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Shraga et al.

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(54) **OPTICAL NETWORK COMMUNICATION SYSTEM**

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(52) **U.S. Cl.** **370/458**; 370/468
(58) **Field of Search** 370/294, 432, 370/442, 458, 459, 468, 470, 471, 473, 474, 498, 521

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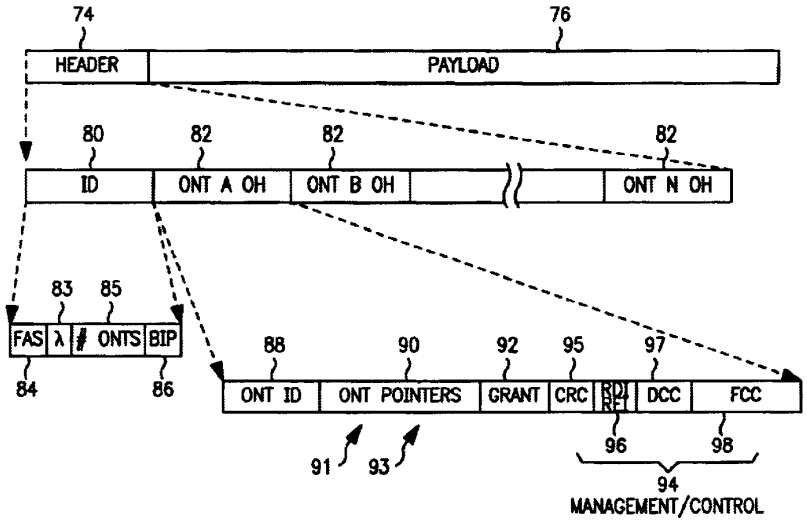
(57) **ABSTRACT**

A method for communication from a central point to end points by time division multiplexing of a sequence of frames divided into multiple timeslots, including receiving at the central point data for transmission to the end points, the data including at least a first quantity of first data for transmission to a first end point and a second quantity of second data for transmission to a second end point. The method further includes allocating in each of the frames a first number of timeslots to carry the first data to the first end point, and a second number of timeslots to carry the second data to the second end point, such that the first and second numbers are variable responsive to variations in the first and second quantities of the data, and transmitting the data from the central point to the end points during the allocated timeslots.

35 Claims, 7 Drawing Sheets



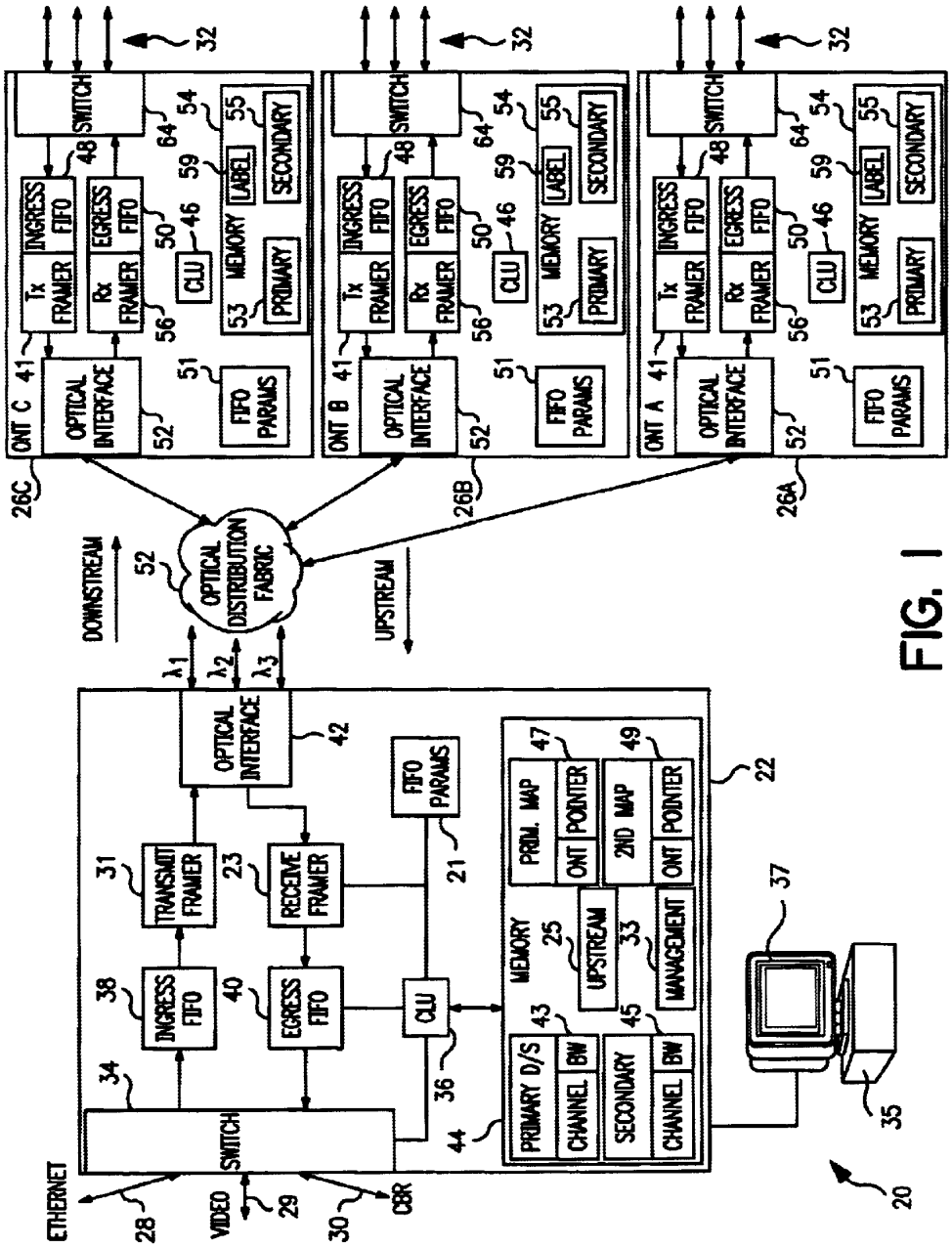

ONT C
ONT B
ONT A
OPTICAL INTERFACE
Tx FRAMER
Rx FRAMER
INGRESS FIFO
EGRESS FIFO
SWITCH
CLU
MEMORY
PRIMARY
LABEL
SECONDARY
FIFO PARAMS
OPTICAL DISTRIBUTION FABRIC
DOWNSTREAM
UPSTREAM
λ1
λ2
λ3
TRANSMIT FRAMER
RECEIVE FRAMER
PRIMARY D/S
CHANNEL
BW
PRIM. MAP
2ND MAP
POINTER
ONT
UPSTREAM
MANAGEMENT
ETHERNET
VIDEO
CBR

FIG. 1

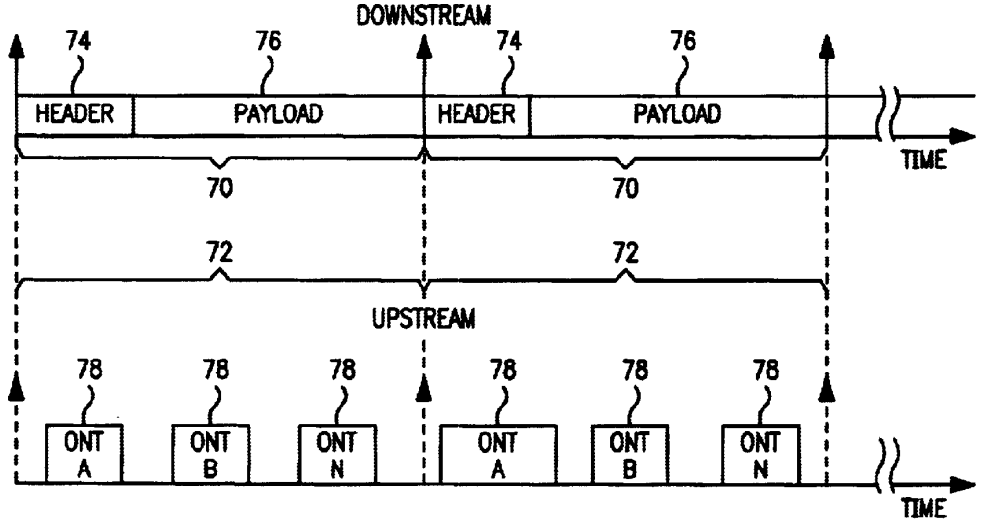

DOWNSTREAM
74
76
74
76
HEADER
PAYLOAD
HEADER
PAYLOAD
TIME
70
70
72
72
UPSTREAM
78
78
78
78
78
78
ONT A
ONT B
ONT N
ONT A
ONT B
ONT N
TIME

FIG. 2

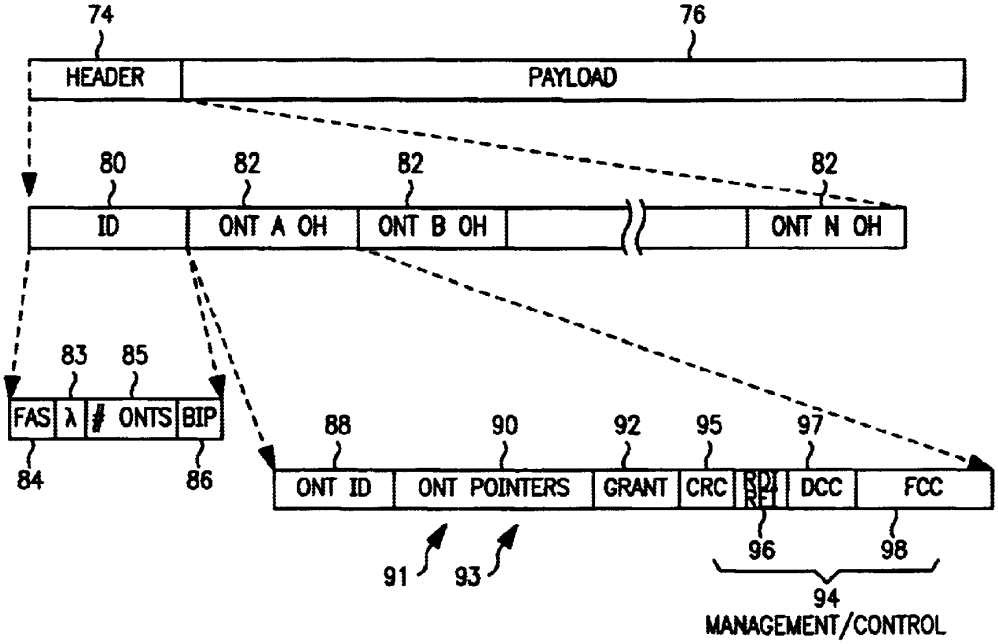

74
76
HEADER
PAYLOAD
80
82
82
82
ID
ONT A OH
ONT B OH
ONT N OH
83
85
FAS
λ
ONTS
BIP
84
86
88
90
92
95
97
ONT ID
ONT POINTERS
GRANT
CRC
RDI
REI
DCC
FCC
91
93
96
98
94
MANAGEMENT/CONTROL

