The Characterization of Radio-over-Fiber Employed GPON Architecture for Wireless Distribution Network

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***Abstract*—Radio-over-Fiber (RoF) technology provides the base platform for the integration of wireless and optical systems. On the other hand, Gigabit Passive Optical Network (GPON) has gained much interest in today's networking due to the flexibility, simple and low cost passive connection. For instance, GPON technology has been successfully deployed in Fiber-to-the-Home (FTTH) that support Triple-Play services which combine the internet data, telephony and video to the home through only single cable. Thus, many research works today focus in accommodating the RoF employed GPON architecture to exploit the bandwidth (BW), maximize the capacity and reduce the cost of development. Hence, this project aimed to characterize the distribution of IEEE 802.11 WLAN service using RoF technique in GPON network architecture by means of simulation which was done in commercial OptiSystem software. The bidirectional transmission was used with fiber length varied from 2-20 km. The analysis was made based on the performance of BER, OSNR and the received power. The simulation results show that the system scheme exhibits the performance standards.**

***Index Terms*— GPON, RoF, OptiSystem, SNR**

I. Introduction

Wireless communication these days demands for high speed, promising, flexible and low cost solutions. The request for high BW is vital in many areas due to rapidly increasing of subscribers, the advance of computing and wide-range of applications being offered such in the satellite communication, the high-definition (HD) video-on-demand and broadband mobile internet, with high quality and guaranteed of data delivery are desired. A new method is needed to fulfill these requirements. The first choice that was seen before is to adopt the picocells concept to serve more users and also shifting from low ISM frequency band that is already congested to high frequency of operations. However, the operations in smaller (micro-/pico-) cells lead to the increasing of hardware development costs while working in high frequency majorly suffers from high signal attenuation.

Lined up with the popularity of wireless networks, optical technology has also played an important role in the telecommunication world. Fiber optic is widely used in the backbone network due to its high BW (up to THz) and low attenuation (~0.2 dB/km) characteristics. Thus, fiber optic is promising to be the core of wireless networks. The integration of wireless and fiber is known as Radio-over-Fiber (RoF) which complements the flexibility of wireless signal and the advantageous properties of fiber optics. Technically, RoF is a hybrid system that integrates the wireless and optical in one system leading towards high capacity, high data rate, transparent and mobility solution [2]. RoF allows the cost reduction and easier controlling and upgrading by a centralized architecture that connects a number of Remote Base Station (RBSs) to the Central Station (CS).

With the incorporation of wireless and fiber, an efficient technology is needed to enhance the system development. Passive optical network (PON) offers more advance features for network access such as broadcasting and capable to exploit maximum capacities with an appropriate development cost and also better security. Moreover, since the development of fiber network involves high marginal cost, the existing PON network provides the cheapest solution without utilizing each wireless and wired signals BW by properly manage the BW allocation plans. Therefore, RoF over PON is an attractive method and provides the most cost-effective architecture for the network plant in delivering the radio signal [4]. Gigabit-PON (GPON) and Ethernet-PON (EPON) are the most two popular PONs in which GPON is widely deployed in America while EPON in Asia [7]. Compared to EPON, GPON is more advantageous, more robust, offers more capacity and has higher profitability [5] [6].

The works on the distribution of the mobile 3G on GPON have been done in [10] [11] with limited number of ONU due to the Universal Mobile Telecommunication System (UMTS) channel limitation. In [13], the integration of wireline and wireless services has been proposed but only concentrating on a single network connection. Good BER (10^{-13}) was achieved with fiber length extended to 45 km. However, the power budget performance was less analyzed. Apart from that, this work will focus on the distribution of wireless based on IEEE 802.11 to a higher number of users employing GPON architecture by using RoF transmission technique.

