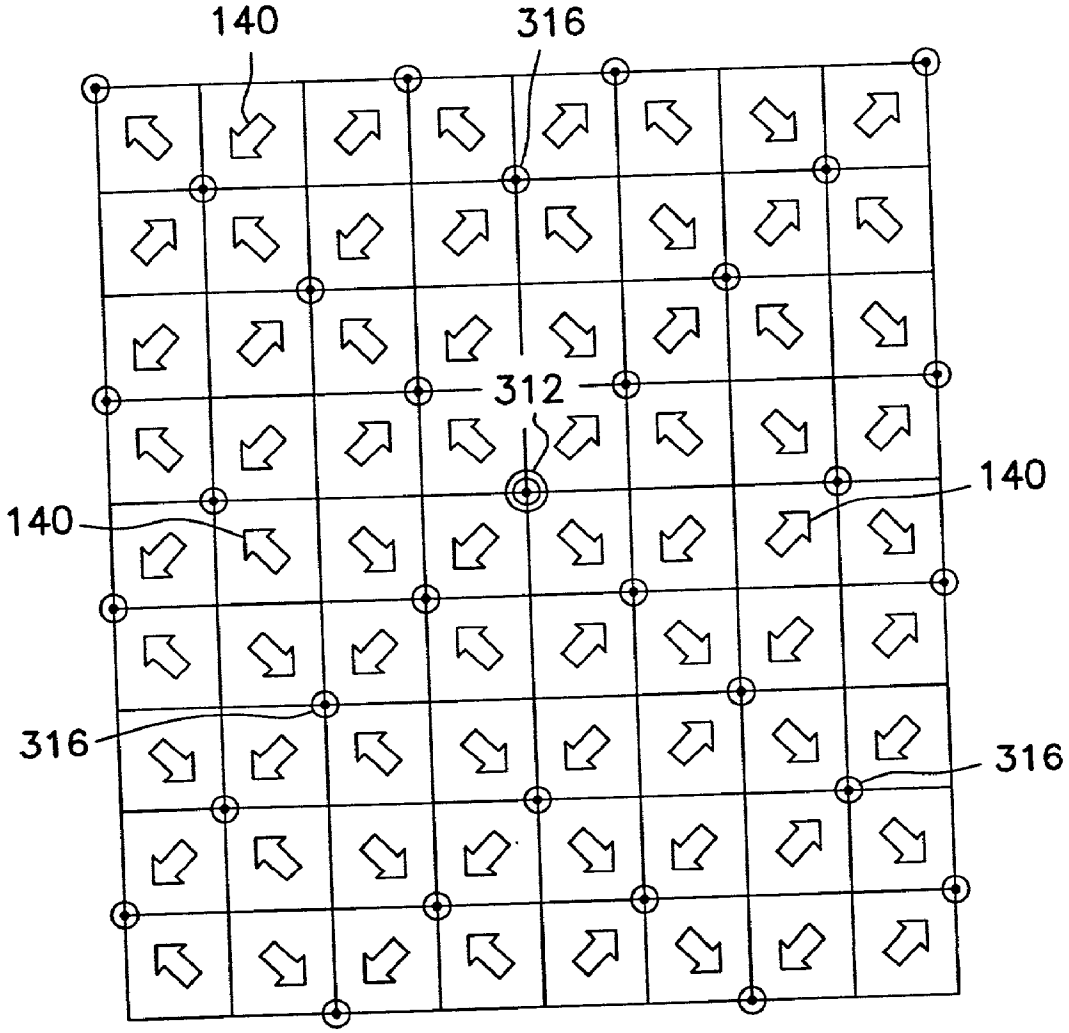


FIG. 4B

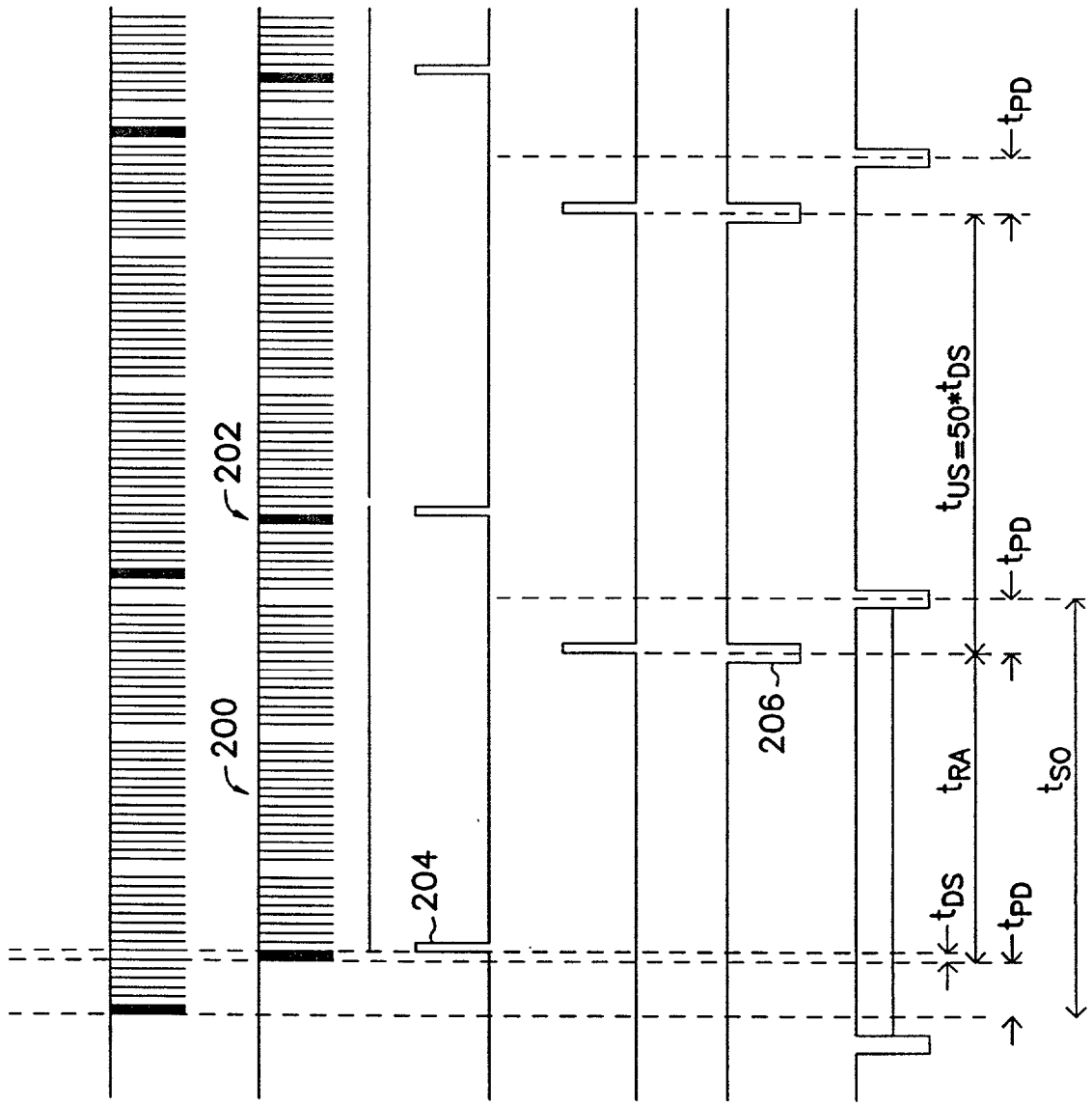


FIG. 5A

FIG. 5B

FIG. 5C

FIG. 5D

FIG. 5E

FIG. 5F

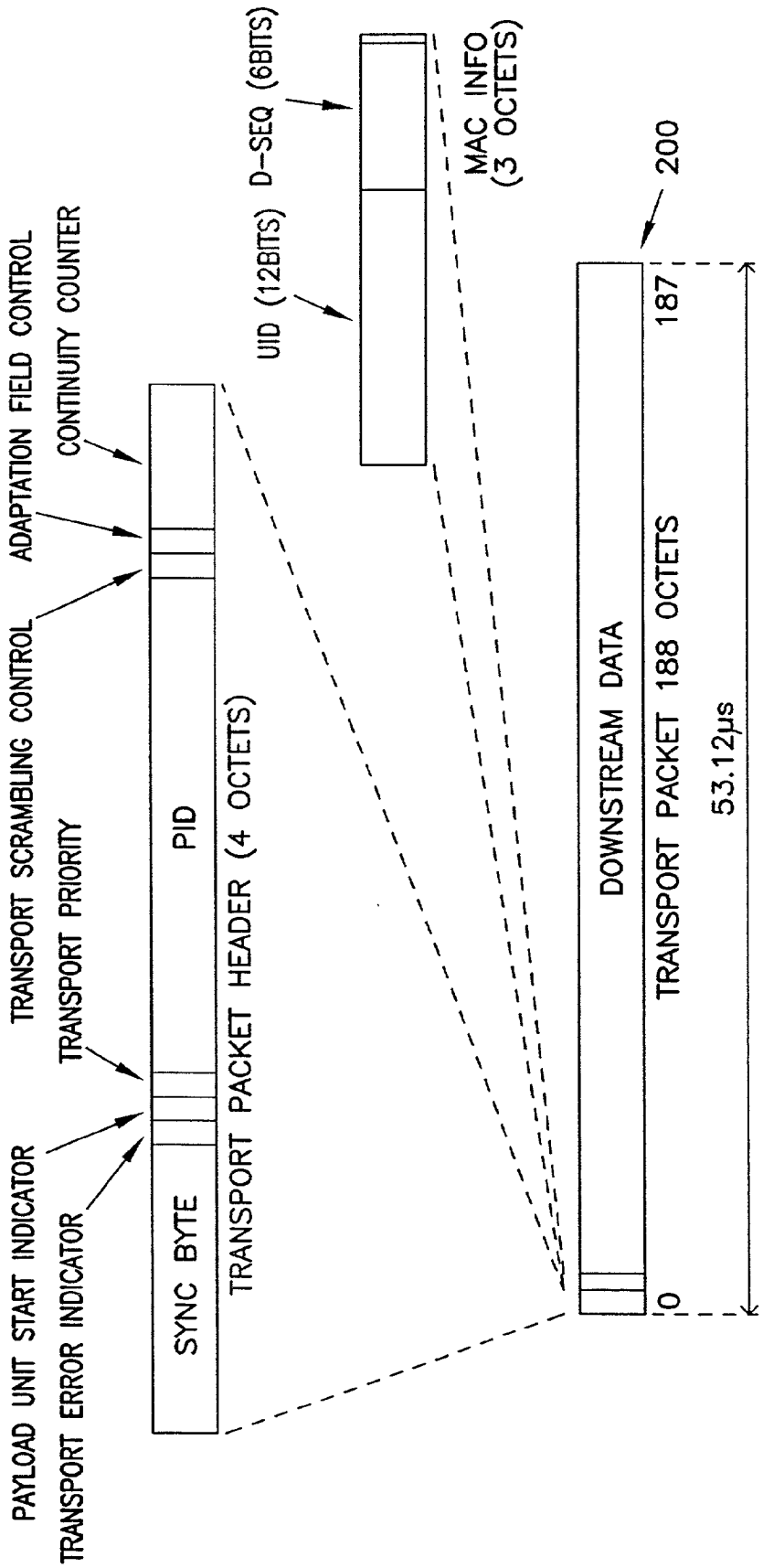

PAYLOAD UNIT START INDICATOR
TRANSPORT ERROR INDICATOR
TRANSPORT PRIORITY
TRANSPORT SCRAMBLING CONTROL
ADAPTATION FIELD CONTROL
CONTINUITY COUNTER
SYNC BYTE
PID
