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INDEX

1. Introduction [Ref.1]

Fibre to the home (FTTH) networks have recently been drawing much attention as a way of providing broadband information services to all customers mainly due to the fact that many electric power companies have already built optical backbone networks for their electric power business. In the years ahead, optical fibres will increasingly be applied to access systems along with the expansion of power system communications network. The high-speed access system for Internet protocol (IP)-based services consists mainly of cable television (CATV) and the asymmetric digital subscriber line (ADSL) in many countries. By the end of December 2002, there were about 2.0 million users of CATV service whereas about 5.1 million people were using ADSL in Japan. [Ref.2] The maximum transmission speed was more than 12Mbit/s for both CATV and ADSL.

On the other hand, FTTH service was launched in March 2001 and was provided by more than a dozen companies including five electric power companies as of December 2002. There were about 206,000 subscribers to FTTH service at the end of December 2002 in Japan. The number of subscribers to FTTH service is anticipated to increase rapidly.

To provide FTTH services as the high-speed access network, the electric power company should keep abreast of movements in the latest optical technologies for access networks.

Outlined in this technical report are new optical technologies for access networks, including the access methods, cable technology, installation technology and maintenance technology, required to realize economic and efficient optical networks for access networks.

2. Background and Present Status

2.1 Access Networks of Electric Power Companies

The access network in this report is defined as a network from a distribution substation or customer service office to customers' communication terminals installed on their premises. Fig. 2.1.1 shows an example of optical communication networks of an electric company in one country.

Since the introduction of optical communication technologies around 1980, electric power companies have been structuring their backbone networks using optical fibres. For their access systems, however, copper cables have been the mainstream. Recently, optical cables have begun to be used largely helped by the lowering price of cables and the development of low-cost optical communication equipment capable of point-to-multipoint communication. Also, the passive double star (PDS) system is being introduced to structure access networks.

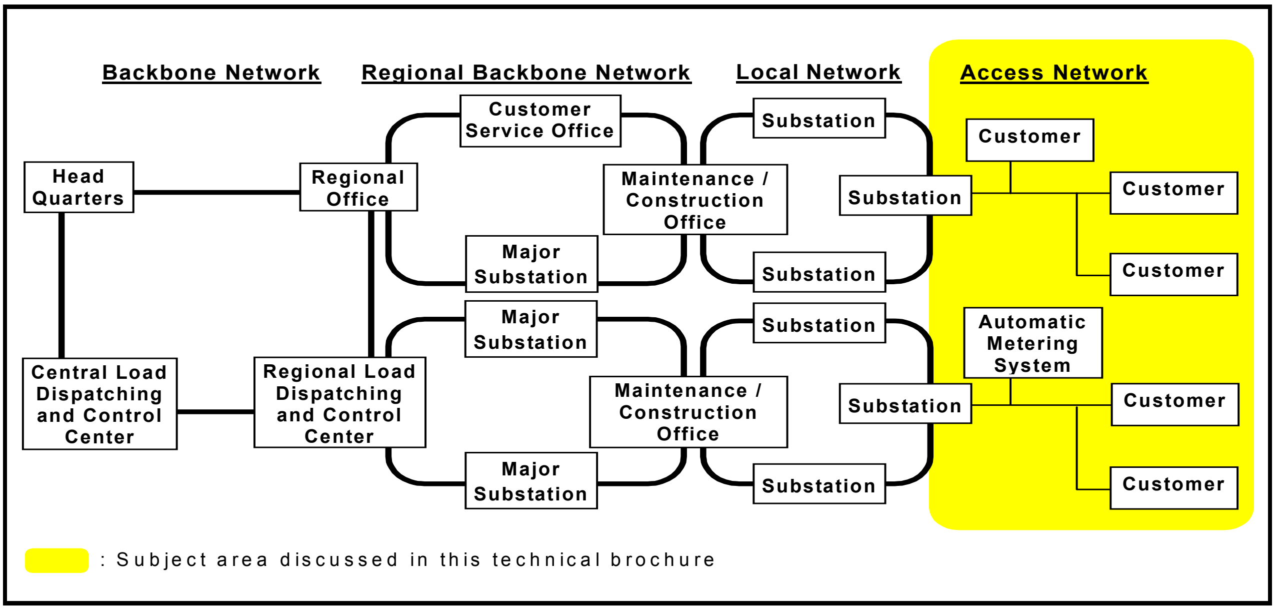


Fig. 2.1.1 Example of optical communication networks of an electric power company

At present, most of the access networks of electric power companies take the form of fibre to the curb (FTTC), fibre to the building (FTTB) or fibre to the pole (FTTP). The transmitted contents over the system are mainly automatic meter reading and a various kind of information services for customers, in addition to the conventional uses of dedicated telephones and load surveys, etc., for major electric power customers of high-voltage contracts. Also, the IP-based information services with higher-speed optical networks in the coming years will be provided not only to high-voltage customers but also to low-voltage ones.

2.2 Deregulation of the Electric Power Industry and FTTH Services of Electric Power Companies

Following the deregulation of electric power industry, a large number of newcomers have entered the business. To cope with the new competitive business environment, the existing electric power companies are taking countermeasures such as lowering the electricity price through cost reduction efforts. While competition in the electric power business is intensifying with the deregulation, the power companies are working to find new sources of revenue.

By the deregulation of telecommunication industry, a lot of new companies are promoting the competition participating in this field. This has resulted in a sharp drop in telephone charges and the diffusion of various new communication services including asymmetric digital subscriber line (ADSL).

Under these circumstances, electric power companies in many countries entered the telecommunications business and lately some of them have started fibre to the home (FTTH) business, for which their optical communication infrastructure has been proved useful. Of ten major electric power companies in Japan, Chubu Electric Power Company started field tests of FTTH service in October 2000 and started FTTH service itself in November 2002. In March 2002, Tokyo Electric Power Company started the similar service with the maximum speed of 100Mbit/s. Also, K-OPTI.COM, a subsidiary of Kansai Electric Power Company, joined the same business in April 2002. As of December 2002, five electric power companies are providing FTTH services themselves, through their subsidiaries or through affiliated companies. Since each electric power company is operating their business based on its own strategies, the type of organization offering service varies with the electric power company, namely the electric company itself, or its subsidiaries/affiliated companies.

2.3 Present Status of the FTTH Service

In Japan, telecommunications mega carriers, electric power companies and their affiliated companies as well as new communication enterprises are offering FTTH services. The maximum speed is from 10Mbit/s to 100Mbit/s for both upstream and downstream. The monthly charges range from $47 to $155 for an individual user, as of December 2002. These charges will be lowered through competitions among the service providers and with the other media such as ADSL. Fig. 2.3.1 shows the increase of subscribers to Internet services using FTTH, ADSL and cable television (CATV) in Japan.

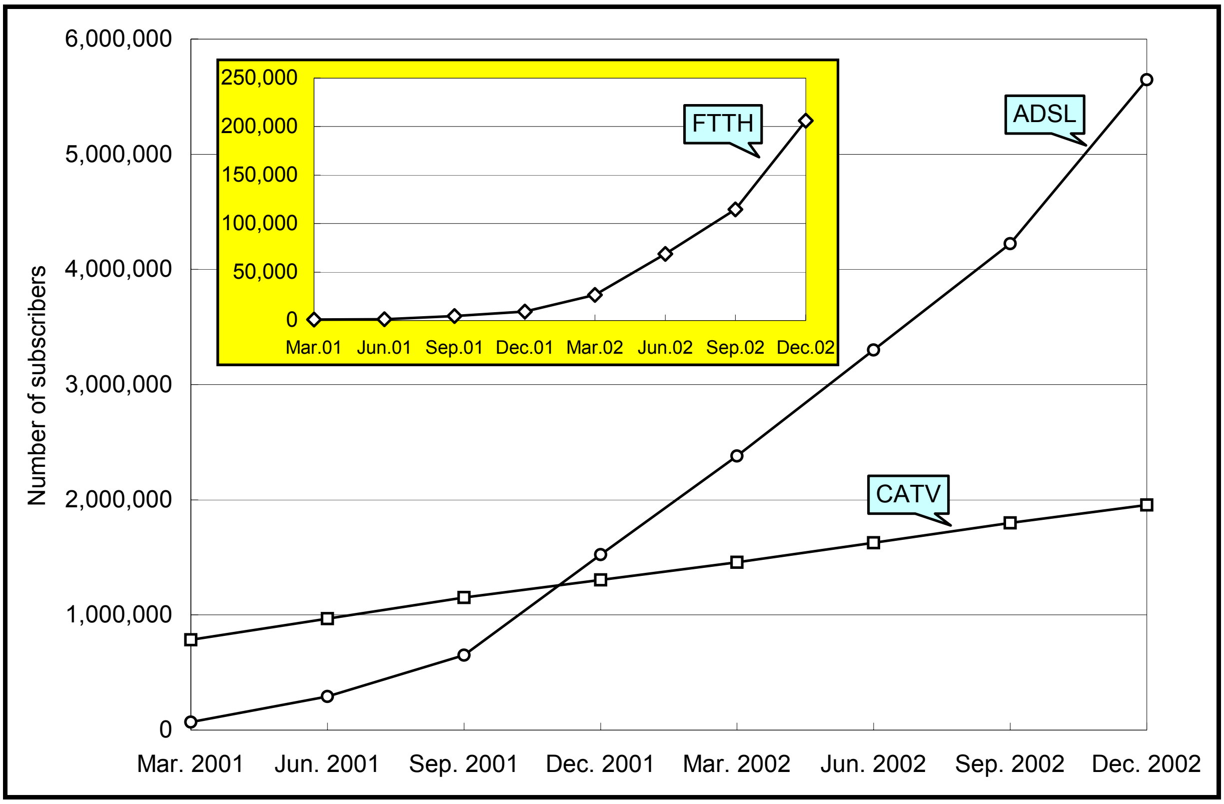


Fig. 2.3.1 Increase of subscribers to Internet services in Japan [Ref.2]

3. Roadmap of Technical Development for new Optical Access Networks

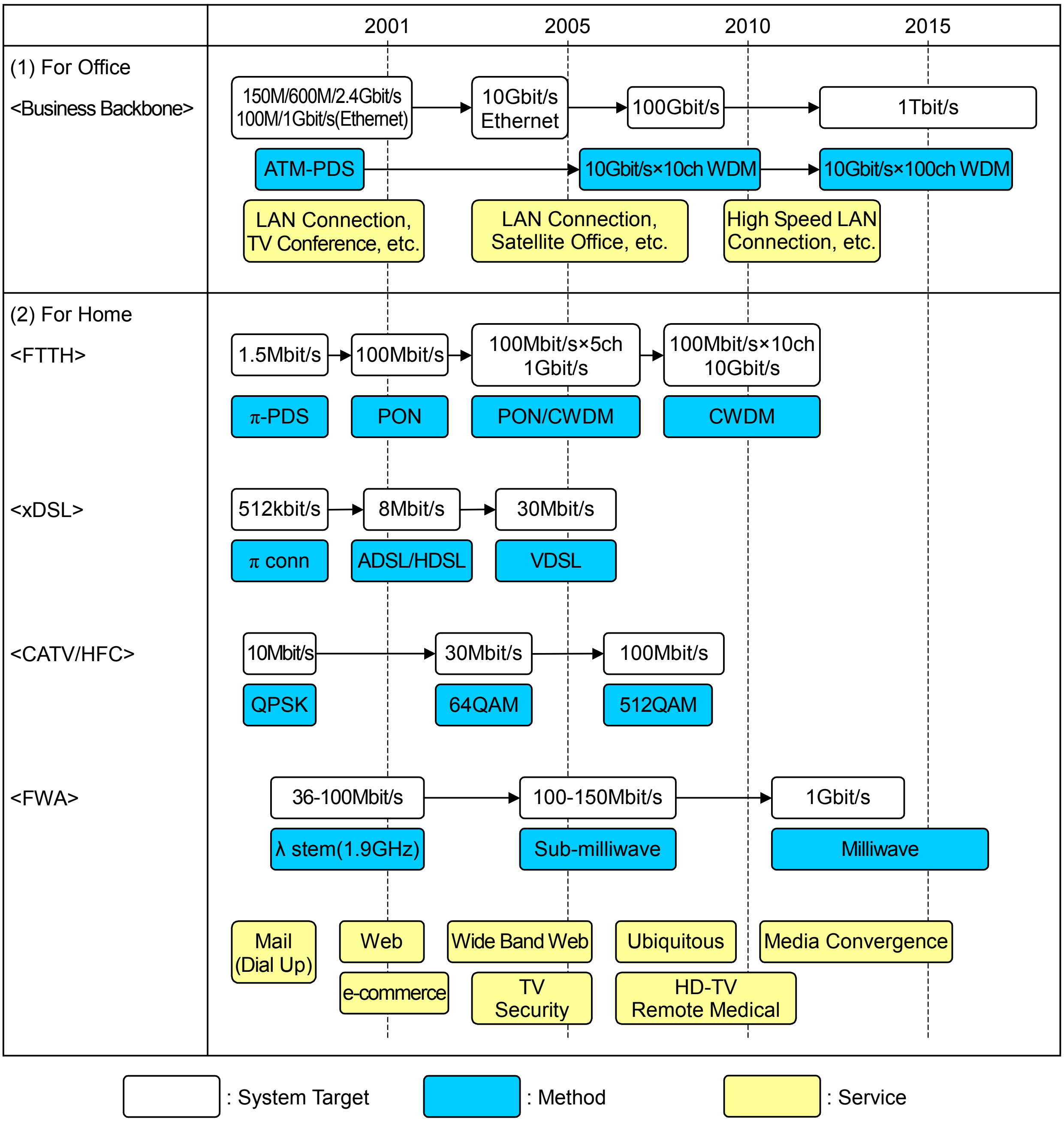
Among present technical trends in the access networks is the increase of transmission speed in accordance with the enlargement of transmission capacity in backbone networks where various multiplication techniques and high-bit rate transmission systems are developed. In the access networks, however, the transmission speed is fixed at a level well below the upper limit of electrical devices because the thorough cost reduction is required and the receiver of the information is a human being. The bit rates are supposed to be a few gigabits at most for homes and 10Gbit/s based wavelength multiplexing for offices by the year 2010.

There are two categories of optical links in the access networks, fixed and mobile ones. The optical access networks that mainly contribute to the former provide the best way to obtain high-speed transmission among various media such as coaxial cables, pair cables, and electric power feeders. However, problems in cost reduction and ease of construction of facilities still remain.

There are three network architectures, passive double star (PDS), active double star (ADS), and single star (SS) that are suitable for so-called fibre to the home (FTTH) and fibre to the office (FTTO). In these networks, subscribers and a node are connected by only using optical fibre. Although PDS seems to be the mainstream at present, ADS and SS are also strong candidates for the access networks. In fact, services providing 100-Mbit/s FTTH have started in big cities, where the SS structure is employed with media converters. This means that every architecture could be applied according to the properties of the service area.

Rapid increase of service menus like Internet access and the video on demand (VOD) are assumed for utilization of these access networks. Enterprises may be easily able to have satellite offices and teleworking may become popular in the near future.

A roadmap of the access networks is shown in Fig. 3.1.1, considering the conditions mentioned above. Necessary time spans for achieving the targets might be shortened because of intense competition in developments and services.



ADSL	Asymmetric Digital Subscriber Line	MAC	Media Access Controll
ATM	Asynchronous Transfer Mode	OCN	Optical Computer Network
CATV	Cable Television	QAM	Quadrature Amplitude Modulation
CWDM	Coarse WDM	QPSK	Quadrature Phase Shift Keying
FWA	Fixed Wirelwss Access	PDS	Passive Double Star
FTTH	Fibre To The Home	PON	Passive Optical Network
HDSL	High-bit-rate Digital Subscriber Line	VDSL	Very High-bit-rate DSL
HFC	Hibrid Fibre Coxial	WDM	Wavelength Division Multiplexing
LAN	Local Area Network		

Fig. 3.1.1 Roadmap for optical access link Ref.3

4. Technology

Increase of transmitted information through the access networks is attributed to popularization of the Internet. The number of hosts connected to the Internet has undergone a rapid increase as shown in Fig. 4.1. The number of users has reached 400 millions, that is 9% of the world's population. It is estimated that the increase rate of the Internet-population will maintain a value between 40 and 50 % a year for the following few years.

Various data formats including text, audio, and video are interchanged using the Internet. Ways of using the Internet are extending from browsing, e-mail, and file transfer to virtual private networks and electric commerce that demand high-grade securities. Especially, e-commerce will prevail all over the world. Various markets such as personal computers, travels, books, flowers, entertainments and so on have been developed on the Internet. Every type of goods and services including foods, commodities, immovable property, and automobiles will eventually appear. Services that consider purchaser's individual habits will become possible. Internet auctions are increasingly popular, and shopping through TV broadcasting is shifting to the Internet auction. Using the Internet reduces the cost of making a catalog. Profits generated by public relations using the Internet are drawing attention. As a result the existing mass media have established their home pages to give various kinds of information to public without demanding fees. Electronic banking systems became more popular in USA than any other country because the cost reduction on checking procedure is attractive in countries like USA.

The data transmission rate for electric commerce is at most a few megabits per second (Mbit/s) because media for the communication are X digital subscriber line (XDSL), cable television (CATV), and wireless systems. It is difficult to predict the transmission rate necessary for the future access network because it depends on the contents. However, a value between a few tens to one hundred Mbit/s is a standard, considering the situation where huge video data like movies can be smoothly downloaded. The media that offer such a high-speed link are limited to optical networks.

The access networks are expected to be categorized in the following few years into two architectures, the passive double star (PDS) and single star (SS) using media converters. In the long term, however, various technologies including those now being developed for the backbone network might be applied. These include coarse wavelength division multiplexing (CWDM), dense WDM, super WDM, and optical code division multiplexing (OCDM).

Concerning the PDS, the 155-Mbit/s asynchronous transfer mode-passive double star (ATM-PDS) was standardized by organizations of such as the Full Service Access Network (FSAN) and International Telecommunication Union-Telecommunication Standardization Sector (ITU-T), and the gigabit passive optical network (Gigabit-PON) is now being discussed at Institute of Electrical and Electronic Engineers (IEEE) and FSAN. On the other hand, inexpensive media converters that are developed for so-called Local Area Networks (LAN) are becoming powerful candidates for realizing the fibre to the home (FTTH) by using the SS structure. 100-Mbit/s services using the media converter have already been begun in large cities. Higher bit rate services by this network might prevail if 10-Gbit/s equipment become inexpensive in the near future.

