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United States Patent Application Publication
Kind Code
Publication Date
Inventor(s)

20250266904
A1
August 21, 2025
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Method for Fault Localization in an Optical Network

Abstract

A method for fault localization in an optical network is provided. The optical network includes at least one span. An optical signal travels through the at least one span. Each of the at least one span has associated amplifiers. The associated amplifiers are connected to launch optical signals into a remainder of a corresponding optical transmission line. The method includes, for each span, respectively acquiring reflected signals generated by the optical signal travelling through the span by at least one power monitoring device, and for each span, determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals. If there is a fault in the corresponding span, localization of the fault is determined based on the corresponding acquired reflected signals.

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Family ID: 1000008462800
Appl. No.: 19/058153
Filed: February 20, 2025

Foreign Application Priority Data

EP 24158819.3 Feb. 21, 2024

Publication Classification

Int. Cl.: H04B10/071 (20130101); H04J14/02 (20060101)
U.S. Cl.:
CPC H04B10/071 (20130101); H04J14/0215 (20130101);

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to European Patent Application No. 24158819.3 filed Feb. 21, 2024, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to a method for fault localization in an optical network, with which the localization of faults in an optical fiber network including at least one span can be determined accurately at low costs.

Description of Related Art

[0003] In long-haul optical communication systems, in particular optical fiber networks including at least one span, for example optical meshed networks, it is required to monitor the health of the system. This is of particular importance if the used fibers cannot be directly inspected visually, which is the typical case. Therefore, detecting faults, such as fiber breaks, is of major importance. Thereby, fast localization of a fault is required to meet the guaranteed availability of services provided over the optical fiber network.

[0004] Known monitoring methods include the use of optical time domain reflectometers (OTDR). An optical time domain reflectometer is an optoelectronic instrument used to characterize an optical fiber and is configured to inject in its simplest embodiment a single optical pulse into the fiber under test and to extract, from the same end of the fiber, light that is scattered or reflected back from points along the fiber. The scattered or reflected signal that is acquired and recorded by the instrument is then used to characterize the optical fiber.

[0005] Equipping optical fiber networks at each network element with additional optical time domain reflectometers enables automatic localization of faults within the spans of the optical fiber network. However, installing such optical time domain reflectometers is quite expensive.

[0006] U.S. Pat. No. 10,142,016 B2 discloses techniques for providing high-resolution, standard-format output for line monitoring equipment (LME) of a wavelength division multiplexing (WDM) communication system, wherein the LME may transmit a plurality of LME test signals via an optical path of the WDM system and may perform gain measurements on reflections associated with the same at predetermined intervals. Gain measurements for each of the plurality of LME test signals may be normalized and filtered to derive LME peak data. The WDM communication system may perform full scans with data points totalling millions/billions (e.g., depending on system length, fiber type, and number of transmitted LME test signals or test pulses) and normalize the same into a relatively small number of resulting data points within the LME peak data. The WDM system may then output an LME results file in a standard format which is compatible with commercial viewers and optical time domain reflectometer (OTDR) equipment. However, implementing these techniques comes with increased complexity.

SUMMARY OF THE INVENTION

[0007] Therefore, there is a need for an improved method for fault localization in an optical network.

[0008] This object is achieved by the method for fault localization in an optical network as described herein.

[0009] This object is further achieved by the system for fault localization in an optical network as described herein.

[0010] According to one embodiment of the invention, a method for fault localization in an optical network is provided, wherein the optical network includes at least one span, and wherein an optical signal travels through the at least one span, wherein each span has associated amplifiers, wherein the associated amplifiers are connected to launch optical signals into a remainder of a corresponding optical transmission line, wherein the method comprises, for each span, respectively acquiring reflected signals generated by the optical signal travelling through the span by at least one power monitoring device, and, for each span, determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding acquired reflected signals.

[0011] Here, the optical network can be a multi-span optical network. Further, the optical network is preferably a wavelength-division multiplexing (WDM) network, wherein the method can be used for any wavelength-division multiplexing network that makes use of one or several wavelength bands, irrespective of the network topology, for example point-to-point, ring, or meshed networks, with any combination of network nodes which use amplifiers with or without embedded variable optical attenuators, including terminal sites, fixed optical add-drop, reconfigurable optical add-drop multiplexer, or amplifier nodes.

