The Design of Communication Network Optical Fiber Cable Condition Monitoring System Based on Distributed Optical Fiber Sensor

Bin-hui Tang
Dept. of computer science and technology
Jincheng College of Sichuan University,610000，
Chengdu; china
e-mail: 565081821@qq.com

Zhen-xing Zhou
Dept. Of palnning
A representative office of the rocket military
Chengdu; china
e-mail: 50344874@qq.com

Abstract—**This paper proposes the solution to improve existing optical fiber cable condition monitoring system using distributed optical fiber sensor. This scheme integrates optical fiber communication network and sensor network. The sensing network utilize the sensing signal sent by the communication channel of the existing optical fiber access network so as to facilitate the transmission in the optical fiber communication network. And for the two different communication signals of sensor signal and communication signal, it is proposed to couple them according to time-division multiplexing in fixed frame, which can not only solve the problem of time slot and bandwidth allocation in multiplex transmission, but also perfect Existing cable monitoring system security management functions. The design does not need to build an additional sensor line, the rapid response to failure and timely detection of network security risks exist in the prevention of optical fiber communication network security incident has an important value.**

Keywords-distributed optical fiber sensor; optical fiber cable condition monitoring system; optical fiber communication network; sensor network; multiplexing transmission

I. INTRODUCTION

In recent years, with the wide application of high-capacity and high-speed optical fiber communication systems, more and more people are concerned about the security of communication networks construction, management and information transmission. How to improve the security of transmission network and make it with high survivability and competitiveness has become the primary consideration of the major operators. The capacity of optical fiber communication system transmission is huge. If there is some problem with the reliability and security of optical fiber communication system, it will have great influence on people's daily life. This paper analyzes the existing fiber optic cable monitoring system in the communication network ,and using distributed optical fiber sensors such as Bril-louin OTDR and fiber Bragg grating sensors[1]to improve the original system. the sensor signal using the existing GPON access network[2] for remote transmission, without changing the original communication network cabling, room equipment based on the standard protocol, the sensing signal is transmitted through the existing communication network to avoid reconstructing the network channel of the sensor network.so the optical fiber cable automatic monitoring system can be used to solve the maintenance problem of the optical fiber communication network, real-time online monitoring of the optical network, fault location alarm and status warning, the function combined to better improve the reliability and security of optical fiber communication system. There are some monitoring and warning programs methods of the traditional transmission lines at home and abroad, such as artificial inspection method, analog wire method and image monitoring method. The artificial inspection method is labor-intensive and costly, and the test results have great difference with the reality. The image monitoring method is effective only for the local inspection site and can only be used as ancillary means. The optical fiber sensing technology in real-time optical network security and health online monitoring, can not only locate the fault but also identify it and make a warning. So the operators can timely detect the potential safety problems and response to it quickly to improve service efficiency[3].

II. TECHNICAL FEATURES OF DISTRIBUTED FIBER OPTIC SENSORS ANALYSIS

Optical fiber sensing technology is a new sensing technology based on light as a carrier and a medium to sense and transmits signals of new sensing technologies. In recent years, optical fiber sensing technology are widely used in power, industry, transportation and other industries, which gives a new way of thinking to the development of communications network fiber optic cable condition monitoring technology. In this paper, the characteristics of communication network, the use of distributed optical fiber sensor (DOFS) for real-time on-line optical cable monitoring, distributed optical fiber sensor not only has all the characteristics of the general optical fiber sensor, but also use optical fiber as the sensing and signal transmission medium. The state distribution information of the sensing optical fiber area is obtained, and the parameters such as the intensity, the frequency, the phase and the polarization of the transmitted light in the sensing optical fiber area are monitored and converted into temperature, stress, additional loss and Micro-bending and other useful signals, and the signals sent to the monitoring system for analysis and processing, when the fiber optic interrupt or bad state of anomalies and other timely warning to quickly determine and locate the

978-1-5386-5752-2/18/$31.00 ©2018 IEEE

fault[4].This paper we mainly use the fiber Bragg grating sensor and Bril-louin OTDR distributed optical fiber sensor, the following describes the working principle of these two types of sensors:

