Overcoming Atmospheric Turbulence Using OFDM-FSO System: A Review

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Abstract **-Nowadays, Free Space Optics (FSO) is gaining a lot of popularity, as it offers more advantages than other communication systems like licence-free operation, high data transmission rates etc. The major drawback of this system is the atmospheric turbulence since the medium that is used in this system is air. Orthogonal frequency-division multiplexing (OFDM) is a method of digital signal modulation in which a single data stream is divided into several separate narrowband channels at different frequencies. One of the main advantages of OFDM is that it is more resistant to frequency selective fading because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels. Using FSO system in combination with Orthogonal Frequency Division Multiplexing (OFDM) scheme, the bad influence of atmosphere can be overcome. There are different methods to mitigate the bad influence of turbulence in OFDM-FSO system which is discussed in this paper.**

Keywords**— atmospheric turbulence, Free Space Optics (FSO), Orthogonal Frequency Division Multiplexing (OFDM), Radio over Free Space Optics (RoFSO).**

I. INTRODUCTION

Free space optics is a type of communication that uses air as medium to transfer data point-to-point. It can be used in areas where normal fibers are not feasible. Mostly, these are the areas where network connectivity lacks. There are many advantages of using FSO like it is a license-free operation, provides high rate of data transmission, full duplex transmission, greater bandwidth and low power consumption [2]. However, the quality of signal received at the receiver side is deteriorated. This is due to atmospheric attenuation. FSO systems are susceptible to weather conditions like fog, snow, rain and dust particles. Therefore, the main challenge of FSO system is to overcome the instability of signal that is caused by turbulence in atmosphere. The instability in the signal is caused due to intensity scintillation and phase fluctuation. Intensity scintillation is the variation in the refractive index which is caused by small-temperature variation [1]. A method called RoFSO i.e. Radio over Free Space Optics is considered suitable for provision of communication networks that provide a reliable and robust links and adaptability towards adverse weather conditions. It is the transmission of radio signal using FSO link. It performs the conversion of electrical domain to optical domain and then returns back to electrical domain in original format at receiver side.[7] RoFSO technique is normally used in underserved areas to extend the connectivity of broadband [1]. Multiple RF signals that carry broadband wireless services can be implemented using advanced DWDM-RoFSO system [3]. OFDM is a common technique to access broadband. OFDM provides high channel efficiency and robustness against frequency selective fading and narrow-band subcarriers to transmit multicarrier data simultaneously. In this technique, using a modulation scheme each subcarrier is modulated by signal carrying information. All the subcarriers are orthogonal to one another and therefore the intersymbol interference (ISI) can be reduced between them. Also, the signal separation gets easier at the receiver side using correlation [4]. By employing OFDM in free space optics, multiple channel transmission is possible.

