Maintenance and Operation Technologies for Optical Access Fiber Network Infrastructure

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SUMMARY   The optical access fiber network is spreading rapidly as a result of the progress made on optical communication technologies and the availability of a wide range of broadband Internet content. If the optical access network is not properly maintained, the service quality will decrease. This paper describes some effective technologies that have been researched and developed to maintain a high quality of service, and to achieve efficient maintenance and operation.
key words: *maintenance, operation, optical access network, testing and monitor, line switching*

1.   Introduction

Optical broadband services have expanded in Japan [1]. The efficient maintenance and operation of optical access line facilities that are being constructed as optical broadband services continue to expand will be a serious problem in the near future. In particular, the next generation network (NGN) service will require the guaranteed provision of high-quality telephone, television broadcasting and other services via optical fiber. That is, ideally the service should be failure free, or should be restored extremely quickly if a failure occurs. Optical access lines link central offices and customers' premises. When there is an equipment failure, time is needed for an engineer to travel from a central office to an outside branch point of a passive optical network (PON). This travel time and the time required to determine the failure at the location should be as short as possible. Moreover, there is also a need to reduce the initial construction cost and the subsequent maintenance and operating costs in order to provide a competitively priced broadband service. Maintenance and operation management technologies for optical access lines are needed that satisfy this demand. Figure 1 shows the main contributions of R&D to the problem of the maintenance and operation management of the optical access fiber network infrastructure. This paper describes these items, namely remote fault location measurement technologies, technologies that assist fieldwork, preventive maintenance technologies, and line switching technologies, as maintenance and operation management technologies for optical access lines.

2.   Remote Fault Location Measurement Technologies

There are various factors that cause the failure of optical

access lines including natural hazards, damage by animals, traffic accidents, and mischief. Prompt recovery measures should be adopted when these sudden failures occur and interfere with communication services. However, a lot of time is required to reach the fault location in an optical access network, which extends in all directions. Therefore, it is necessary to detect a fault location as soon as possible, and preferably before the engineer travels to the site.

In Japan's optical access network, two types of splitters are installed separately; 1×4 splitters are used in central offices and 1×8 splitters are used outdoors. The output ports of a 1×4 splitter in a central office are equipped with an optical coupler for use in in-service test measurements, and an optical time domain reflectometry (OTDR) test can be executed from the test port of the optical coupler. OTDR can remotely measure the location of an outdoor optical fiber fault.

2.1   In-Service Measurement

The service failure is not only permanent disconnection but also the intermittent disconnection. When the intermittent disconnection occurs in an optical access network, we must investigate the cause of the failure without cutting off the service. Moreover, it should be possible to examine an optical fiber without cutting it to achieve the preventive maintenance described below, and this requires an in-service examination. ITU-T Recommendation L.41 defines the wavelength to be used for such examinations [2], [3]. In general, the examination is undertaken using a wavelength of $1.65 \, \mu m$, which is different from the wavelength employed for commercial optical transmission systems. A $1.65 \, \mu m$ test lightwave is launched into an optical fiber at a central office via an optical coupler, thus making it possible to examine the fiber.