Fiber Bragg grating sensor is one of the most frequently used and widest range of fiber optic sensors. This sensor obtains the sensing information by the external parameters of Bragg wavelength modulation. According to the ambient temperature / stress changes to change its reflected light waves Of the wavelength, is a wavelength (or grating) modulated optical fiber sensor, shown in Figure 1:

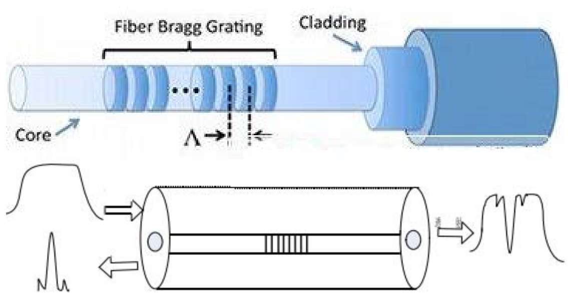

Figure 1. Schematic diagram of fiber Bragg grating sensor

When a beam of broad-spectrum light is propagated to a fiber Bragg grating, each small piece of fiber after its refractive index has been changed will only reflect a specific wavelength of light, and other wavelengths of light will be propagated. The reflected light wavelength is called the Bragg wavelength. As shown in the following equation:

$\lambda_{max} \approx \lambda_B = 2 N_{eff} \Lambda$ [5]. λ_B is the Bragg wavelength, Neff is the equivalent refractive index of the fiber core and Λ is the length of the space between the gratings, called the grating constant. When the FBG is affected by the strain or temperature, there are strain effects, pop-up effects, thermal expansion and contraction effects, and thermo-optic effects. The Neff and Λ will produce the corresponding changes that cause the reflected wavelengths to change, Wavelength changes, can be achieved on the strain, temperature measurement. The main advantage of fiber Bragg gratings is that the detection information is an absolute measurement of the wavelength code that enables the sensor to self-calibrate without being affected by light fluctuations, system and light source power, and connection losses. it is conducive to reuse in a single-mode fiber, and easy to change, increasing the flexibility of sensing wiring.

Brillouin scattering is based on the principle of optical time-domain reflection[6] pulsed light injected into the fiber. In the forward transmission process, the fiber back to the continuous generation of scattered light. When the optical fiber is exposed to external influences, the parameters such as the frequency, power and phase of the scattered light will be changed. By detecting the variation of various parameters of the backscattered light at the incident end of the pulse, the incident along the optical fiber can be monitored. According to the received scattered light the time difference between the light and the emitted pulsed light positions the event point. In 1989, Horiguohi et al. proposed a fiber Brillouin strain sensing technique that analyzes the frequency and intensity of Brillouin scattered light from a sensing fiber to derive temperature and strain information along the fiber. Due to the small attenuation and dispersion received by Brillouin scattering optical signals, it is suitable for distributed sensing over long distances and it becomes the most promising DOFS. It combines Rayleigh scattering with fiber loss, microbending, temperature and strain information to detect and locate faults.[7] Brillouin scattering is the information carried by the inelastic scattering of light and the matter that causes the wavelength of the incident light to change. By using this property, the Brillouin light intensity value of the fiber can be obtained by the BOTDR analyzer. The strain of fiber is calculated by calculating the frequency shift of the Brillouin scattered light before and after the strain in the fiber. Then the deformation of the fiber along the fiber is deduced by calculating the time t when the Brillouin scattering light returns to the starting point of the light source Volume and distance.

III. EXISTING FIBER OPTIC CABLE MONITORING SYSTEM PROBLEMS

Optical Fiber Automatic Monitoring System (OAMS) mainly uses technologies such as alarm, test, database, network control, business process control and geographic information system to comprehensively combine optical fiber testing, network management alarm and maintenance system, Real-time monitoring of optical cable, automatic analysis of alarm information, automatic testing, automatic positioning of the fault and automatic repair, thus minimizing the loss of fault duration.

