Ethernet Passive Optical Network Monitoring using Various Types of Fiber Bragg Grating

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***Abstract*— This paper presents a real-time monitoring system for Ethernet Passive Optical Network (EPON). A fiber Bragg grating (FBG) with a distinct Bragg wavelength, bandwidth and reflectivity is inserted at each distribution fiber. The FBG reflection spectrum is used as the fiber identifier. One Bragg wavelength is shared by two types of FBGs to optimize the bandwidth of monitoring source. Constructive interference concept is also employed in order to ensure high amplitude of FBGs reflection spectra which share the same Bragg wavelength. Thus, more customers can be monitored for the limited bandwidth of monitoring source. From the simulation result, it is found that this monitoring system is capable to monitor up to 32 customers with excess power margin of 2 dB and monitoring power received of -43.5 dBm.**

***Index Terms*— EPON; FBG; Real-time monitoring system.**

I. INTRODUCTION

Ethernet passive optical networks (EPON) is an emerging access network technology that provides a low-cost method of deploying optical access lines between a carrier office (CO) and customer site. Ethernet Passive Optical Networks (EPONs) represents the convergence of low-cost Ethernet equipment and low-cost fiber infrastructure, to be the best candidate for the Next-Generation access network.

Interference is the phenomenon that happens when two waves bump into while traveling along the same medium. The interference of waves causes the medium to take on shapes that result from the net effect of the two individual waves upon the particles of the medium. In this paper, we manipulate the interference signal concept to gain the maximum output of monitoring signal and reduce the signal loss [1]. From recent literature survey it can be concluded that the normal system do not have the ability to monitor failure in a point-to-multipoint (P2MP) network. The fault localization only can be detected by waiting customer to call to the network provider. In conclusion, it can be summarized that a monitoring system is a crucial in order to ensure high quality of service in an optical networks.

A monitoring system has been developed for EPON in [2]. The author employs a phase-shifted fiber Bragg grating (PS-FBG) and uniform FBG in the network. The reflection spectra of the FBGs are used as the fibers' identifiers. However, the use of PS-FBG is not preferred due to high cost. A monitoring technique using FBG has also been demonstrated by [3]. In this technique, the author employs an erbium doped fiber amplifier (EDFA) to amplify the traffic signals. The unused spectrum of the amplifier is used as the monitoring source and the monitoring source is reflected using the FBG that is inserted at each distribution fiber. Even though it does not require any additional monitoring source, however, this method is contradicted with PON principle which does not allow any active devices along the network. In addition, the monitoring bandwidth is also limited due to limited bandwidth of unused EDFA spectrum. A centralized monitoring technique is also developed using periodic optical encoder [4]. Each distribution fiber is assigned a unique code which is produced by the encoder. Even though the author claims that the technique is capable to monitor up to 32 customers in one shot measurement, however the high complexity of this technique in processing the data received will increase the cost and is less favored. One of the limitations in a monitoring system is the requirement of high bandwidth of monitoring source [5]. Thus, this paper presents a technique to optimize the limited bandwidth of monitoring source using bandwidth optimization concept. The FBGs reflection spectra share the same Bragg wavelengths in order to ensure more customers can be monitored. The constructive interference concept is also employed to ensure high amplitude of FBGs spectra is received.

II. DESIGN PRINCIPLE

In TDM-PON, the downstream signal is transmitted from the Optical Line Terminal (OLT) to the Optical Network Unit (ONU). When the downstream signal reaches the power splitter, it reaches this signal by power division to each optical branch, i.e. all ONUs obtain the same downstream signal. Therefore, the downstream signal is encoded by the OLT and every single ONU can correctly decrypt only its particular data. In the upstream path, each ONU transmits its data at a specific time slot arranged by the OLT to evade collision at the optical splitter. In this monitoring system as shown in Figure 1, the monitoring source will co-propagate with the downstream signal and will be transmitted to each branch when the signals reach the optical power splitter. FBGs are placed at a specific location from the splitter. This is to ensure that the FBGs reflection spectra produce a high amplitude spectrum by employing constructive interference concept.

