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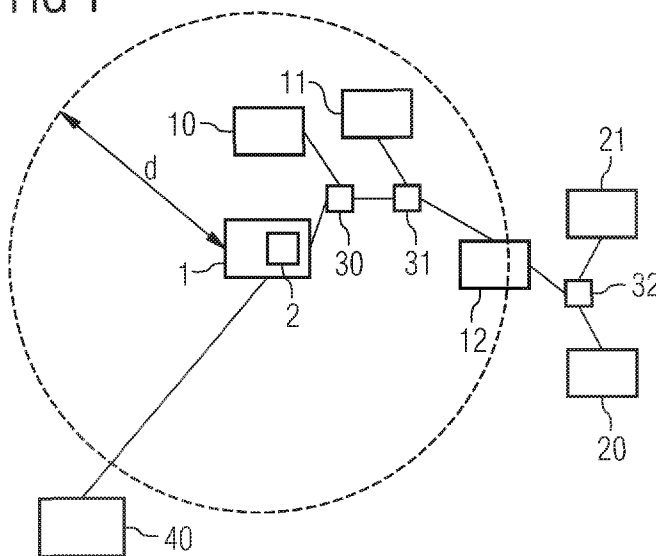
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FIG 1



(57) Abstract: Passive optical network, comprising an optical line termination device and a first and a second optical network unit, the optical line termination device comprising a processor, the processor being configured to send and receive network signals comprised in frames, and the processor being further configured to create a bandwidth map for each of said optical network units, each bandwidth map specifying an allocated upstream data transmission time period, wherein the processor is further configured to include a frame identifier in each of said bandwidth maps, the frame identifier individually specifying a frame for upstream data transmission for the optical network unit, wherein the frame specified for the first optical network unit is different from the frame specified for the second optical network unit.

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## Description

Passive optical network with flexible roundtrip delay

5 The present invention relates to a passive optical network, comprising an optical line termination device and a first and a second optical network unit, the optical line termination device comprising a processor, the processor being configured to send and receive network signals comprised in frames, and  
10 the processor being further configured to create a bandwidth map for each of said optical network units, each bandwidth map specifying an allocated upstream data transmission time period.

15 A passive optical network (PON) typically comprises an optical line termination (OLT) device at a central office of the network, and a plurality of optical network units (ONU) located at, or near, the end user nodes of the network. OLT and ONUs are configured to build a point to multipoint  
20 arrangement. OLT and ONUs are connected via fibre cables and splitters. The splitters are used to split one incoming optical signal passively into two identical outbound signals, so that a plurality of ONUs can be supplied with the signal sent from the OLT. One side effect of such signal splitting  
25 is the reduction of the signal level being supplied at the ONUs.

Due to the different distances between the various ONUs and the OLT, a number of different transmission delay times  
30 between OLT and ONUs occur in a passive optical network (PON). Thus, in order to allow for bandwidth allocation for upstream data transmission in the PON, that is, data transmission from an ONU to the OLT, systems of the state of the art determine a common delay time that is equal for all  
35 ONUs in the system. Usually, this common delay time is determined by the maximum distance between the OLT and the most remote ONU. Since with PONs, upstream data transmissions of ONUs are expected to occur in the same network data frame,

ONUs which are located at only a small distance from the OLT suffer from the relatively large delay time induced by the transmission delay of the most remote OLT.

5 Particularly for applications that require quick data response at end user sites, such transmission delay times often place an undue burden on network usabilities, for instance with network computer game applications or interactive multimedia or audiovisual streaming applications,  
10 such as teleconferencing.

It is thus an object of present invention to provide a passive optical network that overcomes the deficiencies of the state of the art and provides for optimal transmission  
15 delay times for the ONUs present in the network, as well as an optical line termination device, optical network unit, and network data signal therefore.

This object is achieved by the features of independent claims  
20 1, 8, 13, 14, and 16.

