International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

A Review on Performance Improvement Techniques in Wireless Optical Communication

Sam P Joseph[1], Minu Mathew[2]

[1]Department of Electronics and Communication, Government Engineering College, Thiruvanathapuram, Kerala, India

[2]Department of Electronics and Communication, College of Engineering Trivandrum, Thiruvanathapuram, Kerala, India

Abstract: ***Optical Wireless Communication (OWC) otherwise known as Free Space Optical (FSO) communication is a future ready wireless technology which solves many communication bottlenecks at very low implementation cost. The performance of FSO is sensitive towards the atmospheric turbulence. By using a proper error correction code this effect can be mitigated. This paper deals with the basic concept of FSO and reviews recent advancements and development in free-space optical systems. The other aspects on the system design optimization and performance improvement are also discussed in this paper.***

Keywords: FSO, WDM, Mobile FSO, MIMO

1. Introduction

Wireless communication has experienced tremendous growth in the past few decades. The information exchange rate is exponentially increasing and the technologies which can handle such a huge amount of data are in demand. With the technologies such as Wi-Fi, Bluetooth etc short range communication has gained enough significance. Owing to the advancements in semiconductor technologies combined with the availability of unlimited bandwidth FSO communication has gained popularity over optical fiber links as well as RF systems. Free space optics refers to the transmission of information bits using light as the medium and free space or atmosphere as the channel. FSO is a cost effective, fast installed broad band access solution operating at unlicensed spectrum [1]. It is an LOS communication which has a range of a few kms. FSO communication offers a wide variety of applications such as wireless cellular network, LAN, MAN, ship to ship communication, disaster recovery etc[2].

The fiber optical communications work at wavelengths around 1550 nm(C Band) using OOK and direct detection (IM/DD) techniques. In an IM/DD system, the intensity of the transmitted optical signal is modulated by a RF or mm-wave and the receiver, which essentially consists of a photo-detector, responds to the intensity of the received optical signal. We use this same concept in FSO links[1]. Unlike in fiber optic communication which uses fiber as the channel, FSO system uses free space or air for signal transmission. It is an excellent candidate for high speed communication due to the unlimited bandwidth available at optical wavelengths. Since this is an LOS communication, FSO uses highly directed narrow light beam data transmission between two points[3] and hence it guarantees high security. Also the system is immune to electromagnetic interferences and user induced interferences. The system is easily upgradable and it has an open interface. This being a highly compact system, they can be deployed even behind windows this takes away the need for costly roof top rights. Wireless optical communication has already been developed, used and accepted because of its various advantages over radio and microwave communication.

The main factors limiting the link distance of OWC system is the attenuation of optical intensity and fluctuation of the received optical signal by the atmospheric effects. The outdoor OWC has many constraints including LOS requirement, continuous transmitter/receiver alignment and optical signal attenuation due to absorption, scattering and shimmer [4]. Absorption is due to the presence of water particle and carbon dioxide in the air whereas; scattering is due to fog, haze and snow. Shimmer (scintillation) arises from the combination of atmospheric turbulence, light refraction and wind[5]. As the strength of turbulence increases multiple scattering effects must be taken into account.

An accurate OWC system design is required which considers and analyses all factors like components and techniques such as wavelength, modulation, detection, channel modeling, types of mitigation techniques on atmospheric turbulence etc. [6]. The performance can be improved by powerful modulation schemes such as M-ary PPM or QAM. By introducing Forward Error Correction (FEC) like Low Density Parity Check (LDPC) codes, Reed-Solomon (RS) Codes etc, we can combat fading induced by atmospheric turbulence.

The rest of the paper is organized as follows. The design details of the basic FSO system design are provided in section 2 and 3. Section 4 describes the optical link modeling. The various techniques that are developed for the performance improvements are in FSO are described in section 5.