2.2   Remote Measurement Methods

The correlation between fiber length and resolution is shown in Fig. 2 for various technologies designed to measure fault locations remotely. OTDR and coherent OTDR (C-OTDR) [4], [5] are used for troubleshooting access, trunk and local area networks (LAN). OTDR can have a dynamic range of several tens of meters to several tens of kilometers, and can detect a fault location with meter order resolution. Recently, a very inexpensive and simple OTDR technique, which has limited specifications (resolution and dynamic range) has
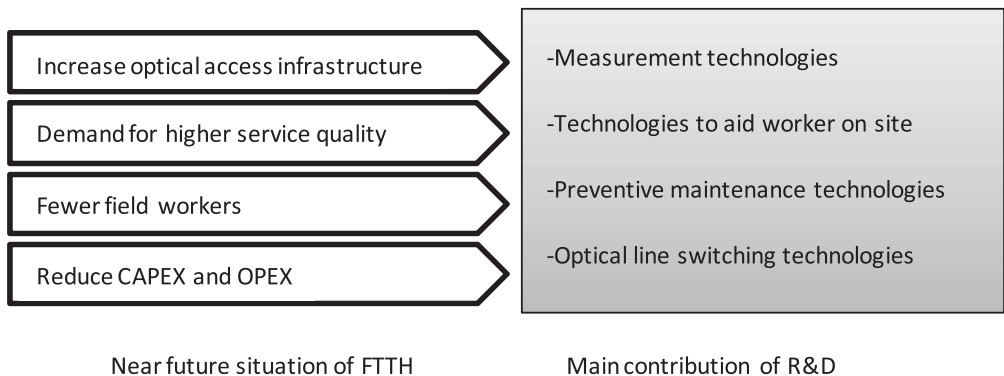
Fig. 1 Maintenance and operational problems of optical access. CAPEX: Capital Expenditure, OPEX: Operating Expenditure.
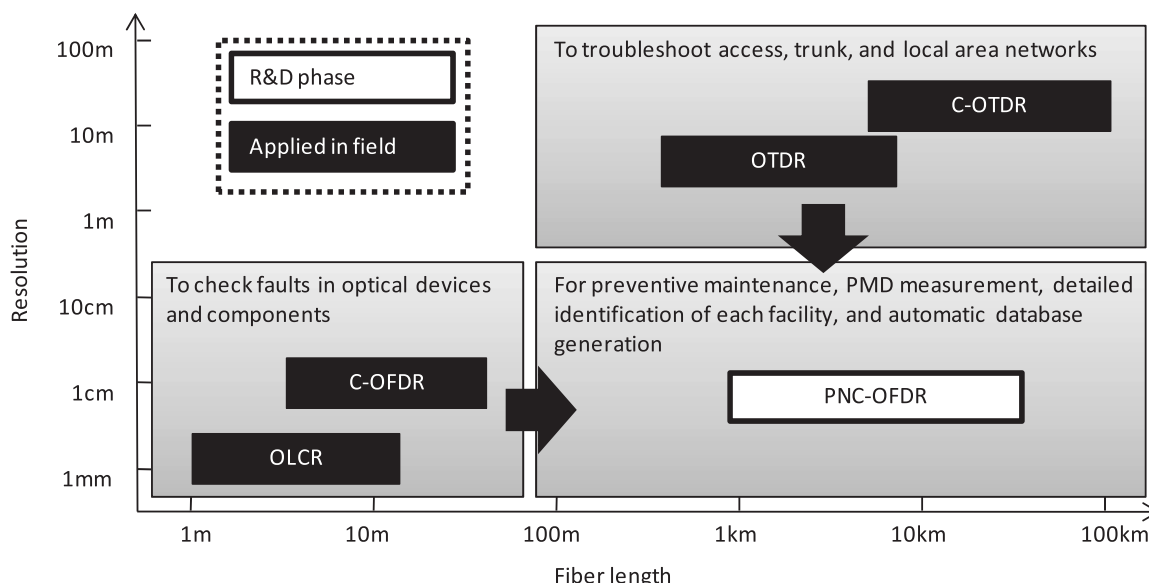

Fig. 2 Remote measurement technologies. OTDR: Optical Time Domain Reflectometry, C-OTDR: Coherent OTDR, OLCR: Optical Low Coherence Reflectometry, C-OFDR: Coherent Optical Frequency Domain Reflectometry, PNC-OFDR: Phase-Noise Compensated OFDR, PMD: Polarization Mode Dispersion.

been developed [6], and it is widely used by many field workers. C-OTDR is applied to long distance trunk lines equipped with an optical amplifier such as submarine optical cables, and has a dynamic range of 100 km or more and a resolution of about 100 m. Optical low coherence reflectometry (OLCR) [7] and coherent optical frequency domain reflectometry (C-OFDR) [8] are used to check for problems in optical devices and components. These are used for final tests and to check optical devices.

