



(51) International Patent Classification:

Not classified

(21) International Application Number:

PCT/US2021/048483

(22) International Filing Date:

31 August 2021 (31.08.2021)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

63/123,368

09 December 2020 (09.12.2020) US

(71) Applicant: FUTUREWEI TECHNOLOGIES, INC.

[US/US]; 5700 Tennyson Parkway, Suite 600, Plano, Texas 75024 (US).

(72) Inventor: EFFENBERGER, Frank; 5700 Tennyson

Parkway, Suite 600, Plano, Texas 75024 (US).

(74) Agent: DIETRICH, William H.; CONLEY ROSE, P.C.,

4965 Preston Park Blvd., Suite 195E, Plano, Texas 75093 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: EFFICIENT PROTECTION SWITCHING IN WDM-PON

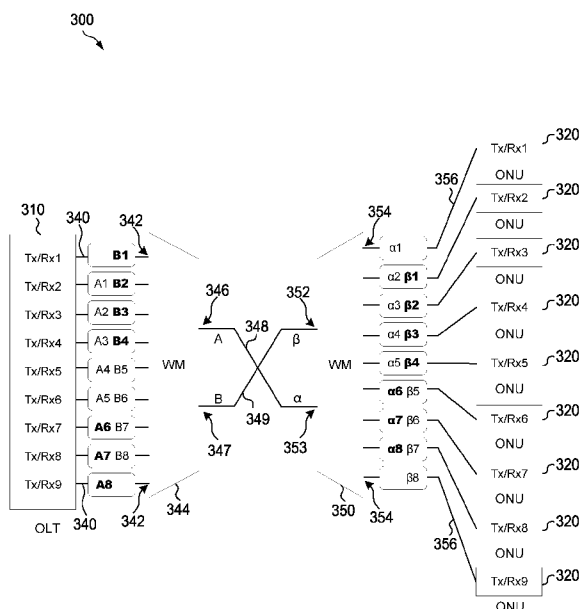


FIG. 3

(57) **Abstract:** An optical wavelength multiplexer having a second output port shifted by one channel relative to a first output port. Because of the shift, the wavelength multiplexer is able to select one of two different wavelengths on several of the channels to protect from failures in a feeder fiber or a transceiver. Thus, the wavelength multiplexer provides protection against failures within the passive optical network (PON).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

- *upon request of the applicant, before the expiration of the time limit referred to in Article 21(2)(a)*
- *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

Efficient Protection Switching in WDM-PON

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 63/123,368 filed December 9, 2020, entitled “Efficient Protection Switching in WDM-PON,” which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure is generally related to the field of optical networks and, in particular, to interleaving in optical networks.

BACKGROUND

[0003] Optical networks are networks that use optical signals to carry data. Light sources such as lasers generate optical signals. Modulators modulate the optical signals with data to generate modulated optical signals. Various components transmit, propagate, amplify, receive, and process the modulated optical signals. Optical networks may implement multiplexing to achieve high bandwidths. Optical networks implement data centers, metropolitan networks, passive optical networks (PONs), long-haul transmission systems, and other applications.

SUMMARY

[0004] The disclosed aspects/embodiments provide a wavelength multiplexer configured to protect a PON against a failure in an optical fiber extending between two wavelength multiplexers or a failure in the transceiver of an OLT. The wavelength multiplexer provides such protection by having a second output port shifted by one channel relative to a first output port. Because of the shift, the wavelength multiplexer is able to select one of two different wavelengths on several of the channels and output the selected wavelength onto one of two different optical fibers via the first output port or the second output port. Thus, the wavelength multiplexer is able to protect a PON against failures without having to fully duplicate the network, which provides a substantial cost savings.

[0005] A first aspect relates to optical line terminal (OLT), comprising: an array of transceivers, wherein each transceiver in the array of transceivers is configured to be tuned from a first of two adjacent wavelengths to a second of the two adjacent wavelengths when a failure indication is received; and a plurality of output ports coupled to the array of transceivers, wherein

each output port of the plurality of output ports is configured to output the first of the two adjacent wavelengths or the second of the two adjacent wavelengths onto an optical fiber.

[0006] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the failure indication indicates an optical fiber failure.

[0007] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the failure indication indicates a transceiver failure.

[0008] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the failure indication is received from one of a plurality of optical network units (ONUs) in communication with the OLT.

[0009] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the each output port of the plurality of output ports is configured to output the first of the two adjacent wavelengths or the second of the two adjacent wavelengths onto the optical fiber toward a wave multiplexer (WM).

[0010] A second aspect relates to a method implemented by an optical line terminal (OLT), comprising: receiving a failure indication; tuning a transceiver from a first of two adjacent wavelengths to a second of the two adjacent wavelengths in response to receipt of the failure indication; and outputting the second of the two adjacent wavelengths onto an optical fiber.

[0011] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the transceiver is one of an array of transceivers in the OLT.

[0012] Optionally, in any of the preceding aspects, another implementation of the aspect provides ceasing to output the first of the two adjacent wavelengths onto the optical fiber after the tuning.

[0013] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the failure indication indicates an optical fiber failure.

[0014] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the failure indication indicates a transceiver failure.

[0015] Optionally, in any of the preceding aspects, another implementation of the aspect provides outputting the second of the two adjacent wavelengths onto the optical fiber toward a wave multiplexer (WM).

[0016] A third aspect relates to an optical wave multiplexer (WM), comprising: a plurality of input ports configured to receive different wavelengths of an optical signal; a first output port coupled to a first subset of the input ports, wherein the first output port is configured to output the different wavelengths received by the first subset of the input ports; and a second output port coupled to a second subset of the input ports, the second output port is shifted by one channel

relative to the first output port, the second output port is configured to output the different wavelengths received by the second subset of the input ports.

[0017] Optionally, in any of the preceding aspects, another implementation of the aspect provides that one or more of the input ports are included in both the first subset and the second subset.

[0018] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the input ports included in both the first subset and the second subset are each configured to receive two of the different wavelengths.

[0019] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to output the different wavelengths received by the first subset of the input ports to a second WM over a first optical fiber, and configured to output the different wavelengths received by the second subset of the input ports to the second WM over a second optical fiber.

[0020] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to receive the different wavelengths of the optical signal from an optical line terminal (OLT) over the plurality of channels.

[0021] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to be used in a passive optical network (PON).

[0022] A fourth aspect relates to a method implemented by an optical wave multiplexer (WM), comprising: receiving, by a plurality of input ports, different wavelengths of an optical signal; outputting, by a first output port coupled to a first subset of the input ports, the different wavelengths received by the first subset of the input ports; and outputting, by a second output port coupled to a second subset of the input ports, the different wavelengths received by the second subset of the input ports, wherein the second output port is shifted by one channel relative to the first output port

[0023] Optionally, in any of the preceding aspects, another implementation of the aspect provides that one or more of the input ports are included in both the first subset and the second subset.

[0024] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the input ports included in both the first subset and the second subset are each configured to receive two of the different wavelengths.

[0025] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to receive the different optical signal wavelengths from an optical line terminal (OLT) over the plurality of channels.

[0026] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to be used in a passive optical network (PON).

[0027] A fifth aspect relates to passive optical network (PON), comprising: an optical line terminal (OLT) configured to transmit an optical signal, wherein the OLT is configured to perform the method in any of the disclosed embodiments; and an optical wavelength multiplexer (WM) configured to receive the optical signal, wherein the optical WM is configured to perform the method in any of the disclosed embodiments.

[0028] A sixth aspect relates to an optical wave multiplexer (WM), comprising: a plurality of input port means configured to collectively receive different wavelengths of an optical signal over a plurality of channels; a first output port means coupled to a first subset of the input port means, wherein the first output port means is configured to output the different wavelengths received by the first subset of the input port means ; and a second output port means coupled to a second subset of the input port means, the second output port means is shifted by one channel relative to the first output port means and configured to output the different wavelengths received by the second subset of the input port means.

[0029] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to receive the different optical signal wavelengths from an optical line terminal (OLT) over the plurality of channels.

[0030] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to be used in a passive optical network (PON).

[0031] A seventh aspect relates to an optical wave multiplexer (WM) system, the WM system comprising: a first WM, comprising: a plurality of first WM parallel ports configured to receive a plurality of optical wavelength signals; a first combination port of the first WM coupled to the plurality of first WM parallel ports and configured to receive a first subset of optical wavelength signals of the plurality of optical wavelength signals from the plurality of first WM parallel ports; and a second combination port of the first WM coupled to the plurality of first WM parallel ports and configured to receive a second subset of optical wavelength signals of the plurality of optical wavelength signals from the plurality of first WM parallel ports; a second WM, comprising: a first combination port of the second WM, the first combination port coupled to the second combination port of the first WM and configured to receive the first subset of optical wavelength signals received from the first WM; a second combination port of the second WM, the second combination port coupled to the first combination port of the first WM and configured to receive the second subset of optical wavelength signals received from the first WM; and a plurality of second WM parallel ports coupled to the first combination port and to the second

combination port of the second WM, the plurality of second WM parallel ports configured to output the plurality of optical wavelength signals.

[0032] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to receive the different optical wavelength signals from an optical line terminal (OLT) over the plurality of channels.

[0033] Optionally, in any of the preceding aspects, another implementation of the aspect provides that the optical WM is configured to be used in a passive optical network (PON).