The invention according to claim 1 provides a passive optical network, comprising an optical line termination device and a first and a second optical network unit, the optical line  
25 termination device comprising a processor, the processor being configured to send and receive network signals comprised in frames and the processor being further configured to create a bandwidth map for each of said optical network units, each bandwidth map specifying an allocated  
30 upstream data transmission time period, characterized in that the processor is further configured to include a frame identifier in each of said bandwidth maps, the frame identifier individually specifying a frame for upstream data transmission for the optical network unit, wherein the frame  
35 specified for the first optical network unit is different from the frame specified for the second optical network unit.

Thus, upstream data transmission of an ONU can take place in any arbitrary frame that has been specified in the bandwidth map created by the OLT. Consequently, an ONU located at a short distance from the OLT can be assigned a frame for upstream data transmission that occurs only shortly after the frame in which the bandwidth map is transmitted to the ONU in question, while an ONU at a relatively large distance from the OLT can be assigned a frame for upstream data transmission that occurs a longer time after the bandwidth map transmission frame. Thus, the frame that is allocated to an ONU for upstream data transmission can be individually selected according to the individual transmission delay time of the respective ONU.

In this way, the advantageous effect of present invention is achieved in that relatively large PONs can be built without impairing the overall delay time for upstream data transmission. In particular, users located near the OLT can benefit from particularly quick response times.

The invention according to claim 8 provides an optical line termination device for use with the passive optical network, the optical line termination device comprising a processor, the processor being configured to send and receive optical signals comprised in frames and the processor being further configured to create a bandwidth map specifying an allocated upstream data transmission time period, characterized in that the processor is further configured to include a frame identifier in said bandwidth map, the frame identifier individually specifying a frame for upstream data transmission.

Thus, a properly adapted optical line termination (OLT) device is provided for establishing a network according to present invention.

The invention according to claim 16 provides a network data signal embodied in a digital carrier wave, comprising a

bandwidth map data structure with an Allocation ID field, a Flags field, a StartTime field, and a StopTime field, characterized in that the Flags field comprises at least one bit specifying a network data frame.

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Thus, an appropriate data structure is given for realizing proper interaction between the OLT and at least one ONU when allocating upstream data transmission frames and/or time slots.

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Preferred embodiments are defined in the dependent claims.

The invention according to claim 13 provides an optical network unit for use with the passive optical network, comprising communication means for receiving and sending optical signals over the passive optical network, characterized in that it further comprises amplification means to amplify received optical signals and to feed the amplified signals into a further passive optical network.

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As an alternative embodiment, the invention as to claim 14 provides an optical network unit for use with the passive optical network, comprising communication means for receiving and sending optical signals over the passive optical network, characterized in that it further comprises amplification means to amplify received optical signals and to feed the amplified signals into a further passive optical network.

25

Both of the aforementioned aspects of the invention allow to further extend the network beyond its normal physical size limitation. By including such an optical network unit (ONU) in the network, a cascading unit is added that allows to access further ONUs that are connected to said ONU acting as a cascading unit, so that the diminished optical signal can be refreshed in the fashion of a network repeater.

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This is generating particularly advantageous synergistic effects in combination with the flexible upstream

transmission data frame allocation of present invention. In this way, the difference between the ONU that is closest to the OLT and the ONU that is most distant to the OLT can be further increased. For example, further ONUs can be added  
5 behind the ONU acting as the cascading unit without affecting the delay times of the other ONUs. Also, when adding a further ONU behind such a cascading ONU, network operation for ONUs between the OLT and the ONU acting as a cascading unit need not be interrupted for ranging procedures until the  
10 minimum delay time for receiving a response from the recently added ONU has passed. Such a minimum delay time can be calculated based on the known delay time between OLT and the ONU acting as a cascading unit.