FIG. 3

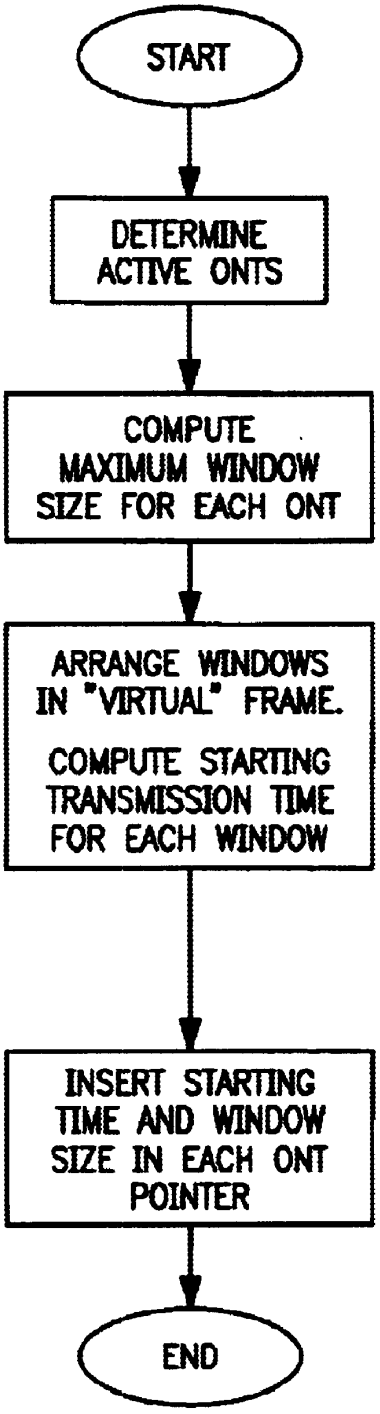

START
DETERMINE ACTIVE ONTS
COMPUTE MAXIMUM WINDOW SIZE FOR EACH ONT
ARRANGE WINDOWS IN "VIRTUAL" FRAME.
COMPUTE STARTING TRANSMISSION TIME FOR EACH WINDOW
INSERT STARTING TIME AND WINDOW SIZE IN EACH ONT POINTER
END

FIG. 4

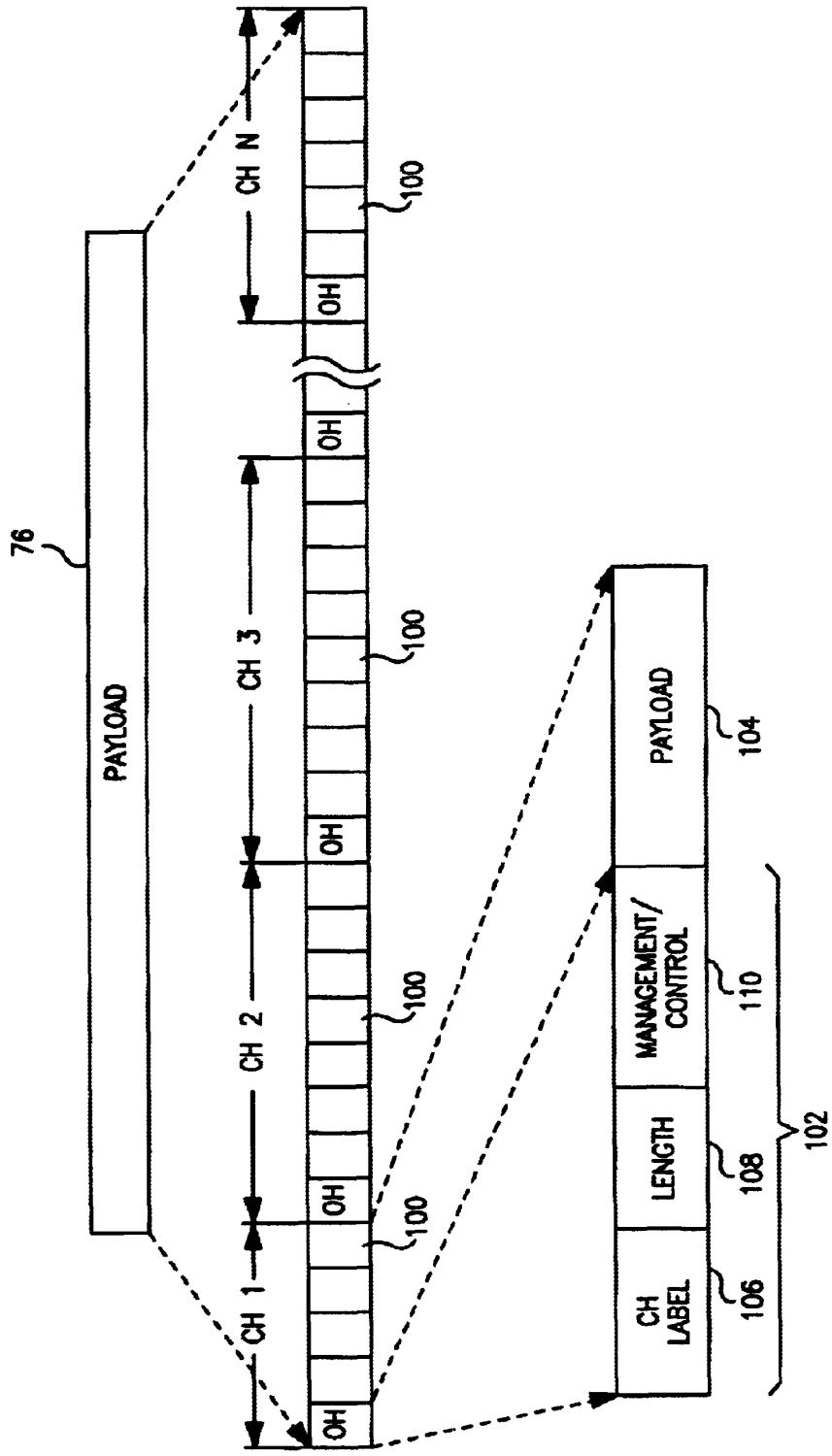

76
PAYLOAD
CH 1
CH 2
CH 3
CH N
OH
100
PAYLOAD
104
MANAGEMENT/
CONTROL
110
LENGTH
108
CH
LABEL
106
102

FIG. 5

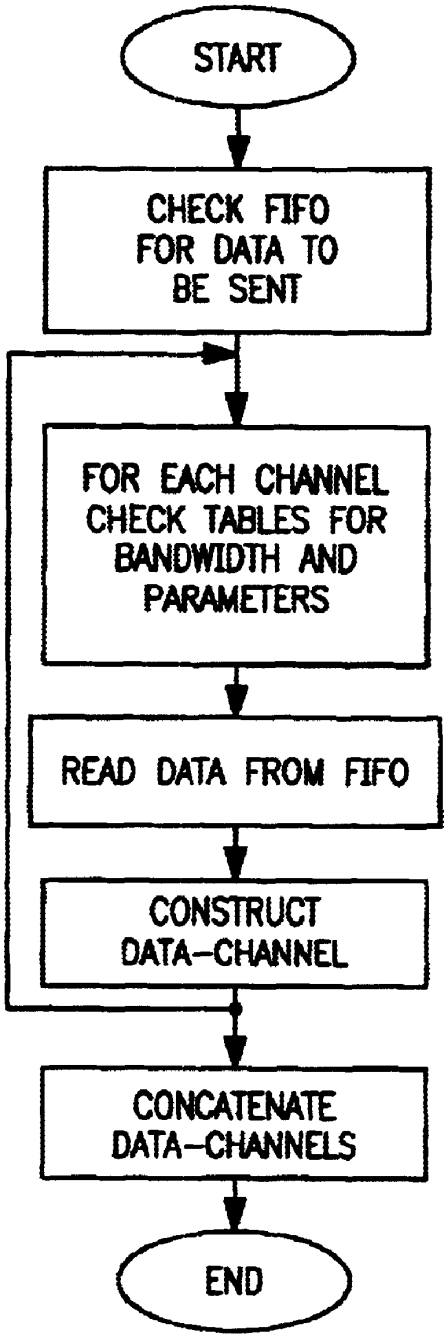

START
CHECK FIFO FOR DATA TO BE SENT
FOR EACH CHANNEL CHECK TABLES FOR BANDWIDTH AND PARAMETERS
READ DATA FROM FIFO
CONSTRUCT DATA-CHANNEL
CONCATENATE DATA-CHANNELS
END