[0034] An eighth aspect relates to a system, comprising: an optical wave multiplexer (WM) comprising: a plurality of input ports configured to collectively receive different wavelengths of an optical signal; a first output port coupled to a first subset of the input ports, wherein the first output port is configured to output the different wavelengths received by the first subset of the input ports to a second optical WM over a first optical fiber; and a second output port coupled to a second subset of the input ports, wherein the second output port is shifted by one channel relative to the first output port and configured to output the different wavelengths received by the second subset of the input ports to the second optical WM over a second optical fiber; and an optical line terminal (OLT) coupled to the optical WM, comprising: an array of transceivers, wherein each of the transceivers in the array is configured to be tuned from a first of two adjacent wavelengths to a second of the two adjacent wavelengths when a failure indication is received; and a plurality of output ports coupled to the array of transceivers, wherein each of the plurality of output ports is configured to output the first of the two adjacent wavelengths or the second of the two adjacent wavelengths onto an optical fiber extending between the OLT and the optical WM.

[0035] For the purpose of clarity, any one of the foregoing embodiments may be combined with any one or more of the other foregoing embodiments to create a new embodiment within the scope of the present disclosure.

[0036] These and other features will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts.

[0038] FIG. 1 is a schematic diagram of a PON.

[0039] FIG. 2 is a schematic diagram of a PON in further detail.

[0040] FIG. 3 is a schematic diagram of a PON according to an embodiment of the disclosure.

[0041] FIG. 4 is a schematic diagram of a PON according to an embodiment of the disclosure.

[0042] FIG. 5 is a schematic diagram of a PON according to an embodiment of the disclosure.

[0043] FIG. 6 is a schematic diagram of a PON according to an embodiment of the disclosure.

[0044] FIG. 7 is a method implemented by an optical wave multiplexer (WM) in a PON according to an embodiment of the disclosure.

[0045] FIG. 8 is a schematic diagram of a network apparatus according to an embodiment of the disclosure.

DETAILED DESCRIPTION

[0046] It should be understood at the outset that although an illustrative implementation of one or more embodiments are provided below, the disclosed systems and/or methods may be implemented using any number of techniques, whether currently known or in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques illustrated below, including the exemplary designs and implementations illustrated and described herein, but may be modified within the scope of the appended claims along with their full scope of equivalents.

[0047] FIG. 1 is a schematic diagram of a PON 100. The PON 100 comprises an OLT 110, one or more ONUs 120, and an optical data network (ODN) 130 that couples the OLT 110 to the ONUs 120 in the example shown. The PON 100 is a communications network that may not require active components to distribute data between the OLT 110 and the ONUs 120. Instead, the PON 100 may use passive optical components in the ODN 130 to distribute the data.

[0048] The OLT 110 communicates with another network or networks (not shown) and the one or more ONUs 120. For instance, the OLT 110 transfers data from another network to the ONUs 120, and likewise transfers data from the ONUs 120 to the another network. The OLT 110 is typically located at a central location such as a central office (CO), but it may also be located at other suitable locations.

[0049] The ODN 130 is a data distribution network that comprises optical fiber cables, couplers, splitters, distributors, or other suitable components. The components include passive optical components that do not require power to distribute data between the OLT 110 and the

ONUs 120. The ODN 130 may extend from the OLT 110 to the ONUs 120 in a branching configuration as shown, or may be configured in any other suitable point-to-multipoint (P2MP) configuration.

[0050] The ONUs 120 communicate with the OLT 110 and with customers (not shown). For instance, the ONUs 120 transfer data from the OLT 110 to the customers and likewise transfer data from the customers to the OLT 110. The ONUs 120 and optical network terminations (ONTs) are similar, and the terms may be used interchangeably. The ONUs 120 are typically located at distributed locations, such as customer premises. However, the ONUs 120 they may also be located at other suitable locations.

[0051] FIG. 2 is a schematic diagram of a conventional PON 200 in further detail. The PON 200 comprises an OLT 210 and a plurality of ONUs 220, which are similar to the OLT 110 and the ONUs 120 of FIG. 1. As shown in FIG. 2, the OLT 210 includes an array of transceivers, which have been labeled Tx/Rx1-Tx/Rx7 for the purpose of discussion. It should be understood that the OLT 210 may include more or fewer transceivers in practical applications. Each of the ONUs 220 includes a corresponding transceiver, which have been labeled Tx/Rx1-Tx/Rx7 for the purpose of discussion. It should be understood that the plurality of ONUs 220 may collectively include more or fewer transceivers in practical applications.

[0052] In the illustrated embodiment of FIG. 2, the OLT 210 is configured to output seven different downstream wavelengths. The seven different wavelengths are output onto seven different optical fibers corresponding to seven different channels 240, which have been labeled 1-7 for the purpose of discussion. That is, the TxRx1 outputs a first wavelength onto the first channel 240 (labeled with the number 1), the TxRx2 outputs a second wavelength onto the second channel 240 (labeled with the number 2), the TxRx3 outputs a third wavelength onto the third channel 240 (labeled with the number 3), and so on.

[0053] The seven different downstream wavelengths are received at a plurality of input/output ports 242 of a first wave multiplexer (WM) 244. Each WM disclosed herein may also be referred to as a wavelength multiplexer, an optical WM, or a field-based WM. The first WM 244 is configured to multiplex the seven different wavelengths together to form a combined optical signal (e.g., a downstream (DS) optical signal). The combined downstream optical signal is output from an input/output port 246 of the first WM 244 and is carried by an optical fiber 248 to a second WM 250.

[0054] The second WM 250 receives the optical signal at an input/output port 252 of the second WM 250. The second WM 250 de-multiplexes the optical signal back into individual wavelengths, which are then output from a plurality of input/output ports 254 and routed to their

corresponding ONUs 220 via seven different drop fibers corresponding to seven different channels 256, which have been labeled 1-7 for the purpose of discussion. That is, the TxRx1 in a first ONU 220 receives the first wavelength through the first channel 256 (labeled with the number 1), the TxRx2 in a second ONU 220 receives the second wavelength through the second channel 256 (labeled with the number 2), the TxRx3 in a third ONU 220 receives the third wavelength through the third channel 256 (labeled with the number 3), and so on.

[0055] In the opposite (i.e., upstream) direction, each of the ONUs 220 are configured to output one of the seven different wavelengths onto one of seven different optical fibers corresponding to the seven different channels 256. That is, the TxRx1 of the first ONU 220 outputs a first wavelength onto the first channel 256 (labeled with the number 1), the TxRx2 of the second ONU 220 outputs a second wavelength onto the second channel 256 (labeled with the number 2), the TxRx3 of the third ONU 220 outputs a third wavelength onto the third channel 256 (labeled with the number 3), and so on.

[0056] The seven different wavelengths are received at the plurality of input/output ports 254 of the second WM 250. The second WM 250 is configured to multiplex the seven different wavelengths together to form a combined or composite upstream optical signal (e.g., an upstream (US) optical signal). The combined upstream optical signal is output from the input/output port 252 and carried by the optical fiber 248 to the WM 244.

[0057] The first WM 244 receives the upstream optical signal at the input/output port 246. The first WM 244 de-multiplexes the upstream optical signal back into individual wavelengths, which are then output from the plurality of input/output ports 242 and routed to the individual transceivers of the OLT 210 via the seven different channels 240. That is, the TxRx1 in the OLT 210 receives the first wavelength through the first channel 240 (labeled with the number 1), the TxRx2 in the OLT 210 receives the second wavelength through the second channel 240 (labeled with the number 2), the TxRx3 in the OLT 210 receives the third wavelength through the third channel 3, and so on. Thus, the PON 200 creates a bidirectional transmission path between the OLT 210 and each ONU 220.

[0058] Unfortunately, the PON 200 of FIG. 2 offers no protection from failures. For example, should the optical fiber 248 fail, the OLT 210 and the ONUs 220 are no longer able to communicate with each other. Should one of the transceivers fail, one of the ONUs will correspondingly fail to receive their designated wavelength.

[0059] One approach to implement protection for the PON 200 would be to fully duplicate the network. That is, the OLT 210 and each ONU 220 would have two transceivers and there would be two separate optical fibers 248 used for communications between the OLT 210 and

each ONU 220. In such a configuration, full 1+1 protection can be implemented, where transmissions are sent on both paths and the receiver simply chooses the best path. However, this scheme has the drawback that the network cost is doubled. Most practical applications cannot tolerate such a cost increase. Therefore, such a protection scheme is not desirable.

[0060] Disclosed herein is a wavelength multiplexer configured to protect a PON against a failure in an optical fiber extending between two wavelength multiplexers or a failure in the transceiver of an OLT. The wavelength multiplexer provides such protection by having a second output port shifted by one channel relative to a first output port. Because of the shift, the wavelength multiplexer is able to select one of two different wavelengths on several of the channels and output the selected wavelength onto one of two different optical fibers via the first output port or the second output port. Thus, the wavelength multiplexer is able to protect a PON against failures without having to fully duplicate the network, which provides a substantial cost savings.

