Wavelength Division Multiplexing-Dense Wavelength Division Multiplexed Passive Optical Network (WDM-DWDM-PON) for Long Reach Terrain Connectivity

Vivek Kachhatiya, Shanthi Prince

***Abstract*—The wavelength division multiplexed and dense wavelength division multiplexed passive optical network (WDM-DWDM-PON) is designed and simulated to serve as long reach passive optical network (LR-PON).WDM-DWDM-PON network is simulated and analyzed upto the fiber reach of 100Km with and without dispersion compensation techniques. 16 Downstream WDM channels are modulated at the peak rate of 10Gb/s and 32 upstream DWDM channels are modulated at the rate of 2.5Gb/s. Optimum launch power and maximum reach of the fiber are calculated for each downstream and upstream case.**

***Index Terms*—Wavelength division multiplexing passive optical network (WDM-PON), Dense wavelength division multiplexing (DWDM-PON), Long reach passive optical network (LR-PON), Tunable optical filter (TOF), Wavelength division multiplexer (WDM-MUX) and Dense wavelength division demultiplexer.**

I. Introduction

THEremote area connectivity is always a challenge for service providers because of its geographical location [1-3].As broadband demands increases globally, the services offered are becoming increasingly bandwidth-intensive and supports large mass of user applications [4, 5]. Customer requested service continues to increase like, high speed internet connectivity, high-definition television (HDTV), voice, video services and telephony services simultaneously [6]. Currently, service provider face a significant problem to fulfilling the need due to the cost of the capital expenditure to deploy traditional networks, to support next generation, bandwidth-intensive services and other operational costs are higher than the revenues that these services generate individually [7, 8]. Passive optical network (PON) offers variety of services and enables different architectures to utilize the bandwidth of the optical fiber [9,10].

Under the scenario of innovative conversions between metro networks and access network, long reach passive optical network (LR-PON) rigorously studied to provide services to terrain region. Dense wavelength division multiplexed passive optical network (DWDM-PON) and wavelength division multiplexed passive optical network (WDM-PON) with advanced modulation schemes, coherence and non-coherence methods are proposed and demonstrated in [11-15].

Proposed WDM-DWDM-PON utilizes the advantages of the WDM-PON networks in downstream direction and utilizes the DWDM-PON network advantages in upstream direction. Architecture supports easy up gradation, transparent traffic, robust architecture and widely accepted standards provides high end to end connectivity in downstream direction. Architecture supports individual 2.5Gb/s upstream link and conserves upstream resources. Architecture designed and studied to serve up to 100Km with compensation and without compensation.

The outline of the paper is as follows. Section II, gives a brief overview on the architecture of WDM-DWDM-PON. Section III, describes about the simulated system architecture. Section IV, discuss about the results. Section V concludes the paper

II. WDM-DWDM-PON Architecture

Fig. 1 shows the block diagram of the WDM-DWDM-PON architecture with 16 WDM downstream wavelengths and 32 DWDM upstream wavelengths. In this architecture, 16 wavelengths are modulated using Mach–Zehnder modulator (MZM) and multiplexed using wavelength division multiplexer (WDM-MUX). Erbium doped fiber amplifier (EDFA) at optical line terminal (OLT) strengthens the downstream signal against connector loss, fiber attenuation and splitting loss at the remote node (RN). 32 optical network units (ONUs) are connected to one of the 32-output port of the 32:1splitter. ONUs are equipped with tunable optical filter (TOF) which filters the particular downstream wavelength and using photodiode (PD) filtered wavelength is detected.