15 The invention will be further described with reference to a number of figures:

Fig. 1 shows a schematic overview over a network according to an embodiment of the invention;  
20

Fig. 2 shows a schematic diagram of a bandwidth map network data structure according to an embodiment of present invention, and

25 Fig. 3 shows a time sequence diagram with timing and interaction between components of the network related to delay time and frame allocation.

30 Fig. 1 shows a schematic overview over an embodiment of the passive optical network (PON) according to present invention. Optical line termination (OLT) device 1 contains processor 2 and is connected to a backbone 40. OLT 1 is further connected to optical network units (ONU) 10, 11, 12, 20, 21 via fibre  
35 optic cable or other light wave conducting means. The optical data communication line between the OLT and the plurality of ONUs is being split in splitters 30, 31, and 32, respectively, in order to distribute the light wave data

signal originating from one light wave conductor to a plurality of receiving units. By splitting the signal, the signal level decreases accordingly.

5 ONU 12 is configured to serve as a cascading unit. Consequently, the cascading ONU 12 receives optical data signals from the fibre optic cable coming from OLT 1 via splitter 31 and repeats these signals after amplification to a second fibre optic cable connected to ONUs 20 and 21 via  
10 splitter 32. ONUs 20 and 21 are said to be cascaded behind the cascading ONU 12. In the same manner, cascading ONU 12 repeats upstream data sent from ONU 20 or 21 to the fibre optic cable leading to OLT 1.

15 The broken circle indicates the maximum distance  $d$  that an ONU may have from the OLT in terms of minimum signal level and/or maximum delay time in the passive optical network. As can be seen from fig. 1, cascaded ONUs 20 and 21 are clearly beyond the maximum distance, that is, the maximum spatial  
20 range of the PON.

Processor 2 of OLT 1 is configured to generate bandwidth maps 100, which are illustrated in more detail in fig. 2. Each bandwidth map is addressed to one of the ONUs 10, 11, 12,  
25 20, 21 to assign time intervals in which an ONU may send data upstream, that is, from the ONU to the OLT. Unlike in conventional PONs, wherein all upstream data communication must take place in one and the same frame of 125  
microseconds, the processor 2 of the present embodiment is  
30 configured to individually assign a frame for each of the ONUs in which the respective ONU may place its upstream communication data as further specified in the StartTime and StopTime information of the bandwidth map data. This  
allocation of an individual upstream communication frame is  
35 based on the delay time of the data transmission between the OLT and the respective ONU.

Thus, the ONU 10 which is close to the OLT may place its upstream data in an earlier frame than ONU 12. Since the delay time of ONU 10 and ONU 11 do not differ significantly, calculation in processor 2 may result in the same frame being assigned to ONU 10 and ONU 11 for upstream data communication. Consequently, users at ONU 10 and ONU 11 enjoy a quicker data response performance than users at ONU 12, or at ONUs 20 or 21, which are being assigned response frames that are much later due to the larger delay time.

In this manner, and particularly with the help of cascading ONU 12, additional ONUs 20 and 21 could be added to the PON beyond its maximum range without affecting the delay time of the ONUs already present in the system.

In a scenario, in which ONUs 10, 11, 12, and 20 are already operational in the network, and ONU 21 has recently been added, so that a ranging procedure is to be performed by OLT 1, OLT 1 can continue normal network operation until a minimum delay time that has been calculated for ONU 21 has passed and in which ONU 21 cannot have successfully answered the ranging request of OLT 1. Such a calculation can be based on the known delay time between OLT 1 and cascading ONU 12. Thus, network operation can continue to the largest extent possible when adding new ONUs behind a cascading unit 12.

Fig. 2 shows the bandwidth map network data structure. Bandwidth map allocation data structure is generally defined in ITU-T recommendation G.984.3 and comprises a number of access data fields, each defining network capacity in which upstream data communication may occur. Each of the access data fields 110, 120, 130 in turn comprise an Allocation ID field 150, a Flags field 160, a StartTime field 170, a StopTime field 180, and a CRC field 190.