There is another method of optical signal transmission to subscribers, called radio on fibre (ROF). The optical waves whose intensity is directly modulated by electrical signals are sent through an optical fibre. It has very interesting properties, as the alternation of the signal formats is easy.

Our viewpoint should be focused on the relationship between electric power companies and optical communication. Electric power companies have their own networks for communication because electric power is supplied over a wide area. Replacement of the transmission lines with optical fibres is proceeding. The kinds of the information transmitted are signals necessary for electric power systems and businesses. The former includes information for operation, protection, and warning. If buying and selling of electric power is deregulated, high efficiency in information exchange between the electric power company and consumers would be necessary because of the increase of service menus and automatic meter reading. The electric power companies will make efforts to construct optical access networks for public telecommunication because they are in a good position to build them. These networks will also be used for various types of e-business as described above.

This chapter is devoted to explaining the architectures used for the access network and technologies necessary for laying them.

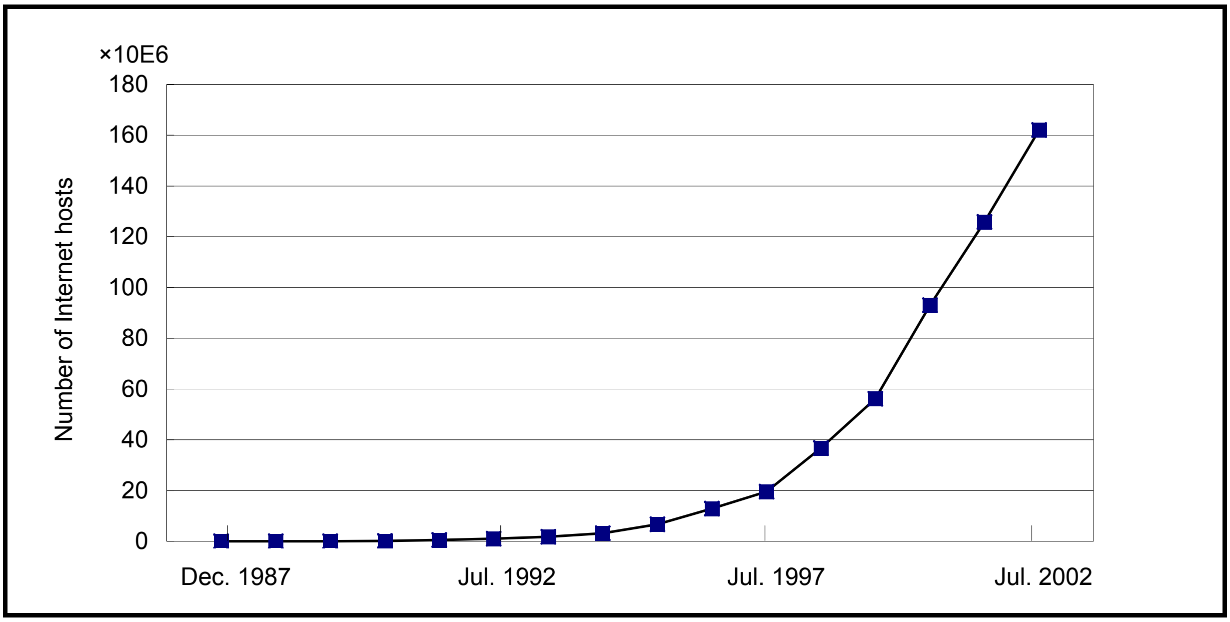


Fig. 4.1 Change of the number of Internet hosts [Ref.4]

4.1 Type of Access Technology

The various access systems are now under study for offices mainly in urban business areas, apartment houses, ordinary houses, and mobile terminals such as a cellular phone, etc., and various choices will be available.

This section covers the following systems:

- Synchronous transfer mode-passive optical network (STM-PON)
- Broadband-passive optical network (B-PON)
- Ethernet-passive optical network (Ethernet-PON)
- Optical add/drop multiplexer (Optical ADM)
- Optical transceiver
- Spatial light transmission
- Radio on fibre (ROF) technology
- Optical CATV technology

4.1.1 STM-PON

The optical transmission systems for access can be classified into the following three types:

1) The single star (SS) system has a 1:1 configuration of center equipment and subscriber unit. This system allows easy service type settings for individual subscribers and high-speed transmission but also has an economical disadvantage that the center equipment, especially, optical parts, cannot be shared.
2) The active double star (ADS) system has a 1:N configuration where the center equipment and subscriber units are connected through a repeater called concentrator. The multiplex transmission of subscriber signals between the center equipment and repeaters makes this system efficient but the running costs for repeater maintenance and others should be considered.
3) The passive double star (PDS) system has a 1:N configuration where optical couplers are inserted into the center-subscriber optical transmission line for dropping. This system is economical with no repeaters but the decrease in optical power due to the divergence of the optical couplers limits the transmission distance.

Fig. 4.1.1 shows the PDS system configuration. The PDS system generally uses star couplers with dropping ratio of 1:2 to 1:16 at one or two stages. Under the PDS system, as the number of drops increases, the loss by dropping becomes great and the maximum transmission distance becomes short.

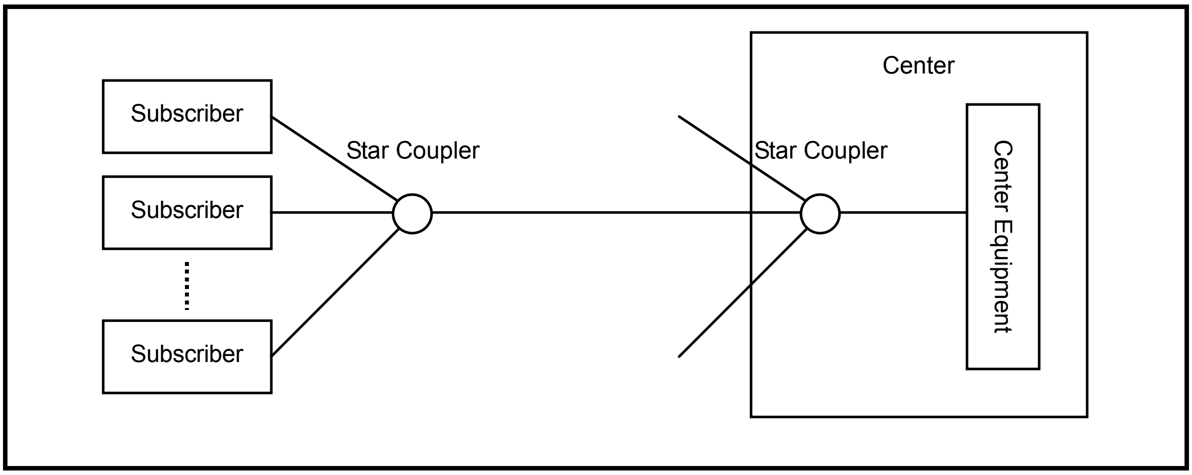


Fig. 4.1.1 PDS system configuration

The PDS system is a kind of multiple access system. For multiple accesses, the following transmission systems are generally used.

For downstream signal transmission from the center equipment to each subscriber unit, the PDS system uses time division multiplexing (TDM) where signals are divided in packets at fixed time intervals for spacing and signals from other channels are arranged sequentially in the spaces. Fig. 4.1.2 shows the downstream signal transmission of the PDS system.

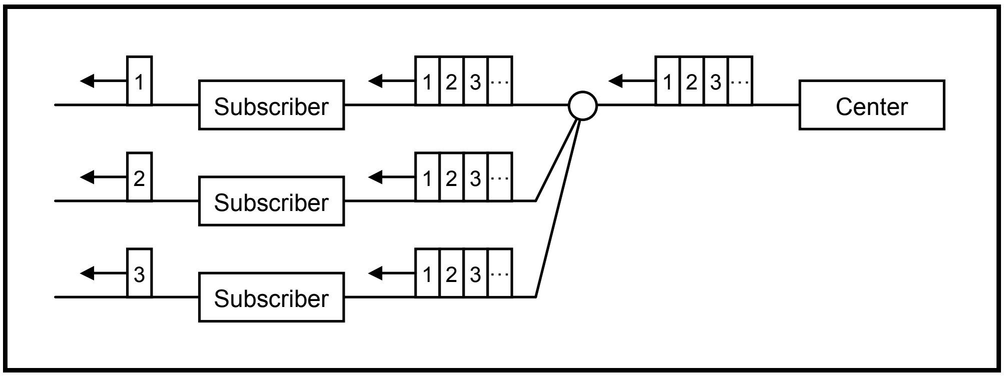


Fig. 4.1.2 Downstream signal transmission of the PDS system

For upstream signal transmission from each subscriber unit to the center equipment, the PDS system uses time division multiple access (TDMA) where signals in the same frequency band are divided by time into several channels allocated to each subscriber who accesses the parent station. Fig. 4.1.3 shows the upstream signal transmission of the PDS system. For efficient transmission, each subscriber unit should transmit signals by staggering transmission timings. The time required for signal propagation from the center equipment to each subscriber unit should be measured in advance and the transmission timing should be instructed to each subscriber unit.

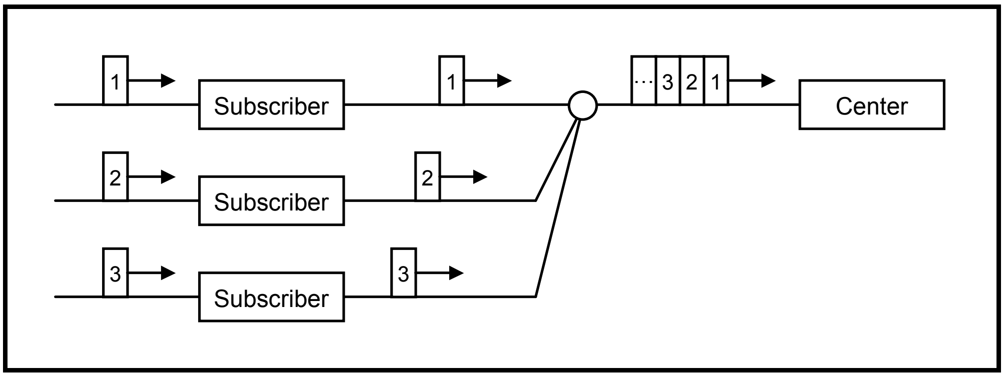


Fig. 4.1.3 Upstream signal transmission of the PDS system

For one-core bi-directional transmission, the PDS system uses test data description (TDD) where Side B only receives signals during transmission from Side A and transmits signals after transmission from Side A. Fig. 4.1.4 shows the one-core bi-directional transmission system using TDD. The upstream and downstream signal timings should be switched by considering the propagation delay time between Sides A and B. For the required transmission speed and efficiency, the signals may be compressed in time domains. This system may also be called time compression multiplexing (TCM).

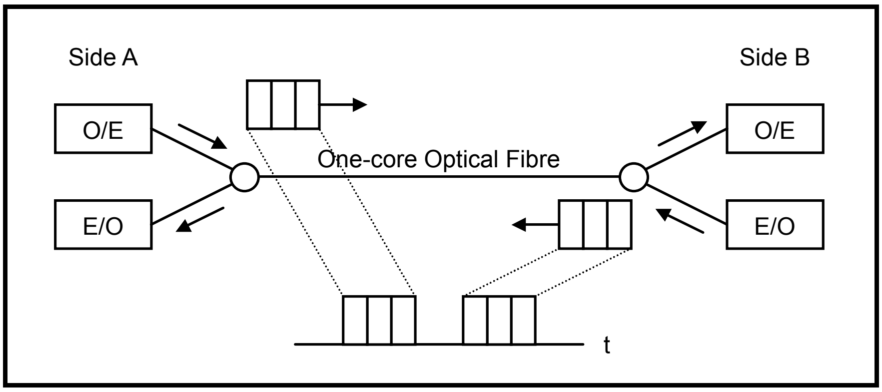


Fig. 4.1.4 One-core bi-directional transmission system using TDD

For one-core bi-directional transmission, WDM is also used in some cases. Different optical wavelengths are used for upstream and downstream signal transmissions to prevent collisions between upstream and downstream signals.

4.1.2 B-PON

4.1.2.1 Outline

B-PON consists of an optical line terminal (OLT) to accommodate several subscribers on the network side and an optical network unit (ONU) installed in each subscriber home. This system has a 1:N configuration like STM-PON where optical couplers are inserted into the OLT ~ ONU transmission line for optical dropping but uses ATM cells for payloads.

Full Service Access Networks-Optical Access Network (FSAN-OAN) first discussed asynchronous transfer mode-passive optical network (ATM-PON) but decided to use the name of broadband-passive optical network (B-PON) in 2000 when discussing broadband access platforms widely by considering ATM merely as one of several methods.

4.1.2.2 Configuration

Fig. 4.1.5 shows an outline of B-PON prescribed in ITU-T G983.1.

For networking, B-PON uses a single-core optical fibre of 1.31-µm zero-dispersion single-mode fibre and wavelength-multiplexed signals of the 1.31-µm and 1.55-µm bands for bi-directional transmission. Downstream signals from OLT to ONU are continuous signals transmitted at the speed of 155.52Mbit/s or 622.08Mbit/s using the 1.55-µm band. Upstream signals from ONU to OLT are burst signals transmitted at the speed of 155.52Mbit/s using the 1.31-µm band.

Up to 32 ONUs can be connected and each ONU captures data addressed to it. Meanwhile, the OLT measures the distance at ONU activation and adjusts the phase so that burst signals received from ONU will not collide with each other. Under system restrictions for this phase adjustment, the maximum distance between OLT and ONU is limited to 20km. The OLT allows up to 4096 virtual paths (VP).

Because of the ATM technology, ATM-PON has a greater capacity and a higher speed than STM-PON and is expected as a means of high-speed Internet access and high-speed inter-LAN connection.

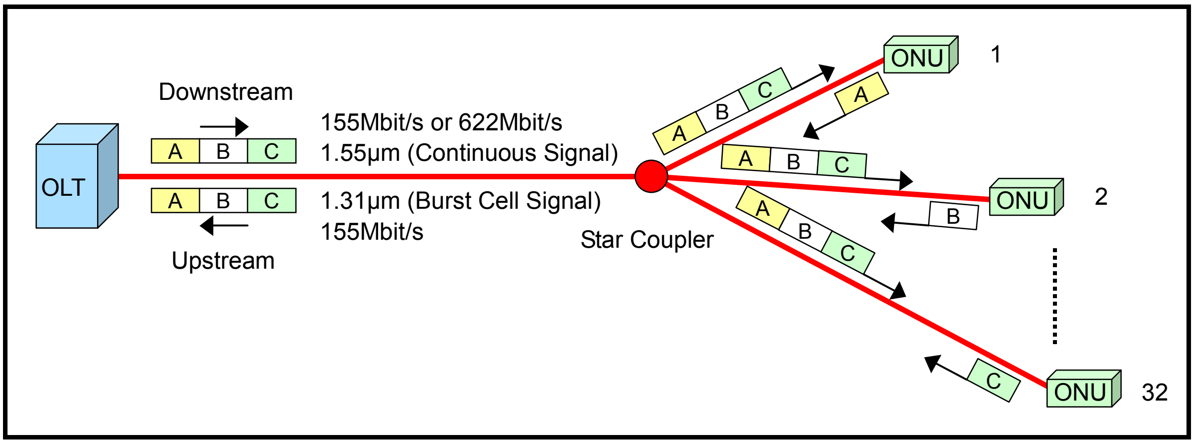


Fig. 4.1.5 B-PON system prescribed in ITU-T G983.1

4.1.2.3 Outlook

In 2001, the following functions were added to the ITU-T recommendations. Products with these functions are expected to appear in the market soon.

4.1.2.3.1 Wavelength Multiplexing Function

For the B-PON system to provide video and data services using a single-core fibre, the wavelength arrangement of the 1.55-µm downstream signal band was modified.

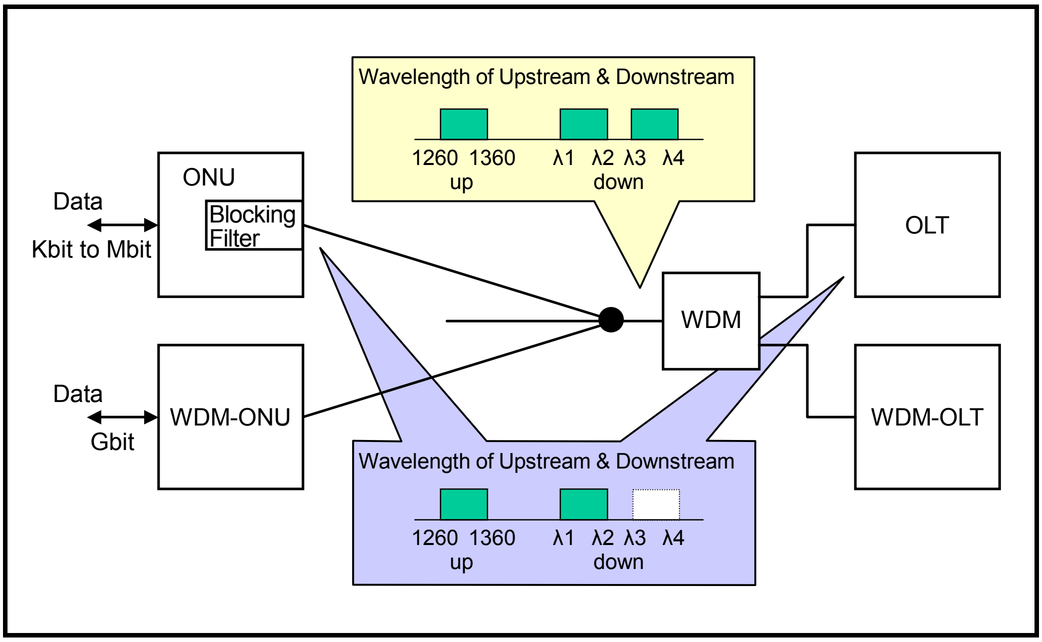


Fig. 4.1.6 Band extension by WDM function

4.1.2.3.2 Dynamic Bandwidth Assignment (DBA)

DBA flexibly accommodates Internet services of strong burst characteristics. The purpose of this function is to accommodate 100Base-T in the user-network interface (UNI) to support services faster than asymmetric digital subscriber line (ADSL) and cable mode.

