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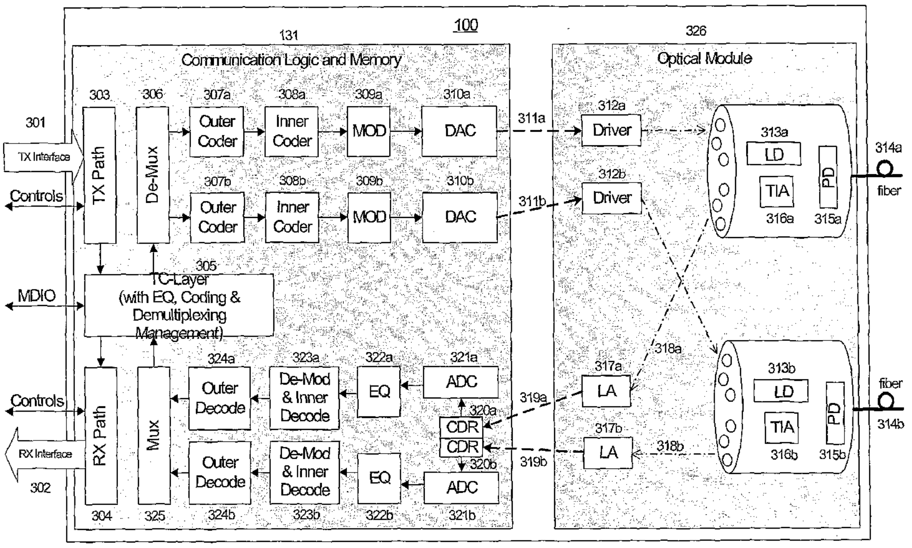
(54) **Title:** SYSTEM AND METHOD FOR PERFORMING HIGH-SPEED COMMUNICATIONS OVER FIBER OPTICAL NETWORKS



(57) **Abstract:** Processing a received optical signal in an optical communication network includes equalizing a received optical signal to provide an equalized signal, demodulating the equalized signal according to an m-ary modulation fornat to provide a demodulated signal, decoding the demodulated signal according to an inner code to provide an inner-decoded signal, and decoding the inner-decoded signal according to an outer code. Other aspects include other features such as equalizing an optical channel including storing channel characteristics for the optical channel associated with a client, loading the stored channel characteristics during a waiting period between bursts on the channel, and equalizing a received burst from the client using the loaded channel characteristics.

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# SYSTEM AND METHOD FOR PERFORMING HIGH-SPEED COMMUNICATIONS OVER FIBER OPTICAL NETWORKS

## CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/477,845 filed June 10, 2003, incorporated herein by reference, and U.S. Provisional Application No. 60/480,488 filed June 21, 2003, incorporated herein by reference.

## FIELD OF THE INVENTION

[0002] The invention relates to optical fiber communications.

## BACKGROUND OF THE INVENTION

[0003] Line coding is a process by which a communication protocol arranges symbols that represent binary data in a particular pattern for transmission. Conventional line coding used in fiber optic communications includes non-return-to-zero (NRZ), return-to-zero (RZ), and biphase, or Manchester. The binary bit stream derived from these line codes can be directly modulated onto wavelengths of light generated by the resonating frequency of a laser. Traditionally direct binary modulation based transmission offers an advantage with regard to the acceptable signal-to-noise ratio (SNR) at the optical receiver, which is one of the reasons direct binary modulation methods are used in the Datacom Ethernet/IP, Storage Fiber-Channel/FC and Telecom SONET/SDH markets for transmission across nonmultiplexed unidirectional fiber links.

[0004] The performance of a fiber optic network can be measured by the maximum data throughput rate (or information carrying capacity) and the maximum distance between source and destination achievable (or reach). For Passive Optical Networks (PONs) in particular, additional measures of performance are the maximum number of Optical Networking Units (ONUs) and/or Optical Networking Terminals (ONTs) possible on a network and the minimum and maximum distance between the Optical Line Terminator (OLT) and an ONU/ONT. These performance metrics are constrained by, among other things, amplitude degradation and temporal distortions as a result of light traveling through an optical fiber.

[0005] Amplitude degradation is substantially a function of length or distance between two end points of an optical fiber. Temporal distortion mechanisms include intramodal (chromatic) dispersion and intermodal (modal) dispersion. Intramodal dispersion is the dominant temporal dispersion on Single-mode fiber (SMF), while intermodal dispersion is dominant on Multi-mode fiber (MMF). Both types of temporal distortions are measured as functions of frequency or rate of transmission (also referred as line rate of a communication protocol) over distance in MHz•km. Temporal distortions are greater, hence a constraint on network performance, with increasing frequency transmission.

## SUMMARY OF THE INVENTION

[0006] In general, in one aspect, the invention includes a method for processing a received optical signal in an optical communication network, the method including: determining a first set of coefficients to equalize a portion of an optical signal received over a first optical link including using a blind equalization method that does not use a known training sequence to equalize the portion of the optical signal, equalizing the portion of the optical signal using the determined coefficients, and demodulating the equalized portion of the optical signal according to an m-ary modulation format.

[0007] Aspects of the invention may include one or more of the following features. The method includes determining a second set of coefficients to equalize a portion of an optical signal received over a second optical link. The method includes selecting one of the first or second set of coefficients based on a source of the portion of optical signal being equalized. The portion of the optical signal includes a burst within a time slot of the first optical link. The method includes storing the determined coefficients. The method includes retrieving the stored coefficients for equalizing a second portion of the optical signal corresponding to a portion received from a same source as generated the first portion of the optical signal. The coefficients are retrieved between signal bursts on the first optical link. The stored coefficients are retrieved for respective portions of the optical signals that correspond to respective signal sources. The first optical link includes a link in a point-to-multipoint passive optical network. The m-ary modulation format is selected from the group consisting of quadrature amplitude modulation and pulse amplitude modulation. The method includes demodulating a received first data stream and demodulating a second data stream received in the optical signal, and multiplexing the first and second data streams.

[0008] In general, in another aspect, the invention includes optical communication system including: a first transceiver coupled by an optical network to a second transceiver and third transceiver, the first transceiver including an equalization block and a modulation block, the equalization block operable to determine a first set of coefficients to equalize a portion of an optical signal received over the optical network from the second transceiver and a second set of coefficients to equalize a portion of the optical signal received over the optical network from the third transceiver, the equalization block including a blind equalization routine that does not use a known training sequence to equalize the portions of the optical signal, the equalization block operable to equalize the portions of the optical signal using the determined coefficients, and the modulation block operable to demodulate equalized portions of the optical signal according to an m-ary modulation format.

[0009] Aspects of the invention may include one or more of the following features. The optical network includes a first optical link for coupling the first and second transceiver, and a second optical link for coupling the first and third transceivers and where the equalization block is operable to select one of the first or second set of coefficients based on a source of the portion of optical signal being equalized. The equalization block is operable to store the first and second sets of coefficients for later retrieval and use to equalize portions of the optical signal. The portion of the optical signal includes a burst within a time slot on the optical network. The equalization block is operable to retrieve the sets of coefficients between signal bursts on the optical network. The optical network includes a link in a point-to-multipoint passive optical network. The m-ary modulation format is selected from the group consisting of quadrature amplitude modulation and pulse amplitude modulation. The system includes a multiplexer, the modulation block operable to demodulating a received first data stream and a second data stream received in the optical signal, and the multiplexer operable to multiplex the first and second data streams. The system includes a transmission convergence layer block for processing data streams received by the first transceiver, the transmission convergence layer block operable to control the demultiplexing of data streams including control of the multiplexer. The optical network is an optical distribution network. The first transceiver is an optical line terminator. The second and third transceivers are optical network terminals or optical network units.

[0010] In general, in another aspect, the invention includes a method for processing data for transmission in an optical communication network, the method including: demultiplexing a data stream into a first demultiplexed data stream and a second demultiplexed data stream, modulating each of the first and second data streams according to an m-ary modulation format, transmitting the first modulated data stream over a first optical link; and transmitting the second modulated data stream over a second optical link.

[0011] In general, in another aspect, the invention includes an optical communication system including: a demultiplexer operable to demultiplex a data stream into a first demultiplexed data stream and a second demultiplexed data stream, a modulation block operable to modulate each of the first and second data streams according to an m-ary modulation format, transmitting means operable to transmit the first modulated data stream over a first optical link and the second modulated data stream over a second optical link.

[0012] In general, in another aspect, the invention includes a method for processing a received optical signal in an optical communication network, the method including: equalizing a received optical signal to provide an equalized signal, demodulating the equalized signal according to an m-ary modulation format to provide a demodulated signal, decoding the demodulated signal according to an inner code to provide an inner-decoded signal, and decoding the inner-decoded signal according to an outer code.

[0013] Aspects of the invention may include one or more of the following features. The m-ary modulation format is selected from the group consisting of quadrature amplitude modulation and pulse amplitude modulation. Equalizing the received optical signal includes equalizing the received optical signal using a blind equalization routine that does not use a known training sequence. Equalizing the received optical signal includes equalizing the received optical signal using a known training sequence. The known training sequence is multiplexed in a frame within the received optical signal. The inner code includes a trellis code. The outer code includes an error correction code. The outer code includes a Reed Solomon code.

[0014] In general, in another aspect, the invention includes a transceiver including: an equalizer for equalizing a received optical signal to provide an equalized signal, a demodulator in communication with the equalizer for demodulating the equalized signal according to an m-ary modulation format to provide a demodulated signal, an inner-decoder in communication with the demodulator for decoding the demodulated signal according to an inner code to provide an inner-decoded signal, and an outer-decoder in communication with the inner-decoder for decoding the inner-decoded signal according to an outer code.

[0015] Aspects of the invention may include one or more of the following features. The transceiver includes an optical module including a first bi-directional optical fiber interface including a first detector and a first driver, and a second bi-directional optical fiber interface including a second detector and a second driver, and management means for managing data flow across the first bi-directional optical fiber interface and across the second bi-directional optical fiber interface. The transceiver includes an optical module including a first bi-directional optical fiber interface including a first detector and a first driver, and a second bi-directional optical fiber interface including a second detector and a second driver, and a multiplexer for multiplexing a first demultiplexed data stream received over the first bi-directional optical fiber interface and a second demultiplexed data stream received over the second bi-directional optical fiber interface into a multiplexed data stream for transmission. The transceiver includes an optical module including a first bi-directional optical fiber interface including a first detector and a first driver, and a second bi-directional optical fiber interface including a second detector and a second driver, and a queue manager for managing traffic for a first bi-directional link associated with the first bi-directional optical fiber interface independently from traffic for a second bi-directional link associated with the second bi-directional optical fiber interface.

