Space Optics: Mitigating Challenges of Airborne Internet Communication

Navneet Kaur
Department of ECE
UIETPU
Chandigarh

Marvi Grover
Department of ECE
UIET PU
Chandigarh

Preeti Singh
Department of ECE
UIET PU
Chandigarh

Pardeep Kaur
Department of ECE
UIET PU
Chandigarh

ABSTRACT
Free Space Optics (FSO) is an emerging technology in telecom industry providing high data rate and security after optical fibre communication. Due to a few limitations of FSO, a new technique hybrid FSO/RF is gaining market-wide acceptance which has RF as a backup link. This technique is very useful in establishing link between aerial vehicles and the ground stations. The paper focuses on the area of space optics and its limiting spheres. Further, the implications of FSO in airborne communication with the challenges faced by aerial vehicles are discussed. The paper also reports few methods, to combat the problems faced by unmanned aerial vehicles (UAVs) and high altitude platforms (HAPs), which are utilized in recent years to enhance performance. The techniques for future research work are also proposed in the paper.

Keywords
FSO, hybrid FSO/RF, Unmanned Aerial Vehicles (UAVs), High Altitude Platforms (HAPs), airborne internet

1. INTRODUCTION
Since the earlier times, communication has become an important way to send and exchange views all around the world as one of the principle interest of human beings. The information is sent via an electromagnetic carrier wave whose frequency can vary from MHz to THz in a communication system. As we are beginning towards a new era, various dramatic changes in communication have been coming across. For example, businesses today rely on high speed networks to meet their daily affairs. Large MNCs which were once using 155 Mbps are now using 1Gbps connections. Thus demand for bandwidth has been increased and at the same time the usage of those technologies which could be cost effective need to be promoted. A large number of communication networks have been employed– wired and wireless. These are used as per different topologies namely mesh, star, bus, ring, tree, and hybrid. Nowadays, optical fibre communication is an emerging trend in telecom industry. It uses light for long distance communication through thin plastic glass fibres [1]. The increasing popularity of optical fibre is due to its low loss property, high bandwidth, immunity to crosstalk, small size and weight, electrical isolation, signal security and low cost. Attenuation loss can be less than 0.2 dB/km and thus decreasing the need for establishing repeaters. These are more flexible and rugged than conventional cables. But to have a higher efficiency rate FSO is utilized in place of optical fibres due to the limitations of more installation cost and time consumption.

2. FREE SPACE OPTICS (FSO)
Free space optics is a technique which is similar to optical fibre infrastructure but no cable is involved. The data is sent through space and air as a medium. The basic working of FSO is shown in fig. 1. It consists of an encoder which is used to code the input sequence. This can be anyone like RZ, NRZ depending on the necessity of the system. The code sequence is then modulated with the optical pulse coming from optical source and finally it is sent to the reception end through FSO channel. The channel can be foggy, hazy, rainy, and clear. At the receiver end we have a detector source which can be a PIN or APD diode whose output is then amplified and demodulated in order to obtain a correct output.It requires line of sight connectivity between receiver and transmitter with a capability of sending up to 125Gbps of data, voice, video communication simultaneously through air and even enable Wavelength Division Multiplexing (WDM) like technologies to operate through free space. It has distinct advantages over other networks like it does not require any license for establishment, is easily deployable and more secure due to directional beams utilization. The data rate is as high as 2.5 Gbps thus providing high bandwidth than other systems [2]. Although FSO is gaining wide market acceptance as a functional wireless, high bandwidth access tool with license free access but still suffers from serious drawbacks. It requires line of sight connectivity between receiver and transmitter.The in-homogeneities in the temperature and pressure of atmosphere cause refractive index changes along transmission path which leads to spatial and temporal variation resulting in fading and performance degradation [3].Thus in order to have an attenuation free link either power to be transmitted is increased or the data is to be sent at a slower rate.

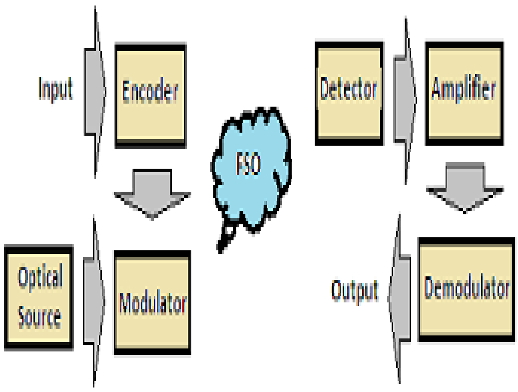

Fig 1: Basic blocks of FSO system

The performance of the network can be analyzed in terms of Bit Error Rate (BER), transmission delays, scintillation index, Signal to Noise Ratio (SNR), Q factor, wavelength, power transmitted, beam divergence, temperature, modulation formats, spread spectrums, wind speed, adaptive power, distance between target and reference point and Field OfView

(FOV). FSO suffers maximum attenuation in foggy and hazy weather while its results are optimum in rain. Due to the limitation of FSO mainly in weather, it is still a lagging technology [4].

