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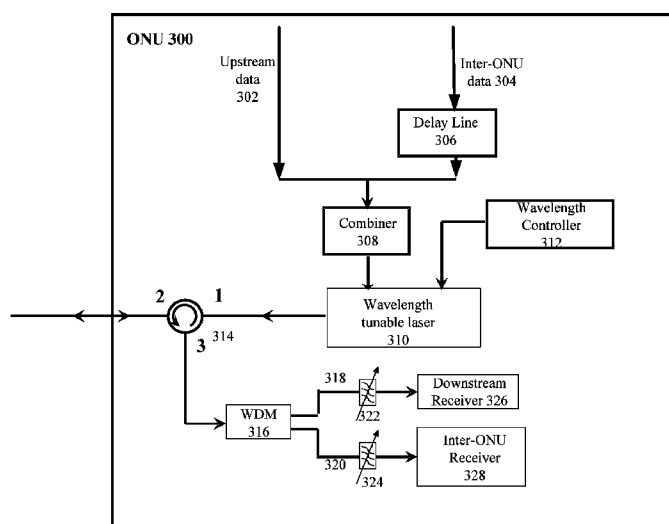


Fig. 3

(57) Abstract: The present application provides an ONU and a remote node for supporting the inter-ONU internetworking. An ONU transmitter for supporting the inter-ONU internetworking in a system comprising a plurality of PONs each having a corresponding upstream/downstream wavelength comprises: a delay line configured to delay inter-ONU data to be transmitted with respect to upstream data to be transmitted, wherein the inter-ONU data refers to data to be transmitted by the ONU to another ONU, and the upstream data refers to data to be transmitted by the ONU to an OLT; a combiner configured to combine the upstream data and the delayed inter-ONU data; and a wavelength tunable laser source configured to generate optical signals with different wavelengths to modulate the upstream data and the inter-ONU data received by the combiner, respectively.

ONU and Remote Node for Supporting Inter-ONU Internetworking

Field

5 The present disclosure generally relates to a Passive Optical Network (PON) and particularly to an Optical Network Unit (ONU) and a Remote Node for supporting inter-ONU internetworking in a system comprising a plurality of PONs.

Background

10 Time and Wavelength Division Multiplexed Passive Optical Network (TWDM-PON) has been recently selected by the Full Service Access Network (FSAN) and ITU-T Q2 group as the primary architecture for NGPON2, featuring in at least 40Gb/s downstream and 10Gb/s upstream
15 system capacity (reference document [1]). By stacking several TDM-PONs with different wavelengths, the legacy TDM-PON systems can be upgraded to a TWDM-PON with higher bandwidth. A typical 40Gb/s TWDM-PON is composed by stacking four pairs of TDM-PONs, each of which has a downstream bit rate of 10Gb/s.

20 In a TWDM-PON system, a tunable laser and a tunable optical filter should be used at the ONU side such that each ONU can arbitrarily receive and generate one of the four wavelengths for downstream signal detection and upstream signal transmission. Due to its backward compatibility, technical maturity and component availability, the
25 TWDM-PON is regarded as being closest to the practical implementation, and thus it has been widely accepted by telecom operators. In this description, the upstream data/signal/link refers to the data/signal/link from an ONU to an OLT, while the downstream data/signal/link refers to the data/signal/link from an OLT to an ONU.

In the TWDM-PON system, in addition to satisfying the bandwidth requirement for intra PON downstream/upstream signals between the Optical Line Terminal (OLT) and each Optical Network Unit (ONU), the internetworking among different ONUs is becoming essential as an ONU
5 may want to share data with other ONUs at a very high speed and low latency. The potential application scenarios for the ONU internetworking in the TWDM-PON include the following scenarios.

1) Long Term Evolution Advanced (LTE-A) Coordinated Multi-Point (CoMP): In the LTE-A CoMP technology, there is an increasing demand
10 for the base stations to directly intercommunicate and cooperate with the others to process multiple antennas via the logical X2 interface (reference document [2]). It has been estimated that the traffic exchanging via the X2 interface in the system could reach up to 10 percent of the main traffic. Therefore, high speed and low latency intercommunication between the
15 base stations is strongly desired. For instance, NSN products recommend the most strict latency in the LTE-A to be lower than 1ms to maintain required quality of service. With high speed and low latencies a must, mobile backhauling via the PON could be a potential solution and future trend. It would be rather attractive by employing the TWDM-PON
20 architecture to support the high speed and low latency base station internetworking in future mobile backhauling network.

2) Proximity service provision: In traditional 3G/LTE network, as depicted in Fig.1 (a), all data traffic has to be aggregated to the core network, even though certain data packets may only need to traverse inner
25 cellular network itself (reference document [3]). Fig. 1 (a) illustrates a schematic diagram of the interworking between base stations via the core network. When this kind of localized data traffic becomes more and more popular, it will cause severe signalling and data traffic pressure to the core network. Thus, inter base station (eNB, for example) direct transmission
30 is desired for the network operators to provide efficient proximity services. Fig.1 (b) illustrates a schematic diagram of a desired proximity service

where the data transmission between the sending user equipment (UE) and the receiving UE is handled via eNB-to-eNB data forwarding.

3) Data sharing for enterprises: With the explosive growth of data traffic, large entities such as universities and enterprises desire to establish a high speed optical link among their different buildings or branch sites. Some emerging large-scale services also require timely collaborative working with the ability to interactively share, process and visualize data that is distributed at different locations.

In traditional PON architecture, since there is only a downstream and an upstream link available between the OLT and each ONU, the ONU internetworking traffic of an ONU must be firstly transmitted to the OLT via a long distance fiber, and then returned back to other ONUs directed to by the ONU internetworking traffic after experiencing O-E-O conversion and complicated electronic processing (reference document [4]). With the long range PON transmission as a requirement for future access network, round trip propagation over 50km fiber could induce a delay as high as $\sim 0.5\text{ms}$, let alone the delay caused by the electronic processing at the OLT. Meanwhile, the workload and power consumption of the OLT would be inevitably increased.

Therefore, it is desirable to develop an innovative and cost effective TWDM-PON to enable high speed and low latency ONU internetworking for various applications.

Reference documents:

[1] FSAN white paper, "Next-generation 2 access network technology", 2012.

[2] Thomas Pfeiffer, "Converged Heterogeneous Optical Metro-Access Networks", ECOC, Tu. 5.B.1, Torino, Italy, 2010.

[3] China Unicom, "Introduction of eNB-to-eNB direct transmission for proximity service provision", 3GPP TSG RAN WG3 #75bis meeting, R3-120571.

[4] Yikai Su, Elaine Wong, et al., "All-optical virtual private network

in passive optical networks”, Laser & Photon. Rev, No.6, 2008.

Summary

Therefore, a main objective of the invention is to provide a novel low cost solution for supporting inter-ONU internetworking without significantly increased cost and decreasing the bandwidth efficiency.