[0016] In general, in another aspect, the invention includes a transceiver including: an optical module including a first bi-directional optical fiber interface including a first detector and a first driver, and a second bi-directional optical fiber interface including a second detector and a second driver, and management means for managing data flow across the first bi-directional optical fiber interface and across the second bi-directional optical fiber interface.

[0017] Aspects of the invention may include one or more of the following features. The management means includes a multiplexer for multiplexing a first demultiplexed data stream received over the first bi-directional optical fiber interface and a second demultiplexed data stream received over the second bi-directional optical fiber interface into a multiplexed data stream for transmission. The management means is configured to demultiplex a data stream over a plurality of fiber links that excludes one or more failed fiber links. The management means includes a queue manager for managing traffic across the first bi-directional fiber interface independently from traffic for the second bi-directional fiber interface. The management means is configured to change the alignment of received data bits to adjust for an order of optical fiber connections to the first bi-directional optical fiber interface and the second bi-directional optical fiber interface.

[0018] In general, in another aspect, the invention includes a method for equalizing an optical channel including: storing channel characteristics for the optical channel associated with a client, loading the stored channel characteristics during a waiting period between bursts on the channel, and equalizing a received burst from the client using the loaded channel characteristics.

[0019] Aspects of the invention may include one or more of the following features. The method includes determining that the waiting period occurs before a burst from the client based on a schedule. The method includes updating the stored channel characteristics. The method includes providing a grant window, transmitting an identification number to the client in response to receiving a serial number from the client after the grant window. The method includes determining a distance from an upstream device to the client. The method includes compensating for communication delays between the upstream device and the client based on the determined distance.

[0020] In general, in another aspect, the invention includes a method for communicating data on a fiber optic network, the method including: modulating and demodulating data traffic on an optical link in the network in an m-ary modulation format; encoding and decoding data traffic on an optical link in the network according to an inner coding routine and an outer coding routine, demultiplexing data traffic from an optical link in the network and transmitting the data traffic across a plurality of optical fiber links in the network, multiplexing the data traffic from the plurality of optical fiber links, and equalizing a receive channel in the network to remove temporal distortions.

[0021] Aspects of the invention may include one or more of the following features. The method includes equalizing the receive channel according to a blind equalization routine. The method includes equalizing the receive channel according to a decision directed equalization routine. The method includes saving and loading coefficients for equalizing the receive channel for each of a plurality of transmitting sources. The method includes saving and loading an inner coding state for the receive channel for each of a plurality of transmitting sources. The method includes saving and loading an outer coding state for the receive channel for each of a plurality of transmitting sources. The method includes excluding one or more failed optical fiber links from the plurality of optical fiber links. The method includes conveying a training sequence for a decision directed equalization routine as part of an in-use communication protocol. A training sequence for a decision directed equalization routine is conveyed as part of the activation process for an optical network terminal or optical network unit. An incorrect connection of an optical fiber link is corrected without having to physically change the connection.

[0022] In general, in another aspect, the invention includes a method for communicating on a passive optical network between a central transmission point and a plurality of receiving client end points, the method including: preparing downstream data for transmission and transmitting an optical downstream continuous mode signal demultiplexed across a plurality of bi-directional fibers using a plurality of wavelengths of light, receiving an optical downstream continuous mode signal demultiplexed from the plurality of bi-directional fibers using the plurality of wavelengths of light and recovering a downstream data transmission, preparing upstream data for transmission and transmitting an optical upstream burst mode signal demultiplexed across the plurality of bi-directional fibers using the plurality of wavelengthss of light, and receiving an optical burst mode signal demultiplexed from the plurality of bi-directional fibers using the plurality of wavelengths of light and recovering an upstream data transmission.

[0023] Aspects of the invention may include one or more of the following features. The central transmission point includes an optical line terminal, and the end points are operative as transceivers in a passive optical network. The upstream and downstream data for transmission are conveyed by respective different industry-standard services.

[0024] Implementations of the invention may include one or more of the following advantages.

[0025] A system is proposed that provides for high-speed communications over fiber optic networks. The system may include the use of the one or more of the following techniques either individually or in combination: m-ary modulation; channel equalization; demultiplexing across multiple fibers, coding and error correction. M-ary modulation allows for increased data throughput for a given line rate due to an increase in the number of bits per symbol transmitted. Channel equalization reduces the effects of temporal distortions allowing for increased reach. Demultiplexing across multiple fibers allows lower lines rates for a given data throughput rate due to the increased aggregate data throughput from the multiplexing. Coding and error correction allows for a greater selection of qualifying optical components that can be used in the network and complements m-ary modulation and channel equalization for overall system performance improvement as measured by transmit energy per bit. These methods when combined (in part or in total) increase the data throughput and reach for fiber optic networks. For PONs in particular, these methods may increase the number of ONU/ONTs and the distance between OLT and ONU/ONT without increasing the line rate as compared to a conventional communication system of equivalent data throughput.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0026] FIG. 1 illustrates a fiber optic data network.

[0027] FIG. 2 illustrates a block diagram of a passive optical network.

[0028] FIG. 3 illustrates a block diagram of a high-speed communication system for fiber optic networks.

[0029] FIG. 4 illustrates a block diagram of an alternative high-speed communication system for fiber optic networks.

[0030] FIG. 5 illustrates a block diagram of an alternative high-speed communication system for fiber optic networks.

[0031] FIG. 6 illustrates a block diagram of an alternative high-speed communication system for fiber optic networks.

[0032] FIG. 7 illustrates a block diagram of an alternative high-speed communication system for fiber optic networks.

[0033] FIG. 8 is a flow diagram for an upstream burst mode communication equalization process.

[0034] FIG. 9 is a flow diagram for a downstream continuous mode communication equalization process.

## DETAILED DESCRIPTION

[0035] Referring to **FIG. 1**, wherein like reference numerals designate identical or corresponding parts throughout the several views, a high-level fiber optic data network **50** includes a first transceiver **100** in communication with a second transceiver **101** via a fiber **108**. The first transceiver **100** and the second transceiver **101** include transmitter circuitry (Tx) **134, 135** to convert electrical data input signals into modulated light signals for transmission over the fiber **108**. In addition, the first transceiver **100** and the second transceiver **101** also include receiver circuitry (Rx) **133, 136** to convert optical signals received via the fiber **108** into electrical signals and to detect and recover encoded data and/or clock signals. First transceiver **100** and second transceiver **101** may contain a micro controller (not shown) and/or other communication logic and memory **131, 132** for network protocol operation. Although the illustrated and described implementations of the transceivers **100, 101** include communication logic and memory in a same package or device as the transmitter circuitry **134, 135** and receiver circuitry **133, 136**, other transceiver configurations may also be used.

[0036] First transceiver **100** transmits/receives data to/from the second transceiver **101** in the form of modulated optical light signals of known wavelength via the optical fiber **108**. The transmission mode of the data sent over the optical fiber **108** may be continuous, burst or both burst and continuous modes. Both transceivers **100,101** may transmit a same wavelength (e.g., the light signals are polarized and the polarization of light transmitted from one of the transceivers is perpendicular to the polarization of the light transmitted by the other transceiver). Alternatively, a single wavelength can be used by both transceivers **100, 101** (e.g., the transmissions can be made in accordance with a time-division multiplexing scheme or similar protocol).

[0037] In another implementation, wavelength-division multiplexing (WDM) may also be used. WDM is herein defined as any technique by which two optical signals having different wavelengths may be simultaneously transmitted bi-directionally with one wavelength used in each direction over a single fiber. In yet another implementation, dense wavelength-division multiplexing (DWDM) may be used. DWDM is herein defined as any technique by which more than two optical signals having different wavelengths may be simultaneously transmitted bi-directionally with more than one wavelength used in each direction over a single fiber with each wavelength unique to a direction. For example, if wavelength division multiplexing is used, the first transceiver **100** may transmit data to the second transceiver **101** utilizing a first wavelength of modulated light conveyed via the fiber **108** and, similarly, the second transceiver **101** may transmit data via the same fiber **108** to the first transceiver **100** utilizing a second wavelength of modulated light conveyed via the same fiber **108**. Because only a single fiber is used, this type of transmission system is commonly referred to as a bi-directional transmission system. Although the fiber optic network illustrated in **FIG. 1** includes a first transceiver **100** in communication with a second transceiver **101** via a single fiber **108**, other implementations of fiber optic networks, such as those having a first transceiver in communication with a plurality of transceivers via a plurality of fibers (not shown), may also be used.

[0038] Electrical data input signals (Data IN 1) **115**, as well as any optional clock signal (Data Clock IN 1) **116**, are routed to the transceiver **100** from an external data source (not shown) for processing by the communication logic and memory **131**.

Communication logic and memory **131** process the data and clock signals in accordance with an in-use network protocol. Communication logic and memory **131,132** provides management functions for received and transmitted data including queue management (e.g., independent link control) for each respective link, demultiplexing/multiplexing and other functions as described further below. The processed signals are transmitted by the transmitter circuitry **134**. The resulting modulated light signals produced from the first transceiver's **100** transmitter **134** are then conveyed to the second transceiver **101** via the fiber **108**. The second transceiver **101,** in turn, receives the modulated light signals via the receiver circuitry **136**, converts the light signals to electrical signals, processes the electrical signals using the communication logic and memory **132** (in accordance with an in-use network protocol) and, optionally, outputs the electrical data output signals (Data Out 1) **119**, as well as any optional clock signals (Data Clock Out 1) **120**.

[0039] Similarly, the second transceiver **101** receives electrical data input signals (Data IN 1) **123**, as well as any optional clock signals (Data Clock IN) **124**, from an external data source (not shown) for processing by the communication logic and memory **132** and transmission by the transmitter circuitry **135**. The resulting modulated light signals produced from the second transceiver's **101** transmitter **135** are then conveyed to the first transceiver **100** using the optical fiber **108**. The first transceiver **100,** in turn, receives the modulated light signals via the receiver circuitry **133**, converts the light signals to electrical signals, processes the electrical signals using the communication logic and memory **131** (in accordance with an in-use network protocol), and, optionally, outputs the electrical data output signals (Data Out 1) **127**, as well as any optional clock signals (Data Clock Out 1) **128**.