[0061] FIG. 3 is a schematic diagram of a PON 300 according to an embodiment of the disclosure. The PON 300 comprises an OLT 310 and a plurality of ONUs 320, which are similar to the OLT 210 and the ONUs 220 of FIG. 2. As shown in FIG. 3, the OLT 310 includes an array of transceivers, which have been labeled Tx/Rx1-Tx/Rx9 for the purpose of discussion. That is, relative to the OLT 210 of FIG. 2, the OLT 310 includes two extra transceivers (e.g., $N+2$ transceivers). It should be understood that the OLT 310 may include more or fewer transceivers in practical applications. The first WM 344 may be operated so that not all of the available transceivers in the OLT 310 are operated for transferring data. When a particular transceiver is not working properly, a currently unused transceiver can be activated in the place of the non-working transceiver. In this way, by having more transceivers than the required number of transceivers in the OLT 310, then a failure or loss in a particular transceiver will not result in a loss of data or a failure of operation. Each of the ONUs 320 includes a corresponding transceiver, which have been labeled Tx/Rx1-Tx/Rx9 for the purpose of discussion. Thus, there are also two extra transceivers (e.g., $N+2$ transceivers) in the array of ONUs 320. It should be understood that the plurality of ONUs 320 may collectively include more or fewer transceivers in practical applications. Each of the ONUs 320 is able to transmit a failure indication to the OLT 310 when the ONU 320 fails to receive an optical wavelength signal. The ONU 320 may fail to receive the optical wavelength signal when, for example, an optical fiber in the PON 300 and/or or a transceiver in the OLT 310 has failed.

[0062] In the illustrated embodiment of FIG. 3, the transceivers of the OLT 310 are configured to be tuned over two adjacent wavelengths. Therefore, one or more of the transceivers

are configured to output two different wavelengths of an optical signal. As used herein, the different wavelengths may be referred to as an A wavelength and a B wavelength. In an embodiment, one or more of the transceivers of the OLT 310 is tuned from, for example, the A wavelength to the B wavelength in response to receiving the failure indication from one or more of the ONU 320.

[0063] As shown, the first transceiver Tx/Rx1 in the OLT 310 is configured to output wavelength B1 onto an optical fiber corresponding to a first of the channels 340. A second transceiver Tx/Rx2 is configured to output wavelength A1 or wavelength B2 onto an optical fiber corresponding to a second of the channels 340. Likewise, a third transceiver Tx/Rx3 is configured to output wavelength A2 or B3 onto an optical fiber corresponding to a third of the channels 340, a fourth transceiver Tx/Rx4 is configured to output wavelength A3 or B4 onto an optical fiber corresponding to a fourth of the channels 340, and a fifth transceiver Tx/Rx5 is configured to output wavelength A4 or B5 onto an optical fiber corresponding to a fifth of the channels 340. Continuing, a sixth transceiver Tx/Rx6 is configured to output wavelength A5 or B6 onto an optical fiber corresponding to a sixth of the channels 340, a seventh transceiver Tx/Rx7 is configured to output wavelength A6 or B7 onto an optical fiber corresponding to a seventh of the channels 340, and an eighth transceiver Tx/Rx8 is configured to output wavelength A7 or B8 onto an optical fiber corresponding to an eighth of the channels 340. Finally, a ninth transceiver Tx/Rx9 is configured to output wavelength A8 onto an optical fiber corresponding to a ninth of the channels 340.

[0064] The various different wavelengths are received at a plurality of input/output ports 342 of a first WM 344. In FIG. 3, the first WM 344 includes nine input/output ports 342 corresponding to the nine transceivers of the OLT 310. The input/output ports 342 configured to receive both an A wavelength and a B wavelength may be referred to herein as the middle input/output ports. The input/output ports 342 configured to receive one, but not both, of the A wavelength and a B wavelength may be referred to herein as the outer input/output ports.

[0065] The first WM 344 comprises a first input/output port 346 and a second input/output port 347. The first input/output port 346 of the first WM 344 is coupled to a subset of the input/output ports 342. In the illustrated example, the first input/output port 346 of the first WM 344 is coupled to the subset of input/output ports 342 associated with the transceivers Tx/Rx2-Tx/Rx9. Therefore, the first WM 344 is able to multiplex the wavelengths A1-A8 and output the result to the first optical fiber 348.

[0066] The second input/output port 347 of the first WM 344 is also coupled to a subset of the input/output ports 342. In the illustrated example, the input/output port 347 of the first WM

344 is coupled to the subset of input/output ports 342 associated with the transceivers Tx/Rx1-Tx/Rx8. Therefore, the first WM 344 is able to multiplex the wavelengths B1-B8 and output the result to the second optical fiber 349.

[0067] The first WM 344 and the second WM 350 are coupled together by two optical fibers instead of a single optical fiber (e.g., the optical fiber 248 of FIG. 2). As shown, a first optical fiber 348 extends between the input/output port 346 of the first WM 344, which is labeled A, and an input/output port 353 of the second WM 350, which is labeled α . A second optical fiber 349 extends between the input/output port 347 of the first WM 344, which is labeled B, and an input/output port 352 of the second WM 350, which is labeled β .

[0068] The input/output ports 346, 353 are shifted by one channel 340 relative to the input/output ports 347, 352, which results in the connectivity illustrated in FIG. 3. In an embodiment, the input/output ports 346, 347, 352, and 353 are cross connected. That is, the input/output port 346, which is the top-left port in FIG. 3, is coupled to the input/output port 353, which is the bottom-right port in FIG. 3. Likewise, the input/output port 347, which is the bottom-left port in FIG. 3, is coupled to the input/output port 352, which is the top-right port in FIG. 3.

[0069] The input/output port 352 of the second WM 350 is configured to receive the wavelengths B1-B8 via the second optical fiber 349. For ease of discussion, the wavelengths received at the input/output port 352 of the second WM 350 are referred to herein as β 1- β 8. The input/output port 353 of second WM 350 is configured to receive the wavelengths A1-A8 via the first optical fiber 346. For ease of discussion, the wavelengths received at the input/output port 353 of the second WM 350 are referred to herein as α 1- α 8.

[0070] The input/output port 352 of the second WM 350 is coupled to a subset of the input/output ports 354. In the illustrated example, the input/output port 352 of the second WM 350 is coupled to the subset of input/output ports 354 associated with the transceivers Tx/Rx2-Tx/Rx9 in the ONUs 320. Therefore, the input/output ports 354 of the second WM 350 are configured to provide one of the wavelengths β 1- β 8 to each of the ONUs 320 including transceivers Tx/Rx2-Tx/Rx9. The input/output port 353 of the second WM 350 is also coupled to a subset of the input/output ports 354. In the illustrated example, the input/output port 353 of the second WM 350 is coupled to the subset of input/output ports 354 associated with the transceivers Tx/Rx1-Tx/Rx8 in the ONUs 320. Therefore, the input/output ports 354 of the second WM 350 are configured to provide the wavelengths β 1- β 8 to the ONUs 320 including transceivers Tx/Rx1-Tx/Rx8.

[0071] The second WM 350 demultiplexes the various wavelengths received from the first WM 344 so that the various wavelengths can be output onto to different channels 356 for delivery to the appropriate ONUs 320.

[0072] As shown, the second WM 350 is configured to output wavelength α_1 onto an optical fiber corresponding to a first of the channels 356 for delivery to the ONU 320 having TxRx1. The second WM 350 is configured to output wavelength α_2 or β_1 onto an optical fiber corresponding to a second of the channels 356 for delivery to the ONU 320 having TxRx2. Likewise, the second WM 350 is configured to output wavelength α_3 or β_2 onto an optical fiber corresponding to a third of the channels 356 for delivery to the ONU 320 having TxRx3, to output wavelength α_4 or β_3 onto an optical fiber corresponding to a fourth of the channels 356 for delivery to the ONU 320 having TxRx4, and to output wavelength α_5 or β_4 onto an optical fiber corresponding to a fifth of the channels 356 for delivery to the ONU 320 having TxRx5. Continuing, the second WM 350 is configured to output wavelength α_6 or β_5 onto an optical fiber corresponding to a sixth of the channels 356 for delivery to the ONU 320 having TxRx6, to output wavelength α_7 or β_6 onto an optical fiber corresponding to a seventh of the channels 356 for delivery to the ONU 320 having TxRx7, and to output wavelength α_8 or β_7 onto an optical fiber corresponding to an eighth of the channels 356 for delivery to the ONU 320 having TxRx8. Finally, the second WM 350 is configured to output wavelength β_8 onto an optical fiber corresponding to a ninth of the channels 356 for delivery to the ONU 320 having TxRx9.

[0073] In the normal operation of PON 300, the transceivers TxRx1, TxRx2, TxRx3, and TxRx4 of the OLT 310 may be activated to output wavelengths B1, B2, B3, and B4, while the transceivers TxRx7, TxRx8, and TxRx9 may be activated to output wavelengths A6, A7, and A8. Because of the shift noted above, the ONU 320 with transceiver TxRx2 receives β_1 , the ONU 320 with transceiver TxRx3 receives β_2 , the ONU 320 with transceiver TxRx4 receives β_3 , the ONU 320 with transceiver TxRx5 receives β_4 , the ONU 320 with transceiver TxRx6 receives α_6 , the ONU 320 with transceiver TxRx7 receives α_7 , and the ONU 320 with transceiver TxRx8 receives α_8 . Therefore, each of the ONUs 320 receives one of the wavelengths. Notably, the transceivers TxRx5 and TxRx6 in the OLT 310 may be switched off.

[0074] Unlike the PON 200 of FIG. 2, the PON 300 of FIG. 3 is able to provide protection against optical fiber or transceiver failure. The PON 300 is able to do so because the PON 300 provides two independent paths to each ONU 320 (e.g., using the first fiber 348 and the second fiber 349). Theoretically, each of the paths has no loss beyond the fiber and multiplexer losses, which is to say that no splitting/combining is happening in the PON 300. In addition, the transceivers in the OLT 310 only need to tune over two adjacent wavelengths to make the PON

300 operate in a manner that provides the protection. Such a small range of tuning can be accomplished inexpensively.

