Analysis of 16 Channel WDM FSO Communication System using MIMO Structure under Different Atmospheric Conditions

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ABSTRACT

In this paper we have analyzed MIMO structure of 16 channel wavelength division multiplexing (WDM) free space optical (FSO) communication system under the influence of different atmospheric conditions like haze, moderate rain and fog. Wavelength of optical signal and aperture area of optical receiver affects quality factor of FSO system. Attenuation constant for haze, moderate rain and fog are 4.3 dB/Km, 9.64 dB/Km and 43 dB/Km respectively. This analysis is performed in Optisystem tool. Performance parameters like Q-factor and bit error rate (BER) are measured with the help of eye diagrams. Value of beam divergence for haze, moderate rain and fog is 13 mrad, 12.4 mrad and 4 mrad respectively.

Keyword: - *Wavelength division multiplexing, FSO, Q-factor, BER, Link Range, Beam divergence*

1. INTRODUCTION

The lowest hierarchy of the telecommunication network is the access network, which broadly covers the entire network between the user's device and the service provider's hub. For most of the last century, the first/last mile of the access network was dominated by copper wire and coaxial cable connections. Digital subscriber loop (DSL) technologies were later introduced to cope with the explosion of internet services and are found in most access networks across Europe, sometimes jointly implemented with radio frequency (RF) and microwave communication technologies for ubiquitous coverage and enhanced mobility. However, the data rates achievable with very high speed digital subscriber loops (VDSLs), RF, millimetre wave and microwave technologies were significantly less than the 10 Gbps which could easily be achieved with an optical carrier.

An alternative optical access technology, notably FSO, has been advanced to complement existing fibre installations in the optical access network. It is expected that a successfully deployed FSO communication system will provide a viable solution to the bottleneck seen in broadband signal transmission to existing homes where fibre could not be installed. Unlike RF communication, FSO communication is immune to multipath fading, and offers a more secure transmission within a huge unregulated bandwidth and with reduced power requirement. FSO systems can also be deployed in the optical access network as an emergency link, alternative back up link or in a hybrid with fibre (either connecting two feeder fibre links together or just as a distribution link in the last mile). In addition, FSO communication links can be extended to provide all optical broadband service to indoor users, with limited mobility.

Generally, an optical access network supports many users. From a service provider's perspective, the viability of such a network is highly dependent on its user capacity and possible scalability. Deployment cost in the optical access network is reduced by network resource sharing among users.

2. FACTORS INFLUENCING FSO SYSTEM

FSO communication systems are influenced by outside interferences from various sources which are as follows:

FSO Attenuation: Absorption and scattering are the two factors contributing to attenuation in FSO channels. Both natural and artificial processes result in an abundance of different gaseous molecules including carbon dioxide (CO_2), ozone (O_3) and water vapour (H_2O) in the atmosphere, which interact with and absorb propagating photons at different wavelengths. Because the rate of absorption is dependent on both the concentration of these gases and wavelength, FSO communications are established at wavelengths around 780 - 1550 nm where absorption is relatively low. Scattering however is an unavoidable source of power loss in the atmosphere. The presence of micro and macro particles in the atmosphere leads to different scattering processes which attenuate the optical power of the propagating signal.

Scintillation: The random fluctuations in signal intensity of an optical beam propagating in the atmosphere which are caused by turbulence are generally referred to as optical scintillation. A common approach used in describing the effect of scintillation along most horizontal paths in the atmosphere is the extended medium model in which the whole range of the signal propagation path is treated as a random medium.

Aperture Averaging: Among the numerous techniques proposed for the mitigation of turbulence effects which include aperture averaging (AA), diversity systems and wave front reconstruction; aperture averaging presents the simplest and most cost effective option applicable to direct detection systems. The basic idea in aperture averaging is to increase the receiving aperture above the cell size of the turbulent eddies responsible for irradiance fluctuations so that such fluctuations are averaged out over a large receiver aperture.

Other Factors: Physical obstacles (such as low flying objects and birds, high rising buildings and mountainous terrains), and external interferences from background ambient signals can be problematic to the propagation of an optical signals in the atmosphere. Additionally, thermal expansion and small movements of buildings caused by high velocity winds, vibrations by heavy machinery and minor earthquakes can increase misalignment and pointing errors above that originally caused by beam wandering. The challenges posed by physical obstacles are mitigated by adequate link path planning during installations, but for FSO links greater than about 100 m range, an automatic pointing, acquisition and tracking (PAT) sub-system is required to mitigate pointing and tracking errors.

