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Performance Analysis of Hybrid WDM-FSO System Under Various Weather Conditions

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Abstract: -- **Free Space Optical (FSO)communication is being realized as an effective solution for future accessing networks, offering light passed through air. The performance of FSOsystemcan be primarily degraded byvarious atmospheric attenuations such as rain, fog, haze and snow. At present, hybridization of Dense Wavelength Division Multiplexing (DWDM) with Coarse Wavelength Division Multiplexing (CWDM) becomes necessary to scale the speed and high bandwidthof the services.In this paper, hybrid WDM system is proposed, designed and the network parameters such as BER,Q Factor and receiver sensitivity are analyzedwith respect tolinkdistanceforvariousweatherconditions.In order to enhance the link distance, the Erbium Doped Fiber Amplifier (EDFA) is inserted at the receiver end. For investigation, 4 CWDM and 8 DWDM channels are considered whose corresponding channel spacing is 20nm and 0.8nm, respectively. From the simulation, it is investigated that the average link distance of proposed hybrid WDM-FSO system with EDFA for DWDM and CWDM system at very clear condition are around973km and936.25km, respectively. The proposed hybrid WDM based FSO systemisdesigned to handle the quality of transmission for 12 users, each at a data rate of 2.5Gbps along an FSO link distance of about 960km.**

Keywords:— **FSO, WDM,CWDM,DWDM,Atmospheric attenuations,Haze,Rain,Fog and snow.**

I. INTRODUCTION

Free Space Optical (FSO) communication is a promising communication technique for various types of communication networks. FSO system is similar to conventional fiber optical system, however, no laying of fiber optical cable is needed, no expensive roof top installations are required [1]. In addition to aaforementionedadvantages, FSO can able to transfer the data rate around 2.5Gbps, unlike the smaller maximum data rate of 10-622Mbps offered by RF communication systems [2, 3]. FSO has good prospects for widespread implementation and continuously ready to utilization as satellite link, terrestrial links and mobile links with the use of new compact laser communication terminal[4].Although the FSO system having significant benefits, it is essential to consider internal parameters such as lasing power, transmission wavelength, transmission bandwidth, receiver sensitivity and external parameters like dislocation due to climatology conditions, atmospheric attenuation, window loss, scintillation, in order to attain higher quality of service [5]. The wide spread deployment of conventional WDM based FSO system severely limited by adverse effects of atmospheric environment such as haze, rain , fog and snow[6]. Typically, the laser beam propagation affected by three factors are absorption, turbulence induced scintillation and multiple scattering effects or geometric losses. Atmospheric trace gas carbon dioxide and water vapor lead to strong broad absorption band [4,7]. However, atmospheric turbulence produces fluctuations in the irradiance of the transmitted optical beam, which is known as atmospheric scintillation, severely degrading the link performance[8].Attenuation due to rain fall rate, snow rate is also called non selective scattering that are made of larger molecules. Generally, geo metrical scattering affects wave length and altitudethose results in high bit error rate or signal loss at receiver end[9].Signal quality always inversely proportional to attenuation factor and Bit Error Rate (BER)[10].

