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Performance Analysis on 16-Channels Wavelength Division Multiplexing in Free Space Optical Transmission under Tropical Regions Environment

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Abstract: Problem statement: Wavelength-Division-Multiplexing (WDM) is a promising technique for meeting the growing demand for increased bandwidth and various types of services in the optical access network. For wide area or metropolitan networks, fibers are deployed to provide huge bandwidth. In access networks, the fiber-to-the-home will partially solve the last mile problem. However, some environmentally sensitive area such as housing areas, tower buildings and national parks are not allowed to deploy fibers. Therefore, Radio Frequency (RF) is normally used to overcome this problem. The incompatibility of RF and optical channels is now widely believed to be the limiting factor in efforts to further increase transport capabilities. Free Space Optical (FSO) communication is the technology that can address any connectivity needed in optical networks, such as core, edge, or access networks. **Approach:** In this project, the simulation software namely Optical System version 7 is used to simulate the design of WDM in FSO transmission. The total losses that have been considered in this design are geometric loss, transmitter and receiver loss and atmospheric attenuation which focus on non-selective scattering during heavy rainfall condition in Malaysian environment. Malaysian weather data are used to reflect the conditions particularly in tropical regions. **Results:** We have presented the results of 16-channels WDM at 100-GHz channel spacing. The simulated results show that this system can support a higher bit rate up to 2.5 Gbps over 2.4 km distance. **Conclusion:** Simulation results showed that WDM FSO system may be a good candidate to solve the last mile problem and also it has capability to accommodate the channels more than 16. By introducing the error correction code or balance detection, the transmission distance might be increased further.

Key words: Free space optical, division multiplexing, selective scattering optical access, geometric loss, bit rate, old topic, receiver loss

INTRODUCTION

In a Wavelength Division Multiplexing (WDM)-based access, the demand for bandwidth has increased in an extremely fast and is a promising solution for data transport in future all-optical wide area networks (Ab-Rahman *et al*., 2009). At the same time, the cost of transporting information bit per km also needs to be reduced. WDM system in Free Space Optical (FSO) is the way to maximize the bandwidth usage but in low cost. It has been quite mature and applied to optical fiber networks universally. Several FSO WDM transmission system have been demonstrated successfully (Kintaka *et al*., 2010 and Sinefeld and Marom, 2010). Although FSO is an old topic, due to the availability of advanced technologies and high demand of broadband communications now, it becomes a new research area.

The advantages of using FSO are no license required from Federal Communications Commission (FCC) for FSO installation. Apart from that, the cost of installation is primarily economic because there is no extra cost of digging the street to lay fiber. In term of communication security, FSO uses narrow laser beam which makes detection, interception and jamming very difficult. Moreover, FSO hardware is also portable and quickly deployable (Cvijetic *et al*., 2010) WDM is a technology which multiplexes multiple optical carrier signals on a single medium by using different signals. It is the technique to carry many separate

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optical signals. Each signal modulated into different wavelength lasers and it transmitted at a different rate from the other signal.

In this study, the analysis on the performance of this system has been done under non-selective scattering in tropical environment. An optical wave propagating through the air experiences fluctuations in amplitude and phase due to atmospheric attenuation (Mie and Non-selective scattering), turbulence and scintillation.

MATERIALS AND METHODS

Atmospheric attenuation: In tropical country, rain dominates the total attenuation coefficient (Prokes, 2009). The attenuation due to rainfall is also called non-selective scattering since the drop size is much larger than the wavelengths making scattering effects wavelength independent (Singh, 2007). In this simulation, the data was taken from the Malaysian Meteorological Department. The atmospheric attenuation τ_a is described by the following Beer's law Eq. 1 and 2 (Downing, 2004):

$$\tau\alpha = e^{-(\beta_{abs}+\beta_{scat})} R \quad (1)$$

Where:

β_{abs} and β_{scat} = The absorption and scattering coefficient, respectively

R = The link distance

The total scattering by rain is given by (Achour, 2002) :

$$\beta_{scat}^{rain} = \sum_{\alpha} \pi\alpha^2 N\alpha Q_{scat}\left(\frac{\alpha}{\lambda}\right) \quad (2)$$

where, Q_{scat} is the scattering efficiency, also referred to as the Mie attenuation coefficient. For ratios a/λ> 30 the Q_{scat} is approximated as equal to 2. N_a is the number of dropsof radius a in a unit volume (cm^3). Fig. 1 below shows atmospheric attenuation versus distance, throughout the year of 2000. It is linearly proportional with 5 dB km^{-1}.

System design: In this project, the simulator software namely Optical System (Optisys) version 7 is used to simulate the design of WDM in FSO transmission. The block diagram of system design is shown in Fig. 2.

From Fig. 2, the transmitter part consists of 16 laser arrays with 10 dBm input power each. The wavelength ranging for the input laser is from 1550 nm to 1552 nm with 100 GHz interspacing between channels. The signals are transmitted through free space as a transmission channel with 8.86 dB km^{-1} attenuation for the worst case scenario (Chan, 2006).