Phase-noise compensated OFDR (PNC-OFDR) is currently being researched as a failure detection technology for the future [9]. This technology has a large dynamic range, and millimeter order resolution can be achieved. When this technology is realized, we will even be able to identify the types of optical devices installed in the optical access network and their location, as well as the cause of the failure in detail.

2.3 Remote Measurement Methods for Branched Fibers

The most difficult location as regards failure detection is the lower side of an outdoor 1 × 8-splitter. Figure 3 shows the test technologies used for fault location after a branch point in a 1 × 8-splitter that are currently being researched and developed.

Figure 3(a) shows a measurement method that manages the reflection peak history. The position and waveform of the 1.65 μm wavelength reflection of a fiber Bragg grating (FBG) inserted in front of an optical network unit (ONU) must first be measured with 1.65 μm OTDR. The reflected waveform of the FBG in the terminal of the corresponding branched optical fiber changes when trouble occurs [10].

Figure 3(b) shows a method that uses an arrayed waveguide grating (AWG) 1 × 8-splitter. Variable wavelength
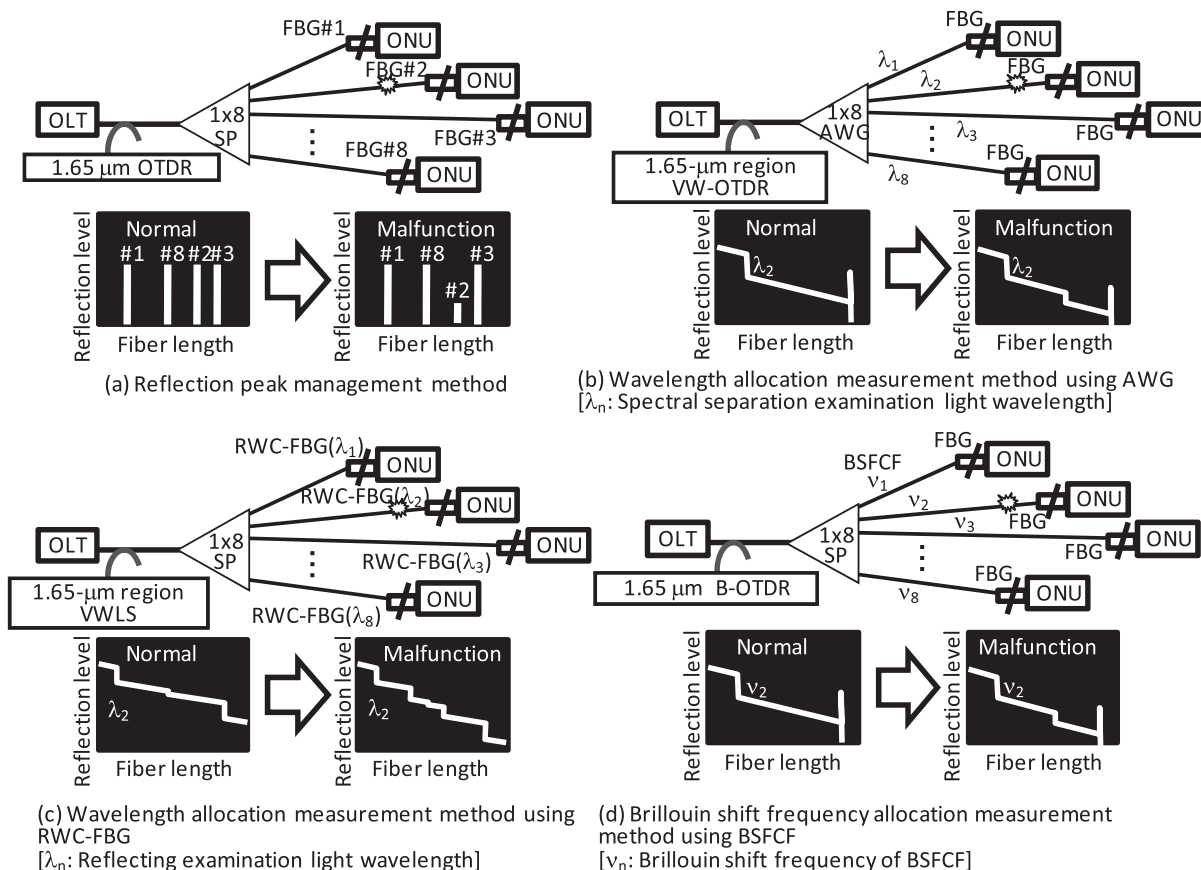
Fig. 3 Test technologies for fault location after a branch point via an optical splitter. OLT: Optical Line Terminal, ONU: Optical Network Unit, VW-OTDR: Variable Wavelength OTDR, FBG: Fiber Bragg Grating, AWG: Arrayed Waveguide Grating, RWC-FBG: Reflection Wavelength Controlled FBG, BSFCF: Brillouin Shift Frequency Controlled Fiber.