4.1.2.3.3 PON-section Dualizing Function

The purpose of this function is to provide business users with high-reliability menus. Fig. 4.1.7 shows an example of a dual system configuration.

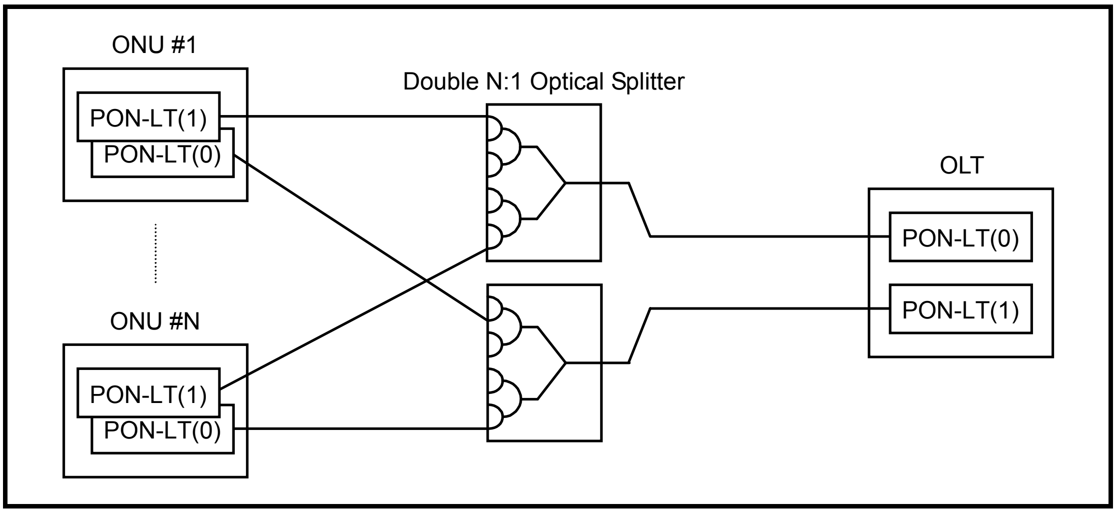


Fig. 4.1.7 Example of a dual system configuration

4.1.3 Ethernet-PON

4.1.3.1 Outline

In the Internet connection service, the growth of large-capacity contents represented by image information is anticipated to increase users seeking a high-speed access environment. As a means of realizing such a high-speed access from 10Mbit/s to 100Mbit/s, the media converters are becoming popular these days. However, the single-star configuration requires a necessary number of fibres to be led into the concentrator according to the number of subscribers. The cost is especially high for a carrier who needs to lease fibres.

The Ethernet-PON system is expected to reduce network maintenance and operation costs greatly because the system reduces the number of fibres led into the concentrator and makes on-pole switching hubs and other active equipment unnecessary at drops.

4.1.3.2 Configuration

Fig. 4.1.8 shows an example of Ethernet-PON. The standardization of Ethernet-PON was only started in 2001 at Ethernet in the First Mile (EFM) of IEEE802.3. And now many vendors are proposing various systems and products.

The PON system can be classified into “Ethernet over ATM-PON” based on ATM-PON and ones based on vendors' own unique systems. The PON-section transmission speed is generally 155Mbit/s for the former but 155Mbit/s to 1.25Gbit/s for the latter. Table 4.1.1 lists the specifications of systems proposed by vendors.

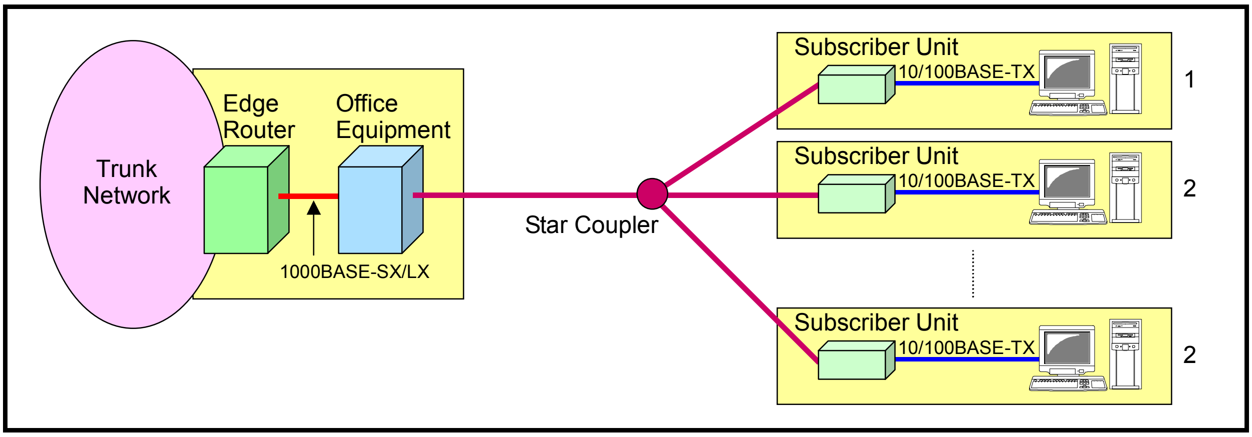


Fig. 4.1.8 Example of Ethernet-PON

4.1.3.3 Outlook

As mentioned before, Ethernet-PON is now being standardized at EFM of IEEE802.3. According to the current schedule, the draft specifications will be issued in 2002 and formal ones in 2003. However, the intention of each vendor is also anticipated to cause difficulties and delay the schedule.

Table 4.1.1 Example of Ethernet-PON systems proposed by vendors

	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E
PON system	Ethernet over ATM-PON	Ethernet over ATM-PON	Unique	Unique	Ethernet over ATM-PON
PON speed	155Mbit/s	155Mbit/s	622Mbit/s	1.25Gbit/s	155Mbit/s
Number of fibre cores	1	1	1	1	1
Wavelength	Up: 1.31µm Down: 1.55µm	Up: 1.31µm Down: 1.55µm	Up: 1.31µm Down: 1.55µm	Up: 1.31µm Down: 1.55µm	Up: 1.31µm Down: 1.55µm
Number of drops	32	32	32	32	32
Maximum transmission distance	15km	10km	12km	15km	20km
Station equipment, High-order IF	1000BASE-SX/ LX × 2 10/100BASE-T × 1	10/100BASE-T × 1	1000BASE-SX/ LX × 1 10/100BASE-T × 1	1000BASE-SX/ LX × 1 10/100BASE-T × 1	10/100BASE-T × 16
Station equipment - PON IF capacity	12	22	2	32	16
Station equipment - Maximum subscriber capacity	384	704	64	1024	512
Subscriber unit - Terminal IF	10/100BASE-T × 1	10/100BASE-T × 1	10/100BASE-T × 1	10/100BASE-T × 4	10/100BASE-T × 1

4.1.4 Optical ADM

4.1.4.1 Outline

The optical add/drop multiplexer (ADM) is expected to be a means of providing business users with high-speed broadband services in small-scale local networks.

Processing a large volume of signals as conventional electrical signals necessitates large-scale equipment and costs a lot. For constructing a low-cost system, ADM devices are effective because wavelength-multiplexed signals can be processed as they are. Optical ADM devices are generally connected on a ring to accommodate users in a certain area effectively.

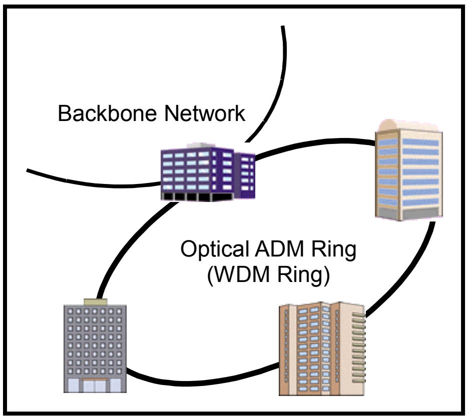


Fig. 4.1.9 Optical ADM ring

4.1.4.2 Configuration

Fig. 4.1.10 shows an example of signal flows on the optical ADM ring. This kind of system has a very large capacity from 2.4 to 10Gbit/s and allows arbitrary connections between optical ADM nodes because different wavelengths are assigned to signals of different destinations for add and drop at optical ADM nodes by wavelengths.

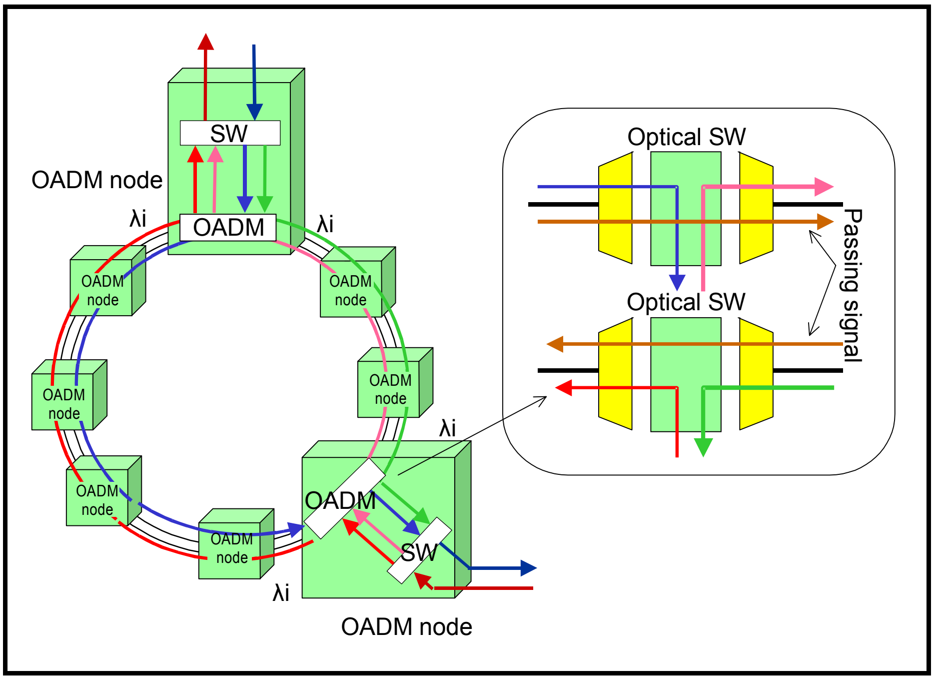


Fig. 4.1.10 Example of signal flows on the optical ADM ring

As the figure shows, this system generally has a unidirectional path (optical wavelength) switching ring using two optical fibres. To ensure highly reliable transmission, the route is changed to a spare one instantaneously in case of cable-cut or node-fault.

A 1-to-N multicast function may also be supported for distributing optical signals by optical switch settings without conversion into optical signals.

4.1.4.3 Outlook

Further cost reductions are expected to grow the optical ADM into a wide access system.
For a greater capacity, further wavelength multiplexing is expected but optical switches need to have greater capacities.

4.1.5 Media Converter

A media converter consists of an optical transmitter module that converts electrical signals into optical ones and an optical receiver module that converts optical signals into electrical ones. Fig. 4.1.11 shows the basic configuration. Especially for an optical LAN, a transceiver module consisting of a transmitter module and a receiver module is used. The optical communication system is of the intensity modulation type that detects signals by optical flashing.

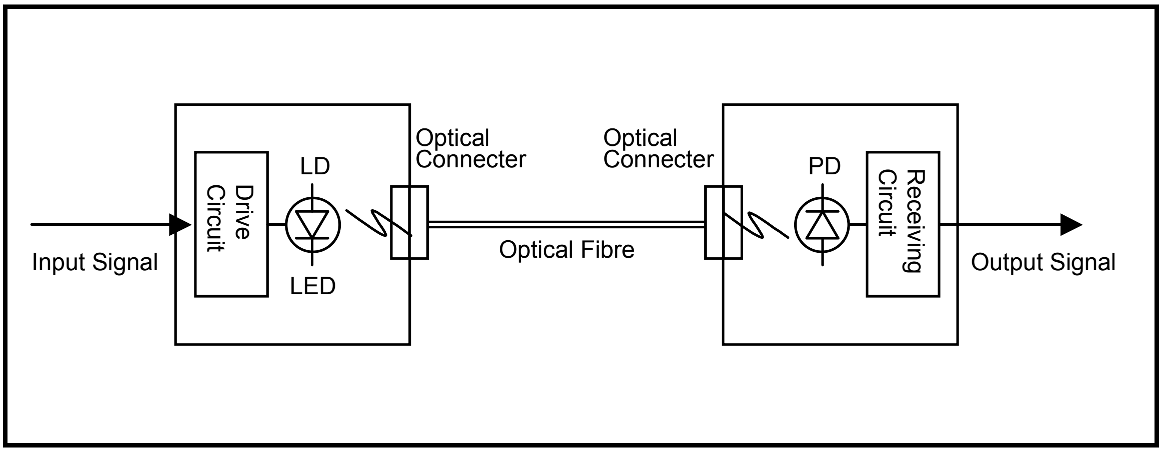


Fig. 4.1.11 Basic configuration of media converter

4.1.5.1 Transmitter and Receiver

A transmitter module converts an electrical signal into an optical one with a laser diode (LD) or light emitting diode (LED) as the light-emitting device and sends the optical signal to an optical fibre. In high-speed communication over several hundred Mbit/s to Gbit/s, the frequency characteristic or waveform distortion of a light-emitting device has a great influence. To solve this problem, a transmitter module has a built-in correction circuit. Since the optical output of an LD depends on the temperature, a transmitter module also requires a correction circuit that detects and corrects characteristic variation by the ambient temperature. Fig. 4.1.12 shows a transmitter module.

A receiver module converts the current of an optical signal from an optical fibre by using a photodiode (PD) as the light-receiving device and then converts the signal into a voltage-by-voltage conversion. The signal is output after conversion to a logical voltage according to the output electrical interface.

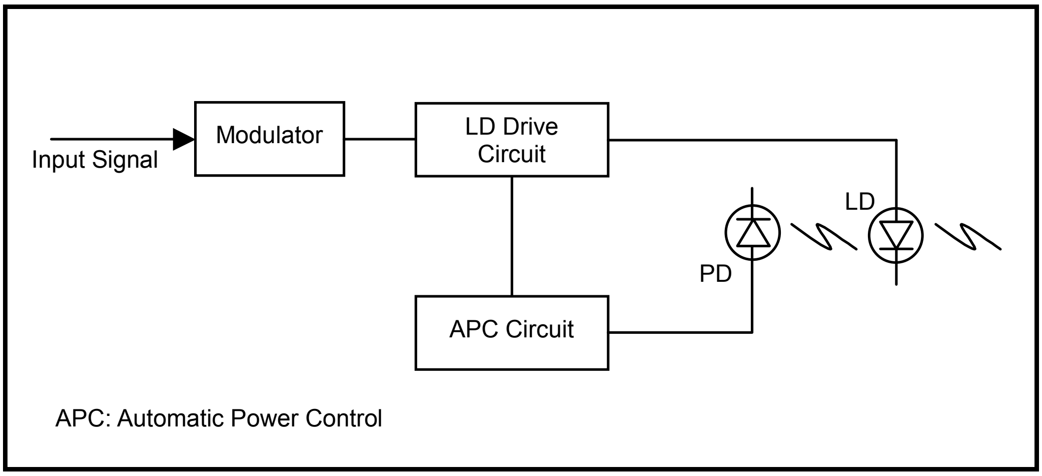


Fig. 4.1.12 LD transmitter module

4.1.5.2 Specification about Media Converter

Table 4.1.2 lists the typical specifications of media converters. The specifications of 100BASE-FX are partially based on specifications of the fibre distributed data interface (FDDI) and those of 1000BASE-SX/LX are based on the fibre channel specifications.

The most recently used connectors are from an SC connector to an MT-RJ connector for efficient mounting because optical transceivers are becoming small. The most recently used gigabit media converter is a gigabit interface converter (GBIC) that can be mounted and removed by hot swapping.

Table 4.1.2 Typical specifications of media converters

	Transmission speed	Modulation system	Optical transmission speed	Waveband	Distance	Typical connector
FORIL	10Mbit/s	Intensity modulation	20Mbit/s	0.85-μm band	(Multimode) 1km max.	ST, (FC)
10BASE-FL	10Mbit/s	Intensity modulation	20Mbit/s	0.85-μm band	(Multimode) 2km max.	ST, (FC)
100BASE-FX	100Mbit/s	Intensity modulation	120Mbit/s	1.3-μm band	(Multimode) 2km max.	SC
100BASE-FX	100Mbit/s	Intensity modulation	120Mbit/s	1.3-μm band 1.55-μm band WDM	(Single mode) 15km max.	SC
1000BASE-SX	1Gbit/s	Intensity modulation	1.25Gbit/s	0.85-μm band	(Multimode) 550m max.	SC
1000BASE-LX	1Gbit/s	Intensity modulation	1.25Gbit/s	1.3-μm band	(Multimode) 550m max. (Single mode) 5km max.	SC

4.1.5.3 Outlook

Media converters are the epitome of optical communication technologies. Now the converters are being improved for easy usability so that users can use the converters without being aware of optical technologies.

If parallel optical modules will be put into practical use for parallel signal communication in future, the media converters may be used for computer communication. As the Internet prevails, the media converters will also be applied to home networks and their demand will increase.

Meanwhile, IEEE802.3 inaugurated a task force of IEEE802.3ae (10-Gigabit Ethernet) that studied the 10-Gbit/s Ethernet. In addition to the transmission of 10Gbit/s extended from the conventional standards, IEEE discussed a parallel link system that supports 4-port parallel transmission of 2.5/3.125Gbit/s for WAN and also long-distance transmissions from 10km to 40km. A new standard was recommended in June 2002.

4.1.6 Spatial Light Transmission

4.1.6.1 Outline

Infrared communication can be classified into four types: a light source of directive or nondirective radiation, direct radiation, and reflective radiation, depending on whether or not a line-of-sight communication is secured. Also by equipment, infrared communication can roughly be classified into Infrared data association (IrDA) popular among notebook personal computers and dedicated infrared communication for networking.

4.1.6.2 IrDA

IrDA is a standardized system for interconnection by infrared data communication: line-of-sight communication, and now Versions 1.0 and 1.1 are available. Table 4.1.3 lists the specifications.