[0012] Therein, a light wave propagating in an optical fiber experiences distributed reflections along the fiber axis due to Rayleigh backscattering and optical connections in the fiber span. Reflected power components are travelling back to the fiber input where they are detected by a corresponding power monitor. Therein, the power measured at the fiber input represents the total power of all components reflected back at different locations over the total length of the span, wherein in case of a fiber cut only power components reflected up to the location of the fiber cut are received at the fiber input. Thus, the total power acquired by the respective power monitor is smaller as compared with the power value measured before the traffic interruption.

[0013] Further, corresponding power monitors are usually already included in optical amplifiers to monitor power inputted in or outputted by the corresponding amplifier or can be installed at low costs.

[0014] Hence, the localization of a fault in a span can be determined accurately at comparatively low costs based on anyhow transmitted data signals, wherein no additional modulation has to be applied to light waves travelling in the span.

[0015] Furthermore, due to the correspondingly fast indication of the location of a fault, in particular a fiber or

cable break, downtimes can be kept low and repair times can be minimized.

[0016] Thus, an improved method for fault localization in an optical network is provided.

[0017] In one embodiment, for each span, the step of respectively acquiring reflected signals generated by the optical signal travelling through the span by at least one power monitoring device of at least one of the corresponding associated amplifiers comprises respectively acquiring reflected signals generated by the optical signal travelling through the span by power monitoring devices installed at both ends of the span. Data transmission in optical networks is typically organized as bidirectional transmission, wherein a data stream and its counterdirectional counterpart are using the same optical path, but typically different fibers in the same cable. Thus, it can be assumed that traffic in both directions will be affected by a fault. Therefore, two measurement signals taken from both sides are available for characterizing a single fiber break and one can choose the signal providing higher accuracy.

[0018] Therein, the method can further comprise the steps of selecting data providing higher accuracy from data characterizing the reflected signals acquired by the power monitoring devices installed at both ends of the span and/or selecting a more accurate fault localization after determining separately the fault localization from the data received from each of the power monitoring devices installed at both ends of the span.

[0019] In particular, determining the localization of a fault can comprise determining the position of the fault with an accuracy that is at least sufficient to find the failure with usual means, but it may also comprise just determining to which of the fiber ends the fault is located more closely.

[0020] Further, the method can comprise the step of, for each span, computing more accurately reflected signals by removing the impact of reflections before the corresponding span from the detected reflected signals, and wherein, for each span, the step of determining whether there is a fault in the corresponding span based on the corresponding detected reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding detected reflected signals, comprises determining whether there is a fault in the corresponding span based on the corresponding more accurately determined reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding more accurately determined reflected signals.

[0021] Here, reflections before the corresponding span can for example be caused by patch panels, wherein the accuracy of the fault localization can be affected by these reflections. Further reflections may be caused by optical connections distributed along the optical span.

[0022] Thus, by removing the impact of these reflections, the accuracy of the fault localization can be further improved.

[0023] The method can further comprise the step of, for each span, separating the reflected signals generated by the signal travelling through the span from the optical signal travelling through the span by at least one separating device.

[0024] Here, the expression that the reflected signals generated by the signal travelling through the span is separated from the optical signal travelling through the span means that the reflected signal and the optical signal are at least in part guided through different optical fibers or waveguides after separation.

[0025] Thereby, the impact of the optical signal as such on the fault localization can be reduced.

[0026] The at least one separating device can comprise an optical circulator and/or at least one power splitter, preferably a 2×2 power splitter.

[0027] An optical circulator is a three- or four-port optical device designed such that light entering any port exits from the next.

[0028] A 2×2 power splitter is designed to enable each of two signals entering the splitter on two input fibers to be distributed among two output fibers.

[0029] These devices are already present in usual optical networks, for example commercial amplifiers offering gain and output power control, wherein these devices can simply be used here without requiring expensive modifications.

