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Application and Analysis of Long-distance EPON In Transmission Lines Monitoring System

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Abstract. Ethernet Passive Optical Network (EPON) has been widely used in the Smart Grid. However, the overlay radius of EPON system is generally a 20 km, which has become the obstacle of application of EPON in Smart Grid. This paper introduces the advantages of EPON and analyzes the need for long-distance EPON of t Transmission Lines Monitoring System. And also this paper analyzes the factors affecting the long-distance transmission of EPON. Then this paper discusses the implementation of long-distance EPON and proposes a scheme of achieving communication network of Transmission Lines Monitoring System based on long-distance EPON.

Introduction

Transmission Lines Monitoring System (TLMS) means that monitoring the status of transmission lines and poles by various means, in order to provide the evidence for the maintenance of transmission lines and poles and guarantee the electric supply. [1]Traditional TLMS mainly accomplishes video monitoring by using above-line tools, such as helicopter, or under-line tools, such as foot and vehicles. The traditional TLMS's cost is very high, and the effect is bad and the real-time ability is low. Now fiber private network and wireless private network and wireless public network are three main communication methods used in TLMS.

Ethernet Passive Optical Network (EPON) is a point-to-multipoint (P2MP) network. In various communication methods, EPON system's topology can naturally meet the needs of power network's access layer. EPON can carry plentiful of service access and simplify the layers of network and is easy to be maintained. As the final mile technology, EPON has many advantages beyond comparison among all the access technologies. It has widely prospect in TMLS.

However, because transmission lines' work environment change diverse and it is susceptible to be influenced by field landform and weather greatly, EPON system will meet the cases that transmission distance is over 20 km in the application, but traditional EPON equipments cannot support to transmit over 20 km. The research of long-distance EPON will be favorable to promote reliability of TLMS and low the construction cost of TLMS.

Application and requirement analyses of EPON in TLMS

(1) TLMS' architecture

The TLMS' architecture is composed of three parts, Monitor Centers and Monitor Terminals and data transfer and information security system. TLMS should meet all the needs of various applications, such as transmission line video monitoring, status measuring, and etc... TLMS' data transmission system needs data transfer with high speed, reliability and transparence between all levels Monitor Centers and Monitor Terminals (MT). TLMS' data transmission system can be divided in two levels, the Core Layer and the Access Layer. The architecture of TLMS is as shown in Fig. 1.

