The Performance Limitation of 10-Gbps-per-Channel-based Coarse Wavelength Division Multiplexed Passive Optical Network

Pimchanok Montha*, Rachata Maneekut**, and Pasu Kaewplung***

Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University

Phayathai Rd., Pathumwan, Bangkok, Thailand, 10330

pimchanok.m@student.chula.ac.th*, rachata.ma@student.chula.ac.th, and pasu.k@chula.ac.th*****

Abstract— **In this paper, we study the performance limitation of the 10-Gbps-per-channel-based coarse wavelength division multiplexed passive optical network (CWDM-PON). The computer simulation results, which are in a good agreement with the theoretical calculation results, show that the transmission of all 16 CWDM channels (1,271-1,571 nm) is successfully obtained at the maximum reach of 68.2 km under FEC limit (BER= 10^{-4}). Both fiber attenuation and fiber dispersion are the main factors that limit the achievable reaches for different channel wavelengths. The power budget, which is useful for the design of the 16×10-Gbps-based CWDM-PON, is found to be 38.65 dB.**

Keywords— **fiber access network, passive optical network, coarse wavelength division multiplexing, fiber attenuation, fiber dispersion.**

I. INTRODUCTION

Nowadays, the data bandwidth consumption is increasing rapidly owing to the growth of broadband services such as IP-3D-HDTV and HD video conference. Fiber-to-the-x (FTTx) based on passive optical network (PON) technology can provide sufficient data rate for those services with the reduction in operation costs. Currently, most of PON technologies available in telecommunication market are utilizing the time-division multiplexed (TDM) scheme, in which the total data rate per PON is shared among subscribers using the dynamic bandwidth allocation (DBA). The incumbent TDM-PON is currently evolving to provide the data rate of 10-Gbps for both uplink and downlink according to 10GE-PON and 10-Gigabit-capable PON (XG-PON), standardized by IEEE and ITU-T, respectively [1], [2].

However, to support the ever-increasing bandwidth demand such as for services of the ultra-high-definition video stream (4K and 8K), which will be certainly available in a very near future, the data rate class of 10-Gbps-per-subscriber without time sharing becomes necessary. For this case, coarse wavelength-division multiplexed (CWDM)-PON is one of the attractive solutions to resolve the bandwidth limitation of existing PON technologies [3]. However, there is still no any common standard which has been established for such CWDM-PON.

In previous work [4], only 4 CWDM wavelengths with the data rate per wavelength less than 10 Gbps has been studied. In this paper, we study the performance limitation of CWDM-PON based on the data rate of 10-Gbps per subscriber using both computer simulation and theoretical calculation. In case that the total data rate is 160 Gbps (16 × 10 Gbps). Our result shows the maximum reach of 68.2 km, and the power budget is found to be 38.65 dB.

II. CWDM-PON SYSTEM CONCEPT

Coarse wavelength division multiplexing (CWDM), defined in ITU-T G.694.2, is a low cost WDM technology in which the usable wavelengths are assigned within the range 1,271 nm to 1,611 nm with the grid 20 nm [5]. In this paper, we use the CWDM wavelengths over the WDM-PON: therefore; we can specify this type of WDM-PON as the CWDM-PON.

Figure 1 shows the configuration of CWDM-PON, which consists of optical line terminal (OLT), 16 optical network units (ONUs), 2 arrayed waveguide gratings (AWGs), and single-mode fiber (SMF) ITU-T G.652.D [6]. Assuming that the OLT has full 16 CWDM wavelengths with the data rate of 10 Gbps per wavelength, it is capable for delivering the total data rate 160 Gbps per PON. One AWG acts as a multiplexer at OLT site, while the other AWG works as a passive wavelength splitter for delivering different CWDM wavelengths to different ONUs locating at subscriber end points.