TRANSPORT PACKET HEADER (4 OCTETS)
UID (12BITS)
D-SEQ (6BITS)
MAC INFO (3 OCTETS)
DOWNSTREAM DATA
200
0
187
TRANSPORT PACKET 188 OCTETS
53.12μs

FIG. 6

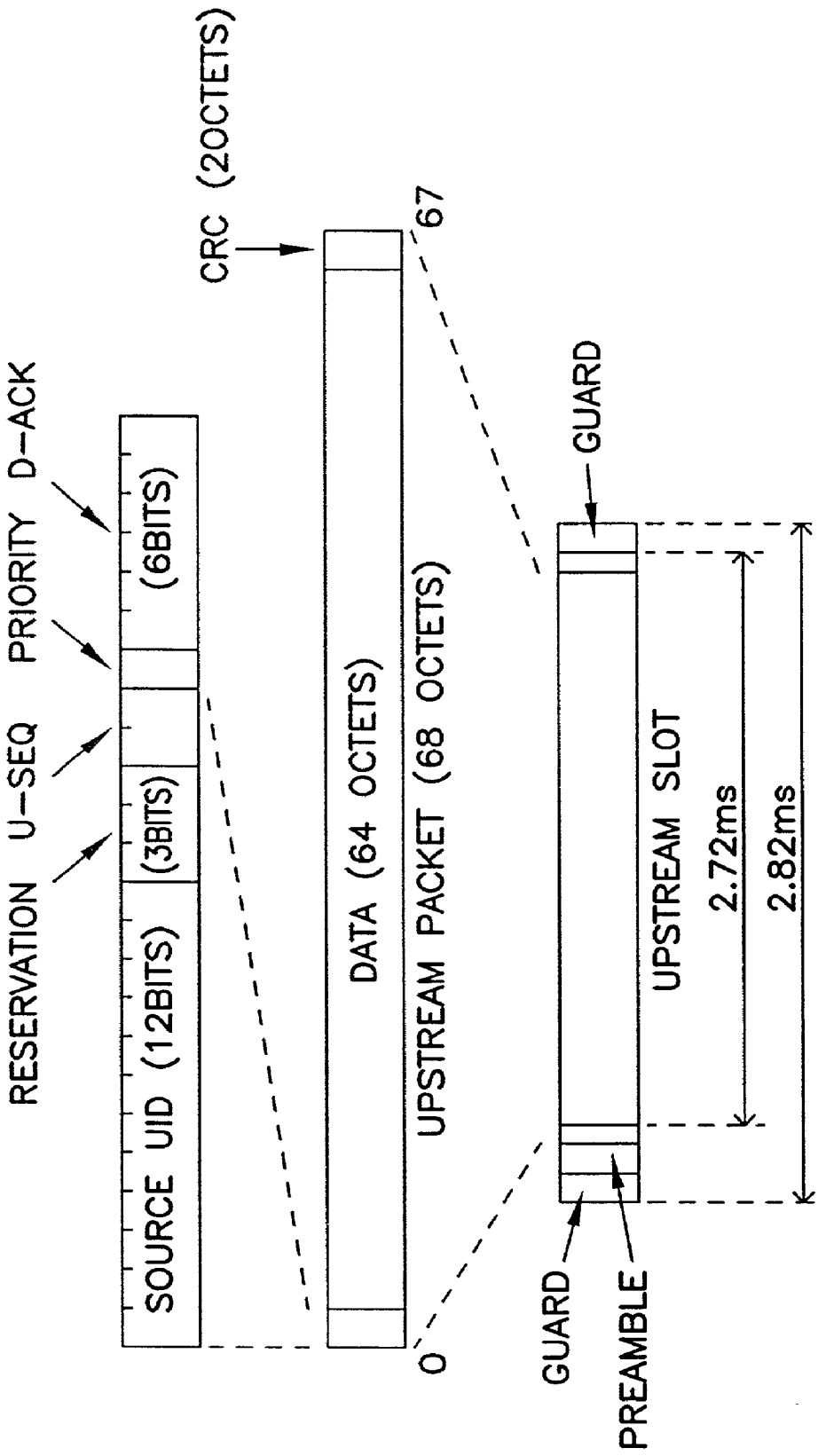

RESERVATION
U-SEQ
PRIORITY
D-ACK
SOURCE UID (12BITS)
(3BITS)
(6BITS)
CRC (2OCTETS)
DATA (64 OCTETS)
UPSTREAM PACKET (68 OCTETS)
0
67
GUARD
PREAMBLE
GUARD
UPSTREAM SLOT
2.72ms
2.82ms