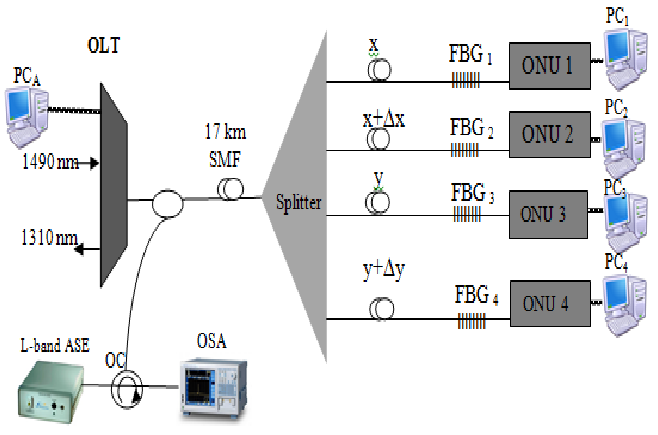

Figure 1: DM-PON architecture and operation

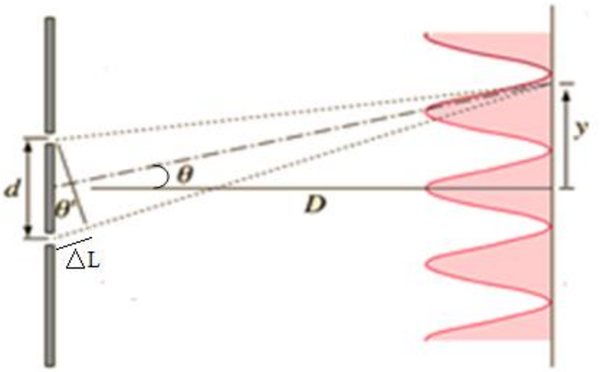

Figure 2: Constructive interference concept [2]

Based on Young's split experiment concept, the exact FBG location can be determined to ensure a constructive spectrum is produced [2]. From Figure 2, the phase difference is associated with the path length difference, ΔL. Assumption of infinite source distance gives plan wave at slit so that all amplitude elements are in phase.

$$\tan(\theta) = \frac{y}{D} \tag{1}$$

For distance screen assumption:

$$\tan(\theta) \approx \sin(\theta) \approx \frac{y}{D} \tag{2}$$

For D >> d, this approaches a right angle and θ'≈ θ and d = slit width. Therefore condition of maximum (constructive interference):

$$d\sin(\theta) = m\lambda \tag{3}$$

$$y = \frac{m\lambda D}{d} \tag{4}$$

Therefore:

$$\theta = \sin^{-1}(\frac{m\lambda}{d}) \tag{5}$$

For constructive interference (condition for maximum) to occur, m must be zero or any integer number. By using the equation above, we can use this requirement for the path length difference, ΔL to produce constructive interference:

$$\Delta L = d\sin(\theta) = m\lambda \tag{6}$$

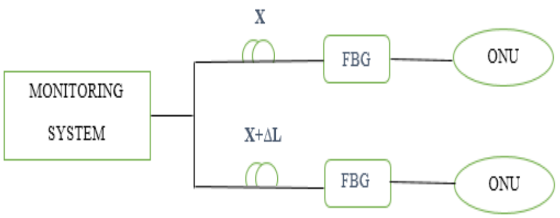

Figure 3: Position of constructive interference in fiber optic cable to occur

In Figure 3, X is representing the length of the fiber cable from splitter to Optical network unit (ONU). Otherwise, ΔL is the path length different between ONU 1 and ONU 2. In this concept, to get fully constructive interference for monitoring signal ΔL must be include at it exact position depends on the calculation result. In addition, a similar distance of fiber length will also produce a constructive spectrum. Different wavelength is used to lead to the differences in path length between two fiber cable (ΔL) values. In this case, to simplify the calculation value of the path length difference, the value of m is fixed to 1×108 and we use the L-band source with the wavelength range between 1587 nm to 1594.5 nm.

III. SIMULATION VALIDATION

In this system, we can identify signal fault for each ONU. Current methods that use an optical time domain reflect meter (OTDR) for fault localization are only suitable for application in point-to-point (P2P) networks, due to the single wavelength of short pulse OTDR signals .Employing an OTDR for point-to-multi-point (P2MP) networks involves engineers to go to the breakdown location, it is difficult to differentiate faulty branches from the multiply spectra of point-to-multipoint (P2MP) networks.