Table 4.1.3 IrDA specifications

Version	Transmission speed	Wavelength	Modulation system	Pulse width	Pulse logic	Maximum communication distance
1.0	2.4 ~ 115.2kbit/s	850 ~ 900nm	RZ	1.6μs ~ 3/16	0:ON 1: OFF	Within 1m
1.1	1.152Mbit/s	Same as above	Same as above	250 ns	Same as above	Same as above
	4 Mbit/s	Same as above	4-valued PPM	-	-	Same as above

Some products make the existing IrDA ports of notebook personal computers available as Internet adapters. This kind of product consists of an Ethernet-connected mother device and an infrared adapter that repeats signals. The adapter automatically connects the IrDA port of a notebook personal computer if it exists within the effective range of adapter, and the communication speed is 115kbit/s or 4Mbit/s.

4.1.6.3 Dedicated Infrared Network Equipment

This type of systems can roughly be classified into short-distance communication systems e.g. indoor LAN and long-distance ones between buildings e.g. LAN, integrated services digital network (ISDN), and image.
Table 4.1.4 lists the specifications of long-distance communication systems manufactured by A, B, and C.

Table 4.1.4 Specifications of long-distance spatial light communication systems

Manufacturer	Communication Distance	Transmission Rate	Interface
A	Within 2km	~ 700Mbit/s	ATM, FDDI, 100M/10M Ethernet
B	1km	25 ~ 622Mbit/s	ATM, FDDI 100M/10M Ethernet
C	25 ~ 250m	10Mbit/s	10M Ethernet

These systems can realize high-speed networks without dedicated lines. Unlike radio communication, Radio Law does not regulate infrared communication. Beam diffusion makes it easy to adjust fluctuations such as optical axis variations, and the automatic tracking mechanism and other functions prevent deviations from the optical axis. Mist and other liquid contents may cause a transmission error by diffusing the light and attenuating its ultimate power. This problem, however, can be solved by limiting the communication distance or by using the transmission control protocol/Internet protocol (TCP/IP) protocol or error corrections. Crows and other birds or animals do not cause any harm because they avoid infrared rays. If they get between the optical beam and the light receiving section, however, a transmission error may occur.

Short-distance communication systems for indoor LAN are available from the manufacturer C and other companies. The basic interface is 10-Mbit/s Ethernet but some systems use RS-232C and other general-purpose interfaces. The communication distance is from several to about 50 meters for indoor communication. The communication style is 1:1 or n:1. These specifications are advantageous for frequent changes of the office layout and useful for carrying notebook personal computers.

4.1.6.4 Outlook

Since spatial light transmission is basically for line-of-sight communication, shields and other blockers have a great influence. For outdoor communication, error corrections are being researched by taking into consideration of the influences of weather conditions. For indoor infrared wireless communication, the transmission pulse waveform and multi-beaming are under research to realize diffuse-reflection channel communication. About the wavelength, a transition to 1.6 or 2.1μm is being studied because they are not harmful to the eye and not absorbed significantly by water.
In the future, optical beacons will be used not only for LAN, ISDN and image communication but also for the pedestrian information and communication systems (PICS), and the intelligent transport system (ITS). An optical beacon is a system for information exchange between a detector mounted on traffic lights and a vehicle-mounted receiver.

4.1.7 Radio on Fibre Technology

4.1.7.1 Outline

The radio on fibre (ROF) converts radio signals into optical signals as they are and transmits them through an optical fibre. This technology features the efficient connection of radio and optical signals and the long-distance transmission of radio signals where the transmission loss of the radio is great.

Dropping optical fibres into subscriber homes is a means of receiving video and other large-capacity data smoothly. However, it is not efficient to lead a fibre into each room of a building or a condominium. The radio is an effective means of access from a moving vehicle.

The ROF technology is expected to help construct access networks in future.

4.1.7.2 Configuration

Fig. 4.1.13 shows the system configuration.

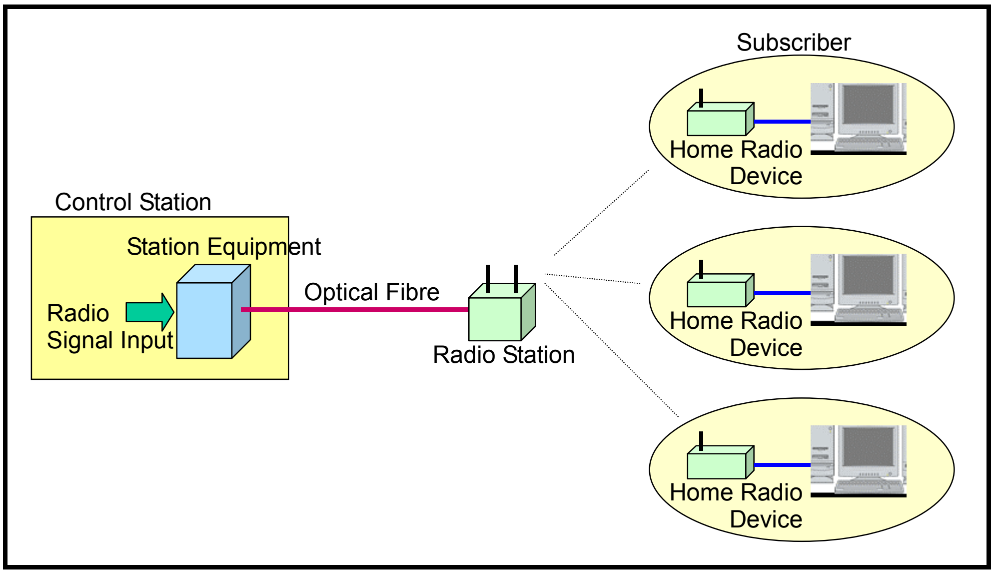


Fig. 4.1.13 System configuration of ROF

For an access-type fibre radio communication system, raising the radio frequency band to microwave or millimeter-wave is a problem to solve for increasing the communication speed and capacity. An optical fibre with a broadband characteristic and limited loss is necessary as a transmission line from a control station to a radio base station.

The control station modulates laser beams into radio signals as service signals and transmits the modulated signals through an optical fibre. The transmitted signals are converted into the original radio signals at the radio station, distributed to a certain area, and received by radio devices at subscribers' homes. The upstream signal flow from a subscriber is the opposite.

4.1.7.3 Outlook

If the number of radio access subscribers increases, there will be a shortage of available frequencies. To make a mobile terminal lightweight, its battery should be made small and the transmission power should be reduced. As a solution to these problems, reducing the area per radio base station is effective. Reducing the cell size can increase the number of repetitive frequency uses and shorten the transmission distance, and consequently can suppress transmission output.

For an economical increase of radio stations, it is necessary to study the topology of an optical transmission line between radio stations, to make power supplies unnecessary, and to make the equipment small.

4.1.8 Optical CATV [Ref.5]

4.1.8.1 Outline

The future spread of satellite and ground digital broadcasting is anticipated to increase the demand for multi-channel digital cable television (CATV). The large-capacity transmission and high-level bi-directional transmission will be necessary for video on demand (VOD) and other services.
Further development of the optical CATV technology is expected in order to realize these services.

4.1.8.2 Current Situations

Subcarrier transmission used for optical-CATV video transmission will remain in use for a long time because a large volume of data can be transmitted at low costs.
The recent main fields of technological research are extending the distance and increasing the capacity.

4.1.8.2.1 Distance Extension

In East Asian countries where not many optical fibres are laid, the long-distance CATV is under active research and development for economical advantages. In other countries, the long-distance transmission between CATV stations is attracting attention to start the satellite or ground digital broadcasting because the burden of digitizing station facilities can be reduced and the facilities can be shared between CATV operators. For long-distance transmission, it may be necessary to guarantee dispersion because great light output from an optical amplifier produces self-phase modulation. However, an experiment has also been reported about long-distance transmission with no compensation of dispersion using low-chirp electro absorption modulated laser (EML).

4.1.8.2.2 Capacity Increase

As a means of increasing the capacity, the WDM technology is now under active study for implementation. WDM is regarded as effective for the multi-channel communication supporting narrowcast information distribution targeted at a specific minority services.

For the efficient configuration of CATV network, researchers are trying to reduce the number of fibres and optical amplifiers by linking hubs on a ring using the optical ADM technology.

4.1.8.3 Outlook

As the demand for narrowcast services grows, more proposals will be made about CATV networks using the wavelength multiplexing technology.
As a preceding communications technology, the IP technology will be applied more actively to CATV. IP is anticipated especially for VOD and other storage video services.

4.1.9 Interconnection of FTTH/FTTC and PLC

4.1.9.1 Outline

Especially for power companies, it is of very high interest to use their existing low-voltage power distribution network for data transmission. The recent advances in communications technologies have made broadband access via the electrical low-voltage power line feasible. This is mainly due to low-cost multi-carrier orthogonal frequency division multiplexing (OFDM) or Spread Spectrum modulation designed on affordable highly-integrated application specific integrated circuits (ASICs) and greater experience in coupling techniques.
Commonly, with power line communication (PLC), there is a head-end equipment installed at the transformer station, which communicates with the customer premise equipment, potentially via intermediate repeaters. The spectrum currently used for the PLC transmission is below 30MHz. International standardization on the frequency bands usable for PLC and the allowed levels of power injection is still in progress and final decisions are not expected earlier than end of the year 2004. Today, the PLC transmission as an access technology allows for speeds of up to 27-Mbit/s downstream and 18-Mbit/s upstream, shared among the customers that are simultaneously transmitting on the same low voltage cables.

The biggest advantages of the PLC technology are the extremely low installation cost and that it is globally available. In general, no new cables have to be installed and virtually any plug can be used to gain broadband data and telephony access. Obviously all this depends on various factors such as the quality of the installation, the radio frequency noise levels, the branch density of the low-voltage cabling topology, the simultaneity of transmission, etc.

The recent studies have shown that FTTH/FTTC-technologies combined with PLC allow for a smooth and cost-effective network roll-out, taking advantage of the existing or any new fibre cabling and the existing PLC low-voltage cabling.

There are various configurations for distribution networks for PLC, including PLC on both low-voltage and medium-voltage cables. The low-voltage head-end equipment can connect to transmission equipment for point-to-point medium-voltage links to form chains of transformer stations performing all data transmission via PLC. This is a very cost-effective solution in scenarios, where the fibre is yet not installed at the medium-voltage (MV)/low-voltage (LV) transformer substation. However, in cases where the fibre is available, or where high-bandwidth services can be offered, an aggregation of the PLC traffic of various low-voltage transformer stations is not reasonable, and the solutions using optical cables are more preferable. For that reason, in the following, we will only focus on interconnecting FTTH/FTTC equipment with the low-voltage PLC.

The combination of the technologies FTTH/FTTC with PLC is very fruitful since customers that are demanding low or medium bandwidth access, and therefore paying less, can be connected via cost effective PLC, whereas customers such as bigger companies, and which are therefore willing to pay more, can be served via fibre and FTTH equipment. For both types of customers, the identical optical distribution network infrastructure can be used.

4.1.9.2 Configuration

In the following examples, we will illustrate the interconnection of FTTH/FTTC equipment with PLC based on PON equipment. Note, however, using point-to-point links with a different technology, such as Gigabit Ethernet, follows almost an identical scheme.

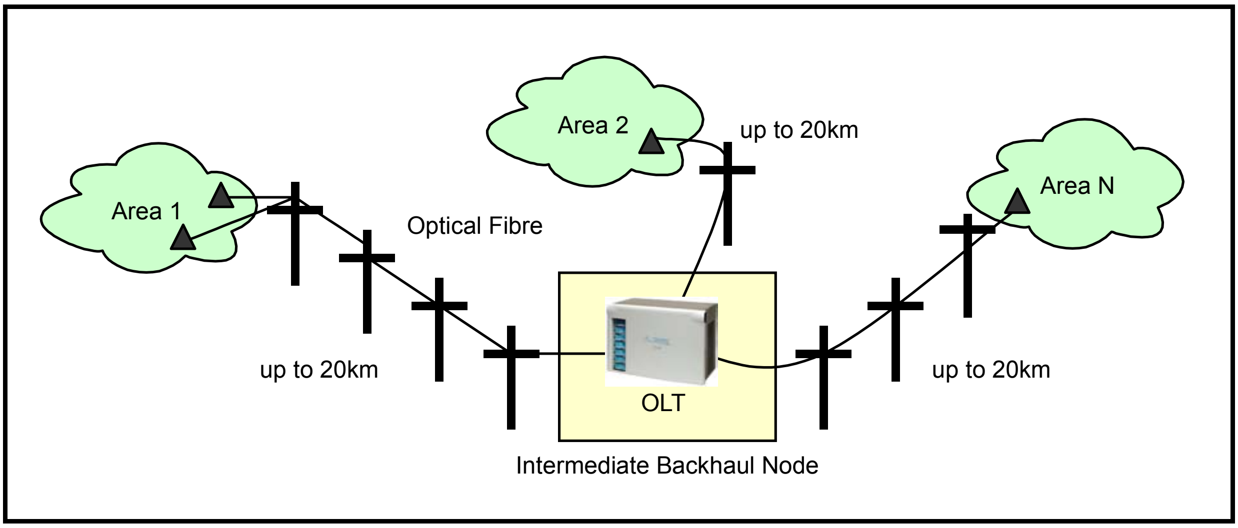


Fig. 4.1.14 Optical distribution network using existing fibre infrastructure following high/medium voltage cabling

Fig. 4.1.14 illustrates the optical distribution network for the typical case that the existing fibre infrastructure, which is following the MV/LV cabling infrastructure can be used. In that case, at an intermediate backhaul node the optical line terminal (OLT) is installed. This node should be located at a point-of-presence (POP) or a backbone node for the service to be offered. From that point, different areas are served, having one or various splitters at defined locations of each area.

In Fig. 4.1.15, an area is depicted in more details: from the splitter of the area, optical fibre links connect to all MV/LV transformer stations. At each MV/LV transformer, an ONU-HE is placed. An ONU-HE is a combination of two equipments: a FTTH/FTTC optical network unit (ONU) and a PLC head-end (HE). Typically, these are two different pieces of equipment, connected via a 1000-Base-TX Ethernet connection. From there, the PLC head-end serves the customers connected to the low-voltage power line grid.

As can be observed, it is very simple in this configuration to add additional business customers that need FTTH access: a direct optical cable is connected from the customer's site to the optical splitter at the intermediate node of the area, and an optical network terminal (ONT) in the PON system is installed at the customer's premise.

As an example for European installations, a typical MV/LV transformer connects to roughly 200 customers that share a branch of the low-voltage grid. Among the simultaneously connected subset of these customers the totally available bandwidth of PLC equipment is shared and aggregated by the ONU-HE for transmission over the optical link to the ONT.

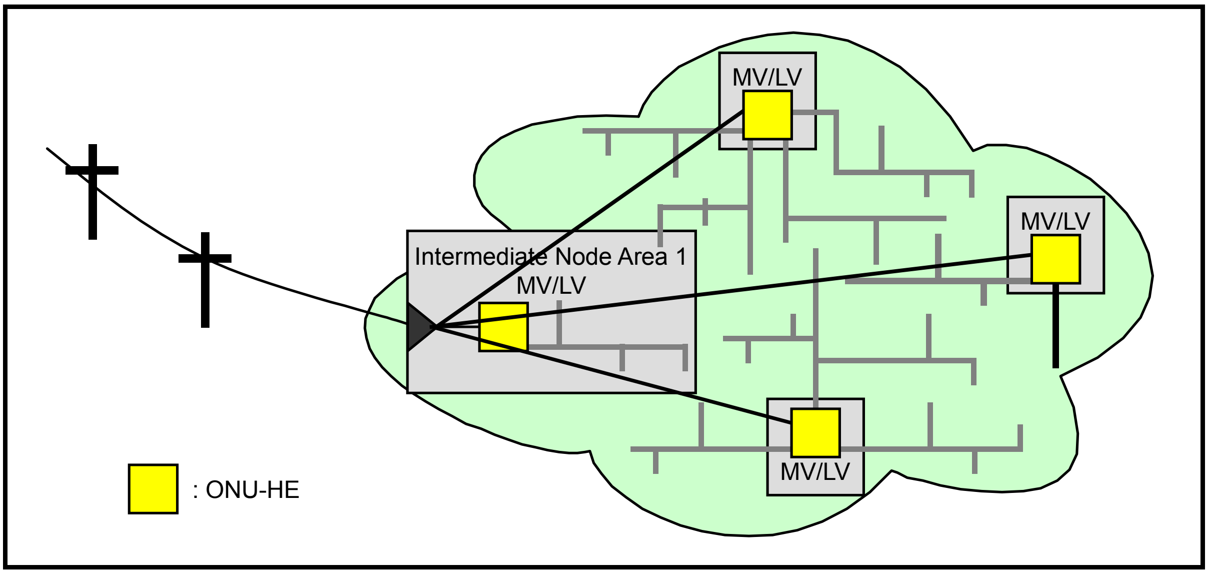


Fig. 4.1.15 Interconnection of the FTTH/FTTC ONU with the PLC head-end equipment at the MV/LV transformers

Note that the above configuration is based on data for European infrastructures and there are many other possible configurations for the interconnection of FTTH/FTTC and PLC, which mainly depend on the local topology of the power grid, the available optical fibers and the bandwidth to be served to each customer.

4.1.9.3 Outlook

The interconnection of FTTH/FTTC with PLC technology is a very promising approach that allows a smooth incorporation of FTTH to customers for high bandwidth access, while, at the same time, offering a cost-effective alternative to customers that demand less bandwidth. As can be observed by the configuration, the integration is quite simple, and even network management can typically be integrated, since both technologies commonly apply simple network management protocol (SNMP)-based configuration and management.

As for the transmission speeds of PLC technology, there are still some advances to be expected in the near future, with some manufacturers offering up to 200 Mbit/s (again, shared among the simultaneously connected customers of the same low-voltage branch).

4.2 Interface

Future information communication networks are expected to consist of only the Internet, and access networks that will be designed and built from the start for an IP-based Internet. Although backbone networks will be designed for the greater speed and capacity available with terabit Photonic Networks, the access networks will have structures different from those of the backbone networks because they will handle a variety of media (IP over Everything), such as optical fibre, wireless, and metallic cable, available to users for a variety of purposes. Also, they will have communication speeds ranging from the 100-kbit/s class to the 100-Mbit/s and Gbit/s class. This section therefore describes some issues that need to be considered for the interface between the backbone network and the access network.

