Hybrid FSO - RF System: A Solution to Atmospheric Turbulences in Long Haul Communication

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Abstract- During the past few decades the Free Space Optical (FSO) communication has done the tremendous job in Communication sector. These days it can act as a good alternative of Radio Frequency (RF). Key differences in the RF and FSO techniques has been discussed keeping in mind: implementation challenges faced by system designer, link design, different modulation schemes based on BER and received power, effects of weather conditions like fog, rain, snow on transmission performance, and wavelength ranges. Also, scintillation due to optical disorder in the atmosphere for FSO which is limiting factor has been discussed. Both the links are affected by the atmospheric conditions. For considerable increase in the availability of link both the technologies can be combined together. This paper focused on the need of hybrid FSO/RF System.

Index Terms— FSO, RF, turbulence, link budget, hybrid system, wireless, BER

1. Introduction

Free Space Optics (FSO) is not a new technology but today's important aspect of research. The working principle is based on the wireless concept. For communication, this technology uses optical beam and data has been transmitted via this optical beam. It provides less complexity as compared to communication through fibers with high data rates. But, optical communication through free space is badly affected by atmospheric conditions. The worst affect is due to fog particles. Radio frequency (RF) links are able to transmit data in foggy conditions but they have low data rates. In this paper, the merits and demerits of FSO and RF communication link have been discussed. FSO is preferred to be used at those places where other means of communication like optical fibers or RF are not feasible [1]. In Section 2, the complete introduction of FSO system is given. Section 3 describes the advantages and disadvantages of RF link. Section 4 discusses the different wavelengths used in FSO and RF links. Section 5 provides the mathematical model for FSO and RF links. Section 6 describes the need of hybrid FSO/RF system. Finally, section 7 concludes the review aspects of the paper.

2. FSO System

The optical wireless channels provide many advantages like high security, low cost, low power usage, and high data rates due to the unregulated bandwidth. After modulation, infrared or visible beams can be transmitted through air to obtain communication by optical means and the system is known as Free Space Optics [2]. For successful operation, FSO terminals require a complete and uninterrupted link. It is difficult to place a detector in the path of the beam for the interception of a signal as it will block the link and terminates the communication. To intercept an FSO transmitted signal the only way is to "pick off" the narrow beam path which is difficult to do and can be prevented by shielding the beam. In this way, it will not travel beyond the reception end. For complete link availability, FSO is limited for short distance communication.

The various atmospheric channel effects are:

- Attenuation
- Beam wandering
- Turbulence caused by Scintillation or Fading.
- Turbid (rain, fog, snow)
- Cloud-free line of sight
- Received Power
- Link Margin
- Data Rate
- Reliability

There are number of ways for mitigating the Turbulence effects. These can be mitigated by using diversity techniques, multiple transmitters, and adaptive optics [3].

There is an exponential attenuation in the laser power which is very similar to the attenuation in fiber optic cable [4]. The level of the attenuation is different during different weather conditions and it is given in Table 1. Due to atmospheric turbulence, attenuation varies from 0.5 dB/km to 350 dB/km for clear weather and dense fog respectively.

Table 1
Attenuation in different weather conditions

Weather condition	Attenuation(dB/km)
Clear weather	0.5
Haze	3
Rain	4.22
Snow	9.52
Fog	30-350

The attenuation in different weather conditions depends upon the visibility. Fog is described as a mass of water droplets in unit volume and this is defined as liquid water content (LWC). It is measured in [g/m3]. From fog sensors this data has been measured to calculate the LWC [5]. The visibility V [km] is calculated from LWC given below:

$$V = d.\ (LWC)^{-0,65} \quad (1)$$

where d is a unit less parameter having specific value in different fog conditions [4].

FSO proves to be an striking alternate for optical fiber links to transfer RF signals after modulation for small distances when LOS is available between two points. While transmitting through FSO, multiple lasers beam channel proved its capability to absorb high attenuation occurring in the transmitter especially at an altitude below 1000m [6].