[0030] According to another embodiment of the invention, a system for fault localization in an optical network is provided, wherein the optical network includes at least one span, and wherein an optical signal travels through the at least one span, wherein each of the at least one span has associated amplifiers, wherein the associated amplifiers are connected to launch optical signals into a remainder of a corresponding optical transmission line, wherein, for each span, at least one power monitoring device is configured to acquire reflected signals generated by the optical signal travelling through the span, wherein the system further comprises at least one determining unit, wherein the at least one determining unit is configured to, for each span, determine whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, and, if there is a fault in the corresponding span, determine the localization of the fault based on the corresponding acquired reflected signals.

[0031] Thus, an improved system for fault localization in an optical network is provided.

[0032] Therein, a light wave propagating in an optical fiber experiences distributed reflections along the fiber axis

due to Rayleigh backscattering and optical connections in the fiber span. Reflected power components are travelling back to the fiber input where they are detected by a corresponding power monitoring device. Therein, the power measured at the fiber input represents the total power of all components reflected back at different locations over the total length of the span, wherein in case of a fiber cut only power components reflected up to the location of the fiber cut are received at the fiber input. Thus, the total power acquired by the respective power monitoring device is smaller as compared with the power value measured before the traffic interruption. Further, corresponding power monitoring devices are usually already included in optical amplifiers to monitor power inputted in or outputted by the corresponding amplifier or can be installed at low costs. Therefore, the localization of a fault in a span can be determined accurately at comparatively low costs based on anyhow transmitted data signals, wherein no additional modulation has to be applied to light waves travelling in the span. Furthermore, due to the correspondingly fast indication of the location of a fault, in particular a fiber or cable break, downtimes can be kept low and repair times can be minimized.

[0033] In one embodiment, for each span, power monitoring devices installed at both ends of the span are respectively configured to acquire reflected signals generated by the optical signal travelling through the span. Data transmission in optical networks is typically organized as bidirectional transmission, wherein a data stream and its counterdirectional counterpart are using the same optical path, but typically different fibers in the same cable. Thus, it can be assumed that traffic in both directions will be affected by a fault. Therefore, two measurement signals taken from both sides are available for characterizing a single fiber break and one can choose the signal providing higher accuracy.

[0034] Therein, the determining unit can receive data characterizing the reflected signals acquired by the power monitoring devices installed at both ends of the span and be configured to select the data providing higher accuracy and/or be configured to select the more accurate fault localization after determining separately the fault localization from the data received from each of the power monitoring devices installed at both ends of the span.

[0035] In particular, determining the localization of a fault can comprise determining the position of the fault with an accuracy that is at least sufficient to find the failure with usual means, but it may also comprise just determining to which of the fiber ends the fault is located more closely.

[0036] Further, the system can comprise at least one computing unit, wherein the at least one computing unit is configured to, for each span, compute more accurately reflected signals by removing the impact of reflections before the corresponding span from the acquired reflected signals, and wherein the at least one determining unit is configured to, for each span, determine whether there is a fault in the corresponding span based on the corresponding more accurately determined reflected signals, and, if there is a fault in the corresponding span, determine the localization of the fault based on the corresponding more accurately determined reflected signals. Therein, by removing the impact of these reflections, the accuracy of the fault localization can be further improved.

[0037] Therein, each span can further comprise at least one separating device, wherein the at least one separating device is configured to separate the reflected signals generated by the signal travelling through the span from the optical signal travelling through the span. Thereby, the impact of the optical signal as such on the fault localization can be reduced.

[0038] The at least one separating device can again comprise an optical circulator and/or at least one power splitter, preferably a 2×2 power splitter. These devices are already present in usual optical networks, for example commercial amplifiers offering gain and output power control, wherein these devices can simply be used here without requiring expensive modifications.

[0039] According to still another embodiment of the invention, an optical network is provided, wherein the optical network includes at least one span, and wherein an optical signal travels through the at least one span, wherein each of the at least one span has associated amplifiers, wherein the associated amplifiers are connected to launch optical signals into a remainder of a corresponding optical transmission line, and wherein the optical network further comprises a system for fault localization in an optical network as described above.