[0075] FIG. 4 is a schematic diagram of a PON 400 according to an embodiment of the disclosure. The PON 400 of FIG. 4 is similar to the PON 300 of FIG. 3. Therefore, a description of the PON 400 is not repeated herein. However, unlike the PON 300 of FIG. 3, the PON 400 of FIG. 4 has experienced a failure 470 in the second optical fiber 349 coupling the first WM 344 and the second WM 350.

[0076] Despite the failure 470, the PON 400 is still able to deliver a wavelength to each of the ONUs 320 configured to receive two wavelengths. For example, the transceivers TxRx3-TxRx9 can be tuned to collectively output wavelengths A2-A8. The first WM 344 can output wavelengths A2-A8 onto the first optical fiber 348. In this scenario, the ONU 320 with transceiver TxRx2 receives α_2 , the ONU 320 with transceiver TxRx3 receives α_3 , the ONU 320 with transceiver TxRx4 receives α_4 , the ONU 320 with transceiver TxRx5 receives α_5 , the ONU 320 with transceiver TxRx6 receives α_6 , the ONU 320 with transceiver TxRx7 receives α_7 , and the ONU 320 with transceiver TxRx8 receives α_8 . Therefore, each of the ONUs 320 receives one of the wavelengths. Notably, the transceivers TxRx1 and TxRx2 in the OLT 310 may be switched off.

[0077] FIG. 5 is a schematic diagram of a PON 500 according to an embodiment of the disclosure. The PON 500 of FIG. 5 is similar to the PON 300 of FIG. 3. Therefore, a description of the PON 500 is not repeated herein. However, unlike the PON 300 of FIG. 3, the PON 500 of FIG. 5 has experienced a failure 570 in the transceiver TxRx4 in the OLT 310, which results in a loss of the wavelengths A3 and B4.

[0078] Despite the failure 570, the PON 500 is still able to deliver a wavelength to each of the ONUs 320 configured to receive two wavelengths. For example, the transceivers TxRx1-TxRx3 can be tuned to collectively output wavelengths B1-B3 and the transceivers TxRx6-TxRx9 can be tuned to collectively output wavelengths A5-A8. The first WM 344 can output wavelengths B1-B3 onto the second optical fiber 349 and A5-A8 onto the first optical fiber 348. In this scenario, the ONU 320 with transceiver TxRx2 receives β_1 , the ONU 320 with transceiver TxRx3 receives β_2 , the ONU 320 with transceiver TxRx4 receives β_3 , the ONU 320 with transceiver TxRx5 receives α_5 , the ONU 320 with transceiver TxRx6 receives α_6 , the ONU 320 with transceiver TxRx7 receives α_7 , and the ONU 320 with transceiver TxRx8 receives α_8 . Therefore, each of the ONUs 320 receives one of the wavelengths. Notably, the transceiver TxRx5 in the OLT 310 may be switched off.

[0079] In an embodiment, it may be beneficial to utilize both the first optical fiber 348 and the second optical fiber 349 simultaneously, even during normal operation (i.e., even without a failure). For example, assume the transceivers TxRx1-TxRx9 are tuned to output the wavelengths A1-A8. In such a scenario, all of the wavelengths A1-A8 are transmitted over the first optical fiber 348. Should a failure occur in the second optical fiber 349, the failure may not be detected because of a lack of transmissions over the second optical fiber 349.

[0080] FIG. 6 is a schematic diagram of a PON 600 according to an embodiment of the disclosure. The PON 600 of FIG. 6 is similar to the PON 300 of FIG. 3. Therefore, a description of the PON 600 is not repeated herein. However, unlike the PON 300 of FIG. 3, the PON 600 of FIG. 6 has experienced failures 670 in the transceiver TxRx4 and the transceiver TxRx7 in the OLT 310, which results in a loss of the wavelengths A3 and B4 and A6 and B7.

[0081] Despite the failures 670, the PON 600 is still able to deliver a wavelength to each of the ONUs 320 configured to receive two wavelengths. For example, the transceivers TxRx1-TxRx3 can be tuned to collectively output wavelengths B1-B3, the transceiver TxRx5 can be tuned to output wavelength B5, the transceiver TxRx6 can be tuned to output wavelength A5, and the transceivers TxRx8-TxRx9 can be tuned to collectively output wavelengths A7-A8. The first WM 344 can output wavelengths B1-B3 and B5 onto the second optical fiber 349 and A5 and A7-A8 onto the first optical fiber 348. In this scenario, the ONU 320 with transceiver TxRx2 receives β_1 , the ONU 320 with transceiver TxRx3 receives β_2 , the ONU 320 with transceiver TxRx4 receives β_3 , the ONU 320 with transceiver TxRx5 receives α_5 , the ONU 320 with transceiver TxRx6 receives β_5 , the ONU 320 with transceiver TxRx7 receives α_7 , and the ONU 320 with transceiver TxRx8 receives α_8 . Therefore, each of the ONUs 320 receives one of the wavelengths.

[0082] Notably, the PON 600 can suffer a failure in two of the transceivers (e.g., TxRx4 and TxRx7) of the OLT 310 as long as those transceivers are spaced apart by an odd number of input/output ports 342. In FIG. 6, TxRx4 and TxRx7 are spaced apart by three of the input/output ports 342. In other words, there are two functioning transmitters, namely TxRx5 and TxRx6, between the failed transceivers TxRx4 and TxRx7.

[0083] In an embodiment, a PON (e.g., PON 300) may be provided with an additional protection against failure by providing each of the ONUs 320 with two transceivers. For example, a single ONU 320 could include TxRx1 and TxRx2 in an embodiment. In such a scenario, the ONU 320 would have two transceivers and two paths to the OLT 310. This makes the OLT 310 more resilient to transceiver failures, as only one of the paths to the ONU 320 needs

to be kept working. This extra degree of freedom gives the PON 300 a greater ability to recover from different failure scenarios.

[0084] FIG. 7 is a method 700 implemented by a WM (e.g., the first WM 344) in a PON (e.g., PON 300) according to an embodiment of the disclosure. The method 700 may be performed upon experiencing a failure in an optical fiber or transceiver of an OLT (e.g., OLT 310) within the PON.

[0085] In block 702, a plurality of input ports (e.g., input/output ports 342) of the WM collectively receive different wavelengths of an optical signal from an OLT over a plurality of channels (e.g., channels 340). The plurality of input ports in some embodiments collectively and substantially concurrently receive the different wavelengths. The different wavelengths can comprises upstream or downstream signals of various wavelengths.

[0086] In block 704, a first output port (e.g., input/output port 346), coupled to a first subset of the input ports, outputs the different wavelengths received by the first subset of the input ports to a second WM (e.g., the second WM 350) over a first optical fiber (e.g., first optical fiber 348). In some embodiments, the different wavelengths received by the first subset of the input ports are outputted over the first optical fiber 348, while the different wavelengths may be outputted to a second WM over the first optical fiber 348, for example.

[0087] In block 706, a second output port (e.g., input/output port 347), coupled to a second subset of the input ports and shifted by one channel relative to the first output port, outputs the different wavelengths received by the second subset of the input ports to the second WM over a second optical fiber (e.g., second optical fiber 349). In some embodiments, the different wavelengths received by the second subset of the input ports are outputted over the second optical fiber 349. The different wavelengths may be outputted to the second WM over the second optical fiber 349, for example.

[0088] In an embodiment, one or more of the input ports are included in both the first subset and the second subset. In an embodiment, the input ports included in both the first subset and the second subset are each configured to receive two of the different wavelengths.

[0089] In an embodiment, the method 700 further comprises determining a status of the first optical fiber and the second optical fiber, and selecting one of two different wavelengths for output over the first optical fiber or the second optical fiber depending on the determination. In an embodiment, the method 700 further comprises outputting the different wavelengths received by the first subset of the input ports when the second optical fiber 349 has failed. In an embodiment, the method 700 further comprises outputting the different wavelengths received by the second subset of the input ports when the first optical fiber 348 has failed.

[0090] In an embodiment, the method 700 further comprises outputting some of the different wavelengths received by the first subset of the input ports and some of the different wavelengths received by the second subset of the input ports when a transmitter of the OLT has failed. In an embodiment, the method 700 further comprises outputting some of the different wavelengths received by the first subset of the input ports and some of the different wavelengths received by the second subset of the input ports when two transmitters of the OLT spaced apart by an odd number of the plurality of input ports have failed. In an embodiment, the WM is an upstream WM and the second WM is a downstream WM.

[0091] FIG. 8 is a schematic diagram of a network apparatus 800 (e.g., an ingress router, an egress router, a network device, etc.). The network apparatus 800 is suitable for implementing the disclosed embodiments as described herein. The network apparatus 800 comprises ingress ports/ingress means 810 and receiver units (Rx)/receiving means 820 for receiving data; a processor, logic unit, or central processing unit (CPU)/processing means 830 to process the data; transmitter units (Tx)/transmitting means 840 and egress ports/egress means 850 for transmitting the data; and a memory/memory means 860 for storing the data. The processor/processing means 830 is communicatively coupled to the I/O devices or I/O means 880, to the memory/memory means 860, to the receiver units/receiving means 820, and to the transmitter units/transmitting means 840. The network apparatus 800 may also comprise optical-to-electrical (OE) components and electrical-to-optical (EO) components coupled to the ingress ports/ingress means 810, the receiver units/receiving means 820, the transmitter units/transmitting means 840, and the egress ports/egress means 850 for egress or ingress of optical or electrical signals.

