Enhanced spectrum slicing: wavelength division multiplexing approach for mitigating atmospheric attenuation in optical communication

Dinesh Arora1 · Hardeep Singh Saini2 · Vinay Bhatia1 · Jagdeep Kaur1

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Abstract
Over last decades, the free space optics (FSO) emerged as most prominent way of communication over radio frequency communication and microwave communication. The FSO works in the same way optical fiber cable (OFC) network works with the only difference that the optical beams were transmitted through the free space and not by using the OFC core i.e. the glass fiber. The presence of mist, fog, rain and clouds in the atmosphere directly affects the performance of FSO and the power of propagating signal is degraded significantly. Since the wavelength of propagating beam is comparable to size of fog particles, they mainly lead to atmospheric attenuation. To mitigate the impact of atmospheric attenuation on signals, the present study develops a spectrum slicing (SS)-wavelength division multiplexing (WDM) system with Pre and Post Amplification. The performance of the proposed SS-WDM-Pre and SS-WDM-Post scheme is analyzed and then compared with the traditional SS-WDM model in the Opti-system in terms of Q-factor and BER values. The analysis of the proposed and traditional scheme is done under varying attenuation and power signals during summer, winter, autumn and spring season. The comparative analysis proved that the performance of the proposed SS-WDM-Post and SS-WDM-Pre-model is more effective and efficient when compared with the traditional SS-WDM model in terms of Q-Factor and BER during all 4 seasons.

Keywords Attenuation · Optical fiber communication · Free space optics (FSO) · Spectrum slicing · Q-Factor · Wavelength division multiplexing (WDM)

* Hardeep Singh Saini
hardeep_saini17@yahoo.co.in

Dinesh Arora
drdinesh169@gmail.com

Vinay Bhatia
vinay4office@gmail.com

Jagdeep Kaur
jagdeep_31@yahoo.co.in

1 Department of ECE, Chandigarh Engineering College, CGC, Landran, Mohali, Punjab 140307, India
2 Department of ECE, Indo Global College of Engineering, New Chandigarh, Mohali 140109, India
1 Introduction

With the latest advancements in the wireless communication and various benefits over the radio frequency (RF), free space optics (FSO) is an attraction for latest research among the researchers. When compared with the 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 reemployed easily. In the current time, wavelength division multiplexing (WDM) provides the ability to hold different distinct and independent optical channel and is capable to carry terabits in a second (Vaishali 2017; Singh and Saini 2014; Saini and Wason 2017). 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 that has high requirement of bandwidth, WDM-FSO is the leading and well known technique for the broadband transmission (Singh and Saini 2014). But apart from these benefits, WDM has their own set of drawbacks such as high operation cost and higher complexity (Saini and Wason 2017; 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 (Rahman et al. 2012).

2 Impact of atmospheric conditions

In various tropical countries, rain defines the coefficient of attenuation. The attenuation occurred due to the rainfall is also termed as the non-selective scattering. Atmospheric conditions can reduce the performance of the system. These conditions can be rain, fog, snow or dust. Main causes of reduction of the performance are factors like the atmospheric attenuation and geometric losses (Riza and Marraccini 2012). But other related factors such as turbulence, scintillation and multipath fading also contribute for 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 high rain drop scattering in the optical beam occurs and this is termed as the scattering (Fadhil et al. 2013). There are factor 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). Following section elaborates the variation of atmospheric attenuation produced due to presence of snow, rain and fog:

- Presence of fog causes atmospheric attenuation. The amount of attenuation can be predicted by Mie scattering. The computations performed for analyzing amount of attenuation are much more complicated, hence detailed form of data related to fog parameters is required. 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).