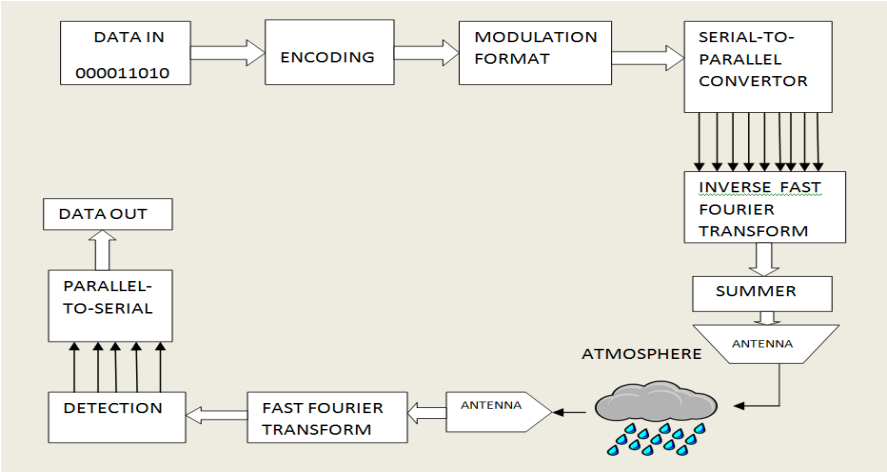

Fig.1 Basic Block Diagram of OFDM-FSO System

II. OFDM-FSO SYSTEM DESCRIPTION

Fig1. Shows the basic block diagram of OFDM-FSO system. It consists of two subsystems, one is transmitting system and other is the receiving system. They represent OFDM transmitter and OFDM receiver subsystem. Firstly the input data is encoded by the OFDM transmitter using any modulation format. The modulation scheme can be used according to the system characteristics. Modulation schemes like Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM) can be used. A serial-to-parallel convertor is used then to transform the data stream. The orthogonal subcarriers are allocated with the parallel data for parallel transmission. The inverse fast fourier transform is used at the transmitter section to realize the set of orthogonal carriers. The summed up signal is then emitted by the antenna. The transmitted signal travels through the atmosphere where it interacts with various levels of turbulence such as weak, moderate and strong. The signal quality gets degraded during its transmission in air. The receiver subsystem comprises of receiving antenna that receives the signal. The signal is detected using a detection method. Direct detection and coherent detection are the methods of detection that can be used. The process of OFDM receiver is just the reverse process of OFDM transmitter.

III. LITERATURE REVIEW ON OFDM-FSO SYSTEM

The major drawback in the system is the atmospheric turbulence which hampers the overall performance of the system. There are many parameters that get affected such as bit error rate, outage probability etc. Using OFDM in combination with FSO, the system performance can be improved. For improvement, the design of the system needs to be modified with new technology. From Fig1, if suitable changes are made at various stages, the outcome of the system can show better results. It was shown that there are two subsystems i.e. OFDM transmitter and OFDM receiver. Changes can be made in either of the subsystems for improved performance of FSO system.

One method is to use coherent detection method using Virtual Local Oscillator at the receiver section. In coherent detection method, the local oscillation light is taken from signal light. This helps in such a way that matching problem of shape of the wave that is between the signal light and local oscillation light is solved. It is not like other existing coherent detection methods that employ an external local oscillator which causes such matching problem. Fiber grating (FG) can be used here to tune a large frequency range. Fiber grating is a good wavelength selector and is insensitive to non-linear effects, polarization and has large bandwidth range. Coherent detection method shows better results than the direct detection method since the error rates are low in coherent method. It was found that compared with the direct detection method, coherent detection can reduce the link loss by 1 dB while achieving the same bit error rate [8]. The receiving sensitivity is also better in case of coherent detection method.

In OFDM technology, each subcarrier is modulated by a signal that carries information using a modulation scheme. As it was told before, that different modulation schemes can be used according to the system characteristics. PSK and QAM modulation schemes were compared and was found that QAM format gives much better BER results than that of PSK modulation formats [4].

The most widely adopted scheme of modulation is ON-OFF Keying (OOK) which is based on intensity modulation or direct detection. But when this scheme is employed in FSO system it is found to be sub-optimal over channels that are affected by atmospheric turbulence. In FSO communication systems, Pulse Position Modulation (PPM) is widely used. But it needs synchronization in symbols. Also, the bandwidth efficiency is poor. To improve this, an innovative hybrid modulation scheme called Pulse Position Modulation-Minimum Shift Keying- Subcarrier Intensity Modulation (PPM-MSK-SIM) can be used, which is based on PPM and MSK subcarrier intensity modulation . It combines the advantages of MSK's strong anti-interference and PPM's high power utilization ratio. It was found that the BER performance of PPM-MSK-SIM was better than PPM [9].

There had been a great demand of high data rates from the past few years by increasing number of end users. A large number of channels cannot be serviced in wavelength division multiplexing RoFSO system so easily since dispersion takes place in multichannel. By modifying the transmitter section demand of high data rates can be fulfilled. A new technique of generating carriers by Mode-Locked laser can help increase serviceable channels in RoFSO. Here, a ring laser cavity which incorporates an add/drop filter is used to produce mode-locked optical carriers. Mode-locked outputs are used where there is a desire of ultra fast pulses. In terms of pulse spectrum, mode-locking is described as a pulse having temporal envelope that evolves on a time scale quite longer than the pulse width [3]. Multiple optical carriers are generated that are modulated with orthogonal frequency division multiplex signals and subsequently optically multiplexed and transmitted to a free space channel using FSO antenna . Using this method, the error vector magnitude (EVM) performance results of the received RF signal are acceptable. In free space, the generated carriers are able to travel with very less dispersion by employing this scheme.

Though OFDM has many advantages, but the disadvantages such as phase noise sensitivity and peak-to-average power ratio (PAPR) hampers performance of the system. By exploiting its advantages with careful design the disadvantages can be minimized. Multilevel Differential Phase Shift Keying (MDPSK)- based nonequalization OFDM is one such method that can be used to compensate the phase and amplitude variation that is caused by atmospheric turbulence. This is done by adding an additional training sequence at the input in transmitter section for the estimation of channel and equalisation [5]. Multilevel DPSK approach guarantees good performance of the system without equalization. Such a technique can be applied either in frequency domain or

in time domain. It is observed that the bit error rate performance is nearly same for both frequency domain and time domain. Yet, frequency domain is considered better as it provides higher spectral efficiency and low complexity hardware.