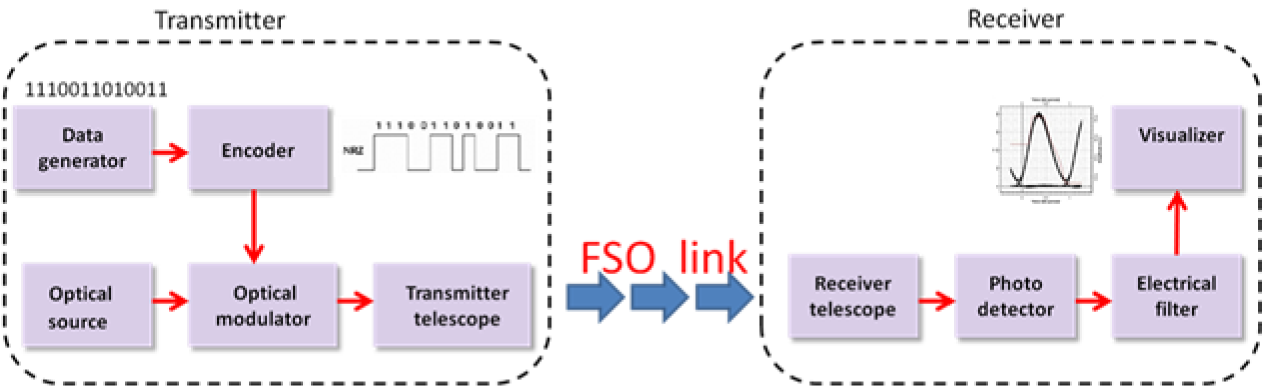

Figure 1: Basic FSO system layout

2. Basic FSO system design

The basic optical wireless communication (OWC) system comprises of a transmitter module, a receiver module and an FSO link[7] . The optical transmitter consists of four sub systems namely, a data generator, an encoder, an optical source and an optical modulator. The data generator produces bit sequences (data to be transmitted) and is followed by an encoder. The encoder is essentially an electric pulse generator that encodes the data at its input. The encoder can be of NRZ or RZ type.

The output from the encoder and the optical source is given to the optical modulator. The simplest digital modulation scheme that can be used here is amplitude shift keying (ASK), also referred to as on off keying (OOK). The function of optical modulator is to vary the intensity of the light source according to the incoming data sequence. For OOK the information is encoded in the output intensity. The output at the modulator is either the laser pulses or no data [8]. By using OOK-NRZ modulation we can achieve high data rate with low bit error rate (BER)[9] and hence the encoder used is of NRZ type and modulation scheme used is OOK.

The working of FSO technology is very simple. The system consists of a pair of optical transceiver units working in full-duplex mode. Each unit uses an optical source and a lens or telescope that transmits light through free space or air which is received by a lens in conjunction with a high sensitivity receiver.

The optical receiver module consists of three subsystems namely, photo-detector, an electrical filter and a visualizer. A photo detector is an opto-electric device that converts received optical power into electrical power with linear response. PIN diode is used in this system as it can be operated from a standard power supply (typically between 5-15V), has lower cost, lower noise, and no gain. The output of the detector is a very weak signal, thus a photo diode circuitry is followed by one or more amplification stages.

3. Selection of transmission wavelength

The choice of optical wavelength used in FSO systems depends on many parameters including power radiated and eye safety concerns. The first IR optical window is around 785nm and 850nm. The second IR window is around 1300nm and the third around 1550nm. Choice of the optical source wavelength is limited by the eye safety issue [10]. Any radiation corresponding to the wavelengths above 1400nm is not directly focused onto the retina of the eye. Therefore, the third window is safer and also allows a higher transmitted power than the first two. Laser beam of wavelength 1550nm are commonly used in FSO communication system.

4. Wireless Optical Link Modeling

A thorough understanding of characteristics of the channel must be known for the implementation of an efficient communication system. A large number of works has already been published on the channel characteristics and the effect of channel on the signal passing through it. The dynamic environment affects the characteristics of optical signal that is propagating through it. This results in amplitude and phase changes and optical losses. The estimated optical irradiance at the receiver strongly depends on the channel model and its accuracy while modeling [11]. Log-normal Turbulence model and are the most important channel models being considered. These models describe the probability distribution functions (pdf) of irradiance fluctuation. Log-normal turbulence model can be used for weak turbulence scenarios while Gamma- Gamma turbulence model is considered for strong turbulence scenarios.