At present, optical fiber cable monitoring systems mostly adopt hierarchical monitoring methods. The network management centers and monitoring centers at all levels are responsible for them. Among them, the provincial monitoring center only grasps major issues, while prefectural-level monitoring centers generally assume the main tasks of maintenance. Traditional fiber optic cable monitoring system is divided into three levels, namely the provincial monitoring center PMC, regional monitoring center RMC and monitoring station MS. The regional monitoring center controls the monitoring station and it is the center for data collection and data processing. The monitoring station consists of the main control unit, OTDR test module, optical power testing and switching unit, and optical fiber test routing unit, so as to realize the optical cable line Optical power monitoring and remote monitoring of automatic monitoring to track changes in optical transmission loss. It is installed in the transmission rack standard rack, which make the unattended condition becomes true. Monitoring center and the main control unit is run on the PC system software to achieve. The OTDR scans the fiber under test for automatic monitoring. Test routing unit through the optical path switch to be monitored fiber switching. Figure 3 shows the overall structure of optical cable monitoring system. As can be seen from the figure, the traditional fiber optic cable monitoring system requires multiple levels of monitoring signals to be relayed. It takes a long time, which is not only conducive to shortening the fault response time, but also easily loses or transmits wrong signals and misjudges the status monitoring. Secondly, since the sensor can only reach the range of tens of kilometers at present, the monitoring station is placed in the machine room. An OTDR analyzer needs to monitor multiple optical states through the optical path switch. This design is not only conducive to collecting status signals, but also it is not suitable for real-time online monitoring and control. Therefore, this monitoring system should be improved to further improve the system's safety management functions.

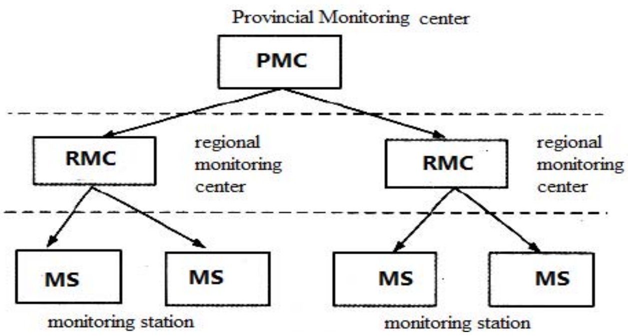

Figure 2. the overall structure of optical cable monitoring system

IV. System Optimization Design

Based on the above actual situation, this paper proposes an improved scheme of optical fiber cable monitoring system by using the excellent performance of distributed optical fiber sensor in order to realize the purpose of optical network fault maintenance and online real-time monitoring. Through the optical fiber network, a certain number of distributed optical fiber sensors are reasonably placed to form a sensor network. Each deployed sensor is responsible for the monitoring of optical networks within a specified range and transmits the monitored information to each monitoring station. Each monitoring station will report the information to the monitoring center, and the monitoring center will analyze and process the comprehensive information. The result report will be presented to the administrator and the opinions of the corresponding handling measures will be given out so as to complete the real-time on-line monitoring task of the entire optical network. In order to ensure the efficient transmission of sensing signals and reduce the fabric cost, the sensing network is integrated with the communication network, the monitoring information sensed by the sensor is coupled to the transmission channel of the optical access network, and transmitted to the monitoring system along with the communication signals demodulate it.

A. Feasibility Analysis

The formation of sensor and communication convergence network, we must first select the appropriate light source, transmission medium and detectors. Commonly used light source devices in optical fiber communication networks include semiconductor lasers (LDs) and semiconductor light emitting diodes (LEDs). The emission wavelength of these two devices is consistent with the low loss or low dispersion wavelength of the optical fiber, and can work continuously at room temperature. The output power meets the requirements of the optical fiber communication system. The optical fiber sensing network needs the light source to have sufficient brightness and small volume. The stability of optical fiber sensing is the most important, requiring that the light source can be continuously operated in a relatively low temperature and low noise environment, and is easy to use. It can be seen that the optical fiber communication network can meet the light source requirements of the fiber sensor network, so it can be used.LD spectral width which can be done very narrow, in order to reduce the impact of dispersion in the fiber. The correlation is better than the LED, if the sensor is relatively high coherence can choose LD light source.In the choice of detectors, optical fiber communication network requirements are high photoelectric conversion efficiency, fast response speed, low noise, high sensitivity, low power consumption, stable performance, reliable, cheap. Optical fiber sensor network of the basic requirements of the detector and communication network, only the sensitivity requirements may be superior. Both PIN photodiodes and avalanche photodiodes (APDs) meet the requirements, except that APDs have higher responsivity and internal gain, which improves the signal-noise ratio of the device and is therefore more suitable for converged networks.It can be seen from the above analysis that the prerequisite for the transmission of the sensing signal in the optical fiber communication network is that the sensing signal and the transmitting signal source of the communication signal are similar to the transmission channel medium and the receiving signal device. Therefore, the optical fiber sensing signal can be realized in the existing optical fiber communication network transmission [8]