4.2.1 Access Networks and Backbone Networks

Future networks are expected to build with a system configuration based on the Internet, a feature of which will be broadband and pervasive networks based on persistent connections. As shown in Fig. 4.2.1, an appropriate system for a variety of media such as ADSL, cable modem, radio waves, and optical fibre is built as an access network, while the backbone network is based on WDM. However, because the access network is based on the Internet, that is IP, it is thought that the access network will also become a system that is totally independent of data links (IP over Everything) and all interfaces with the backbone network will be based on IP, such as 10/100megabit Ethernet, gigabit Ethernet, and 10gigabit Ethernet.

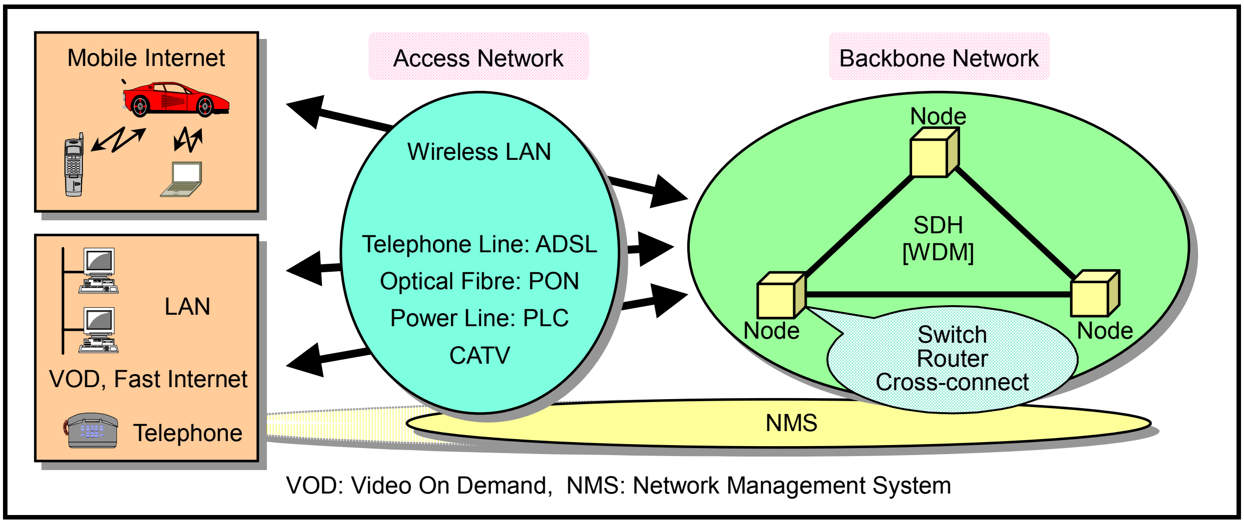


Fig. 4.2.1 Access network and backbone network

4.2.2 IP Network Configuration of Telecommunication Carriers

Fig. 4.2.2 shows a typical IP network configuration of telecommunication carriers. The access networks are integrated into an edge node for connection to a core node configuring the backbone network. Because the edge node functions as a boundary point, the edge node for the access network requires, in addition to basic IP transfer functions, user authentication and billing functions that are specific to the access network, and if the user is mobile in a wide area, the mobility management and wireless application protocol (WAP) processing functions. Also, for security purposes, a firewall needs to be considered.

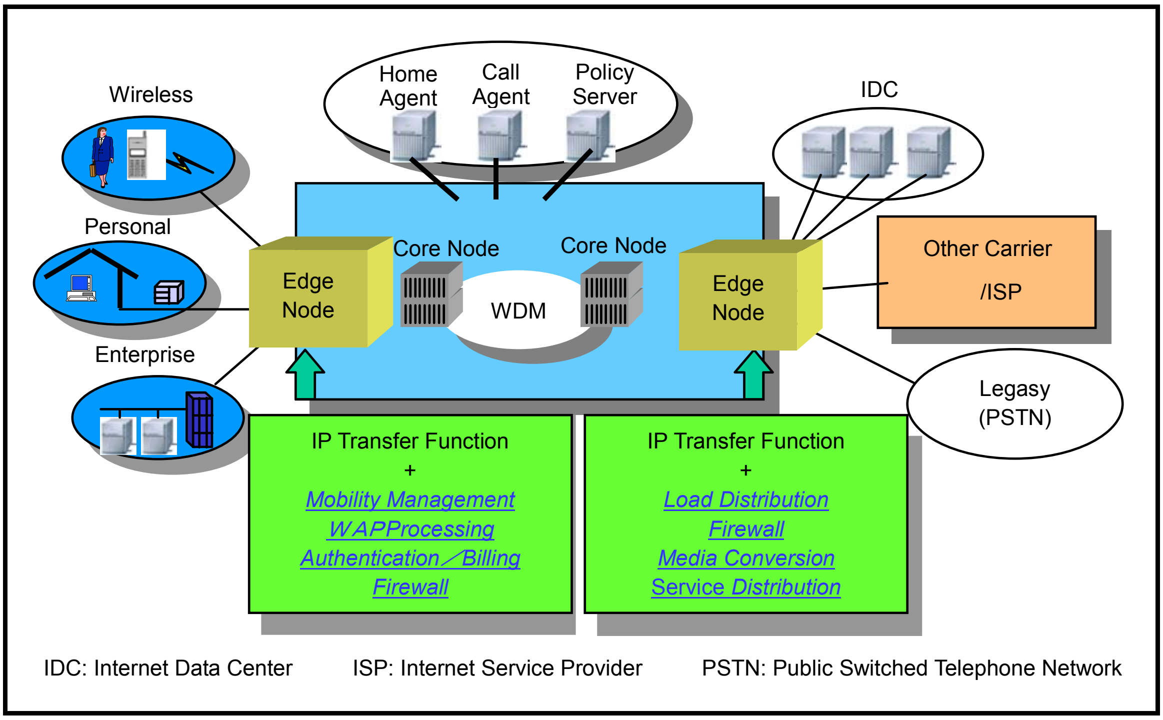


Fig. 4.2.2 A typical IP network configuration of telecommunication carriers

4.2.3 Realizing a Multi-service Network using Future Photonic Networks

Fig. 4.2.3 shows an example of an edge node when the shift from backbone networks to Photonic Networks, enabling total optical information processing, is implemented. The aim of the example is to provide a transmission mode that matches the service, the user is viewed as IP in a uniform way, compatibility with existing service networks, and bridging for different service networks, voice over IP and existing telephones.

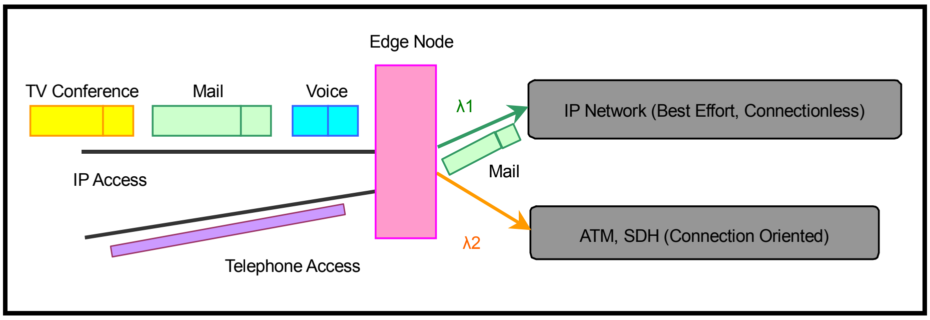


Fig. 4.2.3 Realization of the multi-service network by a future Photonic Network

4.3 Cable Technology

All metallic cables currently in use as feeder cables, distribution cables, and drop cables must be replaced with optical fibre cables to achieve FTTH capabilities. Since feeder cables are located nearby and directly linked to a central office, these feeder cables should be able to accommodate a large volume of optical fibres in a small space to be able to service all subscribers efficiently. Due to limitations in the accommodation capabilities of ducts extending from a central office, cables need to be of the high-density variety. Furthermore, the distribution cables, which link the trunk line cables to nearby access points, must be in excellent working order, because drop cables described in detail below and a good deal of splice work are required to wire the homes of individual subscribers. Wiring all subscribers requires large quantities of drop cable; therefore improvements and/or reductions in overall cost and labor are necessary. In order to achieve this goal, a comparison of each kind of fibre ribbon slot rod type cable is given in the following paragraphs.

4.3.1 Feeder Cable

Cables used as feeder cables have to be high-density cables. Because cables are divided into a number of single and/or dual fibre cables at the distribution point, the time required for splicing should also be taken into consideration. Because 8-fibre ribbons meet both requirements, they are used as feeder cables. Also, 8-fibre ribbons can be divided in two 4-fibre ribbons so as to splice easily with the 4-fibre ribbons used in distribution cables and feeder cables of small count fibres.

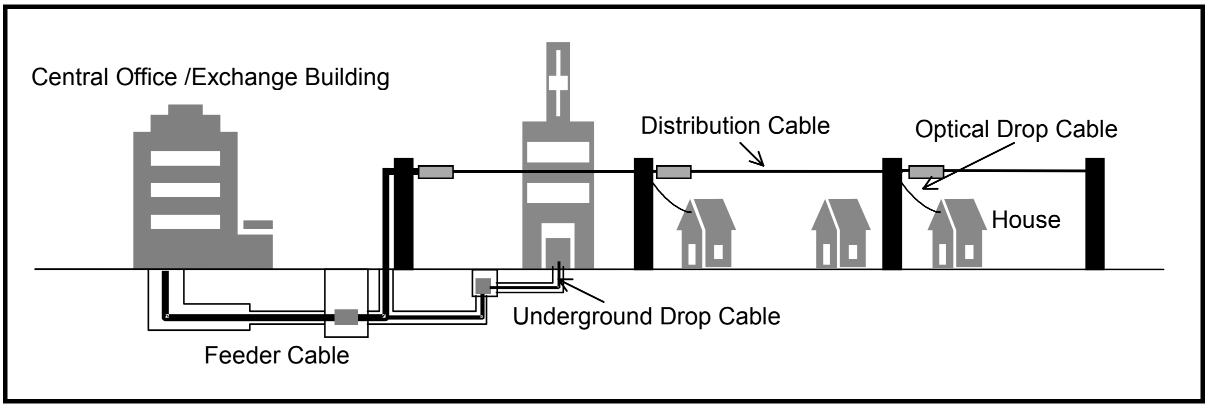


Fig. 4.3.1 Cable configuration for access network

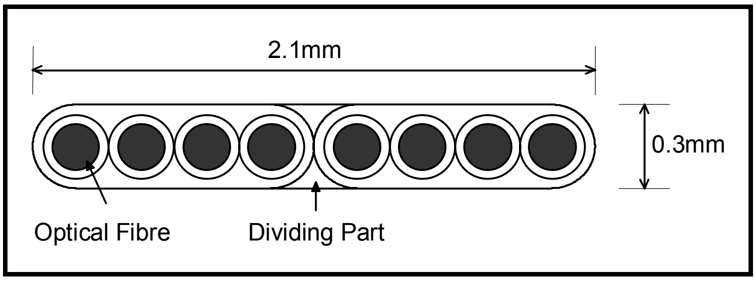
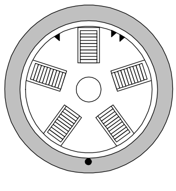
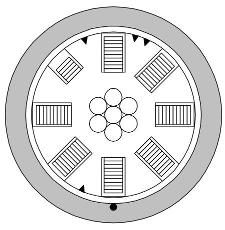
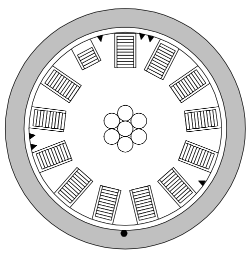


Fig. 4.3.2. Configuration of 8-fibre ribbon

The S type slot rod structure has single direction rotated grooves and this slot rod cable can accommodate a large number of fibre ribbons. There are five to thirteen grooves in a cable and each groove accommodates a stack of ten fibre ribbons, making a super high-density cable with 400 to 1000 fibres possible.

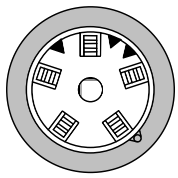
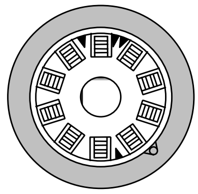
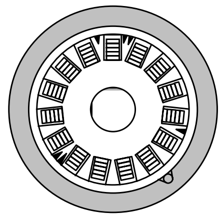
Table 4.3.1 Feeder cable structures

Fibre count	400	600	1000
Cross sectional view			
Diameter (mm)	19	23	28
Mass (kg/km)	340	490	680

4.3.2 Distribution Cable

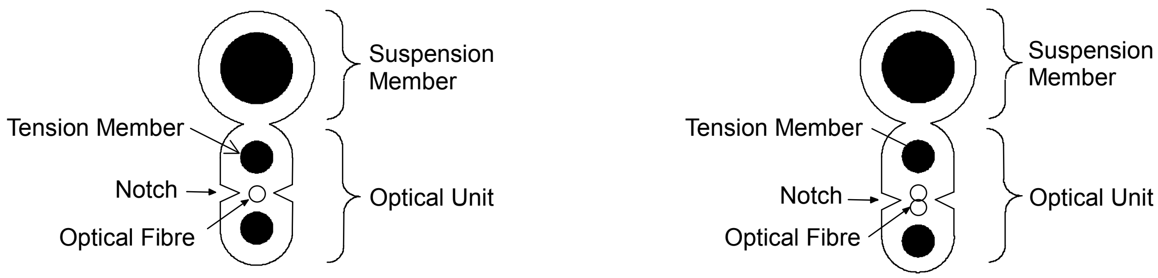
The SZ slot rod type cables are generally used as distribution cables because it is possible to pull a fibre ribbon out of the groove for the mid-span splice and that makes distribution to subscribers possible. The grooves of an SZ slot rod type cable, which accommodates fibre ribbons contra-rotated around the cable and fibre ribbons, can be taken out of the cable by simply removing the outside sheath. For laying a single cable, there is a self-support type that is combined with a suspension wire.

Table 4.3.2 Distribution cable structures

Fibre count	100	200	300
Cross sectional view			
Diameter (mm)	14	17	21
Mass (kg/km)	140	210	350

4.3.3 Optical Drop Cable

The optical drop cables should be small in diameter, easy to lay, and low in cost, for they are used as wiring cables to buildings and houses in large volume. In order to meet these requirements, one or two optical fibres with a 0.25mm diameter are reinforced by two steel tension members on both sides and the optical unit is further combined with a suspension member to achieve a small diameter structure with a low cost. The optical unit has notches on the vertical sides making it easy to access and take out an optical fibre without needing a tool. In some cases, several optical units are combined together in order to access multiple users.



(a) Single fibre structure (2×4.5mm) (b) Duplex fibre structure (2×5mm)

Fig. 4.3.3 Optical drop cable structures

4.3.4 Optical Fibre Composite Polyvinyl-chloride Insulated Drop Cable

Laying optical fibre to homes needs to be performed more economically. Combining optical fibre with the polyvinyl-chloride insulated drop wire (DV) cables used to supply electric power to houses, means that the DV cables can be used as tension members and a reduction in installation cost is possible. Both types, a composite of the power cable and the optical fibre cable, as well as a tube unity type, in which optical fibre can be inserted when a high-speed access is required, are under development.

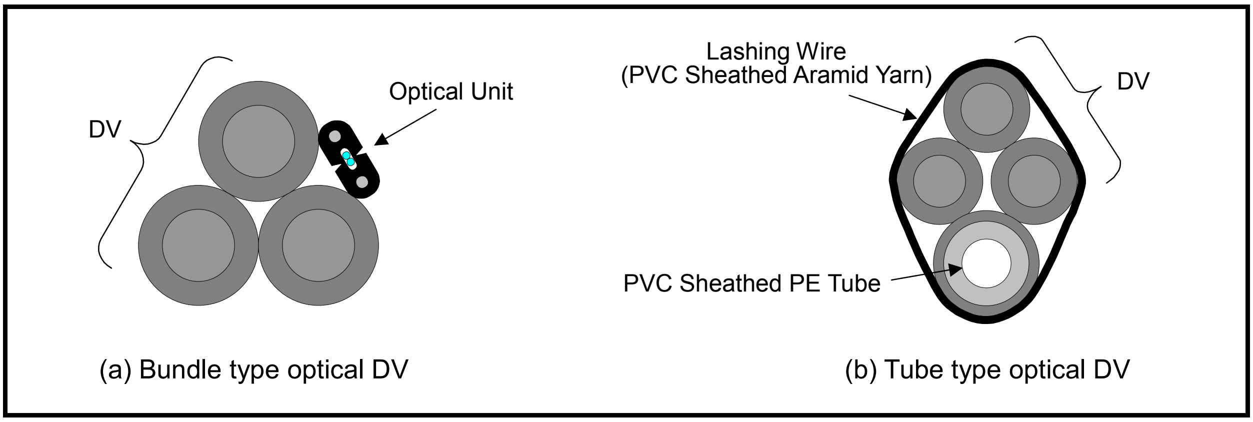


Fig. 4.3.4 Optical fibre composite PVC insulated drop wire cable structures

4.3.5 Underground Drop Cable

An underground duct may be used to lay drop cables to a multistory residence or a housing area. In this case, some fibres can be laid through a tube from a hand hole for distribution to each household. As opposed to aerial cables, since no tension from wind pressure is applied after the cables are installed, the optical fibres need only to withstand tension at the time of installation. Examples of single fibre types and multiple fibre types are explained below. The multiple fibre types are combinations of the single fibre types assembled for easy distribution to each subscriber. Also, using fibre reinforced plastics (FRP) in the construction as the tension members is being studied. It is believed that this may prevent fibres from breaking due to electromagnetic induction from power cables when the optical fibres are laid together in the same duct with power cables.