[0040] Fiber optic data network **50** may also include a plurality of electrical input and clock input signals, denoted herein as Data IN N **117/125** and Data Clock IN N **118/126**, respectively, and a plurality of electrical output and clock output signals, denoted herein as Data Out N **129/121** and Data Clock Out N **130/122**, respectively. The information provided by the plurality of electrical input signals may or may not be used by a given transceiver to transmit information via the fiber **108** and, likewise, the information received via the fiber **108** by a given transceiver may or may not be outputted by the plurality of electrical output signals. The plurality of electrical signals denoted above can be combined to form data plane or control plane bus(es) for input and output signals respectively. In some implementations, the plurality of electrical data input signals and electrical data output signals are used by logic devices or other devices located outside (not shown) a given transceiver to communicate with the transceiver's communication logic and memory **131, 132,** transmit circuitry **134, 135**, and/or receive circuitry **133,136**.

[0041] **FIG. 2** illustrates an implementation of a passive optical network (PON) **52**, where the functions described above associated with the first transceiver **100** and the second transceiver **101** of **FIG. 1**, are implemented in an optical line terminator (OLT) **150** and one ore more optical networking units (ONU) **155,** and/or optical networking terminals (ONT) **160**, respectively. PON(s) **52** may be configured in either a point-to-point network architecture, wherein one OLT **150** is connected to one ONT **160** or ONU **155**, or a point-to-multipoint network architecture, wherein one OLT **150** is connected to a plurality of ONT(s) **160** and/or ONU(s) **155**. In the implementation shown in **FIG. 2,** an OLT **150** is in communication with multiple ONTs/ONUs **160, 155** via a plurality of optical fibers **152**. The fiber **152** coupling the OLT **150** to the PON **52** is also coupled to other fibers **152** connecting the ONTs/ONUs **160, 155** by one or more passive optical splitters **157**. All of the optical elements between an OLT and ONTs/ONUs are often referred to as the Optical Distribution Network (ODN). Other alternate network configurations, including alternate implementations of point-to-multipoint networks are also possible.

[0042] **FIG. 3** shows a system block diagram for an implementation of transceiver **100**. The following is a description of the functions and responsibilities that are part of an implementation of the Communication Logic & Memory **131** of transceiver **100.** The Communication Logic & Memory **131** includes an asynchronous or synchronous system transmit (TX) interface **301** and receive (RX) interface **302** that is supported by the TX Path **303** and RX Path **304** blocks. System interfaces can be selected from conventional interfaces including serial, serial XFI, parallel, GMII, XGMII or XAUI or some other interface may be used. TX Path **303** and RX Path **304** blocks manage the TX and RX interfaces **301,302** and feed data into and get data from the transmission convergence layer (TC-Layer) block **305**. TX Path **303** and RX Path **304** blocks may perform line code adaptation functions (e.g., line coding used outside the transceiver can be terminated by a TX Path block **303** or sourced by a RX Path block **304** to allow a bit stream, cell and/or packet formatted data to be adapted for processing by a TC-Layer block **305**). The TC-Layer **305** block creates the transport system that the data traffic, management and control agents will exploit. TC-Layer **305** block includes a TC-layer protocol stack such as specified in the ITU G.984 specification (incorporated herein by reference), IEEE 802.3ah MAC protocol stack specification (incorporated herein by reference) or a derivative thereof. A variety of other protocol stacks may also be used. The TC-Layer **305** block may perform the additional functions of equalizer, coding, queue and demultiplexing management. The TC-Layer **305** block sends transmit data to a DeMux **306** block, which splits the transmitting data into a plurality of data paths (two paths shown in **FIG. 3**) for demultiplexing data across multiple fibers. Some implementations need not include DeMux **306** block (and hence do not support demultiplexing data across multiple fibers). DeMux **306** block may demultiplex data across a subset of fibers to exclude fibers experiencing link failure to ensure data throughput. The exclusion of fiber links experiencing failure is controlled by the TC-Layer **305** block as part of the demultiplexing management function.

[0043] After DeMux **306** block, in one implementation, the transmit paths have analogous processing blocks. In an alternative implementation, independent signal processing is can be supported in each path. **FIG. 3** shows two transmit paths, though more can be included. In a transmit path, the transmit data is provided to the outer coder **307a, 307b** block. In one implementation, outer coder **307a** performs a reed-solomon coding. Other coding methods can be used. The outer coder **307a, 307b** block provides data to the inner coder **308a, 308b** block. In order to improve the energy per bit required to deliver the transmitting data, an inner coder **308a, 308b** is used. Outer coder **307a, 307b** may be used to support forward error correction (FEC) recovery of bit(s) errors. In one implementation, inner coder **308a, 308b** implements a trellis coding method. Other coding methods may be used. Data from the inner coder **308a, 308b** is provided to Modulation (MOD) **309a, 309b** block. Alternatively, in some implementations, the outer coder **307a, 307b** and inner coder **308a, 308b** blocks are not used, and the output of the DeMux **306** block is provided directly to the MOD **309a, 309b** block.

[0044] To increase the number of bits per symbol transmitted, m-ary modulation is performed in the MOD **309a, 309b** block. In one implementation, an m-ary modulation method such as Quadrature Amplitude Modulation (QAM), 32-QAM, 256-QAM, Pulse Amplitude Modulation (PAM) or 5-PAM is used. Other m-ary modulation methods can be used. After processing by the MOD **309a, 309b** block, the transmit data is converted to an analog signal by a Digital to Analog Converter (DAC) **310a, 310b**. In one implementation, DAC **310a, 310b** is configured to shape, condition or emphasize the signal for improved transmission performance. The DAC **310a, 310b** passes the transmit data via electrical signals **311a, 311b** to the laser driver (Driver) **312a, 312b** as part of an implementation of TX **134** in an Optical Module **326**. The driver **312a, 312b** drives the Laser Diode (LD) **313a, 313b**, which transmits light in response to transmit data signals received from the driver **312a, 312b**. The light emitted from LD **313a, 313b** is directed into the fibers **314a, 314b** with the aid of a fiber optic interface (not shown). The fiber optic interface may include the necessary components (e.g., filters) to implement WDM or DWDM functions.

[0045] On the receive side of the transceiver **100** as part of an implementation of RX **133** in an Optical Module **326**, light propagated across an ODN (not shown in **FIG. 3**) travels over fibers **314a, 314b** through a fiber optic interface (not shown) and is received by the photo diode (PD) **315a, 315b**. In response, the PD **315a, 315b** provides a photocurrent to the TransImpedance Amplifier (TIA) **316a, 316b** that converts the photocurrent into an electrical voltage signal. The electrical voltage signal from the TIA **316a, 316b** is then transmitted to a Linear Amplifier (LA) **317a, 317b** as a differential signal or a single-ended signal **318a, 318b**. The LA **317a, 317b** performs signal conditioning on the received electrical voltage signal to provide increased resolution and system performance. The LA **317a, 317b** provides an electrical signal **319a, 319b** to a Clock Data Recovery (CDR) **320a, 320b** block that recovers clock and data signals, which are provided to an Analog to Digital Converter (ADC) **321a, 321b**. The ADC **321a, 321b** converts analog signals to digital signals, which are provided to an Equalization (EQ) **322a, 322b** block. The EQ **322a, 322b** block performs equalization on the received data, which is then provided to a De-Mod & Inner Decoder **323a, 323b**. An Equalization **322a, 323b** block may implement a blind equalization method or decision-directed equalization method. Blind equalization is discussed further below. Other equalization methods may be used. The De-Mod & Inner Decoder **323a, 323b** block performs complementary demodulation to the m-ary modulation performed in the MOD **309a, 309b** block as well as a complementary decoding method to the coding method performed in the Inner Coder **308a, 308b** block. In one implementation, De-Mod & Inner Decoder **323a, 323b** includes a Viterbi decoder. Other decoding means may be used. Received data is then provided to the outer decoder **324a, 324b** block, which performs a complementary decode to the error detection and/or recovery method chosen in the outer coder **307a, 307b** block. After demodulation and decoding, the received data is then provided to the Mux **325** block that performs a complementary function to the DeMux **306** block. The combined received data is then provided to the TC-Layer **305**. In implementations without Outer Coder **307a, 307b** and Inner Coder **308a, 308b** blocks, the output of the EQ **322a, 322b** block is provided directly to the Mux **325** block.

[0046] The RX **133,136** and TX **134,135** circuitry of transceivers **100,101**, or portions thereof, for example, PD **315a, 315b** and LA **317a, 317b**, can be combined within industry standard optical modules. Common optical module standards are 300pin, XENPAK, X2, and XPAK transponders and XFP or SFP transceivers. These optical modules include unidirectional fiber links with one fiber link for transmit path and a second fiber link for the receive path. However, implementations of optical modules **326, 401, 501** incorporate a plurality of bi-directional fiber links for transmitting demultiplexed data on separate fiber links. Any of a variety of optical couplers may be used to separate and/or combine light propagating into or out of the fiber links. These optical modules **326, 401, 501** used herein can conform to a form factor of standard optical modules such as the 300pin, XENPAK, X2, XPAK, XFP or SFP. Other form factors may also be used.

[0047] Alternatively, in other implementations of transceiver **100**, functions described above may be integrated into various different components. For example, in the implementation of transceiver **100** shown in **FIG. 4**, various functions may be incorporated into optical module **401** such as: digital to analog conversion **310a, 310b**; analog to digital conversion **321a, 321b**; clock data recovery **320a, 320b**; m-ary modulation **309a, 309b**; m-ary de-modulation **323a, 323b**; channel equalization **322a, 322b**; inner coder **308a, 308b**; inner de-coder **323a, 323b**; outer coder **307a, 307b**; outer de-coder **324a, 324b**, and the De-Mux **306** and Mux **325** functions that enable demultiplexing across multiple fibers. The optical module **401** may have an interface that can connect to existing TC-Layer or MAC implementations currently produced. In another alternative implementation the digital to analog conversion **310a, 310b**; analog to digital conversion **321a, 321b,** and the clock data recovery **320a, 320b** functions are incorporated into an optical module (not shown). In yet another alternative implementation of the transceiver **100** as shown in **FIG. 5**, an optical module **501** includes the De-Mux **306** and Mux **325** functions enabling demultiplexing across multiple fibers. The optical module **501** may have an interface that can connect to existing TC-Layer or MAC implementations currently produced.