An ONU transmitter for supporting inter-ONU internetworking in a system comprising a plurality of PONs is provided according to a first aspect of the invention, wherein each of the plurality of PONs has a corresponding upstream/downstream wavelength. The ONU transmitter comprises: a delay line configured to delay inter-ONU data to be transmitted with respect to upstream data to be transmitted, wherein the inter-ONU data refers to data to be transmitted by the ONU to another ONU, and the upstream data refers to data to be transmitted by the ONU to an OLT; a combiner configured to combine the upstream data and the delayed inter-ONU data; and a wavelength tunable laser source configured to generate optical signals with different wavelengths to modulate the upstream data and the inter-ONU data received by the combiner, respectively.

An ONU receiver for supporting inter-ONU internetworking in a system comprising a plurality of PONs is provided according to a second aspect of the invention, wherein each of the plurality of PONs has a corresponding upstream/downstream wavelength. The ONU receiver comprises: an optical circulator configured to separate received downstream data and inter-ONU data from data to be transmitted, wherein the downstream data refers to data received from an OLT, the inter-ONU data refers to data from another ONU, and the downstream data and the inter-ONU data being transmitted on different wavelengths and different time slots; a first optical filter configured to filter out the downstream data according to its wavelength; and a second optical filter configured to filter out the inter-ONU data according to its wavelength.

A remote node for supporting inter-ONU internetworking in a system comprising a plurality of PONs is provided according to a third aspect of the invention, wherein each of the plurality of PONs has a corresponding upstream/downstream wavelength. The remote node comprises: a sampled grating having a plurality of reflective channels, wherein wavelengths of the reflective channels are aligned with the inter-ONU internetworking wavelengths of the plurality of PONs, wherein the sampled grating is configured to forward data from respective ONUs within the plurality of PONs to an OLT, and to reflect and broadcast the inter-ONU data from respective ONUs to all ONUs in the system.

An ONU comprising the above ONU transmitter and ONU receiver is provided according to a fourth aspect of the invention.

A system comprising the above ONU transmitter, ONU receiver and remote node is provided according to a fifth aspect of the invention.

Inter-ONU internetworking with a high speed and low latency can be realized using solutions of the invention.

Brief description of drawings

The present invention will be understood better and other objectives, details, features and advantages of the present invention will become more evident from the description of specific embodiments of the invention given in conjunction with the following figures, wherein:

Fig. 1 (a) illustrates a schematic diagram of the internetworking between base stations via a core network in the prior art;

Fig. 1 (b) illustrates a schematic diagram of a desired proximity service;

Fig. 2 illustrates an architecture of a TWDM-PON system supporting ONU internetworking according to an embodiment of the invention;

Fig. 3 illustrates a schematic diagram of the structure of an ONU supporting inter-ONU internetworking according to an embodiment of the

invention;

Fig. 4 illustrates a schematic diagram of time slot allocation and wavelength allocation for upstream traffic and inter-ONU traffic within a PON according to an embodiment of the invention;

Fig. 5 illustrates a schematic diagram of time slot allocation and wavelength allocation for upstream traffic and inter-ONU traffic within a PON according to another embodiment of the invention;

Fig. 6 illustrates an example of wavelength allocation scheme; and

Fig. 7 illustrates a schematic diagram of structure of a remote node according to the invention.

Detailed description

Previously, some solutions have been proposed for realizing ONU internetworking in TDM-PON and Wavelength Division Multiplexed Passive Optical Network (WDM-PON) systems. However, there are several inevitable technical problems in traditional solutions, which may be summarized as below.

1) In some solutions, the ONU is equipped with two laser sources. In addition to the upstream laser source, each ONU needs an extra transmitter with a different wavelength to generate and transmit the inter-ONU traffic, which consumes one additional laser resource and thus greatly increases the ONU cost.

2) In some other solutions, the remote node utilizes very complex active E-O switches to route the inter-ONU traffic to other ONUs, which greatly introduces high time delay, high complexity and eventually induces high cost of the whole system.

3) Additionally, in some solutions, although a single laser is utilized at the ONU, the inter-ONU traffic is carried at the same wavelength with the upstream signal but at different time slots. In this case, the ONU internetworking is realized by robbing the time slots of the upstream

signal for inter-ONU data sharing. The time interval (or the guard time) between two adjacent ONU data traffics has to be enlarged to insert the inter-ONU data in the time domain. Hence, the normal upstream signal will severely be loaded with the inter-ONU traffic and part of the time slots for normal upstream signal transmission is wasted, which dramatically reduces the bandwidth efficiency and finally degrades the network performance as a whole. Also, an E-O switch array is utilized at the OLT to extract the inter-ONU traffic from the upstream signal in the time domain and then the extracted signal is transmitted back to all the other ONUs. This would induce great delay at the OLT side. More important, it is a challenging task to accurately perform the synchronization to extract the inter-ONU traffic and thus it is not practical to be implemented.

Therefore, all of these solutions can not properly solve the problem of inter-ONU interworking in the TWDM-PON.

In view of this, this invention provides a novel and low cost architecture of TWDM-PON system to achieve inter-ONU internetworking with a fast speed and low latency.

Preferred embodiments of the present invention will now be described in more details in conjunction with accompanying figures. Although preferred embodiments of the present invention are shown in the accompanying figures, it should be understood that the present disclosure can be embodied in various ways but not be limited to the embodiments depicted herein. Instead, the embodiments are provided herein to make the disclosure more throughout and complete and convey the scope of the present disclosure to those skilled in this art.

Fig. 2 illustrates architecture of a TWDM-PON system 200 supporting ONU internetworking according to an embodiment of the invention. As shown in Fig.2, the system 200 includes an OLT 210, one or more ONUs 220 (such as $ONU_1, \dots, ONU_i, \dots, ONU_j, \dots, ONU_n, \dots$), and a remote node 230. The structure of the OLT 210 is the same as conventional used,

therefore it will not be described in detail unnecessarily. Structures of the ONU 220 and the remote node 230 designed according this invention will be described below with reference to Fig. 3 and Fig. 7.

As mentioned above, the TWDM-PON system 200 according this invention is generally achieved by stacking several TDM-PON systems. Hereinafter, an example in which the TWDM-PON system 200 includes four TDM-PON systems (each named PON1 (with downstream wavelength and upstream wavelength of λ_{1d} and λ_{1u} , respectively), PON2 (with downstream wavelength and upstream wavelength of λ_{2d} and λ_{2u} , respectively), PON3 (with downstream wavelength and upstream wavelength of λ_{3d} and λ_{3u} , respectively), and PON4 (with downstream wavelength and upstream wavelength of λ_{4d} and λ_{4u} , respectively), respectively) will be described. The TWDM-PON system 200 according this invention supports both intra-PON and inter-PON ONU internetworking, which is achieved through properly controlling wavelengths of an ONU transmitter and an ONU receiver. Herein, the intra-PON refers to a case in which all OUNs are in the same upstream/downstream wavelength channel, while the inter-PON refers to a case in which different OUNs are in different upstream/downstream wavelength channels.

Taking Fig. 2 as an example, it's assumed that ONU_1 , ONU_i and ONU_n belong to PON1, and ONU_j belongs to PON2. Therefore, as shown by broken line arrow in the right side of Fig. 2, the internetworking between ONU_1 and ONU_i is intra-PON internetworking (i.e., within PON1), while the internetworking between ONU_j and ONU_n is inter-PON internetworking (i.e., between PON1 and PON2).