3. RF SYSTEM

In conventional RF systems, discrete radio channels of different frequencies are assigned to all user groups. These channels are independent of each other. For the specific channel, the users can transmit and receive on a first come first serve basis within that group only. A wireless communication uses radio frequencies to connect end users. The major advantage of RF communication is that it can operate over much larger areas for unlimited number of users and it is dependent on the frequency. In wireless communication systems, the main disadvantage is that the range of the signal is affected by atmospheric turbulence like electrical storms. The other disadvantage is that it cannot work for under water communication [7]. Wide range of applications of RF includes remote control, wireless security systems, hand-held computer and PDA data links, radio and TV broadcasting, cordless and cellular telephones, wireless bar-code readers, wireless keyboards for PCs and consumer electronics, etc.

The main advantage of FSO over RF wireless system is its immunity to interference and other advantages are low BER [8], high directionality, low transmitted power and high speed data transfer. Table 2 shows the difference in the various key parameters of FSO and RF.

TABLE 2
COMPARATIVE ANALYSIS OF FSO AND RF

Parameters	FSO	RF
Channels	Based on LOS	Based on peer to peer
bandwidth	Very high	Less as compared to FSO
Throughput	100 Mbps – few Gbps	Less than 100 Mbps
Channel security	High	Low
Scalability of Networking architecture	Scalable	Non – Scalable
Sources of signal degradation	Atmospheric turbulence and geometry of Lens	Multipath fading & user interference
Direction of transmission	Purely directional	Omnidirectional
licensing	Not required	Required
Immune to interference	Highly	Less
Cost of setup	Less	high
Time required for link set up	Few days	Number of days
Suitable for Underwater communication	Yes	No

4. FSO AND RF WAVELENGTH

The wavelengths can be efficiently deployed corresponding to transmit data onto the SIMO configuration without the leakage of its power (wavelengths) into each other [9]. FSO and RF works in different wavelength ranges. These wavelength ranges are discussed in the following sections:

4.1 Free Space Optics

Free space optical communication typically operates in unlicensed THz spectrum bands (λ = 800–1700 nm). It provides some improvement in signal bandwidth above maximum band signals working in the RF environment. The several transparent windows for transmission whose attenuation is less than 0.2 dB/km are between 80- 1600 nm wavelength range. The commonly used wavelengths are 850nm, 1060nm and 1550nm. FSO hardware in current use can be classified in two classes based on which the working wavelength can be classified as – systems operating in near 800 nm and near 1550 nm. Due to merit of low attenuation, high-quality transmitter and receiver components, 1550nm band is compatible for transmission through free space. This band has reduced solar background radiation and has laser eye safety. Also, it is compatible with existing technology infrastructure [10]. In order to achieve high data rates, it is required to operate at high frequencies and commonly used frequencies are centimeter waves, millimeter waves or optical range [11].

4.2 Radio Frequency

Wireless systems transmit information that may be data or voice using a specific radio frequency (RF) and for receiving data the other end of radios are to be tuned on the same frequency. The common radio messages can be transmitted using frequency range between 30 MHz and 900 MHz for transmission above the RF band within the range (0.05- 900) MHz. These frequencies are dedicated to public use. For transmission in the microwave band the frequency given is between 1GHz and 20GHz. More than 40 millions systems are manufactured every year that utilizes low-power wireless technology (RF) especially for control, security, data links and telemetry [12]. The main characteristics of RF are low power and good operating range. The other characteristics are that it can penetrate in walls and no LOS is required here [13]. Higher frequencies provide comparable band widths suffering from different weather conditions. That's why these are used for increasing the availability. Whereas lower frequencies provide reliable link but there is a loss of data rate. RF link also requires license. Higher carrier frequencies are used for high data rates to fully exploit the link bandwidths. To achieve higher link availability at low data rates the preference will be given to lower operating frequencies [7].

5. Mathematical model for FSO/RF Link

The link availability is the latest research topic in FSO. The performance of a communication link also depends upon the quality of apparatus in use. Link budget is one of the mode to quantify the performance of the link.