In this monitoring system an L-band ASE source is used as the monitoring source. The downstream signal, at wavelengths of 1490 nm, propagates with the monitoring source along 18 km of feeder fiber to the remote node. Along in the fiber link, several losses have to be included based on real application. The optical circulator insertion loss is 1 dBm [6]. The attenuation coefficient, a, of the single mode fiber (SMF) distribution is 0.2 dB/km [7]. The symmetrical power splitter insertion loss be governed by the splitting ratio based on the insertion loss. The insertion loss for 1x4, 1x8, 1x16, 1x24 and 1x32 are 7.2dBm, 10.5dBm, 13.5dBm, 15dBm, and 16.5dBm, respectively [8]. In this system, the amplitude of different branches is determined due to the different bandwidth that we used. When fiber failure is detected, the digital signal processor (DSP) triggers the switch, allowing the OTDR for fault localization. The monitoring and fault localization system result are shown in Figure 4 and Figure 5.

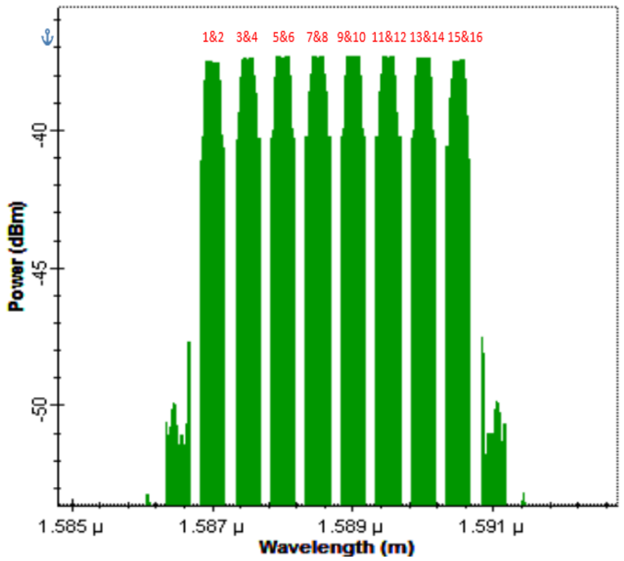

Figure 4: The monitoring system for 8 spectra represents 16 customers

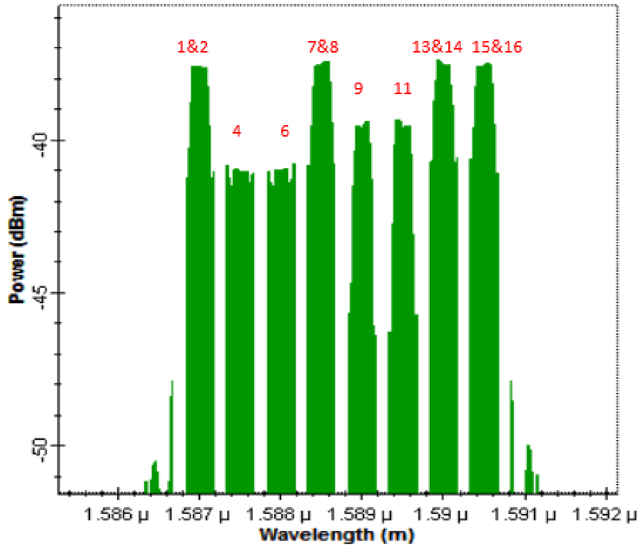

Figure 5: The monitoring system for 8 spectra represents 16 customers (ONU) with fault localization

Figure 4 shows normal condition for 16 customers. From the figure, it can be perceived that there are 8 FBGs spectra which represent 16 customers. One Bragg wavelength represents 2 customers based on bandwidth optimization concept. 16 customers are represented by the 8 FBGs spectra with difference wavelength, bandwidth reflectivity, and fiber optic length between FBG and ONU. The L-band source in this system is from 1565 nm to 1615 nm. The path difference in each wavelength is 0.5 nm to prevent the destructive interference. To maximize the monitoring spectrum and overcome the limited bandwidth for L-band source problem, we placed one wavelength for every two customer. Two types of FBG spectrum is used; an FBG with bandwidth of 0.3nm and 95% reflectivity and another FBG with bandwidth of 0.85 nm and reflectivity of 65% are placed at the specific location. To produce a fully constructive interference for monitoring purpose the distance of the FBG from the splitter must be calculated. The different fiber optic length in this system must be place accordingly to the interference formula as show in equation (1). The theoretical values show us that the constructive interference signal will produce four times greater when two signal combine, Figure 5 shows the monitoring system for 8 FBG spectra that represent 16 customers with fault at branch 3, 5, 10 and 12. There is no reflection spectrum of the FBG, indicating that there is a fiber breakdown at branch 3, 5, 10 and 12 of the optical network user.