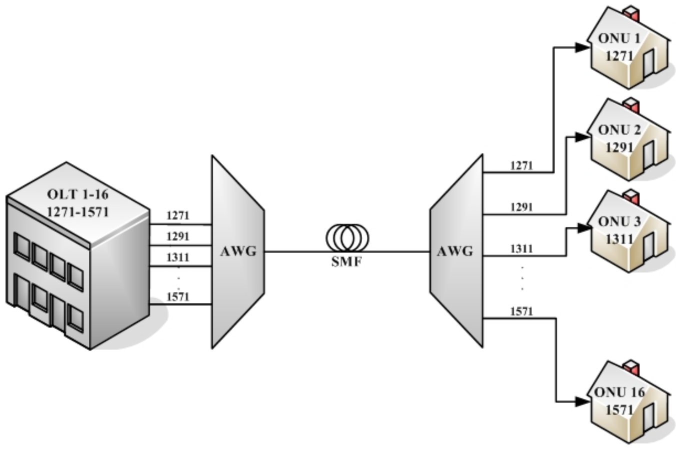

Figure 1. Configuration of CWDM-PON

III. PERFORMANCE ANALYSES

A. Theoretical Calculation

TABLE 1. CHARACTERISTIC PARAMETERS OF CDWM-PON

Items	Applications	Max. values	Units	Ref.
SMF's attenuation coefficient	1271 nm	0.385	dB/km	[6]
	1291 nm	0.370		
	1311 nm	0.350		
	1331 nm	0.340		
	1351 nm	0.320		
	1371 nm	0.300		
	1391 nm	0.320		
	1411 nm	0.275		
	1431 nm	0.243		
	1451 nm	0.225		
	1471 nm	0.213		
	1491 nm	0.203		
	1511 nm	0.196		
	1531 nm	0.191		
	1551 nm	0.190		
	1571 nm	0.192		
Connector loss	SMF	0.5	dB	[7]
Splice loss	SMF	0.1	dB	[8]
AWG insertion loss	16-ch CWDM	4.0	dB	[9]
SMF's dispersion coefficient	1271 nm	-4.300	ps/km/nm	[6]
	1291 nm	-2.100		
	1311 nm	-0.093		
	1331 nm	1.730		
	1351 nm	3.473		
	1371 nm	5.143		
	1391 nm	6.744		
	1411 nm	8.283		
	1431 nm	9.761		
	1451 nm	11.185		
	1471 nm	12.557		
	1491 nm	13.882		
	1511 nm	15.161		
	1531 nm	16.399		
	1551 nm	17.597		
	1571 nm	18.758		

The power budgets of the CWDM-PON from OLT (Tx) and to ONU (Rx) is given by

$$P_T = P_{Tx} - P_{Rx} = \sum l_c + \sum l_s + \sum l_{AWG} + \alpha L + G_{margin}, \qquad (1)$$

where P_T is the power budget, P_{Tx} is the transmit power, P_{Rx} is the receiver sensitivity, l_c is the connector loss, l_s is the splice loss, l_{AWG} is the AWG insertion loss, α is the attenuation coefficient, L is the fiber length and G_{margin} is the power margin. All are in dB unit.

In (1), substituting P_{Tx} = 10 dBm, P_{Rx} = -30 dBm, according to Table 1, the total connector loss = 1 dB, the total splice loss = 0.4 dB, the total AWG insertion loss = 8 dB, G_{margin} = 3 dB, and α, which is dependent of CWDM wavelengths, we can estimate the maximum reach limited by fiber attenuation.

Moreover, since the accumulated dispersion tolerance for the data rate of 10 Gbps is 1,600 ps/nm [10], we can also calculate the maximum reach of each wavelength limited by fiber dispersion. Both maximum reaches determined by the fiber attenuation and the fiber dispersion are shown in Table 2 for different CWDM wavelengths.