One more drawback of FSO system is the short range link since the system gets affected by the atmospheric disturbances. With M-QAM, the distance of communication can be increased. In this technique, OFDM modulation is used with M-ary Quadrature amplitude modulation encoder. . It is observed that the BER value is feasible for the distance upto 7km. The value of outage probability also gets increased if the number of subcarriers is increased. The system performance worsens if number of subcarriers increases or the distance between transmitter and receiver is increased [6].

Table1. Inferences drawn from Literature Review

REF NO.	TECHNIQUE	PARAMETERS	FINDINGS
[1]	Coherent OFDM-FSO system is tuned with virtual local oscillator.	• Number of subcarriers-256 • Electrical bandwidth-10GHz • System temperature in atmospheric turbulence-300K	a) The symbol error rate increases as the number of subcarriers increases (N). Symbol error probability performance is 1.58×10^{-11} , 1.54×10^{-10}, and 2.29×10^{-9} for N=128, 256, and 1024, respectively. b) Interrupt probability is large in case of large number of subcarriers and strong fluctuation. Outage probability for N=128 rises to 0.040, and rises to 0.060 and 0.135 for N=256 and N=1024.
[2]	Transmission of OFDM based signals over FSO link	Signal transmission parameters • carrier frequency-473.14MHz • Number of carriers- 5617 • Wavelength- 1551.72nm • LD output power- 5.8dBm • Relative intensity noise- -130dBm • Detector responsivity-0.8A/W	The overall performance of the system may increase if an appropriate optimal modulation index is selected.
[3]	Generation of carriers using mode-locked laser for RoFSO system.	a) For OFDM • DAC sampling rate-10GSa/s • IFFT size- 256 • Subcarrier frequency separation- 39.0625-MHz • Bandwidth- 2.5GHz b) For RoFSO • Wavelength- 155nm • Transmission power-100Mw • Coupling loss-5dB • Antenna aperture-80mm	a) The carriers produced possesses stability with low dispersion to travel in free space. b) For FSO lengths of 800, 1000 and 1200m , the EVM of less than 10% was observed for -1dBm received power. The error vector magnitude (EVM) of the received RF signal was acceptable, which makes the RoFSO system capable of servicing extra channels.
[4]	OFDM-RoFSO scheme using phase shift keying(PSK) and quadrature amplitude modulation(QAM) formats.	• OFDM symbol duration- 1ms • Operating wavelength-1.55µm • Average transmitted optical power- 20dBm • Detector responsivity-0.9A/W • Relative intensity noise- -130dB/Hz	a) QAM technique gives better BER results than the PSK for the same modulation indexes. For N=12000, the BER of 64-PSK is 10^{-1} and for 64-QAM, it is less than 10^{-1}. b) Average BER of QAM OFDM link and PSK OFDM link are quite close to each other. c) For low values of CNDR , the outage probability is low.
[5]	MDPSK- based nonequalization OFDM	• Transmission rate-10Gbaud/sec • No. Of subcarriers- 256 • BER-10^{-3}	a) For M=16, the SNR penalties of FD-16DPSK based NE-OFDM and 16PSK with equalisation OFDM were 1dB and 2.4dB respectively. b)High spectral efficiency is observed if used in frequency domain.
[6]	OFDM with M-ary QAM encoder	• Wavelength-1550nm • Distance between transmitter and receiver- 7000 • Symbol duration-3.29µsec • Transmitted optical power-20dB • Pilot insertion-1 per 8 symbol	a) The BER is 10^{-5} at a distance of 7km. b) Improved values of SNR and outage probability were observed. c) The system performance worsens if number of subcarriers increases or the distance between transmitter and receiver is increased.

IV. CONCLUSION

Though, FSO offers many advantages over other communication system, the system performance gets affected by the atmospheric disturbances. Research is going on to overcome the impairments in FSO link that is caused by atmospheric turbulence. New technologies are being implemented in FSO system like using Orthogonal Frequency Division Multiplexing (OFDM) scheme in combination with FSO. The system performance gets better using OFDM-FSO. Such a system has a big scope in near future and can be extended further to consider more complicated scenarios.

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