Wavelength Division Multiplexing (WDM) technique is one of the primary multiplexing technique in optical communication in order to enhance the bandwidth utilization for high demand broadband applications, where many number of signals with its designated wavelength are multiplexed with single medium and its separated at its destination. WDM is used to simultaneously transmit the different wireless service signals independently over the FSO link [11]. There are two types of WDM implementation, coarse wavelength division multiplexing (CWDM) and Dense Wavelength division multiplexing (DWDM).In conventional fiber optical communication system, DWDM (ITU-T G.694.1) channelswith the channel spacing of 1.6nm/0.8nm/0.4nm (200GHz/100GHz/50GHz) andCWDM (ITU-T G.694.2) channels with the channel spacing of 20nm are utilized for conventional fiber optical communication [12]. Typically, the wavelength range of CWDM system is 1260 nm – 1625nm whereas DWDM spans from 1470 nm – 1625 nm. Recently,combination of CWDM and DWDM system (Hybrid WDM) is proposed in order to enhance the quality and utilization of the network. Inhybrid WDM system,the DWDM channels and CWDM channels are multiplexed and transferred through optical fiber and the receiver separated the multiplexed signalsusingdemultiplexer and sent to its corresponding destination. In hybrid WDM-FSO system, the DWDM and CWDM signals are combined and transmitted through free space andit’s collected by the receiver. In general, DWDM is the best choice for applications where channel density/bandwidth is of high priority. At the same time, CWDM remains an excellent option for applications where deployment costs are to be considered[13]. Conventional FSO systems operate near the 850 nm spectral range. Unfortunately, optical devices using the 850 nm spectral range cannot operate above 2.5 Gbps because of the power limitations imposed for eye safety. In order to overcome the power limitations, 1550 nm wavelength is selected for new ultra high speed FSO systems and its advantages apart from being eye safety include reduced solar background radiation and compatibility with existing optical fiber technology infrastructure [14-20]. By using 1550nm wavelength, Mbps wireless transmission can be achieved by leveraging the technology developed for long haul optical communication.The hybrid WDM-FSO is a new research area which is proposed to overcome the limited received power, limited distance and limited scalability which are occurred in normal FSO system [21].

In the literature, so far there is no much attempt is made in hybrid WDM-FSO. However there are some attempts is made to for hybrid WDM using single beam [14-20] and multibandconcept [21-23] where they have considered only DWDM channels with the channel spacing of 0.8 nm over the wavelength range of around 850 nm and 1550 nm.Also, the authors did not accounted CWDM channels. In multibeam hybrid WDM-FSO, the source and detector is kept on increasing according to the number of incoming channels which in turn increases the overall cost of the network. In this paper, hybrid WDM-FSO system is proposed and designedand the network parameter such as BER,Qfactor and Receiver sensitivity are analyzed for various atmospheric conditions.

The paper is organized as follows; the calculation of attenuation for various atmospheric conditions is discussed in Section 2. The design of hybrid WDM-FSO system is discussed in section 3.The effect of link distance and Quality factor with respect tovarious atmospheric conditions with/without EDFA is reported in Section 4. Finally, Section 5 concludes the paper.

II. CALCULATION OF ATTENUATION FOR DIFFERENT WEATHER CONDITIONS.

Attenuation is one of the most important parameters that are limiting the performance of the FSO systems. Typically, the attenuation is varying with respect to the atmospheric conditions. The attenuation is the reduction of signal power at the receiver point. The attenuation of an optical beam as it propagates through the air is given by the Beers-Lambert law [24] where, ‘ ’and ‘ ’ are the transmitted and the received power, ‘ ’ is atmospheric attenuation coefficient and ‘Z’ is the link range. The coefficient of atmospheric attenuation depends on the type of scattering, signal wavelength, size of the particles of the atmosphere and the link visibility.FSO links significantly depends upon different visibility ranges and atmospheric conditions. The visibility range is the distance that light intensity drops to 2% of its original value[24]. The signal attenuation for air, haze and fog is based on the visibility range estimation is computed by employing Kim and Kurse model [25-27].

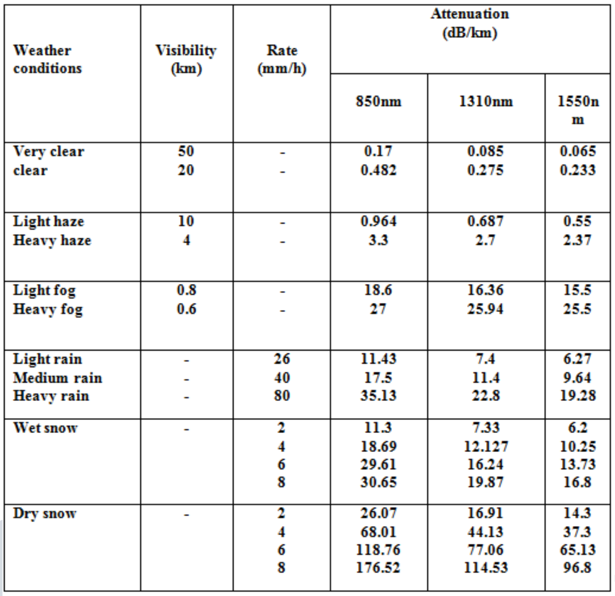
$$\alpha = \left(\frac{3.91}{v}\right)\left(\frac{\lambda}{550nm}\right)^{-q} \quad 2)$$

where,
α = attenuation coefficient
v = visibility in kilometers
λ = Wavelength in nanometers
q = The size distribution of the scattering particles.