FIG. 6

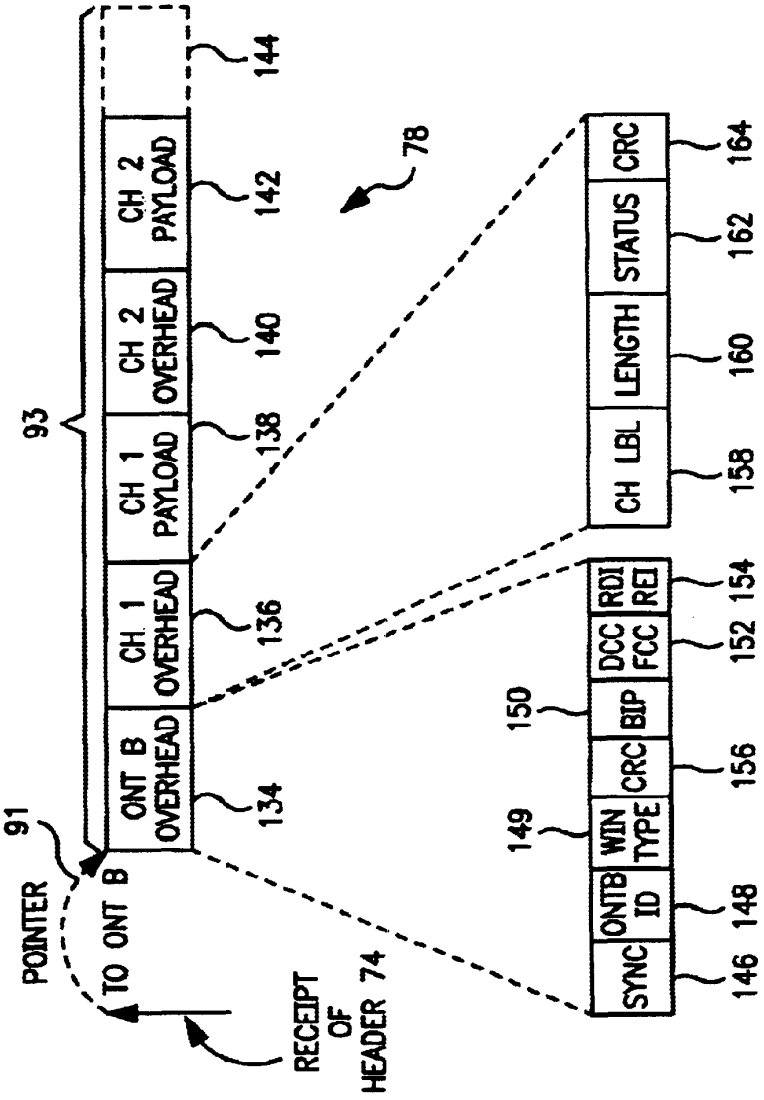

93
91
POINTER
TO ONT B
ONT B OVERHEAD
134
CH 1 OVERHEAD
136
CH 1 PAYLOAD
138
CH 2 OVERHEAD
140
CH 2 PAYLOAD
142
144
78
RECEIPT OF HEADER 74
SYNC
146
ONTB ID
148
149
WIN TYPE
CRC
156
150
BIP
DCC FCC
152
RDI REI
154
CH LBL
158
LENGTH
160
STATUS
162
CRC
164

FIG. 7

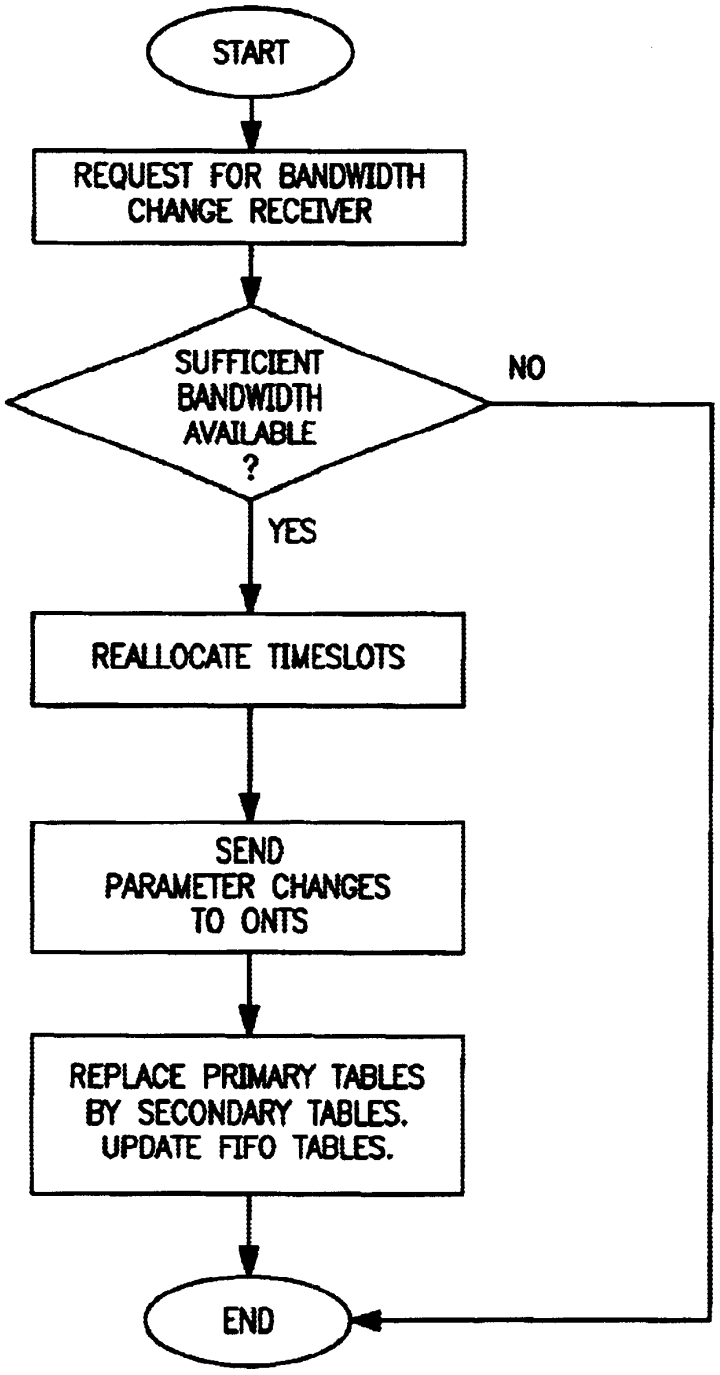

START
REQUEST FOR BANDWIDTH CHANGE RECEIVER
SUFFICIENT BANDWIDTH AVAILABLE ?
NO
YES
REALLOCATE TIMESLOTS
SEND PARAMETER CHANGES TO ONTS
REPLACE PRIMARY TABLES BY SECONDARY TABLES. UPDATE FIFO TABLES.
END

FIG. 8

OPTICAL NETWORK COMMUNICATION SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to information transfer in a communication network, and specifically to a protocol for transmission over a passive optical network.

BACKGROUND OF THE INVENTION

A point-to-multi-point passive optical network (PON) operates as a communication system by broadcasting optical signals downstream from a central unit, herein termed an optical line termination (OLT), to optical network terminations (ONTs). The signals are transferred from the OLT to the ONTs via fibre optic cables and passive optical splitters, which comprise the physical fabric of the network. For upstream communication, each ONT must be able to transmit signals which are not interfered with by other ONTs. One of the methods known in the art for performing such upstream and downstream transmissions is by using time domain multiple access (TDMA), wherein each ONT is allocated a window when only it can transmit, and where the OLT also has windows for transmission to specific ONTs. Other methods for avoiding interference include transmitting signals at different wavelengths, using wavelength domain multiple access (WDMA). Combinations of TDMA and WDMA are also known in the art.

U.S. Pat. No. 5,173,899 to Ballance, whose disclosure is incorporated herein by reference, describes a method for communication in a passive optical network. An OLT transmits downstream TDM frames, the frames including information, a synchronization signal, and grants (to transmit upstream) to downstream ONTs. The ONTs transmit upstream TDM signals responsive to the grants and the synchronization signal.

U.S. Pat. No. 5,355,368 to Dore et al., whose disclosure is incorporated herein by reference, describes a method for allocating timeslots in a TDMA point-to-multi-point network. The network operates in a half-duplex manner, i.e., terminals of the network alternate between sending and receiving. The method reduces the "dead" time needed between adjacent downstream timeslots of an OLT, the dead time being the round-trip time of transmission between the OLT and an ONT in the network. The reduction is implemented by giving a first ONT an authorization to send while it is receiving information addressed to a second ONT.

U.S. Pat. No. 5,515,379 to Crisler et al., whose disclosure is incorporated herein by reference, describes a system for timeslot allocation within a communication system. A communication unit transmits a first packet of data requesting permission to transmit to a timeslot allocator. The packet contains either a request for allocation of a number of timeslots, or a request to transmit multiple packets of data. In either case, the allocator allocates contiguous time slots to the unit which the unit uses for transmission of its packets.

U.S. Pat. No. 5,528,592 to Schibler et al., whose disclosure is incorporated herein by reference, describes a method for route processing asynchronous transfer mode (ATM) cells. (A packet is comprised of a plurality of ATM cells.) The method consists of receiving, in a route cell buffer, cells corresponding to the beginning and end of a packet. A router determines routing information for the packet from these cells. The information includes a routing label determining an output port for the packet, and an identifier that determines switching paths connecting a packet source to a destination of the packet.

U.S. Pat. No. 5,838,687 to Ramfelt, whose disclosure is incorporated herein by reference, describes a slot reuse method in a Dynamic Synchronous Transfer Mode (DTM) segmented network. Access to slots is controlled by slot tokens, and writing to a slot may only be performed by a controller owning the corresponding token for that slot. A block token is used to represent a group of tokens in a single control message. The method consists of extending the DTM block token format to include parameters describing segments between source and destination nodes. Block token capacity is reserved only on segments between the nodes, and enables simultaneous transmissions in the same slot over disjointed segments of the network.

U.S. Pat. No. 5,982,780 to Bohm et al., whose disclosure is incorporated herein by reference, describes centralized and distributed management of communication resources in a DTM network. In the centralized version a server node is assigned tokens corresponding to time slots for unidirectional data flow on a communications link. The server, if it has available capacity, reserves and transfers tokens to other nodes on the link, according to requests from those nodes. In the distributed version the function of the server is spread amongst two or more nodes connected to the link.

SUMMARY OF THE INVENTION

It is an object of some aspects of the present invention to provide a method for transmitting signals in a communications network.

It is a further object of some aspects of the present invention to provide a method for transmitting TDM signals in a passive optical network (PON).

In a preferred embodiment of the present invention, an optical line termination (OLT) transmits optical signals downstream to a plurality of optical network terminations (ONTs). The OLT is coupled via a passive optical distribution fabric to the ONTs, so forming a PON. The OLT acts as a controller of the downstream signals, and also of signals sent upstream by the ONTs and received by the OLT. The downstream signals are sent in the form of frames having a constant period, and each downstream frame comprises a number of "timeslots." Each timeslot is a fixed number of bytes, and within each frame the OLT allocates timeslots directed to each of the ONTs in a dynamic manner. Timeslot allocation for each frame is implemented according to quantities of data to be transmitted to/from each ONT, as determined by the OLT. Most preferably, the allocation of timeslots for each downstream frame is performed at substantially the same rate as the frames are transmitted. By allocating varying numbers of timeslots to each downstream frame or to an upstream window (explained below), the OLT effectively configures each frame or window in a variable TDM manner, with variable length times for each ONT which receives data.