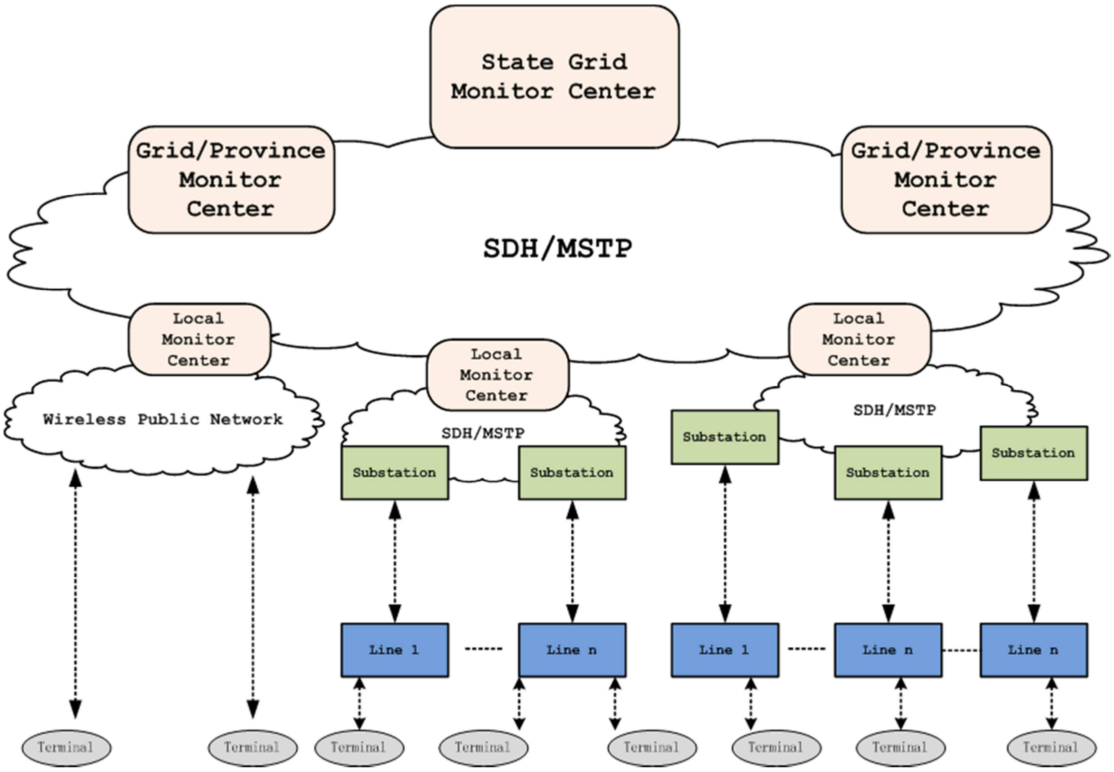

Fig. 1 The architecture of TLMS

(2) The solution of Access layer of TLMS based on EPON and WiFi

OPGW fibers have covered all lines between the all levels monitor center and substation, and all lines among substations. Fiber ring network has been build. So the Core layer of TLMS' data transmission system will make use of power fiber core network based on SDH/MSTP, and the Core layer will not need to be built again. The solution of TLMS' data transmission system mainly solves the problem of communication between Monitor Terminal and substation.

Monitor Terminal is usually located on the pole. The Monitor Center needs to make communication with the monitor terminal on each pole. In consideration of the access cost and the maneuverability, it is impossible for each pole to realize fiber communication. We can put an optical network unit (ONU) on the pole with fiber interface box at intervals. Thus fiber communication between optical line terminal (OLT) and ONU will come true. The monitor terminal on the pole without fiber interface box can make use of various wireless communication technologies to access to the closest ONU. The wireless AP, which is the access point of WiFi, connected with ONU, will realize to cover whole transmission lines by wireless. All of collection equipments will make use of WiFi client point (CP) integrated to have access to the WiFi network to realize the communication with the monitor centers at different level.

The communication network of access layer of TLMS' data transmission system based on EPON and WiFi is as shown in Fig. 2.