The attenuation is calculated using equation (2) and listed in Table 1. Rain is the highest attenuation factor in atmosphere for laser beam compared to haze intensity factor. In general, rain intensity factors could reduce the visibility and also affect the FSO performance [9]. The scattering coefficient can be calculated using stroke law.

$$\alpha_{rainscat} = \Pi a^2 N a Q_{scat}\left(\frac{a}{\lambda}\right) \quad (3)$$

where
a = radius of rain drop (0.001-0.1cm)
Na = rain drop distribution,
Q_{scat} = scattering efficiency
λ = wavelength.



Weather conditions	Visibility (km)	Rate (mm/h)	Attenuation (dB/km)		
			850nm	1310nm	1550nm
Very clear	50	-	0.17	0.085	0.065
clear	20	-	0.482	0.275	0.233
Light haze	10	-	0.964	0.687	0.55
Heavy haze	4	-	3.3	2.7	2.37
Light fog	0.8	-	18.6	16.36	15.5
Heavy fog	0.6	-	27	25.94	25.5
Light rain	-	26	11.43	7.4	6.27
Medium rain	-	40	17.5	11.4	9.64
Heavy rain	-	80	35.13	22.8	19.28
Wet snow	-	2	11.3	7.33	6.2
		4	18.69	12.127	10.25
		6	29.61	16.24	13.73
		8	30.65	19.87	16.8
Dry snow	-	2	26.07	16.91	14.3
		4	68.01	44.13	37.3
		6	118.76	77.06	65.13
		8	176.52	114.53	96.8

Rain fall is characterized by its amount, intensity and distribution in time.The rain drop distribution, Na can be calculated using

$$Na = \left(\frac{za}{4/3\left(\Pi a^3\right) va}\right).$$

za is rainfall rate (cm/s),
For 26mm/hr za = 7.22x10^{-4}
For 40mm/hr za is 1.11x10^{-3}
For 80mm/hr za is 2.22x10^{-3}
va = limit speed precipitation

$$va = \left(\frac{2a^2 \rho g}{9\eta}\right)$$

ρ is water density(1g/cm^2)
g is gravitational constant(980cm/s^2)
η is viscosity of air (1.8x10^{-4}(g/cm)s).

Snow is another important attenuation factor considered in FSO. The attenuation of the light not only depends on visibility ranges and it is proportional to size of snow particles. The snowflakes as large as 20mm have been reported [28] and large snow molecules can cause link failure it is not ignorable. The density of snow varies as a function of temperatures. The density of snow isheavily dependent upon the liquid content of snow. Two classifications for snow are 'wet snow' and 'dry snow'. The Liquid

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Equivalence Ratio (LER) is lies between 10:1 to 5:1, it is denoted as wet snow and for dry snow LER is between 10:1 to 30:1. If 'S' is the snow rate in mm/hr then specific attenuation can be calculated by

$$\alpha_{snow} = a.S^{b} \quad (4)$$

If λ is the wavelength, a and b are as follows for dry snow,

$a=5.42\text{x}10^{-5}\text{x}\lambda+5.4958776$, (5) $b=1.38$

The same parameters for wet snow are given as follows

$a=1.023\text{x}10^{-4}\text{x}\lambda+3.7855466$,(6) $b=0.72$

For dry snow a=5.495and b=1.38 and for wet snow, a=3.78 and b=0.72.The attenuation parameters, visibility ranges and its calculated attenuation values are reported in Table1.

Table1. Various Weather Conditions and Its attenuation values at 850 nm, 1310 nm and 1550 nm

III.HYBRID WDM-FSO SYSTEM MODEL

The proposed hybrid WDM based FSO system model is illustrated in Fig. 2 which is comprised of three parts namely, transmitter, receiver and FSO link or atmospheric conditions.