B. Optical Fiber Condition Monitoring System Process Optimization

In this paper, the monitoring mode of point-to-multipoint is used to optimize the traditional fiber optic cable condition monitoring system. The system is logically divided into four functional layers: information acquisition layer, information processing layer, information analysis layer and decision report layer.The information acquisition layer includes the monitoring module and the signal multiplexing module to collect the status information of the optical cable and monitor the useful information such as temperature, pressure and transmission power distributed along the optical cable line in real time and transmit the sensing information. After some processing of the information, it is transmitted to each monitoring station together with the communication information. Sensory information of the monitoring station into terminal processing information transmitted through the packet switching network to all levels of monitoring center.The information processing layer includes a filtering module and a clustering merging module. The error information uploaded by each monitoring station is filtered and repeated information is merged to further reduce the data processing volume The information analysis layer is the core of the system, including the fault early warning module, the correlation and causality between the use status information, and further determine the accuracy of the fault warning. The decision reporting layer contains a conclusion report module, which is mainly intended to facilitate the function that the network administrator presents as the judgment and response to the analysis results.

C. System Architecture Design

The design still adopts a monitoring center to monitor the multiple sensing networks uniformly and transmit the sensing signals as a type of service signals through the optical fiber communication network. The design is an effective and cost-effective system architecture, which can not only greatly reduce the problem of waste of resources, but also solve the problem which can not be monitored on-site. In order to achieve remote monitoring, the sensing information collected by the distributed optical fiber sensor is transmitted to the communication network through the communication channel of the existing optical fiber communication network. This method can not only reduce the difficulty of construction, but also save a lot of costs, and have practical significance in practical application.

At present, the access technologies are mainly EPON, GPON.The GPON not only has more high-speed, longer transmission distance, low maintenance costs, high security and anti-interference ability, as well as a new transmission convergence (GTC) layer., can carry ATM, GEM and other user signals[9] . Therefore, this paper selects GPON as the sensor network access object, GPON GEM can achieve a variety of business mapping, and complete high-level diversification of business adaptation without the need for protocol conversion. It can also support the original formatted data packets effectively and TDM streams encapsulate fixed-length or variable-length data directly. Because of this characteristic of GPON, this design mainly encapsulates the sensing information in the GEM frame, and realizes the remote high-speed transmission, and the self-sensing data structure of the sensing information can not be damaged. The sensor information carried by the optical fiber sensor mainly includes the position and type of the sensor and the parameter values to be measured. The sensor information data arriving at the monitoring center via the transmission network is small, usually only a few bytes, as compared with that of the GPON Time resources are quite abundant. In order to effectively use this time resource, avoid for each sensor setting a separate access interface to acess network. it is necessary to setting a unified access processing system is provided in the system, the data of each sensor network is accessed A unified access processing system for processing, and then access the identity of the user ONU, the sensed signal is sent to the ONU port. At the same time, in order to expand the monitoring center and make full use of resources, we can design multiple access processing system. The overall system architecture design, as follows:

Sensing information before entering GPON go through the access processing system, the node is mainly to complete the sensing signal code speed adjustment, sense the data frame encapsulation and send, and in what way to access work. In order to enable the sensing signal to be transmitted efficiently in the optical fiber communication network without influencing other communication signals, the main consideration in the design is to connect the sensing signal as a common data service to the fast Ethernet port of the ONU unit. That is, the sensed data is encapsulated into an Ethernet frame by the Ethernet network card before being connected to the ONU, so that the data is recognized by the optical fiber communication network to realize the remote transmission of the sensed information. Sensing data at the ONU is time division multiplexed with data of other services and uploaded to the OLT to transmit the received sensing data to a remote sensing monitoring center through a transmission network. The monitoring center processes the received sensing data Analysis and comparison with the threshold set in advance. If the threshold is exceeded, it means that the environment monitored by the sensor is abnormal, and the monitoring center will take the corresponding measures to alert the area where the emergency occurs so as to really realize The purpose of remote monitoring. In addition, the monitoring center can utilize the advanced technology and equipment to store the sensing network information monitored by it. It can conveniently query the sensing information of the monitoring point at any time, and provide an important reference for the decision-making of relevant departments.

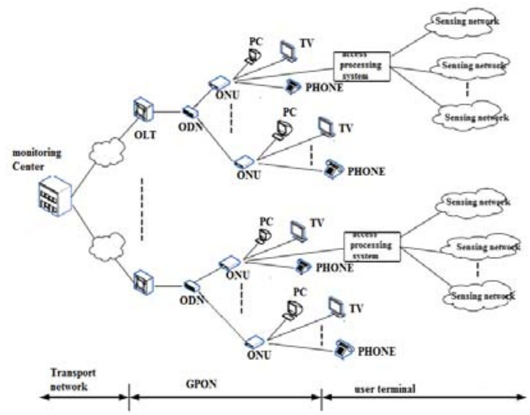

Figure 3. The design chart of overall system architecture

D. Time-DivisionMultiplexing Access Design

In order to avoid directly accessing the ONUs for each sensing subnet and occupying a large amount of resources, data in different sensing subnets are multiplexed and sent to an access processing system in this paper, and then uploaded to GPON. Multiplexed subnet information is transmitted over a single channel by multiplexing. This design not only saves the limited channel resources, but also effectively avoids collision caused by multiple data transmission at the same time and reduces the lost bit rate. Due to the high cost of WDM optical components, laser source synchronization is harsh, and if each sensor subnet is assigned a wavelength, it will cause serious waste of bandwidth resources. Limited wavelength resources also limit the transmission Sense of the size of the network. But Time division multiplexing (TDM), a physical channel by time divided into multiple time slices, multiple user signals in accordance with the specified time slot for data transmission technology, the receiver using the time synchronization to demodulate the signal, the multiplex signal in the specified time slot transmission, to avoid the collision of the data packet, to achieve the purpose of multichannel communication, the sensor subnet data frame compared to the GPON data frame byte is very small, so rich in time resources, reusable A large number of sensor network. Therefore, taking into account the characteristics of the sensor network itself and from the perspective of resource conservation, time multiplexing is the best access scheme for sensing the multiplexing of data frames.Time-division multiplexing is the key technology to keep the system in sync, sensing sub-network and sensing control center are not the same, the sensor information is correctly received and demodulated key is how to maintain system synchronization. The data frame length from each sensor network is small, while the GPON uplink speed can reach 1.25Gbit / s and the frame length is 125us, so we can regard the sensor data frame from each sensor network as the low-order group signal [10].To keep the system in sync, you first need to adjust the code rate of the sensing data frame to make it suitable for transmission in the communication network and to keep the system in sync. TDM access design, as follows:

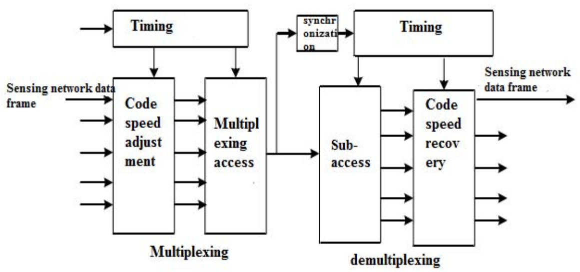

Figure 4. The design chart of Time-division multiplexing access

Data frames from different sensor networks are firstly adjusted to a uniform data code rate by a code speed adjusting unit and then to a GPON system through a digital multiplex unit to reach a monitoring center by remote transmission. In order to keep the system synchronous, the transmitting end and the receiving end Need to adopt a unified clock, each frame has a beginning of a framing pulse, marking the beginning of the frame, the selected framing pulse power should be significantly higher than the data pulse power, to facilitate the user to demodulate the correct pass Sensory information.In practical applications, the optical cable status will not change much in a short time, so it is not necessary to always reflect the monitored status information to the monitoring system. However, the requirements of users for communication are very high. If short-term information is delayed or interrupted, the end users will obviously feel. In view of the high real-time and reliability requirements of communication signals, the real-time requirements of the sensor signals are far less than those of communication signals.

In this paper, a method of multiplexing the sensor signals and communication signals according to the fixed-length frame multiplexing is proposed. The frame period is 125us, then 1s transmits 8000 frames. The first frame of every second is used to transmit the sensing signal and the other frames still transmit the communication signal. Only one user is allowed in each frame, and different frames carry the information of different users. Frames with the same address identifier are sent to the same ONU, so that each ONU only receives those frame information whose address labels are consistent, discards other information, and then sends the information carried in each frame to different users. In this way, only one frame per second is used for sensing signals, which does not affect the real-time performance of the communication signals and sends the sensing information instantly. The use of the address mark enables the sensing signals of multiple transmission subnets to be able to select ONU access nearby and efficiently perform real-time online monitoring.

V. Conclusion

In this paper, based on the mature optical fiber communication network, the proposal of integrating the optical fiber sensor network into the communication network realizes real-time on-line monitoring of the status of the optical fiber cable and transmits the sensing signal of the monitoring system by using the optical fiber communication channel. Thereby avoiding the reconstruction of optical fiber sensing Network communication channel, can not only ease the situation of urban underground pipe congestion, but also save a lot of costs. The realization of the Internet really has some practical significance. The research of this topic will play a certain role in promoting the further practical use of sensor networks. But there is still work to be further improved, such as the optimized design of multiplexed frame structure of sensing information and the improvement of transmission performance of optical sensor network.

References

[1] Chen Bingyun; Hu Longhua; Huo Ran; Yang Rui new.Combination of FBG and BOTDR in tunnel [J] .Journal of Highway and Transport Science and Technology (Application Technology Edition), 2011 (10): 228-230

[2] Lang weiming;Dongsheng. EPON / GPON from principle to practice {Ml. Beijing: People's Posts and Telecommunications Press, 2010: 20-22

[3] Zhang Xu Ping; Wu Jianling; single Yuanyuan; Liu Yang; Wang Feng; Zhang Yi Xin.. On-line Monitoring of Transmission Lines in Smart Grid Based on Distributed Optical Fiber Sensing Technology [Jl Optoelectronics, 2017 (04): 221-229

[4] CHEN Y, ZHANG Z, CHEN X.Novel Monitoring Method of Power Transmission Line Galloping Based on Fiber Bragg Grating Sensor. Optical Engineering. 2011

[5] Lu, Yuelan, Zhu, Tao, Chen, Liang, Bao, Xiaoyi.Distributed vibration sensor based on coherent detection of phase-OTDR. Journal of Lightwave Technology. 2010

[6] Bi Weihong; Zhang Yanjun; Yuan Baoyi. Distributed optical fiber temperature sensor network based on light scattering and its application in smart grid [J] .Journal of Yanshan University, 2010 (05): 337-382

[7] Song M, Xia Q, Feng K, Lu Y, Yin C. 100 km Brillouin optical time-domain reflectometer based on unidirectionally pumped Raman amplification. Optical and Quantum Electronics. 2016

[8] Zhang Ying; Long Hainan. Fiber optic cable automatic monitoring system research and analysis[Jl.Modern Electronics Technology .2010 (07): 104-106

[9] Ma Chong. GPON based fiber grating sensor network access system {Dl. Qinhuangdao: Yanshan University master's degree thesis, 2011: 26-28

[10] Next generation hierarchical CWDM / TDM-PON network with scalable bandwidth deliverability to the premises. Stamatios V Kartalopoulos. Optical Switching and Networking. 2005