[0048] An alternative implementation of transceiver **100** utilizing a single fiber link **314a** (without demultiplexing across multiple fibers) is illustrated in **FIG. 6**. Alternatively, an implementation of the transceiver **100** may utilize multiple fiber links **314a, 314b** while not performing demultiplexing across multiple fibers, as illustrated in **FIG. 7**. In this implementation, the TC-Layer **701** block manages the fiber links as independent fiber links that all connect to the same end point(s) on the network. In one implementation, TC-Layer **701** block is a derivative of the Transmission Convergence Layer specified in ITU G.984 or MAC specified in IEEE 802.3ah, with the added functionality of queue management of the traffic across the plurality of independent fiber links. The TC-Layer **701** block may exclude use of one or more fiber links if the fiber link experiences a failure. This exclusion of failed fiber links enables the TC-Layer **701** block (i.e., queue management function) to continue providing service across a PON using the remaining active links. Each fiber can be deployed across physically different paths to provide optical fiber distribution path diversity and improved protection against failures. Failures may originate in the optical module or across elements of the ODN such as fiber or connector breaks.

**Channel Equalization**

[0049] An implementation for a channel equalization routine executed in the EQ **322a, 322b** block includes determining coefficients or weights that are applied to the received data to remove undesired information or noise from the received data.

Channel equalization can include a training or convergence period in which characteristics of the channel are learned or accounted for and coefficients or weights are adapted before processing the received data. Decision-directed equalization is an equalization method in which a known training sequence is sent during the training period and the receiver/transceiver uses the knowledge of the training sequence to learn about the channel characteristics. The training sequence can be multiplexed within a PON's TC-Layer framing protocol. Blind equalization is a process during which an unknown input data sequence is recovered from the output signal of an unknown channel (i.e., current equalization data for a given channel is unknown or otherwise unavailable).

[0050] One mode of communications used by a PON, e.g., for upstream data traffic (ONU/ONT to OLT direction), is "burst mode" communications. For example, upstream communications on a PON may include a link shared among multiple clients or ONUs/ONTs via time division multiplexing under control by an OLT. The upstream direction is divided into time slots; each time slot includes a defined number of bits. A given ONU/ONT is granted some number of time slots during which to transmit an upstream frame of data to an OLT. The upstream direction uses an orchestrated collection of bursts from the different ONU/ONTs, coordinated by the OLT that tries to maximize upstream traffic bandwidth efficiency by minimizing empty slots.

[0051] A flow chart for an exemplary upstream burst mode communication equalization process is shown in **FIG. 8**. To read or interpret the upstream data traffic from a client ONU/ONT, an OLT trains and/or equalizes the channel for that client ONU/ONT. Since the ONU/ONTs may be at different distances from the OLT and all do not share the same fiber, different channel characteristics result. Communication efficiencies may be obtained by determining **800** a set of equalization coefficients for a channel during a burst from a client, saving **801** the determined equalization coefficients, entering a wait period **802** (also known as a PON's silence period when no client ONU/ONTs are transmitting upstream), and loading **803** the stored equalization coefficients before a next burst from the client (during the wait period), to avoid re-training or re-equalizing on every burst communication. The OLT has prior knowledge of which ONU/ONT will be transmitting data during which time slots and can use this knowledge during the time between burst communications (during the wait period) to load **803** an appropriate set of coefficients pertaining to the particular ONU/ONT transmitting prior to receiving **804** its next upstream burst. This process continues for subsequent bursts. In one implementation, periodic (though not coincident with each communication burst) updates to the channel characteristics may be made (and stored). The OLT can save **801** coefficients that have converged or have been trained after receiving burst communications from the first ONU/ONT and load **803** a new set of coefficients during the wait period between bursts (i.e., before an incoming upstream burst from a second ONU/ONT). In one implementation, in addition to or alternative to storage of coefficient data, the OLT may also save and load inner and/or outer coding states between bursts improving the efficiency of communication, similar to the equalization process of **FIG. 8**.

[0052] Another mode of communications used by a PON, e.g., for downstream data traffic (OLT to ONU/ONT direction), is "continuous mode" communications. In one implementation, a receiver, such as an ONU/ONT, equalizes a received data channel using either one of a blind equalization or a decision directed equalization method.

[0053] A flow chart for an exemplary PON activation process is shown in **FIG. 9**. In a PON in which a decision directed method is used for training an ONU/ONT receiver, a continuous mode transmitter, such as an OLT transmitter, sends a training sequence **900** multiplexed within a PON's TC-Layer downstream frame protocol. In a PON in which a blind equalization method is used, the OLT needed not send this training sequence **900**. An ONU/ONT equalizes its received downstream channel **901** before it is able to receive and interpret PON network parameters **902**. If the OLT has not been previously informed of the existence of the ONU/ONT then the ONU/ONT awaits an upstream grant window **903** available for new ONU/ONTs to respond to the OLT with its serial number **904**. After the ONU/ONT has received an upstream grant window and processed PON system parameters, the ONU/ONT sends a training sequence **905** and then its serial number **904** to the OLT. In a PON in which blind equalization is used the ONU/ONT need not send a training sequence **905**. After the OLT has received the ONU/ONT serial number the OLT will assign and send the ONU/ONT an identification number. If the

ONU/ONT does not receive an identification number **906a**, the ONU/ONT returns to waiting for an upstream grant window for new ONU/ONTs **903**. Once the ONU/ONT receives an identification number **906b**, the OLT performs ranging **907** to determine the distance between the OLT and ONU/ONT and then compensates for the communication timing delays. The ONU/ONT can perform updates continuously or periodically depending on the equalization method employed. After the downstream continuous mode channel and the upstream burst mode channel have been equalized, both ends of the PON transmission link are equalized and the ONU/ONT enters its normal operating state **908**.

## Link Connection Errors

[0054] A system has been proposed that includes demultiplexing across multiple fibers as is shown above with reference to **FIG.s 3-6.** In systems using demultiplexing across multiple fibers, fibers can be connected incorrectly at installation. For example, a first transceiver **100**, such as is shown in **FIG. 3**, with fibers **314a** and **314b** can be connected to a second transceiver **101** with fiber **314b** connected in place of fiber **314a**, and fiber **314a** connected in place of fiber **314b**. The incorrect connection in this example may cause the first and second transceivers to not establish communications due to misalignment of bits during multiplexing of received data.

[0055] Information in a frame is used to synchronize a receiver (e.g., transceiver **101**) with the beginning of a frame (e.g., a "frame delimiter"). The process of discovering the beginning of a frame is called "frame synchronization." In specific protocols such as G.984, the downstream frame delimiter is called Psync, the upstream frame delimiter is called Delimiter and the process of frame synchronization in the downstream is called the HUNT. In one implementation, TC-Layer **305** block performs frame synchronization. In one implementation, specific bit patterns or values for frame delimiters are used that are unique for each fiber to differentiate one fiber from another or the order of fiber connections to correctly multiplex received data. The use of unique frame delimiters allows the TC-Layer **305** block to change the alignment of received data bits during multiplexing to adjust for the order of the fiber connections, without having to physically change the connections. Management of the bit alignment in this implementation forms part of the TC-Layer's **305** block demultiplexing management responsibilities and functions.

[0056] Alternatively, the TC-Layer **305** block may assume an order for the fiber connections to determine the alignment of bits for multiplexing the received data and attempt frame synchronization. After a period of time with no frame synchronization success, the TC-Layer **305** block may assume a different order for the fiber connections and change the alignment of bits during multiplexing and attempt frame synchronization again. The process may repeat, including changing the alignment of bits to reflect other configurations during the multiplexing, and frame synchronization attempts continue until frame synchronization succeeds. In yet another alternative implementation, the TC-Layer **305** block may assume and attempt frame synchronization on all possible combinations of bit alignments in parallel, one of which will succeed in achieving frame synchronization.

[0057] Although the invention has been described in terms of particular implementations, one of ordinary skill in the art, in light of this teaching, can generate additional implementations and modifications without departing from the spirit of or exceeding the scope of the claimed invention. Accordingly, it is to be understood that the drawings and descriptions herein are proffered by way of example to facilitate comprehension of the invention and should not be construed to limit the scope thereof.

What is claimed is:

1. A method for processing a received optical signal in an optical communication network, the method comprising:

determining a first set of coefficients to equalize a portion of an optical signal received over a first optical link including using a blind equalization method that does not use a known training sequence to equalize the portion of the optical signal;

equalizing the portion of the optical signal using the determined coefficients; and

demodulating the equalized portion of the optical signal according to an m-ary modulation format.

2. The method of claim 1, further comprising determining a second set of coefficients to equalize a portion of an optical signal received over a second optical link.

3. The method of claim 2 further comprising selecting one of the first or second set of coefficients based on a source of the portion of optical signal being equalized.

4. The method of claim 1, wherein the portion of the optical signal comprises a burst within a time slot of the first optical link.

5. The method of claim 1, further comprising storing the determined coefficients.

6. The method of claim 5, further comprising retrieving the stored coefficients for equalizing a second portion of the optical signal corresponding to a portion received from a same source as generated the first portion of the optical signal.

7. The method of claim 6, wherein the coefficients are retrieved between signal bursts on the first optical link.

8. The method of claim 7, wherein the stored coefficients are retrieved for respective portions of the optical signals that correspond to respective signal sources.

9. The method of claim 1, wherein the first optical link comprises a link in a point-to-multipoint passive optical network.

10. The method of claim 1, wherein the m-ary modulation format is selected from the group consisting of quadrature amplitude modulation and pulse amplitude modulation.

**11.** The method of claim 1, further comprising demodulating a received first data stream and demodulating a second data stream received in the optical signal, and multiplexing the first and second data streams.

12. A optical communication system comprising:

a first transceiver coupled by an optical network to a second transceiver and third transceiver,

the first transceiver including an equalization block and a modulation block, the equalization block operable to determine a first set of coefficients to equalize a portion of an optical signal received over the optical network from the second transceiver and a second set of coefficients to equalize a portion of the optical signal received over the optical network from the third transceiver, the equalization block including a blind equalization routine that does not use a known training sequence to equalize the portions of the optical signal, the equalization block operable to equalize the portions of the optical signal using the determined coefficients, and

the modulation block operable to demodulate equalized portions of the optical signal according to an m-ary modulation format.

13. The system of claim 12, wherein the optical network includes a first optical link for coupling the first and second transceiver, and a second optical link for coupling the first and third transceivers and where the equalization block is operable to select one of the first or second set of coefficients based on a source of the portion of optical signal being equalized.

14. The system of claim 12, wherein the equalization block is operable to store the first and second sets of coefficients for later retrieval and use to equalize portions of the optical signal.

15. The system of claim 12, wherein the portion of the optical signal comprises a burst within a time slot on the optical network.