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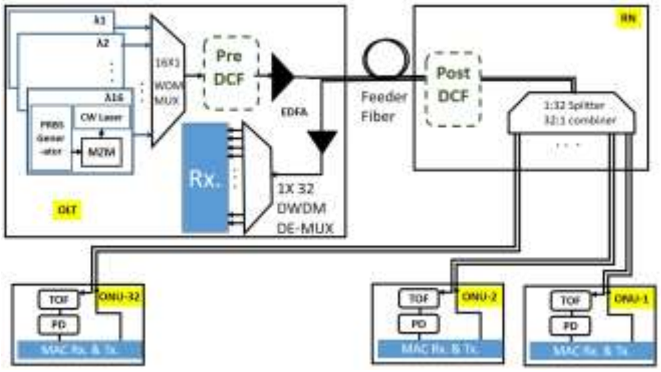
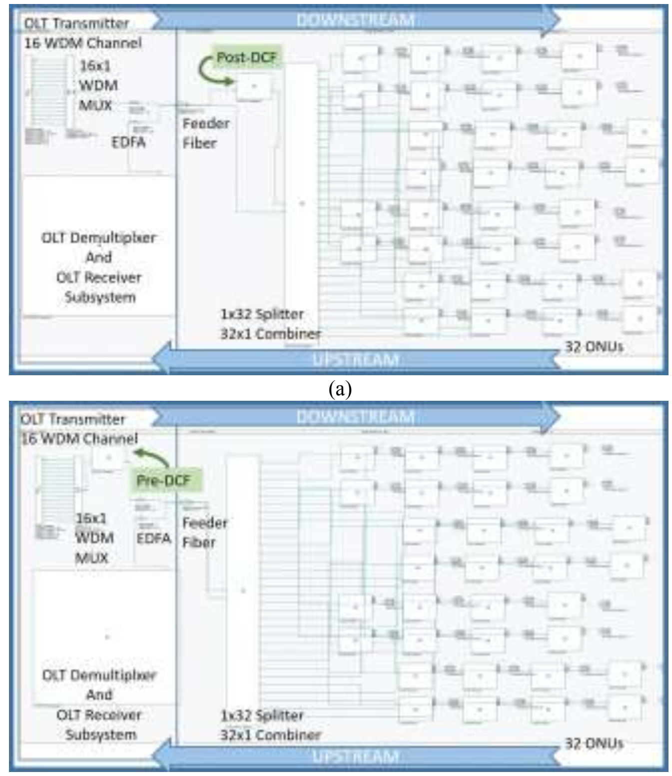


Fig. 1. Proposed architecture of WDM-DWDM-PON

Each ONU transmits at the fixed dedicated wavelength such that frequency spacing (DWDM spacing) between adjacent channels is 50GHz. Combiner combines the upstream wavelength and is fed to bidirectional optical fiber. OLT amplifies the upstream wavelengths using EDFA and demultiplexes the signal using dense wavelength division demultiplexer (DWDM-DE-MUX). Demultiplexed wavelengths are detected at the receiver block. For post-dispersion compensation, dispersion compensation fiber (DCF) is connected at the RN before 32:1 splitter. For pre-dispersion compensation, DCF is connected at OLT before EDFA.WDM-PON downstream and DWDM-PON upstream utilizes the advantages of WDM-PON such as High data rate, transparent data rate and easy upgradability. DWDM-PON reduces spacing between the adjacent channel and conserving resources.

III. Simulated System Architecture

Proposed WDM-DWDM-PON architecture is designed in optical communication design software OptiSystem as shown in Fig. 2. Simulated architecture of the Post-DCF and Pre-DCF are shown in Fig. 2(a) and Fig. 2(b) respectively.16 WDM wavelengths are uniformly spaced (100GHz) between each other starting from 192.1 to 193.6THz. Each of the wavelengths are modulated with 10Gb/s pseudorandom non return to zero (NRZ) bit sequence (order 10^7-1) using MZM external modulator of extinction ratio of 10dB. C-band wavelengths are used in upstream and downstream in system design. 16:1 WDM-MUX is used to multiplex downstream wavelengths and EDFA amplifier with a gain of 20dB is used to amplify multiplexed signal strength. Now in case of uncompensated PON and Post-DCF compensation case, amplified signal is launched in to the bidirectional optical fiber whereas in case of pre-DCF compensation multiplexed optical signal is first launched into DCF of negative dispersion value of -667ps/nm, dispersion slop of -1.95 ps/nm^2 and total attenuation of 5dB and then amplified using EDFA with gain 20dB. Bidirectional fiber has attenuation of 0.22dB/Km, dispersion factor of 16.75ps/nm/Km, polarization mode dispersion (PMD), group velocity dispersion and third order dispersion is enabled in simulation.



(a)

(b)

Fig. 2. Simulated architecture of WDM-DWDM-PON for (a) Post-DCF dispersion compensation and (b) Pre-DCF dispersion compensation.