3. WAVELENGTH DIVISION MULTIPLEXING (WDM)

In wavelength division multiplexing (WDM), a range of wavelengths within the bands in the International telecommunication union-telecommunication (ITU-T) grid is used and each fixed central wavelength is assigned for the transmission of a specific signal in a common channel. Adequate spacing is provided between the central wavelength assigned for the transmission of each signal and the central wavelength assigned for the transmission of the next adjacent signal, just like the guard band in a TDM/TDMA PON, with wider spacing required for coarse-WDM (CWDM) applications than dense-WDM (DWDM). In a WDM PON, a dedicated central wavelength is used for both the upstream and downstream transmission of signal between the OLT and the ONU.

4. PROPOSED DESIGN

In this paper we have shown performance of 16 channel WDM FSO link for different values of link range under various climate conditions like haze (4.3 dB/Km), moderate rain (9.64 dB/Km) and fog (43 dB/Km). Value of beam divergence for haze, moderate rain and fog is 13 mrad, 12.4 mrad and 4 mrad respectively. MIMO technique is used in WDM FSO system to minimize the effect of turbulence on the performance of the FSO link. All simulations have been performed in OPTISYSTEM simulation tool.

Some parameters used for designing of WDM FSO which are kept constant are as follows:

Laser power = 10 dBm, frequency range = 193.1 THz to 194.6 THz, input and output ports = 16, extinction ratio = 30 dB, bandwidth = 10 GHz, amplifier gain = 20 dB, transmitter aperture diameter = 10 cm, receiver aperture diameter = 30 cm, amplifier noise figure = 4 dB and filter type = Bessel.

Proposed design is shown in Fig 1.