[0040] Thus, an optical network is provided that comprises an improved system for fault localization in an optical network. Therein, a light wave propagating in an optical fiber experiences distributed reflections along the fiber axis due to Rayleigh backscattering and optical connections in the fiber span. Reflected power components are travelling back to the fiber input where they are detected by a corresponding power monitoring device. Therein, the power measured at the fiber input represents the total power of all components reflected back at different locations over the total length of the span, wherein in case of a fiber cut only power components reflected up to the location of the fiber cut are received at the fiber input. Thus, the total power acquired by the respective power monitoring device is smaller as compared with the power value measured before the traffic interruption. Further, corresponding power monitoring devices are usually already included in optical amplifiers to monitor power inputted in or outputted by the corresponding amplifier or can be installed at low costs. Therefore, the localization of a fault in a span can be determined accurately at comparatively low costs based on anyhow transmitted data

signals, wherein no additional modulation has to be applied to light waves travelling in the span. Furthermore, due to the correspondingly fast indication of the location of a fault, in particular a fiber or cable break, downtimes can be kept low and repair times can be minimized.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] The terms Fig., Figs., Figure, and Figures are used interchangeably in the specification to refer to the corresponding figures in the drawings.

[0042] The invention will now be described in further detail with reference to the attached drawings.

[0043] FIG. 1 illustrates a flowchart of a method for fault localization in an optical network according to embodiments of the invention;

[0044] FIG. 2A illustrates the steps of determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, in case there is no fault;

[0045] FIG. 2B illustrates the step of determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, in case there is a fault;

[0046] FIG. 3 illustrates a system for fault localization in an optical network according to embodiments of the invention.

[0047] FIG. 4 illustrates the setup of a power monitoring device using an optical circulator as separating device.

[0048] FIG. 5 illustrates the setup of a power monitoring device using an optical coupler as separating device.

[0049] FIG. 1 illustrates a flowchart of a method for fault localization in an optical network 1 according to embodiments of the invention.

DESCRIPTION OF THE INVENTION

[0050] In particular, FIG. 1 illustrates a method for fault localization in an optical network 1, wherein the optical network includes at least one span, and wherein an optical signal travels through the at least one span, wherein each span has associated amplifiers, wherein the associated amplifiers are connected to launch optical signals into a remainder of a corresponding optical transmission line.

[0051] Meshed optical networks usually comprise many spans that are embedded between amplifiers placed at both ends of the span. Each of these amplifiers is further usually equipped with power monitoring devices at its input and its output.

[0052] Further, knowing the exact position of a fiber break is very advantageous, since this allows the corresponding repair team to directly travel to the corresponding place, whereby the time of repair can be kept at a minimum. Thereby, the availability of services offered over the network can be further increased. However, it is already beneficial to know which of the ends of the span is closer to a fiber break.

[0053] It is known to determine the location of a fiber break using mobile optical time domain reflectometers (OTDR). Therein, in case a traffic interruption is detected, a repair team moves to one of the terminal locations of a span and records a trace of the fiber span with a mobile OTDR. However, if the fiber break is not located equidistantly from both ends of the span, the choice of the terminal location that is used for the OTDR measurement is important regarding the total repair time.

[0054] The method 1 shown in FIG. 1 comprises a step 2 of, for each span, respectively acquiring reflected signals generated by the optical signal travelling through the span by at least one power monitoring device, and a step 3 of, for each span, determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding acquired reflected signal.

[0055] Therein, a light wave propagating in an optical fiber experiences distributed reflections along the fiber axis due to Rayleigh backscattering and optical connections in the fiber span. Reflected power components are travelling back to the fiber input where they are detected by a corresponding power monitoring device. Therein, the power measured at the fiber input represents the total power of all components reflected back at different locations over the total length of the span, wherein in case of a fiber cut only power components reflected up to the location of the fiber cut are received at the fiber input. Thus, the total power acquired by the respective power monitoring devices is smaller as compared with the power value measured before the traffic interruption.

[0056] Further, corresponding power monitoring devices are usually already included in optical amplifiers to monitor power inputted in or outputted by the corresponding amplifier or can be installed at low costs.