Fiber ends at the RN, in case of uncompensated-PON and pre-DCF-PON architecture RN equipped with 32:1 passive power splitter and 32:1 passive combiner whereas in case of post-DCF-PON architecture RZ is equipped with post DCF compensation fiber with negative dispersion value of -667ps/nm, dispersion slop of -1.95 ps/nm^2 and total attenuation of 5dB. After post-DCF compensation, 32:1 splitter splits spectrum to each of the output arm with theoretical loss of 15dB. Each ONU connected to one of the splitter output point. ONUs are equipped with TOF which filters any particular downstream frequency and filtered wavelength is detected using PD with responsivity of 0.9A/W and 10nA dark current. 3R-regenerator is use to regenerate the original transmitted signal and using BER analyzer received optical signal is compared with the regenerated signal.

ONU transmitter is equipped with the continuous wave (CW) laser of C-band wavelength and optical launch power of 0dBm. Every ONUs is equipped with separate CW laser with unique operating wavelengths such that spacing between wavelengths are 50GHz and frequency of the channel starts from 194.55THz to 196.1THz. Each upstream wavelength is modulated at the peak data rate of 2.5Gb/s using MZM modulator of extinction ration of 10dB. 32:1 combiner at the RN combines the spectrum and launches into the bidirectional fiber (upstream). Upon reception of upstream signal, OLT first amplifies the signal using EDFA of gain 13dB, and demultiplexes the upstream signal using DWDM-DE-MUX. Every distinct DWDM demultiplexed wavelengths detected and analyzed independently at the OLT receiver subsystem.

IV. Results and Discussion

Simulations are carried out for three distinct downstream long reach passive optical network (LR-PON) scenarios. First without any dispersion compensation in the link and reach of the fiber varied from 10Km to 110Km. In second case at remote node (RN) with dispersion compensation fiber (DCF) placed immediately after bidirectional feeder fiber as post-dispersion compensation technique. In third simulation scenario, DCF placed immediately after 16X1 WDM-MUX and before EDFA amplifier as pre-dispersion compensation techniques. For second and third both cases fiber reach were varied from 20km to 120km.Performance of the optical network is measured in terms of the minimum logarithm of bit error rate (Min. Log(BER)) and Min Log(BER)value lower than -9 is consider to be error free in optical access networks. Upstream DWDM 32 wavelengths performance were simulate to obtain optimum launch power and max reach of the fiber.

A. Upstream analysis

Optimum upstream lasers launch power were determined by simulating with fixed fiber reach of 50Km and varying launching power from -15dBm to 0dBm. Upstream performance were analyzed in terms of Min Log(BER) as shown in Fig. 3. It observed from Fig. 3 that after launch power of -10dBm all the wavelengths performs error free. Since, simulations were carried out to find optimum launch power and it is selected to be 0dBm by keeping power saving constrain. Now, maximum reach of the upstream DWDM PON is determined for a fixed launch power of 0dBm by varying the lengths of bidirectional optical fiber from 10Km to 110Km. Fig. 4 shows the plot of maximum reach of the fiber to Min Log (BER), it is found that upstream reach can be extended up to 100Km and performs error free without any dispersion compensation.