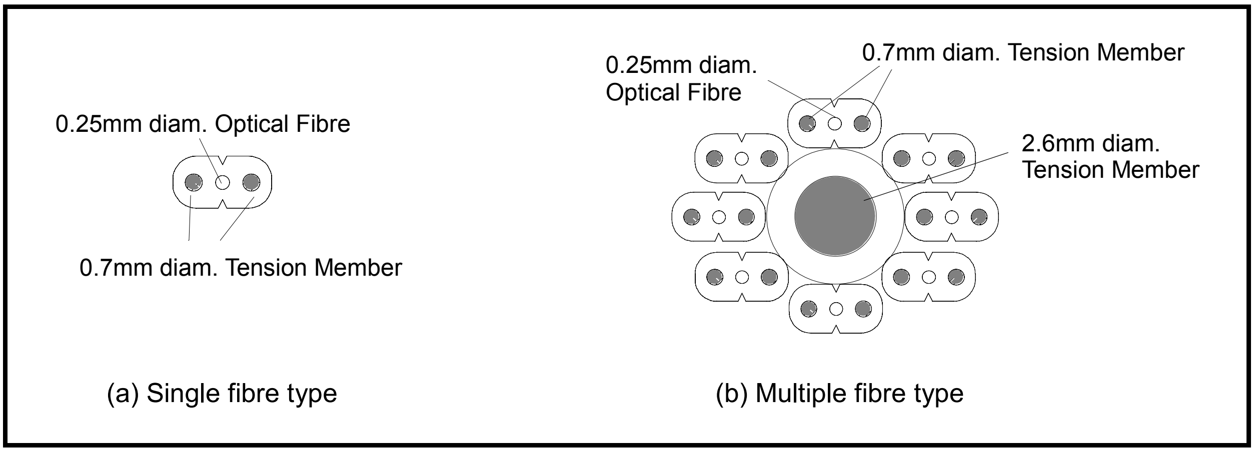


Fig. 4.3.5 Underground drop cable structures

4.4 Construction Technology

4.4.1 Outline

In access communication networks, more efficient mid-span joint techniques are being called for to meet an expected expansion of access communication networks in which a large amount of mid-span joint construction work will occur. Mid-span joint methods are considered: construction in which an extra length of cable is used that is set aside in advance, construction in which the backbone line is cut and insertion occurs, mid-span jointing by a new type closure and mid-span jointing by the SZ cable.

4.4.2 Mid-span Joint Construction

4.4.2.1 Mid-span Joint by a new Type Closure

It is possible to branch and connect by identifying the types of optical fibre ribbon contained in the one-directionally twisted optical cable slots and only taking out the fibre ribbon. Non-disruption has been confirmed in a variety of construction work.

The fibre ribbon is taken out by pulling together between the gripping brackets inside the backbone cable closure and bending the cable slot. In order to allow that the fibre ribbon can branch in both directions of the cable, it is cut at the center of the backbone line and the fibres are made to be short. In order to perform this kind of construction, a new type of closure is required in the inner part that has a mechanism for pulling the cable together.

4.4.2.2 Mid-span Jointing by SZ Cable

Access networks, unlike backbone networks, are frequently branched and drop cables are provided to connect the user, so that there is a need to be able to branch flexibly at any location. In the one-directionally twisted cables, the length of fibre required for connection was difficult to achieve. SZ cables have simplified branching and connecting work, since the direction of the groove that houses the ribbon is reversed at regular intervals. This causes the fibre ribbon to have some slack, and the fibre ribbon is easily taken out without cutting the

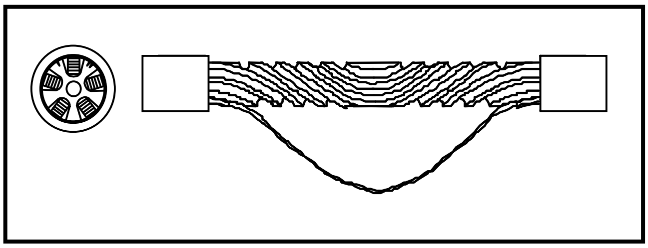


Fig. 4.4.1 Structure of SZ slot cable

Fig. 4.4.2 Aerial mid-span joint closure

slot. The mid-span joint closure is combined with SZ cables, so that closures may be set at any desired location without cutting a slot, and the necessary number of drop cables can be branched.

As aerial mid-span jointing work increases, the commercialization of small-scale and lightweight simplified fusion splicers has progressed in order to simplify fibre connection work at user homes or on poles.

Fig. 4.4.3 Mass small-scale fusion splicer

4.4.2.3 Cable-dropping Method from Underground

In city areas there are many regions with underground power cables, with the result that many drop cables do not come from aerial but from underground cables. For this reason, branching closures need to be waterproof and suitable for underground use. These drop cables need to have a higher tensile strength than aerial drop cables because they are routed to the user from underground pipelines.

4.4.3 Subscriber User Drop Cable

When dropping an optical fibre from an aerial closure to user homes, it is usual to use an optical drop cable from a neighboring distribution pole to an outside junction box under the eaves of the home, where the outdoor optical cable is connected to an indoor optical cable. By installing the junction box outdoors, the division of responsibilities between the enterprise and the individual subscriber is made clear; but with a view to reducing materials, it has also become common to drop a cable indoors directly to the transmission equipment using non-metallic optical drop cables.

The existing optical drop cables use steel wire with high tensile strength to protect the optical fibre. This means, however, that thunderbolts from outdoors can travel through the conductive steel wire directly to various indoor appliances and cause power surges. For this reason, two high-tensile-strength non-metallic optical drop cables that use non-conductive FRP have been positioned on either side of the optical fibre. These non-metallic drop cables are being produced commercially. Thus it has become possible to route optical drop cables into homes directly, reducing connection fees and junction box fees. Note that while the supporting part of the cable does use steel wire, this is cut before the cable is routed indoors, hence there is no need to use non-conducting material.

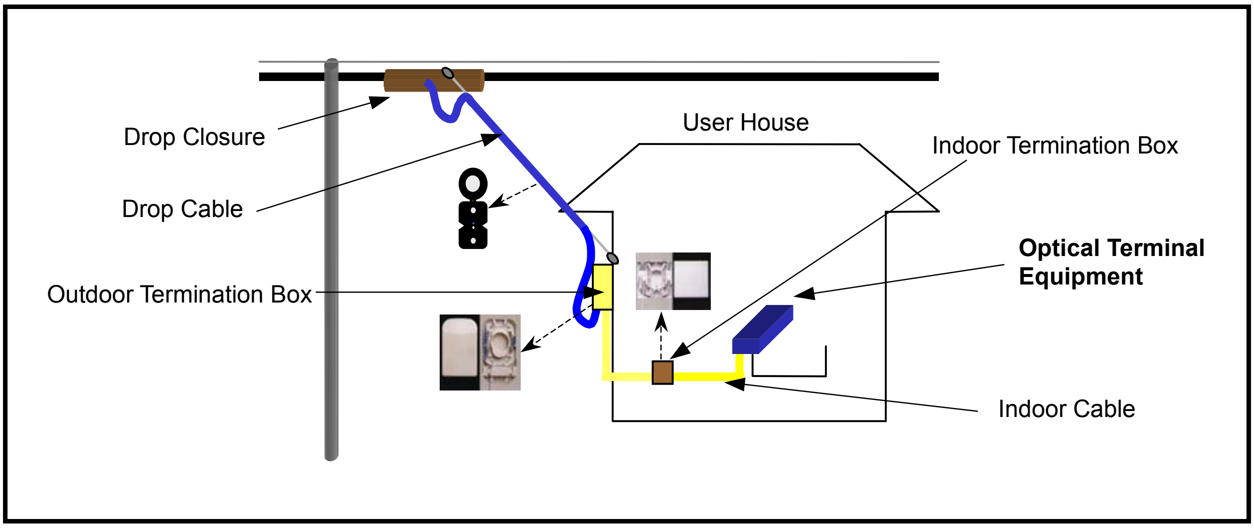


Fig. 4.4.4 Example of drop cable wire

4.4.4 Cable Identification Technology

The present system for identifying optical cables to replace or remove is to check the facility's blueprint or to look at the label that is attached to the cable itself. Nevertheless, for in-between cables in underground manholes or cable tunnels, the fact that many cables are laid together in the same place means that when using this kind of identification, there is a higher probability of mistakenly cutting the wrong cable. For that reason, there is now a lot of discussion going on about how to easily identify the optical fibre cable when there are many together in the same place. We mention several ways to identify cables.

4.4.4.1 Optical Cable Identification using Raman Spectra

An optical fibre is used for transmission of information, but may also be used as a sensor. The types of scattered light that are used as sensors are divided into three types:

- Laser light
- Brillouin light
- Raman spectra

Raman spectra in particular are known to be highly reliant on temperature, and this principle is used. The cable identification equipment, in order to extract the location of temperature change, measures the scattered light before heating and compares this to the state after heating. It uses this temperature change to identify the cable.

4.4.4.2 Optical Cable Identification using Light Coherence

This method of identification uses light coherence. A path is formed via a coupler between the light source and the receiver. Each light that is branched in the coupler is transmitted in the opposite direction within the loop until it is recombined once again at the coupler into a mutually coherent state and is detected at the receiver. The phases produced at the coupler normally cancel each other out, but by applying oscillation, the photo-elastic effect causes the refractive index to fluctuate. The fluctuations at the detecting level occur as a result of this strain, and the oscillation can be detected.

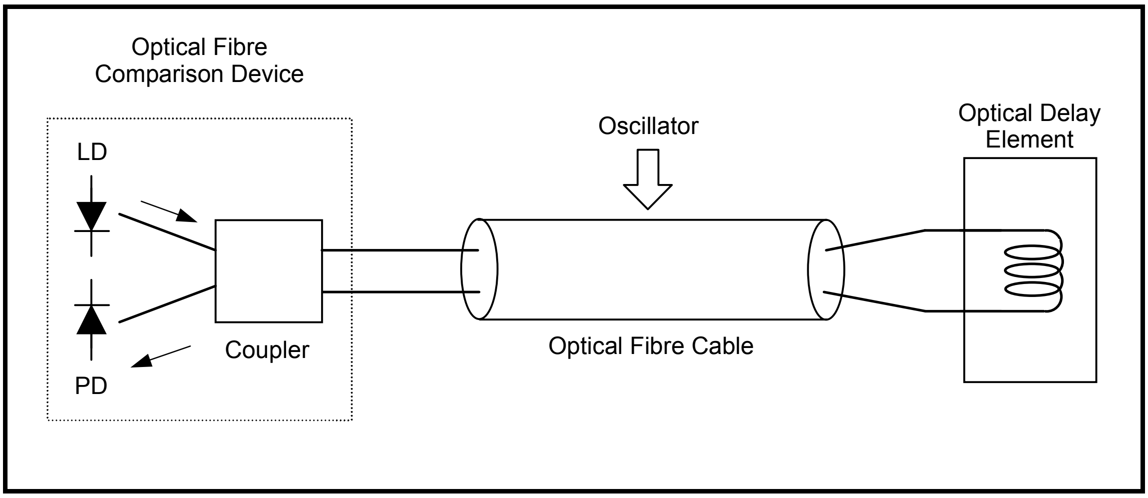


Fig. 4.4.5 Principle of cable comparison system using light coherence effect

4.4.4.3 Polarization Fluctuation

This method identifies cables using polarization modulation technology to externally modulate the optical polarized wave surface using ultrasonic waves. While light passes through the inside of the optical fibre axially, stress of ultrasonic frequency ω is applied from the y axial direction by piezoelectric elements. This stress causes the density in the y axial direction to be greater, and the density in the x axial direction lower, so that a difference in the refractive index occurs. This means that a phase difference occurs that is transmitted into the fibre. It passes through the analyser, which is on the receiver side, is converted into an intensity-modulated signal, and received.

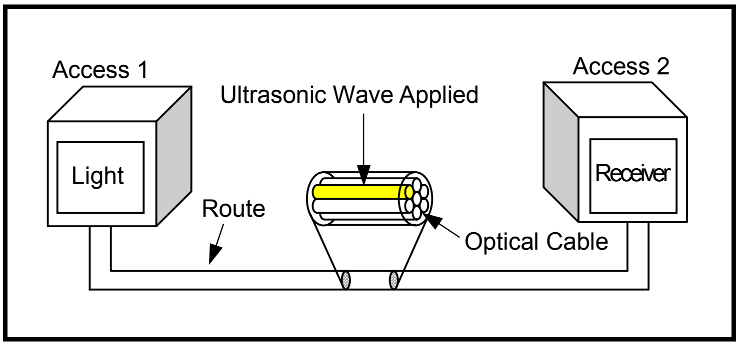


Fig. 4.4.6 Principle of system cable comparison using polarization fluctuations

4.5 Maintenance Technique

In general, a fault point in an optical network is located by the optical time domain reflectometer (OTDR). But then, OTDR or a similar technique would be unworkable for searching out one in a PDS network, unless modified with adequate consideration. Consequently, this section describes bottlenecks of the OTDR technique in searching a fault in a PDS network, and then explains a few methods of fault locating in this type of network.

Meanwhile, the intermediate distribution frame (IDF) for connector-coupled terminals may be furnished in the station to facilitate possible rewiring work. In particular, if access systems were involved in there, the fibres, usually massed in bulk, would be wired by mistake. Worst of all, some active fibres might be broken; and to prevent those undesirables, the fibres in each IDF need to be made identifiable with accuracy. Accordingly, an optical-fibre identifier, workable in spite of the fibre under test being active or not, is described later on.

4.5.1 Bottlenecks of OTDR over PDS Networks

The OTDR acts by launching test signals into a fibre and by receiving the return light, most of which is comprised of backscattered light by Rayleigh scattering. [Ref.6] The return light arrives earlier if reflected earlier, or later if reflected later. OTDR reads a time lapse between the launch and receipt of test signals, based on which, each equivalent distance up to the backscattering spot can be determined. Moreover, the backscattered light power, P_A and P_B, represent the return signals from locations, A and B, in a fibre, respectively. The difference between P_A and P_B refers to the loss incurred in a round trip between locations, A and B, thereby enabling the fibre loss to be specified.

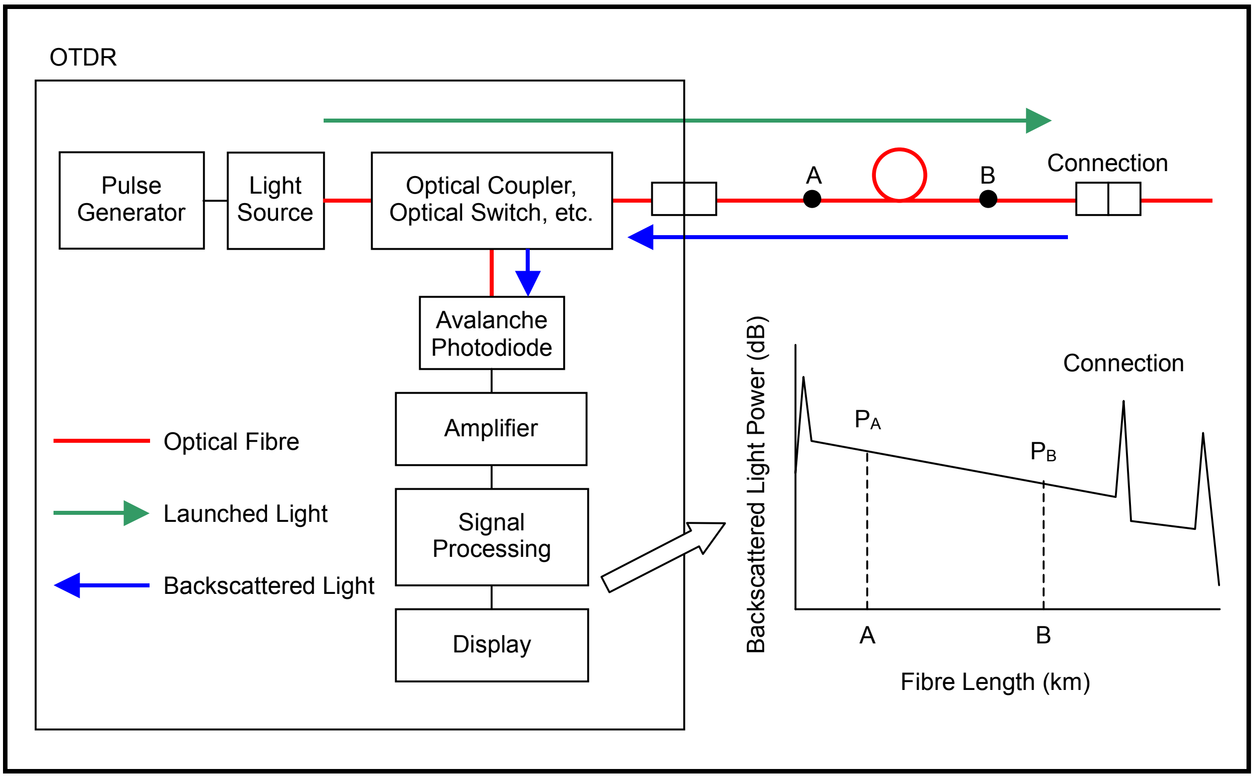


Fig. 4.5.1 Principle of OTDR

In searching into a PDS network by OTDR, there is a problem: the launched test signals are branched into the discrete fibres by an optical coupler, through which, the pulse signals of backscattered light return and arrive as unidentifiably overlapped.

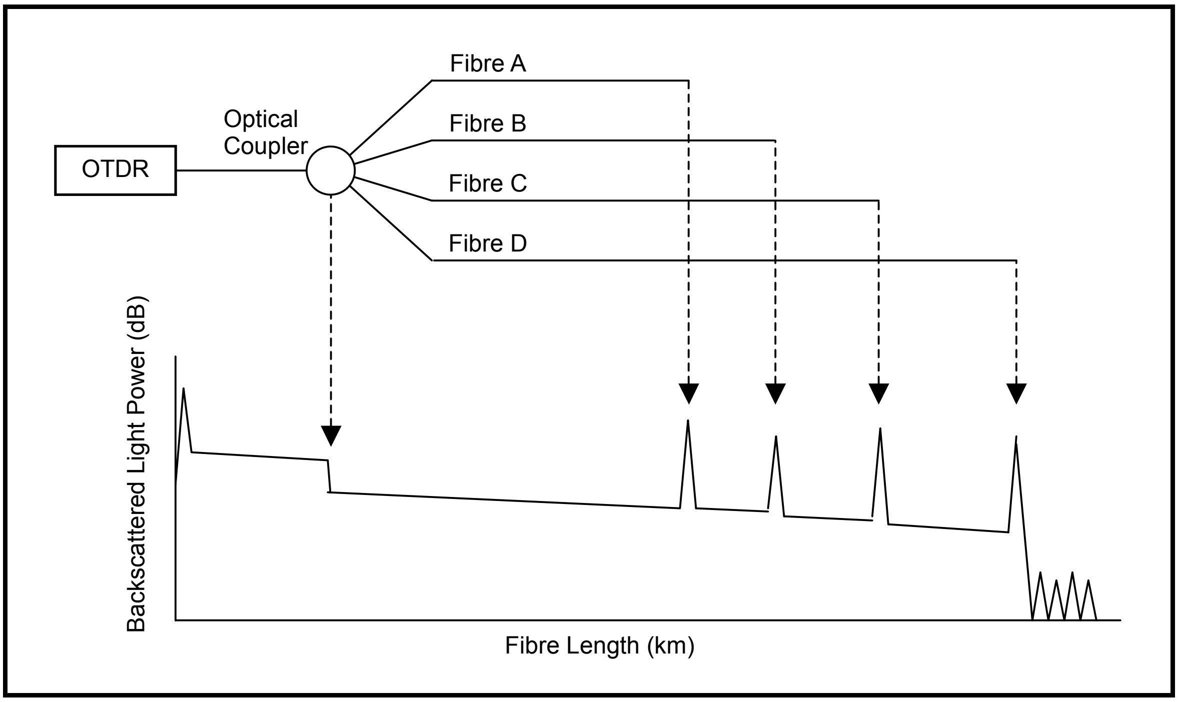


Fig. 4.5.2 OTDR waveform on a PDS network

Clearing up the forgoing bottlenecks, technical publications and presentations have cast light on the following four approaches in a broad sense, with a plan to locate a fault point in a PDS network:

- Fibre length control method
- Reference reflector method
- Wavelength routing method
- Waveform operation method with a test signal pass filter

4.5.2 Fibre Length Control Method [Ref.7]

Stepwise-varied distances are set between the star coupler and the discrete filters. The initial data and reflected data on scattering points, scattering amounts, with reference to filters, are compared in order to pinpoint the failed branch line.