The Flags field 160 in the embodiment of present invention contains a number of bits (a bit field) 162 that identify a frame which is allocated to an ONU for upstream data

communication. Further, Flags field 160 contains one bit which is used as a flag indicating the presence of a cascading ONU 12 in the communication path between the OLT and the ONU addressed in the Allocation ID field 150.

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Said bit (flag) indicating the presence of a cascading ONU 12 is, in this example, implemented to indicate that allocation ID field 150 is an extended address field, which may have been extended by 8 or 16 or more bits of address space. Such an extended address space is useful since the number of ONUs participating in the PON according to present invention may be significantly larger than in an usual PON. If, however, a vendor chooses not to use the indicator flag 162, the vendor can use the address field in the usual manner.

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Fig. 3 is a sequential interaction diagram showing communication timelines and communication parties relative to the sequence of frames in the passive optical network.

20 A message sent from OLT 210 (1 in fig. 1) to ONU 230 (12 in fig. 1) would take at least the time indicated by the continuous arrow going from line 210 to line 230. Thus, the total transmission delay of the roundtrip after an instantaneous response from ONU 230 (the response being indicated by the arrow from line 230 to line 210) amounts to the distance along line 210 from the starting point of the outbound arrow to the receiving point of the inbound arrow along the time axis, that is, from frame 201 to frame 204. In conventional PONs, this roundtrip transmission delay time would be used as the uniform delay time used for all ONUs in the system, for instance for ONU 220 as well, even if a shorter communication roundtrip had been possible for the ONU 220 (10 in fig. 1) which is closer to OLT 1. In such a case, an ONU 240 (20 in fig. 1) that is located beyond the maximum service distance could not be served at all.

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In the embodiment of present invention, however, ONU 230 is individually assigned frame 204 for its upstream data

transmission, and, in a similar manner, frame 206 is assigned to ONU 240 (20 in fig. 1) for its upstream data communication, without affecting the shorter communication delay and assignment of an earlier frame of ONU 230.

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In this manner, the present embodiment provides for optimal transmission delay times for all ONUs present in the network while allowing an extended maximum service range and improved network operation when adding new nodes to the network.

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## Reference numerals

	1	Optical line termination (OLT) device
5	2	Processor
	10, 11	Optical network unit
	12	Cascading ONU
	20, 21	ONU
	30, 31, 32	Splitter
10	40	Backbone
	100	Bandwidth map
	110	First access element of bandwidth map
	120	Second access element of bandwidth map
	130	n-th access element of bandwidth map
15	150	Allocation ID field
	160	Flags field
	162	Frame identifier bit field
	164	Cascaded flag bit
	170	StartTime field
20	180	StopTime field
	190	CRC field
	201 - 208	Data frames
	210	OLT
	220	ONU 11
25	230	ONU 12
	240	ONU 20

## Claims

1. Passive optical network, comprising an optical line  
termination device (1) and a first (12) and a second (10, 20)  
5 optical network unit, the optical line termination device  
comprising a processor (2), the processor being configured to  
send and receive network signals comprised in frames (201 -  
208) and the processor being further configured to create a  
bandwidth map (100) for each of said optical network units,  
10 each bandwidth map specifying an allocated upstream data  
transmission time period (170, 180),

characterized in that

15 the processor is further configured to include a frame  
identifier (162) in each of said bandwidth maps, the frame  
identifier individually specifying a frame (204, 206) for  
upstream data transmission for the optical network unit,  
wherein the frame (204) specified for the first optical  
20 network unit is different from the frame (206) specified for  
the second optical network unit.

2. Network according to claim 1, characterized in  
that the frame identifier is included in the Flags field  
25 (160) of the bandwidth map.

3. Network according to any one of the preceding claims,  
characterized in that the processor is configured to  
create the frame identifier for each of said optical network  
30 units based on a transmission delay time between the optical  
network unit and the optical line termination device.