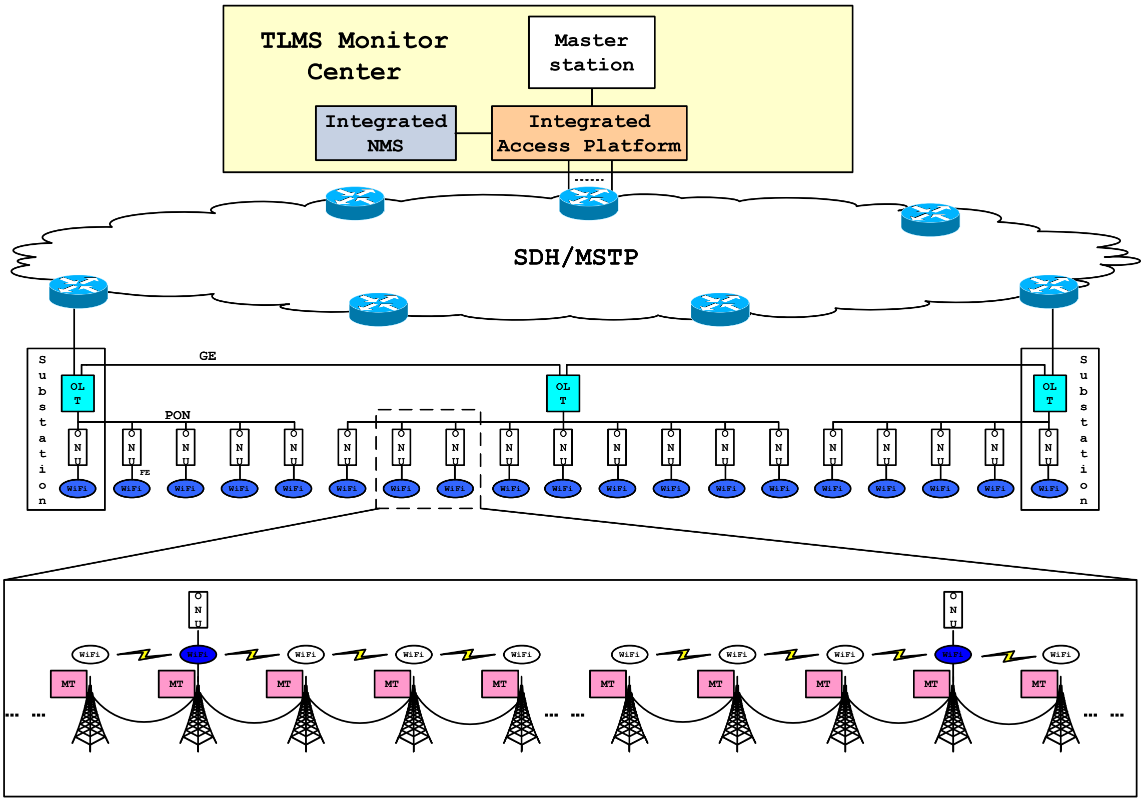

Fig. 2 The solution of communication based on EPON and WiFi

WiFi can usually cover the field within a radius of over 3km when the antenna gain is high. Therefore one ONU is needed at intervals about 6km at most. An overlay radius of EPON system is generally a 20 km, but data transmission distance by using EPON will be farther when the number of ONU in the EPON system is less. If the extra line length for line hanging and connection is considered, it is good that each OLT manages 9 ONUs whose overlay radius is 24km.

Every OLT connects the other OLT with Gigabit fiber Ethernet and the OLT located at substation is access to the SDH/MSTP network with one of Gigabit fiber Ethernet ports. As a result a logical ring of OLTs is constructed so that hand in hand protection mode can be supported. This function can prevent OLT from invalidation of one point, or prevent OPGW from fiber breaking of one point.

(3) Requirement analysis of EPON

- Because equipments working outside can only adopt a solar energy supply method, it is requested to reduce the power of equipments. However the power of OLT is very high, the number of OLT located at pole must be as low as possible. It means the EPON's transmission distance must be longer.
- Because the environment outside has a great effect on transmission line, the interval of poles cannot be measured accurately. So it maybe takes place that the distance between the OLT and the farthest ONU of the OLT will over 20km.

Therefore the problem of long-distance transmission of EPON system in TLMS must be solved.

The factors affecting the long-distance transmission of EPON

The factors affecting the long-distance transmission of EPON mainly include optical path loss, mode allocation noise and max Round Trip Time (RTT).

(1) Optical Path Loss

The optical power on the EPON is limited, optical path loss must meet as rule as Formula 1,

$$\text{Optical path loss} < (\text{OLT's transceiver optical power} - \text{ONU's receiver sensitivity}) \tag{1}$$

Usually optical path loss is smaller than 22 dB.

The fiber length loss of EPON is: upstream(1310nm): 0.36dB/km, downstream(1490nm): 0.22 dB/km. Considering application requirement, the value of fiber length loss is 0.4 dB/km.

The actual EPON's optical path loss $\mathrm{loss_{epon}}$ is equal to:

$$\mathrm{loss_{epon}} = \sum \mathrm{loss_{splitter\_insert}} + \mathrm{loss_{connector}} + \mathrm{loss_{fiber}} + \mathrm{loss_{ext}} \tag{2}$$

where:

$\mathrm{loss_{splitter\_insert}}$ = the optical splitter's insertion loss.

$\mathrm{loss_{connector}} = \mathrm{Num_{conntector}} \times 0.2$, the optical connector's loss, typically one connector has 0.2dB loss.

$\mathrm{loss_{fiber}} = \mathrm{Len_{fiber}} * 0.4$, the sum of fiber length loss.

$\mathrm{loss_{ext}}$ = the extra loss if application circumstance is considered. Typically this value is 2 dB.

The typical optical splitter's insertion loss is as show in Table 1.

Table 1 Typical optical splitter's insertion loss

Splitter type	Insertion loss
1:2 Splitter (5%:95%)	11dB:0.4dB
1:2 Splitter (50%:50%)	3dB:3dB

An overlay radius of EPON system is generally 20 km. If long-distance EPON system is needed, it must be made use of optical amplifier to promote optical power. The solution of optical amplifier is shown in Fig. 3.