FIG. 7

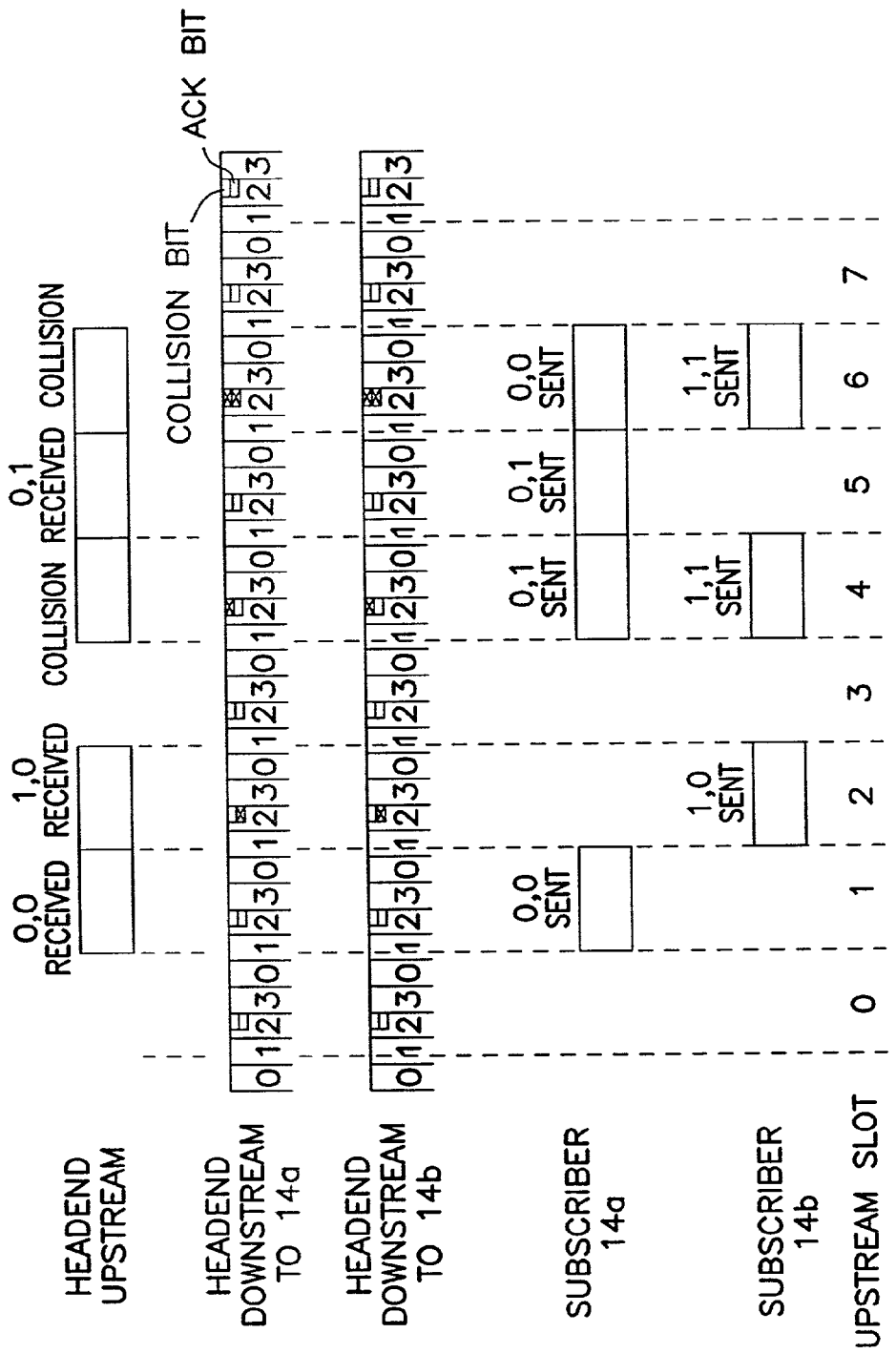


FIG. 8A

FIG. 8B

FIG. 8C

FIG. 8D

FIG. 8E

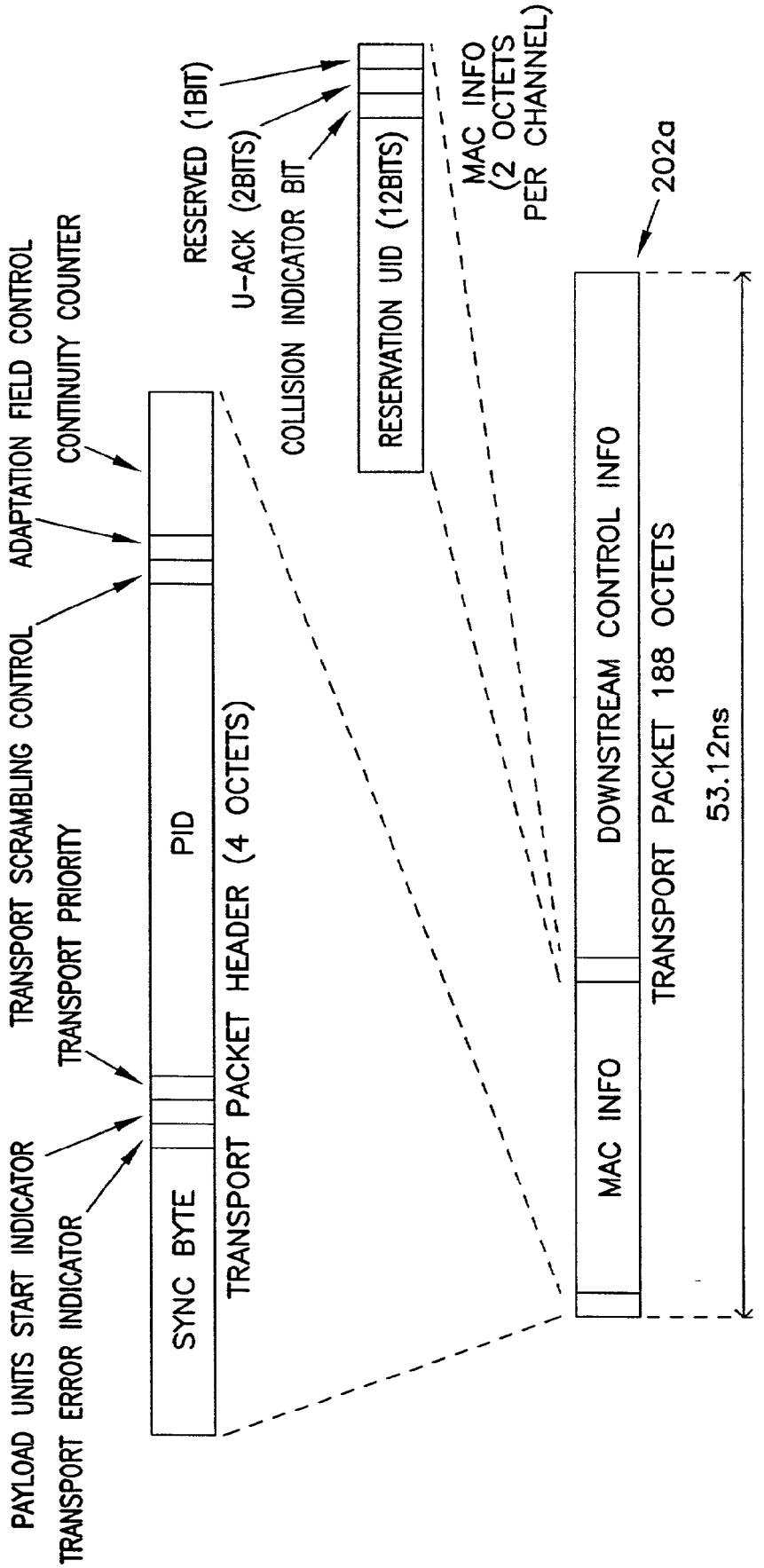

PAYLOAD UNITS START INDICATOR
TRANSPORT ERROR INDICATOR
TRANSPORT SCRAMBLING CONTROL
TRANSPORT PRIORITY
ADAPTATION FIELD CONTROL
CONTINUITY COUNTER
SYNC BYTE
PID
TRANSPORT PACKET HEADER (4 OCTETS)
RESERVED (1BIT)
U-ACK (2BITS)
COLLISION INDICATOR BIT
RESERVATION UID (12BITS)
MAC INFO (2 OCTETS PER CHANNEL)
202a
MAC INFO
DOWNSTREAM CONTROL INFO
TRANSPORT PACKET 188 OCTETS
53.12ns