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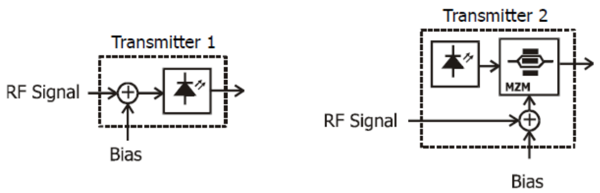
II. RoF on GPON Architecture

A. Radio-over-Fiber (RoF) Techniques

The RoF techniques have been discussed in many research works [1-4]. RoF is fundamentally an analog transmission system because it distributes the radio waveform directly at the radio carrier frequency. The analog signal can be RF signal, IF signal or baseband (BB) signal. However, the modulation format of the radio signal itself such as Quadrature Phase Shift Keying (QPSK) and Quadrature Amlitude Modulation (QAM) that are used in WLAN systems remains in digital form.

All of the optical links transmitting microwave signals apply the intensity modulation of light as the direct intensity modulation is the simplest compared to the external modulation and remote heterodyning method [1]. A direct modulation as shown in Figure 1 defines for a semiconductor laser that directly converts a small-signal modulation (around a bias point set by a dc current) into a corresponding small-signal modulation of the intensity of photons emitted (around the average intensity at the bias point). Thus, a single device serves both of the optical source and the RF/optical modulator. Combining the direct detection at the photodetector (PD), this method is named as the Intensity Modulation-Direct Detection (IM-DD).

In RoF networks, simple and cost effective components are needed to cover the high number of BSs. Therefore, the direct intensity modulation with cheap lasers can be used. However, by using the external modulator such as Mach Zehnder Modulator (MZM), the dispersion effect can be minimized; thus, this is preferred most in any RoF system [4].



(a) (b)

Fig. 1. IM-DD technique (a) Directly modulated RF (b) Using external modulator

B. GPON Architecture

GPON is an all-optical transmission based network which aims at providing a high speed network connection. The characteristics of GPON technology has been standardized by International Telecommunication Union-T (ITU-T) in Recommendation G.984 series [10]. GPON supports data rate of 2.5 Gbps for downstream and two options of 1.25/2.5 Gbps for upstream transmission. The physical configurations can be seen by the splitting ratio and the distance of OLT-ONU. Theoretically, the splits can be up to 64 but due to the current hardware limitations, the development so far can only reach 32. The maximum physical length from the OLT to ONU is 20 km. The downstream and upstream traffics are transmitted at 1490 nm and 1310 nm while 1550 nm wavelength is allocated for RF or video analog [8]. Table 1 summarizes the properties of GPON technology.

Figure 2 shows the integration of RoF on GPON architecture. The signal processing such as electrical-optical modulation is done in the CS before the Optical Line Termination (OLT) transmits the optical signal to the fiber. A passive splitter at the Optical Distribution Network (ODN) routes the signal to the respective users. The simplest RoF on GPON design is to use an independent RF module at the CS and also RAU at the ONU/BS. This is to ensure that this integration will not utilize the existing GPON data signal BW itself (wired applications). Then, handover method for wireless scheme will be easier when any mobile user moves to the other BS coverage area [13]. Since this work focuses on the distribution of the RoF technique using the GPON network architecture, the existing GPON wired data signal BW will be not considered.

TABLE I: GPON Properties

Quantity	Value
Standard	ITU-T G.984
Data rate (downstream)	1.25/2.5 Gbps
Data rate (upstream)	2.5 Gbps
Wavelength (downstream)	1490 or 1550 nm
Wavelength (upstream)	1330 nm
Max PON splits	64 (Theoretical) 32 (Developed)
Max Distance	60 km (Theoretical) 20 km (Developed)

In BS, the signal conversion and regeneration took placed where the Optical Network Unit (ONU) is responsible for optical signal detection. In the downstream direction, GPON uses the method of broadcasting the signals to all users while in upstream direction, the concept of Time Division Multiple Access (TDMA) applied where all BSs are allocated specific time for data transmission.

