Enhanced Spectrum Slicing–Wavelength Division Multiplexing Approach for Mitigating Atmospheric Attenuation in Optical Communication

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Abstract

Over the last decades, free-space optics (FSO) emerged as a prominent way of communication over radio frequency communication and microwave communication. Working of FSO in comparison with optical fiber cable (OFC) network is the same. The only difference between FSO & OFC is the transmission of an optical beam. The optical beam is transmitted through the free space in the case of FSO. Whereas the transmission of optical beam takes place using OFC core, i.e. glass fiber in the case of OFC. Fog, haze, rain, and clouds in the atmosphere directly affect FSO performance and the power of signal propagation. Further added, the wavelength of propagating beam is based on the size of fog particles which leads to atmospheric attenuation. To mitigate the impact of atmospheric attenuation on signals, the proposed study is based on a spectrum slicing (SS) - wavelength division multiplexing (WDM) system with Pre and Post Amplification. The analysis of SS-WDM-Pre and SS-WDM-Post has been done over various values of attenuation. The comparison analysis proves that the SS-WDM-Post is more efficient than both SS-WDM-Pre and traditional SS-WDM in terms of Q-factor.

1. Introduction

With the latest advancements in wireless communication and various benefits over the radio frequency (RF), free-space optics (FSO) is an attraction for the latest research among researchers. When compared with optical fiber communication, FSO is more popular as it is highly flexible and cost-effective (Rashidia et al. 2016). It is also more rapid and can be deployed and re-employed easily. In the current time, wavelength division multiplexing (WDM) provides the ability to hold a distinct and independent optical channel and is capable to carry terabits in a second (Vaishali and Sancheti 2017; Singh and Saini 2014; Saini and Wason 2019). It can effectively incorporate with the system based on free-space optics that can improve the speed of data transmission. To meet the demand of services, there is a huge requirement of bandwidth; WDM-FSO is the leading and well-known technique for broadband transmission (Singh and Saini 2014). But apart from these benefits, WDM has its own set of drawbacks such as high operation cost and higher complexity (Saini and Wason 2019; Malik and Singh 2015; Singh et al. 2012). To find a solution to these limitations, spectrum slicing technology is used over the WDM, where the spectrum slicing technique has an operation that does have less complexity when compared with WDM (Nor et al. 2011). The spectrum sliced WDM provides all the advantages of WDM. Additionally, it is a less complex system when compared with WDM. It is a low-cost and power-efficient system (Rehman et al. 2012).

2. Impact Of Atmospheric Conditions

In various tropical countries, rain defines the coefficient of attenuation. The attenuation that occurred due to the rainfall is also termed as non-selective scattering. Atmospheric conditions can reduce the performance of the system. These conditions can be rain, fog, snow, or dust. The main causes of performance reduction are due to factors like atmospheric attenuation and geometric losses (Riza and Marraccini 2012). But other related factors such as turbulence, scintillation, and multipath fading also contribute to the same. Atmospheric condition changes with the change in the region such as heavy

snow and fog for the temperature region and heavy rain for the tropical region (Vitasek et al. 2011). Rain is considered as the key attenuation factor for the light rays due to which FSO is highly affected. Due to higher rain drop scattering in the optical beam occurs, and this is termed as the scattering (Fadhil et al. 2013). There are factors affecting the link performance that further leads to the Q-factor and power degradation. Based on various atmospheric and weather conditions, different research has been done for designing the new models for an effective system for these conditions. The main weather factors considered were haze, fog, snow, and rain (Khan et al. 2012). The following section describes the variation of climate change caused by snow, rain, and fog:

- The presence of fog causes atmospheric attenuation. The amount of attenuation can be predicted by Mie scattering. The computations performed for analyzing the amount of attenuation are much more complicated; therefore a detailed examination of the data related to the fog parameters is essential. Through details of the range of visibility, empirical models are designed in order to predict attenuation caused by fog particles as an alternative method (Shah et al. 2016; Jodha et al. 2018).
- The size of the snowflake and the rate of snow is directly proportional to the amount of attenuation in snow- affected weather conditions. Snowflakes provide deep shades to the signal compared to the rain droplets because the size of raindrops is smaller than that compared to snowflakes. For reference consider a snowflake with 20mm size, it is capable enough to obstruct the entire path of propagating signal that is determined by signal beam width (Jodha and Chauhan 2018; Garg et al. 2014).
- Raindrops are directly related to the precipitation rate. Therefore, the independent scattering process causes attenuation in the presence of rain droplets.