FIG. 9

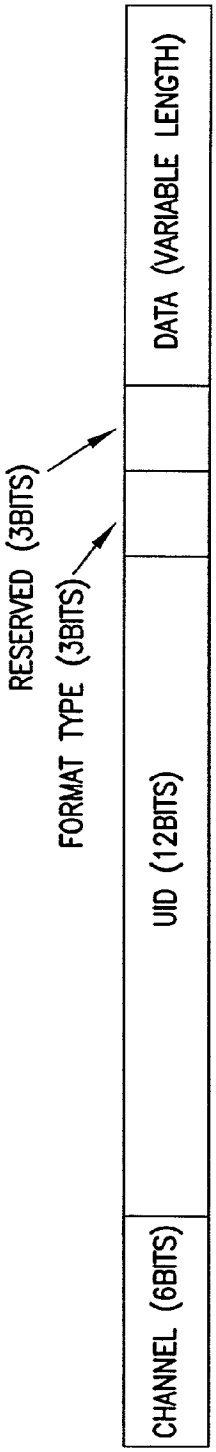


FIG. 10A GENERAL FORMAT OF DOWNSTREAM CONTROL INFORMATION. PACKET SIZE IS SYSTEM DEPENDENT

CHANNEL (6BITS)	UID (12BITS)	000	000	RECEVIED POWER AND CHANNEL SELECT

FIG. 10B FORMAT FOR POWER CONTROL AND RANGING

CHANNEL (6BITS)	UID (12BITS)	001	000	CONDITIONAL ACCESS KEY

FIG. 10C FORMAT FOR CONDITIONAL ACCESS KEY DOWNLOAD

CHANNEL (6BITS)	UID (12BITS)	010	000	DATA (VARIABLE LENGTH)

FIG. 10D FORMAT FOR ETHENET PACKET

SYSTEM AND METHOD FOR TRANSMITTING DATA

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates generally to the field of telecommunications and, in particular, to a system and method for transmitting data.

BACKGROUND OF THE INVENTION

[0002] Consumers have an insatiable appetite for information and entertainment, colloquially referred to as "content." This can be seen in the popularity of television, the internet and other content based media that are delivered to subscribers or users over various "pipelines." A pipeline is a system that transmits data from a content provider, e.g., television station, website on the internet, etc., to a subscriber. For example, internet service providers such as AmericaOn Line use the telephony system as a pipeline to transmit information to its subscribers. The subscribers use a computer modem to dial-in to an internet service provider. Once on-line, the subscribers have access to various content providers (websites) and can download or upload information. Unfortunately, this is often a slow and cumbersome technique for conveying large quantities of data because the telephony system has transmission speed and bandwidth limitations. Certain subscribers have installed specialized high-speed telephonic connections, but the practice is not widespread because of the prohibitive costs.

[0003] Similarly, various conventional pipelines deliver video information from content providers with varying degrees of success. Conventionally, television stations use a wireless pipeline for delivering content to users. The television stations simply broadcast signals in a dedicated portion of the electromagnetic spectrum. Users access the signals with roof-top antennas. Cable systems are also used in many areas. These systems use coaxial cable to deliver video with increased quality and quantity directly to a user's home or premises. However, conventional cable systems do not allow for interactive feedback to the content providers over the cable system. Retrofitting the existing cable systems with this feature will be expensive and time consuming.

[0004] In recent years, the industry has developed another broadcast based pipeline for delivering video data to end users. This system is commonly referred to as "wireless cable." Wireless cable transmits microwave signals to subscribers from a central transmitter. The subscribers receive the signals with a microwave antenna that is placed on the roof-top of the subscriber's premises and aimed at the central transmitter.

[0005] A main drawback to the wireless cable systems is that there is a limited frequency spectrum that is available. Further, consumers desire to have access to interactive services over this pipeline. Some wireless cable systems have dabbled with providing two-way communication over their wireless cable systems. However, developers are left with the task of increasing the capacity of this pipeline by more efficiently using the limited spectrum that is available.

[0006] For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for a transmission system that efficiently uses the assigned spectrum and allows for bidirectional communication.

SUMMARY OF THE INVENTION

[0007] The above mentioned problems with transmission system and other problems are addressed by the present invention and which will be understood by reading and studying the following specification. A transmission system is described which provides a more efficient use of assigned spectrum while allowing bi-directional communication.

[0008] In particular, an illustrative embodiment of the present invention provides a transmission system that communicates data to a number of subscribers. The transmission system includes a transceiver that has a number of highly directional antennas. A number of digital repeaters are disposed in a geographic region serviced by the transceiver. The repeaters include a sectorized antenna that communicates with subscribers in a number of sectors of the geographic region of the repeater. The repeater also includes an upstream demodulator/modulator circuit. The upstream demodulator/modulator circuit demodulates data from signals from subscribers that were modulated with a first modulation technique, and generates a re-modulated signal with the data using a second modulation technique. The second modulation technique is different from the first modulation technique such that the signals from the subscribers from the number of sectors are combined in the re-modulated signal so as to increase the capacity of the transmission system. The digital repeaters also include a highly directional antenna, that is coupled to the demodulator/modulator circuit and that communicates the re-modulated signal to the transceiver.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] **FIG. 1** is a representational diagram of an illustrative embodiment of a transmission system according to the teachings of the present invention;

[0010] **FIG. 2** is a block diagram that illustrates an embodiment of an upstream communication portion of an rf repeater for use in the transmission system of **FIG. 1**;

[0011] **FIG. 3** is a spectral diagram that illustrates a portion of the electromagnetic spectrum that embodiments of the present invention may use for upstream and downstream transmissions;

[0012] **FIGS. 4A and 4B** are schematic diagrams of exemplary spatial distributions of a number of digital repeaters in embodiments of the transmission system of **FIG. 1** that form various cellular layouts;

[0013] **FIGS. 5A through 5F** are timing diagrams that illustrate embodiments of data transmission in a transmission system;

[0014] **FIG. 6** is a diagram that illustrates an embodiment of the frame format of downstream data packets;

[0015] **FIG. 7** is a diagram that illustrates an embodiment of the format of upstream data frames;

[0016] **FIGS. 8A through 8E** are timing diagrams that illustrate an embodiment of a collision detection method in upstream communications;

[0017] **FIG. 9** is a diagram that illustrates an embodiment of downstream acknowledgment frames; and

[0018] **FIGS. 10A through 10D** are diagrams that illustrate embodiments of a command format for control frames for downstream communications in a transmission system according to the teachings of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0019] In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, mechanical and electrical changes may be made without departing from the spirit and scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

[0020] **FIG. 1** is a representational diagram of an illustrative embodiment of a transmission system, indicated generally at **10**, according to the teachings of the present invention. Transmission system **10** provides for bi-directional transmission of data between central hub **12** and a number of subscribers. Central hub **12** is also referred to as a transceiver due to the bidirectional nature of its operation. Transmission system **10** may include a number of central hubs **12**. In **FIG. 1**, subscribers **14***a* and **14***b* are shown for sake of clarity and illustration only. It will become clear from this specification, that transmission system **10** is designed to operate with a much larger number of subscribers on the order of 10,000 to 200,000 subscribers per central hub **12**. Thus the subscribers of system **10** are generically referred to as "subscribers **14**."