Upstream signals are transmitted in a TDM manner from individual ONTs in windows, the windows being transmitted according to time pointers allocated by the OLT.

Both upstream and downstream signals comprise data transmitted according to one or more services, which may individually operate according to completely different protocols. Services typically include constant bit rate services and packet based services. Preferred embodiments of the present invention transfer data regardless of the type of service the data is transmitted under.

Upstream and downstream signals are transferred between the OLT and the ONTs via channels which are mapped as a one-to-one mapping from the services. The

channels and channel parameters, such as bandwidth, are allocated by an operator of the PON, either at initialization or during operation of the PON. Each channel uses timeslots which are allocated according to bandwidth requirements of the channel's service.

Data for a specific channel in a downstream frame may be distributed within the frame non-contiguously. Also, data for a specific channel in an upstream window may be distributed within the window non-contiguously. Enabling a specific channel in upstream windows and downstream frames to be arranged non-contiguously significantly enhances the flexibility and efficiency of transmission of these signals, compared to systems which do not allow non-contiguous transmission.

There is therefore provided, according to a preferred embodiment of the present invention, a method for downstream communication from a central transmission point to a plurality of receiving end points by time division multiplexing of a sequence of frames, each of which is divided into multiple timeslots, the method including:

receiving at the central transmission point data for transmission to the end points, the data including at least a first quantity of first data for transmission to a first end point among the plurality of the end points and a second quantity of second data for transmission to a second end point among the plurality of the end points, such that the first and second quantities are variable from each of the frames to the next in the sequence;

responsive to the first and second quantities, allocating in each of the frames a first number of the timeslots to carry the first data to the first end point, and a second number of the timeslots to carry the second data to the second end point, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data; and

transmitting the data from the central transmission point to the end points during the allocated timeslots.

Preferably, the central transmission point includes an optical line terminal (OLT), and the end points include optical network terminals (ONTs), wherein the OLT and ONTs are operative as transceivers in a passive optical network.

Preferably, the data includes sets of data which are conveyed via respective different industry-standard services.

Preferably, the plurality of end points includes sets of end points operative at different wavelength groups, and the data includes respective sets of data which are conveyed between the central transmission point and the respective sets of end points via the different wavelength groups.

Preferably, the data includes sets of data which are conveyed via respective different channels, wherein each channel transfers data via a service coupled to the central transmission point and at least one of the end points.

Further preferably, the method includes assigning each channel a respective bandwidth, wherein allocating the first and the second numbers of timeslots includes allocating the first and the second numbers of timeslots responsive to the bandwidth of each of the channels.

Preferably, assigning each channel the respective bandwidth includes changing the respective bandwidth to a different bandwidth responsive to a request received by the central transmission point.

Further preferably, the first and second numbers of timeslots are allocated responsive to respective first and second data parameters stored in a memory comprised in the central transmission point.

Preferably, a total of the first number and the second number of the timeslots is less than or equal to a bandwidth of each of the sequence of frames.

Further preferably, the data includes one or more further quantities of data for transmission to respective one or more further end points among the plurality of the end points, such that the one or more further quantities are variable from each of the frames to the next in the sequence, and including allocating respective one or more further numbers of timeslots to be carried respectively to the one or more further end points.

Preferably, a period of each of the sequence of frames is substantially constant.

Preferably, each of the sequence of frames includes a header including respective window parameters for each of the plurality of end points, each window parameter including a time and a size of a window of upstream data which each of the plurality of end points is permitted to transmit to the central transmission point.

Further preferably, the respective window parameters are allocated by the central transmission point so that the windows do not collide at the central transmission point.

Preferably, the data includes at least a third quantity of third data for transmission to the first end point, such that the third quantity is variable from each of the frames to the next in the sequence, and including, responsive to the third quantity, allocating in each of the frames a third number of timeslots to carry the third data to the first end point, such that the third number is variable from each of the frames to the next in the sequence, and such that the first and third number of timeslots are not contiguous.

There is further provided, according to a preferred embodiment of the present invention, apparatus for downstream communication in a passive optic network by time division multiplexing of a sequence of frames, including:

a passive optical distribution fabric which is adapted to receive and convey data;

a plurality of receiving optical network terminations (ONTs) coupled to the fabric including first and second ONTs which are adapted to receive the data from the fabric; and

a central optical line terminal (OLT) coupled to the fabric which is adapted to receive the data for transmission into the network, the data including at least a first quantity of first data for transmission to the first ONT and a second quantity of second data for transmission to the second ONT, such that the first and second quantities are variable from each of the frames to the next in the sequence, to allocate in each of the frames a first number of timeslots to carry the first data to the first ONT and a second number of timeslots to carry the second data to the second ONT, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data, and to transmit the data during the allocated timeslots.

Preferably, the data includes sets of data which are conveyed via respective different industry-standard services.

Preferably, the plurality of ONTs includes sets of ONTs operative at different wavelength groups, and the data includes respective sets of data which are conveyed between the OLT and the respective sets of ONTs via the different wavelength groups.

Further preferably, the data includes sets of data which are conveyed via respective different channels, wherein each of the channels transfers data via a service coupled to the OLT and at least one of the ONTs.

Further preferably, each of the channels is assigned a respective bandwidth, and allocating the first and the second numbers of timeslots includes allocating the first and the second numbers of timeslots responsive to the bandwidth of each of the channels.

Preferably, assigning each of the channels the respective bandwidth includes changing the respective bandwidth to a different bandwidth responsive to a request received by the OLT.

Preferably, the OLT includes a memory, and the first and second numbers of timeslots are allocated responsive to respective first and second data parameters stored in the memory.

Further preferably, a total of the first number and the second number of the timeslots is less than or equal to a bandwidth of each of the sequence of frames.

Preferably, the data includes one or more further quantities of data for transmission to respective one or more further ONTs among the plurality of ONTs, such that the one or more further quantities are variable from each of the frames to the next in the sequence, wherein the OLT is adapted to allocate respective one or more further numbers of timeslots to be carried respectively to the one or more further ONTs.

Preferably, a period of each of the sequence of frames is substantially constant.

Preferably, each of the sequence of frames includes a header including respective window parameters for each of the plurality of ONTs, each window parameter including a time and a size of a window of upstream data which each of the plurality of ONTs is permitted to transmit to the OLT.

Preferably, the respective window parameters are allocated by the OLT so that the windows do not collide at the OLT.

Further preferably, the data includes a third quantity of third data for transmission to the first end point, such that the third quantity is variable from each of the frames to the next in the sequence, and the OLT, responsive to the third quantity, is adapted to allocate in each of the frames a third number of timeslots to carry the third data to the first end point, such that the third number is variable from each of the frames to the next in the sequence, and such that the first and third number of timeslots are not contiguous.

There is further provided, according to a preferred embodiment of the present invention, a method for communication between a transmission point of a network and an end point of the network by time division multiplexing of a sequence of frames, each of which is divided into multiple timeslots, the method including:

receiving at the transmission point data for transmission to the end point, the data including at least a first quantity of first data for transmission to the end point and a second quantity of second data for transmission to the end point, such that the first and second quantities are variable from each of the frames to the next in the sequence;

responsive to the first and second quantities, allocating in each of the frames a first number of the timeslots to carry the first data to the end point, and a second number of the timeslots to carry the second data to the end point, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data; and

transmitting the data from the transmission point to the end point during the allocated timeslots.

Preferably, the first data is conveyed via a first channel and the second data is conveyed via a second channel between the transmission point and the end point, wherein the first data is conveyed via a first service and the second data is conveyed via a second service, the first and second services being coupled to the transmission point and the end point and being external to the network.

Preferably, the data includes a third quantity of first data for transmission to the end point, such that the third quantity is variable from each of the frames to the next in the sequence, and including, responsive to the third quantity, allocating in each of the frames a third number of timeslots to carry the third quantity to the end point, such that the third number is variable from each of the frames to the next in the sequence, and such that the first and third number of timeslots are not contiguous.

There is further provided, according to a preferred embodiment of the present invention, apparatus for communication in a network by time division multiplexing of a sequence of frames, including:

a receiver coupled to the network which receives data from the network; and

a transmitter coupled to the network which is adapted to receive the data for transmission into the network, the data including at least a first quantity of first data for transmission to the receiver and a second quantity of second data for transmission to the receiver, such that the first and second quantities are variable from each of the frames to the next in the sequence, to allocate in each of the frames a first number of timeslots to carry the first data to the receiver and a second number of timeslots to carry the second data to the receiver, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data, and to transmit the data during the allocated timeslots.

Preferably, the first data is conveyed via a first channel and the second data is conveyed via a second channel between the transmitter and the receiver, wherein the first data is conveyed via a first service and the second data is conveyed via a second service, the first and second services being coupled to the transmitter and to the receiver, and being external to the network.

Preferably, the data includes a third quantity of first data for transmission to the receiver, such that the third quantity is variable from each of the frames to the next in the sequence, and including, responsive to the third quantity, allocating in each of the frames a third number of timeslots to carry the third quantity to the receiver, such that the third number is variable from each of the frames to the next in the sequence, and such that the first and third number of timeslots are not contiguous.

The present invention will be more fully understood from the following detailed description of the preferred embodiments thereof, taken together with the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a passive optical network, according to a preferred embodiment of the present invention;

FIG. **2** is a schematic timing diagram showing overall structure of a downstream frame and a virtual upstream frame transmitted in the network of FIG. **1**, according to a preferred embodiment of the present invention;

FIG. **3** is a schematic diagram showing structure of a downstream frame header, according to a preferred embodiment of the present invention;

FIG. **4** is a flowchart showing how the header of FIG. **3** is computed, according to a preferred embodiment of the present invention;

FIG. **5** is a schematic diagram of a payload section of the downstream frame, according to a preferred embodiment of the present invention;

FIG. **6** is a flowchart showing how the payload section is computed, according to a preferred embodiment of the present invention;

FIG. **7** is a schematic diagram showing details of an upstream window of the network of FIG. **1**, according to a preferred embodiment of the present invention; and

FIG. **8** is a flowchart showing steps involved in implementing a change in bandwidth of a channel, according to a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now made to FIG. **1** which is a schematic diagram of a passive optical network (PON) **20**, according to a preferred embodiment of the present invention. PON **20** comprises an optical line terminal (OLT) **22** at the head end of a passive optical distribution fabric **24**, the OLT acting as a central transmission point and an overall controlling device for PON **20**. Fabric **24** is terminated at its downstream side by a plurality of generally similar optical network terminations (ONTs) **26**A, **26**B, **26**C, . . . acting as respective receiving end points. Hereinbelow ONT **26**A, ONT **26**B, ONT **26**C, . . . are also referred to herein collectively as ONTs **26**, and respectively as ONT A, ONT B, ONT C, ... OLT **22** and ONTs **26** operate as data modems, so that OLT **22** is coupled at its upstream side to industry-standard data transfer services such as an Ethernet line **28**, a video line **29**, and a constant bit rate (CBR) line **30**, and ONTs **26** are coupled at their respective downstream sides to data lines **32** which provide corresponding or lower-rate services to downstream clients of PON **20**. PON **20** transfers data between OLT **22** and ONTs **26** in the form of downstream frames and upstream "virtual" frames, the frames being transmitted in a fully duplex manner. Full-duplex methods of transferring data, such as using different wavelengths for transmitting and receiving, are well known in the optical network art. Both downstream and upstream frame formats are described in more detail hereinbelow.