TABLE 2. MAXIMUM REACHES BY THEORETICAL CALCULATION

Items	Wavelengths	Reaches limited by fiber attenuation [km]	Reaches limited by fiber dispersion [km]
PON reach	1271 nm	71.69	372.10
	1291 nm	74.59	761.90
	1311 nm	78.86	17183.98
	1331 nm	81.18	925.11
	1351 nm	86.25	460.70
	1371 nm	92.00	311.11
	1391 nm	86.25	237.23
	1411 nm	100.36	193.18
	1431 nm	113.58	163.91
	1451 nm	122.45	143.04
	1471 nm	129.76	127.41
	1491 nm	136.03	115.26
	1511 nm	141.10	105.53
	1531 nm	144.65	97.57
	1551 nm	145.88	90.93
	1571 nm	144.13	85.30

B. Computer Simulation

We perform the computer simulation based on configuration of CWDM-PON shown in Figure 2 by using OptiSystem software.

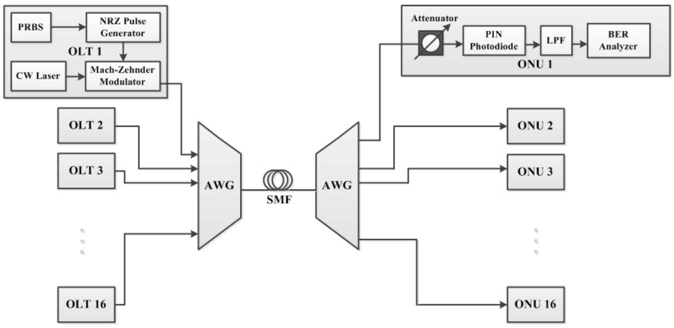

Figure 2. System configuration of CWDM-PON System

16 CWDM optical carriers are generated by using an array of CWDM continuous-wave (CW) laser. Each CW laser is modulated to exhibit the non-return-to-zero on-off keying (NRZ-OOK) shape by a Mach-Zehnder modulator with the signal power of 10 dBm and the data rate of 10-Gbps-per-channel, respectively. Then, all modulated signals are multiplexed by AWG and launched into a fiber. Then, the second AWG, installed outside plant, is a passive wavelength splitter for delivering different CWDM wavelengths to different ONUs. At each ONU, the optical signal is detected follow by a 7.5 GHz low-pass filter (LPF) which exhibits Bessel Shape. Finally, we calculate the numerical BER of the detected signal at maximum eye opening [11].

IV. RESULT AND DISCUSSION

Figure 3 depicts the relation between maximum reach and numerical BER, for all 16 CWDM channels ranged from 1,271 nm to 1,571 nm. The achievable reaches for different CWDM wavelengths are determined at BER = 10^{-4} (with FEC). As obtained from figure 3, the maximum reach for CWDM-PON operated with full 16 CWDM wavelength is 68.2 km obtained at the wavelength of 1,271 nm.

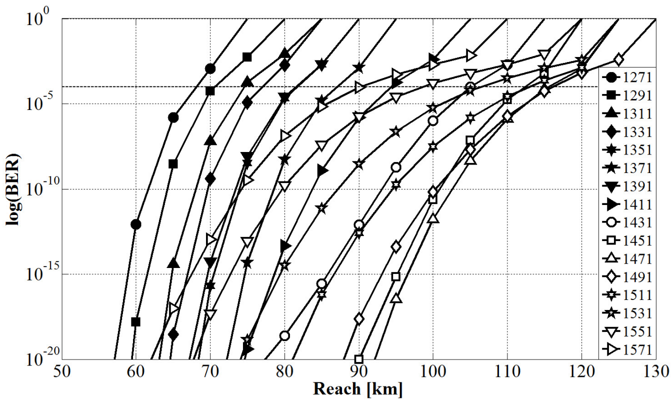

Figure 3. Relation between maximum reach and numerical BER, for all 16 CWDM wavelengths.