[0021] Transmission system **10** can transmit audio, video, or other data for use by a computer, a television, a telephone or other appropriate terminal of subscribers **14**. Transmission system **10** provides a pipeline between communication service providers **18** and subscribers **14**. Communication service providers **18** may, for example, provide services such as video, interactive video, internet connection, telephony or access to other content based services. Transmission system **10** includes head end **17** coupled between communication service providers **18** and central hub **12**. Head end **17** can communicate with communication service providers **18** and central hub **12** over any appropriate communication link such as wireless, including satellite and microwave or wired communication link as shown in **FIG. 1**. Transmission system **10** further includes a number of digital repeaters, represented here by digital repeaters **16***a* through **16***c*. It is understood that transmission system **10** includes an appropriate number of digital repeaters referred to collectively as "digital repeaters **16**."

[0022] Digital repeaters **16** are spatially distributed in a geographic region to form a cellular-type layout. Use of a cellular approach allows frequency re-use to increase the spectrum efficiency of transmission system **10**. Subscribers **14** that communicate through different digital repeaters **16** can use the same frequency at the same time. Exemplary embodiments of cellular layouts are described below with respect to **FIGS. 4A and 4B**.

[0023] In the embodiment of **FIG. 1**, transmission system **10** transmits digital data using the portions of the frequency spectrum currently licensed in the United States for analog multichannel multipoint distribution systems (MMDS), multipoint distribution systems (MDS) and instructional television fixed services (ITFS), as shown in **FIG. 3**. Specifically, transmission system **10** uses the two MDS channels for upstream communication and the 31 MMDS and ITFS channels for down stream communication. These channels are specified as standard 6 MHz video channels as used in conventional analog video transmission. The two upstream channels occupy the spectrum between 2.15 and 2.16 GHz and the 31 downstream channels occupy the spectrum between 2.5 and 2.69 GHz. In one embodiment, five of the 31 downstream channels are reserved for data transmission such as for connection to the internet and the remaining twenty-six channels are reserved for video transmission such as commercial or pay television channels.

[0024] Transmission system **10** uses packets of digital data to increase the number of effective channels of the system. Specifically, transmission system **10** uses MPEG compression so as to transmit as many as 6 video channels in one 6 MHz channel. Similarly, transmission system **10** transmits multiple data channels in a single 6 MHz channel.

[0025] For upstream communication, transmission system **10** uses highly directional transmission between subscriber **14** and digital repeater **16** and between digital repeater **16** and central hub **12**. Advantageously, this allows transmission system **10** to more efficiently use the available electromagnetic spectrum by using the same two MDS 6 MHz transmission channels for transmissions between subscribers **14** and digital repeaters **16** and between digital repeaters **16** and central hub **12**.

[0026] Each subscriber **14** includes cardioid antenna **20** that is directed at an assigned digital repeater **16**. Cardioid antenna **20** is disposed at an elevation sufficient to allow line-of-sight transmission to repeater **16**. Typically, cardioid antenna **20** is disposed between 2 and 10 feet above roof **22** of subscriber **14**.

[0027] Further, digital repeater **16** includes antenna **24** and cardioid antenna **26**. Antenna **24** may, for example, be a sectorized antenna to divide a cell into as many as six sectors. For example, **FIG. 4A** is a schematic diagram that shows a cellular layout wherein the cell boundaries are designated by a double line and sector boundaries within a cell are designated by a single line. It is understood that this is an idealized hexagonal cellular layout and that in practice the cells will overlap and have irregular shapes due to the terrain and other factors known to those skilled in the art. Other cellular and sectorization schemes may be used substituted as known to a person of ordinary skill in the art. Each sector is assigned to one of the two MDS 6 MHz channels such that adjacent sectors use different upstream channels. As shown in **FIG. 4**A, for example, the sectors labeled "A" use channel MDS **1** to communicate with digital repeaters **216** and the sectors labeled "B" use channel MDS **2**. This produces a three-times frequency re-use and further reduces the risk of interference being introduced into the transmissions from subscribers **14**. To further isolate adjacent sectors and reduce potential interference, alternating

sectors could use different polarization. For example, the sectors could alternate between left and right circular polarization, horizontal and vertical polarization or other appropriate polarizations.

[0028] Cardioid antenna **26** is disposed so as to direct transmissions at central hub **12**. Cardioid antenna **26** is disposed at an elevation approximately six feet or more above antenna **24** so as to reduce potential interference between transmissions from subscribers **14** and transmissions to central hub **12** since these transmissions can use the same MDS channels. Potential interference could further be reduced by varying the polarization of the transmissions to and from digital repeater **16**. For example, in one embodiment subscribers **14** transmit signals with left hand circular polarization and digital repeater **16** transmits signals to central hub **12** with right hand circular polarization, or vice versa. Alternatively, vertical and horizontal polarization could be used. Central hub **12** includes at least one cardioid antenna **28** for each digital repeater **16**. To further reduce the potential interference and improper signals being received by central hub **12**, digital repeaters **16** can be positioned such that subscribers **14** do not transmit toward central hub **12**. Such a layout is shown in **FIG. 4B** using 90 degree sectors. In this embodiment, arrows **140** are situated to indicate the digital repeater **316** used by subscribers in each cell to communicate with central hub **312**. This approach is equally applicable to sectorization techniques with other numbers of sectors. The key is to assign subscribers to a digital repeater such that the transmissions to the digital repeater are not aimed at the central hub.

[0029] For upstream communications, each MDS 6 MHz channel is divided into 48 narrowband transmission channels. The narrowband transmission channels have a bandwidth of 100 kHz and separation of 125 kHz. Subscribers **14** use quadrature phase shift keying (QPSK) modulation, for example, which accommodates two bits of data for each hertz of bandwidth. Thus subscribers **14** can transmit data at a rate of 200 kilobits per second (kbps). It is noted that transmission system **10** can further increase the number of available channels by using a 1 to 4 time division multiplexing technique to allow four users to share one 100 kHz channel.

[0030] QPSK modulation allows effective communication at low power. In transmission system **10**, subscribers **14** typically will transmit at low power due to financial constraints on transmission equipment for subscriber **14**. Further, the limited elevation of cardioid antenna **20** results in attenuation of power in signals from subscriber **14** due to ground effects and other interference. Thus, QPSK is an acceptable modulation technique for this low power transmission. Other modulation techniques which provide for robust transmission at low power levels could similarly be used.

[0031] Since each MDS 6 MHz channel is used by three sectors in this embodiment, transmission system **10** uses a different modulation technique to transmit between digital repeaters **16** and central hub **12**. This allows the same two MDS 6 MHz channels to be re-used and carry up to three times the information as the MDS channels carried between subscribers **14** and digital repeaters **16**. To accomplish this, digital repeaters demodulate the transmissions from subscribers **14** and use a quadrature amplitude modulation technique with 64 points in the constellation (QAM 64) to generate the signals to be transmitted to central hub **12**. QAM 64 accommodates six bits per hertz of bandwidth as opposed to the two bits for QPSK, thus this produces the needed three-fold increase in spectral efficiency. Further, each MDS 6 MHz channel is divided into 144 sub-channels of 33.3 kHz with 41.7 kHz of separation for transmissions from digital repeater **16** to central hub **12**. Transmissions from digital repeater **16** to central hub **12** are not as susceptible to ground effect attenuation or other forms of interference. Thus, a less robust modulation technique such as QAM 64 can be used. It is understood that other modulation techniques that provide for the re-use of frequencies in the different sectors can be used in place of QAM 64.