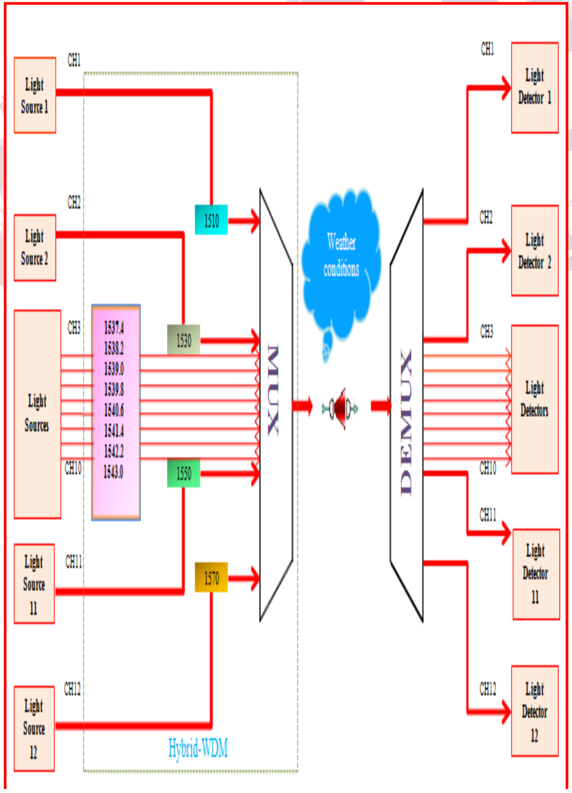

Fig.1.Design of Hybrid WDM-FSO model

The transmitter consists of CW laser, Mach-Zehnder modulator, Pseudo-Random Bit Sequence (PRBS)Generator, NRZ Pulse Generator and hybrid wavelength division multiplexing.HybridWDM comprising four CWDM channels spaced by 20 nm, a set of eight DWDM channels spaced by 0.8nmwhere as in receiver partdemultiplexerisused to separate the optical beam profile at a high rate of 2.5Gbps with different wavelengths.The designated wavelengths for DWDM channels are (1537.4nm- CH3, 1538.2nm-CH4, 1539nm-CH5, 1539.8nm-CH6, 1540.6nm-CH7, 1541.4nm-CH8, 1542.2nm-CH9, 1543nm-CH10) and CWDM channels (1510nm-CH1,1530nm-CH2,1550nm-CH11,1570nm-CH12).APD photodiode is utilized to convert optical signal in to electrical signal, followed by low pass Bessel filter to filter the unwanted signal. The space between transmitter and receiver is considered as FSO link distance or atmospheric distance.The simulation parameters are listed in Table2.

Table 2.Simulation Parameters of Free Space Optical Communication System

Parameters	**Values**
Data Rate	**2.5Gbps**
Launch Power	**20dBm**
Channel spacing: CWDM/DWDM **Laser linewidth: CWDM/DWDM**	**20nm/0.8nm** **10MHz/2500MHz**
Transmitter's & Receiver's Apertures	**30cm**
Dark Current	**10nA**
Extinction Ratio	**30dB**
Amplifier and Gain	**EDFA and 5dB**

IV. SIMULATION RESULTS AND DISCUSSIONS

The FSO system parameter such as Bit Error Rate (BER), receiver sensitivity, quality factor and transmission distance is estimatedfor the proposed Hybrid WDM-FSO system. The transmitted hybrid WDM-FSO signal after the multiplexer is shown in Fig. 2 whose corresponding signal power is about 15 dBm for DWDM Channels and 5 dBm for CWDM channels. This variation in received power is due to the losses in the components that are employed in the link and linewidth of the proposed system.