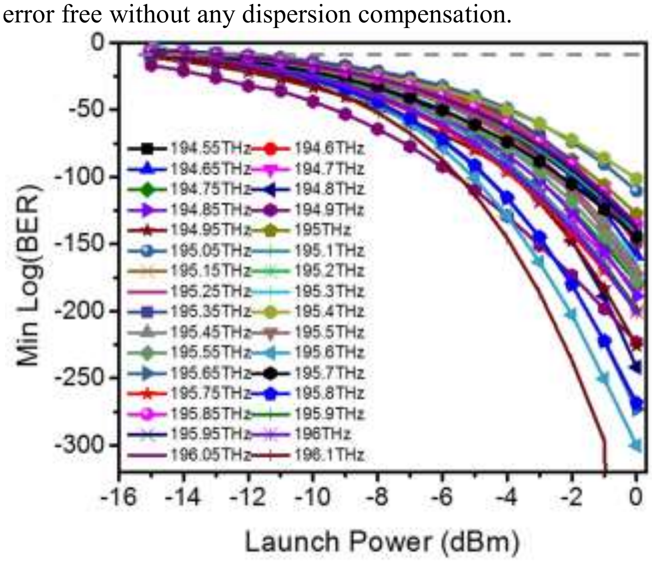


Fig. 3. Min Log (BER) vs laser launch power of each of 32 wavelengths

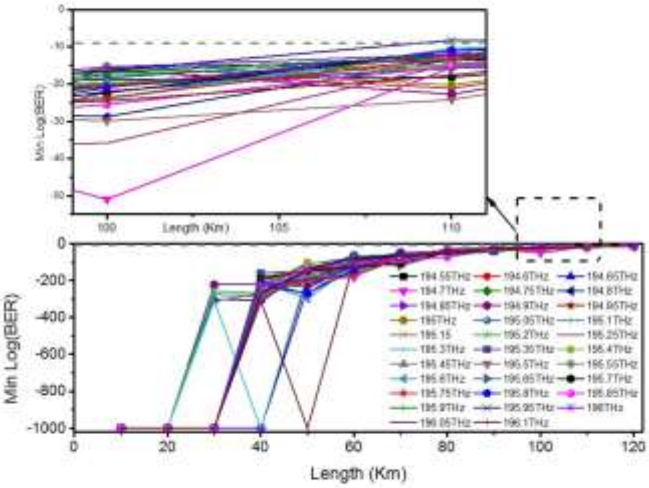


Fig. 4. Min Log (BER) vs reach of the fiber without dispersion compensation technique

B. Downstream analysis

Before analyzing the maximum reach for each downstream scenarios, optimum launch power for 16 WDM downstream wavelengths has to be calculate. Simulation were carried out in first downstream case by keeping fiber length constant at 50Km, laser launch power of the all 16 wavelengths were varied from -10dBm to 0dBm and the performance parameter is analyzed in terms of Min Log(BER). Plot of optimum launch power of proposed WDM-DWDM-PON vs Min Log(BER) shown in Fig. 5. It is observed from the Fig. 5, that as launching power increases from -10dBm to -5dBm, performance of the proposed system architecture increases exponentially and attains peak at -4dBm due to increase in strength of the launching signal power resulted in to increase in signal to noise ratio at receiver and decrease in Min Log(BER). As launching power further increased from -4dBm to 0dBm performance of the network decreases exponentially due to nonlinearity in the components and the bidirectional optical fiber. Hence, in further all simulation scenarios and dispersion analysis launching power of the laser kept constant at the -4dBm.

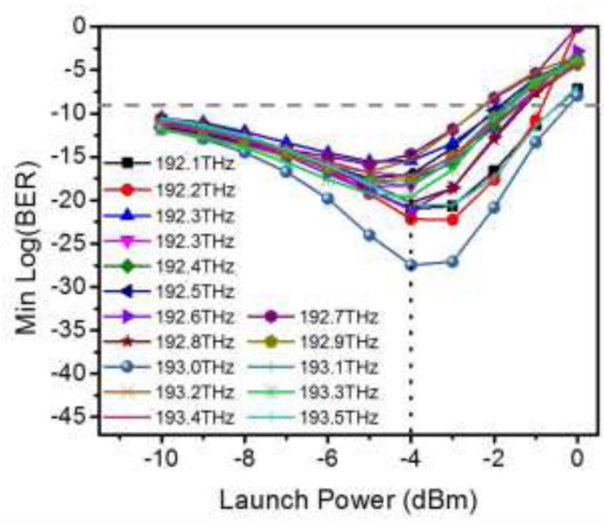


Fig. 5. Min Log (BER) vs laser launch power of each of 16 wavelengths

Maximum reach of the fiber simulated without any dispersion compensation technique as shown in Fig. 6. It clearly seen from the Fig. 6 that, all downstream wavelength performs error free means respected values are below the bar represented by dash-line until 60km of the fiber reach. As length of the fiber increased beyond 60km, few wavelengths fails to preform error free and as reach increased even further all the wavelength of the system performs poorly. It is implicit that without any compensation maximum reach is 60Km.

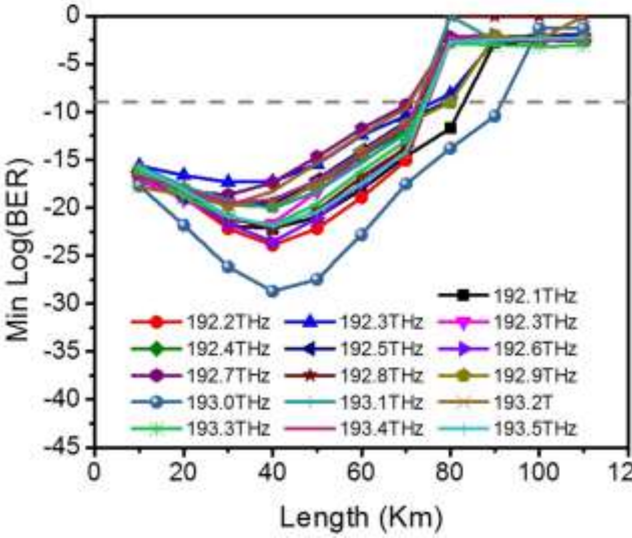


Fig. 6. Min Log (BER) vs reach of the fiber without dispersion compensation for every 16 wavelengths.