4. Network according to any one of the preceding claims,  
characterized in that the first optical network unit  
35 (12) is configured to connect to the second optical network  
unit (20), the second optical network unit not being directly  
connected to the optical line termination device, such that  
the first optical network unit forms a cascading unit.

5. Network according to any one of the preceding claims, characterized in that the processor is further configured to include a flag (164) in the bandwidth map, the flag being indicative of a cascading unit (12) present in the communication path.

6. Network according to any one of the preceding claims, characterized in that the processor is further configured to, upon adding a further optical network unit (21) behind a cascading unit, determine a minimum transmission delay time between the optical network unit and the optical line termination device, and continue normal network service until the minimum transmission delay time has passed.

7. Network according to any one of the preceding claims, characterized in that the calculation of the minimum transmission delay time is based on the transmission delay time between the cascading unit and the optical line termination device.

8. Optical line termination device (1) for use with a passive optical network according to any one of claims 1 to 6, the optical line termination device comprising a processor (2), the processor being configured to send and receive optical signals comprised in frames (201 - 208) and the processor being further configured to create a bandwidth map (100) specifying an allocated upstream data transmission time period, characterized in that the processor is further configured to include a frame identifier (162) in said bandwidth map, the frame identifier individually specifying a frame (204, 206) for upstream data transmission.

9. Optical line termination device according to claim 8, characterized in that the frame identifier is included in the Flags field (160) of the bandwidth map.

10. Optical line termination device according to claim 8 or 9, characterized in that the processor is configured to create the frame identifier based on a transmission delay time between the optical line termination device and an  
5 optical network unit (10 - 12, 20, 21) in the passive optical network.

11. Optical line termination device according to any one of claims 8 to 10, characterized in that the processor  
10 is further configured to include a flag (164) in the bandwidth map, the flag being indicative of a cascading unit (12) present in the communication path between the optical line termination device and an optical network unit in the passive optical network.

12. Optical line termination device according to any one of claims 8 to 11, characterized in that the processor  
15 is further configured to, upon adding an optical network unit (21) behind a cascading unit (12) in the passive optical network, determine a minimum transmission delay time between the optical line termination device and the optical network unit and continue normal network service until the minimum transmission delay time has passed.

13. Optical network unit (12) for use with a passive optical network according to any one of claims 1 to 7, comprising communication means for receiving and sending optical signals over the passive optical network, characterized in that it further comprises amplification means to amplify  
25 received optical signals and to feed the amplified signals back into the network.  
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14. Optical network unit (12) for use with a passive optical network according to any one of claims 1 to 7, comprising communication means for receiving and sending optical signals over the passive optical network, characterized in that it further comprises amplification means to amplify  
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received optical signals and to feed the amplified signals into a further passive optical network.

15. Optical network unit (12) according to claim 13 or 14,  
5 characterized in that it contains a processor configured to evaluate a frame identifier (162) included in a bandwidth map (100) received over the passive optical network, and to start upstream transmission in the frame (204) specified by the frame identifier.

10

16. Network data signal embodied in a digital carrier wave, comprising a bandwidth map data structure (100) with an Allocation ID field (150), a Flags field (160), a StartTime field (170), and a StopTime field (180), characterized  
15 in that the Flags field comprises at least one bit (162) specifying a network data frame (204, 206).

17. Network data signal according to claim 15,  
characterized in that the Flags field comprises at  
20 least one bit (164) indicative of a cascading unit (12).