16. The system of claim 12, wherein the equalization block is operable to retrieve the sets of coefficients between signal bursts on the optical network.

17. The system of claim 12, wherein the optical network comprises a link in a point-to-multipoint passive optical network.

18. The system of claim 12, wherein the m-ary modulation format is selected from the group consisting of quadrature amplitude modulation and pulse amplitude modulation.

19. The system of claim 12, further comprising a multiplexer, the modulation block operable to demodulating a received first data stream and a second data stream received in the optical signal, and the multiplexer operable to multiplex the first and second data streams.

20. The system of claim 19, further comprising a transmission convergence layer block for processing data streams received by the first transceiver, the transmission convergence layer block operable to control the demultiplexing of data streams including control of the multiplexer.

21. The system of claim 12, wherein the optical network is an optical distribution network.

22. The system of claim 12, wherein the first transceiver is an optical line terminator.

23. The system of claim 12, wherein the second and third transceivers are optical network terminals or optical network units.

24. A method for processing data for transmission in an optical communication network, the method comprising:

demultiplexing a data stream into a first demultiplexed data stream and a second demultiplexed data stream;

modulating each of the first and second data streams according to an m-ary modulation format;

transmitting the first modulated data stream over a first optical link; and transmitting the second modulated data stream over a second optical link.

25. A optical communication system comprising:

a demultiplexer operable to demultiplex a data stream into a first demultiplexed data stream and a second demultiplexed data stream;

a modulation block operable to modulate each of the first and second data streams according to an m-ary modulation format;

transmitting means operable to transmit the first modulated data stream over a first optical link and the second modulated data stream over a second optical link.

26. A method for processing a received optical signal in an optical communication network, the method comprising:

equalizing a received optical signal to provide an equalized signal;

demodulating the equalized signal according to an m-ary modulation format to provide a demodulated signal;

decoding the demodulated signal according to an inner code to provide an inner-decoded signal; and

decoding the inner-decoded signal according to an outer code.

27. The method of claim 26, wherein the m-ary modulation format is selected from the group consisting of quadrature amplitude modulation and pulse amplitude modulation.

28. The method of claim 26, wherein equalizing the received optical signal comprises equalizing the received optical signal using a blind equalization routine that does not use a known training sequence.

29. The method of claim 26, wherein equalizing the received optical signal comprises equalizing the received optical signal using a known training sequence.

30. The method of claim 29, wherein the known training sequence is multiplexed in a frame within the received optical signal.

31. The method of claim 26, wherein the inner code comprises a trellis code.

32. The method of claim 26, wherein the outer code comprises an error correction code.

33. The method of claim 31, wherein the outer code comprises a Reed Solomon code.

34. A transceiver comprising:

an equalizer for equalizing a received optical signal to provide an equalized signal;

a demodulator in communication with the equalizer for demodulating the equalized signal according to an m-ary modulation format to provide a demodulated signal;

an inner-decoder in communication with the demodulator for decoding the demodulated signal according to an inner code to provide an inner-decoded signal; and

an outer-decoder in communication with the inner-decoder for decoding the inner-decoded signal according to an outer code.

35. The transceiver of claim 34, further comprising:

an optical module including

a first bi-directional optical fiber interface including a first detector and a first driver, and

a second bi-directional optical fiber interface including a second detector and a second driver; and

management means for managing data flow across the first bi-directional optical fiber interface and across the second bi-directional optical fiber interface.

36. The transceiver of claim 34, further comprising:

an optical module including

a first bi-directional optical fiber interface including a first detector and a first driver, and

a second bi-directional optical fiber interface including a second detector and a second driver; and

a multiplexer for multiplexing a first demultiplexed data stream received over the first bi-directional optical fiber interface and a second demultiplexed data stream received over the second bi-directional optical fiber interface into a multiplexed data stream for transmission.

37. The transceiver of claim 34, further comprising:

an optical module including

a first bi-directional optical fiber interface including a first detector and a first driver, and

a second bi-directional optical fiber interface including a second detector and a second driver; and

a queue manager for managing traffic for a first bi-directional link associated with the first bi-directional optical fiber interface independently from traffic for a second bi-directional link associated with the second bi-directional optical fiber interface.

38. A transceiver comprising:

an optical module including

a first bi-directional optical fiber interface including a first detector and a first driver, and

a second bi-directional optical fiber interface including a second detector and a second driver; and

management means for managing data flow across the first bi-directional optical fiber interface and across the second bi-directional optical fiber interface.

39. The transceiver of claim 38, wherein the management means includes a multiplexer for multiplexing a first demultiplexed data stream received over the first bi-directional optical fiber interface and a second demultiplexed data stream received over the second bi-directional optical fiber interface into a multiplexed data stream for transmission.

40. The transceiver of claim 38, wherein the management means is configured to demultiplex a data stream over a plurality of fiber links that excludes one or more failed fiber links.

41. The transceiver of claim 38, wherein the management means includes a queue manager for managing traffic across the first bi-directional fiber interface independently from traffic for the second bi-directional fiber interface.

42. The transceiver of claim 38, wherein the management means is configured to change the alignment of received data bits to adjust for an order of optical fiber connections to the first bi-directional optical fiber interface and the second bi-directional optical fiber interface.

43. A method for equalizing an optical channel comprising:

storing channel characteristics for the optical channel associated with a client;

loading the stored channel characteristics during a waiting period between bursts on the channel; and

equalizing a received burst from the client using the loaded channel characteristics.

44. The method of claim 43, further comprising determining that the waiting period occurs before a burst from the client based on a schedule.

45. The method of claim 43, further comprising updating the stored channel characteristics.

46. The method of claim 43, further comprising:

providing a grant window;

transmitting an identification number to the client in response to receiving a serial number from the client after the grant window.

47. The method of claim 43, further comprising determining a distance from an upstream device to the client.

48. The method of claim 43, further comprising compensating for communication delays between the upstream device and the client based on the determined distance.

49. A method for communicating data on a fiber optic network, the method comprising:

modulating and demodulating data traffic on an optical link in the network in an m-ary modulation format;

encoding and decoding data traffic on an optical link in the network according to an inner coding routine and an outer coding routine;

demultiplexing data traffic from an optical link in the network and transmitting the data traffic across a plurality of optical fiber links in the network;

multiplexing the data traffic from the plurality of optical fiber links; and

equalizing a receive channel in the network to remove temporal distortions.

50. The method of claim 49, further comprising equalizing the receive channel according to a blind equalization routine

51. The method of claim 49, further comprising equalizing the receive channel according to a decision directed equalization routine.

52. The method of claim 49, further comprising saving and loading coefficients for equalizing the receive channel for each of a plurality of transmitting sources.

53. The method of claim 49, further comprising saving and loading an inner coding state for the receive channel for each of a plurality of transmitting sources.

54. The method of claim 49, further comprising saving and loading an outer coding state for the receive channel for each of a plurality of transmitting sources.

55. The method of claim 49, further comprising excluding one or more failed optical fiber links from the plurality of optical fiber links.

56. The method of claim 49, further comprising conveying a training sequence for a decision directed equalization routine as part of an in-use communication protocol.

57. The method of claim 49, wherein a training sequence for a decision directed equalization routine is conveyed as part of the activation process for an optical network terminal or optical network unit.

58. The method of claim 49, wherein an incorrect connection of an optical fiber link is corrected without having to physically change the connection.

59. A method for communicating on a passive optical network between a central transmission point and a plurality of receiving client end points, the method comprising:

preparing downstream data for transmission and transmitting an optical downstream continuous mode signal demultiplexed across a plurality of bi-directional fibers using a plurality of wavelengths of light;

receiving an optical downstream continuous mode signal demultiplexed from the plurality of bi-directional fibers using the plurality of wavelengths of light and recovering a downstream data transmission;

preparing upstream data for transmission and transmitting an optical upstream burst mode signal demultiplexed across the plurality of bi-directional fibers using the plurality of wavelengthss of light; and

receiving an optical burst mode signal demultiplexed from the plurality of bi-directional fibers using the plurality of wavelengths of light and recovering an upstream data transmission.

60. The method of claim 59, wherein the central transmission point comprises an optical line terminal, and the end points are operative as transceivers in a passive optical network.

61. The method of claim 59, wherein the upstream and downstream data for transmission are conveyed by respective different industry-standard services.

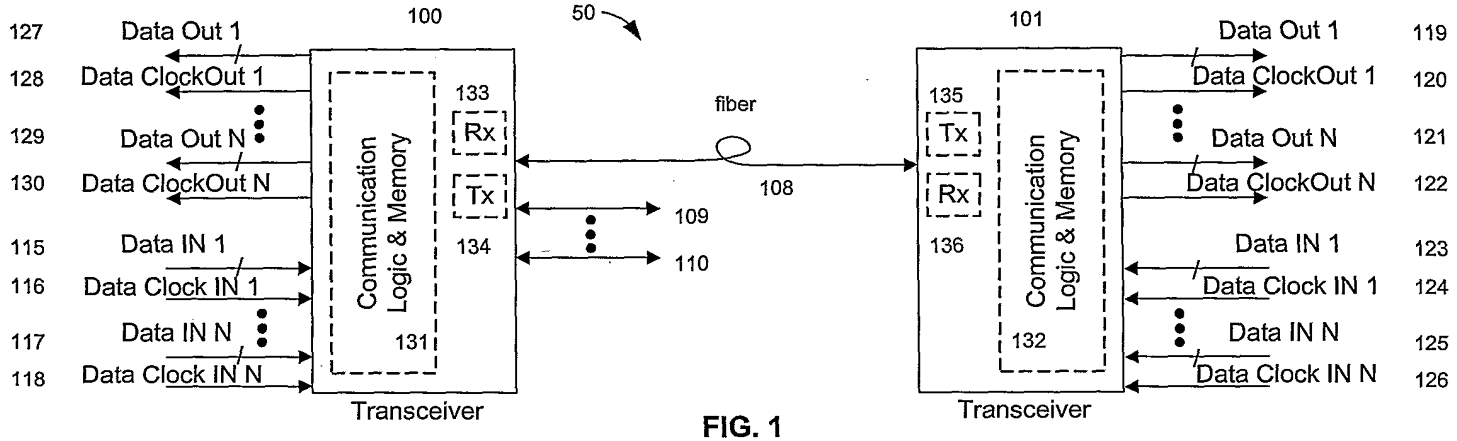
50
100
Transceiver
Communication Logic & Memory
131
133
Rx
Tx
134
127 Data Out 1
128 Data ClockOut 1
129 Data Out N
130 Data ClockOut N
115 Data IN 1
116 Data Clock IN 1
117 Data IN N
118 Data Clock IN N
fiber
108
109
110
101
Transceiver
Communication Logic & Memory
132
135
Tx
Rx
136
Data Out 1 119
Data ClockOut 1 120
Data Out N 121
Data ClockOut N 122
Data IN 1 123
Data Clock IN 1 124
Data IN N 125
Data Clock IN N 126