[0057] Therefore, the localization of a fault in a span can be determined accurately at comparatively low costs based on anyhow transmitted data signals, wherein no additional modulation has to be applied to light waves travelling in the span.

[0058] Furthermore, due to the correspondingly fast indication of the location of a fault, in particular a fiber or

cable break, downtimes can be kept low and repair times can be minimized.

[0059] Thus, an improved method for fault localization in an optical network **1** is provided.

[0060] Therein, the expression “localization” has to be interpreted in a broad sense. This expression may indicate that the position of a fiber break is determined with an accuracy that is at least sufficient to find the failure with usual means, but it may also indicate that it is just determined to which of the fiber ends the fiber break is located more closely. Furthermore, the term “signals” refers to power components or light waves propagating in an optical waveguide, e.g. an optical fiber.

[0061] The expression “light wave” refers to an electromagnetic wave with a wavelength in the range from 400 nm to 2000 nm.

[0062] In particular, the basic idea of the shown method **1** is to derive the location of a fiber break from power readings determined before and during the fiber break.

[0063] Therein, a power monitoring device for acquiring reflected signals generated by the optical signal travelling through the span can for example be placed at the input of the span, wherein power reflected back to the fiber input by Rayleigh backscattering can be described by the following equation:

[00001] $P_{\text{refl}} = P_{\text{in}} \cdot \text{Math.}_{\text{Rayleigh}} / 2 \cdot \gamma_{\text{sub.Rayleigh}} \cdot [1 - e^{-2 \gamma_{\text{sub.Rayleigh}} L}]$, (1) [0064] wherein $P_{\text{sub.in}}$ is the input power launched into the fiber, L is the length of the fiber and $\gamma_{\text{sub.Rayleigh}}$ is the Rayleigh backscattering coefficient.

[0065] Further, the attenuation coefficient $\alpha_{\text{sub.Np}}$ is linked to the attenuation coefficient α_{dB} in decibel per distance according to the following equation:

[00002] $\alpha_{\text{sub.Np}} = \ln(10) / 10 \cdot \alpha_{\text{dB}}$ (2)

[0066] Therefore, the power levels $P_{\text{sub.op}}$ and $P_{\text{sub.cut}}$ detected during normal operation, respectively after a cut, respectively break, are given by the following equations:

[00003] $P_{\text{op}} = P_{\text{in}} \cdot \text{Math.}_{\text{Rayleigh}} / 2 \cdot \gamma_{\text{sub.Rayleigh}} \cdot [1 - e^{-2 \gamma_{\text{sub.Rayleigh}} L_{\text{sub.fiber}}}]$ (3)

$P_{\text{cut}} = P_{\text{in}} \cdot \text{Math.}_{\text{Rayleigh}} / 2 \cdot \gamma_{\text{sub.Rayleigh}} \cdot [1 - e^{-2 \gamma_{\text{sub.Rayleigh}} L_{\text{sub.cut}}}]$, (4) [0067] wherein $L_{\text{sub.fiber}}$ is the length of the total fiber, and wherein $L_{\text{sub.cut}}$ is the length, respectively distance, from the input of the span until the cut.

[0068] Thus, the ratio of the power levels $R_{\text{sub.power}}$ can be expressed by the equation

[00004]

$$R_{\text{power}} = P_{\text{cut}} / P_{\text{op}} = (P_{\text{in}} \cdot \text{Math.}_{\text{Rayleigh}} / 2 \cdot \gamma_{\text{sub.Rayleigh}} \cdot [1 - e^{-2 \gamma_{\text{sub.Rayleigh}} L_{\text{sub.cut}}}] / (P_{\text{in}} \cdot \text{Math.}_{\text{Rayleigh}} / 2 \cdot \gamma_{\text{sub.Rayleigh}} \cdot [1 - e^{-2 \gamma_{\text{sub.Rayleigh}} L_{\text{sub.fiber}}}] \quad (5)$$

[0069] and is the smaller the closer the fiber cut is to the fiber input.

[0070] For each span, the step of respectively acquiring reflected signals generated by the optical signal travelling through the span by at least one power monitoring device can also comprise respectively acquiring reflected signals generated by the optical signal travelling through the span by power monitoring devices installed at both ends of the span, in order to further increase the accuracy.