3. HYBRID FSO/RF

A branch of FSO becoming popular is hybrid FSO. It is the use of FSO with Radio Frequency (RF) link as backup. The performance of FSO system can be affected by fog, haze, snow but it works well in rain but on the other hand the efficiency of RF is affected by rain while it does well in other conditions. The building blocks of the system are shown in fig. 2. It contains a transmitter section consisting of input source, encoder, optical source and modulator. After modulating a switch is used in order to decide whether the data should be sent by FSO or by RF channel by the means of attenuation level.

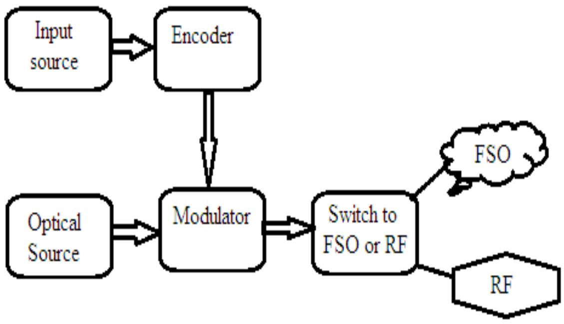

Fig 2: Transmitter section of Hybrid FSO/RF system

The message is received at the reception end using detector, amplifier and modulator. Although, the use of microwaves is deployable but it is affected by rain. For link distances greater than approximately 140m, FSO /RF links could be used which would also solve the problem of Line Of Sight (LOS) i.e. when there is no LOS access RF link can be used[5]. So efficiency of the network connection would be improved but the only weather that could affect transmission of hybrid FSO/RF is heavy rain and dense fog [6]. These systems fit precisely in emergency situation, for instance, earthquakes, tsunamis.

Table 1. Comparison among different techniques

PARAMETERS	RF	FSO	FSO/RF
Data rate	low	High	High with more reliability
Impact of weather	Immune to cloud blocking but affected by rain	Better in clear/ haze condition and less degradation due to rain	RF operation in cloudy weather and FSO link in rain
Further benefits			Size, weight and power (SWAP) focus and more economical

In FSO/RF link system, the data rates for FSO and RF are 1.25Gbps and 100Mbps respectively with an average overall data rate of 183 Mbps. Such a system would help to combat all the challenges posed to RF and FSO approach individually. A comparison of these techniques is given in table 1.

3.1 Applications

There is always a need for high capacity and throughput in aircraft communications both in military and civil aviations. The military specifically transmits and receives video, data, voice and other information among various dismounted, maneuver force elements, air-borne and maritime assets. So the need for better performance gives way to the demand for high band-width which in turn increases data rate. FSO has various applications such as in [8]:

Security management: it is not detectable and no license is required so it can be used as a last mile access providing high data rate without any kind of interference.

Enterprise connectivity: as FSO are easily upgradable so they can be used to connect two buildings or among buildings with Local Area Wireless networks (LANs), Storage Area Networks (SANs). Thus it can be used to establish a link between buildings, ships, aero-planes to ground stations.

Defense: since these are easy to deploy and have more reliability so they can be used in military operations may it be for communication or rescue operation.

Disaster recovery: during any natural calamity all the established links get ruptured so at that time FSO or hybrid FSO/RF can be used as a backup and the further operation can be carried on.

Mobile backhaul connectivity: it can be used to extend the network of cellular phones, bring traffic back to any specific channel or take it to any base station with a very high speed.

Fig 3: HAPs system scenario [7]

Nowadays, FSO is employed in applications over large distances such as between satellites, HAPs, UAVs, aircrafts, ground stations and other areas for airborne internet. HAPs are quasi static airships operating at altitude of 17-22 km in stratosphere. The main problem with HAPs is pointing error which is decreased by using laser beams with small divergence [9]. The HAP system scenario is shown in fig 3.