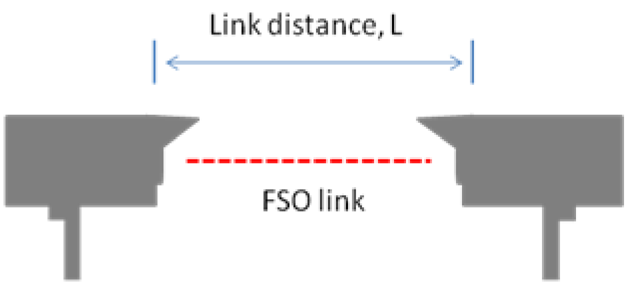

Figure 2: LOS of FSO transceivers

4.1 Log-normal Turbulence Model

A weak atmospheric turbulence regime is characterized by single scattering event and can be characterized by single scattering process (Rytov approach). The Rytov variance, representing the field amplitude changes in atmospheric turbulence, is given by equation (1),

$$\sigma_l^2 = 1.23 C_n^2 k^{7/6} L^{11/6} \tag{1}$$

C_n^2 is the refractive index parameter; L is the optical link range and k is the wave number. The log-normal distribution function is given by equation (2),

$$p(I) = \frac{1}{\sqrt{2\pi\sigma_i^2}}\frac{1}{I}\exp\left\{-\frac{\left(\ln(\frac{I}{I_0}) - E[I]\right)^2}{2\sigma_i^2}\right\} \quad I \geq 0 \qquad (2)$$

Where I is the field irradiance in the turbulent channel and I_0 is the irradiance in no turbulence condition.

4.2 The gamma–gamma Turbulence model

As atmospheric turbulence increases, multiple scattering effects must be considered and log-normal statistics shows large deviations. The gamma-gamma turbulence model was proposed by Andrews et al. [12]. The turbulence atmosphere consists of small scale and large scale effects. The small scale effect is associated with scattering while large scale is associated with refraction. The gamma-gamma irradiance distribution function is given by equation (3),

$$p(I) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{((\alpha+\beta)/2)-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta.I}) \ , \ I > 0 \qquad (3)$$

Where α and β represents the effective number of small and large scale eddies, K(.) represents the second order Bessel function and $\Gamma(.)$ represents the gamma function. The gamma-gamma turbulence model is valid for weak and as well as strong atmospheric scenarios. The pdf of this model depends on the two parameters α and β. They are related to the atmospheric condition by the following equations (4) and (5).

$$\alpha = \left[\exp\left(\frac{0.49\sigma_l^2}{(1+1.11\sigma_l^{12/5})^{7/6}}\right) - 1\right]^{-1} \qquad (4)$$

$$\beta = \left[\exp\left(\frac{0.51\sigma_l^2}{(1+0.69\sigma_l^{12/5})^{5/6}}\right) - 1\right]^{-1} \qquad (5)$$

5. New generation FSO communication techniques

FSO is a high bandwidth short range communication technique with a link distance of less than 5 kms. From time to time cloud and fog appears between the transmitters and receivers. This is a severe problem in the case of OWC. The optical beam traversing through the atmosphere gets attenuated due to the presence of fog, cloud, snow, rain, dust etc. Of these fog and clouds has adverse effect on the performance of FSO links[13]. This imposes optical power loss and temporal broadening further leading to reduction of SNR. In 2005 Aharonovich et. al [14] proposed a OWC system with decision feedback equalizer (DFE). It could mitigate the atmospheric multipath effects that produced ISI. Also this system improved the immunity to ISI in foggy conditions and maintained low BER and high throughput. In the following years many modifications and innovative ideas came along with this due to the growing demand in low cost-high bandwidth communication field.

5.1 Coding schemes

Scintillation effect degrades the performance of communication link, even if the sky is clear. As mentioned before, a FEC can combat fading introduced by atmospheric turbulence. Many coding schemes are proposed and being used in optical communication systems. For example, Convolutional code, Reed-Solomon (RS) code, Turbo & LDPC (Linear Density Parity Check) Code. It is found that for weak turbulence typical Convolutional or RS code performs well, but strong turbulence fading requires more complex code like LDPC or turbo code[15].