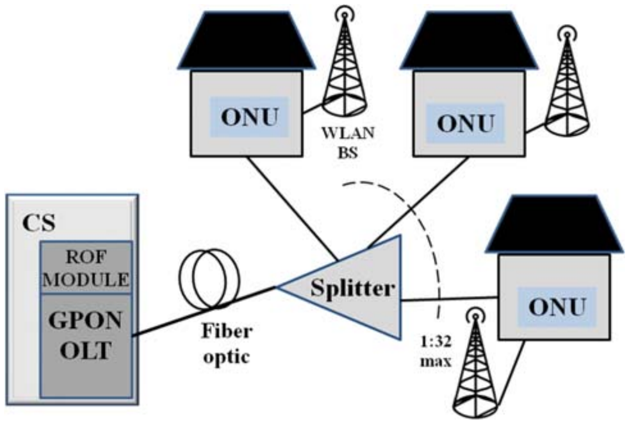


Fig. 2. A typical RoF on GPON architecture

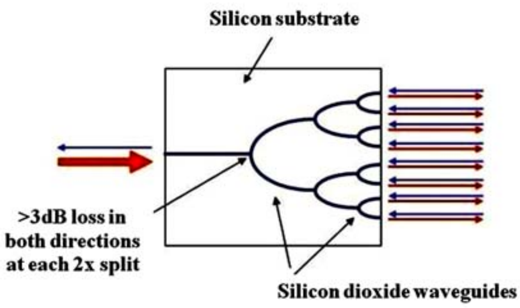


Fig. 3. A planar lightwave circuit (PLC) splitter

One of the important devices that makes GPON is an attractive networking solution is the existence of unpowered, passive optical splitter. The splitter is available in a variety of splitting ratios, including 1:8, 1:16 and 1:32. Both Planar Lightwave Circuit (PLC) splitter and Fused Biconical Taper (FBT) splitter are used in GPON network. One type of 1:8 PLC splitters use silica dioxide waveguide is shown in Figure 3. Each 1:2 split introduces 3 dB loss in both splitter directions. A commercial 1:32 splitter insertion loss is about 17 dB [15].

III. Simulation Design

This section briefly describes the simulation setup in OptiSystem where all necessary parameters are based on the GPON standardized properties. The design in Figure 4 shows the development of the bidirectional transmission for RoF employed GPON architecture. One transmitter (Tx) and receiver (Rx) are used at OLT and distributed to the 32 ONUs. Bidirectional fiber is used with length varied from A bidirectional 1:32 passive optical splitter is used to connect the ONUs to the backbone fiber. Finally, the upstream and downstream signal separated by the optical circulator and optical delay introduced at the fiber to ensure the correct timing of circulation.

Figure 4 shows the schematic design of Tx and Rx module that is identical for both OLT and ONU. At the Tx, the data signal is generated by the Pseudo-Random Bit Sequence Generator (PRBS) where the bit rate is set at 2.5 Gbps and the chosen working frequency is 5 GHz which operated as IEEE 802.11a signal. The data is then modulated by a Phase Shift Keying (PSK) modulator. Rectangle band-pass filter used at both Tx and Rx to obtain only the required spectrum. The optical modulation that consists of CW Laser Diode (LD) and Mach Zehnder Modulator (MZM) which works at 1490 nm prepared the electrical signal to be transported through the bidirectional fiber. At the Rx, after photodetection (PD), the signal is amplified and filtered to regenerate the desired signal. The signal then fed into the spectrum and BER analyzers for data analysis. These hardware configurations are summarized in Table 2.