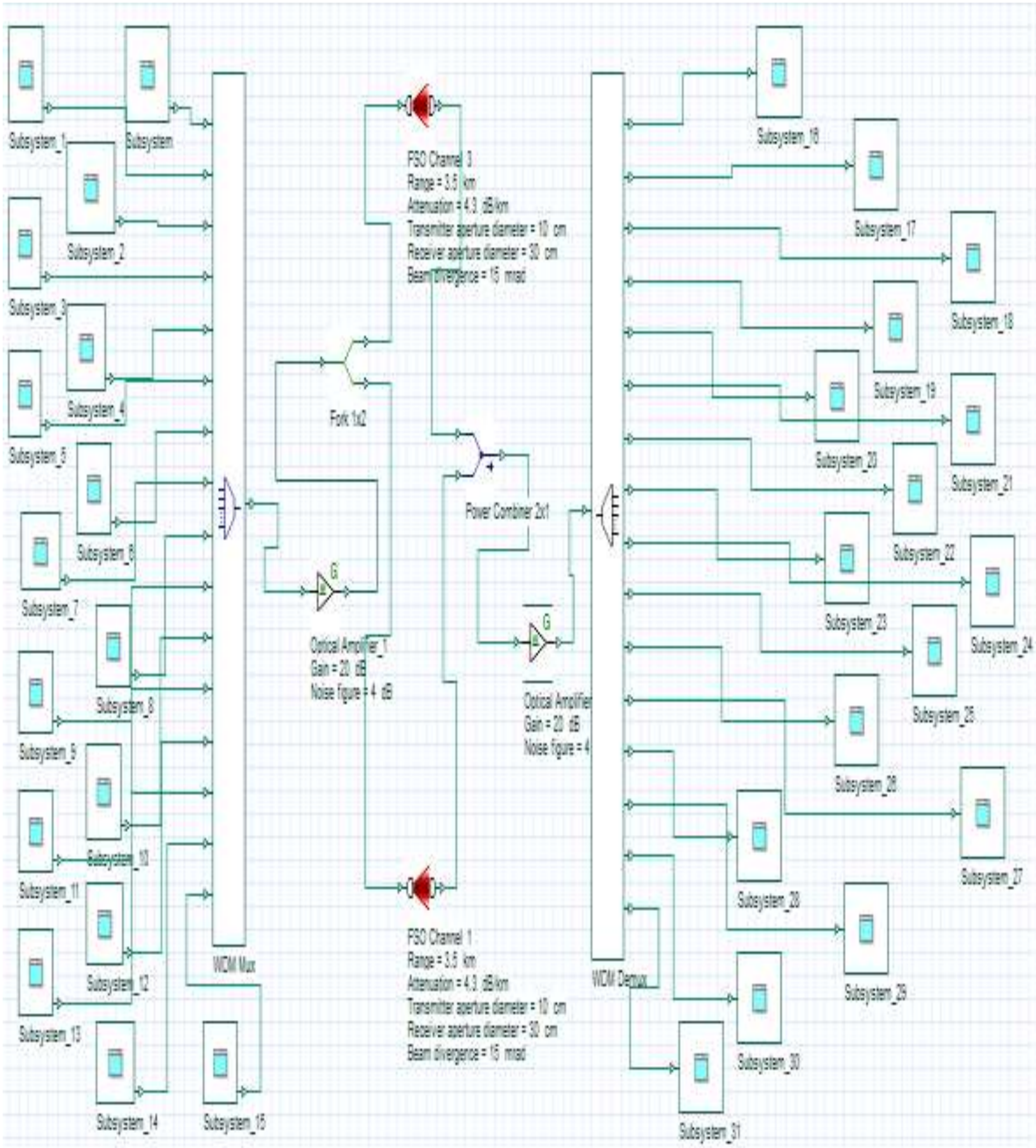


Fig 1 16 channel WDM FSO system

In this 16 channel WDM-FSO system (2x2) 16 subsystems (Subsystem to Subsystem_15) are added at transmitter side with WDM mux. Each subsystem contains pseudo random bit sequence generator, NRZ pulse generator, CW laser and Mach Zehnder modulator as shown in Fig. 2.

This circuit uses two FSO channels with the same configuration to increase the efficiency of the system. Two amplifiers are also added at both the sides of FSO channel as pre-amplifier and post-amplifier to amplify the signal. These amplifiers add noise in the signal therefore we have introduced noise figure of 4 dB in the system.

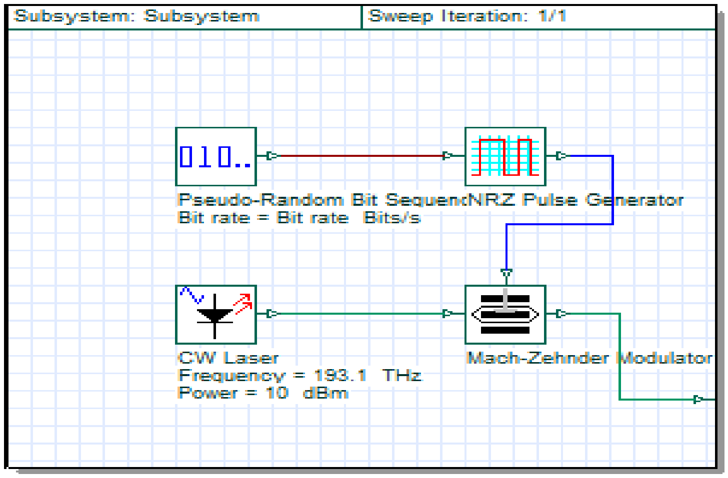


Fig 2 Transmitter side subsystem

At receiver side WDM demux is connected to 16 subsystems (Subsystem_16 to Subsystem_31). Each subsystem contains avalanche photo-detector (APD), low pass Bessel filter, 3R regenerator and BER analyzer in Fig 3.