[0032] In operation, transmission system **10** transmits upstream communications from subscribers **14** to communication service provider **18** through central hub **12**. For example, subscriber **14***a* modulates a carrier with data using a QPSK modulation technique. Subscriber **14***a* transmits this signal with cardioid antenna **20**. Digital repeater **16***a* receives signals from subscribers including subscriber **14***a* with antenna **24**. Digital repeater **16***a* demodulates the signals from the subscribers and re-modulates the signals using QAM 64 modulation. Digital repeater **16***a* transmits the re-modulated signals to central hub **12**. Central hub **12** transmits the signals to communication service provider **18** through head end **17**. Similarly, transmission system **10** also transmits data downstream to subscribers **14**. To accomplish this, transmission system **10** can use the same antennas or can include a separate set of antennas for downstream transmission.

[0033] **FIG. 2** is a block diagram of an embodiment of the upstream communication of a digital repeater, indicated generally at **116**, and constructed according to the teachings of the present invention. It is understood that digital repeater **116** includes appropriate circuitry for transmitting downstream data to subscribers **14**. Digital repeater **116** includes sector antennas **126***a* through **126***f* that are coupled to receivers **130***a* through **130***f*, respectively. Receivers **130***a*, **130***c*, and **130***e* are tuned to the first MDS 6 MHz channel. Further, receivers **130***b*, **130***d*, and **130***f* are tuned to the second MDS 6 MHz channel. Receivers **130***a* through **130***f* are coupled to QPSK demodulators **132***a* through **132***f*, respectively. Further, QPSK demodulators **132***a* through **132***f* are coupled to QAM64 modulators **134***a* through **134***f*. The output of each QAM64 modulator is coupled to IF mixer **136**. The output of IF mixer **136** is coupled through broadband transmitter **138** to cardioid antenna **126**.

[0034] In operation, digital repeater **116** receives signals from subscribers **14** and changes the modulation of the signals so as to efficiently use the electromagnetic spectrum reserved for upstream communications. For example, subscriber in sector **1** transmit signals that are received at antenna **124***a* and receiver **130***a*. The output of receiver **130***a* is supplied to QPSK demodulator **132***a* as a 6 MHz band of signals. QPSK demodulator **132***a* demodulates the signals from the subscribers in sector **1** to produce 48 digital channels of 200 kbps each. QAM64 modulator **134***a* generates a signal with a 2 MHz bandwidth from the output of QPSK demodulator **132***a* using QAM 64 modulation of the 48 digital channels. IF mixer **136** combines the signal from QAM64 modulator **134***a* with similar signals from QAM modulators **134***b* through **134***f* to produce a signal with a 12

MHz bandwidth. Broadband transmitter **138** upconverts, amplifies, filters and transmits the signal to central hub **12** with cardioid antenna **126**.

[**0035**] In one embodiment, transmission system **10** of **FIG. 1** is controlled by a media access control (MAC) protocol. The MAC protocol supports video-on-demand services, data services, and control functions. The MAC protocol is an asymmetric protocol which uses fixed size MPEG 13818-1 transport stream transport packets for downstream transmissions and short, fixed size slots for upstream transmission. The protocol is consistent with DAVIC Technical Specifications 1.2 for MMDS by using transport packets for downstream. DAVIC presently leaves the upstream undefined ("reserved"). The MAC protocol of this embodiment is described in conjunction with **FIGS. 5A through 10**.

[**0036**] The downstream protocol is based on a single high speed (27 Mbps) channel which contains data packets for many users and provides reliable packet delivery using automatic repeat request (ARQ). The downstream link protocol used is based on the GoBackN protocol with N set to 4 (i.e., 2 bits). The upstream protocol is a slotted collision detect protocol distributed over many low speed (200 Kbps) channels with explicit acknowledgment of packets. Again, the ARQ protocol used is GoBackN, with N set to 64 (i.e., 6 bits). The upstream bandwidth is also managed by a bandwidth reservation system controlled by headend **17**. This system permits headend **17** to reserve upstream slots for particular subscriber **14** and is used to improved protocol efficiency. The complete protocol is designed to be simple and flexible, yet efficient.

[**0037**] **FIGS. 5A through 5F** are timing diagrams that illustrate embodiments of data transmission in transmission system **10** of **FIG. 1**. A definite timing relationship is maintained between the downstream and upstream packets, e.g., 50:1 in this embodiment. Downstream packet sizes are 188 bytes at a data throughput rate of 27 Mbps. Upstream slots are 68 bytes with additional preamble and guards to maintain the correct ratio.

[**0038**] Downstream packet delivery is composed of two types of MPEG-2 transport packets, data transport packets and acknowledgment transport packets. Data transport packets are identified by a unique packet identification (PID) and acknowledgment transport packets are identified by a different unique PID. As illustrated in **FIGS. 5A** and **5B**, the downstream data stream is composed of a sequence of 50 data transport packets **200** followed by an acknowledgment transport packet **202**.

[**0039**] **FIG. 5A** illustrates the downstream packet sequence generated by headend **17**. Each slot in the downstream takes one downstream slot time (t_{DS}) to be transmitted. **FIG. 5B** shows a propagation delay (t_{PD}) from the transmission of the acknowledgment packet to the arrival of the first bit of the acknowledgment packet at subscriber **14**. **FIGS. 5C and 5D** illustrate that once the entire packet has been received, subscriber **14** uses the packet as a timing mark **204** and delays transmitting on the upstream for ranging adjustment (t_{RA}). **FIG. 5E** shows that if the subscriber has any data to transmit and the slot has not been reserved as described below, the subscriber may attempt to send an upstream packet **206**. **FIG. 5F** illustrates a propagation delay (t_{PD}) from the transmission of the first bit of the upstream packet to the arrival of the upstream packet at headend **17**. Because the upstream slot size is determined by a fixed ratio (e.g., 50:1), the time to transmit the upstream slot, i.e., upstream slot time (t_{US}) is defined by $50 \times t_{DS}$.

[**0040**] The ranging adjustment time (t_{RA}) is set for each subscriber **14** so that upstream slots from all subscribers arrive at headend **17** at the same time. This ensures that either a packet is received by headend **17** during the fixed slot time or one or more packets collide in a synchronized manner at headend **17**. In the case in which collision occurs, all packets are assumed to be lost. Packet collision is detected by a failure to recognize a packet and is aided by using a cyclic redundancy check (CRC).

[**0041**] **FIG. 6** is a diagram that illustrates the frame format of the downstream data packets **200**. The basic form of the packet is an MPEG 13818-1 transport packet of fixed size (e.g., 188 bytes) and contains a 4 byte header. In general, transport packet PIDs are used to indicate program content including video and audio streams. In order to prevent any conflict with video programming the PID field is used only in the most limited manner. Specifically, two PIDs are used, one to indicate "normal" downstream data and the other for downstream acknowledgment.

[**0042**] The MAC protocol includes two additional fields that immediately follow the transport header field and are as follows:

[**0043**] 1) The User Identification (UID) field is 12 bits. Each subscriber **14** is assigned a unique UID number for the channel in which it resides. The UID is used in all dialogues between headend **17** and the subscriber **14**. There will typically be a mapping between the UID and other subscriber identification numbers, e.g., Ethernet MAC address, IP address, or subscriber billing number. The UID has a context only between headend **17** and subscriber **14** and should be otherwise transparent. If a subscriber **14** is reassigned to a new channel (as may happen as system load increases) the subscriber **14** will receive a new UID.

[**0044**] 2) The Downstream Sequence Number (D-Seq) field is 6 bits. The D-Seq field is used to permit multiple unacknowledged frames to be maintained in a transmission buffer for the subscriber **14**. The protocol used with the D-Seq field is GoBackN.

[**0045**] **FIG. 7** is a diagram that illustrates the format of upstream data frames **206**. The frame length is defined to be some integer number of downstream packets and is synchronized to the downstream packet rate. For this embodiment the ratio is 50:1.

[**0046**] The fields in the upstream frame format are as follows:

[**0047**] 1) The guard field contains a variable number of bits that are used to provide space between slots.

[**0048**] 2) The preamble field contains 16 bits, 01010101 01111110, that are used to synchronize the incoming packet at headend **17**.