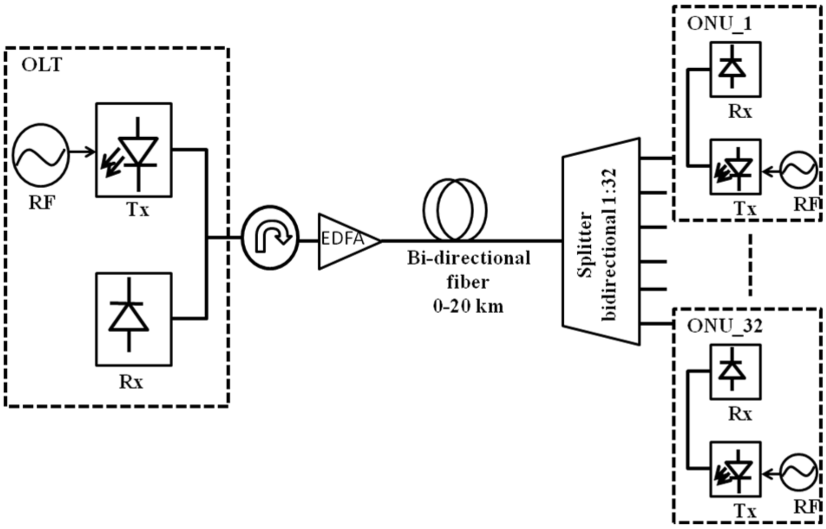


Fig. 4. Simulation set up in OptiSystem

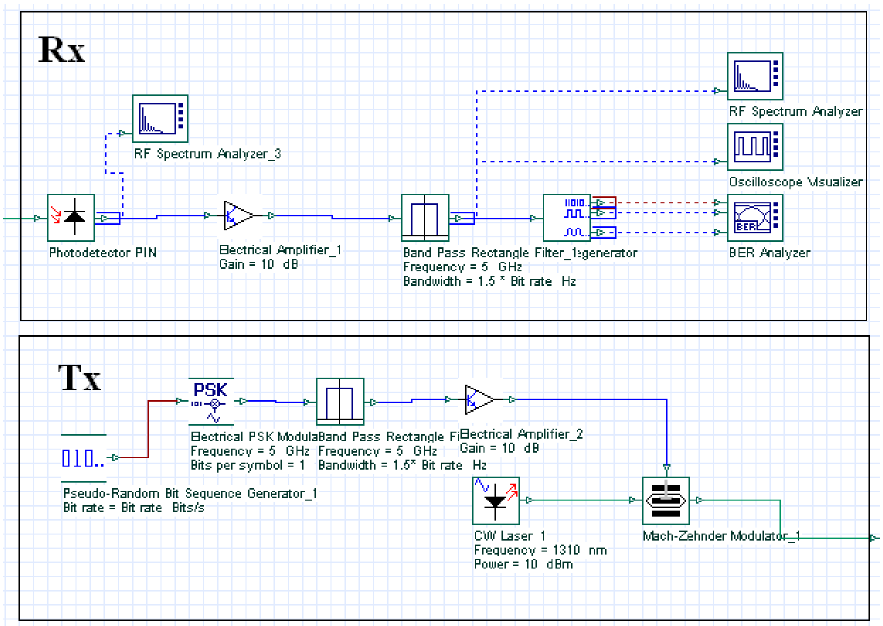


Fig. 5. Simulation set up in OptiSystem

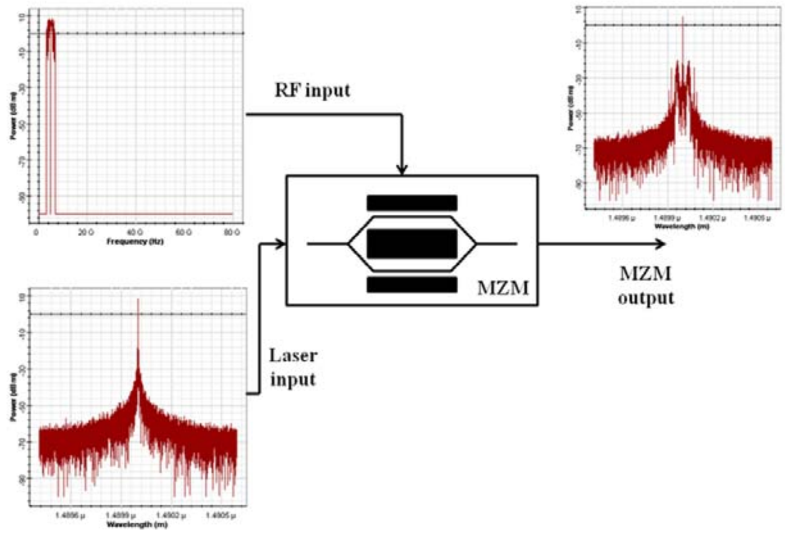


Fig. 6. Modulation of a Mach Zehnder modulator at the CS

TABLE II: HARDWARE CONFIGURATIONS

Quantity	Value
Fiber optic	Attenuation = 0.2 dB/km
	Dispersion = 16.75 ps/nm/km
	Length = 2-20 km
Erbium Doped Fiber Amplifier (EDFA)	Length = 5 m
Pseudo Random Bit Sequence (PRBS) Generator	2.5 Gbps (DS/US)
Laser diode	Power = 10 dBm
Mach-Zehnder Modulator	Extinction ratio = 30 dB
Photodetector	Responsivity = 0.9 A/W
Phase Shift Keying (PSK) Modulator	Frequency = 5 GHz
Rectangle band-pass filter	0.75*Bit rate
Splitter bidirectional	1x32

At the CS, the modulation at the MZM can be seen in Figure 6. The laser is modulated by the RF signal and produced at the output with the positive and negative sides. In addition, the Sub-carrier Multiplexing (SCM) modulation technique where a number of RF signals are multiplexed and transmitted on a single wavelength, there will produce more sidebands at the MZM output. Thus, SCM is attractive to deliver several wireless schemes using RoF technique over a single optical network.

I. SIMULATION RESULTS AND ANALYSIS

Based on the above design, the simulation is done and the analysis of the outcomes is presented. Similar performance observed for both downstream and upstream transmission. The results are also identical for 32 ONUs. The eye diagram that is