[0071] As shown in FIG. **1**, the method **1** further comprises the step **4** of, for each span, computing more accurately reflected signals by removing the impact of reflections before the corresponding span from the acquired reflected signals, wherein, for each span, the step **3** of determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding acquired reflected signals, comprises determining whether there is a fault in the corresponding span based on the corresponding more accurately determined reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding more accurately determined reflected signals.

[0072] The reflections before the corresponding span are known from the OTDR traces taken when installing the optical network, wherein their impact can be removed by taken this known information, removing it from the acquired reflected signals and correspondingly adopting the equations described above.

[0073] According to the embodiments of FIG. **1**, the method **1** further comprises the step **5** of, for each span, separating the reflected signals generated by the signal travelling through the span from the optical signal travelling through the span by at least one separating device.

[0074] Therein, the at least one separating device can comprise an optical circulator and/or at least one power splitter, preferably a 2×2 power splitter.

[0075] FIG. **2A** illustrates the step of determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, in case there is no fault.

[0076] In particular, FIG. **2A** illustrates the power **10** reflected back to the fiber input by Rayleigh backscattering in case of an intact fiber **11**.

[0077] In this case, as shown in FIG. **2A**, power components reflected over the whole length of the fiber are

received at the fiber input.

[0078] FIG. 2B illustrates the step of determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, in case there is a fault.

[0079] In particular, FIG. 2B illustrates the power **10** reflected back to the fiber input by Rayleigh backscattering in case of a fiber cut.

[0080] In this case, as shown in FIG. 2B, only power components reflected up to the location of the fiber cut are received at the fiber input. Thus, the total power acquired by the respective power monitoring device is smaller as compared with the power value acquired before the traffic interruption.

[0081] FIG. 3 illustrates a system for fault localization in an optical network **20** according to embodiments of the invention.

[0082] In particular, FIG. 3 illustrates a system for fault localization in an optical network **20**, wherein the optical network includes at least one span **21**, and wherein an optical signal travels through the at least one span, wherein each span **21** has associated amplifiers **22**, wherein the associated amplifiers **22** are connected to launch optical signals into a remainder of a corresponding optical transmission line.

[0083] In the embodiment shown, all links of the optical network **20** are configured for bidirectional operation. Therefore, each span **21** comprises at least two fibers **30**, wherein one of the fibers is transmitting signals **32** in one direction and the other fiber is transmitting signals **32** in the opposite direction. Bidirectional transmission helps to increase the accuracy of the technique described, but is not a mandatory requirement for using the technique.

[0084] The optical network can be understood as an optical system with a single span **21**.

[0085] Therein, for each span **21**, at least one power monitoring device **23** is configured to acquire reflected signals generated by reflections generated by the optical signal travelling through the span **21**, wherein the system **20** further comprises at least one determining unit **24**, wherein the at least one determining unit **24** is configured to, for each span **21**, determine whether there is a fault **25** in the corresponding span **21** based on the corresponding acquired reflected signals, and, if there is a fault **25** in the corresponding span **21**, determine the localization of the fault **25** based on the corresponding acquired reflected signals.

[0086] Therein, the optical network can be an optical mesh network and the amplifiers can be erbium-doped fiber amplifiers with integrated power monitoring devices.

[0087] The at least one determining unit can further for example be realized based on code that is stored in a memory and executable by a processor.

[0088] As shown in FIG. 3, according to the embodiments of FIG. 3, for each span **21**, power monitoring devices **23** installed at both ends **26**, **27** of the span **21** are respectively configured to acquire reflected signals generated by the optical signal travelling through the span **21**.

[0089] Providing data **56** about acquired reflected signals from the power monitoring device **23** at one of the fiber ends **26** to the determining unit **24** is sufficient for providing the described functionality, but using additional data **58** about acquired reflected signals from the further power monitoring device **23** at the other fiber end **27** to the determining unit **24** helps to improve accuracy. For example, the determining unit **24** can select from the power ratios determined from data provided by the two power monitoring devices **23** the one providing higher accuracy.