FIG. 1

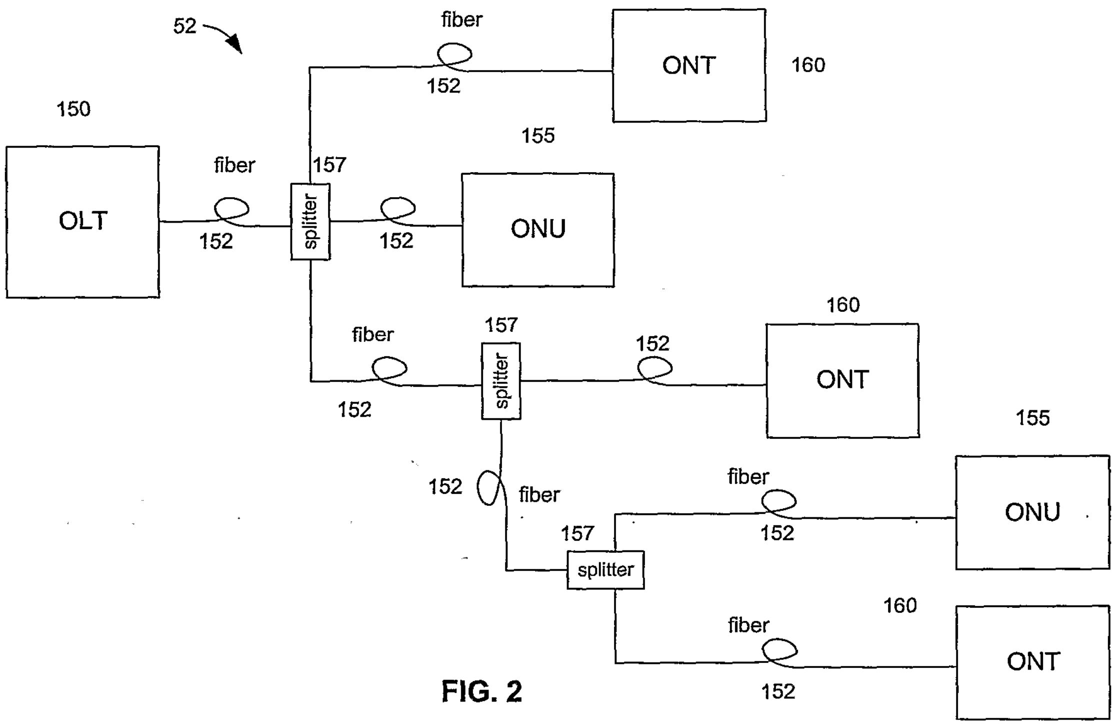
52
150
OLT
fiber
152
157
splitter
155
ONU
160
ONT
fiber
152
splitter
157
152
fiber
splitter
157
ONU
155
ONT
160

FIG. 2

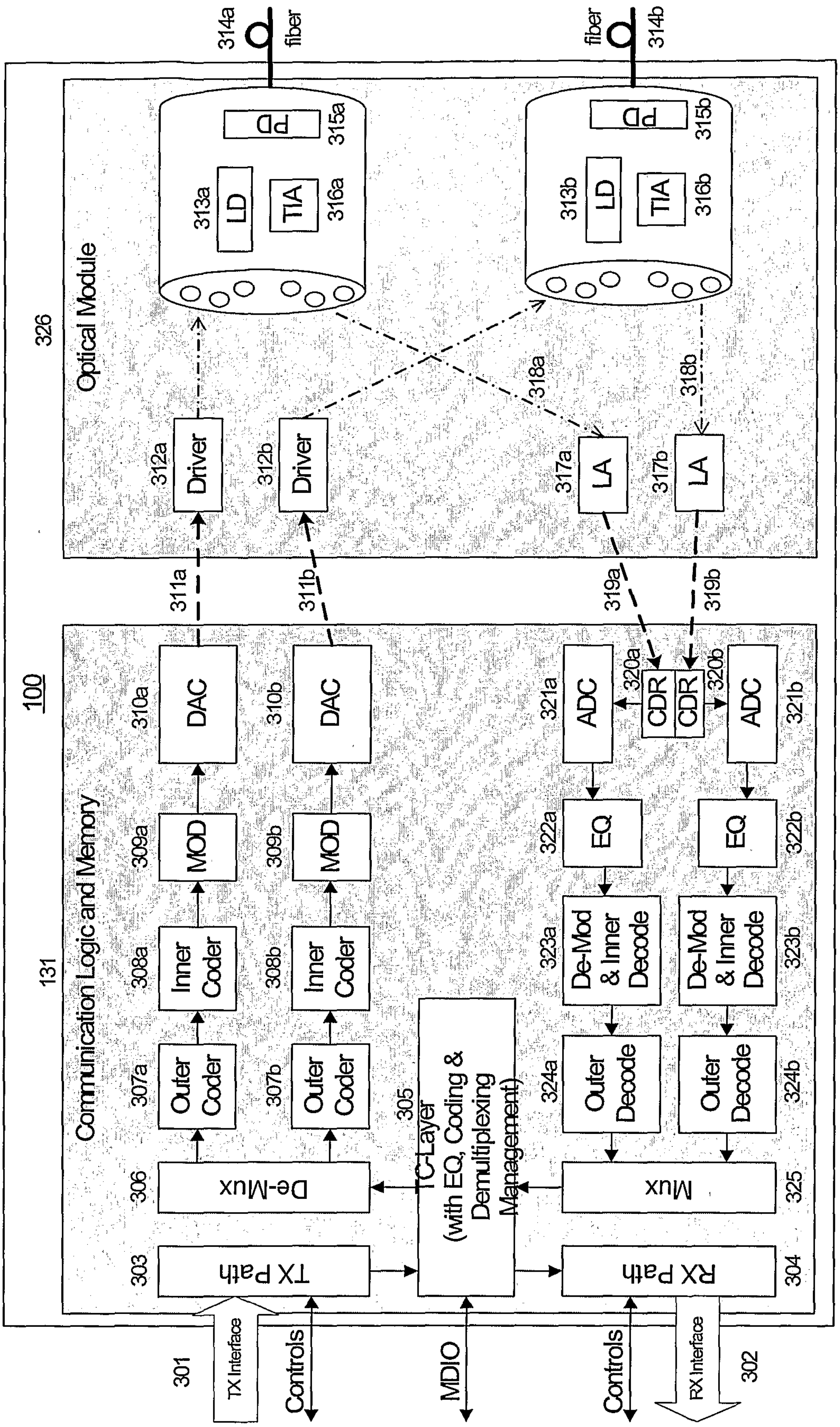
100
131
Communication Logic and Memory
326
Optical Module
301
TX Interface
Controls
MDIO
Controls
RX Interface
302
303
TX Path
304
RX Path
305
TC-Layer (with EQ, Coding & Demultiplexing Management)
306
De-Mux
325
Mux
307a
Outer Coder
307b
Outer Coder
308a
Inner Coder
308b
Inner Coder
309a
MOD
309b
MOD
310a
DAC
310b
DAC
311a
311b
312a
Driver
312b
Driver
313a
LD
313b
LD
314a
fiber
314b
fiber
315a
PD
315b
PD
316a
TIA
316b
TIA
317a
LA
317b
LA
318a
318b
319a
319b
320a
CDR
320b
CDR
321a
ADC
321b
ADC
322a
EQ
322b
EQ
323a
De-Mod & Inner Decode
323b
De-Mod & Inner Decode
324a
Outer Decode
324b
Outer Decode

FIG. 3

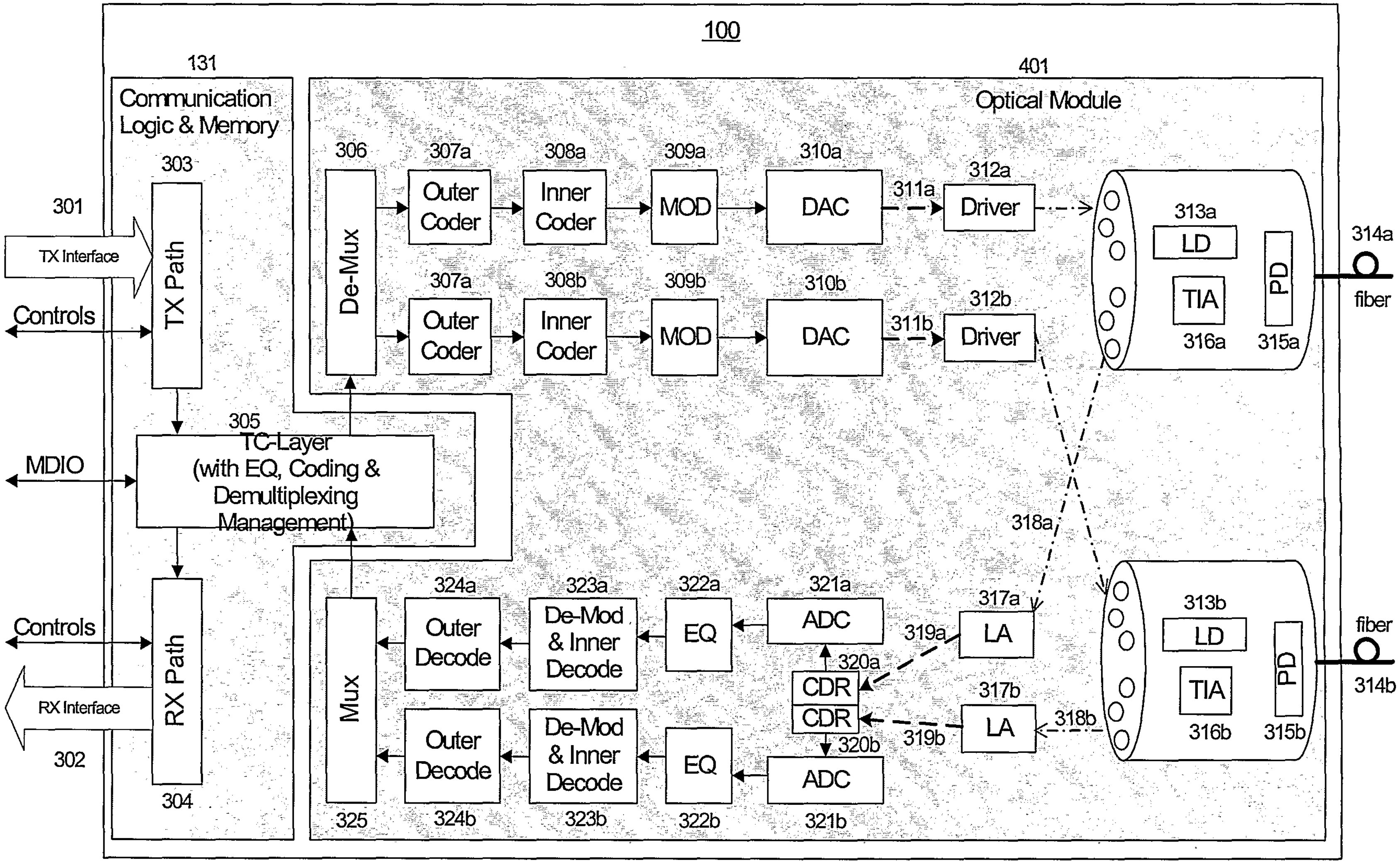
100
131
Communication Logic & Memory
401
Optical Module
301
TX Interface
Controls
303
TX Path
305
TC-Layer (with EQ, Coding & Demultiplexing Management)
MDIO
Controls
RX Interface
302
RX Path
304
306
De-Mux
307a
Outer Coder
308a
Inner Coder
309a
MOD
310a
DAC
311a
312a
Driver
307a
Outer Coder
308b
Inner Coder
309b
MOD
310b
DAC
311b
312b
Driver
313a
LD
TIA
PD
316a
315a
314a
fiber
318a
313b
LD
TIA
PD
316b
315b
fiber
314b
324a
Outer Decode
323a
De-Mod & Inner Decode
322a
EQ
321a
ADC
317a
LA
319a
320a
CDR
CDR
320b
317b
LA
318b
319b
325
Mux
Outer Decode
324b
De-Mod & Inner Decode
323b
EQ
322b
ADC
321b