Downstream frames from OLT **22** are transmitted into fabric **24** in a substantially continuous sequence of constant period frames. Most preferably, downstream frames have a period of 125 s, and are implemented to transfer data downstream at a rate of approximately 2.5 Gb/s, although other periods and rates may be used. Fabric **24** splits the downstream transmissions passively so that all ONTs **26** receive the frames in a generally broadcast manner. In the upstream direction separate transmissions from the plurality of ONTs **26** are transmitted as windows which are combined in a virtual frame so that the separate windows do not collide when they arrive at OLT **22**. The virtual upstream frames are implemented to have substantially the same period as the downstream frames. Upstream data transmissions are preferably transmitted at a rate approximately equal to the downstream rate, although another upstream rate may also be used.

OLT **22** comprises a control and logic unit (CLU) **36** which controls, via management software **33** comprised in a memory **44**, the overall operation of PON **20** together with the operation of individual elements of the OLT. OLT **22** is coupled to a network monitor **37** and a keyboard **35**, which enable an operator of PON **20** to both track behavior of the network and implement changes to the network via software **33**. OLT **22** comprises a switch **34** which switches between coupled services to the OLT, according to controlling signals received from CLU **36**. The CLU also controls the operation of a data ingress (from the upstream direction) First-In First-Out FIFO logical memory **38**, a data egress (to the upstream direction) FIFO logical memory **40**, a transmit framer **31**, a receive framer **23**, and a FIFO parameter table **21**. The functions and operations of the FIFOs, framers, table **21**, and of management software **33** are described in more detail hereinbelow.

OLT **22** also comprises an optical interface **42**, which is controlled by CLU **36**. Interface **42** converts data from transmit framer **31** to an optical format, most preferably by modulating a laser comprised in the interface and transmitting the laser output into fabric **24**. Interface **42** also receives optical signals from fabric **24** and converts the signals to data which is then transferred to receive framer **23** wherein it is disassembled prior to upstream transmission via FIFO **40** and switch **34**.

Preferably, interface **42** is able to transmit and receive its optical output in multiple discrete wavelength groups [**1**], [**2**], [**3**], . . . , substantially simultaneously, so that the capacity of PON **20** is effectively increased by the number of wavelength groups used. Each wavelength group comprises a first wavelength at which OLT **22** transmits downstream data and a second wavelength at which the OLT receives upstream data. PON **20** comprises sets of ONTs **26**, each ONT **26** in a specific set operating in one of the wavelength groups by receiving the first wavelength and transmitting the second wavelength. Alternatively, interface **42** transmits and receives in one wavelength group, so that all ONTs **26** are comprised in one set. The format of frames transmitted in the multiple wavelength system and the single wavelength system is substantially the same, so that for clarity PON **20** is assumed to operate in one wavelength group, except where described otherwise hereinbelow.

Each ONT **26** comprises a CLU **46**, an ingress FIFO **48**, an egress FIFO **50**, a transmit framer **41**, a receive framer **56**, a FIFO parameter table **51**, an optical interface **52**, a switch **64**, and a memory **54**, which respectively function in a generally similar manner to CLU **36**, ingress FIFO **38**, egress FIFO **40**, transmit framer **31**, receive framer **23**, table **21**, optical interface **42**, switch **34**, and memory **44**. When multiple discrete wavelength groups [**1**], [**2**], [**3**], . . . , are used in PON **20**, each optical interface **52** is implemented to transmit and receive data at one of the discrete groups, and not to respond to wavelengths of the other groups, most preferably by an optical filter within the optical interface.

Communications in PON **20** are categorized into channels, each channel transferring data of a specific service between OLT **22** and a specific ONT **26** or set of ONTs, so that there is a one-to-one mapping between services supported by the PON and channels used for the transfer. OLT **22** and each ONT **26** maintain primary and secondary tables of channel parameters. OLT **22** comprises a primary downstream channel table **43**, in memory **44**, mapping channels to their allocated downstream bandwidths and channel labels, and a secondary downstream table **45** which is used when adjustments to channel downstream bandwidths are made. OLT **22** also comprises primary and secondary pointer tables **47** and **49**, used respectively for tracking and updating ONT **26** window parameters. OLT **22** further comprises a table **25** mapping ONTs **26** and respective channel labels. Functions of tables **25**, **43**, **45**, **47**, and **49** are described in more detail below.

Each ONT **26** comprises a primary upstream channel table **53** in respective memory **54**, each primary table

mapping channels of the specific ONT **26** to their allocated upstream bandwidths and channel labels. Each ONT **26** also comprises a respective secondary upstream channel table **55** which is used when adjustment to channel upstream bandwidths are made, and a table **59** of downstream channel labels. More details of the operation of these tables are given below.

A channel is provisioned in PON **20** for a service which is coupled to the PON. Most preferably, the provisioning is implemented by an operator of the PON, via keyboard **35** and monitor **37**, the operator also allocating resources, such as upstream and downstream bandwidths, to the channel.

Channels are most preferably classified at provisioning as being either constant bit rate (CBR) channels or packet-based (PB) channels. For example, a channel for data originating from Ethernet line **28** will typically be a PB channel. When a channel is provisioned, parameters comprising a channel label and an upstream and downstream bandwidth allocated to the channel are entered into the respective upstream and downstream primary tables. Most preferably, bandwidth is allocated in terms of 4-byte timeslots, although any other convenient timeslot size may be used. The bandwidth allocated for a particular channel is most preferably greater than the incoming data rate. For example, for a CBR channel on line **30** where the frequency is 1.544 Mbit/s, the necessary bandwidth of a 125 s frame is 193 bits, which is accommodated by setting the bandwidth of the channel at seven 4-byte timeslots. More details of frame characteristics used in network **20**, and of bandwidths and adjustments to bandwidths assigned to specific channels, including PB channels, are given hereinbelow.

Ingress FIFO **38** acts as an initial buffer for downstream data to OLT **22**, and most preferably comprises separate memories according to the types of services coupled to OLT **22**. Data from CBR channels are written to FIFO **38** at the clock rate of the CBR service. Most preferably, only valid packets, i.e., no idle bytes, are written from PB channels to FIFO **38**. The data is written to FIFO **38** after receipt from lines **28**, **29**, and **30** and after transferring through switch **34**. As appropriate, parameters for channels written to FIFO **38** are written to FIFO parameter table **21**. For example, for a PB channel, table **21** preferably includes an allocated maximum burst size (MBS), an allocated maximum burst rate (MBR) of the channel and a guaranteed bit rate (GBR); for a CBR channel table **21** preferably includes a GBR of the channel.

In reading from FIFO **38**, CLU **36** reads the channel's allocated downstream bandwidth from primary table **43**, and data from table **21**. Data, up to the allocated bandwidth, subject to any limitations of parameters in table **21**, is transferred to transmit framer **31** from FIFO **38** by CLU **36**. Framer **31** is used by CLU **36** to assemble data prior to transmission into fabric **24**. The manner of transmission of downstream data is described in more detail below.

In ONTs **26** ingress FIFO **48** and transmit framer **41** operate generally as FIFO **38** and framer **31** respectively. In reading from FIFO **48**, each CLU **46** reads the channel upstream bandwidth from the respective primary table **53**, and also reads channel parameters from table **51**. For each ONT **26** data, subject to limitations of table **21**, is transferred to transmit framer **41** from FIFO **48** by CLU **46**, the framer being used to assemble data prior to transmission into fabric **24**. Transmission of upstream data is described in more detail below.

FIG. **2** is a schematic timing diagram, showing overall structure of a downstream frame **70**, and a virtual upstream frame **72**, according to a preferred embodiment of the present invention. Each downstream frame **70** is transmitted from OLT **22** with a substantially equal period, hereinbelow termed a network period, most preferably set at 125 s. Each downstream frame **70** comprises a header **74**, at least part of which serves, inter alia, as a means for receiving ONTs to identify a beginning of the frame, and thus acts as a starting marker for frame timing throughout PON **20**. Each downstream frame **70** also comprises a payload section **76**, wherein data from OLT **22** (from services transmitting on lines **28**, **29**, and **30**) for transfer to ONTs **26** is entered. Downstream frames **70** are transmitted on a substantially continuous basis, with no idle time between adjacent frames.

During each network period defined by respective adjacent downstream headers **74**, each ONT **26** is able to send upstream data. For each period, OLT **22** allocates each ONT **26** respective windows of time **78** within which it is able to transmit the upstream data, divided in the window according to channels. Each window **78** comprises a start time, relative to the starting marker defined by frame header **74**, and a length of time during which the specific ONT is permitted to transmit. By way of example, windows **78** for adjacent virtual frames **72** are shown in FIG. **2** for ONT A, ONT B, and ONT N. As described in more detail below, window start times and lengths are allocated within each virtual frame **72** so that windows **78** do not overlap, ensuring that there are no collisions of data from different ONTs at OLT **22**. The allocations are determined by CLU **36**, and are communicated to ONTs **26** in downstream frames **70**. It will be appreciated that start times and lengths of windows **78** are dynamic, and may be changed from frame to frame. In addition to conveying upstream data for respective services in channels, as described above, windows **78** may also convey other data. Data in such windows includes bandwidth change requests and ranging information data, which are described in more detail below, as well as other management and control windows.