[**0049**] 3) The source UID is 12 bits that indicate the source user identification number.

[**0050**] 4) The reservation field is 3 bits that provide reservation information as described in more detail below.

[0051] 5) The Upstream Sequence Number (U-Seq) filed is 2 bits that permit multiple unacknowledged frames to be maintained in a transmission buffer of headend **17**. The protocol used with the U-Seq field is GoBackN.

[0052] 6) The priority field is 1 bit that indicates the message priority to headend **17**.

[0053] 7) The D-ACK field is a 6 bit acknowledgment field that is used by the MAC layer of headend **17** to identify when a downstream data packet is out of sequence. The protocol used (in conjunction with the D-SEQ field) is GoBackN.

[0054] 8) The data field is 64 bytes.

[0055] 9) The cyclic redundancy check (CRC) field is a 16 bit field that permits headend **17** to identify when an incoming packet is in error. In one embodiment CCITT-16 is used.

[0056] **FIGS. 8A through 8E** are timing diagrams that illustrate an embodiment of a collision detection method in upstream communications for the MAC protocol. This method provides an efficient mechanism for ensuring that subscribers **14** are aware when a collision has taken place. As described above, there is exactly one downstream acknowledgment packet in each upstream slot time. This packet is timed to be delivered somewhere in the middle of the upstream slot time (although this time reference will vary depending on the distance of the subscriber from headend **17**) and is used to provide a collision detection function for each of the upstream slot times. Thus by inspecting the downstream collision indication in the slot immediately following an upstream transmission, subscriber **14** is able to determine if an upstream packet was received by headend **17**.

[0057] **FIGS. 8B and 8C** show the use of a single acknowledge (ACK) and collision bit as they relate to two subscribers **14***a* and **14***b*, respectively, on the same channel. The ACK and collision bits form part of the downstream acknowledge packet. This packet includes bits for all channels as discussed below. The ratio between up and downstream slots is only 4 for illustrative purposes.

[0058] **FIGS. 8D and 8E** show transmissions from subscribers **14***a* and **14***b*, respectively. **FIG. 8A** shows the result at headend **17**. **FIGS. 8B and 8C** show headend **17** transmission with embedded acknowledgments and collision notifiers.

[0059] Upstream slot **0** shows neither subscriber using the channel. Upstream slot **1** shows subscriber **14***a* sending a frame (i.e., frame **0,0**). Upstream slot **2** shows subscriber **14***b* sending a frame (i.e., frame **1,0**) and subscriber **14***a* receiving an ACK indicating frame **0,0** was received by headend **17** without collision. Upstream slot **3** shows neither station using the channel, however, subscriber **14***b* receives an ACK for frame **1,0**. Upstream slot **4** shows both subscribers **14***a* and **14***b* attempting to send data. A collision occurs and both stations are made immediately aware of the situation via the downstream collision indication bit. Upstream slot **5** shows subscriber **14***a* sending a frame. Upstream slot **6** shows subscribers **14***a* and **14***b* attempting to send another frame. A collision occurs which both stations are made immediately aware of. In addition, subscriber **14***a* receives an ACK indicating frame **0,1** was received correctly.

[0060] **FIG. 9** is a diagram that illustrates an embodiment of a downstream acknowledgment frame, indicated generally at **202***a*, for the MAC protocol. The acknowledgment frame **202** is identified by a PID in the transport packet header, e.g., PID=2. The frame is divided into two parts, a "MAC Info" part and a "Control Info" part.

[0061] The MAC Info part of the frame is used for MAC protocol collision and acknowledgment for each of the downstream channels under control by headend **17** as described above. Thus, each upstream channel is mapped into a particular pair of bytes in the MAC Info part. The first pair of bytes corresponds to channel **0**, the second pair to channel **1**, and so on. The two-byte Mac Info for each channel contains the following fields:

[0062] 1. The Reservation UID field is 12 bits. The reservation UID is used by the downstream to indicate which UID is permitted to use the next upstream slot on that channel. Details of the reservation mechanism are discussed below.

[0063] 2. The Collision Indicator field is 1 bit. This bit indicates when a collision has occurred.

[0064] 3. The User Acknowledgment (U-ACK) field is 2 bits. The U-ACK field is used by the subscriber MAC layer to identify when an upstream data is out of sequence. The protocol used (in conjunction with the U-SEQ field) is GoBackN. This field is similar to the ACK field as described above.

[0065] 4. The Reserved field is 1 bit.

[0066] **FIGS. 10A through 10D** are diagrams that illustrate embodiments of a command format for control frames for downstream communications in a transmission system according to the teachings of the present invention. Specifically, **FIGS. 10A through 10D** illustrate various embodiments of the Control Info part of transport packets **202***a* of **FIG. 9**. The Control Info part is used for downstream control information (e.g., for system configuration, ranging, power control, and conditional access keys) and as a downstream for the Video On Demand (VOD) control services. However, the channel may also be used for downstream data services.

[0067] In **FIGS. 10A through 10D** the following fields are common:

[0068] 1. The Channel field is 6 bits. The field indicates the channel to which this downstream control packet refers. Each Subscriber Unit is in one and only one channel, thus, if the Channel number and UID match, the packet is destined for this subscriber unit.

[0069] 2. The User Identification (UID) field is 12 bits.

[0070] 3. The Format Type field is 3 bits. A number of different frame formats are supported. The particular format to be decoded is identified by this field.

[0071] 4. The Reserved field is 3 bits. The field indicates that the packet is reserved for future use.

[0072] In this embodiment, three acceptable formats are initially defined for the Format Type field. Format **000** is used for downstream ranging, power control, and UID assignment as shown in **FIG. 10B**. Format **001** is used for downstream conditional access key download as shown in **FIG. 10C**. The conditional access key is transmitted with the packet and is used to enable the subscriber to receive a particular video channel (as identified by the transport PIDs). Format **010** is used to convey downstream Ethernet packets as shown in **FIG. 10D**. This can also be used for VOD services which require general data transfer capabilities. It is envisaged that the subscriber unit will have an Ethernet aware protocol stack for this environment. Other frame formats may be defined as required.

[0073] The reservation protocol used by the MAC protocol is extremely flexible and designed to permit maximum control of the bandwidth by headend **17**. Thus, the subscriber unit is kept as simple as possible.

[0074] Referring again to **FIG. 9, a** Reservation UID is identified for each downstream channel. In each channel, this Reservation UID is used by headend **17** to indicate which subscriber **14** can transmit in the following upstream time slot. The protocol works as follows: Each time a subscriber **14** sends an upstream frame, it includes a three bit field to indicate the number of additional frames the unit still needs to transmit (0=0 frames, 7=7+ frames).

[0075] If the frame from subscriber **14** is received (via the U-ACK), subscriber **14** must then wait to be allocated a slot by headend **17**, even if the channel is idle. Headend **17** maintains an estimate of the number of frames buffered by each subscriber **14** and uses this information to increase the upstream bandwidth utilization. Headend **17** may also track subscriber upstream data usage and demands, and constrain subscriber transmissions for appropriate sharing of the channel.

[0076] The scheduling policy for headend **17** is based on an assumption that the underlying traffic model is characterized by data bursts generated through either Near Video On Demand (NVOD) commands or web browsing traffic. In the event that the traffic characteristics changed, it is entirely possible to implement a new scheduling policy at headend **17** with no modification to subscribers **14**.

[0077] The current embodiment attempts to accommodate the transmission of a typical data burst from a subscriber unit. Assuming that the typical burst length is B slots, a logical construct called a macro-slot, which is an integer multiple of B, is used for scheduling. The upstream is considered a sequence of macro-slots. Each macro-slot is divided into two portions, a sequence of reservation slots and a sequence of contention slots. Subscribers **14** participating in the reservation process burst data during the reservation slots in a round robin fashion. The round robin algorithm is used to ensure fairness. At the end of each macro-slot headend **17** is responsible for using statistics obtained from the previous macro-slot (e.g., number of collisions, ratio of reserved slots to contention slots and number of successfully transmitted packets in the contention period) to determine the ratio of the next macro-slot. The algorithm used to compute the ratio presently increases the number of contention slots when the number of collisions is too high and decreases the number of contention slots when the number of collisions is too low. This approach increases the channel throughput.