5.1 FSO link design

The performance of FSO link depends upon various factors like link length, wavelength, modulators, detectors & efficiencies of the transmitter and the receiver [4, 14]. The power received at the detector for the link budget is given by the Friis transmission formula,

$$P_R = P_T \,.\, \eta_T \,.\, \eta_R \,.\, (\lambda / 4 \pi Z)^2 . G_T . G_R . L_T \,.\, L_R \qquad (2)$$

where λ is wavelength of transmitted signal, P_R represents the signal power at the receiving end, P_T indicates the transmitted power of signal, η_T and η_R represent the efficiencies of transmitter and receiver respectively, Z , the link distance. The two factors G_T and G_R represent gain of transmitter and receiver respectively; L_T and L_R are the pointing loss factor of transmitter and receiver respectively due to pointing errors atmospheric attenuation. The most important factor that has to be considered for evaluation of FSO is the atmospheric attenuation [15]. Various weather conditions can attenuate the power of signal. The most important phenomena which can affect signal power is scattering. The scattering can be divided into Rayleigh, Mie and Geometrical scattering depending upon the cause of it. The relation between the radius of the atmosphere particles and the selected wavelength of the FSO system can be used to determine the Beers-Lambert Law that describes the attenuation of laser power through atmosphere

$$P_R = P_T . \exp(-\sigma Z) \qquad (3)$$

where, σ is attenuation, P_R is the power received, P_T is power transmitted, and Z is the link distance.

5.2 RF Link Design

The data and voice transmission over specific radio frequency is done to other radios tuned at the same transmission frequency using wireless systems. The transmission of common radio messages can be done between 0.05 MHz and 900 MHz over RF band. The frequency range 30-900 MHz is dedicated to public. It is used mostly for the public safety communications like radio transmission [16]. Various applications like cell phones and systems e.g. global positioning receivers, electronic signs, irrigation systems, call boxes and mobile command units used for the transmission of information from remote areas, transmit between 1 GHz and 20 GHz of the microwave band. The received power in RF communication link is calculated using the Friis power transmission equation given as:

$$P_R = P_T . G_T . G_R . (\lambda / 4 \pi R)^2 . 1/ Lsys \qquad (4)$$

P_T, G_T and G_R are the same parameters explained in equation (1). Lsys is system loss which is representing the summation of various losses like pointing error, atmospheric loss due to antenna, feed mismatch, and polarization loss. R is the link distance.

6. Need of Hybrid Networks

To cop up with the issues related to both the FSO and RF links, the hybrid network has been formed which is a combination of both FSO and RF links. In this hybrid system RF link can act as backup when FSO is not working. RF link is preferably used as an alternative because of its various features stated above. It can operate over much larger areas for unlimited number of users. In hybrid network, FSO can act as primary network because of high bandwidth as compared to RF. Whenever the link falls below certain threshold the secondary link gets triggered for activation to ensure complete connection. The complete operation of hybrid link is influenced by visibility which depends upon the atmospheric conditions. The RF link is not affected by fog, but its performance is reduced due to rainfall only. Since RF bandwidth requirement is less as compared to FSO, use of more than one RF maintains Quality of Service (QoS) between the two terminals. For getting the maximum benefit of hybrid network, the communication must remain through FSO domain as long as possible [17]. The main issue in hybrid technique is that the bandwidth of one channel is wasted because at one time only one channel is getting used. Therefore, for best use of bandwidth of both the channels the various coding schemes are used [18-20]. Hybrid coding scheme [21] has maximum utilization of complete bandwidth of both the channels. In all these schemes the prior rate selection at the transmitter or receiver end is necessary.

7. Conclusion

An introduction of the fundamentals of FSO has been presented. This brief survey has focused on the basic model of outdoor FSO optical links and describes some simple models of the atmosphere. High frequency laser beam is the main advantage of FSO. Attenuation and fluctuation in the optical power at the receiver due to the atmospheric turbulence is the main disadvantage of FSO. The LOS is the major requirement of FSO during the course of communication.

For improving the reliability of link, a hybrid approach of FSO and RF can be used. FSO link is affected severely by fog where as RF link has adverse effects of rain. So for all weather conditions the combination of FSO and RF can be preferred to use.

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