OTDR (VW-OTDR) can be controlled by controlling the wavelength corresponding to the spectral separation characteristic of an AWG. The fault location after the branch point of an AWG 1×8 splitter can be clearly measured with this method by changing the wavelength [11].

Figure 3(c) shows a method for installing a reflection wavelength controlled FBG (RWC-FBG) terminal that has high wavelength dependent reflection. VW-OTDR can be varied by changing the wavelength corresponding to the spectral separation characteristic of each RWC-FBG. The pulse lightwave that is reflected by the RWC-FBG becomes a virtual pulse light source, and the fiber response characteristic of this light source can be measured. This makes it possible to locate a fault after a branch point in a 1×8 splitter by calculating the response waveform shapes of each wavelength [12].

Figure 3(d) shows a method for allocating optical fiber with an individually controlled Brillouin frequency shift value (BSFCF) as a wiring and drop fiber after a branch point in a 1×8 splitter. This technique can determine a fault location by measuring the response characteristic of the Brillouin shift frequency range of each BSFCF by using a Brillouin OTDR (B-OTDR) [13].

These measurement technologies are challenging themes in a very difficult measurement region, and are unique in terms of research interest. However, they have not reached the practical stage. A further examination is necessary to improve the remote failure measurement of an optical access fiber network and thus reduce maintenance and operation costs.

3. Technologies for Assisting Fieldwork

Tools for assisting fieldwork are needed for the various types of maintenance and operation work required by the optical access fiber network. In particular, we must avoid accidentally cutting an optical fiber providing a service. This complex work leads to human error, and results in communication service failure. It is very difficult to train every worker sufficiently to avoid all failures. Therefore, it is important to develop facility equipment and tools that require only minimal levels of skill and experience.

Therefore, technologies are described below that make it easy to identify optical access fiber network equipment thus making it possible to work effectively.

3.1 Fiber Identification Technologies

When the work needed for a new order or for terminating a service is undertaken, it is necessary to choose one optical fiber from many. The fiber is identified by inputting an optical modulated signal from the cable wiring terminal in a central office, receiving a leaked lightwave by bending the optical fiber in the field, and confirming the presence of the modulated optical signal [14], [15].

In the near future, it will be possible to use a new optical fiber in the optical access fiber network that does not suffer from optical bending loss. One such example is single-mode hole assisted fiber (SM-HAF) [16]. However, this fiber identification method may be unusable with SM-HAF, because the above identification technique involves bending the optical fiber and leaking a lightwave. An identification method that employs the different polarization characteristics of optical fiber is being studied as a way of identifying this new optical fiber [17]. Thus identification methods that do not depend on the bending loss characteristic are likely to be used for various future fibers.