Process of intra-PON and inter-PON internetworking according this invention will be described briefly in combination with Fig.2 hereinafter. For the intra-PON internetworking, as shown in Fig.2, when ONU_1 needs to establish an intra-PON internetworking with ONU_i , ONU_1 may transmit upstream traffic and inter-ONU traffic at wavelengths of λ_{1u} and λ_{1-int} in

different time slots, where λ_{1-int} refers to a wavelength used by the ONU₁ for the inter-ONU internetworking. At the remote node 230, the inter-ONU traffic from ONU₁ at the wavelength of λ_{1-int} will be reflected back to ONU_i by a sampled grating (such as a sampled fiber Bragg grating (SFBG)) while the upstream traffic from ONU₁ at the wavelength of λ_{1u} will be directly transmitted to the OLT. At ONU_i, the tunable optical filter therein can be properly adjusted to let λ_{1-int} pass through, thus the internetworking between ONU₁ and ONU_i is achieved.

For the inter-ONU internetworking, as shown in Fig.2, when ONU_j needs to establish an inter-PON internetworking with ONU_n, ONU_j may transmit upstream traffic and inter-ONU traffic at wavelengths of λ_{2u} and λ_{2-int} in different time slots, where λ_{2-int} refers to a wavelength used by the ONU_j for the inter-ONU internetworking. At the remote node 230, the inter-ONU traffic with the wavelength of λ_{2-int} from the ONU_j will be reflected back to the ONU_n by a sampled grating in the remote node 230, while the upstream traffic with the wavelength of λ_{2u} from the ONU_j will be directly transmitted to the OLT. At the ONU_n, the tunable optical filter can be properly adjusted to make the λ_{2-int} pass through, thus the internetworking between the ONU_j and ONU_n is achieved. Therefore, an inter-PON ONU all-optical internetworking with high speed and low latency could be established.

Structures and operating principles of the ONU and the remote node according to the invention will be described below with reference to Figs. 3-6.

Fig. 3 illustrates a schematic diagram of the structure of an ONU 300 supporting inter-ONU internetworking according to an embodiment of the invention. The ONU 300 may be used as the ONUs 220 such as ONU₁, ..., ONU_i, ..., ONU_j, ..., ONU_n, ... as shown in Fig.2.

The ONU 300 will be described hereinafter from the transmitter's perspective and receiver's perspective respectively.

From transmitter's perspective, as shown in Fig. 3, the ONU 300

includes two branches 302 and 304 both configured to generate, receive or otherwise acquire upstream data and inter-ONU data. The upstream data 302 refers to data to be transmitted by the ONU 300 to an OLT (such as the OLT 210 in Fig. 2), while the inter-ONU data refers to
5 internetworking data to be transmitted by the ONU 300 (such as the ONU_i or ONU_j in Fig. 2) to another ONU (such as the ONU_i or ONU_n in Fig. 2).

The ONU 300 further includes a delay line 306 configured to delay the inter-ONU data 304 by a time Δt with respect to the upstream data 302. The delay line 306 enables the upstream data 302 and the inter-ONU data
10 304 to be transmitted on different time slots. The delay time Δt will be further described below with reference to Fig. 4 and Fig. 5.

Next, a combiner 308 combines the inter-ONU data 304 delayed by the time Δt through the delay line 306 and the upstream data 302, and provides the combined signal to a wavelength tunable laser source 310.

Different from the ONU structure using two laser sources as mentioned above, the ONU 300 shown in Fig. 3 only includes one laser source 310 whose wavelength is tunable such that optical signals with different wavelengths may be used to modulate the upstream data 302 and the inter-ONU data 304. That is to say, the upstream data 302 and the
20 inter-ONU data 304 may share one laser source instead of using two separate laser sources.

In one implementation, the ONU 300 further includes a wavelength controller 312 configured to generate a wavelength control signal to trigger the wavelength tunable laser source 310 to adjust the wavelength.

In one implementation, the wavelength adjustment of the wavelength tunable laser 310 is implemented by a small step Δ as a unit. For example, if the total number of steps of adjustment for upstream wavelength between two adjacent PONs (such as the PON1 and the PON2) is M (which is an integer equal to or greater than 1), then $\lambda_{2u} - \lambda_{1u} = M * \Delta$.

Therefore, by applying a proper wavelength control signal, the upstream data 302 and the inter-ONU data 304 of the ONU 300 can be
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transmitted at different time slots and with different wavelengths by the ONU 300 according to the invention. In this manner, the transmission of the inter-ONU traffic does not need to rob the time slot for upstream data.

Fig. 4 illustrates a schematic diagram of time slot allocation and wavelength allocation for upstream traffic and inter-ONU traffic within a PON according to an embodiment of the invention. For the intra-PON traffic, no time slot allocation is required for the inter-ONU internetworking because upstream/downstream wavelengths for different PONs are different.

As shown in Fig. 4, it's assumed that $ONU_1, \dots, \text{and } ONU_n$ all belong to PON1 (whose downstream wavelength and upstream wavelength are λ_{ld} and λ_{lu} , respectively). Upstream data of these ONUs construct upstream frames (such as upstream frame 1, upstream frame 2, ...). Upstream data of $ONU_1, \dots, \text{and } ONU_n$ are transmitted on time slots $T_1, \dots \text{ and } T_n$ respectively. The time interval between two adjacent time slots is called as a guard time GP. That is to say, $GP = T_2 - T_1 = T_3 - T_2 = \dots = T_n - T_{n-1}$.

Fig. 4 particularly shows a case in which a wavelength tuning time τ is smaller than the guard time GP. The wavelength tuning time τ is a parameter of the wavelength tunable laser source 310 and thus is that of the ONU 300, which is determined by the characteristic of the wavelength tunable laser source 310 itself.

The inter-ONU data of $ONU_1, \dots, \text{and } ONU_n$ are delayed by a time Δt with respect to time slots $T_1, \dots \text{ and } T_n$ respectively. The inter-ONU data of these ONUs construct the inter-ONU frames (such as inter-ONU frame 1, inter-ONU frame 2, ...). The inter-ONU data of $ONU_1, \dots, \text{and } ONU_n$ are transmitted on time slots $T_1 + \Delta t, \dots, \text{and } T_n + \Delta t$ respectively. It can be understood that the delay time Δt is only required to be not small than the wavelength tuning time τ .

When transmitting the inter-ONU data, the wavelength controller 312 is triggered to control the wavelength of the wavelength tunable laser source 310 to shift several steps (Δ) to modulate the inter-ONU data. For

example, a wavelength for the inter-ONU data of the ONU₁ may be λ_{1-int} , then the number of steps for wavelength adjustment from the transmission of upstream data of the ONU₁ to that of the inter-ONU data of the ONU₁ is $(\lambda_{1-int}-\lambda_{1u})/\Delta$.

5 A wavelength (such as λ_{1-int} , λ_{2-int} , λ_{3-int} , λ_{4-int} for PON1, PON2, PON3, PON4 respectively) for transmitting the inter-ONU data may be set to be any wavelength between two adjacent upstream wavelengths.

In one implementation, wavelengths λ_{1-int} , λ_{2-int} , λ_{3-int} , λ_{4-int} for transmitting the inter-ONU data may be set to be the middle between two adjacent upstream wavelengths. Thus, for the wavelength adjustment from a wavelength for upstream data transmission of an ONU to that for inter-ONU data transmission of the ONU (from λ_{1u} to λ_{1-int} , for example), the number of steps for the wavelength adjustment is only half of that for a normal PON upstream wavelength tuning (from λ_{1u} to λ_{2u} , for example).