- The size of snowflake and rate of snow are directly proportional to amount of attenuation in snow affected weather conditions. Snowflakes provide deep shades to the signal compared to the rain droplets because the size of raindrop is smaller than that compared to snowflakes. For reference consider a snowflake with 20 mm size, it is capable enough to obstruct the entire path of propagating signal that is determined by signal beam width (Garg and Singh 2014).
- Rain droplets have a linear relationship with the rate of rainfall. 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 comes into an existence as a novel analysis (Khan et al. 2011). The Fig. 1 illustrates that because of the atmospheric attenuation a WDM mechanism is deliberated to conquer the confront of FSO signal degradation (Wu et al. 2011). Among longer link distance the high data rate is probable as the WDM has higher capability. 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 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 other. Connectivity for the last mile (Yu et al. 2014), extension ability for metro and other telecom network are achievable at very low expenses is also considered as the application of FSO. However by utilizing the atmosphere the FSO
presentation shows negative impact which it promulgates. The effects like turbulence in atmosphere and haze were considered as one of the most common reason of the interference (Goyal et al. 2015). The light features are adapted by these particles and the light passage is obstructed. The transmitted beam power density is reduced consecutively by this and the FSO link’s efficient distance is 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 much number of consumers. When we consider the optical networking communication region, FSO is a network that can easily be expanded that makes it more appropriate. For the reasons of these advantages in the research this techniques is widely accepted by the 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 the 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 the signal modulation is to pull out the 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 the spectral efficiency improvement (Aladeloba et al. 2013). The reason of deploying the FSO with WDM gives enough budgets of the power and supporting the high capacity transmission with an improvement of the stability. In FSO, high wireless link 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 the stoppages generally WDM DSO links are used. WDM FSO is used for the reason of providing high range and better data rate. Figure 2 Block Diagram of SS-WDM-FSO Communication System.

SS-WDM is considered as a good alternative of multiple coherent laser (MCL) (Nain et al. 2016). This network has the ability to get expanded and provides the support to high bandwidth option. This shows the ability providing the option of maximizing according to the developed system definite area. This mechanism is capable of optical signal modulation and can also achieve the communication at high speed without the process of optical-electrical-optical signal propagation. This further leads to enhancement on the factor of optical

Fig. 2 Block Diagram of SS-WDM-FSO Communication System (Malik and Singh 2015)
system dispersion tolerance that is a major factor of signal obstruction for the transmission (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 atmosphere as a carrier frequency. For a 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 the transmission.

This transmitted signal aspects different hindrance as it travels in multiple type of propagation medium. That leads to corruption of data and information loss. A narrow bandwidth was offered by the FSO technique that makes it a secured way of communication. The technique of Spectrum Slicing is been collaborated with technique of FSO for an improved performance and efficiency by the FSO channel. As this technique supports higher data rate, it requires the implementation of the 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 2015).

5 Problem formulation

Optical communication system is quite popular among the users due to its various features such as reliable data delivery, fastest in speed etc. But it gets affected by weather; strong atmospheric instability (because of rain, fog, haze etc.) is a major problem in optical communication system. Various authors perform analysis on the concept that how this communication system reacts with the variations in the weather. The traditional work had been done to analyze the performance of the WDM communication system in heavy rains. In traditional approach (SS-WDM with FSO) (Rashidia et al. 2016), the 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 the 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 the communication.

6 Proposed work

FSO is an encouraging and trending communication technology which is applicable to the different type of services in the entire optical access network. In FSO communication system, the sender can transmit the modulated beam via atmosphere and this communication is known as the direct line of sight communication. As per the statement defined in the problem formulation section, it is observed that there is a requirement to reduce the error rate from the optical communication system. Therefore, the proposed work aims to implement the optical communication system by WDM based multi-beam FSO link for a different atmospheric condition like summer, winter, autumn, and spring. Input power, length of FSO link, frequency, type of optical are some of the parameters that are taken into consideration while designing the system. Other than this, there are some other parameters that are also used in the system; those are defined in Table 1.