The maximum reach, as a function of CWDM wavelength, for the results obtained by computer simulation comparing with those shown in Table 2 is illustrated in Figure 4. Since the fiber attenuation at the wavelength range of 1,271-1,471 nm is higher than the attenuation at 1,491-1,571 nm, it is clearly seen that the fiber attenuation becomes the main factor that limits the achievable distance of the CWDM-PON system, rather than the fiber dispersion, which is higher at the wavelength range of 1,491-1,571 nm than the dispersion at 1,271-1,471 nm. Since the fiber dispersion increases with the wavelength, at 1,491-1,571 nm, where the fiber attenuation is relatively low, we obtain longer reach for the signal at 1,491 nm, comparing with the reach obtained from the signal at 1,571 nm. However, for this case when all 16 CWDM wavelengths are fully used, the CWDM-PON system must support the transmission of all 16 wavelengths to all subscribers. Therefore, the maximum reach of the CWDM-PON using all 16 wavelengths are limited by the fiber attenuation at 1,271 nm, and is found to be 68.2 km with FEC (BER = 10^{-4}). The simulation results, shown in Fig. 4, are in a good agreement with the calculation results, shown in Table 2.

The maximum reach of 68.2 km, obtained from simulation, can be utilized to estimate the power budget by substituting L = 68.2 km back to Eq. (1). Then, the power budget is found to be 38.65 dB. It should be noted that this power budget is a simplified parameter used for the design of CWDM-PON based on link budget calculation.

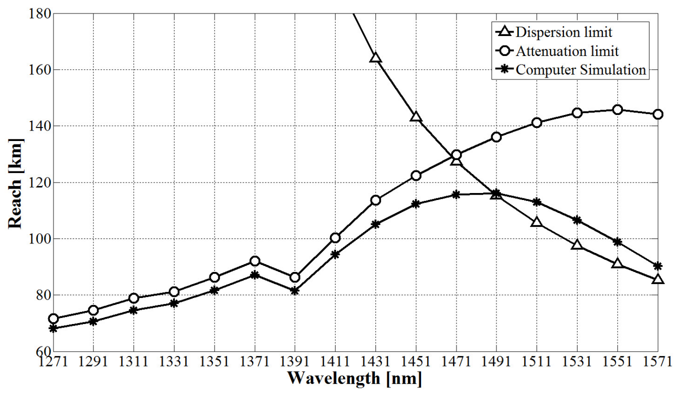

Figure 4. Comparison of maximum reaches obtained by theoretical calculation and computer simulation.

V. CONCLUSIONS

In this paper, we have studied the performance limitation of 10-Gbps-per-channel-based CWDM-PON. Both results obtained from theoretical calculation and computer simulation indicated that the fiber attenuation and the fiber dispersion are the dominant factors that limit the maximum reaches at the wavelength range of 1,271-1,471 nm, and 1,491-1,571 nm, respectively. For CWDM-PON which operates with all 16 CWDM wavelengths, the maximum reach was found to be

68.2 km. This limitation is caused by fiber attenuation at 1,271 nm. Finally, the power budget used for the design of CWDM-PON was estimated to be 38.65 dB.

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Pimchanok Montha received B.E degree from microwave and lightwave communication laboratory (MLC), department of electrical engineering, faculty of engineering, Chulalongkorn University, Thailand in 2012. She is studying the M.E. degree in electrical engineering from Chulalongkorn University. Her research about optical fiber optical, passive optical network technologies.

Rachata Maneekut received B.E and M.E degrees from microwave and lightwave communication laboratory (MLC), department of electrical engineering, faculty of engineering, Chulalongkorn University, Thailand in 2007 and 2010, respectively. He is currently puesuing the Ph.D in electrical engineering from Chulalongkorn University. His research interests are including optical fiber communication , passive optical network technologies using advance modulation scheme and optical code division multiplexing.

Pasu Kaewplung is an assistant professor at the department of electrical engineering, faculty of engineering, Chulalongkorn University, Thailand. He received the B.S. and M.S. degrees in electrical engineering from Yokohama National University, Yokohama, Japan, in 1996 and 1998, and Ph.D. in electrical engineering from Chulalongkorn University, Thailand. His research activities have been devoted to long-distance large-capacity optical fiber transmission systems, dispersion compensations, and the applications of nonlinear optical effects.