plotted in Figure 7 shows a good opening of the signal and system noise with some numbers of harmonic with the eye height is about 1.2 m a. u. In order to reduce the harmonic, a suitable filter would be the main improvement factor.

Figure 8 simplified the BER at varied fiber length from 2 to 20 km. The performance of the BER is related to the existence of noise in the system. The system noise is mainly contributed by the amplification process by the EDFA. However, other components also have their own noise such as fiber optic dispersion and the Intersymbol Interference (ISI) effects. Obviously, it can be seen in Figure 8 that BER increases with increasing fiber length. Nevertheless, considering the worst case, at 20 km the BER is observed to be 10^{-17} which is lower than the standardized minimum 10^{-10} BER for GPON technology [8].

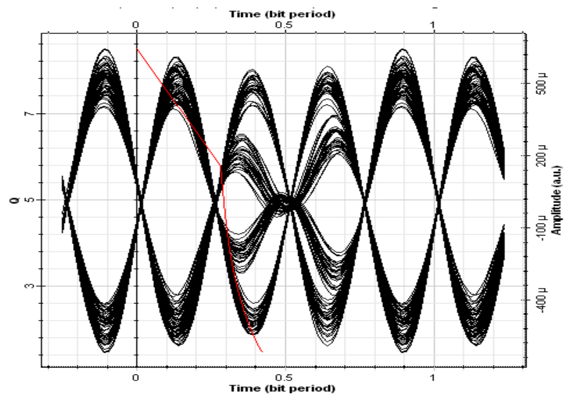


Fig. 7. Eye opening at 20 km fiber

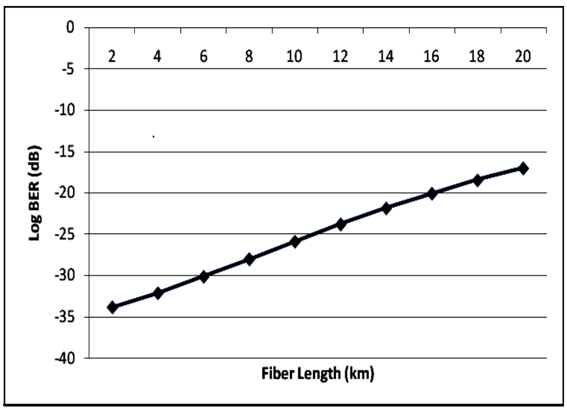


Fig. 8. BER (dB) for 2-20 km fiber

The OSNR performance for the varied fiber length is shown in Figure 9. It can be seen that the OSNR has a decrease pattern along the extension of fiber length. OSNR presents the difference between the amplitude of optical carrier data signal and the noise signal. In order to have higher OSNR, noise power in the system must be properly controlled. In certain optical system, the OSNR must reach 20 dB [16]. From the result, at 20 km, the OSNR achieves 44.4 dB which is particularly good for this network.