LDPC is one of the most efficient coding schemes and it gained popularity as a code with strong error correction capability. Low-density parity-check (LDPC) codes are linear error correcting codes proposed by Gallager in the 1960's, and later discovered by Mackay and Neal appears as a capacity-approaching codes that can yield very good performance near Shannon limit. They are a class of linear block codes. These codes are constructed with the help of a sparse parity check matrix. The performance of LDPC code depends on the decoding complexity, which is directly related to the density of 1s in this matrix[15].

In 2011, Barua et. al[16] investigated the application of multiple lasers and multiple apertures with and without LDPC code. They aimed to mitigate the effects of the atmospheric turbulence using this method. LDPC coded system showed significant coding gain of 20dB with BER 10-12 for the above method over the un-coded system. Ultimately their study showed that LDPC coded system gives better performance under strong turbulence conditions.

The performance of LDPC coded orbital-angular-momentum (OAM) modulation had been studied under atmospheric turbulence by Djordjevic et. al[17]. OAM is a property present in certain types of laser beams. This property is exploited as an alternative to single mode transmission. This also leads to a system design which is energy efficient. With the increase in dimension, OAM modulation becomes more sensitive towards the atmospheric turbulence. By using a proper error correction code (LDPC) this effect can be mitigated.

5.2 Multiple beam and Multiplexing

In general, a single beam FSO system has low link range at a desired performance. And from the literatures we have known that a single beam FSO is vulnerable to atmospheric conditions. To enhance the performance of traditional FSO system we could use multiple beam FSO system. This is a replacement of the single beam transceiver by multi beam transceiver. The effect of turbulent atmosphere such as loss of power in the detector and scintillation can be reduced to a greater extent using Multi-beam FSO system[18]. This spatial diversity technique to addresses link failure problems due to temporary obstructions, as well as other atmospheric conditions, and provides for greater availability.

The concept of multi beam FSO system with wavelength division multiplexing (WDM) is mentioned in[19]. Multiple optical signals can be multiplexed on a single medium by using different wavelengths. Wavelength-division multiplexing (WDM) techniques provide many advantages by allowing enough power budget and margins to support a record high capacity transmission. By using multi beam transceiver the link performance can be enhanced and the effect of turbulent atmosphere can be reduced. This is a promising system that could overcome the atmospheric attenuation especially the effect of tropical weather.

A cost effective multihop FSO WDM system is proposed by Trinh et. al in[20]. The system discussed is an all optical multihop WDM based FSO communication system which uses an optical amplify and forward (OAF) technique. A pulse position modulation (PPM) was employed in order to improve the overall system performance. With multihop FSO one could achieve longer link range without the need of intermediate processing. The effect of atmospheric turbulence can be mitigated by combining OAF technique with PPM modulation scheme.

5.3 MIMO systems

From the above literatures we can observe that neither coding alone nor diversity techniques alone is sufficient to completely mitigate fading. Integration of diversity and modulation techniques and channel coding has become a mature technology for overcoming fading induced error[15]. In wireless, MIMO systems are known to provide higher capacity and throughput than SISO. Several schemes have been proposed for MIMO in the RF domain and they differ in the complexity at transmitter or the receiver or both.

LDPC coded multiple input - multiple output (MIMO) system under atmospheric turbulence is explained in [21]. This work proposes an efficient optical link design, based on MIMO system to mitigate the effects of fading and turbulence, thereby increasing the channel capacity through spatial multiplexing. LDPC codes are used to enhance the performance of the system. The MIMO system transmits an LDPC coded Q-ary optical Pulse-position modulated (PPM) signal through atmosphere at different turbulence conditions, namely weak and strong. For weak turbulence scenarios lognormal channel model is used while gamma-gamma channel model is used in case of strong turbulence scenarios.