FIG. **3** is a schematic diagram showing structure of downstream frame header **74**, according to a preferred embodiment of the present invention. Header **74** comprises a frame identification section **80**, which in turn consists of a frame alignment signal (FAS) section **84**, a wavelength identification section **83**, a number of ONTs section **85**, and a bit interleaved parity (BIP) section **86**. FAS section **84** preferably comprises eight bytes, and is used by the ONTs as a start-of-frame identifier. When PON **20** operates with more than one wavelength, section **83** identifies which wavelength group [**1**], [**2**], [**3**], . . . the frame is using, and section **85** indicates the number of ONTs operating in that wavelength group. When a single wavelength group is used in PON **20**, section **85** indicates the number of ONTs operative within the network. BIP section **80** is used as an error monitoring function, and preferably comprises a BIP-8 code function, as is known in the art, using even parity calculated on all bits of an immediately preceding frame.

Header **74** also comprises one or more ONT header sections **82**, each of sections **82** being directed to a specific ONT **26**. The number of header sections **82** corresponds to the number of ONTs **26** with which frame **70** communicates. Each ONT header section **82** comprises a one-byte ONT identification section **88**, and a window pointer section **90**. Pointer section **90**, preferably three bytes long, comprises information to be used by the specific ONT in transmitting its data upstream. Pointer section **90** consists of a start window transmission time **91** (measured from receipt of FAS section **84**) when the specific ONT is to begin transmitting its data in a respective window **78**. Section **90** also

includes a maximum length **93** of window **78** the ONT is permitted to transmit. Length **93** corresponds to the overall upstream bandwidth allocated to the specific ONT **26**, and is calculated by management software **33** on the basis of total upstream channel bandwidth requests received from all ONTs **26**.

A grant section **92**, preferably 4 bits long, comprises a control code used by OLT **22** to control the upstream transmission from each ONT. The control code preferably comprises codes, which each receiving ONT interprets, describing the data which each specific ONT should, or should not, transmit. For example, grant section **92** instructs a specific ONT to transmit its window **78**, to halt transmission, or to send one of a number of management or control types of data-window.

An ONT management and control channel section **94** is used, inter alia, as a protection check for sections **88**, **90**, and **92**. Section **94** comprises a cyclic redundancy check (CRC) section **95**, a remote monitoring section **96**, a data communication channel (DCC) section **97**, and a fast communication channel (FCC) section **98**. CRC section **95** is used to protect section **88**, section **90** (comprising time **91** and length **93**), and section **92**. The ONT identified in section **88** compares a CRC received in section **95** with a value expected for sections **88**, **90**, and **92**. If an error is detected by the comparison, the ONT most preferably halts upstream transmission until a frame is received with a correct CRC in section **95**. Remote monitoring section **96** comprises a remote defect indication (RDI) and a remote error indication (REI). An RDI is sent from OLT **22** to a specific ONT when OLT **22** detects a defect, such as an absence or loss of a window **78** from the ONT, or if there is excessive error in the received window. The REI comprises a count of a number of errors detected by OLT **22** in the last data-window received by the OLT.

DCC section **97** and FCC section **98** comprise regions enabling OLT **22** to send management information specific to the ONT **26**, and/or any other management related information. For example, changes in a downstream bandwidth for a specific channel handled by the ONT **26** may be sent via DCC section **97**. Decoding of section **97** is preferably implemented by software in the specific ONT **26**. FCC section **98** is most preferably implemented by a combination of hardware, at the physical level of the ONT, and software, so that section **98** may be used to convey management and/or control messages to the ONT **26** at a faster rate than DCC section **97**.

FIG. **4** is a flowchart showing how header **74** is computed by CLU **36** using management software **33**, according to a preferred embodiment of the present invention. The steps of the flowchart are most preferably implemented by CLU **36** before each downstream frame **70** is transmitted from the OLT. In a first step, CLU **36** determines how many ONTs **26** are active in PON **20**. Methods for performing such determination are known in the art, and include noting which ONTs **26** have transmitted data to OLT **22** during a predetermined time period prior to the step being implemented. Most preferably, the method used includes processes for noting when a new ONT **26** comes on-stream, as well as when an ONT **26** goes off-stream.

In a second step, CLU **36** computes a maximum window size, in timeslots, of each window **78** for each respective active ONT **26** determined in the first step. The total of the maximum sizes is set by CLU **36** to be less than the downstream bandwidth capacity. Within this limitation, the window size for each ONT **26** is set according to data parameters of each active channel being conveyed upstream by the specific ONT **26**. Preferably, the data parameters of each channel include whether the channel is a CBR or a PB channel, a priority which is assigned by an operator of PON **20**, the amount of data for the specific channel in the respective ingress FIFO **48**, and the bandwidth assigned to the channel in the primary table **53** of the ONT **26**. (The bandwidth is known to OLT **22** from when the channel is provisioned, or, as described below, when a bandwidth change is implemented.) Data parameters for each PB channel most preferably also comprise an upstream guaranteed bit rate (GBR) and an upstream maximum burst rate (MBR) allocated by the network operator. Most preferably, the number of timeslots allocated to each PB channel exceeds the upstream GBR. The number of timeslots allocated to each CBR channel most preferably exceeds a worst-case possible upstream frequency of the channel.

Most preferably, at least some of the data parameters are transmitted in a management and control data-packet sent by the specific ONT **26**, and at least some are preferably stored in FIFO parameters table **21**. The management and control data-packet is most preferably sent by the ONT **26**, prior to OLT **22** computing the window size for the ONT **26**, in one or more previous windows **78**, in response to a request generated by software **33**.

In a third step, CLU **36** arranges the windows **78** computed in step two preferably contiguously in a "virtual" frame, and determines an initial start time for each window **78** relative to a frame starting time, corresponding to the beginning of header **74**. A ranging time and a margin time, described below, are added to each initial start time, to generate a start window transmission time which is to be used for each window **78**.

Each ONT **26** is some distance from OLT **22**, the distance causing a delay in signal transmission from the specific ONTs **26** to OLT **22** proportional to the distance, due to the finite speed of transmission of the optical signals. The distance of each ONT **26** from OLT **22** is compensated for by adding the ranging time to each ONT's initial window start time. The ranging time for each ONT **26** is determined by one of the ranging methods known in the passive optical network art, such as by sending a ranging signal from OLT **22** into PON **20**, and waiting for corresponding responses being received from active ONTs **26**. Preferably, the ranging signal is sent when PON **20** initializes. Alternatively or additionally, the ranging signal is sent while network **20** is operative, such as when OLT **22** determines that a new ONT **26** has come on-stream, or when there has been an effective change in operating parameters of an existing ONT **26**. OLT **22** determines the ranging time for each ONT **26** once ranging signal responses have been received from each ONT **26** operative in PON **20**.

CLU **36** adds a margin time to the initial start time and the ranging time, to insure that there is some temporal separation of windows **78** arriving at OLT **22**. The margin time also allows for errors in arrival times at OLT **22**, due to factors such as differences and/or drifts in clocks in each of the ONTs **26**, physical changes over time of components of PON **20**, and inaccuracies in the ranging process.

In a final step, CLU **36** inserts the computed start window transmission time, the maximum window size, and CRC section **95**, into pointer section **90** of each ONT header section **82**. The time and size of each window are also stored, according to the specific ONT **26**, in pointer table **47**.

FIG. **5** is a schematic diagram of payload section **76** of downstream frame **70**, according to a preferred embodiment

of the present invention. Payload section **76** comprises data sent from OLT **22** to the plurality of ONTs **26**. The data is incorporated into section **76** on a variable time multiplexed basis, so that for each frame **70** OLT **22** allocates one or more data-channels **100** for each of the ONTs to which data is to be transmitted. A size of each data-channel is calculated by CLU **36** using management software **33**, according to predetermined criteria, as described with reference to FIG. **6** below, and for each ONT **26** the size of the respective data-channel is able to vary from frame to frame.

A data-channel is constructed from a group of timeslots. Each data-channel is identified by a channel label (described below) and transports data belonging to a single channel, the channel label being read from table **43**. Most preferably, each data-channel **100** in payload **76** is contiguous with adjacent data-channels **100**. Alternatively, adjacent data-channels **100** are separated by one or more "idle" bits. Each data-channel **100** comprises a channel overhead section **102** and a channel payload section **104**. Channel overhead sections **102** are substantially similar in size and construction. Channel payload sections **104** typically differ in size from each other, and from frame to frame, the size for each channel being calculated on an on-going basis.

Each channel overhead section **102** comprises a channel label field **106**, a length field **108**, a management and control field **110**, and a CRC section which guards the preceding data. Channel label field **106** comprises a unique label which is assigned by CLU **36** when the channel is provisioned, and which is stored in table **43** of OLT **22** and in respective tables **59** of relevant ONTs **26**. As described below, channels, their lengths, and their labels, are tracked in both OLT **22** and each ONT **26**.

Length field **108** gives a size of payload section **104**, in terms of timeslots, of the associated data-channel **100**. Field **108** is most preferably divided into two sections, a 2-bit multiplier section and a 10-bit length section. The size of the payload is calculated by multiplying a value associated with the 2-bit value by the 10-bit value. Management and control field **110** is preferably generally similar in form and function to management and control section **94** (FIG. **3**). Field **110** most preferably comprises sub-fields which enable OLT **22** to set a channel priority and/or generate a channel alarm such as if an incorrect CRC checksum has been previously received in the specific channel. Preferably, field **110** also enables OLT **22** to communicate channel management information to the specific ONT **26**.

FIG. **6** is a flowchart showing construction of payload section **76** using management software **33**, according to a preferred embodiment of the present invention. The steps of the flowchart are performed before each downstream frame **70** is sent from OLT **22**.

In a first step, CLU **36** checks ingress FIFO **38** for data to be incorporated into section **76**.

In a second step, for each channel of data in FIFO **38**, CLU **36** determines from primary table **43** the allocated downstream bandwidth of the channel and the channel label. For each channel CLU **36** also determines data parameters in table **21**.

In a third step, data for each channel, up to the channel's allocated bandwidth and subject to any limitations generated by parameters in table **21**, is read from FIFO **38**.

In a fourth step, channel overhead section **102** is constructed, incorporating the channel label and length, and the data read from the FIFO is incorporated into channel payload section **104**, to form data-channel **100** for the specific channel.

Steps two to four are repeated for each channel of data in FIFO **38**, and in a final step the data-channels **100** which are generated for each channel are concatenated to form downstream payload section **76**. Steps two to four and the final step are most preferably implemented by CLU **36** using transmit framer **31** when constructing section **76**.