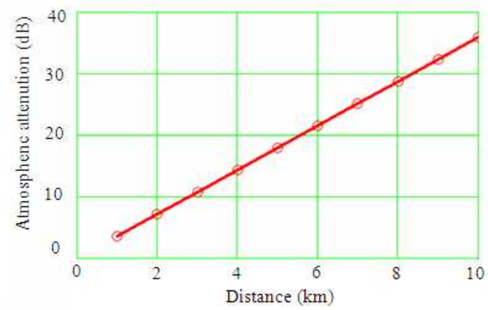

Fig. 1: Atmospheric attenuation as a function of link distance

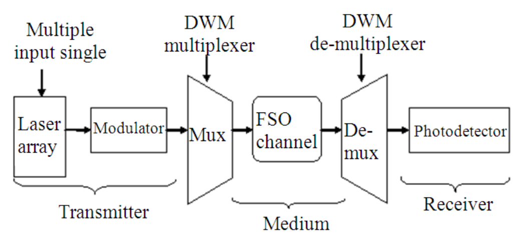

Fig. 2: Block diagram of WDM system in FSO transmission

Table 1: Typical parameters used in the simulation for the signal model and the noise model

	Signal model
Transmitter power	P_T = 10 dBm
Optical loss	L_{OP} = 9 dB
Atmospheric loss (heavy rainfall)	8.86 dB
Pointing loss	L_{MP} = 3 dB
Quantum efficiency	η = 0.8
Operating wavelength	λ = 1550 nm
Planck's constant	h = 6.66×10^{-34} Js
Distance	R = 1-10 km
Speed of light	c = 3×10^{8} m sec^{-1}
Noise model	
Bolzmann's constant	k = 1.38×10^{-23} J/K
Absolute temperature	T = 290 K
Observation bandwidth	B = 311 MHz
Dark current	I_{DC} = 100 µA

This system needs the optical amplifiers for every channel to amplify the signals due to FSO losses after the photodetector. For simulation purposes, the parameters as listed in Table 1 are used which they are selected by referring to the actual values in the market and commercial product (Kim *et al*., 1998).

Design parameter*:* Any changes to design parameters will also change the performance of the circuit. Two most significant design parameters considered are the distance and bit rate.

Performance parameter: The performance parameters that will be observed are the Bit Error-Rate (BER) and output power To make a good optical receiver design, it is critical to understand and varying the different parameters that will affect the overall receiver performance.

RESULTS

Figure 3 shows the effect of distance to the system parameter. Bit rate of 2.5 Gbps was used in this simulation as it was the highest bit rate used in the commercial product (LWPS, 2009). The power transmitting was set to 10 dBm and normally the range of input power is from 0-13 dBm for FSO (AC, 2011).

Figure 4 shows the effect of Bit Rate to the system performance. The distance is set to 2.4 km and the power transmitting is 10 dBm. Bit rates ranging from 0.155-10 Gbps is used during this simulation. Number of channel set to 16 channels and the spacing between channels is set to 100 GHz (0.8 nm) based on ITU standard. The wavelength used in this simulation is 1550 nm.

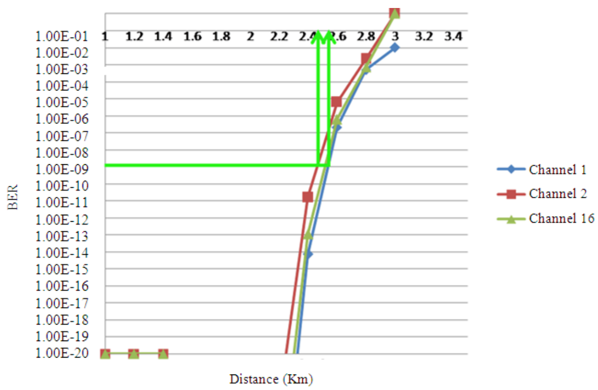

Fig. 3: BER in Relation to Increasing distance for WDM FSO system operating at 2.5 Gbps under the condition of heavy rainfall

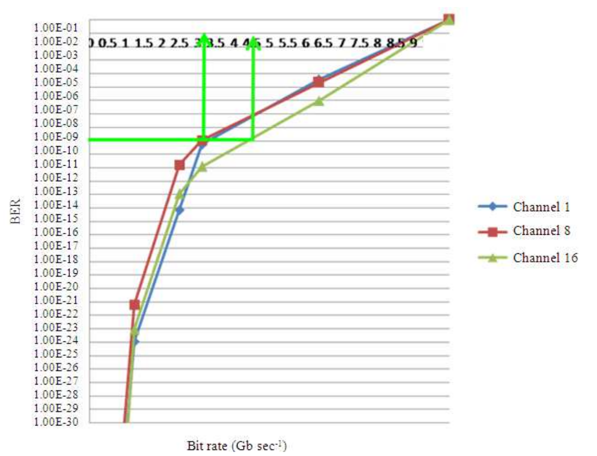

Fig. 4: BER Measured against Bit Rate over a 2.4 km distance under the condition of heavy rainfall

Figure 5 shows the effect of the different wavelength to the systems performance. The range for the wavelength is from 850-1550 nm based on commercial product in lightpointe and bit rate was set to 2.5 Gbps. The power transmitting was set to 10 dBm.