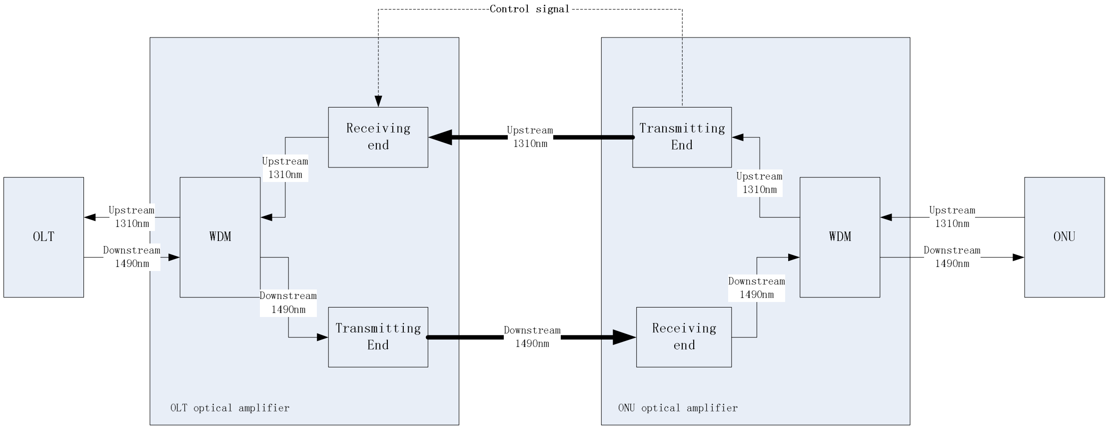

Fig. 3 The solution of optical amplifier

The function of WDM is to solve the problem that EPON's upstream wavelength and downstream wavelength must be amplified together. As we known, the traditional optical amplifiers are EDFAs or SOAs, but these amplifiers only can amplify the fixed range wavelengthes. WDM can solve this problem. The wave multiplexer and de-multiplexer are the key of WDM technology. Their performance has great effect on the EPON's transmission quality.

(2) Mode Allocation Noise

Mode allocation noise will arouse the code interference and scope noise. As a result optical power and error ratio are promoted. FEC technology can resolve this problem.

FEC is an effective method by which long-distance and big splitting ratio and low costs of optical components can be realized. FEC can promote the effective sensitivity of OLT and ONU's receivers. In theory it can add 4~4.5 dB power which correspond to extend 10km transmission distance. Considering the working environment and optical components' effect, FEC can add 2~3 dB power for downstream of EPON and add 1 dB power for upstream. It is correspond to extend 2.5 km in the bus topology of EPON.

Cost, latency, efficiency and complexity are the main faults of FEC in EPON system. Efficiency is not main problem because the bandwidth of EPON is very high for EPON application in TLMS' data transmission system. Latency can be solved by adjusting RTT parameters. And also complexity and cost will not be the obstacle of FEC's application because FEC function has been supported in current OLT and ONU ASIC chips.

(3) Max RTT

In EPON system, synchronization is required because every ONU's slot must accord with the slot assigned by the OLT to avoid collisions of their upstream data. For the OLT, every ONU has a different distance and the round trip time (RTT) will change with the changes of time and the environment, thus transmission overlap of upstream data will also occur. To avoid the collision of upstream data, RTT between every ONU and the OLT is measured and inserted with the corresponding equalization delay to make the logical distances between the OLT and all the ONUs the same.

The maximum RTT affects how long the fiber span of the PON can be. The RTT must be known to the OLT firmware to perform ONU ranging during discovery and in scheduling, in order to determine how far in advance to send grants. Therefore max RTT must be used with optical amplifying in order to realize long-distance EPON.

Max RTT is related with ONU's discovery and registration, as shown in Fig. 4.