[0092] The processor/processing means 830 is implemented by hardware and software. The processor/processing means 830 may be implemented as one or more CPU chips, cores (e.g., as a multi-core processor), field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), and digital signal processors (DSPs). The processor/processing means 830 is in communication with the ingress ports/ingress means 810, receiver units/receiving means 820, transmitter units/transmitting means 840, egress ports/egress means 850, and memory/memory means 860. The processor/processing means 830 comprises a multiplexing module 870. The multiplexing module 870 is able to implement the methods disclosed herein. The inclusion of the multiplexing module 870 therefore provides a substantial improvement to the functionality of the network apparatus 800 and effects a transformation of the network apparatus 800 to a different state. Alternatively, the multiplexing module 870 is implemented as instructions stored in the memory/memory means 860 and executed by the processor/processing means 830.

[0093] The network apparatus 800 may also include input and/or output (I/O) or devices/I/O means 880 for communicating data to and from a user. The I/O devices or I/O means 880 may include output devices such as a display for displaying video data, speakers for outputting audio data, etc. The I/O devices or I/O means 880 may also include input devices, such as a keyboard, mouse, trackball, etc., and/or corresponding interfaces for interacting with such output devices.

[0094] The memory/memory means 860 comprises one or more disks, tape drives, and solid-state drives and may be used as an over-flow data storage device, to store programs when such programs are selected for execution, and to store instructions and data that are read during program execution. The memory/memory means 860 may be volatile and/or non-volatile and may be read-only memory (ROM), random access memory (RAM), ternary content-addressable memory (TCAM), and/or static random-access memory (SRAM).

[0095] While several embodiments have been provided in the present disclosure, it may be understood that the disclosed systems and methods might be embodied in many other specific forms without departing from the spirit or scope of the present disclosure. The present examples are to be considered as illustrative and not restrictive, and the intention is not to be limited to the details given herein. For example, the various elements or components may be combined or integrated in another system or certain features may be omitted, or not implemented.

[0096] In addition, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or integrated with other systems, components, techniques, or methods without departing from the scope of the present disclosure. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and may be made without departing from the spirit and scope disclosed herein.

CLAIMS

What is claimed is:

1. An optical line terminal (OLT), comprising:
an array of transceivers, wherein each transceiver in the array of transceivers is configured to be tuned from a first of two adjacent wavelengths to a second of the two adjacent wavelengths when a failure indication is received; and
a plurality of output ports coupled to the array of transceivers, wherein each output port of the plurality of output ports is configured to output the first of the two adjacent wavelengths or the second of the two adjacent wavelengths onto an optical fiber.
2. The OLT of claim 1, wherein the failure indication indicates an optical fiber failure.
3. The OLT of claim 1, wherein the failure indication indicates a transceiver failure.
4. The OLT of claim 1, wherein the failure indication is received from one of a plurality of optical network units (ONUs) in communication with the OLT.
5. The OLT of claim 1, wherein the each output port of the plurality of output ports is configured to output the first of the two adjacent wavelengths or the second of the two adjacent wavelengths onto the optical fiber toward a wave multiplexer (WM).
6. A method implemented by an optical line terminal (OLT), comprising:
receiving a failure indication;
tuning a transceiver from a first of two adjacent wavelengths to a second of the two adjacent wavelengths in response to receipt of the failure indication; and
outputting the second of the two adjacent wavelengths onto an optical fiber.
7. The method of claim 6, wherein the transceiver is one of an array of transceivers in the OLT.
8. The method of claim 6, further comprising ceasing to output the first of the two adjacent wavelengths onto the optical fiber after the tuning.

9. The method of claim 6, wherein the failure indication indicates an optical fiber failure.
10. The method of claim 6, wherein the failure indication indicates a transceiver failure.
11. The method of claim 6, the outputting further comprising outputting the second of the two adjacent wavelengths onto the optical fiber toward a wave multiplexer (WM).
12. An optical wave multiplexer (WM), comprising:
 - a plurality of input ports configured to receive different wavelengths of an optical signal;
 - a first output port coupled to a first subset of the input ports, the first output port is configured to output the different wavelengths received by the first subset of the input ports ;
 - and
 - a second output port coupled to a second subset of the input ports, the second output port is shifted by one channel relative to the first output port, the second output port is configured to output the different wavelengths received by the second subset of the input ports.
13. The optical wave multiplexer of claim 12, wherein one or more of the input ports are included in both the first subset and the second subset.
14. The optical wave multiplexer of claim 13, wherein the input ports included in both the first subset and the second subset are each configured to receive two of the different wavelengths.
15. The optical wave multiplexer of any of claims 12-14, wherein the optical WM is configured to output the different wavelengths received by the first subset of the input ports to a second WM over a first optical fiber, and configured to output the different wavelengths received by the second subset of the input ports to the second WM over a second optical fiber.
16. The optical wave multiplexer of any of claims 12-15, wherein the optical WM is configured to receive the different wavelengths of the optical signal from an optical line terminal (OLT) over the plurality of channels.

17. The optical wave multiplexer of any of claims 12-16, wherein the optical WM is configured to be used in a passive optical network (PON).

18. A method implemented by an optical wave multiplexer (WM), comprising:
receiving, by a plurality of input ports, different wavelengths of an optical signal;
outputting, by a first output port coupled to a first subset of the input ports, the different wavelengths received by the first subset of the input ports; and
outputting, by a second output port coupled to a second subset of the input ports, the different wavelengths received by the second subset of the input ports, wherein the second output port is shifted by one channel relative to the first output port.
19. The method of claim 18, wherein one or more of the input ports are included in both the first subset and the second subset.
20. The method of claim 19, wherein the input ports included in both the first subset and the second subset are each configured to receive two of the different wavelengths.
21. The method of any of claims 18-20, wherein the optical WM is configured to receive the different optical signal wavelengths from an optical line terminal (OLT) over the plurality of channels.
22. The method of any of claims 18-21, wherein the optical WM is configured to be used in a passive optical network (PON).

23. A passive optical network (PON), comprising:
an optical line terminal (OLT) configured to transmit an optical signal, wherein the OLT is configured to perform the method in any of claims 7-11; and
an optical wavelength multiplexer (WM) configured to receive the optical signal, wherein the optical WM is configured to perform the method in any of claims 18-22.
24. An optical wave multiplexer (WM), comprising:
a plurality of input port means configured to receive different wavelengths of an optical signal over a plurality of channels;
a first output port means coupled to a first subset of the input port means, the first output port means is configured to output the different wavelengths received by the first subset of the input port means; and
a second output port means coupled to a second subset of the input port means, the second output port means is shifted by one channel relative to the first output port means and configured to output the different wavelengths received by the second subset of the input port means.
25. The optical WM of claim 24, wherein the optical WM is configured to receive the different optical signal wavelengths from an optical line terminal (OLT) over the plurality of channels.
26. The optical WM of claim 24, wherein the optical WM is configured to be used in a passive optical network (PON).

27. An optical wave multiplexer (WM) system, the WM system comprising:
a first WM, comprising:
a plurality of first WM parallel ports configured to receive a plurality of optical wavelength signals;
a first combination port of the first WM coupled to the plurality of first WM parallel ports and configured to receive a first subset of optical wavelength signals of the plurality of optical wavelength signals from the plurality of first WM parallel ports;
and
a second combination port of the first WM coupled to the plurality of first WM parallel ports and configured to receive a second subset of optical wavelength signals of the plurality of optical wavelength signals from the plurality of first WM parallel ports;
a second WM, comprising:
a first combination port of the second WM, the first combination port coupled to the second combination port of the first WM and configured to receive the first subset of optical wavelength signals received from the first WM;
a second combination port of the second WM, the second combination port coupled to the first combination port of the first WM and configured to receive the second subset of optical wavelength signals received from the first WM; and
a plurality of second WM parallel ports coupled to the first combination port and to the second combination port of the second WM, the plurality of second WM parallel ports configured to output the plurality of optical wavelength signals.
28. The optical WM system of claim 27, wherein the optical WM is configured to receive the different optical wavelength signals from an optical line terminal (OLT) over the plurality of channels.
29. The optical WM system of any of claims 27-28, wherein the optical WM is configured to be used in a passive optical network (PON).

30. A system, comprising:
- an optical wave multiplexer (WM) comprising:
 - a plurality of input ports configured to collectively receive different wavelengths of an optical signal;
 - a first output port coupled to a first subset of the input ports, wherein the first output port is configured to output the different wavelengths received by the first subset of the input ports to a second optical WM over a first optical fiber; and
 - a second output port coupled to a second subset of the input ports, wherein the second output port is shifted by one channel relative to the first output port and configured to output the different wavelengths received by the second subset of the input ports to the second optical WM over a second optical fiber; and
 - an optical line terminal (OLT) coupled to the optical WM, comprising:
 - an array of transceivers, wherein each of the transceivers in the array is configured to be tuned from a first of two adjacent wavelengths to a second of the two adjacent wavelengths when a failure indication is received; and
 - a plurality of output ports coupled to the array of transceivers, wherein each of the plurality of output ports is configured to output the first of the two adjacent wavelengths or the second of the two adjacent wavelengths onto an optical fiber extending between the OLT and the optical WM.