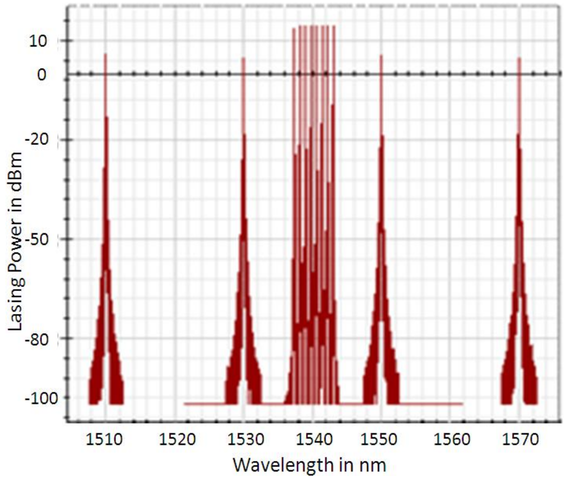

Fig. 2. Power spectrum of transmitted signal in the proposed hybrid WDM-FSO system

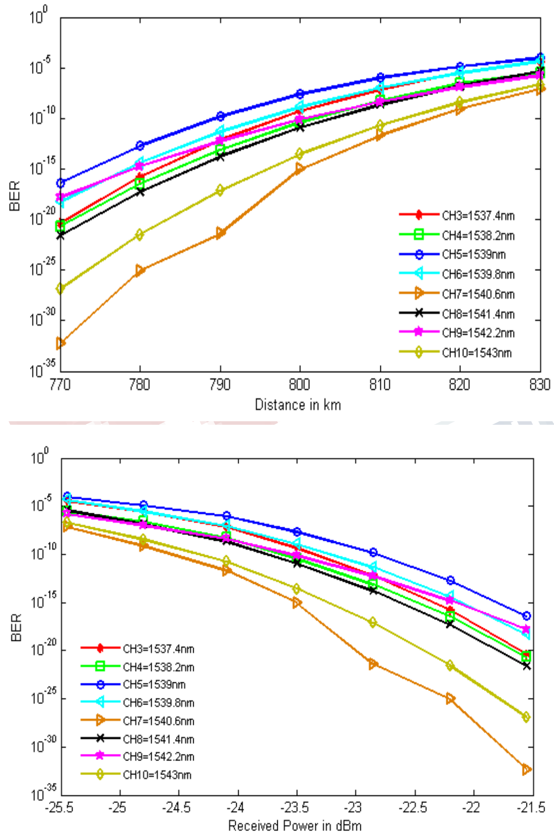

Fig.3. (a) BERvsDistance (b)BERvs Received the proposed hybrid WDM-FSO system

Fig. 3 (a) and (b) shows the effect of BER with respect to link distance and receiver sensitivity of the proposed hybrid WDM-FSO system at very clear conditions for DWDM channels. The average link distance and receiver sensitivity for the BER of 10-9 for DWDM channels are 810km and -21 dBm. Similarly, the average link distance for CWDM channels are 780km which is depicted in Figs. 4. It is noticed that the receiver sensitivity for CWDM and DWDM channels are about -21dBm and the link distance for CWDM channels are reduced than DWDM Channels as the linewidth of the CWDM channels are higher than DWDM channels. BER determine the FSO receiver performance at high data rate of 2.5Gbps.The signal quality is reduced while increasing BER at receiver resulting in minimum transmission distance. It is investigated that the minimum received power to obtain the desired BER (10-9) lies -21 dBm for DWDM and CWDM channels.