Along with this pre and post amplification is applied to mitigate the effect of attenuation in the signals. The pre amplification is applied at transmitter end and the post amplification is applied at receiver end. The Figs. 3 and 4 defines the architecture of the proposed
Table 1  Configurational parameters of the proposed system

| Parameter                  | Value                        |
|----------------------------|------------------------------|
| Input power (dB)           | 0, 2, 4                      |
| FSO length (km)            | 2.5                          |
| Frequency (THz)            | 193.1                        |
| Filter type                | Low pass Gaussian filter     |
| Filter cut-off freq        | 0.75                         |
| Photodetector              | PIN                          |
| Optical type               | Optical amplifier            |
| Autumn attenuation (dB/km) | 1.5, 1.8, 4.1                |
| Spring attenuation (dB/km) | 3.25, 4.3, 6.3               |
| Summer attenuation (dB/km) | 3.5, 4.5, 6.5                |
| Winter attenuation (dB/km) | 1.8, 2.3, 2.6                |

Fig. 3  Pre-Amplification process of proposed work

Fig. 4  Post-Amplification process of proposed work
work with respect to the both amplifications i.e. pre and post. The Fig. 3 depicts the pre-amplification process. In this the optical amplifiers 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, the post amplification is implemented. The only difference is that that in pre-amplification process, the 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 present study the WDM-FSO is applied for analyzing the various climatic conditions such as winter, summer, autumn and spring by applying pre and post amplifications. The performance of the proposed work is evaluated in the terms of Q-Factor and BER with varying attenuation and power signals. The comparison analysis is also drawn for measuring the efficiency of the proposed work over 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 to 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 by Table 2.

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

| Attenuation | Q-factor (SS-WDM) (Rashidia et al. 2016) | 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 proposed work over traditional work with respect to the spring. The analysis is done for various level 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 bar in red defines the SS-WDM-Pre. The respective values for Q-factor of considered techniques are shown in Table 3.

The graph in Fig. 7 explicates the Q-Factor analysis for 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 Q-factor for the three techniques on the range of various attenuations in depicted in Table 4.

The Q-Factor of SS-WDM-Post and SS-WDM-Pre is the higher for winters whereas the Q-Factor of SS-WDM is the lower for considered range of attenuation. The Table 5 explains that the Q-Factor for 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 45.99 dB/km and 46.108 dB/km respectively.

Similarly, the graph in Fig. 8 demonstrates the results of proposed and traditional work in terms of winter season. The observed facts and figures are shown in Table 5.

The BER of proposed and traditional work is shown in Table 6. 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 both systems outperforms than the traditional work.
In addition to this, the performance of the proposed pre and post amplification models is also analyzed in terms of Q-factor and BER when the input power signals are varied continuously. The performance of the suggested SS-WDM pre and Post amplification scheme is compared with the conventional SS-WDM model during autumn season in terms of Q-factor and is shown in Fig. 9.

After observing the above graph, it is observed that the value of Q-factor in proposed SS-WDM-pre and SS-WDM-post mechanism is quite higher than the value of Q-factor in traditional SS-WDM models with changing power values.

Similarly, the performance of the proposed model and the traditional SS-WDM model during the spring season with varying power signals is given in Fig. 10. The analysis is done for varying power in signals such as 0, 2 and 4 dB. After analyzing the graph, it is analyzed that the value of Q-factor in conventional SS-WDM model is quite low when

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**Table 4** Performance analysis (Q-Factor) of proposed work for summer

| Attenuation | Q-factor (SS-WDM) (Rashidia et al. 2016) | 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                  |

**Table 5** Performance analysis (Q-Factor) of proposed work for winter

| Attenuation | Q-factor (SS-WDM) (Rashidia et al. 2016) | 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                  |
compared with the suggested SS-WDM-pre and SS-WDM post systems during spring season. This proves the efficacy of the suggested model in spring season.

In addition to this, the efficiency of the proposed SS-WDM pre and SS-WDM-post model is determined and later on compared with the traditional SS-WDM model in terms of Q-factor with varying input power signals in the summer and winter season. The graph obtained for the same are given in Figs. 11 and 12.