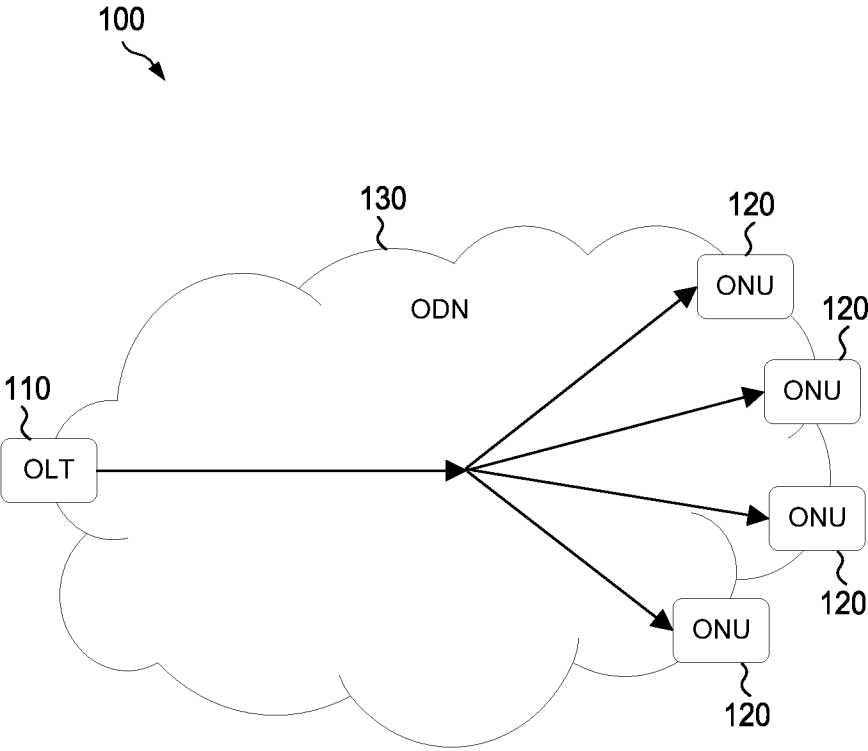


FIG. 1

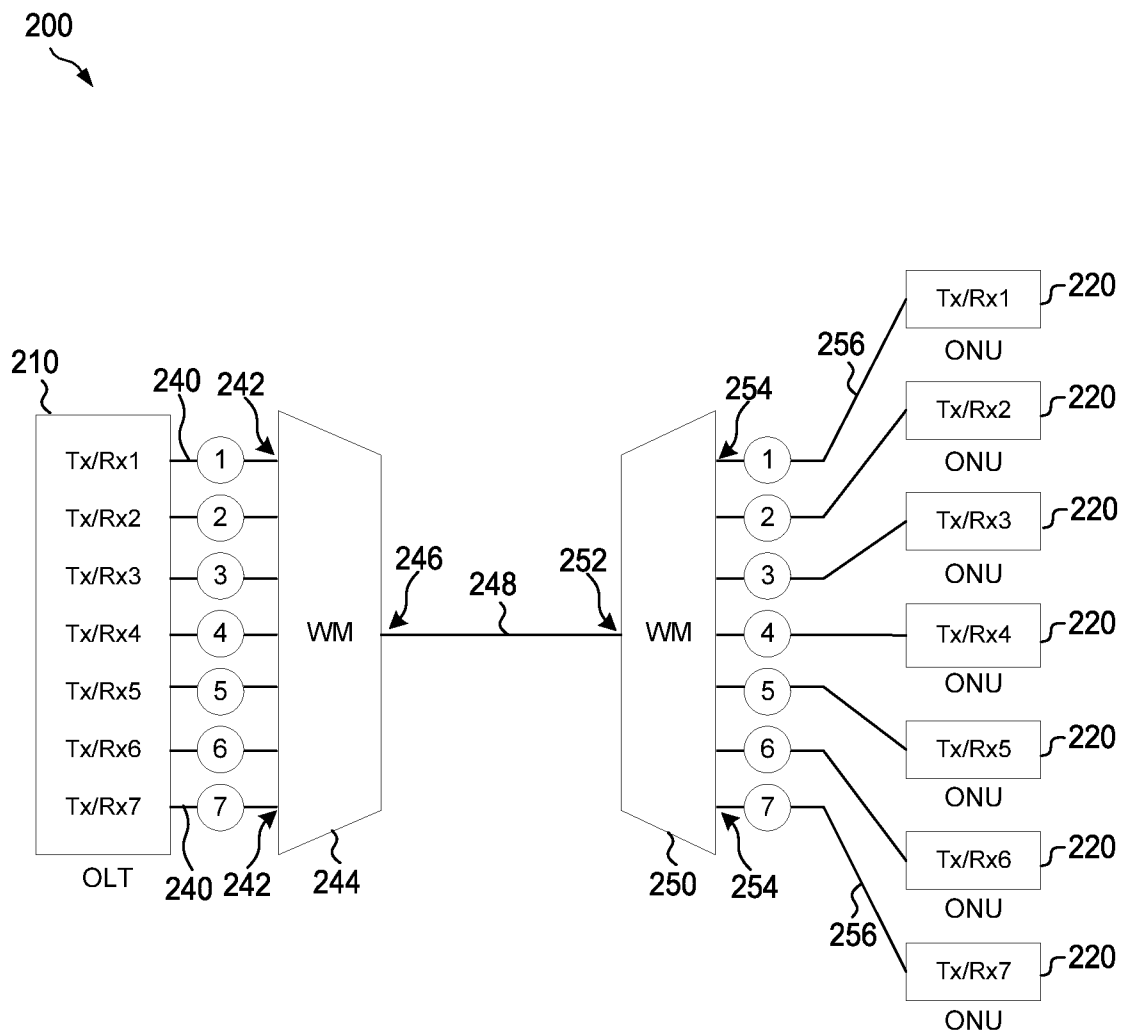


FIG. 2

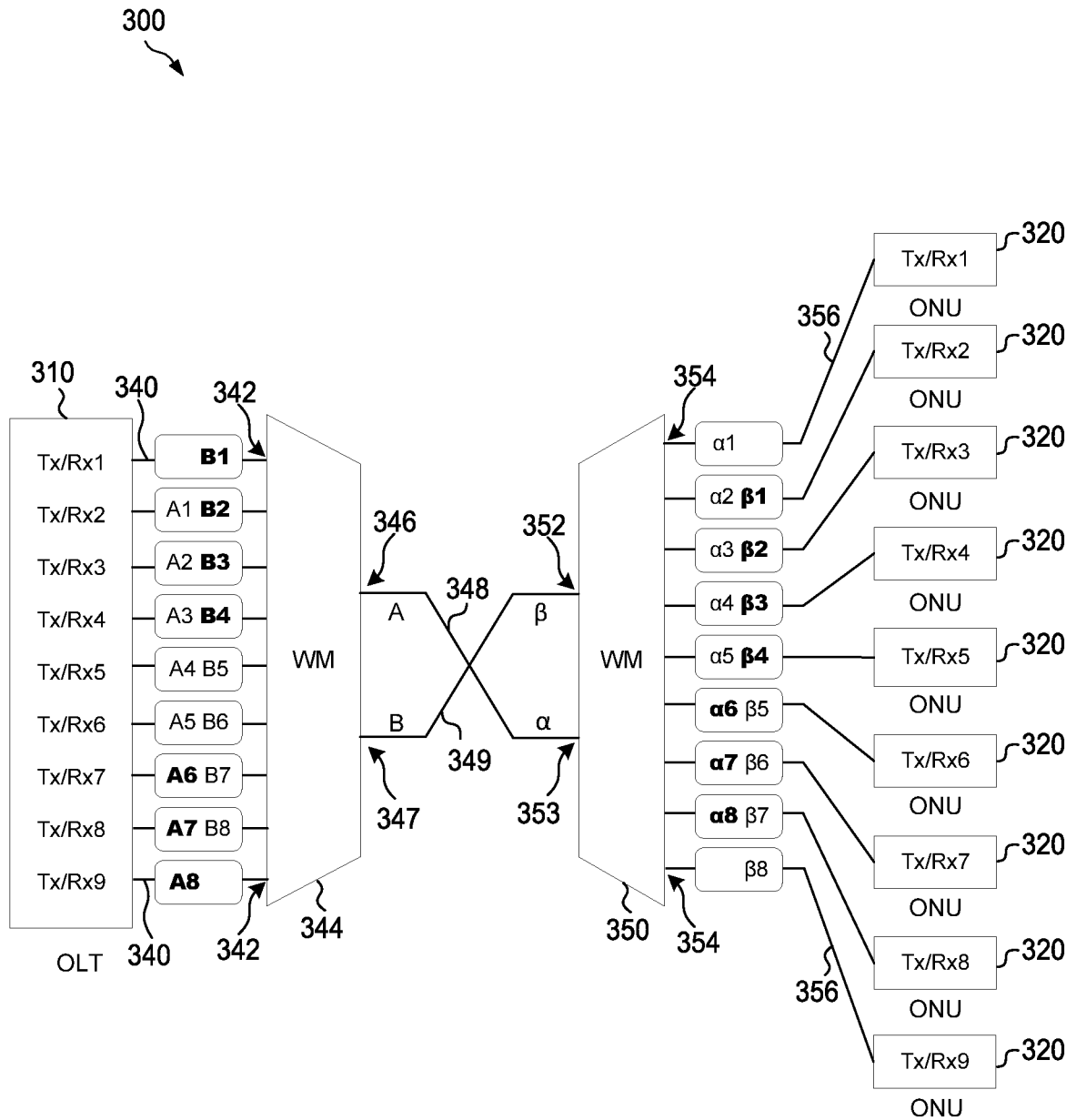