3. Wavelength Division Multiplexing (Wdm) - Free Space Optics (Fso)

On a single medium, the WDM is multiplexing mechanisms that carry more than one optical signal. Though the FSO mechanism is an emerging mechanism so, in the communication region, the WDM mechanism has come into existence as a novel analysis (Khan et al. 2017). Figure 1 illustrates that due to atmospheric attenuation the WDM method is intended to overcome the destruction of the FSO signal. Among longer link distances the high data rate is probable as the WDM has the higher capability (Wu et al. 2011). The various beams FSO-WDM transmission mechanism has been effectively illustrated, to enhance the data rate, although more than one wavelength is utilized.

4. Spectrum Slicing (Ss)-wdm-fso

Due to their transmission ability at low expenses, FSO becomes a known name in the telecom industry. Due to the advantages like the simple installation process, easy long-range licensing, better security, higher bandwidth, and ability to work on full-duplex, FSO becomes a better option compared to others. Connectivity for the last mile (Yu et al. 2014), extension ability for metro and other telecom networks are achievable at very low expenses is also considered as the application of FSO. However, by utilizing the

atmosphere the FSO presentation shows the negative impact which it promulgates. The effects like turbulence in the atmosphere and haze were considered as one of the most common reasons for interference (Goyal et al. 2015). The light features are adapted by these particles whenever light passage is obstructed. Due to this, the transmitted beam power density is reduced consecutively and the FSO link's efficient distance will be reduced. Different techniques such as SS-WDM are applied in order to find the solution of the problem. Through offering greater capacity and a wide-ranging array the finest is served that aids many number of consumers. When we consider the optical networking communication region, FSO is a network that can easily be expanded which makes it more appropriate. For the reasons of these advantages in research, this technique is widely accepted by researchers (Zhao et al. 2013). For the modulation purpose of the optical signal generally, the technique of spectrum slicing is utilized. For the optical signal modulation purpose and for analyzing the spectrum about the parameters related to that these spectrums are sliced by using different techniques. The technique of Spectrum Slicing has adequate potential for the upcoming fiber targeting to the home access network that can be used with the other optical mechanism where minimum power utilization is chosen. The key target of signal modulation is to pull out maximum data by utilizing the minimum spectrum. For quantifying the data transferred, spectra efficiency is an important factor for a particular assigned bandwidth (Prabu et al. 2014). Various techniques were used for spectral efficiency improvement (Aladeloba et al. 2013). The reason for deploying the FSO with WDM gives enough budgets of power and supporting the high capacity transmission with an improvement in stability. In FSO, high wireless links can be created at the cost of the drop in the quality of the transmission for the reason of the external factors based on the environment like scattering, turbulence, and misalignment losses. Signal beams get scattered leading to the signal intensity reduction. For cutting down stoppages generally, WDM DSO links are used. WDM FSO is used for the reason of providing a high range and better data rate. Figure 2 illustrates the block diagram of the SS-WDM-FSO communication system.

SS-WDM is considered a good alternative to multiple coherent laser (MCL) (Nain et al. 2016; Prabu et al. 2017). This network has the ability to get expanded and provides support to high bandwidth options. This shows the ability to providing the option of maximizing according to the developed system definite area. This mechanism is capable of optical signal modulation and can also achieve communication at high speed without the process of optical-electrical-optical signal propagation. This further leads to enhancement on the factor of optical system dispersion tolerance that is a major factor of signal obstruction for the transmission (Prabu et al. 2017; Radhi et al. 2013). FSO is a channel that gives an opportunity for the transmission of point-to-point communication by propagating optical signal in an atmosphere as a carrier frequency. For two-point communication through the wireless medium that is concentrated at the line of sight (LOS), FSO is considered that includes all the formats of data taking the air as a medium of transmission.