10 It could be understood that if there is no ONU internetworking demand, the wavelength shifting is unnecessary.

After making the above mentioned adjustment to the wavelength of wavelength tunable laser source 310 under the control of the wavelength controller 312, a light with the adjusted wavelength is used to modulate the inter-ONU internetworking data for transmission. The inter-ONU data from different ONUs constitute the inter-ONU frames for the ONU internetworking. Note that in this case, the inter-ONU traffic can reuse the time slots that are also loaded with other ONU's upstream traffic (e.g. inter-ONU data of the ONU₁ can overlap with the ONU₂'s upstream data in the time slot of T₂, as shown in Fig. 4) since they are operating in different wavelengths. The same wavelength tuning and ONU internetworking data generation method can be similarly applied to all the ONUs.

25 Next, after transmission of the inter-ONU internetworking data (such as the inter-ONU frame 1) at wavelength of λ_{1-int} , wavelength of the laser source 310 is reversely adjusted the same number of steps under the

control signal of the wavelength controller 312 such that the ONU 300's wavelength could be returned to the normal state at λ_{lu} for transmitting upstream data in the upstream frame 2. This process can be repeated for the generation and wavelength shifting for other upstream data and inter-ONU data of inter-ONU frames.

Fig. 5 illustrates a schematic diagram of time slot allocation and wavelength allocation for upstream traffic and inter-ONU traffic within a PON according to another embodiment of the invention. Fig. 5 particularly shows a case in which for the ONU 300, the wavelength tuning time τ is larger than the guard time GP. As shown in Fig. 5, if the wavelength tuning time τ is larger than the guard time, the inter-ONU data traffic is still only needed to be delayed by a time Δt which is no less than the wavelength tuning time τ . Then, the wavelength shifting and inter-ONU data modulation could be done in the same way as described with respect to Fig. 4. In this case, the inter-ONU data can also temporally overlap with the upstream data of other ONUs. For instance, in Fig. 5, the inter-ONU data of ONU₁ can reuse the upstream time slot T₃ of ONU₃. After the inter-ONU data transmission, similar method for the wavelength tuning and normal upstream data modulation can be applied.

It can be seen from Fig. 4 and Fig. 5 that the delay time Δt is only required to be no smaller than the wavelength tuning time τ , no matter whether the wavelength tuning time τ is large or small. Also, there is no strict requirement for the relation between the delay time Δt and the guard time GP. That is to say, there is no restrict for the wavelength tuning time τ of the ONU, and thus the present invention may be applied to any existing and future presented wavelength tunable ONUs having various wavelength tuning times. The proposed approach in this invention has no strict requirement for the wavelength tuning speed.

Fig. 6 illustrates an example of a wavelength allocation scheme. The upstream wavelength channel spacing is assumed to be 100GHz. The ONU internetworking wavelength for each channel is set to be 50GHz

apart from the PON upstream wavelength individually. For instance, λ_{1-int} is set to be shifted by 50GHz from λ_{1u} . Each time when the inter-ONU internetworking is initiated, the wavelength of the tunable ONU transmitter 310 is tuned to a corresponding one of λ_{1-int} , λ_{2-int} , λ_{3-int} , λ_{4-int} , which coincides with one of the reflective wavelengths of the SFBG, so the inter-ONU traffic will be directly reflected back to other ONUs and no complicated O-E-O conversion and long distance propagation between the OLT and ONU are required any more.

Turning back to Fig. 3, the ONU 300 will be described from receiver's perspective below.

The ONU 300 used as a receiver includes an optical circulator 314 configured to separate received downstream data and inter-ONU data from upstream data and inter-ONU data to be transmitted. In particular, modulated upstream data 302 and inter-ONU data 304 transmitted by the wavelength tunable laser source 310 are outputted from a port 2 of the optical circulator 314 and transmitted to a remote node (such as a remote node 230) after passing through the optical circulator 314. The downstream data from the remote node 230 (from the OLT 210) and the inter-ONU data (from ONUs other than the ONU 300) are outputted from a port 3 of the optical circulator 314 after passing through the optical circulator 314.

The ONU 300 further includes a Wavelength Division Multiplexing (WDM) filter 316 configured to separate the downstream data and the inter-ONU data on different wavebands into two branches 318 and 320. Since the downstream signal and the ONU internetworking signal occupy different wavelength bands (e.g. L+ wavelength band for downstream signal, and C- wavelength band for inter-ONU signal), a coarse WDM filter 316 may be used to separate the two kinds of signals. Herein, for convenience, the separated downstream data and inter-ONU data are called as downstream data 318 and inter-ONU data 320 respectively.

In the branch 318, the ONU 300 further includes an optical filter 322 configured to filter out the downstream data. For example, the optical filter 322 is a band pass filter (BPF) with a centre wavelength of λ_{1d} , which can filter out the downstream data 318 with the wavelength of λ_{1d} .

5 In the branch 320, the ONU 300 further includes a tunable optical filter 324 configured to filter out the inter-ONU data 320. For example, the optical filter 324 is a band pass filter (BPF) with a tunable centre wavelength, whose centre wavelength is tunable among λ_{1-int} , λ_{2-int} , λ_{3-int} , and λ_{4-int} to filter out the inter-ONU data 320 with the wavelengths of λ_{1-int} ,
10 λ_{2-int} , λ_{3-int} , or λ_{4-int} .

Herein, when the wavelength of the inter-ONU data 320 filtered out by the optical filter 324 is the same with the inter-ONU wavelength of the ONU 300, it can be determined that the inter-ONU data 320 is the inter-ONU internetworking data from another ONU within the same PON,
15 i.e. intra-PON internetworking data. However, when the wavelength of the inter-ONU data 320 filtered out by the optical filter 324 is different from the inter-ONU wavelength of the ONU 300, it can be determined that the inter-ONU data 320 is the inter-ONU internetworking data from another ONU within a different PON, i.e. inter-PON internetworking data.

20 Next, the downstream data 318 and the inter-ONU data 320 filtered out by the optical filters 322 and 344 are forwarded to corresponding downstream receiver 326 and ONU internetworking receiver 328 for processing respectively.

In this way, both the downstream traffic and the inter-ONU traffic can
25 be simultaneously detected in each ONU. By adjusting the tunable optical filter 324, arbitrary ONU internetworking in either intra-PON or inter-PON can be supported.

It can be understood by those skilled in this art that the WDM filter 316 may not be included in the ONU 300. In this case, the ONU 300 does
30 not separate the received downstream data and inter-ONU data cursorily according to the wavelength bands. Instead, the downstream data and

inter-ONU data are filtered out directly by the optical filter 322 and the tunable optical filter 324 according to the wavelengths.

Fig. 7 illustrates a schematic diagram of structure of a remote node 700 according to the invention. The remote node 700 may be used as the remote node 230 shown in Fig. 2.

As shown in Fig. 7, the remote node 700 includes an optical splitter/combiner 710 and a sampled grating 720.