FIG. 3

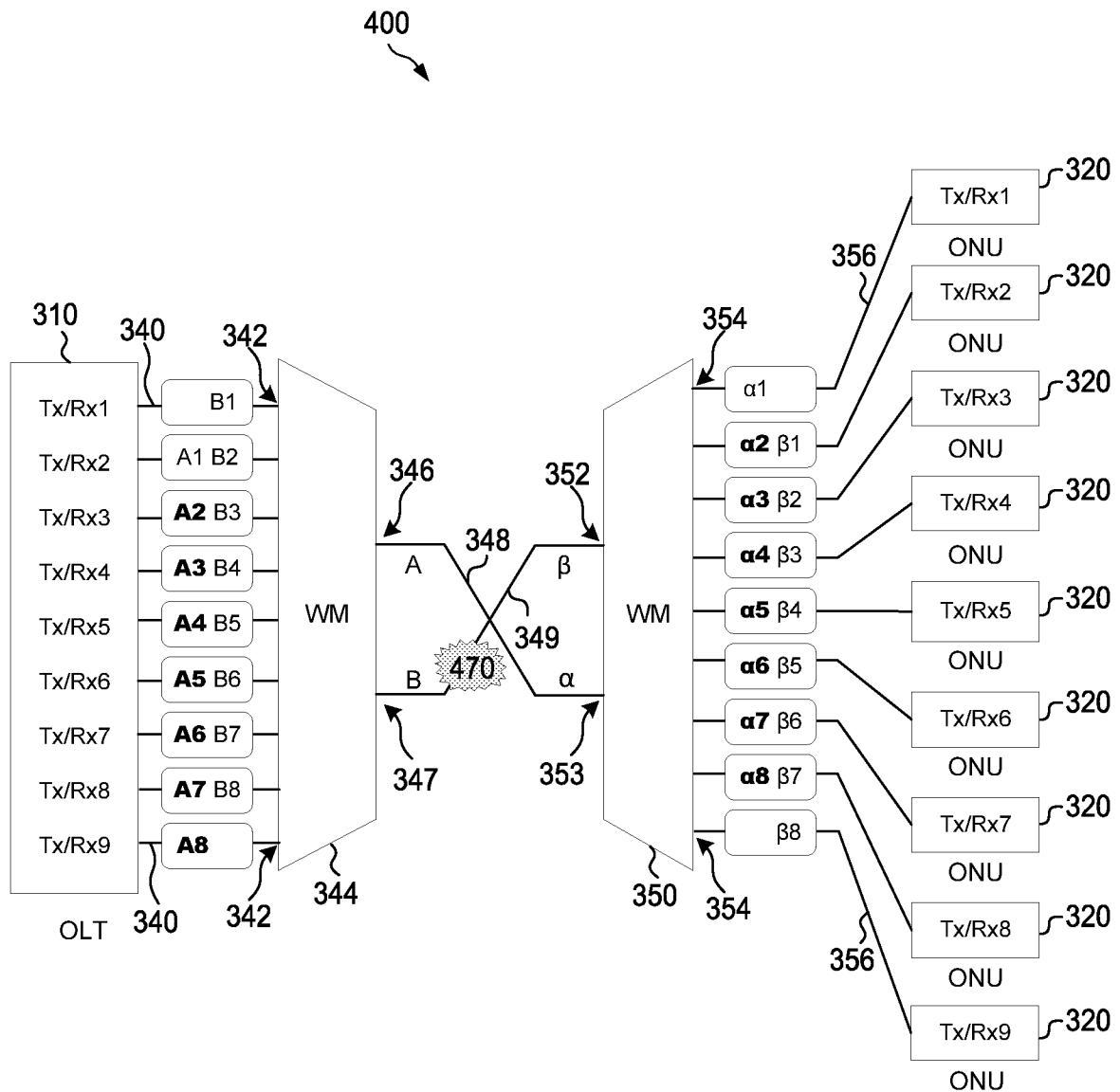


FIG. 4

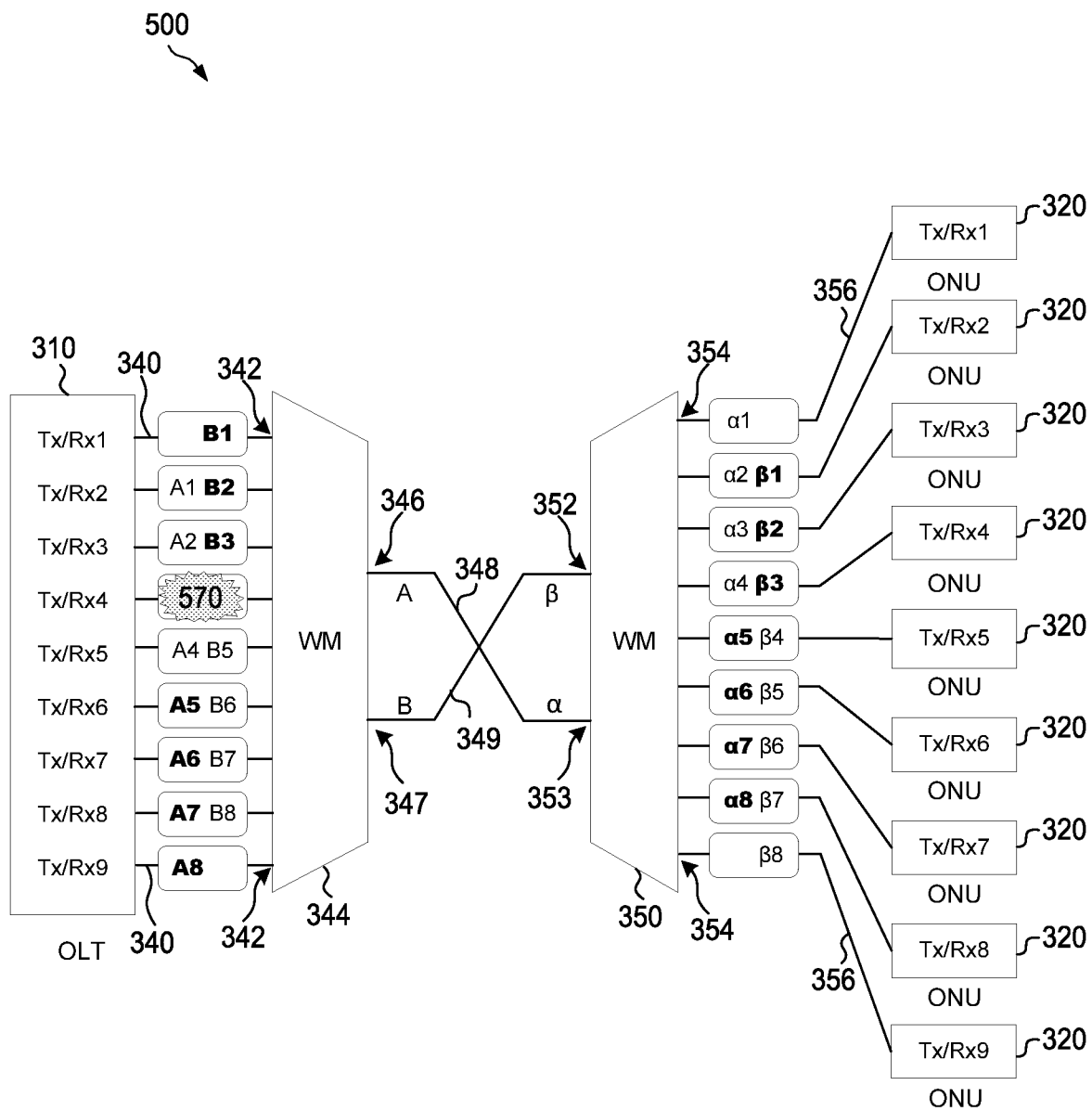
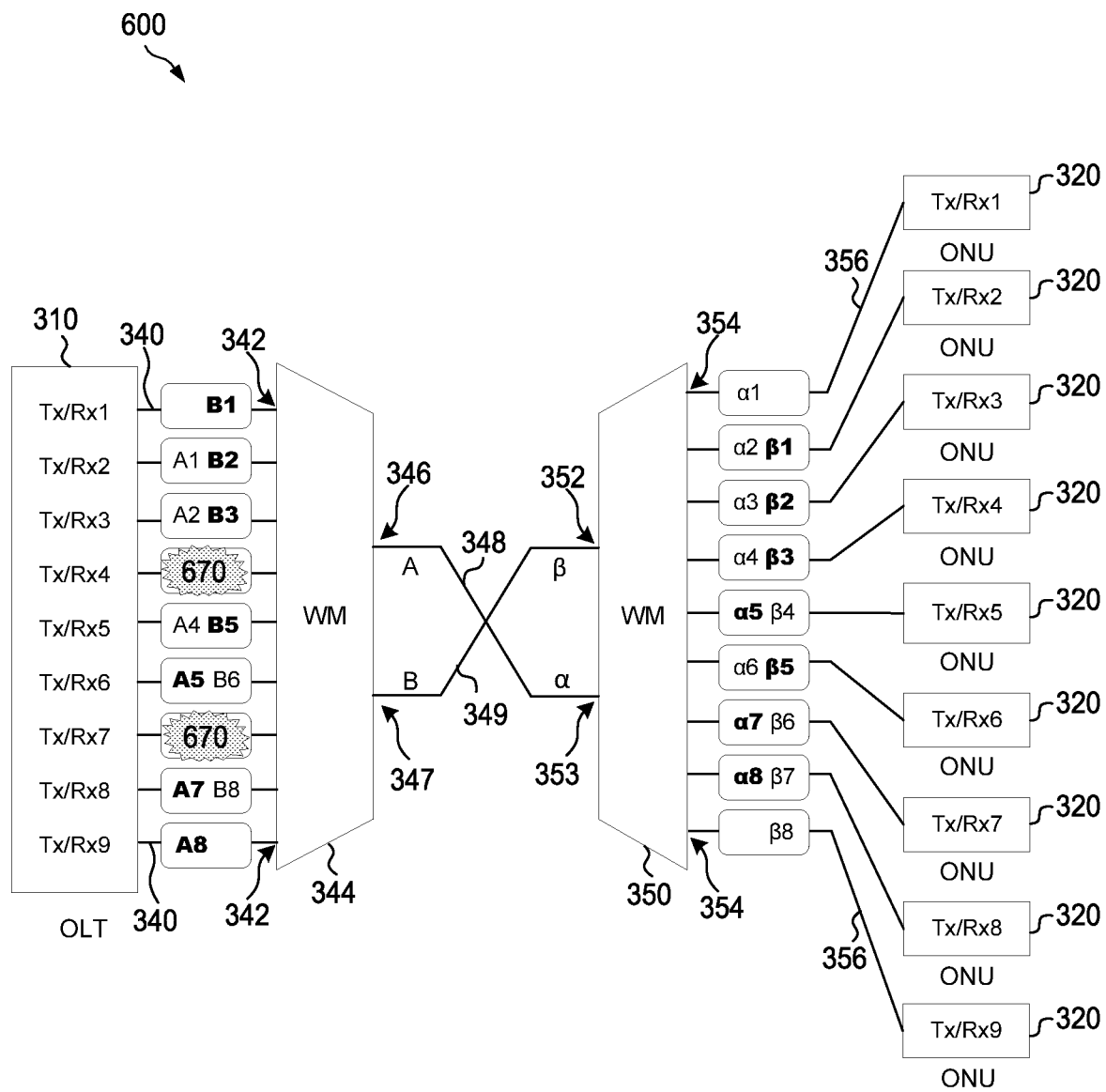