[0090] As further shown in FIG. 3, the optical system **20** further comprises at least one computing unit **28**, wherein the at least one computing unit **28** is configured to, for each span **21**, compute more accurately reflected signals by removing the impact of reflections before the corresponding span **21** from the acquired reflected signals, wherein the at least one determining unit **24** is configured to, for each span **21**, determine whether there is a fault **25** in the corresponding span **21** based on the corresponding more accurately determined reflected signals, and, if there is a fault **25** in the corresponding span **21**, determine the localization of the fault **25** based on the corresponding more accurately determined reflected signals.

[0091] The at least one computing unit can again for example be realized based on code that is stored in a memory and executable by a processor.

[0092] Localizing the fiber cut with an OTDR requires the repair team to move to one of the fiber ends **26** or **27**. Once the fiber cut has been localized, the repair team needs to travel from the respective fiber end **26**, **27** to the location of the fiber cut. As illustrated in FIG. 3, travel route **50** including fiber end **26** for traveling from the start position **54** of the repair team to the location of the fiber cut **25** is shorter than travel route **52** including fiber end **27**. Thus, traveling via route **50** results in shorter repair time. The above-described method can therefore be used for identifying the best suited fiber end for determining the exact fault location with a mobile OTDR.

[0093] The shown system **20** is further configured to execute a method for fault localization in an optical network as described above.

[0094] FIG. 4 illustrates the setup of a power monitoring device using an optical circulator as separating device.

[0095] In particular, FIG. 4 illustrates a power monitoring device **23** receiving at port **44** an optical signal **42** to be transferred via port **46** to the optical span **21**. At port **46**, the power monitoring device **23** also receives reflected power from the span **21**. There is further shown a separating device **29**, wherein the separating device **29** is

respectively configured to separate the reflected signal **40** generated by the signal travelling through the span **21** from the optical signal **42** travelling through the span **21**. The power monitoring device **29** furthermore comprises a power monitoring device, respectively a power monitor **36** connected to the separating device **29** and configured to receive the reflected signal **40**, wherein power monitor **36** can have a simpler setup than power monitoring device **23** and can for example be a photodiode.

[0096] The separating devices **29** respectively are optical circulators or fiber optical couplers, wherein FIG. **4** shows an embodiment using an optical circulator.

[0097] An embodiment making use of an optical coupler as separating device **29** is illustrated in FIG. **5**.

[0098] FIG. **5** illustrates the setup of a power monitoring device using an optical coupler as separating device.

[0099] Therein, the separating device **29** branches off part of the optical signal **42** traveling through the span **21** and directs this part to power monitor **60** for measuring the power launched into the span **21**. Furthermore, the separating device **29** branches off part of the reflected signal **40** generated from the optical signal **42** traveling through the optical signal and directs this part to power monitor **36** for determining the reflected power. The remaining part of the reflected signal **44** generated from the optical signal **42** is blocked by an optical isolator **62** such that it does not further propagate into an optical amplifier connected to port **44** of the power monitoring device **23** or to the remaining part of the amplifier comprising the power monitoring device **23**.

[0100] Typical optical amplifiers **22** already comprise an isolator **62** and an optical coupler at their output. Thus, it is sufficient for implementing the above-described method to add a further power monitoring device, respectively power monitor **60**, for measuring reflected power. In addition, some commercial amplifiers already include this power monitoring devices such that the method can be implemented with almost no additional cost or even without additional cost.

REFERENCE SIGNS

[0101] **1** method [0102] **2** method step [0103] **3** method step [0104] **4** method step [0105] **5** method step [0106] **10** power [0107] **11** fiber [0108] **20** optical network or system [0109] **21** span [0110] **22** amplifier [0111] **23** power monitoring device [0112] **24** determining unit [0113] **25** fault [0114] **26** end [0115] **27** end [0116] **28** computing unit [0117] **29** separating device [0118] **30** optical fiber [0119] **32** signals [0120] **36** power monitor [0121] **40** reflected signal [0122] **42** signal transmitted over span [0123] **44** device port [0124] **46** device port [0125] **50** travel route [0126] **52** travel route [0127] **54** start position [0128] **56** data about acquired reflected signals [0129] **58** data about acquired reflected signals [0130] **60** power monitor [0131] **62** isolator

Claims

1. A method for fault localization in an optical network, wherein the optical network comprises at least one span, and wherein an optical signal travels through the at least one span, wherein each of the at least one span has associated amplifiers, wherein the associated amplifiers are connected to launch optical signals into a remainder of a corresponding optical transmission line, wherein the method comprises the steps of: for each span, respectively acquiring reflected signals generated by the optical signal travelling through the span by at least one power monitoring device; and for each span, determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding acquired reflected signals.