A bit- interleaved LDPC coded MIMO system is presented in[22] for transmission of optical data over turbulence channel. To improve the spectral efficiency, a pulse amplitude modulation (PAM) scheme is used along with bit-interleaved (BI) LDPC-coding. The system provides excellent coding gain along with the advantages of LDPC codes. Also a structured LDPC codes facilitates high speed system implementation. Further improvement in performance under turbulence condition can be achieved by using a DVB-S2 LDPC coded system along with channel interleaver with on-off keying (OOK)[23]. Time diversity is exploited in this system. Digital Video Broadcasting - Satellite - Second Generation (DVB-S2) is a digital television broadcast standard. DVB-S2 LDPC codes have an efficient encoding and decoding algorithms which can be easily implemented on hardware. This system showed a coding gain of 16.74 dB at 10^{-5} BER.

5.4 Mobile-FSO communication system

Over these years tremendous researches and developments are going on with FSO because they are the solution to very high data rate short range communication system. One of the most important necessities of FSO system is the line of sight (LOS). These systems are initially meant for fixed platforms. The transceivers are fixed at the building tops (or behind the window glasses at a height) and the data exchange is being done. The current demand on mobile communication is a challenge for FSO developers and researchers. One of the older techniques to avoid the line of sight problem was the Relay Transmission. The message signal from the source is relayed to the receiver through an intermediate node called relays. The main attractiveness of this technique is to achieve increased free space link coverage by using multiple relays. Kaadan et. al [24] in 2014 presented the first open loop alignment/stability analysis to maintain an FSO link .

The system was developed and tested for communication between hovering multirotors, ie. air to air (A2A) communication system. A Flat Transmitter - Flat Receiver Model has been used here. In the model they evaluated parameters like communication distance, wavelength, and platform deviation along with many. With current multirotor platform and by employing suitable optical array, the throughput was observed to be 30%. By further development in the throughput this can be the solution for future Mobile-FSO communication system.

6. Conclusion

This paper presents some new generation FSO systems that were designed to efficiently solve the problems faced by the current FSO system. It is seen that multipath effects can be greatly reduced by incorporating a DFE, whereas LDPC proves to be better under strong turbulence. The efficient encoding and decoding algorithms of DVB-S2 LDPC codes can be easily be implemented on hardware. The use of multiple beam (WDM) and multihop FSO systems can solve low link range problems and also support high capacity transmission thereby reducing the effect of atmospheric turbulence. Free space optics is one of the trending areas where lot of research work is happening. It can completely transform the way wireless communication is happening. A lot of new performance improvement techniques are upcoming and holds wide interest among researchers.

References

[1] Leitgeb, Erich, Thomas Plank, Pirmin Pezzei, David Kraus, and Juraj Poliak. "Integration of FSO in local area networks-Combination of Optical Wireless with WLAN and DVB-T for last mile internet connections." In Networks and Optical Communications-(NOC), 2014 19th European Conference on, pp. 120-125. IEEE, 2014.

[2] Uysal, Murat, Jing Li, and Meng Yu. "Error rate performance analysis of coded free-space optical links over gamma-gamma atmospheric turbulence channels." Wireless Communications, IEEE Transactions on 5, no. 6 (2006): 1229-1233.