FIG. 5



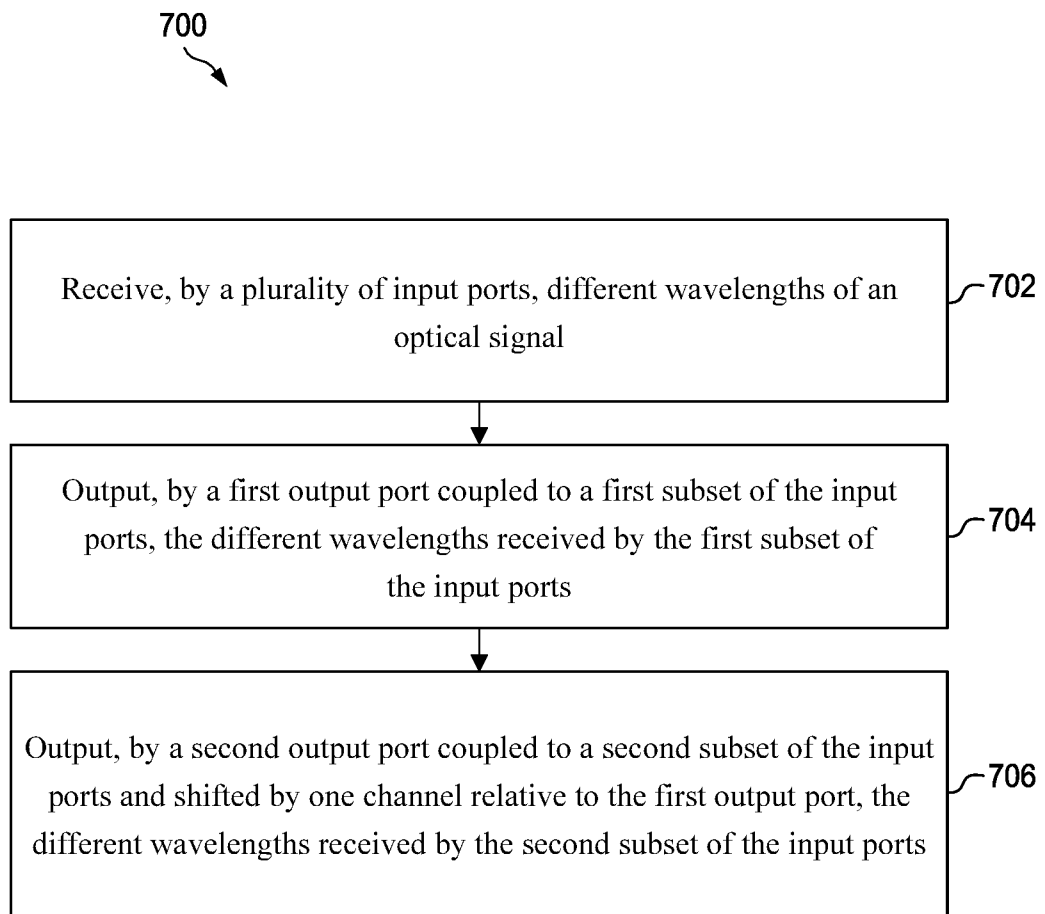


FIG. 7

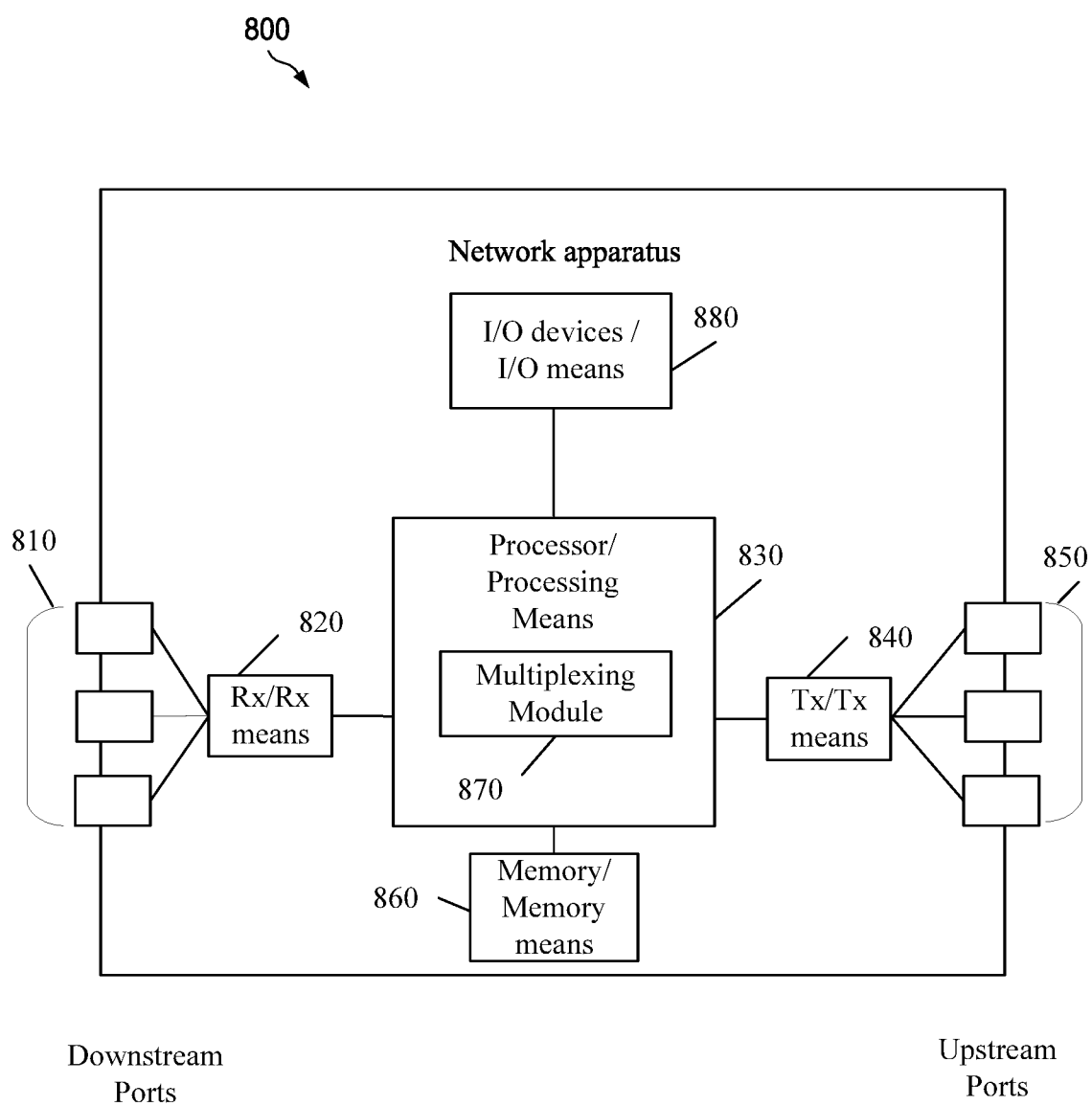


FIG. 8