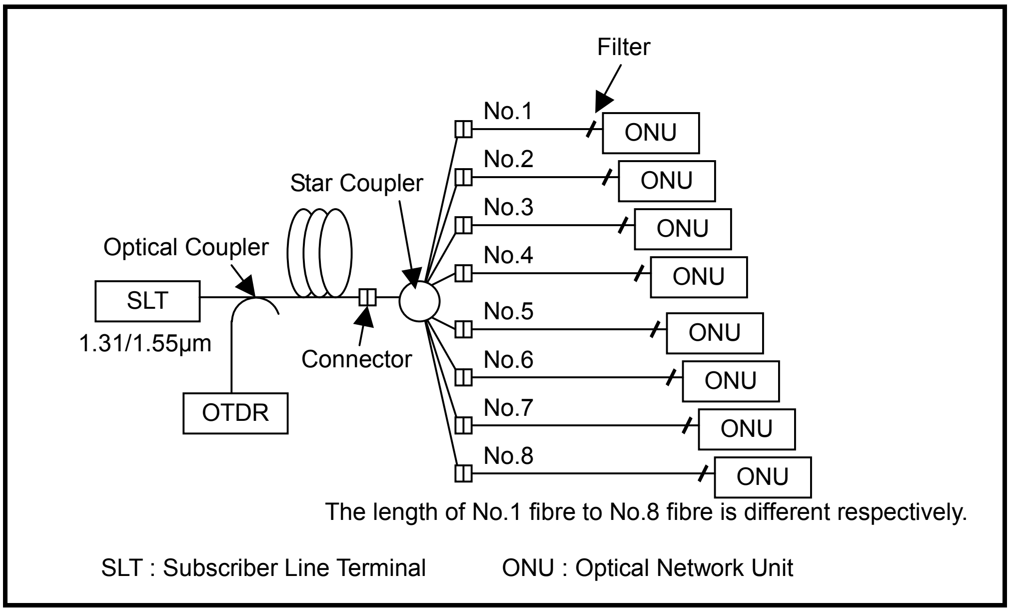


Fig. 4.5.3 Principle of fibre length control method

This scheme is subject to some limitations of circuitry design due to its requirement for stepwise-varied branch lengths. Still, the intensity of reflection from the facet of each end is measured for failure analysis and therefore can hardly locate fault points.

4.5.3 Reference Reflector Method [Ref.8]

The opposite end of each branched line is attached with a reflector unit, made up of a branching filter, a band-pass filter and a reflection mirror, which reflects no other than the test signals at a specific wavelength in a test band. From the station, the test signals are launched into each branched line, at its preset wavelength for the reflector unit. The returned, reflective intensity is examined against the starting data: comparison of the initial intensity and then found intensity to specify a fault point, if any.

OTDR needs to be operable at a number of wavelengths, where fault points can hardly be located.

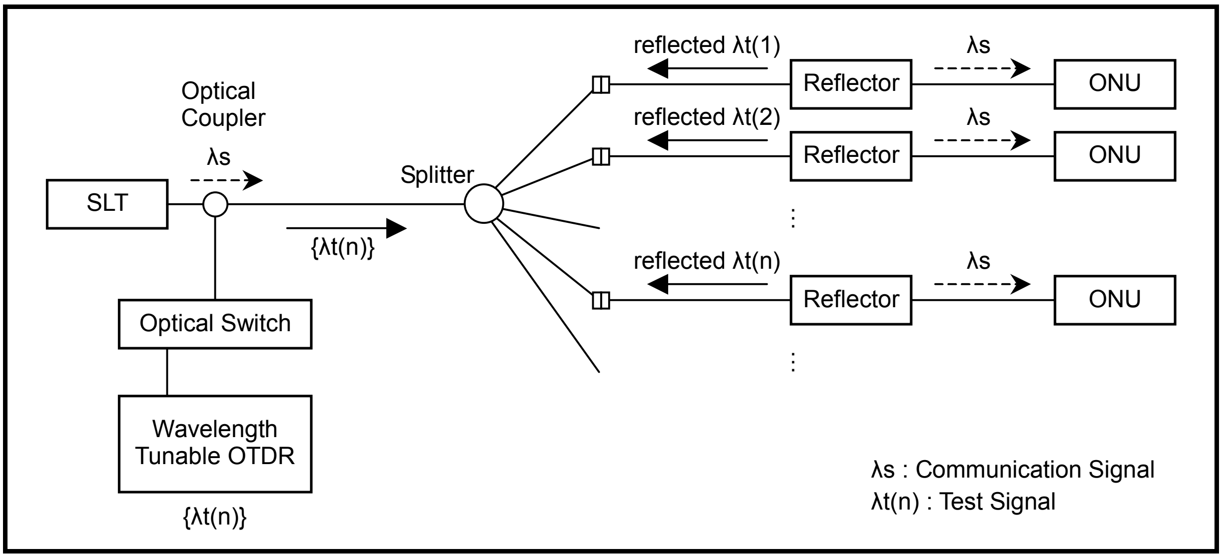


Fig. 4.5.4 Principle of reference reflector method

4.5.4 Wavelength Routing Method [Ref.9]

Monitoring is performed with a branched line capable of wavelength routing.

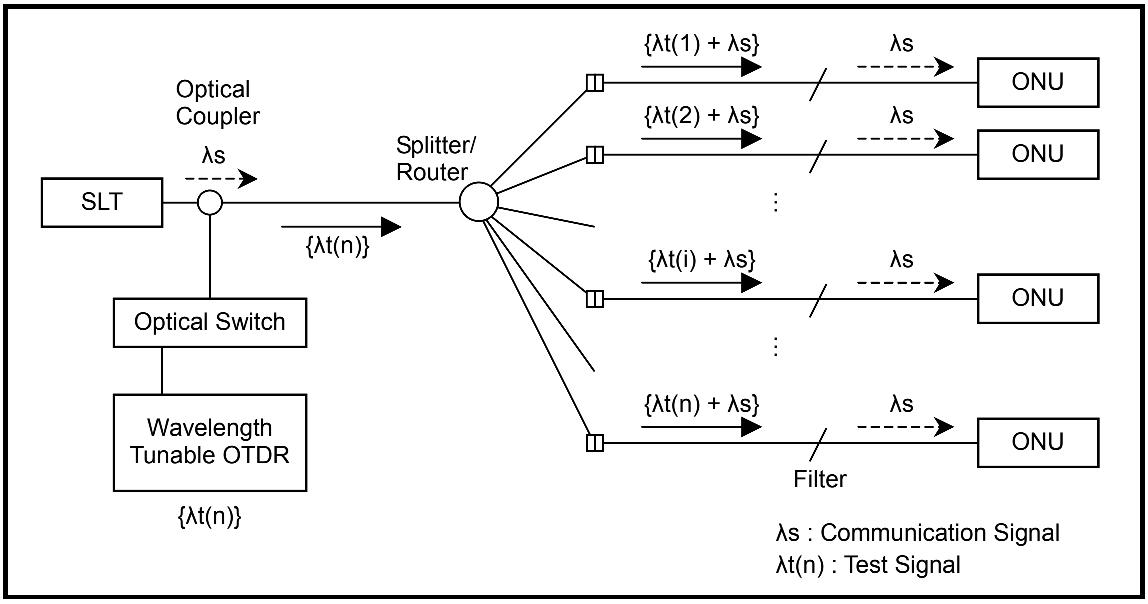


Fig. 4.5.5 Principle of wavelength routing method

Communication signals (λs) launched from the subscriber line terminal (SLT) are distributed into the discrete branched lines via the splitter. OTDR shoots test signals at a wavelength of λt (n): n=1 to 16, which will be directed to the discrete branched lines by the router.

All the test signals directed to the branched lines are at their preset wavelengths and are easy to identify. Therefore, this method is capable of locating fault points.

For reference, a unit of splitter/router is under development.

4.5.5 Waveform Operation Method with a Test-signal Pass Filter[Ref.10]

Coupling a filter to selectively pass test signals to a branch line, using a wavelength-tunable OTDR, some waveform data are taken and numerically processed. Thus, as a result, the waveform signature of discrete branch lines is obtained, and branch line is monitored using that waveform signature.

See a brief testing system configuration in Fig. 4.5.6.

Workings of the filters to pass test signals (F1, F2, ..., Fn-1) attached to the discrete branch lines:

F1: blocking out test signals of $\lambda t(2)$, $\lambda t(3)$, ..., $\lambda t(n)$,
passing transmission signals of λs, test signals of $\lambda t(1)$

F2: blocking out test signals of $\lambda t(3)$, ..., $\lambda t(nm)$,
passing transmission signals of λs, $\lambda t(1)$, $\lambda t(2)$

F3: blocking out test signals of $\lambda t(n)$
passing transmission signals of λs, test signals of $\lambda t(1)$, $\lambda t(2)$, ..., $\lambda t(n-1)$

The OTDR launches test signals of $\lambda t(1)$ to $\lambda t(n)$ in wavelength, where each waveform data is obtained. The waveform data at $\lambda t(1)$ called waveform 1 results from the receipt of all backscattered light from the branch lines 1 to n. And the waveform data at $\lambda t(2)$ called waveform 2 results from the receipt of all backscattered light from the branch lines 2 to n. Therefore, the true waveform for branch line 1 is obtained by subtracting waveform 1 from waveform 2. The same procedure is repeated for the other branch lines; thus, all the waveforms can be determined. This waveform operation can worsen the S/N ratio of a waveform to be drawn. But, a possible failure can be located, by comparing each measured waveform and the starting data.

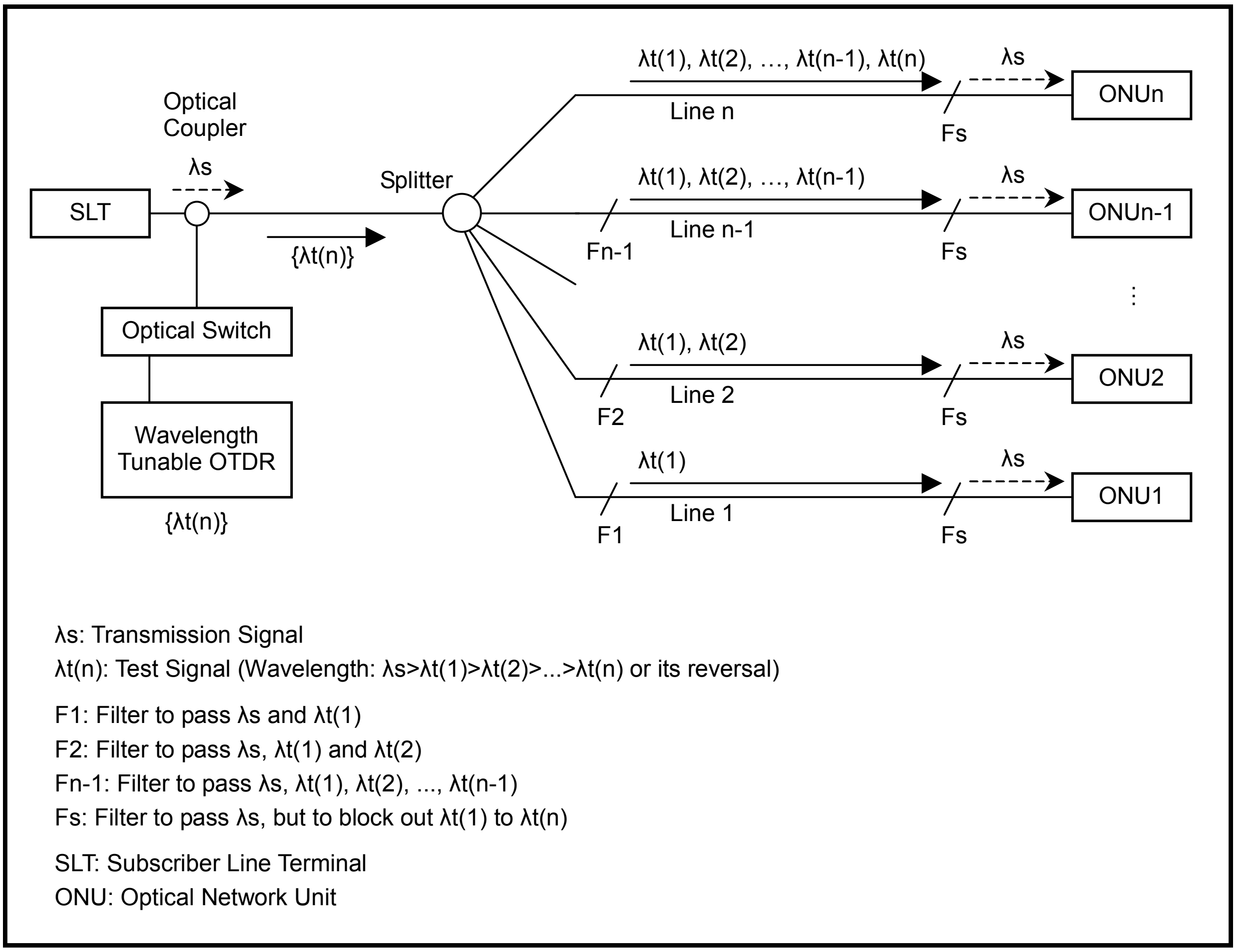


Fig. 4.5.6 Principle of waveform operation method with a test-signal pass filter

4.5.6 IDF Optical Fibre Identification Technique

The prevailing method of active-fibre identification around IDF is Local Detection, which is in principle described and then characterized as follows:

The mechanism of Local Detection is to catch the extracted light from a fibre, by bending the fibre. A fibre cable with communication signals or traffic can be tapped to get extracts of light. However, test signals as modulated at a specific frequency may be launched into a dark fibre to minimize the interference with active fibres.

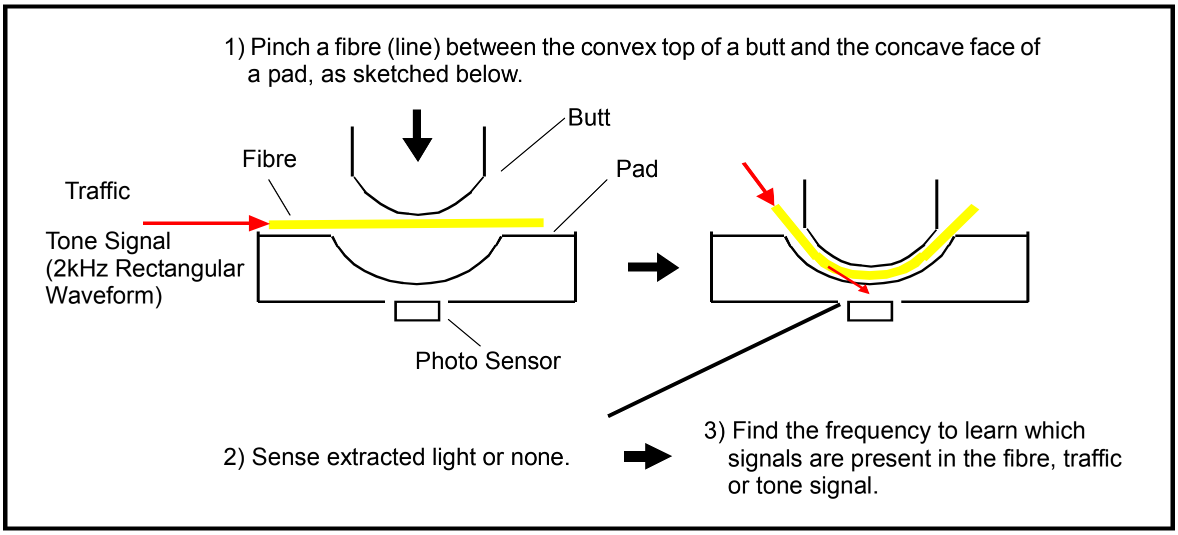


Fig. 4.5.7 Principle of Local Detection

4.5.7 Features of IDF Optical Fibre Identifier

IDF optical fibre identifiers are classified into either a type of cord or a type of fibre application [Ref.11], because of each designed readiness to sense the extracted light.

4.5.7.1 Optical Fibre Identifier

The optical fibre identifier is of a handy type to identify fibre ribbons and nylon coated fibres as characterized below:

- Identifying SM fibre tapes (2 fibres, 4 fibres), ϕ0.25SM fibre (single fibre)
- Identifying 0.9SM nylon fibres
- Receiving 1.55-μm tone signals at 270Hz, 1kHz or 2kHz
- Identifying signal-travelling directions

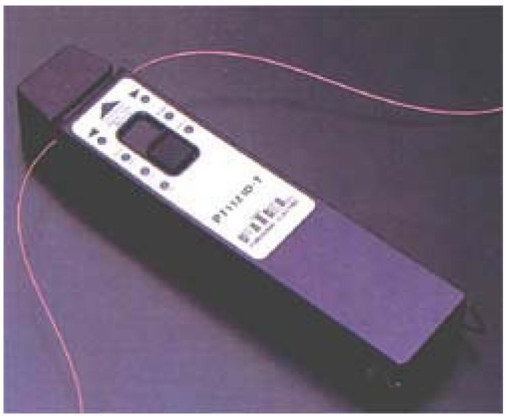


Fig. 6.5.8 Optical fibre identifier

4.5.7.2 Fibre Cord Identifier

A fibre cord, with inner aramid fibre and outer sheathing around the fibre, is harder to identify the extracted light from its pinched segment by Local Detection.