FIG. 4

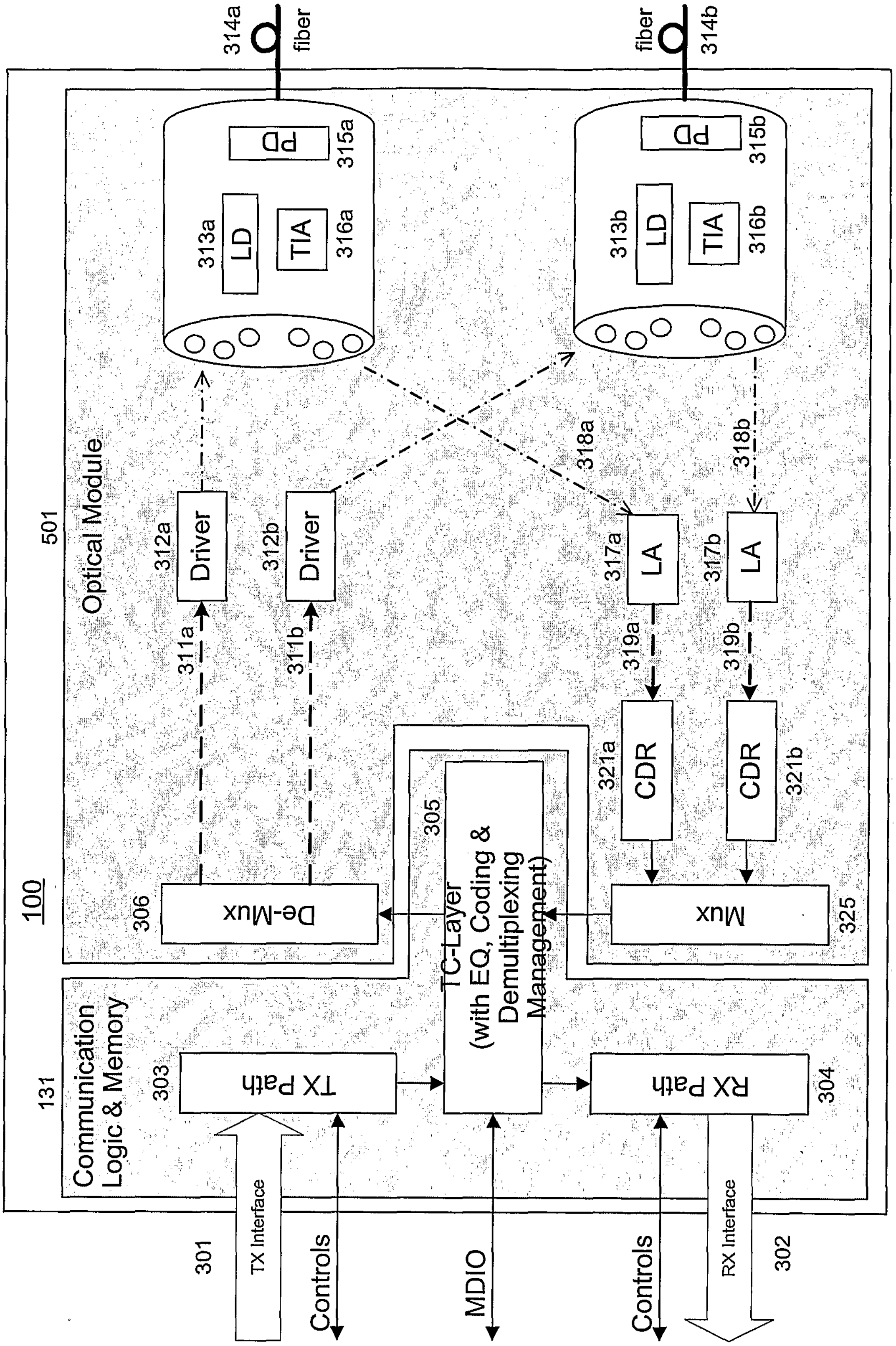
100
501
Optical Module
131
Communication Logic & Memory
314a
fiber
314b
fiber
PD
315a
LD
313a
TIA
316a
PD
315b
LD
313b
TIA
316b
318a
318b
Driver
312a
Driver
312b
311a
311b
LA
317a
LA
317b
319a
319b
CDR
321a
CDR
321b
De-Mux
306
Mux
325
305
TC-Layer (with EQ, Coding & Demultiplexing Management)
TX Path
303
RX Path
304
301
TX Interface
Controls
MDIO
Controls
RX Interface
302

FIG. 5

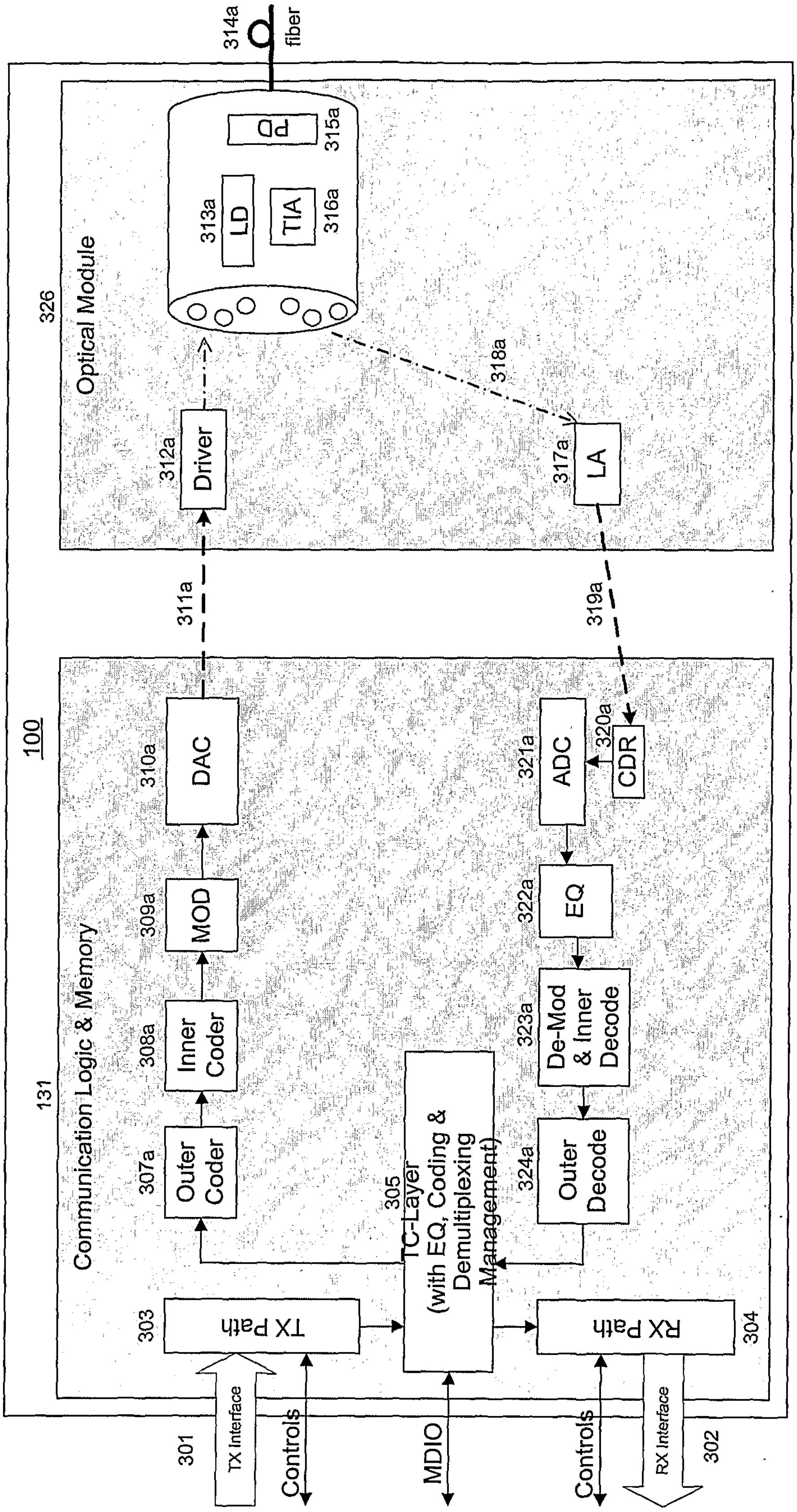
100
131
Communication Logic & Memory
326
Optical Module
301
TX Interface
Controls
MDIO
Controls
RX Interface
302
303
TX Path
305
TC-Layer
(with EQ, Coding & Demultiplexing Management)
304
RX Path
307a
Outer Coder
308a
Inner Coder
309a
MOD
310a
DAC
311a
312a
Driver
313a
LD
314a
fiber
315a
PD
316a
TIA
318a
317a
LA
319a
320a
CDR
321a
ADC
322a
EQ
323a
De-Mod & Inner Decode
324a
Outer Decode