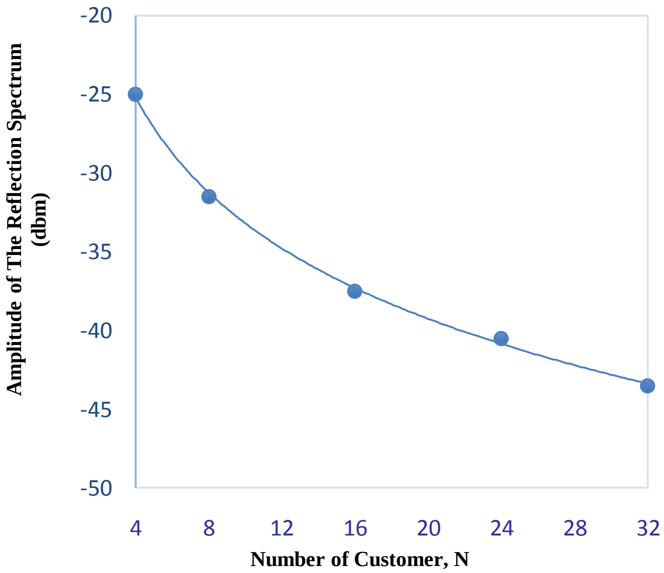

Figure 6: Amplitude power of the first peak reflection spectrum versus number of customer

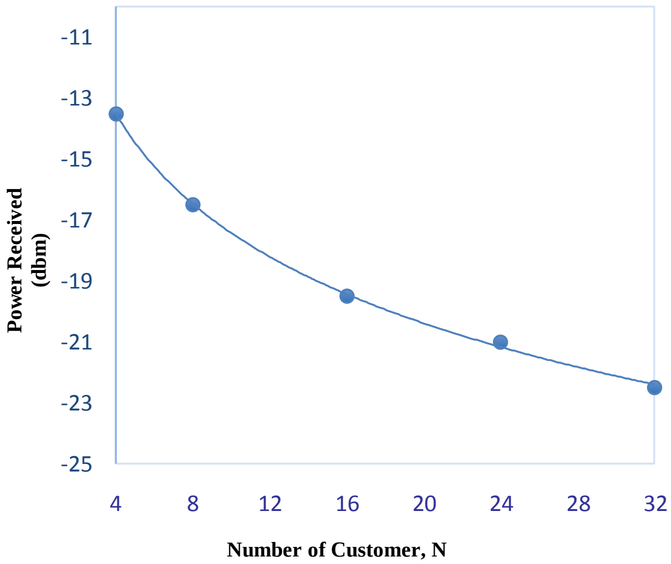

Figure 7: Monitoring power received versus number of customer

Figure 6 shows the amplitude power of the first peak reflection spectrum against optical network unit (ONU) which drops as the number of optical network unit (ONU) increases. This happen due to higher insertion loss of the splitter as number of customers increase. The lowest amplitude detected is at 32 customers and the value is -43.5 dBm. The highest amplitude detected is at 4 user which is the value is -25 dBm. For the monitoring power received versus number of customer in Figure 7 the received power inversely proportional with the number of customer, N. The monitoring power received for 4, 8, 16, 24 and 32 customers is -13.5 dBm, -16.5 dBm, -19.5 dBm, -21 dBm, and -22.5 dBm, respectively. Figure 8 displays the bit error rate (BER) performance with monitoring system and without monitoring system for the downstream signal at optical network user (ONU) versus power received. Besides, there is a very slight power penalty of 0.2 dB for the optical network with and without the monitoring system. Thus, this monitoring system had a very minimum effect on the network, which is negligible.