This transmitted signal aspects different hindrances as it travels in multiple types of propagation mediums. That leads to corruption of data and information loss. A narrow bandwidth has been offered by the FSO technique that makes it a secured way of communication. The technique of Spectrum Slicing has been done with the technique of FSO for improved performance and efficiency of the FSO channel.

As this technique supports a higher data rate, it requires the implementation of higher-order modulation. A spectrum parted with spacing that is not equal and added multiple ports in the de-multiplexer for finding the spectrum performance and efficiency of the channel (Malik and Singh, et al. 2015).

5. Problem Formulation

The optical communication system is very popular among the users due to various features like reliable data delivery, fast speed, however, it is influenced by the environment; Strong weather instability (due to rain, fog, etc.) is a major problem in optical communication systems (Jodha and Chauhan 2018). Various authors analyze the concept of how this communication system responds to climate change. Traditional work was done to analyze the performance of the WDM communication system in heavy rains. In the traditional approach (SS-WDM with FSO) (Rashidia et al. 2016), analysis was done for heavy rain weather of China. The analysis involved communication over 3 km with the data rate of 1.56 Gb/s at 1550 nm wavelength. The WDM de-multiplexing was also used to slice the system. Along with this, NRZ modulation was applied. After analyzing, the observed results were not found to be effective as the effect of attenuation was still there that reduced the quality of communication.

6. Proposed Work

FSO is an innovative and sophisticated communication technology that works on a wide variety of services in an optical access network. In an FSO communication system, the sender can transmit the modulated beam over the air and this communication is called a direct line of sight communication. According to the statement described in the problem-formulation phase, it is clear that there is a need to reduce the number of errors from the optical communication system. The proposed research, therefore, aims to use an optical communication system with a multi-FSO WDM link with different weather conditions such as summer, winter, autumn, and spring. Along with this pre and post-amplification is applied to mitigate the effect of attenuation in the signals. The pre-amplification is applied at the transmitter end and the post-amplification is applied at the receiver end.

Figs. 3 and 4 define the architecture of the proposed work with respect to both amplifications i.e. pre and post. Fig. 3 depicts the pre-amplification process. In this, an optical amplifier is applied before FSO and then the DEMUX is applied at both ends i.e. receiver and transmitter. Then, Mach Zehnder modulation is applied to the transmitter end in between multiplexer and de-multiplexer. Similarly, post-amplification is implemented. The only difference is that in the pre-amplification process, optical amplifiers are applied before applying the communication channel, whereas, in post-amplification, the optical amplifiers are applied after applying the communication channel i.e. FSO.

7. Results And Discussion

In the present study, the WDM-FSO is applied for analyzing various climatic conditions such as winter, summer, autumn, and spring by applying pre and post-amplification. The performance of the proposed

work is evaluated in terms of Q-factor and BER. The comparison analysis is also drawn for measuring the efficiency of the proposed work over the traditional one. The graph in Fig. 5 depicts the Q-factor of traditional (SS-WDM) and Proposed (SS-WDM Pre, SS-WDM Post) mechanism for autumn. The Q-factor is analyzed on the basis of the effect of attenuation on the signals.

The graph proves that the Q-factor of traditional SS-WDM is lower whereas the Q-factor of SS-WDM-Pre and SS-WDM-post is higher with respect to the various values of the attenuation. The facts and figures observed from the graph are shown in Table 1.

Table 1
Performance analysis (Q-Factor) of proposed work for autumn

Attenuation	Q- factor (SS-WDM) [1]	Q-factor (SS-WDM-Pre)	Q-factor (SS-WDM-Post)
1.5	34.67	54.3913	54
1.8	29.25	45.9	46.1
4.1	7.85	12.45	12.5

Similarly, the graph in Fig. 6 calibrates the analysis of the proposed work over traditional work with respect to the spring. The analysis has been done for different levels of attenuation in signals such as 3.25, 4.5, and 6.5 dB/km.

The bar with blue defines the Q-factor of SS-WDM, the bar in green marker depicts the performance of SS-WDM-Post, and the bar in red defines SS-WDM-Pre. The respective values for the Q-factor of considered techniques are shown in Table 2.