The optical splitter/ combiner 710 is configured to couple upstream data from respective ONUs onto the same optical fiber to be transmitted to the OLT (such as the OLT 210) and to distribute downstream data from the OLT to all ONUs. The optical splitter/combiner 710 is the same as conventionally used in the art and thus will not be described in detail.

The sampled grating 720 is specially designed to have four reflective channels. Wavelengths of these reflective channels are spectrally aligned with the inter-ONU internetworking wavelengths (λ_{1-int} , λ_{2-int} , λ_{3-int} , and λ_{4-int}) respectively.

In one implementation, the sampled grating 720 includes a sampled fiber Bragg grating (SFBG).

Using the specially designed SFBG 720, at the remote node 700, downstream and upstream wavelengths (λ_{1d} , λ_{2d} , λ_{3d} , λ_{4d} and λ_{1u} , λ_{2u} , λ_{3u} , λ_{4u}) can be transmitted through the SFBG 720 directly, while the inter-ONU internetworking wavelengths (λ_{1-int} , λ_{2-int} , λ_{3-int} , and λ_{4-int}) will be reflected and broadcasted to all OUNs.

This invention proposes a novel method and apparatus for ONU all-optical internetworking with high speed and low latency in TWDM-PON. The main advantages of this invention against solutions in the prior art are summarized as below:

1. Low cost: Unlike utilizing two ONU laser sources for upstream and inter-ONU traffic transmission in the prior art, only a single

wavelength tunable ONU laser source that is essential in TWDM-PON is employed for modulating the upstream signal and the inter-ONU internetworking signal, thus it could greatly save the ONU cost with advanced functionality of internetworking.

5 2. Improved bandwidth efficiency: Unlike the conventional solution that simply loading the inter-ONU traffic into the upstream traffic by enlarging the time interval between two adjacent ONU upstream traffics, which greatly reduce the upstream bandwidth efficiency, in this invention, the time slot assignment of the ONU upstream traffics is not affected by
10 the internetworking. The inter-ONU data traffic does not rob the time slot of the upstream PON signal since the two kinds of traffics are transmitted at different wavelength channels, which is enabled by the wavelength tunable ONU laser source. The inter-ONU data can even be overlapped with the upstream traffic of other ONUs in the time domain, so the
15 bandwidth efficiency can be greatly improved, doubled from conventional method, for example.

 3. Low latency: Rather than transmitting the inter-ONU traffic to the OLT for complicated E-O switching and electronic processing in the conventional approach, a compact sampled FBG (SFBG) is utilized at the
20 remote node to enable efficient all-optical ONU internetworking in the TWDM-PON architecture at very low cost and low latency. The internetworking traffic can be easily extracted from the upstream traffic by the SFBG in the spectral domain, so no complicated E-O switches and time domain synchronization are required for separation of both types of
25 traffics. Also, the OLT's workload and power consumption can be greatly reduced. For a 5km distribution link between the ONU and remote node, the ONU internetworking latency could be as low as 50us.

 4. Arbitrary ONU internetworking: All-optical ONU internetworking between any ONUs including both the intra-PON and the inter-PON
30 communications can be supported by using the ONU structure designed by the invention, through selecting appropriate wavelength.

5. Improved system capacity: All the internetworking data traffics transmitted from different ONUs at different wavelengths can be simultaneously supported in the system, so the system capacity and network efficiency for the inter-ONU internetworking is greatly enhanced.

Considering these benefits, the proposed technique is an attractive solution for high speed and low latency inter-ONU internetworking in TWDM-PON. The proposed method may become a promising solution for the X2 interface between the BBU hotels in future optical-wireless converged access network.

This invention is described above by using the TWDM-PON system formed by four overlapped TDM-PON systems as an example. However, this invention is not limited thereto, instead can be applied to any systems containing a plurality of PONs having different upstream/downstream wavelengths to realize the inter-ONU internetworking.

In one or more exemplary designs, the functions of the present application may be implemented using hardware, software, firmware, or any combinations thereof. In the case of implementation with software, the functions may be stored on a computer readable medium as one or more instructions or codes, or transmitted as one or more instructions or codes on the computer readable medium. The computer readable medium comprises a computer storage medium and a communication medium. The communication medium includes any medium that facilitates transmission of the computer program from one place to another. The storage medium may be any available medium accessible to a general or specific computer. The computer-readable medium may include, for example, but not limited to, RAM, ROM, EEPROM, CD-ROM or other optical disc storage devices, magnetic disk storage devices, or other magnetic storage devices, or any other medium that carries or stores desired program code means in a manner of instructions or data structures accessible by a general or specific computer or a general or specific processor. Furthermore, any connection may also be considered as a computer-readable medium. For

example, if software is transmitted from a website, server or other remote source using a co-axial cable, an optical cable, a twisted pair wire, a digital subscriber line (DSL), or radio technologies such as infrared, radio or microwave, then the co-axial cable, optical cable, twisted pair wire, digital subscriber line (DSL), or radio technologies such as infrared, radio or microwave are also covered by the definition of medium.

The various illustrative logical blocks, modules, and circuits described in connection with the disclosure herein may be implemented or performed with a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any normal processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the disclosure herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope

of the present disclosure.

The above depiction of the present disclosure is to enable any of those skilled in the art to implement or use the present invention. For those skilled in the art, various modifications of the present disclosure are obvious, and the general principle defined herein may also be applied to other transformations without departing from the spirit and protection scope of the present invention. Thus, the present invention is not limited to the examples and designs as described herein, but should be consistent with the broadest scope of the principle and novel characteristics of the present disclosure.

CLAIMS

1. An Optical Network Unit (ONU) transmitter for supporting inter-ONU internetworking in a system comprising a plurality of Passive Optical Networks (PONs) each having a corresponding upstream/downstream wavelength, comprising:

a delay line configured to delay inter-ONU data to be transmitted with respect to upstream data to be transmitted, wherein the inter-ONU data refers to data to be transmitted by the ONU to another ONU, and the upstream data refers to data to be transmitted by the ONU to an Optical Line Terminal (OLT);

a combiner configured to combine the upstream data and the delayed inter-ONU data; and

a wavelength tunable laser source configured to generate optical signals with different wavelengths to modulate the upstream data and the inter-ONU data received from the combiner, respectively.

2. The ONU transmitter according to claim 1, further comprising:

a wavelength controller configured to generate a wavelength control signal to trigger the wavelength tunable laser source to adjust wavelengths.

3. The ONU transmitter according to claim 1, wherein wavelength adjustment of the wavelength tunable laser is implemented by a small step as a unit.

4. The ONU transmitter according to claim 1, wherein a wavelength for transmitting the inter-ONU data by the wavelength tunable laser is set to be any wavelength between two adjacent upstream wavelengths.

5. The ONU transmitter according to claim 1, wherein a wavelength for transmitting the inter-ONU data by the wavelength tunable laser is set to be at middle between two adjacent upstream wavelengths.

6. The ONU transmitter according to claim 1, wherein the wavelength tunable laser adjusts reversely its wavelength to the upstream wavelength for transmitting the upstream data after transmitting the inter-ONU data.