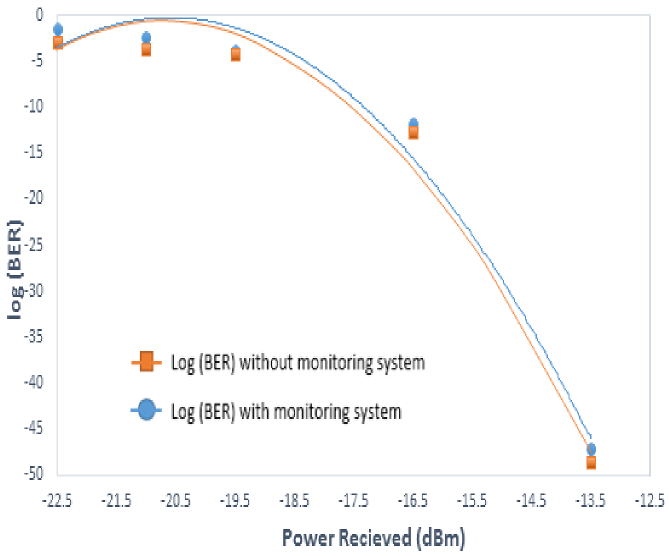

Figure 8: BER performance with monitoring system and without monitoring system for the downstream signal at ONU 1 versus power received

This technique has a lot of advantages compared to the normal system. By using this technique, the system failure can be detected early without waiting customer to call or complain like a normal system. Secondly, this system is able to monitor any failure in the ONUs without going to the site while the transmission and reception of the data in the network is not been disturbed. Moreover, the system applies optimized wavelength for monitoring thus, will save the bandwidth slot and cost of the operation. On top of that, this system will adapt to the existing optical network without disturbing the infrastructure of the network. Finally, we can conclude that this system can only monitor up to 32 customers with excess power margin of 2 dB and monitoring power received of -43.5 dBm.

IV. CONCLUSION

In this paper, real-time monitoring of Ethernet passive optical network is demonstrated. A Fiber Bragg Grating (FBG) is inserted at each distribution fiber at specific location by employing constructive interference concept so that the FBGs spectra generated is . The advantages of this monitoring system are that it saves the monitoring bandwidth, low cost of operation and low complexity. This system is capable to monitor up to 32 customers with excess power margin of 2 dB and monitoring power received of -43.5 dBm. It can be concluded, the efficient monitoring and fault localization system that can monitor a large number of customers is achieved.

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REFERENCES

[1] J. Walker, D. Halliday, and R. Resnick, Fundamentals of Physics, 10 ed.: John Wiley & Sons, Inc. , 2013.

[2] N. F. Naim, M. S. Ab-Rahman, H. A. Bakarman, and A. A. A. Bakar, "Real-time monitoring in passive optical networks using a superluminescent LED with uniform and phase-shifted fiber Bragg gratings," Optical Communications and Networking, IEEE/OSA Journal of, vol. 5, pp. 1425-1430, 2013.

[3] N. F. Naim, M. S. Ab-Rahman, N. H. Kamaruddin, and A. A. A. Bakar, "Real-time monitoring and fault locating using amplified spontaneous emission noise reflection for tree-structured Ethernet passive optical networks," Optical Engineering, vol. 52, pp. 096112-096112, 2013.

[4] M. A. Esmail, N. N. Alotaibi, and H. Fathallah, "Fiber Ring Encoder for PON Fault Monitoring," in Communication Networks and Services Research Conference (CNSR), 2010 Eighth Annual, 2010, pp. 69-73.

[5] M. M. Rad, K. Fouli, H. A. Fathallah, L. A. Rusch, and M. Maier, "Passive optical network monitoring: challenges and requirements," Communications Magazine, IEEE, vol. 49, pp. s45-S52, 2011.

[6] Fiber optical circulator, OZOptic, 219 westbrook Road, Ottawa, ON, Canada, KOA 1L0. sales@ozoptics.com

[7] HFBR-EXXYYYZ Series (POF), Plastic Optical Fiber Cable and Accessories for Versatile Link, Avago Technologies. www.avagotech.com

[8] 3M Planar Light Circuit (PLC) Splitters, Communication Markets Division 6801 River Place Blvd. Austin, TX 78726-9000 800/426 8688 Fax 800/626 0329 www.3M.com/Telecom.