[3] Korevaar, Bloom SE, J. Schuster, and H. Willebrand. "Understanding the Performance of Free Space Optics." Journal of Optical Networking (2003).
[4] Leitgeb, E., S. Sheikh Muhammad, B. Flecker, Ch Chlestil, M. Gebhart, and Tomaž Javornik. "The influence of dense fog on optical wireless systems, analysed by measurements in Graz for improving the link-reliability." In Transparent Optical Networks, 2006 International Conference on, vol. 3, pp. 154-159. IEEE, 2006.
[5] Akbulut, Ahmet, H. Alparslan Ilgin, and Murat Efe. "Adaptive Bit Rate Video Streaming Through an RF/Free Space Optical Laser Link." Radioengineering 19, no. 2 (2010).
[6] Jabeena, A., T. Jayabarathi, Ratul Aggarwal, and Luve Singh. "Review on Optimization of Wireless Optical Communication System." Trends in Opto-Electro & Optical Communications 4, no. 2 (2014): 9-19.
[7] Ruslan, Wan Rizal Hazman Wan, Sevia Mahdaliza Idrus, Arnidza Ramli, Norhafizah Ramli, Abu Sahmah Mohd Supa'at, and Farizal Mohd Nor. "Terrestrial Free Space Optic Propagation Analysis Considering Malaysia Weather Condition." Jurnal Teknologi 54, no. 1 (2012): 217-229.
[8] Henniger, Hennes, and Otakar Wilfert. "An introduction to free-space optical communications." Radioengineering 19, no. 2 (2010): 203-212.
[9] Paudel, Rupak, Hoa Le Minh, Zabih Ghassemlooy, and Sujan Rajbhandari. "High speed short range optical wireless ground-to-train communications." (2010).
[10] Reidenbach, Hans-Dieter. "Laser Safety." In Springer Handbook of Lasers and Optics, pp. 1251-1276. Springer New York, 2007.
[11] Ghassemlooy, Zabih, Wasiu Popoola, and Sujan Rajbhandari. Optical wireless communications: system and channel modelling with Matlab®. CRC Press, 2012.
[12] Andrews, Larry C., Ronald L. Phillips, and Cynthia Y. Hopen. Laser beam scintillation with applications. Vol. 99. SPIE press, 2001.
[13] Muhammad, Sajid Sheikh, Benno Flecker, Erich Leitgeb, and Michael Gebhart. "Characterization of fog attenuation in terrestrial free space optical links." Optical Engineering 46, no. 6 (2007): 066001-066001.
[14] Aharonovich, Marius, and Shlomi Arnon. "Performance improvement of optical wireless communication through fog with a decision feedback equalizer." JOSA A 22, no. 8 (2005): 1646-1654.
[15] Sandhu, Harinder, and D. Chadha. "Terrestrial Free Space LDPC Coded MIMO Optical Link." In Proceedings of the World Congress on Engineering and Computer Science, vol. 1. 2009.
[16] Barua, Bobby, and Dalia Barua. "Evaluate the Performance of a LDPC Coded FSO System Employing Q-PPM as Modulation." (2011).
[17] Djordjevic, Ivan B., Jaime Anguita, and Bane Vasic. "Error-correction coded orbital-angular-momentum modulation for FSO channels affected by turbulence." Lightwave Technology, Journal of 30, no. 17 (2012): 2846-2852.
[18] Kashani, F. D., M. Reza Mahzoun, and B. Ghafary. "Beam propagation analysis of a multi beam FSO system with partially flat-topped laser beams in turbulent atmosphere." Optik-International Journal for Light and Electron Optics 123, no. 10 (2012): 879-886.
[19] Mohammad, Abu Bakar. "Optimization of FSO system in tropical weather using multiple beams." In Photonics (ICP), 2014 IEEE 5th International Conference on, pp. 109-112. IEEE, 2014.
[20] Trinh, Phuc V., Ngoc T. Dang, and Anh T. Pham. "Optical amplify-and-forward multihop WDM/FSO for all-optical access networks." In Communication Systems, Networks & Digital Signal Processing (CSNDSP), 2014 9th International Symposium on, pp. 1106-1111. IEEE, 2014.
[21] Djordjevic, Ivan B. "LDPC-coded MIMO optical communication over the atmospheric turbulence channel using Q-ary pulse-position modulation." Optics express 15, no. 16 (2007): 10026-10032.
[22] Djordjevic, Ivan B., Stojan Denic, Jaime Anguita, Bane Vasic, and Mark A. Neifeld. "LDPC-coded MIMO optical communication over the atmospheric turbulence channel." Journal of Lightwave Technology 26, no. 5 (2008): 478-487.
[23] Czaputa, Martin, Tomaž Javornik, Erich Leitgeb, Gorazd Kandus, and Zabih Ghassemlooy. "Investigation of punctured LDPC codes and time-diversity on free-space optical links." In Telecommunications (ConTEL), Proceedings of the 2011 11th International Conference on, pp. 359-362. IEEE, 2011.
[24] Kaadan, Asaad, Hazem H. Refai, and Peter G. LoPresti. "Multielement FSO Transceivers Alignment for Inter-UAV Communications." Journal of Lightwave Technology 32, no. 24 (2014): 4183-4193.