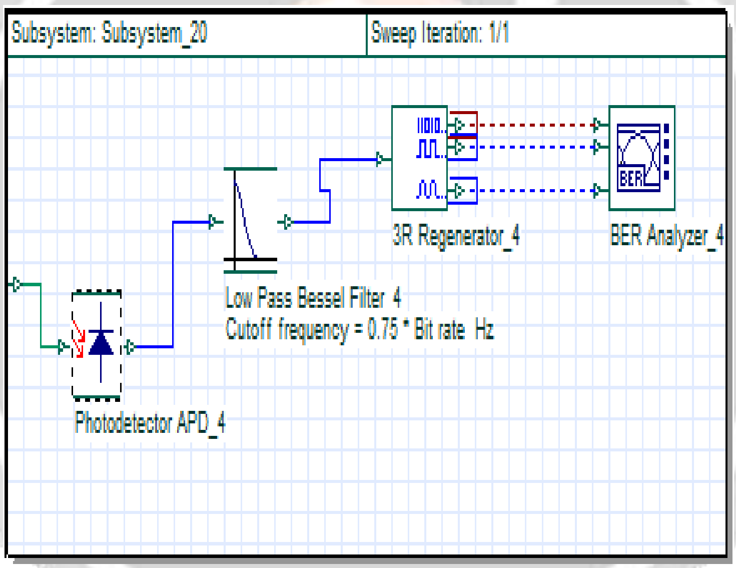


Fig 3 Receiver side subsystem

5. FSO ANALYSIS FOR DIFFERENT LINK RANGE

Proposed 16 channel WDM FSO systems is simulated to determine the Q-factor and BER when bit rate is constant at different atmospheric conditions and different link range of communication. Simulation results of this analysis are shown below: Bit rate = 2.5 Gbps,

1. For haze climate, Attenuation = 4.3 dB/Km, beam divergence = 13 mrad
2. For moderate rain climate, Attenuation = 9.64 dB/Km, beam divergence = 12.4 mrad
3. For fog climate, Attenuation = 43 dB/Km, beam divergence = 4 mrad