It will be appreciated that downstream data frames **70** are transmitted in a broadcast manner, so that a specific ONT **26** receives data which is not directed to that ONT. Most preferably, data transmitted in payload sections **104** is encrypted so that only the ONT to which the data is directed is able to decrypt the data. Such methods of encryption and decryption are well known in the art, and include "churning" of the data. If churning is used, most preferably a churning key is generated by each ONT **26**, and is sent in a management and control upstream window **78** to OLT **22**, which then churns the channel payload data before it is entered into payload section **104**. De-churning is then performed at the ONT using the churning key. Most preferably a new churning key is sent from each ONT **26** at regular intervals of less than 1 s.

It will be understood that the structure of downstream payload section **76** enables changes in bandwidths for transmitted channels to be implemented for each downstream frame **70**. Such changes are most preferably implemented using secondary table **45**, as described in more detail below with reference to FIG. **8**.

Downstream payload section **76** is constructed on a time multiplexed "per-channel" basis, each data-channel **100** being defined by its channel header **102** (FIG. **5**). Each specific ONT **26** recovers data-channels directed to it from section **76** by comparing labels **106** in headers **102** with the channel labels in tables **59** of each ONT **26**. It will be appreciated that data-channels directed to a specific ONT **26** do not necessarily have to be contiguous in section **76**, since each ONT **26** checks for channel labels. Thus any specific ONT **26** may receive its time multiplexed data in a fragmented form, the fragmentation being by channel. It will be appreciated that allowing fragmentation of data transmitted to a specific ONT significantly increases the "packing" efficiency of section **76**.

FIG. **7** is a schematic diagram showing details of upstream window **78** of ONT **26**B, according to a preferred embodiment of the present invention. Data in upstream window **78** is generated and transmitted by ONT **26**B, although it will be understood that the following description applies, *mutatis mutandis*, to transmission and generation of data in an upstream window **78** from any ONT **26**. Window **78** is implemented by ONT **26**B so that on reception of the window at OLT **22**, the window does not overlap with any other windows **78** transmitted by other ONTs **26**, as shown schematically in FIG. **2**. Window **78** is only transmitted from ONT **26**B after receipt by the ONT of an ONT **26**B overhead section **82** (FIG. **3**). As described with reference to FIG. **3**, section **82** comprises pointer section **90** having start window transmission time **91** and maximum window length **93**.

Window **78** comprises a general ONT **26**B overhead section **134**, followed by alternating channel overhead and channel payload sections. By way of example, window **78** for ONT **26**B is assumed to comprise two channels, each having an overhead section **136** and **140**, and a payload section **138** and **142**. General overhead section **134** comprises a synchronization field **146**, an identification field **148**, a window type field **149**, a CRC field **156**, a BIP field **150**, a DCC/FCC field **152**, and an RDI/REI field **154**. Fields **146** and **148** enable OLT **22** to identify ONT **26**B as the

transmitting ONT, and also enable the OLT to synchronize a burst-mode receiver comprised in the OLT. Field **149** indicates a window composition, such as a data window. CRC field **156** provides a checksum for protecting data transmitted in synchronization field **146**, identification field **148** and window type field **149**. BIP field **150** is implemented and functions in a generally similar manner to BIP section **80** (FIG. **3**). DCC/FCC field **152** is implemented and functions in a generally similar manner to sections **97** and **98**, providing a field for general management and control messages for ONT **26**B. RDI/REI field **154** is implemented and functions in a generally similar manner to section **96**, acting as a remote monitoring field.

Each channel overhead section **136** and **140** comprises a channel label field **158** and a channel length field **160**. Field **158** is derived from channel label table **53** in ONT **26**B. Field **160** is most preferably substantially similar in form to length field **108** described above with reference to FIG. **5**. Each channel overhead section also preferably comprises a status field **162**, used, for example, to convey an alarm regarding the specific channel to OLT **22**, and a CRC field **164**, which comprises a checksum protecting fields **158**, **160**, and **162**. Each channel overhead section is followed by its channel payload section, having a length defined by its respective channel overhead section **160**.

The length of each channel payload section is determined by CLU **46** of ONT **26**B, according to the overall constraint that the length of window **78** is less than or equal to maximum window length **93** received in pointer **90**. Within this constraint, CLU **46** constructs channel payload sections by reading, from ingress FIFO **48**, FIFO parameters table **51**, and primary table **53**, specific channel data, data parameters, and the corresponding allocated bandwidth of each channel. After construction of window **78**, ONT **26**B transmits the window upstream at start window transmission time **91** after receipt of header **74**.

FIG. **8** is a flowchart showing steps involved in implementing a change in bandwidth of a channel, according to a preferred embodiment of the present invention. Typically, when a channel is provisioned the channel is assigned an upstream and a downstream bandwidth according to the type of service which provides the channel and/or according to a service level agreement (SLA) between an operator of PON **20** and a user of the network. Each channel label and respective downstream bandwidth are written to primary table **43** of OLT **22**. Primary table **53** of each ONT **26** contains channel labels and upstream bandwidths of channels transferred through the particular ONT **26**. The flowchart of FIG. **8** is implemented by CLU **36** using management software **33**.

In a first step, a request for a change in bandwidth of a channel is received by CLU **36**. Preferably, the request is initiated by a user of the channel, and typically comprises a request to increase an upstream and/or a downstream bandwidth of the channel. Most preferably, the request is implemented by the operator of the network via keyboard **35**.

In a second step, CLU **36** checks if sufficient spare bandwidth is available to accommodate any requested increase, by evaluating the total number of timeslots already allocated to downstream frame **70**, and/or to upstream virtual frame **72**. If there is sufficient spare bandwidth available, the request for bandwidth change continues; if there is insufficient bandwidth available, the process halts.

In a third step CLU **36** reallocates timeslots for the channel. If the new bandwidth allocation is for downstream bandwidth, the reallocated timeslots may be in an existing data-channel **100** location (FIG. **5**). Alternatively, more bandwidth may be assigned to a specific channel by generating a second data-channel **100** with a label **106** corresponding to the channel. The two data-channels may reside anywhere in section **76**, and do not necessarily have to be contiguous, thus increasing the flexibility with which section **76** may be arranged, and the packing efficiency of the section.

If the new bandwidth allocation is for upstream bandwidth, adjustments are made to the size and position of windows **78** as necessary. For example, referring to FIG. **7**, an increase in channel **1** bandwidth may be accomplished by adding a second section for channel **1** (the section comprising channel **1** overhead and payload sections) in a region **144**, maintaining section **93** fixed. The two sections for channel **1** do not have to be contiguous, so that the advantages described for downstream frames also apply.

If a larger increase in upstream bandwidth is requested, section **93** may have to be increased in size, and/or positions of other windows **78** may have to be adjusted within virtual frame **72**. Size and/or position changes of windows **78** are conveyed to ONTs **26** via appropriate sections **90** of downstream frame **70**.

In a fourth step, channel changes are transmitted to appropriate ONTs **26**, i.e., those ONTs **26** which are affected by the changes implemented, via downstream frame **70**. The changes may be transferred via section **94** (FIG. **3**) and/or sections **110** (FIG. **5**) of frame **70**, and are incorporated in respective secondary tables **55**.

In a final step, primary table **43** is replaced by table **45** in OLT **22** and primary tables **53** are replaced by their respective secondary tables **55**. FIFO parameter tables **21** and **51** are also updated as necessary. Operation of PON **20** then continues with the updated bandwidths.

It will be understood that generally the same process as described hereinabove applies to provisioning a new channel and de-provisioning of an existing channel.

It will be further understood that preferred embodiments of the present invention may be implemented in communication networks, including a network consisting of one transmitter and one receiver, other than passive optical networks such as PON **20**. All such networks are included within the scope of the present invention. Furthermore, it will be appreciated that data transferred by preferred embodiments of the present invention is not specific to any one protocol or service, and may be transmitted into and from the network according to substantially any protocol or service.

It will thus be appreciated that the preferred embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art.

What is claimed is:

1. A method for downstream communication from a central transmission point to a plurality of receiving end points by time division multiplexing of a sequence of frames, each of which is divided into multiple timeslots, the method comprising:

receiving at the central transmission point data for transmission to the end points, the data comprising at least a first quantity of a first data for transmission to a first

end point among the plurality of end points and a second quantity of a second data for transmission to a second end point among the plurality of end points, such that the first and second quantities are variable from each of the frames to the next in the sequence;

responsive to the first and second quantities, allocating in each of the frames a first number of the timeslots to carry the first data to the first end point, and a second number of the timeslots to carry the second data to the second end point, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data;

inserting in each of the frames at least one first end-point field and at least one second end-point field respectively identifying the first and the second numbers of timeslots in each of the frames; and

transmitting the data from the central transmission point to the end points during the allocated timeslots.

2. A method according to claim **1**, wherein the central transmission point comprises an optical line terminal (OLT), and the end points comprise optical network terminals (ONTs), wherein the OLT and ONTs are operative as transceivers in a passive optical network.

3. A method according to claim **1**, wherein the data comprises sets of data which are conveyed via respective different industry-standard services.

4. A method according to claim **1**, wherein the plurality of end points comprises sets of end points operative at different wavelength groups, and wherein the data comprises respective sets of data which are conveyed between the central transmission point and the respective sets of end points via the different wavelength groups.

5. A method according to claim **1**, wherein the data comprises sets of data which are conveyed via respective different channels, wherein each channel transfers data via a service coupled to the central transmission point and at least one of the end points.

6. A method according to claim **5**, and comprising assigning each channel a respective bandwidth, and wherein allocating the first and the second numbers of timeslots comprises allocating the first and the second numbers of timeslots responsive to the bandwidth of each of the channels.

7. A method according to claim **6**, wherein assigning each channel the respective bandwidth comprises changing the respective bandwidth to a different bandwidth responsive to a request received by the central transmission point.

8. A method according to claim **1**, wherein the first and second numbers of timeslots are allocated responsive to respective first and second data parameters stored in a memory comprised in the central transmission point.

9. A method according to claim **1**, wherein a total of the first number and the second number of the timeslots is less than or equal to a bandwidth of each of the sequence of frames.

10. A method according to claim **1**, wherein the data comprises one or more further quantities of data for transmission to respective one or more further end points among the plurality of the end points, such that the one or more further quantities are variable from each of the frames to the next in the sequence, and comprising allocating respective one or more further numbers of timeslots to be carried respectively to the one or more further end points.