7. An Optical Network Unit (ONU) receiver for supporting inter-ONU internetworking in a system comprising a plurality of Passive Optical Networks (PONs) each having a corresponding upstream/downstream wavelength, comprising:

5 an optical circulator configured to separate received downstream data and inter-ONU data from data to be transmitted, wherein the downstream data refers to data received from an Optical Line Terminal (OLT), the inter-ONU data refers to data from another ONU, and the downstream data and the inter-ONU data being transmitted on different wavelengths and different time
10 slots;

a first optical filter configured to filter out the downstream data according to its wavelength; and

a second tunable optical filter configured to filter out the inter-ONU data according to its wavelength.

15 8. The ONU receiver according to claim 7, wherein the second tunable optical filter is a band pass filter with tunable center wavelengths which correspond to corresponding wavelength for transmitting the inter-ONU data in the plurality of PONs, respectively.

9. The ONU receiver according to claim 7, furthering comprising:

20 a Wavelength Division Multiplexing (WDM) filter configured to be preceding the first optical filter and the second tunable optical filter to separate the downstream data and the inter-ONU data according to different wavebands at which the downstream data and the inter-ONU data are located respectively.

25 10. A remote node for supporting inter-Optical Network Unit (ONU) internetworking in a system comprising a plurality of Passive Optical Networks (PONs) each having a corresponding upstream/downstream wavelength, comprising:

a sampled grating having a plurality of reflective channels, wherein
30 wavelengths of the reflective channels are aligned with inter-ONU internetworking wavelengths of the plurality of PONs,

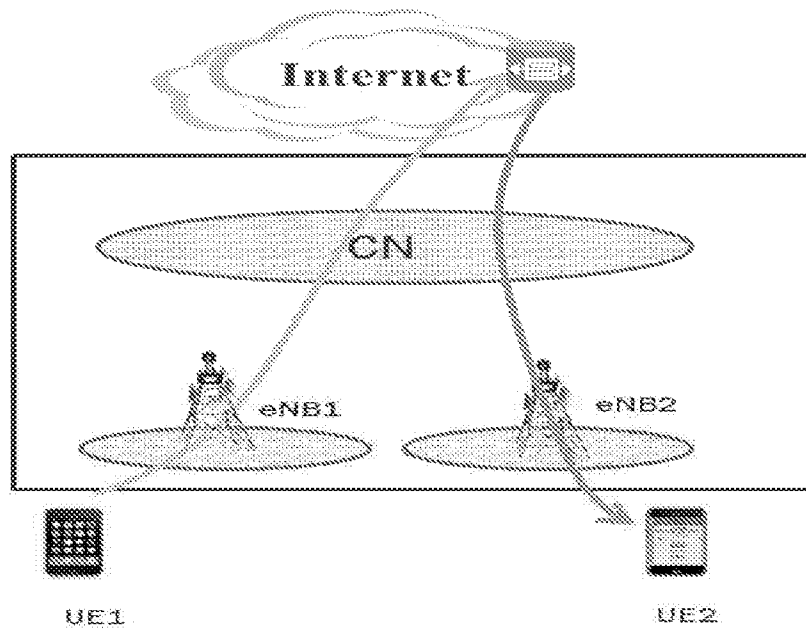
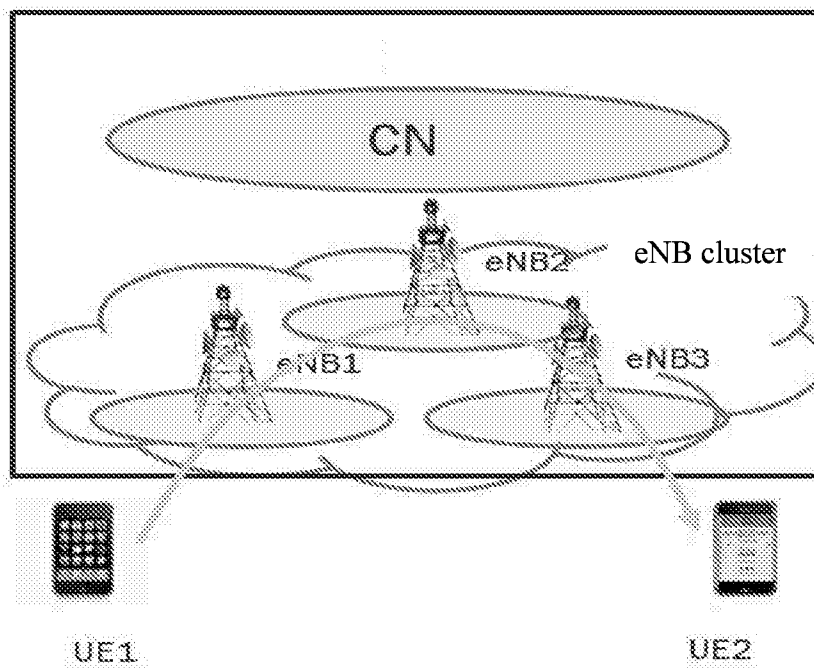
wherein the sampled grating is configured to forward data from respective ONUs within the plurality of PONs to an Optical Line Terminal (OLT), and to reflect and broadcast the inter-ONU data from respective ONUs to all ONUs in the system.

5 11. The remote node according to claim 10, further comprising:

an optical splitter/combiner configured to couple upstream data from respective ONUs onto a same optical fiber to be transmitted to the OLT and to distribute downstream data from the OLT to all ONUs.

10 12. An Optical Network Unit (ONU) for supporting inter-ONU internetworking in a system comprising a plurality of Passive Optical Networks (PONs), comprising the ONU transmitter according to any one of claims 1-6 and the ONU receiver according to any one of claims 7-9.

15 13. A system for supporting inter-Optical Network Unit (ONU) internetworking and comprising a plurality of Passive Optical Networks (PONs), comprising the ONU transmitter according to any one of claims 1-6, the ONU receiver according to any one of claims 7-9 and the remote node according to any one of claims 10-11.