Moreover, we must check the customer's utilization of the optical fiber in question in the outside field. An FBG adaptor that reflects $1.65\,\mu$m wavelength light is always connected to the terminal of the optical fiber that is serving the customer. Conversely, an FBG adapter is not connected when the optical fiber is not serving a customer. On this basis, an optical fiber that is serving a customer can be confirmed by the presence of an FBG [18]. The method employs test lights operating at two wavelengths, only one of which is strongly reflected by an FBG, and a nondestructive macrobending technique.

3.2 Database Management Technologies

A huge amount of information is required for the management of optical access fiber network facilities. In particular, it is necessary to manage accurately the optical fiber route information between an optical line terminal (OLT) in a central office and an ONU on the customer's premises. The design of the optical fiber route is automatically selected by the operating system. However, the possibility of human error is present in many aspects of fiber connection work. The result may be a difference between an actual facility and the database. Management technologies are needed that can detect this difference.

One ideal method for solving this problem is to update the database automatically at the moment the optical fiber is connected. In a central office wiring system, a mechanism for updating a facility's connection information at the database in real time has been examined by using radio frequency identification (RFID) communication [19] and light emitting diode (LED) visible light communication [20].

Moreover, a clue for determining the facility position remotely can be added by providing a feature function point in the optical fiber network. For instance, it is possible to use it as a facility address by combining some short BF-SCFs that have different Brillouin shift frequencies. High-resolution B-OTDR is used to measure the facility address remotely [21]. When such an optical identification technology is achieved, the database will correspond exactly to the facilities. This approach is very effective.

4. Preventive Maintenance Technologies

Failures occur suddenly. Field workers and the tools they need for their work must always be prepared for sudden failures. Even so, it may not always be possible to respond to
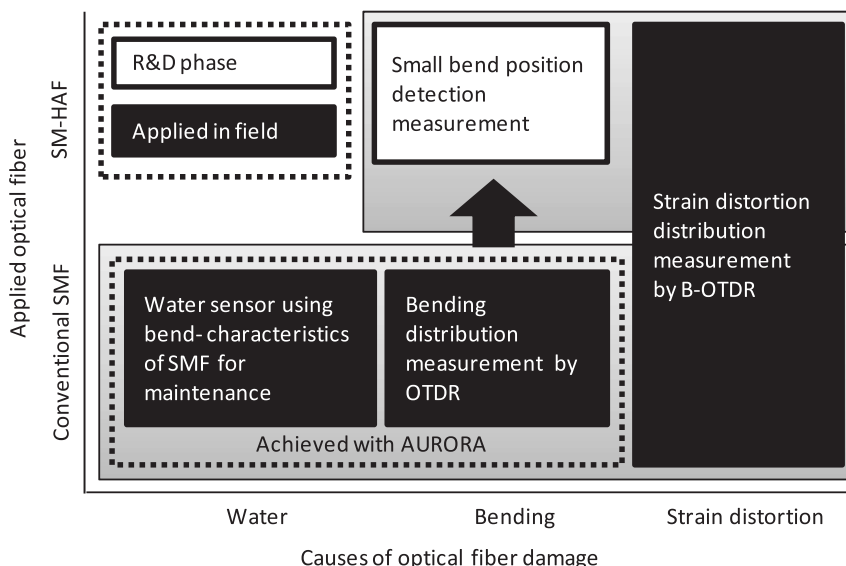

Fig. 4   Preventive maintenance technologies.