FIG. 6

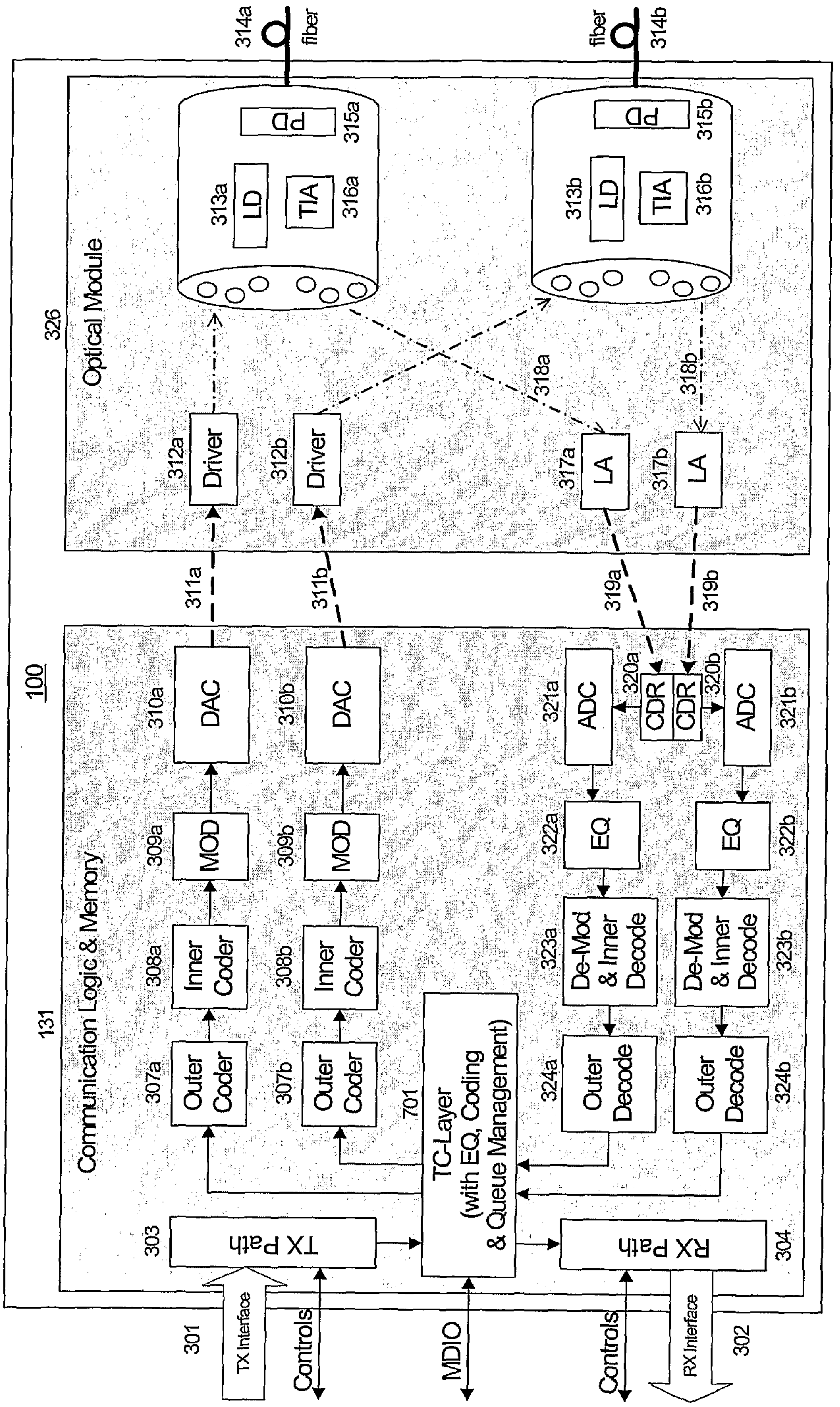
100
131
Communication Logic & Memory
326
Optical Module
301
TX Interface
Controls
MDIO
Controls
RX Interface
302
303
TX Path
304
RX Path
701
TC-Layer (with EQ, Coding & Queue Management)
307a
Outer Coder
308a
Inner Coder
309a
MOD
310a
DAC
307b
Outer Coder
308b
Inner Coder
309b
MOD
310b
DAC
311a
311b
312a
Driver
312b
Driver
313a
LD
316a
TIA
315a
PD
314a
fiber
313b
LD
316b
TIA
315b
PD
314b
fiber
318a
318b
317a
LA
317b
LA
319a
319b
320a
CDR
320b
CDR
321a
ADC
321b
ADC
322a
EQ
322b
EQ
323a
De-Mod & Inner Decode
323b
De-Mod & Inner Decode
324a
Outer Decode
324b
Outer Decode

FIG. 7

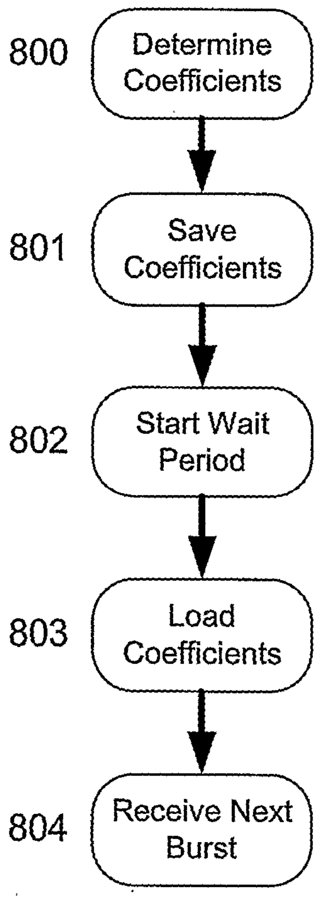
800
Determine Coefficients
801
Save Coefficients
802
Start Wait Period
803
Load Coefficients
804
Receive Next Burst

FIG. 8

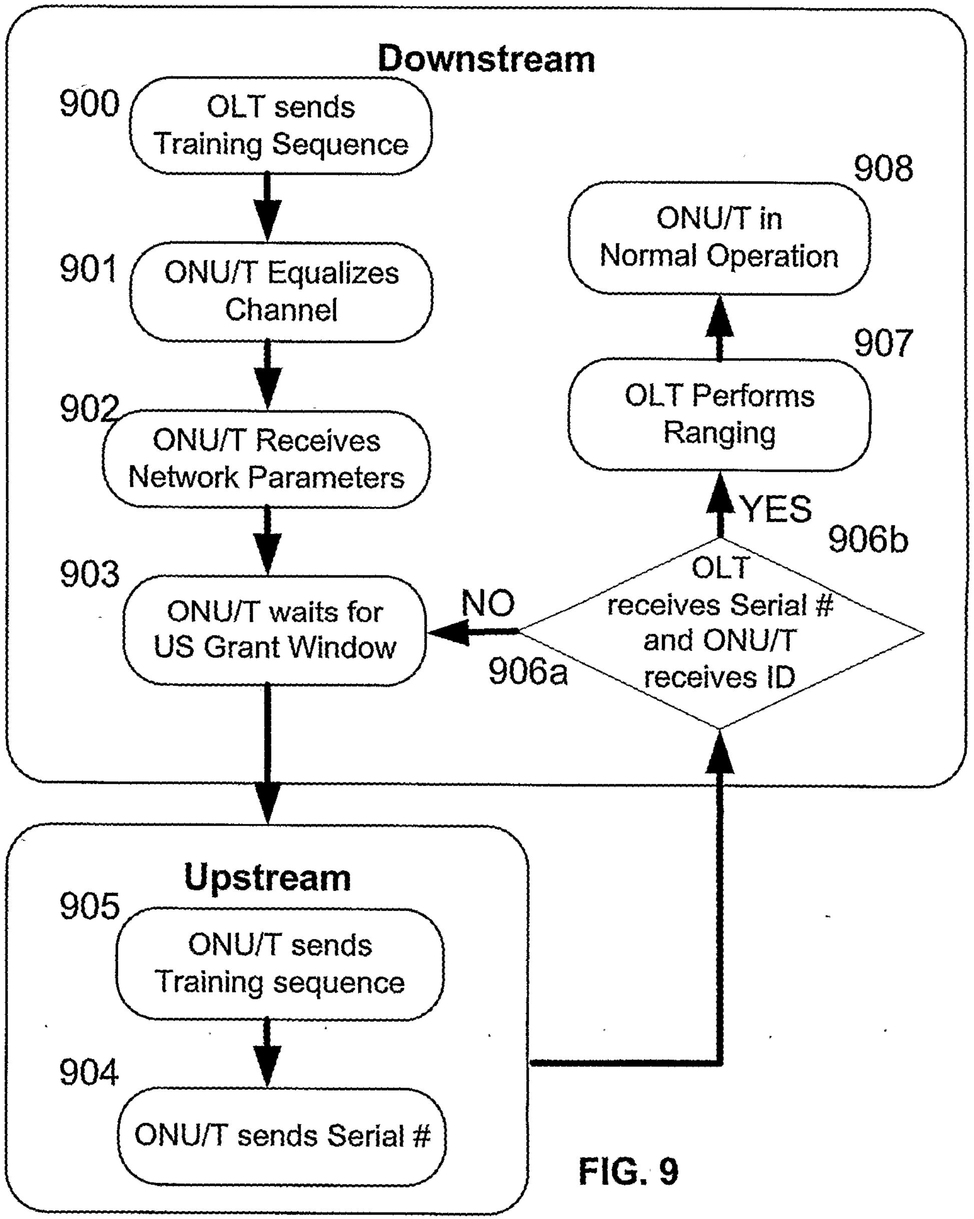
Downstream
900
OLT sends Training Sequence
901
ONU/T Equalizes Channel
902
ONU/T Receives Network Parameters
903
ONU/T waits for US Grant Window
908
ONU/T in Normal Operation
907
OLT Performs Ranging
YES
906b
OLT receives Serial # and ONU/T receives ID
NO
906a
Upstream
905
ONU/T sends Training sequence
904
ONU/T sends Serial #

FIG. 9