FIG 1

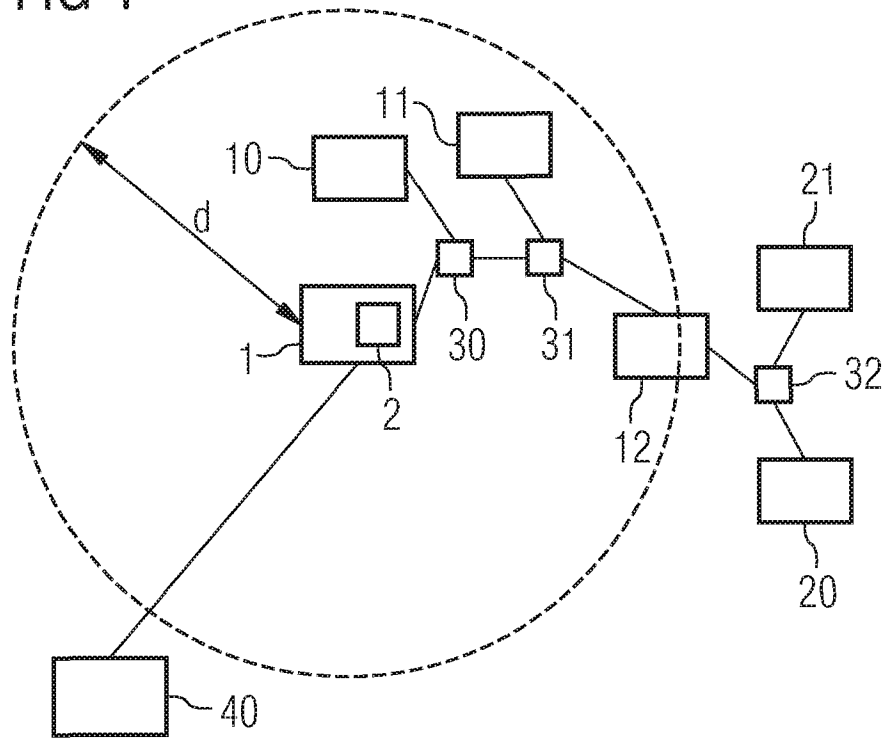


FIG 2

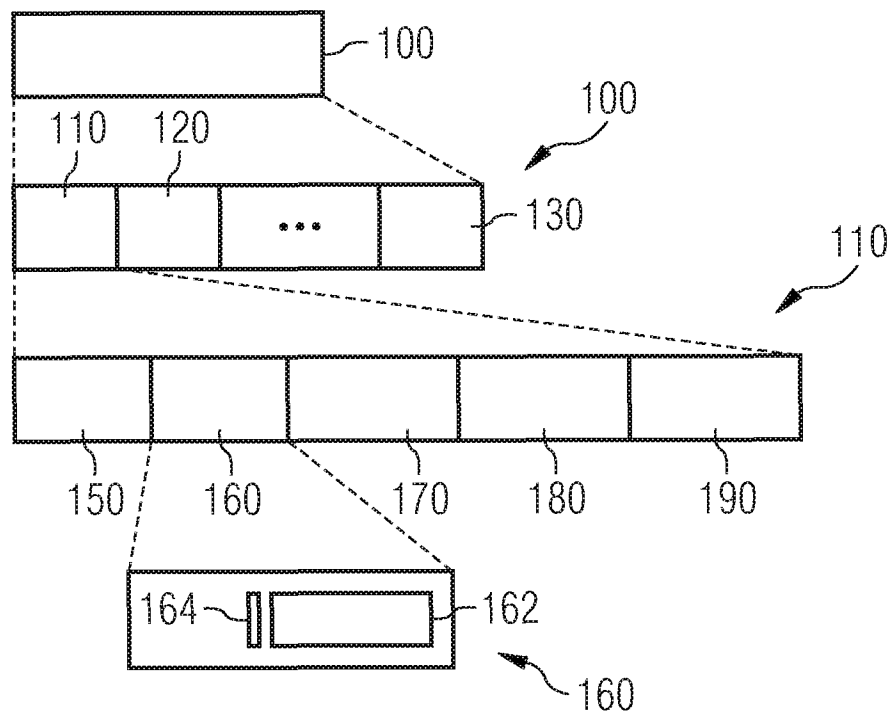


FIG 3