(a) Work flow of an optical CATS system   (b) Work flow of line switching system without interruption
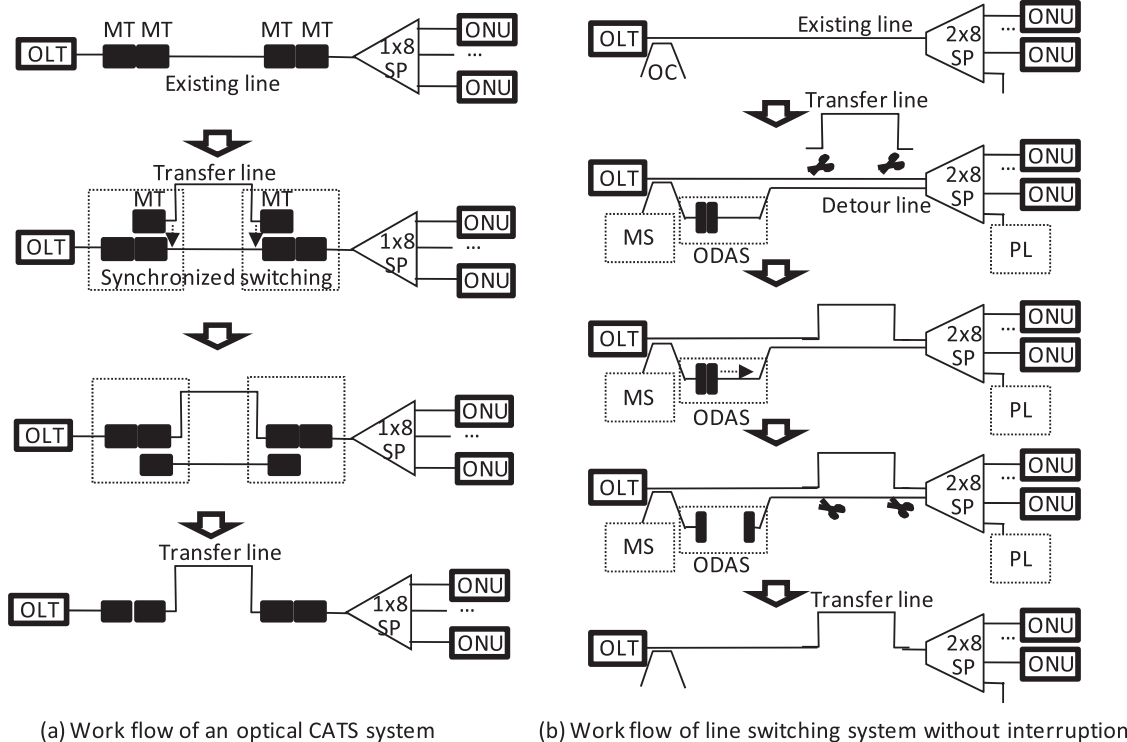
Fig. 5 Optical line switching technologies. SP: Optical Splitter, OC: Optical Coupler, MT: MT Optical Connector, MS: Measurement Setup, ODAS: Optical Delay Adjustment Setup, PL: 1.65 μm Pulse Lght Source.

a failure quickly. It is preferable to detect a potential failure and to repair it before it occurs. Figure 4 shows preventive maintenance technologies. These technologies are described here.

The automatic optical fiber operations support system (AURORA) [22] is a preventive maintenance technology. Indications prior to failure can be detected by performing periodic in-service measurements of the optical fiber loss distribution, and by comparing optical loss histories. As a result, we can release a bend before the fiber breaks.

Moreover, this system can remotely detect flooding in an optical closure equipped an optical fiber sensor [23]. When an optical fiber is immersed in water for a long period, the strength and transmission function deteriorate. This degradation can be prevented by using this function.

Another effective preventive maintenance technique involves measuring the strain distortion distribution of an installed optical fiber cable. For instance, changes in the ground caused by an earthquake impose strain distortion on an optical cable, and sooner or later there is the possibility that it will break when the strain distortion is large. The strain distortion distribution of optical fiber can be measured by B-OTDR. It can be understood that the optical cable may break when an abnormal strain distortion is measured along the same optical fiber.

In future, we must establish methods of preventive maintenance if we are to extend the use of optical fiber with low bending loss to optical access networks.