Figure 11 illustrates the graph for Q-factor with varying input power signals in summer season. The blue lines depict the performance of the traditional SS-WDM model whereas, the orange and blue colored lines depict the performance of the proposed SS-WDM-pre and SS-WDM-post mechanisms respectively. The graphs demonstrate that the Q-factor in proposed SS-WDM pre and post model is very high when compared with the traditional SS-WDM models in summer season. In the same manner, the value of Q-factor is analyzed

Table 6  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 | 3.82E−92  |
|         | 1.27E−12  | 6.36E−29 | 3.94E−29  |
|         | 0.0145    | 0.00024  | 0.00023   |
| 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 |
Fig. 9  Analysis of Q-factor for Autumn

Fig. 10  Analysis of Q-factor for Spring

Fig. 11  Analysis of Q-factor for Summer
for the winter season with varying input power signals that is shown in Fig. 12. The graph illustrates that the value of Q-factor is quite higher in both cases of proposed SS-WDM pre and post amplification models, whereas, the value of Q-factor in traditional SS-WDM model came out to be quite lower. The values obtained for Q-factor in each for each season i.e. autumn, spring, summer and winter are recorded in Table 7.

On the other hand, the value of the proposed SS-WDM pre and SS-WDM post model is also analyzed and compared with the traditional SS-WDM model in terms of its BER value during summer, winter; autumn and spring seasons with varying input power signals. The values obtained for the BER in each case are mentioned in Table 8.

After observing the above graphs and tables, it is observed that the suggested pre and post model outperforms the traditional model in terms of Q-factor and BER during all four seasons (summer, winter, autumn and spring) with varying attenuation and input power signals.

Table 7 Performance analysis (Q-Factor) of proposed work in four seasons

| Season  | Power (dB) | Q-factor SS-WDM | Proposed Q-factor (pre) | Proposed Q-factor (post) |
|---------|------------|-----------------|-------------------------|--------------------------|
| Autumn  | 0          | 34.67           | 54.196                  | 54.46                    |
|         | 2          | 54.28           | 83.65                   | 83.75                    |
|         | 4          | 83.82           | 124.74                  | 124.16                   |
| Spring  | 0          | 12.8            | 20.23                   | 20.32                    |
|         | 2          | 20.22           | 31.87                   | 32                       |
|         | 4          | 31.85           | 50.01                   | 50.12                    |
| Summer  | 0          | 11.09           | 17.52                   | 17.62                    |
|         | 2          | 17.53           | 27.6                    | 27.78                    |
|         | 4          | 27.64           | 43.3                    | 43.59                    |
| Winter  | 0          | 29.25           | 45.99                   | 46.1                     |
|         | 2          | 45.94           | 71.54                   | 71.43                    |
|         | 4          | 71.45           | 108.69                  | 107.81                   |
8 Conclusion

The optical communication is highly vulnerable to the atmospheric conditions. The weather such as heavy rain, fog and haze affects the quality of the 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 receiver and transmitter end individually. The analysis of SS-WDM-Pre and SS-WDM-Post is done in the terms of Q-Factor and BER with varying attenuation and input power signals in the Opti system. The results observed after analysis and implementation delineate that the SS-WDM-Post has more efficiency than the SS-WDM-Pre and SS-WDM system when attenuation is varied. The Q-Factor of SS-WDM-Post is found to be quite effective over different conditions with different range of attenuation. In addition to this, when the input power signals are varied, the performance of both suggested SS-WDM pre and post came out to be best and efficient during all seasons. In order to enhance the present work in future, advanced modulation schemes can be implemented.

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Table 8 BER analysis of proposed and traditional work

| Season  | Power (dB) | BER(T)       | BER(pre) | BER(post) |
|---------|------------|--------------|----------|-----------|
| Autumn  | 0          | 9.99E-264    | 0        | 0         |
|         | 2          | 0            | 0        | 0         |
|         | 4          | 0            | 0        | 0         |
| Spring  | 0          | 7.36E-38     | 2.38E-91 | 3.82E-92  |
|         | 2          | 2.97E-91     | 3.19E-223| 4.10E-225 |
|         | 4          | 2.97E-91     | 0        | 0         |
| Summer  | 0          | 6.57E-29     | 4.81E-69 | 7.97E-70  |
|         | 2          | 3.68E-69     | 5.19E-168| 3.14E-170 |
|         | 4          | 1.56E-168    | 0        | 0         |
| Winter  | 0          | 2.06E-188    | 0.00E+00 | 0.00E+00  |
|         | 2          | 0.00E+00     | 0.00E+00 | 0.00E+00  |
|         | 4          | 0.00E+00     | 0        | 0         |
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