**Fig. 1 (a)****Fig. 1 (b)**

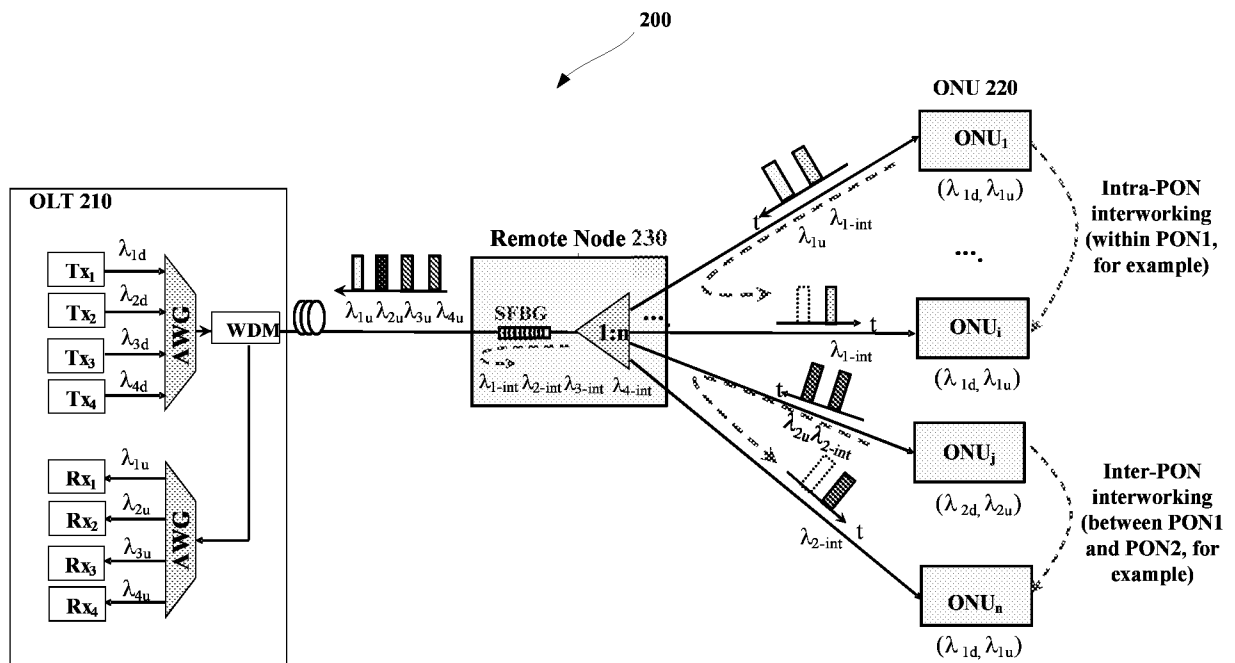
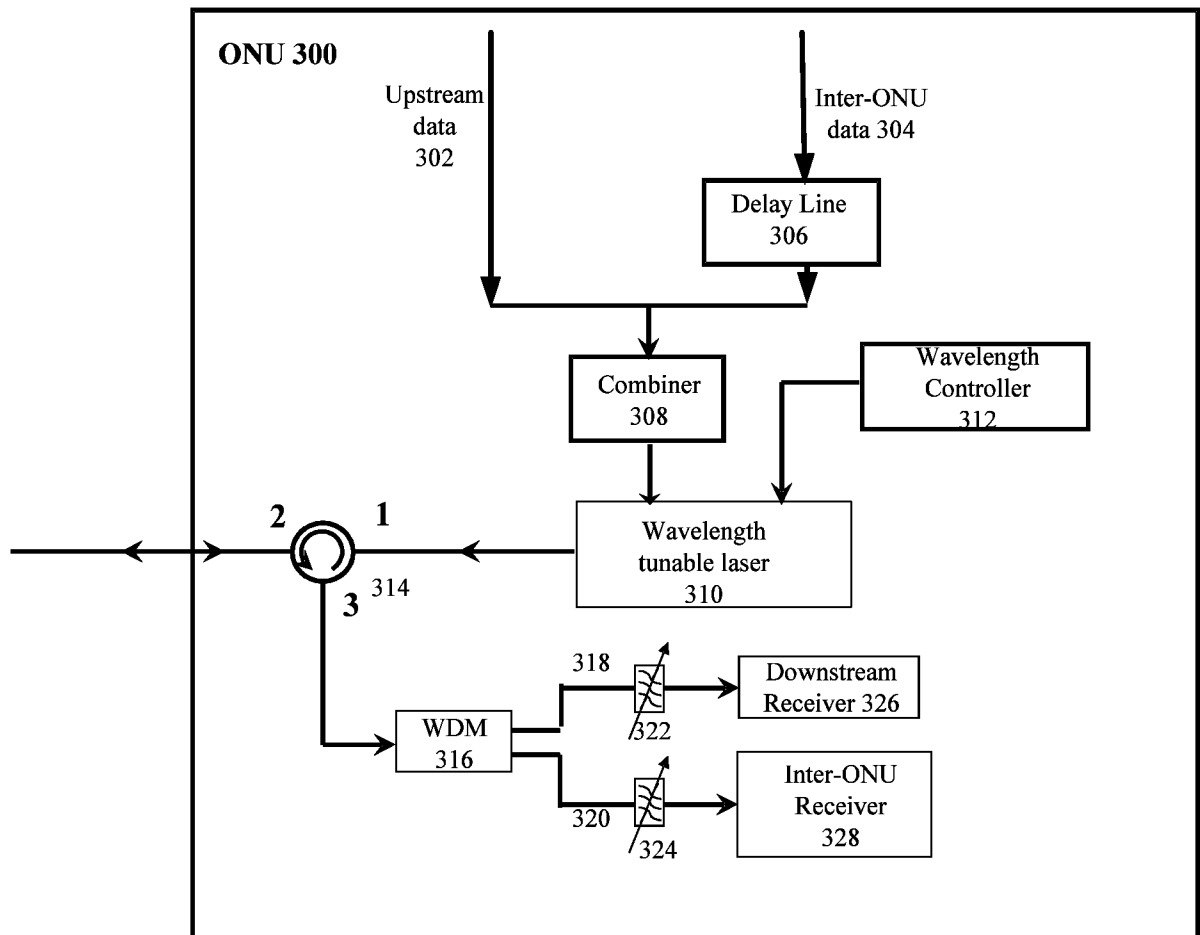
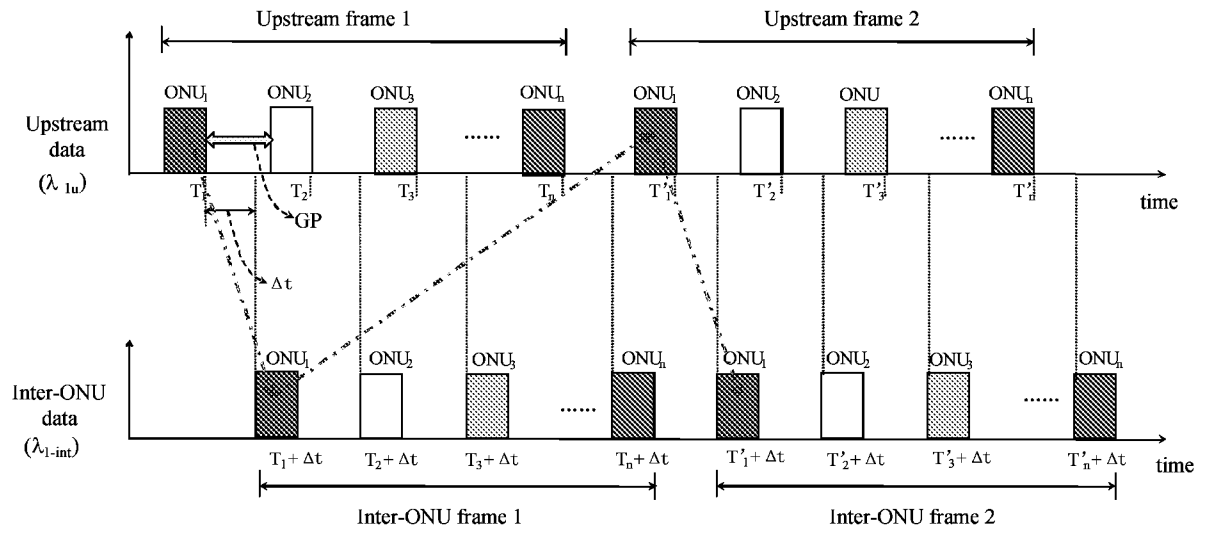
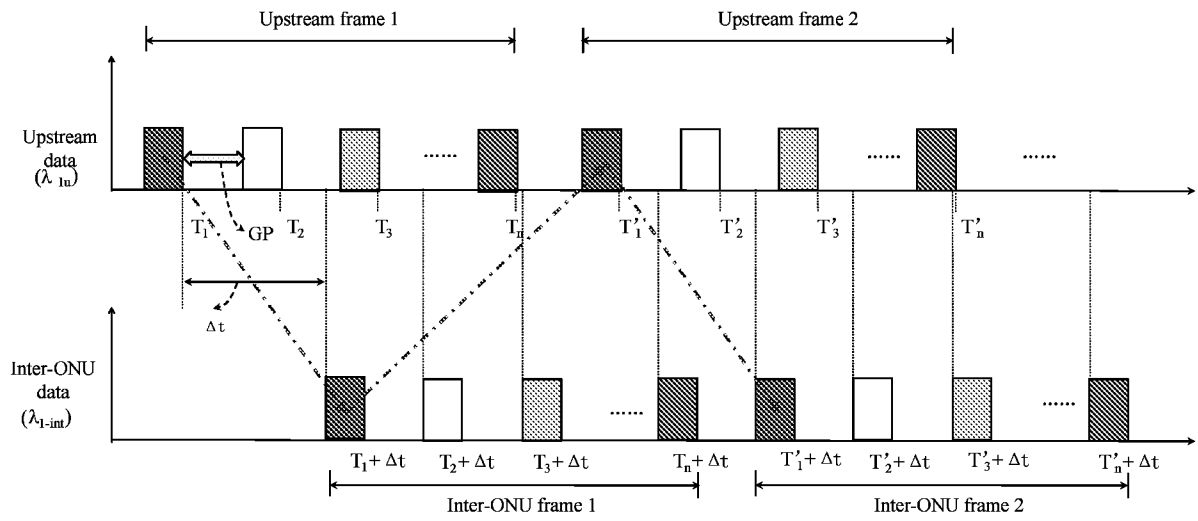
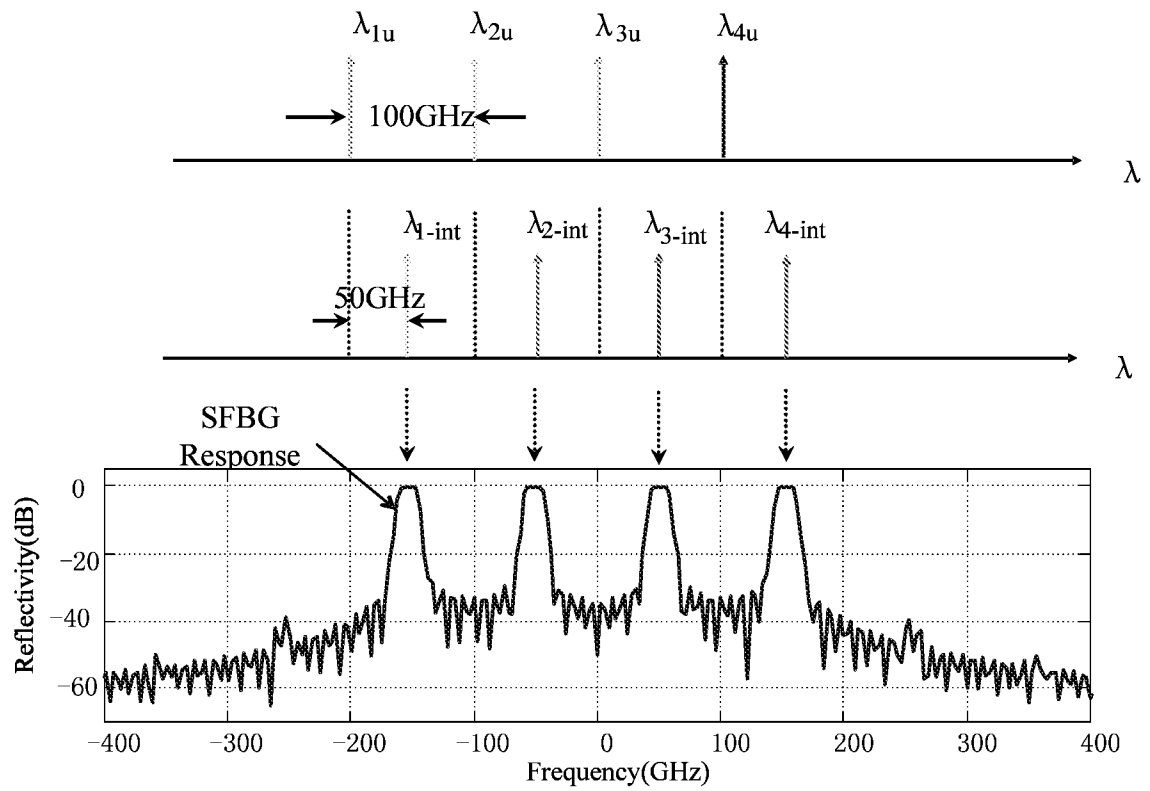