5. Line Switching Technologies

The optical access network is wired to customers' premises in underground and aerial sections. This installed optical fiber cable may have to be replaced by another cable for unavoidable reasons. Such reasons include public road work and building construction work. Then, the service is usually temporarily interrupted. Line switching technologies have been developed that reduce the interruption time as much as possible. Figure 5 shows some line switching systems.

One system that can switch efficiently is the optical cable transfer splicing (CATS) system [24] shown in Fig. 5(a). This system can be mechanically switched instantaneously by synchronizing optical connectors at two locations. The lightwave interruption time caused by switching is about 35 ms. Unfortunately this means that the communication service is cut off.

Recently, a switching system that does not involve intermittent service discontinuity has been studied as shown in Fig. 5(b) [25]. This system uses a method whereby an optical fiber route between a 2×2 coupler in central-office and an outside 2×8 splitter is temporarily doubled. The twin optical fibers must be almost the same length. The optical length adjustment employs free space optics (FSO) [26]. The adjustment accuracy is of millimeter order. To obtain this adjustment accuracy, a measurement approach using an interference method has been developed. This method

avoids any intermittent discontinuity in the GE-PON service, and a dedicated business Ethernet service line can be realized by using this method [27]. The performance of maintenance and operation work on optical access networks will improve greatly if this technology is put to practical use.

6. Conclusion

The trend of some recent optical technologies for the maintenance and operation of the optical access network were described. R&D products related to the construction technologies needed for optical access networks have been the main concern thus far, because our goal was to provide the customer with an optical broadband service as quickly as possible. However, in the near future, management technologies for stably maintaining a large number of optical facilities will become very important. It is necessary to establish the technologies introduced in this paper at an early stage, and to apply them to the optical access network field.

References

[1] Ministry of Internal Affairs and Communications in Japan, Dec. 2008 [Online]. Available: http://www.soumu.go.jp/menu_news/s-news/090318_1.html

[2] Optical Fibre Cable Maintenance Criteria for in Service Fibre Testing in Access Networks, ITU-T Rec. L.66, May 2007.

[3] N. Nakao, H. Izumita, T. Inoue, Y. Enomoto, N. Araki, and N. Tomita, "Maintenance method using 1650-nm wavelength band for optical fiber cable networks," J. Lightwave Technol., vol.19, no.10, pp.1513–1520, Oct. 2001.

[4] M. Tateda and T. Horiguchi, "Advances in optical time-domain reflectometry," J. Lightwave Technol., vol.7, no.8, pp.1217–1224, 1989.

[5] H. Izumita, Y. Koyamada, I. Sankawa, and S. Furukawa, "A coherent optical time-domain reflectometer with a 40-dB dynamic range enhanced with erbium-doped fiber amplifiers," Technical Digest of OFC'92, WK6, p.147, 1992.

[6] K. Suzuki, N. Araki, A. Natsume, and Y. Kozawa, "Development of OTDR that easily locates a fault in an optical drop cable below an optical splitter," 57th IWCS, pp.22–26, Nov. 2008.

[7] K. Takada and M. Horiguchi, "Jaggedness-free millimeter-resolution low coherence reflectometry," J. Lightwave Technol., vol.12, no.4, pp.658–663, April 1994.

[8] Y. Koshikiya, X. Fan, and F. Ito, "Long range and cm-level spatial resolution measurement using coherent optical frequency domain reflectometry with SSB-SC modulator and narrow linewidth fiber laser," J. Lightwave Technol., vol.26, no.18, pp.3287–3294, Sept. 2008.

[9] X. Fan, Y. Koshikiya, and F. Ito, "Phase-noise-compensated optical frequency-domain reflectometry," IEEE J. Quantum Electron., vol.45, no.6, pp.594–602, June 2009.

[10] Y. Enomoto, H. Izumita, and M. Nakamura, "Highly developed fiber fault location technique for branched optical fibers of PONs using high spatial resolution OTDR and frequency domain analysis," Rev. Laser Eng., vol.33, no.9, pp.609–614, Sept. 2005.