At the receiver, the 16-channels 2.5 Gbps signals are shown in Fig. 6. Channel 1 has about 14 dBm and channel 16 has about 4 dBm. The performance varies from channel to channel because different channel has different error floor. However, the BER of 10^{-9} is reachable.

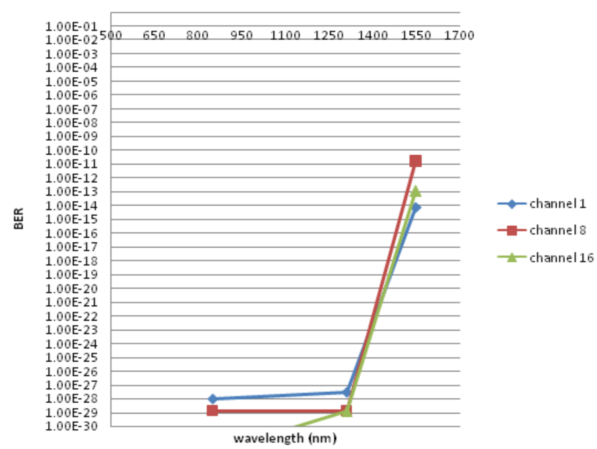

Fig. 5: BER in relation to increasing wavelength for WDM FSO system.

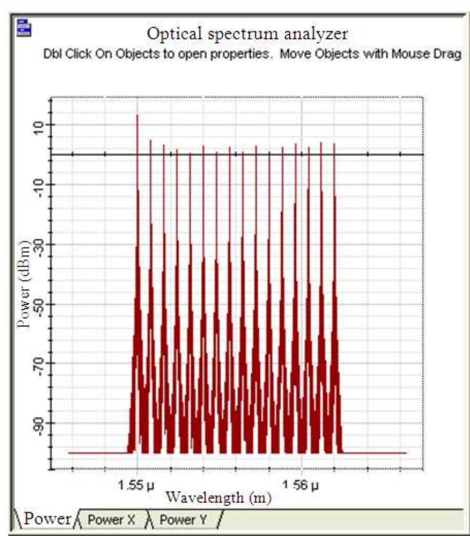

Fig. 6: Power of each channel

DISCUSSION

From Fig. 3 shown above, BER appears to increase when the distance is increased because a longer distance will influence the performance of three of the measured means: loss, non-selective scattering and noise. From the graph, the highest distance that gives the best BER of 10^{-9} is at 2.4 km until 2.5 km.

From the result in Fig. 4, increasing the bit rate will decrease the pulse width and affect the quality of the received signal. It is known to suffer dispersion under heavy rainfall and a loss in transmission. Changing the bit rate will also affect the noise associated with the receiver circuitry (Wayne, 2004). The result from the simulation shows that the BER for all channel almost the same where at BER of 10^{-9} the bit rate for 1, 8 and channel 16 are 3.25-3.25 and 4.5 Gbps respectively. This is because the spacing between channels is sufficient to avoid crosstalk or interference.

From Fig. 5, the 850 nm wavelength produced a better result than 1550 nm. With respect to transmission performance, availability and reliability of components, the 850 and 1550 nm wavelength ranges are the most economical and best performing wavelength ranges for operating FSO systems (LWPS, 2009). However 1550 nm wavelength is well suited for free space transmission due to its low attenuation, as well as the proliferation of high-quality transmitter and detector components. Components include very high-speed semiconductor laser technology suitable for WDM operation as well as amplifiers (EDFA, SOA) used to boost transmission power. Because of the attenuation properties and component availability at this range, development of WDM free space optical systems is feasible.

CONCLUSION

From the results analysis, they show that the performance of WDM in FSO transmission is successfully achieved even though in worst case scenario. The conventional Intensity Modulation Direct Detection technique does not seem to be a promising candidate for long distance (more than 1 km) in the same environment. So far, this technique, operating at 2.5 Gbps bit rate, is presented over links of 0.8 km in heavy rainfall/low visibility (Lightpinte, 2010). However, WDM FSO system with the parameters specification as in the System Design section can be implemented in higher bandwidth and good performance. The capacity of WDM FSO is also possible to be increased up to 32-channels if any methods of error corrections or detection are introduced. Since the FSO transmission is totally depends on the weather condition and the obstacle between transmitter and receiver, the system only suitable for short distance and low bit rate.

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