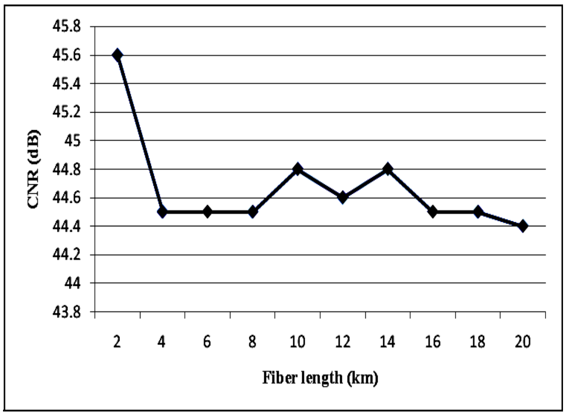


Fig. 9. BER (dB) for 2-20 km fiber

BER and OSNR are two important performance parameters in any data transmission system which shows the capability and accuracy of the system configurations. The relation between the BER and OSNR can be stated in the following equation:

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{OSNR}{2}}\right) \quad (1)$$

As the fiber length increases, there are more noise involved in the system and power attenuation will be severed. Thus, OSNR will be reduced which in turn, worsen the BER value. In designing any system, choosing hardwares with low noise is an essential solution to improve the OSNR and BER performances.

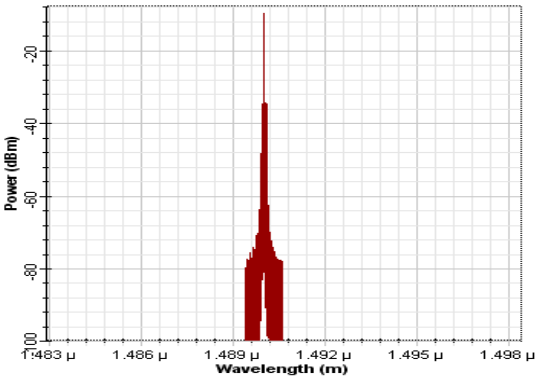


Fig. 10. Optical spectrum at Rx detection

The optical carrier spectrum after the splitter at one of the ONU Rx detection is presented in Figure 10. The operating wavelength for this system is 1490 nm. Figure 11 illustrates the received optical power at different fiber length. The power is found to be reduced linearly with the increasing fiber length. The higher signal attenuation occurred at longer fiber distance. It can be observed from the figure, at 20 km fiber, the optical power at the Tx section is 10.13 dBm and the received optical power at the Rx section with 20 km fiber is -9.72 dBm. The total signal attenuation from fiber spans is about 19.85 dB. This value is in range specified by the G.984 [8]. For long-haul communication, a usage of repeater is required since the attenuation become worsens.

After the photodetection, an electrical amplification is necessary to gain up the electrical signal. Finally, by means of filtering, the data signal is regenerated at the 5 GHz working frequency as shown in Figure 12.