[11] K. Tanaka, M. Tateda, and Y. Inoue, "Measuring individual attenuation distribution of passive branched optical networks," IEEE Photonics Technol. Lett., vol.8, no.7, pp.915–917, July 1996.

[12] K. Enbutsu, N. Araki, N. Honda, and Y. Azuma, "Individual fiber line testing technique for PONs using TLS-OTDR enhanced with reflected backward light analysis method," OSA/OFC/NFOEC, NWA1, March 2009.

[13] N. Honda, D. Iida, H. Izumita, and Y. Azuma, "In-service line monitoring system in PONs using 1650-nm brillouin OTDR and fibers with individually assigned BFSs," J. Lightwave Technol., vol.27, no.20, pp.4575–4582, Oct. 2009.

[14] K. Arakawa, K. Yoshida, and H. Ikeya, "A method for identifying single-mode fibers in an operating fiber cable system," Proc. IWCS, pp.88–93, Nov. 1989.

[15] Y. Aoyagi, K. Shiraki, H. Yamamoto, and M. Nakamura, "Low insertion loss optical fiber identifier realized by using asymmetric bending," Proc. IWCS, pp.484–488, Nov. 2003.

[16] K. Nakajima, T. Shimizu, C. Fukai, T. Kurashima, and M. Shimizu, "Single-mode hole-assisted fiber with low bending loss characteristics," Proc. IWCS, Nov. 2009.

[17] K. Enbutsu, N. Araki, N. Honda, and Y. Azuma, "Novel optical fiber identification method for PONs based on polarization modulation caused by pressure-induced retardation," ECOC, Sept. 2009.

[18] I. Ogushi, N. Araki, and Y. Azuma, "A new optical fiber line testing function for service construction work that checks for optical filters below an optical splitter in a PON," J. Lightwave Technol., vol.27, no.23, pp.5385–5393, Oct. 2009.

[19] M. Waki, S. Uruno, Y. Enomoto, and Y. Azuma, "Novel optical-fiber network management system in central office using RFID and LED navigation technologies," APNOMS, LNCS 5787, pp.71–81, Sept. 2009.

[20] M. Waki, S. Uruno, Y. Enomoto, and Y. Azuma, "Optical-fiber distribution management system using LED navigation and visible light communication technologies," IEICE Technical Report, OFT2009-34, Oct. 2009.

[21] N. Honda, M. Inoue, N. Araki, and Yuji Azuma, "New optical fibre line testing system function for facility location and identification using multivalued brillouin frequency shift assigned fibre," ECOC, Sept. 2009.

[22] N. Tomita, H. Takasugi, N. Atobe, I. Nakamura, F. Takaesu, and S. Takashima, "Design and performance of a novel automatic fiber line testing system with OTDR for optical subscriber loops," J. Lightwave Technol., vol.12, no.5, pp.717–726, May 1994.

[23] S. Tomita, H. Tachino, and N. Kasahara, "Water sensor with optical fiber," J. Lightwave Technol., vol.8, no.12, pp.1829–1832, Dec. 1990.

[24] K. Tanaka, M. Zaima, M. Tachikura, and M. Nakamura, "Downsized and enhanced optical fiber cable transfer splicing system," Proc. IWCS, Nov. 2002.

[25] K. Tanaka, T. Tsujimura, K. Yoshida, K. Katayama, and Y. Azuma, "Frame-loss-free line switching method for in-service optical access network using interferometry line length measurement," OSA/OFC/NFOEC, PD6, March 2009.

[26] K. Yoshida, T. Tsujimura, and T. Kurashima, "Seamless transmission between single-mode optical fibers using free space optics system," SICE Annual Conference, pp.2219–2222, Aug. 2008.

[27] K. Katayama, T. Tsujimura, K. Yoshida, K. Tanaka, Y. Azuma, and M. Shimizu, "Study of error-free optical line switching method for high-speed ethernet optical access system," 15th MOC, J94, pp.310–311, Oct. 2009.

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