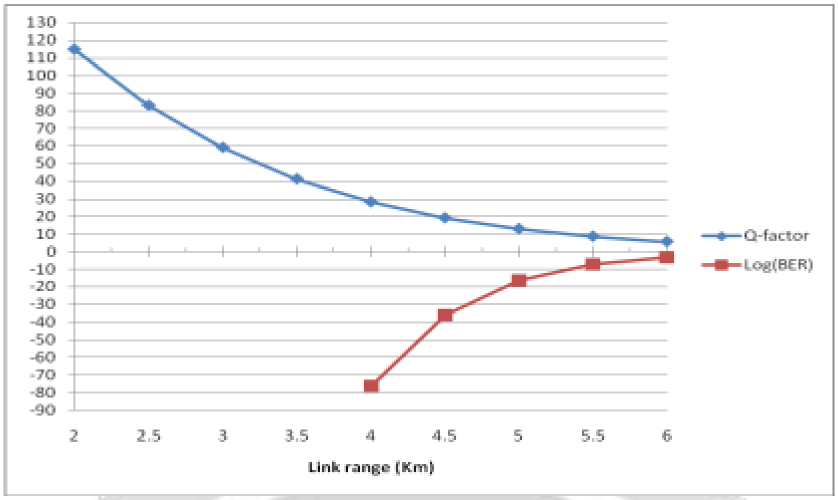


Fig 4 Simulation results for constant bit rate at haze climate

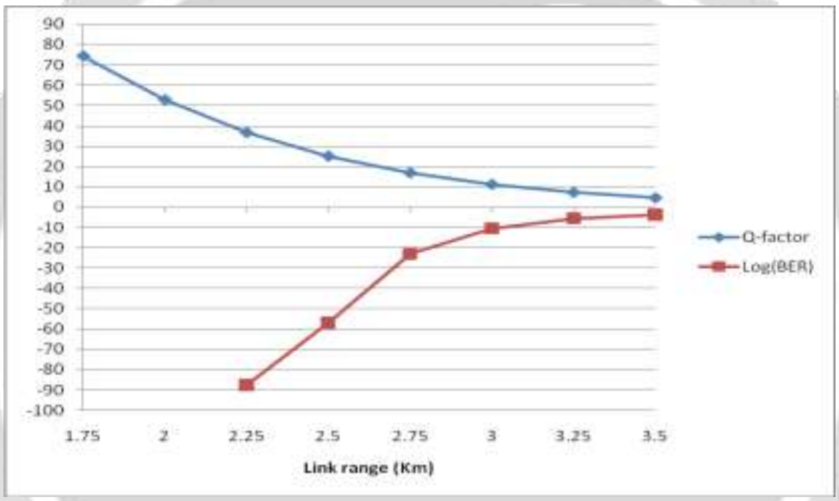


Fig 5 Simulation results for constant bit rate at moderate rain climate

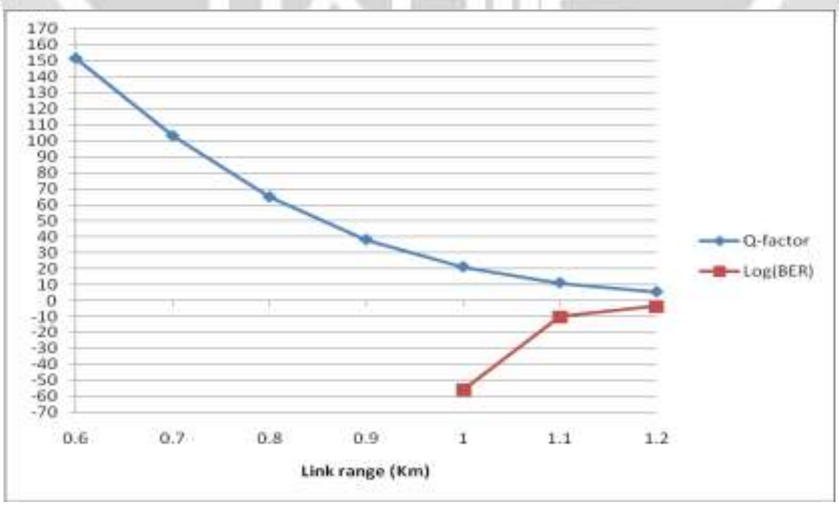
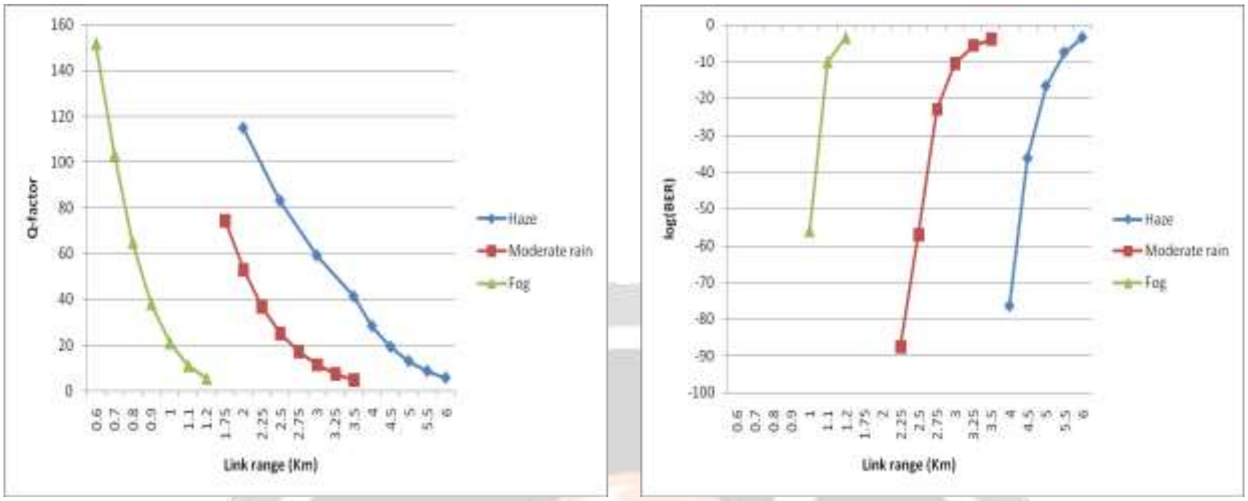


Fig 6 Simulation results for constant bit rate at fog climate

6. COMPARISON OF OUR RESULT

Our simulation results are shown graphically for link range variation under different atmospheric conditions.



(a) Link range vs Q-factor (b) Link range vs log (BER)

Fig 7 Comparison graphs

6. CONCLUSIONS

In this work we have successfully analyzed 16 channel WDM FSO system. For this analysis three attenuation factors are considered such as 4.3 dB/Km for haze climate, 9.64 dB/Km for moderate rain climate and 43 dB/Km for fog climate. Three different values of beam divergence are considered which are 13 mrad for haze climate, 12.4 mrad for moderate rain and 4 mrad for fog climate. A different design of 16 channel WDM FSO i.e. 2x2 (2 transmitters and 2 receivers) is proposed to increase the performance of system. Proposed design of WDM FSO is simulated at all attenuation factors for different link range when bit rate is constant. It is found that the maximum attainable link range (at the bit rate of 2.5Gbps) is 5.9 km, 3.4 km and 1.18 km for haze, moderate rain and fog respectively. In our next publication we will analyze the same design for different bit rate and will compare our results with the results of previous literature.

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