[0078] In addition to scheduling there is a requirement to impose rate control on the traffic. The recommended algorithm for headend **17** is based on restricting the upstream (downstream) flow to subscriber units based on the leaky bucket traffic model and is outlined as follows:

[0079] 1. Headend **17** maintains a bucket for each subscriber which corresponds to an average data rate as determined by simulation studies. At present this is expected to be 20 Kbps (384 Kbps) and is filled at this rate.

[0080] 2. Whenever an upstream packet is received, the bucket is drained at 200 Kbps (1 Mbps).

[0081] 3. If the bucket is not empty and the reservation bits indicate the subscriber has more data to transfer.

[0082] The above two algorithms are used to demonstrate how headend **17** may define the upstream and downstream protocols. The actual protocol to be used can be varied based on various system constraints.

[0083] In the event that it was deemed necessary to support a signaling plane between headend **17** and subscriber **14** for multiple services classes (e.g., isochronous services, etc.) there are at least two approaches possible:

[0084] 1. A separate UID could be assigned to each subscriber **14** which is dedicated to signaling.

[0085] 2. A single bit in the upstream packet could be used to distinguish user data from control data. A bit that is presently unused and could be used for this function is the priority bit.

[0086] By including this feature it would be possible to support a variety of provisioned services such as those defined in Asynchronous Transfer Mode (ATM) by appropriate modification of the upstream and downstream scheduling policies used in headend **17**. Such changes could be made transparent to previously deployed subscribers **14**.

[0087] Although the protocol is the same for both Video On Demand and Data it exhibits different characteristics as indicated below. In particular, it is expected that particular channels will be designated as upstream (downstream) data channels and others as upstream (downstream) Near Video on Demand channels (NVOD). Thus a subscriber unit will be assigned to one or the other but cannot be both (however, the flexibility of the protocol does not preclude accessing data from a NVOD channel or Videos from a data channel).

[0088] For data services, bandwidth allocation will typically be one downstream channel and 32 upstream channels. Most of the downstream Transport Packets will have PID either 1 or 2 and all subscribers **14** will be tuned to the same downstream channel (the system is scalable in the sense that the entire concept may be replicated on multiple downstream/upstream channel sets). The ACK packet (PID=2) must be transmitted every 50 transport packets in order for the upstream protocol to operate properly. Since the upstream bandwidth is significant, it is expected that many upstream channels will be assigned to data services and thus the number of channels represented in the downstream MAC Info field will be large (perhaps 32) leaving little room for the Control Info field.

[0089] For VOD services, each downstream channel will be composed mainly of Video and Audio Transport Packets, however, the ACK packet (PID=2) is always required. As before, the ACK packet (PID=2) must be transmitted once for every 50 transport packets in order for the upstream protocol to operate properly. In general, the ACK packet will be used to provide the MAC functions and limited control functions required for VOD services. With this in mind, it is likely that only a few upstream channels will be assigned to VOD services and these will be used to accommodate a large number of simultaneous users. Typically the number of channels represented in the downstream MAC Info field will be small (perhaps only 4) leaving correspondingly more space for the Control Information. This space may be used to transmit general purpose Ethernet packets downstream if required. The downstream data rate is limited to about 380 Kbps in this case unless additional data transport packets are sent.

[0090] Associated with the protocol will be a number of time-outs. These are used to improve the efficiency of the protocol but do not contribute to the basic protocol correctness. The essential time-outs required are as follows:

[0091] 1. Upstream retransmission timer for each subscriber **14** is set whenever an upstream packet is sent by the subscriber. If there is no acknowledgment by headend **17** within some time limit the subscriber will retransmit the packet.

[0092] 2. Upstream ack timer for each subscriber is set whenever a downstream packet is received by the subscriber unit. If no upstream data is received from the subscriber unit within some time limit the subscriber unit will send an acknowledgment packet (i.e., repeat the last upstream packet with the correct D-ACK field set).

[0093] 3. Headend **17** unit downstream retransmission timer is set whenever a downstream packet is sent by headend **17**. If there is no acknowledgment by the within some time limit, headend **17** unit will retransmit the packet.

[0094] Other timers may be required to implement non-essential components of the protocol, e.g., support for the priority scheme. These are not described here.

[0095] The protocol also provides a limited facility for expedited data upstream. The priority field in the upstream packet is used by the subscriber to indicate to headend **17** that the data in the packet should be expedited. This information may be used or ignored by headend **17** depending on the upstream algorithm implemented in headend **17**.

Conclusion

[0096] Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. For example, the specific cellular layout can be varied from the four and six sector layouts shown in the Figures. Further, it is contemplated that other modulation techniques can be used in place of the QPSK and QAM 64 techniques so long as they provide adequate frequency re-use among the sectors in the upstream direction. Further, other types of antennas may be used that provide highly directional communication between the central hub and the digital repeaters and between the digital repeaters and the subscribers.

What is claimed is:

1. A transmission system that communicates data to a number of subscribers, the transmission system comprising:

a transceiver that has a number of highly directional antennas;

a plurality of digital repeaters disposed in a geographic region serviced by the transceiver, the repeaters including:

a number of antennas, each disposed to communicate with subscribers in a sector of the geographic region of the repeater;

an upstream modulation circuit that demodulates data from carrier signals from subscribers that were modulated with a first modulation technique, and generates a re-modulated signal with the data using a second modulation technique, different from the first modulation technique such that the signals from the subscribers from the number of sectors are combined in the re-modulated signal so as to increase the capacity of the transmission system; and

a highly directional antenna, coupled to the upstream modulation circuit, that communicates the re-modulated signal to the transceiver.

2. The transmission system of claim 1, wherein the upstream modulation circuit demodulates data from signals that were modulated with quadrature phase shift keying.

3. The transmission system of claim 2, wherein the upstream modulation circuit generates the re-modulated signal using quadrature amplitude modulation.

4. The transmission system of claim 3, wherein the upstream modulation circuit generates the re-modulated signal using quadrature amplitude modulation with a 64 point constellation.

5. The transmission system of claim 1, wherein the highly directional antenna of the transceiver and the highly directional antenna of the repeaters comprise cardioid antennas.

10. A method for upstream communication between a subscriber and a communication service provider over a transmission system, comprising the steps of:

receiving signals with a number of sectorized repeaters from subscribers, the signals being modulated with data using a first modulation technique;

demodulating the data from the signals;

generating a re-modulated signal with the data from the subscribers using a second modulation technique that is different from the first modulation technique so as to increase the capacity of the transmission system;

communicating the re-modulated signal to a transceiver of the transmission system.

11. A transmission system comprising:

a head end; and

a number of digital repeaters disposed in a geographic region to communicate signals between the head end and a number of subscribers;

wherein the digital repeaters include a modulation circuit that uses a first modulation technique to communicate with the head end and a second, different modulation technique to communicate with the subsrcibers so as to increase the capacity of the transmission system.

12. The transmission system of claim 11, wherein each digital repeaters comprises a sectorized antenna that divides the geographic region into three sectors.

13. The transmission system of claim 11, wherein the head end includes a number of highly directional antenna for communicating with the digital repeaters.

14. The transmission system of claim 11, wherein the first modulation technique comprises quadrature phase shift keying.

15. The transmission system of claim 14, wherein the second modulation technique comprises quadrature amplitude modulation with a 64 point constellation.

16. A digital repeater for a transmission system, the digital repeater comprising:

a sectorized antenna that receives upstream signals generated by subscribers using a first modulation technique;

an upstream modulation circuit that converts the upstream signals to increase the spectral efficiency of the upstream signals using a second, different modulation technique; and

a highly directional transmitter, coupled to the upstream modulation circuit, that transmits the converted upstream signals to a head end of the transmission system.

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