Maximum reach of the fiber after introducing post-DCF were simulated with launch power of -4dBm for each of 16 WDM laser. Performance plot of the MinLog(BER) vs reach of the fiber is shown in Fig. 7. It depicted from the Fig. 7 that network performs error free in between 50Km to 110Km due to fixed negative DCF compensation value of -667ps/nm. Whereas from 20km to 40km poor performance is observed due to over compensation of the dispersion after fiber nonlinearity and dispersion impairments.

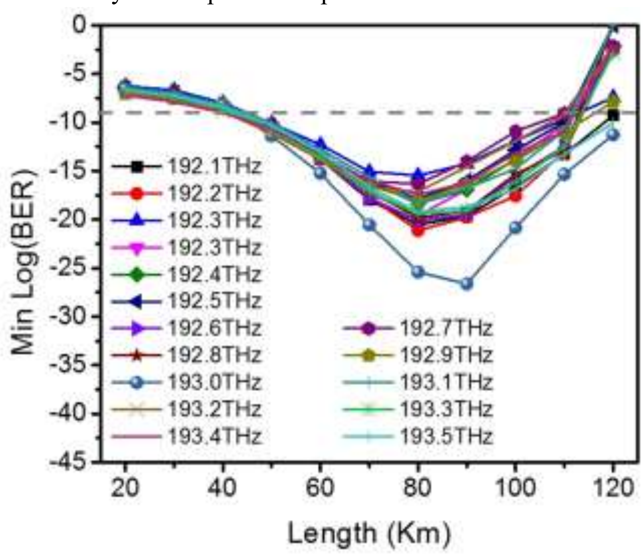


Fig. 7. Min Log (BER) vs reach of the fiber with post dispersion compensation for every 16 wavelengths.

Maximum reach of the fiber with pre-DCF compensation scenario had simulated with launch power of -4dBm and performance plotted as shown in Fig. 8. It is observed from the Fig. 8 that, network performs error free from 20Km to 100Km depicted presence of pre-DCF compensation. Results of the three simulated scenarios were compare as shown in Fig. 9 at a wavelength with frequency 193.0THz.

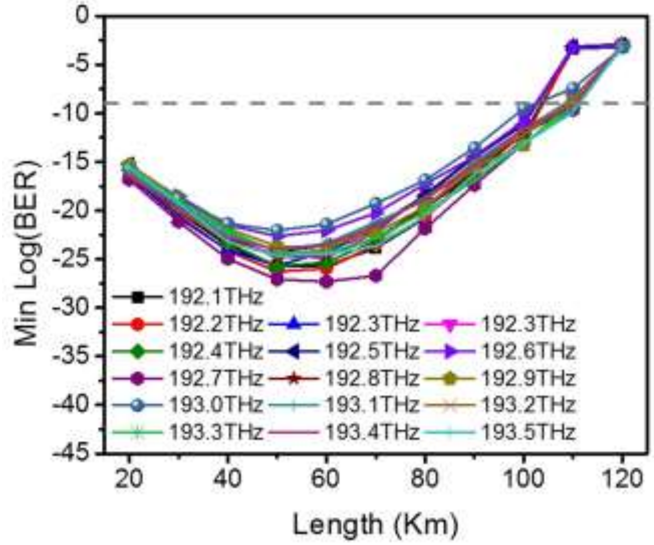


Fig. 8. Min Log (BER) vs reach of the fiber with pre dispersion compensation for every 16 wavelengths.

It is observed from the Fig. 9 that , on comparisons of three different scenarios post-DCF compensation technique has highest reach of the fiber 113Km but minimum reach to attain error free performance is also at 50Km. pre-DCF compensation performs error free up to 103Km of fiber reach. For entire range of the fiber reach, performance of the pre-DCF is batter as compare with normal uncompensated system. Pre-DCF outperforms post-DCF in terms of performance from 20Km to 90Km of fiber reach. At fiber reach of 90km, post-DCF and pre-DCF Min Log(BER) values are almost similar.