11. A method according to claim **1**, wherein a period of each of the sequence of frames is substantially constant.

12. A method according to claim **1**, wherein each of the sequence of frames comprises a header comprising respective window parameters for each of the plurality of end points, each window parameter comprising a time and a size of a window of upstream data which each of the plurality of end points is permitted to transmit to the central transmission point.

13. A method according to claim **12**, wherein the respective window parameters are allocated by the central transmission point so that the windows do not collide at the central transmission point.

14. A method according to claim **1**, comprising:

inserting in each of the frames a frame header including first-end-point-parameters directed to a first end point and second-end-point-parameters directed to a second end point, wherein the first-end-point-parameters include values indicative of a first timing window during which the first end point is able to transmit first end point upstream data to a central transmission point, and wherein the second-end-point-parameters include values indicative of a second timing window during which the second end point is able to transmit second end point upstream data to the central transmission point, and wherein the first timing window does not overlap the second timing window.

15. A method for downstream communication from a central transmission point to a plurality of receiving end points by time division multiplexing of a sequence of frames, each of which is divided into multiple timeslots, the method comprising:

receiving at the central transmission point data for transmission to the end points, the data comprising at least a first quantity of a first data for transmission to a first end point among the plurality of the end points and a second quantity of a second data for transmission to a second end point among the plurality of the end points, such that the first and second quantities are variable from each of the frames to the next in the sequence;

responsive to the first and second quantities, allocating in each of the frames a first number of the timeslots to carry the first data to the first end point, and a second number of the timeslots to carry the second data to the second end point, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data; and

transmitting the data from the central transmission point to the end points during the allocated timeslots,

wherein the data comprises at least a third quantity of a third data for transmission to the first end point, such that the third quantity is variable from each of the frames to the next in the sequence, and comprising, responsive to the third quantity, allocating in each of the frames a third number of timeslots to carry the third data to the first end point, such that the third number is variable from each of the frames to the next in the sequence, and such that the first and third number of timeslots are not contiguous.

16. An apparatus for downstream communication in a passive optic network by time division multiplexing of a sequence of frames, comprising:

a passive optical distribution fabric which is adapted to receive and convey data;

a plurality of receiving optical network terminations (ONTs) coupled to the optical distribution fabric comprising first and second ONTs which are adapted to receive the data from the optical distribution fabric; and

a central optical line terminal (OLT) coupled to the optical distribution fabric which is adapted to receive the data

for transmission into the optic network, the data comprising at least a first quantity of a first data for transmission to the first ONT and a second quantity of a second data for transmission to the second ONT, such that the first and second quantities are variable from each of the frames to the next in the sequence, to allocate in each of the frames a first number of timeslots to carry the first data to the first ONT and a second number of timeslots to carry the second data to the second ONT, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data, to insert in each of the frames at least one first ONT-field and at least one second ONT-field respectively identifying the first and the second numbers of timeslots in each of the frames, and to transmit the data during the allocated timeslots.

17. Apparatus according to claim **16**, wherein the data comprises sets of data which are conveyed via respective different industry-standard services.

18. Apparatus according to claim **16**, wherein the plurality of ONTs comprises sets of ONTs operative at different wavelength groups, and wherein the data comprises respective sets of data which are conveyed between the OLT and the respective sets of ONTs via the different wavelength groups.

19. Apparatus according to claim **16**, wherein the data comprises sets of data which are conveyed via respective different channels, wherein each of the channels transfers data via a service coupled to the OLT and at least one of the ONTs.

20. Apparatus according to claim **19**, wherein each of the channels is assigned a respective bandwidth, and wherein allocating the first and the second numbers of timeslots comprises allocating the first and the second numbers of timeslots responsive to the bandwidth of each of the channels.

21. Apparatus according to claim **20**, wherein assigning each of the channels the respective bandwidth comprises changing the respective bandwidth to a different bandwidth responsive to a request received by the OLT.

22. Apparatus according to claim **16**, wherein the OLT comprises a memory, and wherein the first and second numbers of timeslots are allocated responsive to respective first and second data parameters stored in the memory.

23. Apparatus according to claim **16**, wherein a total of the first number and the second number of the timeslots is less than or equal to a bandwidth of each of the sequence of frames.

24. Apparatus according to claim **16**, wherein the data comprises one or more further quantities of data for transmission to respective one or more further ONTs among the plurality of ONTs, such that the one or more further quantities are variable from each of the frames to the next in the sequence, wherein the OLT is adapted to allocate respective one or more further numbers of timeslots to be carried respectively to the one or more further ONTs.

25. Apparatus according to claim **16**, wherein a period of each of the sequence of frames is substantially constant.

26. Apparatus according to claim **16**, wherein each of the sequence of frames comprises a header comprising respective window parameters for each of the plurality of ONTs, each window parameter comprising a time and a size of a window of upstream data which each of the plurality of ONTs is permitted to transmit to the OLT.

27. Apparatus according to claim **26**, wherein the respective window parameters are allocated by the OLT so that the windows do not collide at the OLT.

28. An apparatus according to claim **16**, wherein the OLT is adapted to insert in each of the frames a frame header comprising first-ONT-parameters directed to the first ONT and second-ONT-parameters directed to the second ONT, wherein the first-ONT-parameters include values indicative of a first timing window during which the first ONT is able to transmit first ONT upstream data to a central OLT, and wherein the second-ONT-parameters include values indicative of a second timing window during which the second ONT is able to transmit second ONT upstream data to the central OLT, and wherein the first timing window does not overlap the second timing window.

29. An apparatus for downstream communication in a passive optic network by time division multiplexing of a sequence of frames, comprising:

a passive optical distribution fabric which is adapted to receive and convey data;

a plurality of receiving optical network terminations (ONTs) coupled to the optical distribution fabric comprising first and second ONTs which are adapted to receive the data from the optical distribution fabric; and

a central optical line terminal (OLT) coupled to the optical distribution fabric which is adapted to receive the data for transmission into the optic network, the data comprising at least a first quantity of first data for transmission to the first ONT and a second quantity of second data for transmission to the second ONT, such that the first and second quantities are variable from each of the frames to the next in the sequence, to allocate in each of the frames a first number of timeslots to carry the first data to the first ONT and a second number of timeslots to carry the second data to the second ONT, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data, and to transmit the data during the allocated timeslots,

wherein the data comprises a third quantity of a third data for transmission to the first end point, such that the third quantity is variable from each of the frames to the next in the sequence, and wherein the OLT, responsive to the third quantity, is adapted to allocate in each of the frames a third number of timeslots to carry the third data to the first end point, such that a third number is variable from each of the frames to the next in the sequence, and such that a first and the third number of timeslots are not contiguous.

30. A method for communication between a transmission point of a network and an end point of the network by time division multiplexing of a sequence of frames, each of which is divided into multiple timeslots, the method comprising:

receiving at the transmission point data for transmission to the end point, the data comprising at least a first quantity of a first data for transmission to the end point and a second quantity of a second data for transmission to the end point, such that the first and second quantities are variable from each of the frames to the next in the sequence;

responsive to the first and second quantities, allocating in each of the frames a first number of the timeslots to carry the first data to the end point, and a second number of the timeslots to carry the second data to the end point, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data;

inserting in each of the frames at least one first field and at least one second field, respectively, identifying the first and the second numbers of timeslots in each of the frames; and

transmitting the data from the transmission point to the end point during the allocated timeslots.

31. A method according to claim **30**, wherein the first data is conveyed via a first channel and the second data is conveyed via a second channel between the transmission point and the end point, wherein the first data is conveyed via a first service and the second data is conveyed via a second service, the first and second services being coupled to the transmission point and the end point and being external to the network.

32. A method for communication between a transmission point of a network and an end point of the network by time division multiplexing of a sequence of frames, each of which is divided into multiple timeslots, the method comprising:

receiving at the transmission point data for transmission to the end point, the data comprising at least a first quantity of a first data for transmission to the end point and a second quantity of a second data for transmission to the end point, such that the first and second quantities are variable from each of the frames to the next in the sequence;

responsive to the first and second quantities, allocating in each of the frames a first number of the timeslots to carry the first data to the end point, and a second number of the timeslots to carry the second data to the end point, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data; and

transmitting the data from the transmission point to the end point during the allocated timeslots,

wherein the data comprises a third quantity of a third data for transmission to the end point, such that the third quantity is variable from each of the frames to the next in the sequence, and comprising, responsive to the third quantity, allocating in each of the frames a third number of timeslots to carry the third quantity to the end point, such that the third number is variable from each of the frames to the next in the sequence, and such that the first and third number of timeslots are not contiguous.

33. An apparatus for communication in a network by time division multiplexing of a sequence of frames, comprising:

a receiver coupled to the network which receives data from the network; and

a transmitter coupled to the network which is adapted to receive the data for transmission into the network, the data comprising at least a first quantity of a first data for transmission to the receiver and a second quantity of a second data for transmission to the receiver, such that the first and second quantities are variable from each of the frames to the next in the sequence, to allocate in each of the frames a first number of timeslots to carry the first data to the receiver and a second number of timeslots to carry the second data to the receiver, such that a first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data, to insert in each of the frames at least one first field and at least one second field respectively identifying the first and the second numbers of timeslots in each of the frames, and to transmit the data during the allocated timeslots.

34. Apparatus according to claim **33**, wherein the first data is conveyed via a first channel and the second data is conveyed via a second channel between the transmitter and the receiver, wherein the first data is conveyed via a first service and the second data is conveyed via a second service, the first and second services being coupled to the transmitter and to the receiver, and being external to the network.

35. An apparatus for communication in a network by time division multiplexing of a sequence of frames, comprising:

a receiver coupled to the network which receives data from the network; and

a transmitter coupled to the network which is adapted to receive the data for transmission into the network, the data comprising at least a first quantity of a first data for transmission to the receiver and a second quantity of a second data for transmission to the receiver, such that the first and second quantities are variable from each of the frames to the next in the sequence, to allocate in each of the frames a first number of timeslots to carry the first data to the receiver and a second number of timeslots to carry the second data to the receiver, such that the first and second numbers are variable from each of the frames to the next in the sequence responsive to variations in the first and second quantities of the data, and to transmit the data during the allocated timeslots,

wherein the data comprises a third quantity of a third data for transmission to the receiver, such that the third quantity is variable from each of the frames to the next in the sequence, and comprising, responsive to the third quantity, allocating in each of the frames a third number of timeslots to carry the third quantity to the receiver, such that the third number is variable from each of the frames to the next in the sequence, and such that the first and third number of timeslots are not contiguous.

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