Power for DWDM system at very clear condition

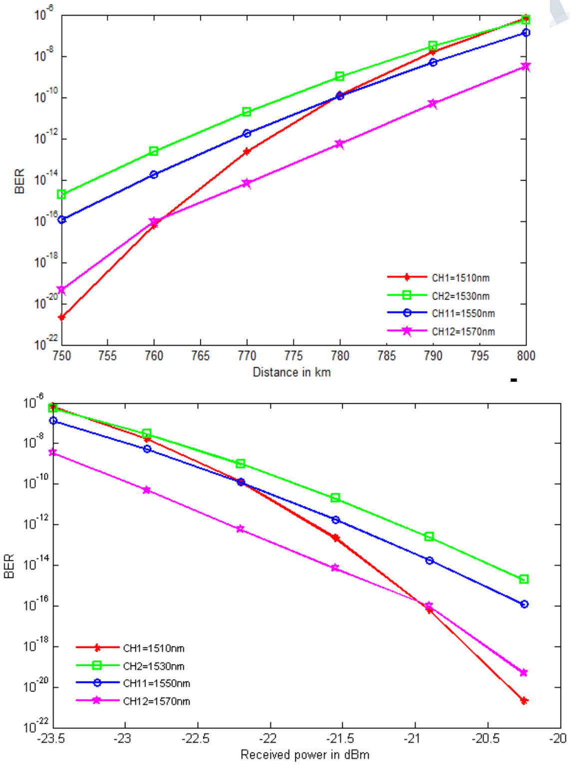

Fig.6. (a) BERvsDistance (b)BERvs Received Power for CWDM system at very clear condition

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Table.3.Maximum Link Range of proposed hybrid WDM-FSO system for various atmospheric conditions

Weather Conditions	DWDM Channels							
	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10
Very clear Clear	798 225	810 225	795 222	800 224	825 229	810 227	810 227	820 228
Light haze Heavy haze	95 22.1	95 22.1	94 22	95 22.1	97 22.4	96 22.3	96 22.2	98 22.5
Light fog Thick fog	3.4 2.05	3.5 2. 06	3.35 2.04	3.4 2.05	3.5 2.06	3.47 2.06	3.47 2.06	3.55 2.1
Light rain Medium rain Heavy rain	8.35 5.55 2.65	8.4 5.6 2.62	8.27 5.4 2.6	8.3 5.5 2.65	8.45 5.7 2.68	8.4 5.5 2.65	8.4 5.5 2.65	8.5 5.8 2.7
Wet snow	8.45 5.1 3.82 3.16	8.5 5.15 3.82 3.16	8.37 5.05 3.78 3.05	8.4 5.15 3.85 3.18	8.55 5.18 3.85 3.18	8.5 5.15 4.6 3.19	8.5 5.15 4.5 3.22	8.6 5.2 4.5 3.25
Dry Snow	3.64 1.4 0.8 0.54	3.65 1.41 0.82 0.56	3.63 1.39 0.79 0.53	3.64 1.4 08 0.54	3.68 1.43 0.87 0.57	3.66 1.42 0.81 0.55	3.66 1.42 0.81 0.55	3.69 1.44 0.88 0.59

Table.4.Maximum Link Range of hybrid WDM-FSO system for various atmospheric conditions with EDFA

CWDM Channels			
CH1	CH2	CH11	CH12
785 220	780 210	790 220	800 222
93 21.5	92 21	93 21.5	94 22
3.25 2	3.2 2	3.25 2.03	3.35 2.04
8.15 5.2 2.55	8.15 5.2 2.55	8.2 5.2 2.5	8.27 5.4 2.6
8.25 5 4.2 2.96	8.25 4.95 3.8 2.96	8.3 5 2.1 2.95	8.37 5.05 4.1 3.05
3.58 1.37 0.74 0.51	3.58 1.36 0.73 0.51	3.58 1.37 0.74 0.52	3.62 1.39 0.79 0.53

It is noticed that DWDM channels can able to transfer the data longer distance than CWDM system. From the result it is noticed that after insertion of EDFA the link distance is increased significantly. The maximum link distance for CWDM system is limited to the channel width and nature of the wavelength. In addition, link distance is decreased while increasing attenuation value.

V. CONCLUSION

In this paper,hybrid WDM-FSO system is proposed,designed and the network parametersnamely BER, QFactor, Receiver sensitivity are analyzed .The attenuation values for various atmospheric conditions are determined for 850nm,1310nm,1550nm.For the transmission of 2.5Gbps data, the proposed hybrid WDM-FDO system supports the optical link range up to 960.8km under veryclear weather condition. When the atmospheric attenuation is increased (dry snow condition), the achievable distance is diminished to0. 64km with acceptable BER.Inaddition, that the link distance for DWDM system is higher than CWDM system owing to the lindwidth of CWDM channels.Also,the travelling distance is decreased while increasing the attenuation values.The hybrid WDM network could be a right candidate to solve the last mile problems and the rapid increase in capacity without any new infrastructure by combining CWDM and DWDM channels.

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