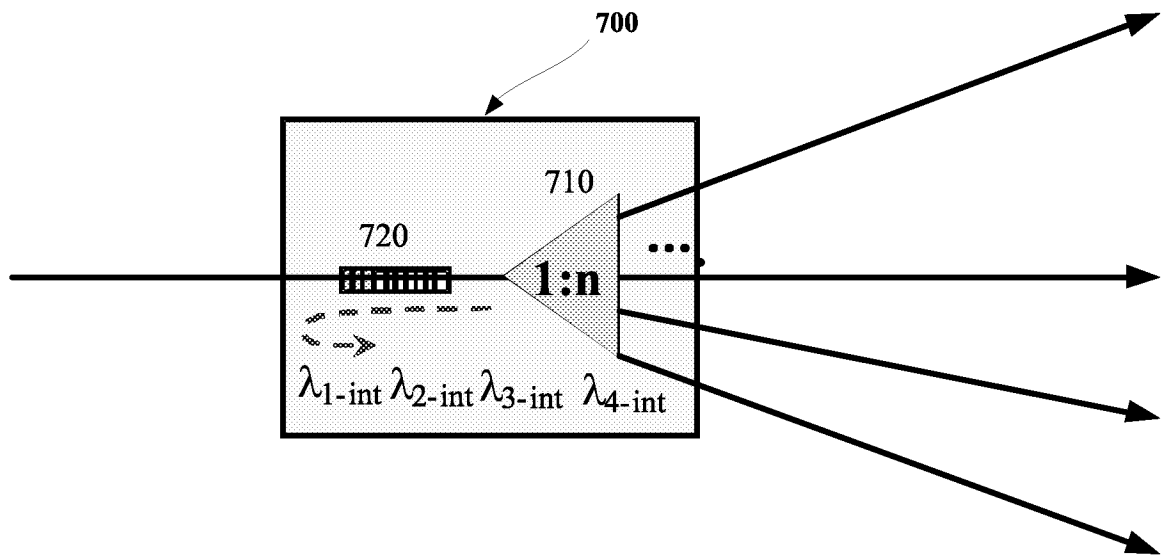
Fig. 2

**Fig. 3**

**Fig. 4**

**Fig. 5**

**Fig. 6**

**Fig. 7**