Table 2
Performance analysis (Q-Factor) of proposed work for spring

Attenuation	Q-factor (SS-WDM) [1]	Q-factor (SS-WDM-Pre)	Q-factor (SS-WDM-Post)
3.25	12.8	20.23	164.7
4.3	6.99	11.098	135.23
6.3	2.18	3.48	81.69

The graph in Fig. 7 explicates the Q-factor analysis for the climatic condition of summer. The analysis defines that the Q-Factor of SS-WDM-Post amplification is higher and efficient than the Q-factor of SS-WDM-Pre and SS-WDM. The values of the Q-factor for the three techniques on the range of various attenuations are depicted in Table 3.

Table 3
Performance analysis (Q-factor) of proposed work for summer

Attenuation	Q-factor (SS-WDM) [1]	Q-factor (SS-WDM-Pre)	Q-factor (SS-WDM-Post)
3.5	11.095	17.54	17.624
4.5	6.235	9.895	9.93
6.5	1.901	3.104	3.109

The Q-Factor of SS-WDM-Post and SS-WDM-Pre is higher for winters whereas the Q-factor of SS-WDM is lower than the considered range of attenuation. Table 4 explains that the Q-factor of the traditional method with respect to the 1.8 dB/km attenuation is 29.25 whereas, for SS-WDM-Pre and SS-WDM-Post, it is 45.99dB/km and 46.108dB/km respectively.

Similarly, the graph in Fig. 8 demonstrates the results of proposed and traditional work in terms of the winter season. The observed facts and figures are shown in Table 4.

Table 4
Performance analysis (Q-factor) of proposed work for winter

Attenuation	Q-factor (SS-WDM) [1]	Q-factor (SS-WDM-Pre)	Q-factor (SS-WDM-Post)
1.8	29.25	45.99	46.108
2.3	22.028	34.708	34.84
2.6	18.568	29.27	29.39

Table 5
BER analysis of proposed and traditional work

Season	BER(T)	BER(pre)	BER(post)
Autumn	8.97E-264	0	0
	2.07E-188	0	0
	1.95E-15	6.98E-36	3.72E-36
Spring	7.36E-38	2.38E-91	0
	1.27E-12	6.36E-29	0
	0.0145	0.00024	0
Summer	6.57E-29	3.18E-96	7.97E-70
	2.25E-10	2.17E-23	1.53E-23
	0.0285	0.00095	0.00093
Winter	2.07E-188	0	0
	9.10E-108	2.94E-264	2.82E-266
	2.88E-77	1.06E-188	2.78E-190

The BER of proposed and traditional work is shown in Table 5. The BER is analyzed for different weather conditions i.e. Spring, Summer, Autumn and Winter. On the basis of the facts, it is observed that the proposed Pre and Post systems outperforms than traditional work.

8. Conclusion

Optical communication is highly vulnerable to atmospheric conditions. The weather such as heavy rain, fog, and haze affects the quality of data transmission. This reduction in the quality of communication is due to the attenuation of signal i.e. reduction in signal strength. This study develops a novel mechanism, i.e. SS-WDM-Pre and SS-WDM-Post for reducing the effect of attenuation on the signals. For this purpose, the Pre and Post amplification to the signals is applied at the receiver and transmitter end individually. The analysis of SS-WDM-Pre and SS-WDM-Post is done in terms of Q-Factor over various values of attenuation in the signals. The results observed after analysis and implementation delineate that the SS-WDM-Post has more efficiency than the SS-WDM-Pre and SS-WDM systems. The Q-Factor of SS-WDM-Post is found to be quite effective over different conditions with a different range of attenuation. In order to enhance the present work in the future, advanced modulation schemes can be implemented.

9. Declarations

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Code availability: The data can be obtained on demand

Authors' contributions: Equal Participation of all authors

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Figures

Figure 1

Block diagram of WDM-FSO system (Khalighi and Uysal 2014)

Figure 2

Block Diagram of SS-WDM-FSO Communication System (Malik and Singh, et al. 2015)

Figure 3

Pre-Amplification process of proposed work

Figure 4

Post-Amplification process of proposed work

Figure 5

Analysis of Q-factor for Autumn

Figure 6

Analysis of Q-factor for Spring

Figure 7

Analysis of Q-factor for Summer

Figure 8

Analysis of Q-factor for Winter