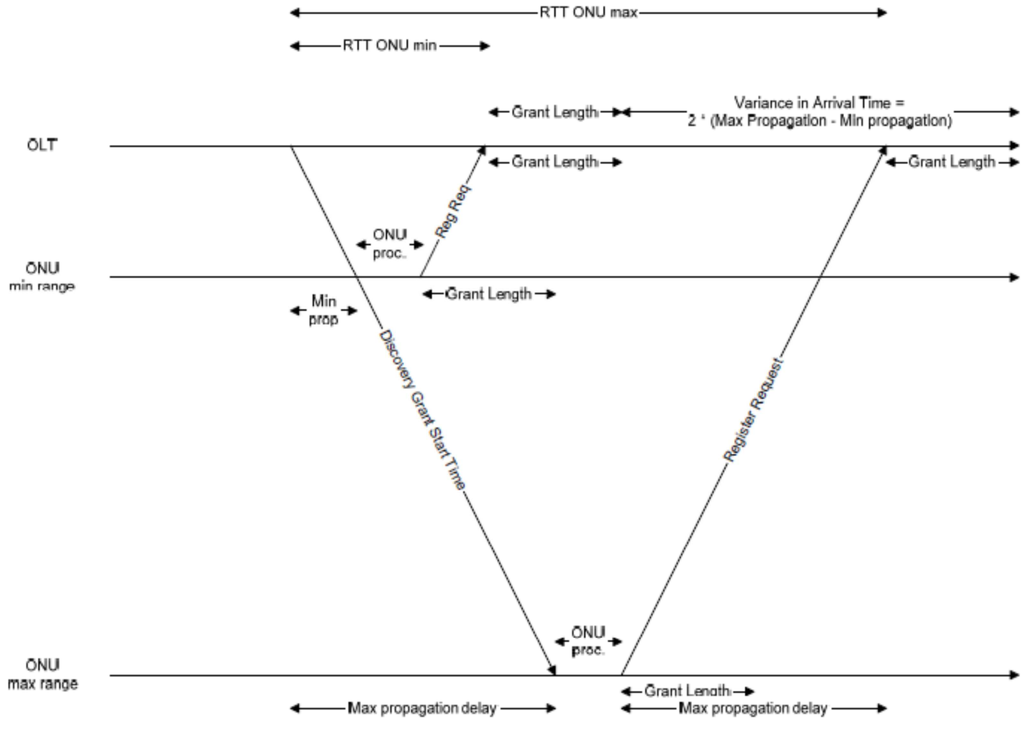

Fig. 4 Max RTT related with ONU's discovery and registration

Per the 802.3ah standard, RTT is calculated by the OLT based on the following:

The propagation delay of the optical signal between the OLT and the ONU, plus a combined processing delay for the OLT and the ONU

The equation for calculating the RTT is:

$$\text{RTT} = (2 \times [\text{propagation delay between OLT and ONU}]) + (\text{combined OLT and ONU processing delays}) \tag{3}$$

The propagation delay of the optical signal between the OLT and the ONU is based on the flight time for the optical signal. This value is 5μsec/km.

For Teknovus Corps' OLT and ONU chips, max RTT supported is 54272 TQ, where TQ is the time unit in EPON system, 1 TQ = 16nsec or 0.016μsec. This max RTT value is biggest in EPON ASIC chips now. So the max distance supported by teknovus EPON chips is about 81km if optical power is guaranteed.

The solution of power long-distance EPON

According to the TLMS' architecture, the main topology of EPON system in TLMS' data transmission system is bus topology. The solution of different long-distance EPON in bus topology is as below:

(1) 20km~40km's solution

Firstly, adjusting max RTT value according the max distance needed. It will guarantee the discovery of the farthest ONU;

Secondly, configuring the number of cascaded splitters in bus topology and the splitting ratio of splitter. Reducing the number of fiber connectors. It will reduce the splitter's insertion loss and connector's loss and guarantee the optical loss is mainly used to add the length of fiber.

In the topology shown in Figure 2, the splitters used are usually all 5%:95% ones in all level except the last level in which the splitter is 50%:50%. Under this circumstance, according to Eq. 1 and Table 1, for the farthest ONU,

$$\mathrm{loss}_{\mathrm{epon}} = (\mathrm{n}-1)\times 0.4 + 3 + \mathrm{Num}_{\mathrm{conntector}} \times 0.2 + \mathrm{Len}_{\mathrm{fiber}} * 0.4 + 2 < 22\ \mathrm{dB} \tag{4}$$

If optical power of EPON is not promoted, the distance of the farthest ONU is 42 km at most where there is only one ONU and the number of connectors is zero.

By the way, the distance of the farthest ONU can be increased 2.5 km when FEC is enabled.

(2) 40km~81km's solution

Firstly, adjusting max RTT value according the max distance needed. It will guarantee the discovery of the farthest ONU;

Secondly, promoting optical power of EPON by using the optical amplifiers shown in Figure 3.

In this way, we can realize to extend the distance of the farthest ONU to 80 km.

Conclusion

Three kinds of methods proposed in this paper have been applied in Transmission Lines Monitoring System in North China Power Grid. Long-distance EPON should use all three kinds of methods because the performance is not good if only one method is used. However extending distance of EPON is at cost of lowing effective bandwidth, adding active components, adding ONU's discovery time…and etc. These faults must be considered in EPON application. The max distance of EPON is about 81km now. If farther distance is needed, EPON chips must support to set bigger max RTT value. At the same time, optical amplifier should make use of optical regenerative repeater in order to low the counts of photo-electricity transform and transmission costs, promote the quality and reliability of EPON's transmission. The technology of optical regenerative repeater in EPON system will be the key point of next stage of the research on the power long-distance EPON.

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