2. The method according to claim 1, wherein, for each span, the step of respectively acquiring reflected signals generated by the optical signal travelling through the span by at least one power monitoring device comprises respectively acquiring reflected signals caused by the optical signal travelling through the span by power monitoring devices installed at both ends of the span.

3. The method according to claim 2, wherein the method further comprises the steps of selecting data providing higher accuracy from data characterizing the reflected signals acquired by the power monitoring devices installed at both ends of the span and/or selecting a more accurate fault location after determining separately the fault location from the data received from each of the power monitoring devices installed at both ends of the span.

4. The method according to claim 1, wherein the method further comprises the step of, for each span, computing more accurately reflected signals by removing the impact of reflections before the corresponding span from the acquired reflected signals, and wherein, for each span, the step of determining whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding acquired reflected signals, comprises determining whether there is a fault in the corresponding span based on the corresponding more accurate reflected signals, wherein, if there is a fault in the corresponding span, localization of the fault is determined based on the corresponding more accurate reflected signals.

5. The method according to claim 1, wherein the method further comprises the step of, for each span, separating

- the reflected signals generated by the signal travelling through the span from the optical signal travelling through the span by at least one separating device.
- 6.** The method according to claim 5, wherein the at least one separating device comprises an optical circulator and/or a power splitter.
- 7.** A system for fault localization in an optical network, wherein the optical network comprises at least one span, and wherein an optical signal travels through the at least one span, wherein each of the at least one span has associated amplifiers, wherein the associated amplifiers are connected to launch optical signals into a remainder of a corresponding optical transmission line, wherein, for each span, at least one power monitoring device is configured to acquire reflected signals generated by the optical signal travelling through the span, wherein the system further comprises at least one determining unit, wherein the at least one determining unit is configured to, for each span, determine whether there is a fault in the corresponding span based on the corresponding acquired reflected signals, and, if there is a fault in the corresponding span, determine the localization of the fault based on the corresponding acquired reflected signals.
- 8.** The system according to claim 7, wherein, for each span, power monitoring devices installed at both ends of the span are respectively configured to acquire reflected signals caused by the optical signal travelling through the span.
- 9.** The system according to claim 8, wherein the determining unit receives data characterizing the reflected signals acquired by the power monitoring devices installed at both ends of the span and is configured to select the data providing higher accuracy and/or is configured to select the more accurate fault localization after determining separately the fault localization from the data received from each of the power monitoring devices installed at both ends of the span.
- 10.** The system according to claim 7, wherein the system further comprises at least one computing unit, wherein the at least one computing unit is configured to, for each span, compute more accurately reflected signals by removing the impact of reflections before the corresponding span from the acquired reflected signals, and wherein the at least one determining unit is configured to, for each span, determine whether there is a fault in the corresponding span based on the corresponding more accurate reflections, and, if there is a fault in the corresponding span, determine the localization of the fault based on the corresponding more accurate reflections.
- 11.** The system according to claim 7, wherein each span further comprises at least one separating device, wherein the at least one separating device is configured to separate the reflected signals generated by the signal travelling through the span from the optical signal travelling through the span.
- 12.** The system according to claim 11, wherein the at least one separating device comprises an optical circulator and/or a power splitter.
- 13.** An optical network, wherein the optical network comprises at least one span, and wherein an optical signal travels through the at least one span, wherein each of the at least one span has associated amplifiers, wherein the associated amplifiers are connected to launch optical signals into a remainder of a corresponding optical transmission line, and wherein the optical network further comprises a system for fault localization in an optical network according to claim 7.
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