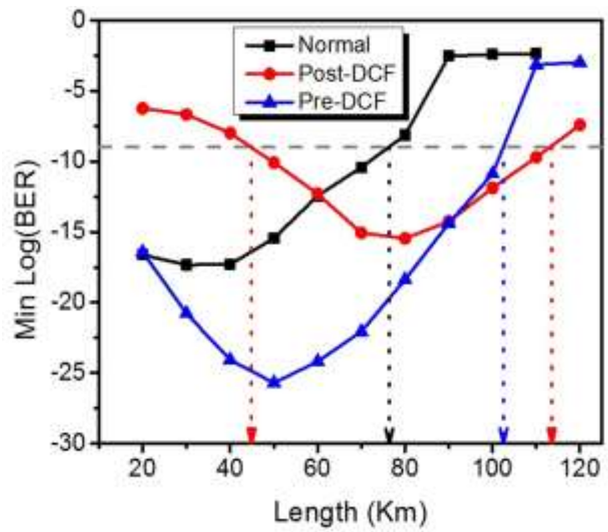
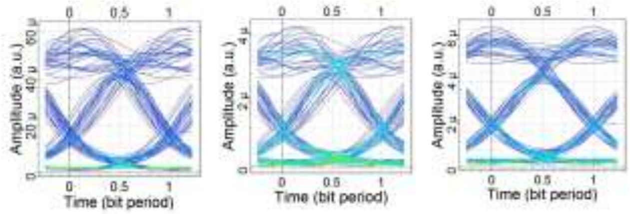


Fig. 9. Min Log (BER) vs reach of the fiber at 193.0THz frequency for uncompensated, post-compensated and pre dispersion compensated system architecture.

Fig. 10 Shows eye diagram of downstream channel 193.0THz. Eye diagram of uncompensated downstream channel 193.0THz at 70Km observed in Fig. 10 (a) with Min Log(BER) of -17.53 and quality factor of 8.627. Eye diagram of post-DCF compensated downstream channel 193.0THz at 110Km is shown in Fig. 10(b) with Min Log(BER) of -15.34 and quality factor of 8.034. Eye diagram of pre-DCF compensated downstream channel 193.0THz at 100Km is observed in Fig.10(c) with Min Log(BER) of -9.49613 and quality factor of 6.163.



(a) (b) (c)

Fig. 10. Eye diagram of downstream channel 193.0THz for (a) Uncompensated wavelength at 70Km, (b) Post-DCF compensated wavelength at 110Km, (c) Pre-DCF compensated wavelength at 100Km.

V. CONCLUSION

Proposed WDM-DWDM-PON deliver aggregate high data rate of 160Gb/s downstream at the distance of 100Km with compensation techniques and utilized all the major advantage of WDM-PON. System architecture successfully served the LR-PON requirement of 100Km without placing active devices like amplifier or multiplexer in between OLT and ONU. 80Gb/s aggregated upstream data also delivered at distance of 100Km without any dispersion compensation by using separate laser for each ONU with spacing between adjacent channels are 50GHz. It is clearly perceptible from simulated results that uncompensated wavelengths perform error free only till maximum reach of the 70Km with Min Log(BER) of -17.53 and quality factor of 8.627. Whereas post-DCF compensated wavelengths performs error free from 50Km to 110Km and at 110Km Min Log(BER) is -15.34 and quality factor is 8.034.pre-DCF compensated wavelengths perform error free till 100Km with Min Log(BER) of -9.49613 and quality factor of 6.163. Advantage of pre-DCF compensations are optimum performance were obtained when compared with uncompensated and post-DCF cases. it performs error free for 20Km as well, whereas post-DCF compensation requires minimum of 50Km reach of the fiber to perform error free. Pre-DCF compensation not only performs better than uncompensated WDM-PON case but also for the Post-DCF case up to 90Km. 16 Downstream wavelengths are shared among 32 users, 32 upstream wavelengths modulated with 2.5Gb/s hence 80Gb/s aggregated data been transferred upstream towards OLT from ONUs. Uncompensated wavelengths are able to transfer data at the reach of 100Km on DWDM upstream wavelengths with Min Log(BER) of -15.26 and quality factor of 8.008 at upstream channel of 195THz. WDM-DWDM-PON architecture supports high data rate upstream and downstream with dedicated 32 users at the maximum distance of 100Km.

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