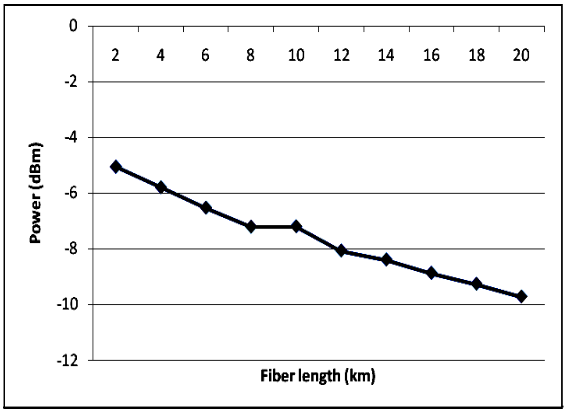


Fig. 11. Optical power at the Rx

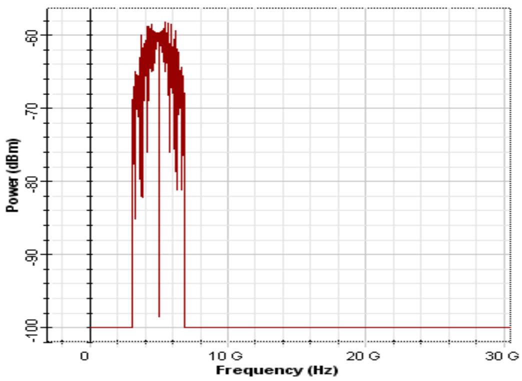


Fig. 12. RF spectrum regenerated at the 5GHz working frequency

II. Conclusion

In this work, a performance characterization of RoF employed GPON architecture has been made to analyze the physical capabilities of the system in transporting wireless internet. Good results obtained at the maximum fiber distance where lower BER, and higher OSNR observed than the value specified in the standard. Good power budget has also been calculated. As a result, the data signal has been captured at the desired working frequency with simple hardware configurations.

With high bandwidth, flexible and simple assessment, RoF and GPON technology is indeed a promising solution for today's communication to support the continuous increasing figure of wireless internet users. The concept of Wavelength Division Multiplexing (WDM) can be applied as future recommendations to efficiently utilize the available BW resources.

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REFERENCES

[1] H.B.,Kim, "Radio over Fiber Based Network Architecture", *IEEE Proceedings in Optoelectronics*, vol. 143, no. 6, pp. 329, October, 2005.

[2] M. Sauer, A. Kobyakov & J. George "Radio over Fiber for Picocellular Network Architectures", *IEEE J. on Lightwave Tech.,* v25 n11, p3301-p3320, 2007.

[3] A. M. J. Koonen and M. Garcia Larrode, "Radio-over-Fiber Techniques-Part II: Microwave to Millimeter-wave Systems", Journal of Lightwave Technology, vol. 26, No. 15, August 1, 2008.

[4] Hamed Al-Raweshidy and Shozo Komaki, "Radio over Fiber Technologies for Mobile Communications Networks", Artech House, Norwood, ISBN 1580531482, 2002

[5] A. V. Osadchiv, K. Prince and I. T. Monroy, "Converged Delivery of WiMax and Wireline Services over an Extended Reach Passive Optical Network", Journal of Optical Fiber Tecnology, Vol. 16, p. 182-186

[6] S. Lallukka and P. Raatikainen, "Link Utilization and Comparison of EPON and GPON Access Network Cost", Proceeding of IEEE Globecome, 2005

[7] M. L. Bonilla, F. R. Barbosa, and E. Moschim, "Techno-Economical Comparison Between GPON and EPON Networks", Proceeding of ITU-T Kaleidoscope Academic Conference, 2009

[8] S. Pato, J. Santos, J. Pedro, P. Monteiro and H. Silva, "On Supporting Radio over Fiber and Passive Optical Network Systems with a Common Fiber Plant: Compatibility Aspects," Proceeding of ITCON, 2008

[9] ITU-T Recommendation G.983.1, "Broadband optical access system based on Passive Optical Network (PON)", ITU 2005.

[10] ITU-T Recommendation G.984.1, "Gigabit-capables passive optical network (GPON)", ITU, 2008.

[11] Bras, H.L. and M. Moignard, "Distribution of 3G Base Stations on Passive Optical Network Architecture, Microwave Photonics, International Topical Meeting, 2006: p. 1-4.

[12] Kaoru Imai, et.al., "3G Cellular Phone Signal Optical Transmission over Gigabit E-PON System", Microwave Photonics, MWP, International Topical Meeting, 2005: p. 47-50.

[13] Gangxiang Shen, et. al., "Fixed Mobile Convergence Architectures for Broadband Access: Integration of EPON and WiMAX", *IEEE Communication Magazine*, Aug. 2007.

[14] A. Vukovic, K. Maamoun, H. Hua and M. Savoie, "Performance Characterization of PON Technologies",

[15] Datasheet www.samsungfiberoptics.com

[16] John M. Senior, "Optical Fiber Communications: Principle and Practice", 3rd Edition, Prentice Hall, UK, ISBN 9780130326812, 2009.

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