Therefore, a more suitable pinching curve between the butt and pad should be designed and a shield to repel ambient light should also be taken into consideration.

The cord identifier is characterized as below:
- Identifying SM fibres in jumper cords
- Receiving 1.30 and 1.55μm of wavelength
- Identifying if a fibre cord is active or not, based on the traffic
- Identifying a fibre cord by receipt of tone signals (270Hz, 2kHz)

Fig. 6.5.9 Fibre cord identifier

4.6 IP Network Transmission Equipment Resistant to Adverse Environmental Condition

4.6.1 Outline

When optical access networks are laid, it is estimated that high-speed IP networks will be necessary. In order to provide subscribers with an efficient high-speed IP network, transmission equipment such as switching hubs (SW-HUBs) and optical transmission equipment, etc. is necessary to be installed on poles or inside power stations. The measures that cater to the adverse installation environment are necessary.

4.6.2 Waterproof & Dustproof

In case the equipment with a built-in circuit board is installed on poles, it is especially necessary to ensure that the contents of the case are sufficiently airtight to prevent wind and rain from getting in. Similarly, it is necessary to prevent dust and insects from getting in. Therefore, the measures to seal the case lid and the hole where the end of the cable is introduced are necessary.

4.6.3 Surrounding Temperature Scope

As the transmission equipment is designed for ordinary office use, almost all stipulate a surrounding temperature of 0°C ~ 40°C. In order to make the equipment suitable for outdoor use, it is either necessary to introduce measures to control the temperature of the case, or to use material that can cope with such a temperature environment.

4.6.4 Surrounding Humidity Scope

Measures are necessary to maintain a low humidity state inside the case to prevent dew from getting in.

4.6.5 Other Conditions

It is necessary to use suitably vibration-proof, corrosion-resistant, and noise-proof material and design. In addition, installation and maintenance work such as optical cable connection, etc. must be able to be easily performed. In case of installing the equipment on poles, it is necessary to reduce the mass of the equipment as much as possible so that it does not hinder the use of bucket elevators, or pose difficulties for construction work on the pole.

4.7 Consideration on Security

4.7.1 Physical Security on Optical Fibre Cable

4.7.1.1 How to install Fibres

When the fibres of telecommunications meant for stable electric power supply and the ones for telecommunications business are installed in the same slotted core ribbon cable, it has to be avoided that the operation of the one kind of fibre should not affect that of the other. For this reason, the purpose of the use has to be assigned to each slot in a slotted core ribbon cable. Since fibre ribbons in the same slot of cable are stored in a splice tray, the purpose of the use has to be assigned to each tray in a closure.

Although different kinds of fibres can be installed in a slotted core ribbon cable, only one kind of fibre is installed in one slot. Each customer is assigned to fibres in a slot.

4.7.1.2 Delimiting Point of the Cable

The delimiting point between the optical cable of the telecommunication carrier run by the electric power company and customer’s one shouldn’t be put on premises of the electric power company basically to avoid customers of the telecommunication carrier entering to it.
If the delimiting point has to be put on poles of the electric power company for some reason, a splice box or a closure has to be installed on a public road.

If the delimiting point has to be put on customer’s premises for some reason, a splice box or a closure has to be installed on customer’s premises or a public road. The electric power company conducts splicing at the delimiting point.

4.7.1.3 Where to install a Repeater

If a repeater for a customer of the telecommunication carrier run by the electric power company has to be installed on premises of the electric power company, the customer have to own the repeater and put it in the clearly divided section from the section for a repeater put by the electric power company.

Considering the case that several customers install the repeaters in a single section, a rack that has a door with a lock has to be installed for each customer.

4.7.2 Security at Subscribers' Terminal Units

In any information system connected to subscribers' terminal units, arrangements are needed for certification of terminals to ensure that the subscribers will not connect any terminal unit other than those specified.

On subscribers' terminal units, it is important for them to avoid installing a standard LAN interface or to provide a physical guard for such interface, if installed, in order to preclude the connection of any equipment other than those specified for the system. Another important consideration is to refuse the connection of any unspecified equipment whenever it is detected.

4.7.3 Security at Subscriber-serving Station

At the subscriber-serving circuit in the local station, the information to the backbone network should be controlled completely so that the upload information from any of subscribers' terminal units will be forwarded to the specified address.

An important consideration in this process is to provide the capability to detect any information other than the one prescribed for the system and to refuse its transmission. Therefore, only the information prescribed for the system is to be transmitted into the specified route.

5. Application for Electric Power Utilities

Electric power companies have their own widely spread optical networks for operation and maintenance of electric power systems. Nowadays, optical links for the access network along the distribution lines are increasing. Another example of optical networks for the electric power company in Japan is shown in Fig. 5.1. This example has a three-hierarchal structure and others have two or four hierarchies. The data transmission speed for the trunk network is mainly 600Mbit/s and the introduction of 2.4-Gbit/s equipment has been started. Automatic meter reading for the large consumer is carried out using the access network having the SS architecture centered at the sales office or the substation. The bit rate for it is the class of kilobits per second.

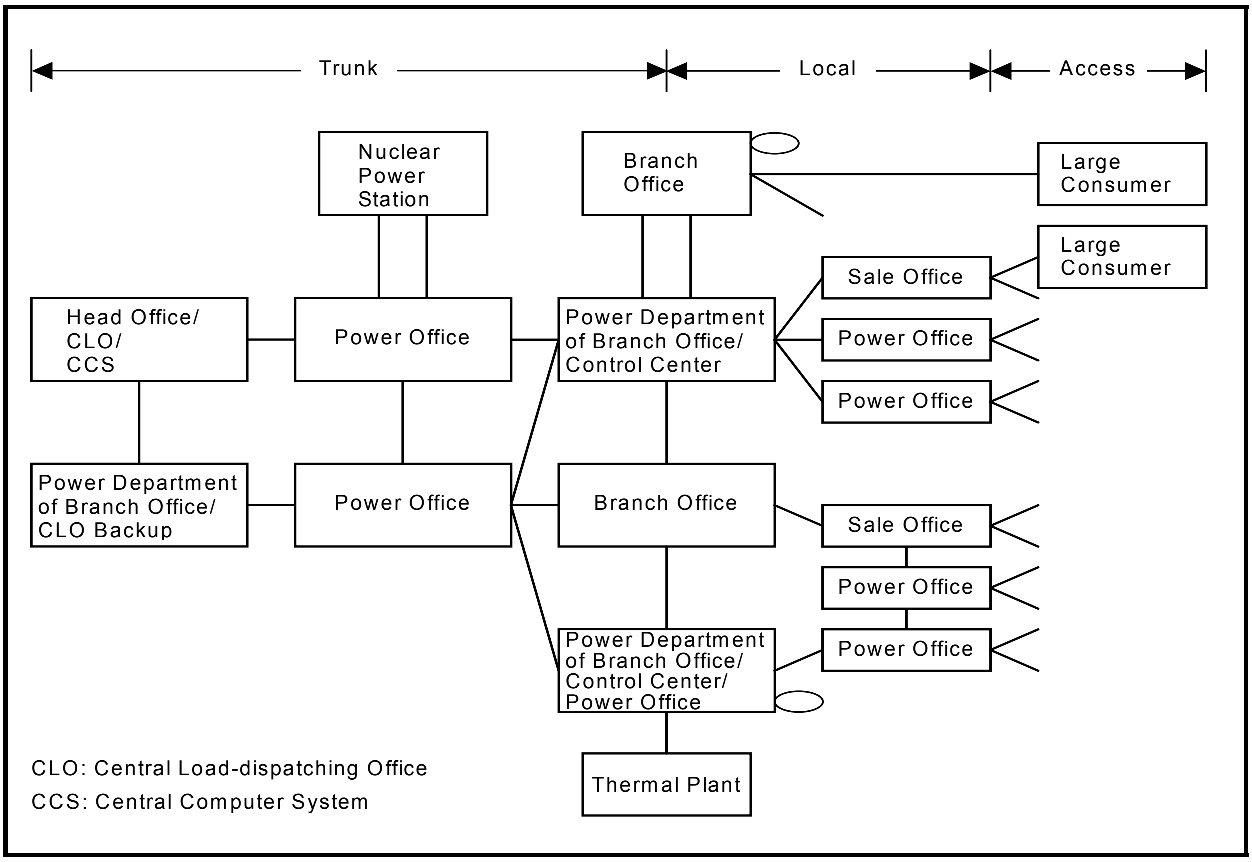


Fig. 5.1 Example of communication networks at present for an electric power company

In the near future, electric power companies will be urged to expand their services because of increase of competition among energy industries. Buying and selling of retail electric power will become free in accordance with deregulation. To cope with this trend, employment of automatic operation and control of electric power distribution to a big user has started, with the following objectives:

- Quick recovery from an electrical accident by the remote control of the switch set on a distribution pole
- Efficient operation of the electric power system by supervision and control

- Efficient control of load equalization
- Efficient business regarding meter reading and notice of power failure

An example of such a network is shown in Fig. 5.2, where the bit rate for the customers is a class of 100Mbit/s.

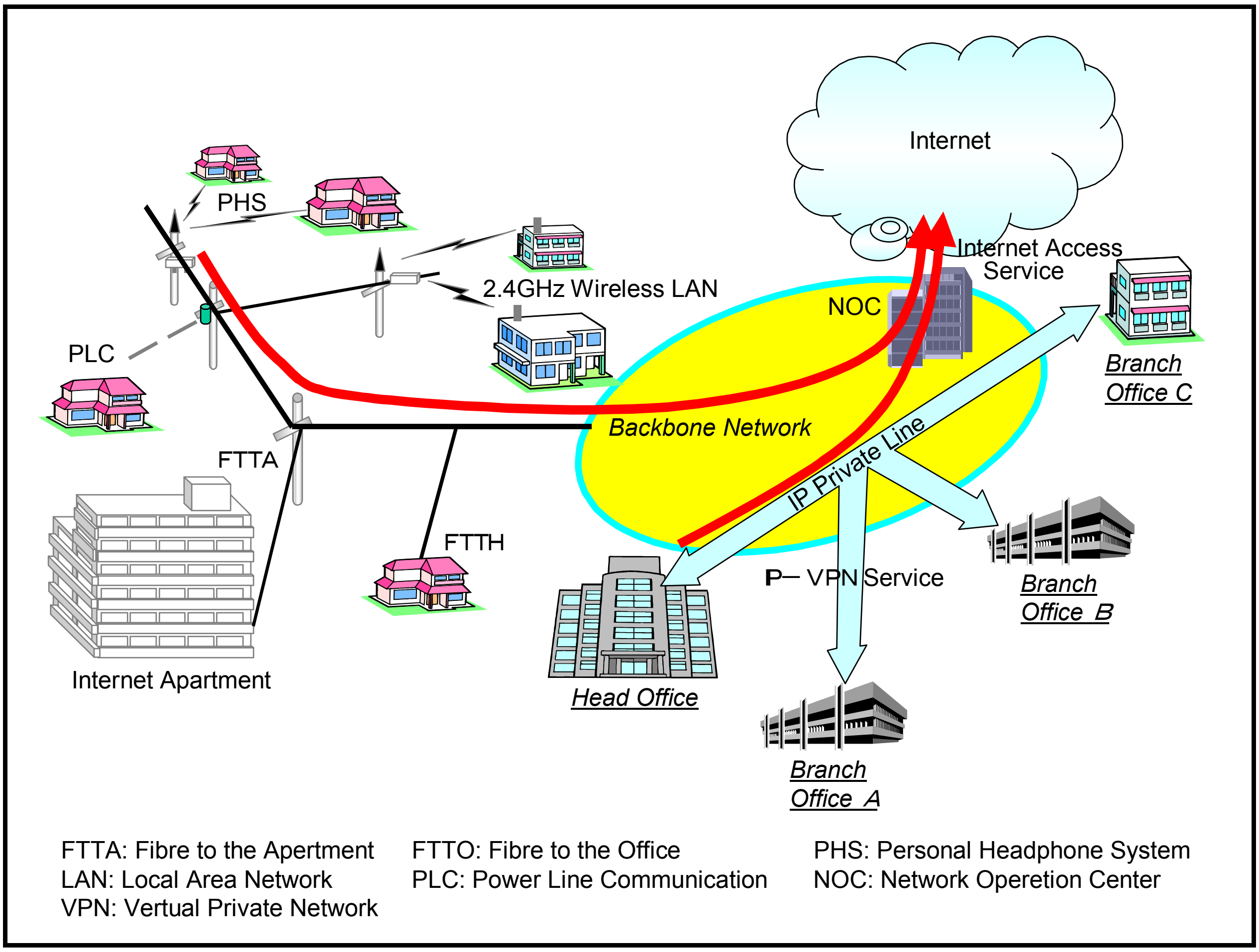


Fig. 5.2 Example of the future optical network for electric power company

All major electric power companies in Japan have started public telecommunication services using optical fibre cables installed along electric power lines. An example of the network is shown in Fig. 5.3. Full-time Internet connection and IP telephone are served using the most preferable first access line among various media including wireless access, considering conditions around the house.

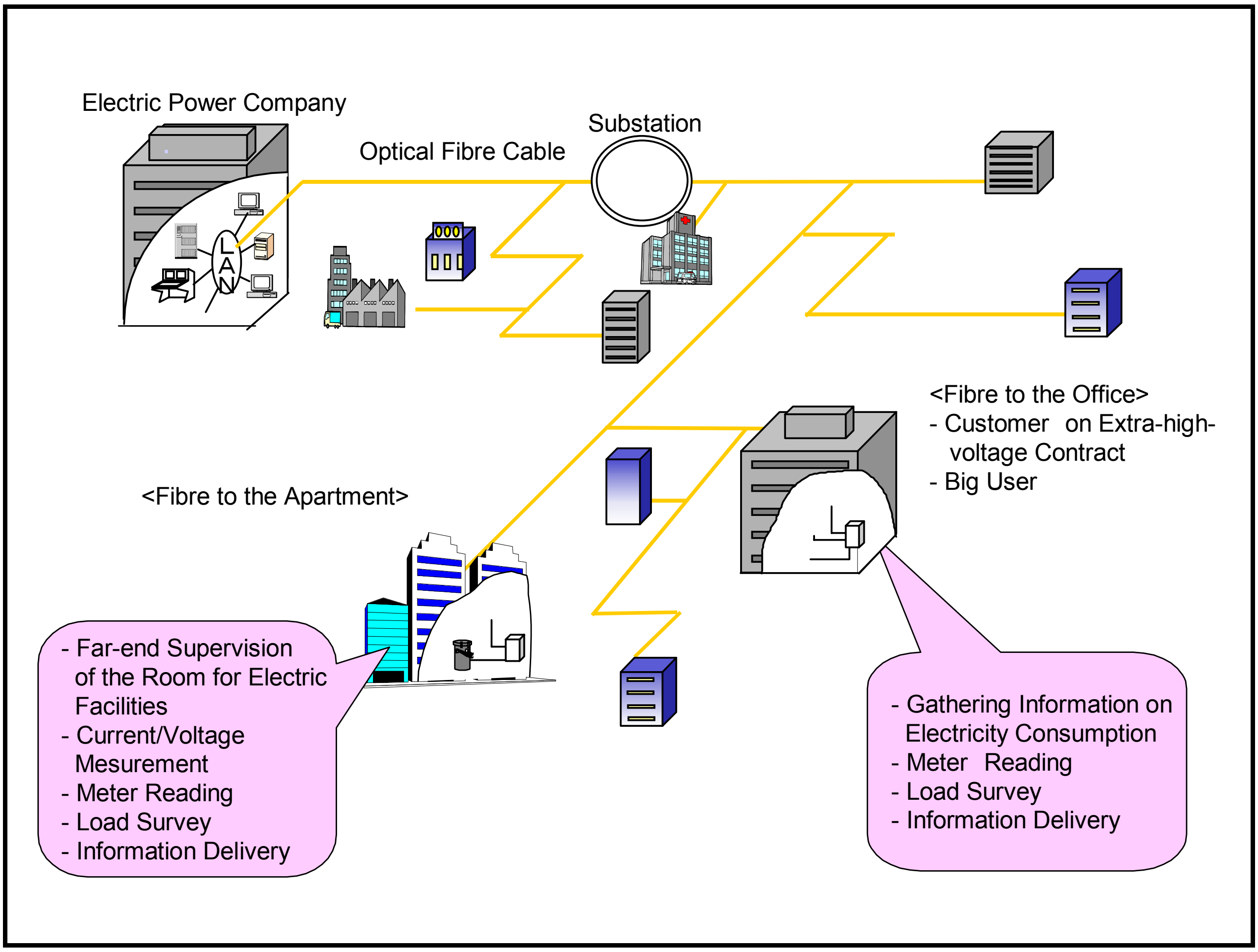


Fig. 5.3 Example of the communication network served by a company related to an electric power company

6. Conclusions

With the development of telecommunication technologies, the demand of broadband communications is growing for transmission of a wide variety of information not only among enterprises but also among individuals. In the business world, the use of large-capacity and low-cost communication services such as Internet protocol-virtual private network (IP-VPN) or wide area LAN based on the IP technology has become a mainstream. In the services for individuals, various types of communication terminals such as conventional personal computers (PCs), personal digital assistances (PDAs), mobile phones, etc. have been commercialized, and the demand of the connection to the IP network is growing rapidly as the service contents are enriched. In particular, the broadband access service using the constant connection type of IP network is growing faster along with the spread of access lines.

Under these circumstances, optical communication technologies are now beginning to be also applied for access networks because of their wideband capabilities. The electric power companies have applied the optical access technologies to their telecommunication business in addition to their conventional power system communication. This technical brochure introduces the optical access technologies at present and in future.

At present, the fibre to the home (FTTH) service as an optical access network, can offer the fastest broadband Internet connection. In order to increase the number of subscribers, there are a lot of subjects such as fascinating contents, methods to install the cable, etc. to be solved to realize more economical optical access networks. The electric power utilities, which shoulder part of the FTTH services, are trying to solve these problems by engaging in the development of optical access technology. Moreover, they are expected to offer more value-added and lower-priced services by applying the new optical access technology.

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