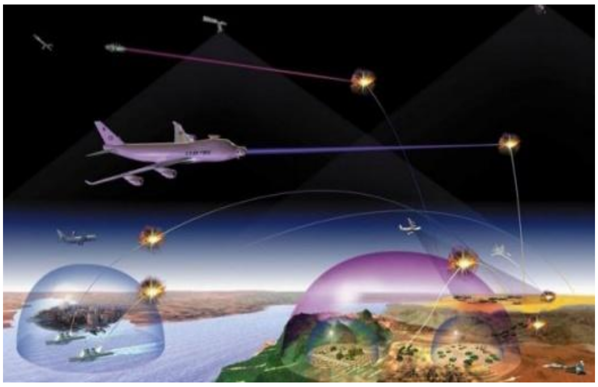

Fig 4: Air-borne internet scenario [10]

4. AIRBORNE INTERNET

Airborne internet is a new way to provide a general purpose, multi-application data channel. The principle behind airborne internet is to establish a reliable, flexible digital channel to aircraft in order to send data. It helps searching aircrafts and using them in natural calamity areas, fig 4. The use of FSO is there due to its high bandwidth but as discussed limiting factors are also many. So the use of FSO/RF link is wise and economical. Here we are discussing the areas and different techniques used to remove the drawbacks.

4.1 Ground – Aircraft link

The communication for aerial vehicles starts from ground station and then the information reaches UAVs or HAPs whichever are equipped. The rays have to travel through different layers of atmosphere so various weather phenomenon are there which obstructs the path of optical waves namely fog, rain and snow. For optimal placement the number of trans-receivers to be used could be decided precisely so that both in good and worst weather conditions they could give better performance. The use of visibility codes are proposed for switching to other trans-receiver in case visibility from one decreases than a threshold level. The lifetime of hybrid FSO/RF is two times that of single RF link [11, 12]. The main problem is only with the battery life but if three threshold levels are used then energy could be saved as proved experimentally. But there is one other drawback of three threshold level i.e. the use of On-Off Keying (OOK) which increases bandwidth wastage. Thus employing other modulation formats like Four Pulse Position Modulation (4PPM) for FSO and Quadrature Phase Shift Keying (QPSK) for RF increases performance [13]. In addition to these formats, a new method of hybrid channel have also been used where Low Density Parity Check (LDPC) codes with media diversity scheme gives 33% better performance than the current existing system [14].Using FSO Modulating Retro Reflector (MRR) allows lasercom communication with those platforms which do not support laser communication otherwise; thus facilitating large FOV that in turn gives better results in UAV communication. The limiting factor of turbulence, whose effects has been reduced with experiments using equal gain diversity receivers for equal gain combining by Double Generalized Gamma distribution and BER, has been decreased [15, 16]. Luby Transform (LT) codes are also reported in transmitting and receiving at ground station because they are prone to erasing. A technique of Bit Interleaved Coded Modulation with Iterative Decoding (BICM-ID) with asymmetric data rates is used. An interleaver is mapped with FSO/RF hybrid link instead of RF or separate FSO link and the data bits are encoded using 10:1 ratio and observed that SNR is more than 7 dB [17].The transmission system adapts itself to the channel quality even if there is bit and power loading. The interleaving is done separately over each subsequence m = 1, . . . , M with different random interleavers ΠIm. At transmission time interval n, the bits cn = (cn1, . . . , cnm) from the M interleaved sub sequences are mapped to a complex symbol xn = μ (cn) chosen from the signal constellation X as per the binary labelling map μ: {0, 1} M → X. The number of possible bit labels 2M may exceed the number of signal points |X| and multiple distinct bit sequences may be mapped to the same signal point. Orthogonal evolutionary codes are used and the performance as observed is better for asymmetrical data rate links. The attenuation and distortion due to refractive index variation are also limiting factors for communication between ground stations to aerial vehicles. Thus many techniques have been deployed, using many transmitters and receivers, different optical amplifiers, changing wavelengths, which give good results for up to 1-35 km range on a clear day, as analyzed. The atmospheric losses have been calculated using Beer's law in relation to wavelength and visibility. It is observed that noise increases with distance and become constant after 36 km but SNR decreases. The network between aerial vehicle and ground station is slant so scintillation is there which causes high error rate for long distance [18, 19]. Thus finding SNR, scintillation index, power of optical receiver and BER; it is analyzed that after 3 km BER degrades in slant to 10-9 instead of 9 km in horizontal case. Moreover, there is a misconception among designers and researchers that 1550nm is not affected due to attenuation. But, it is only in hazy weather when visibility is greater than 2 km otherwise in foggy weather when visibility is less than 500m attenuation is independent of wavelength which is also same as in rain and snow. That is why FSO is mostly affected by weather. A formula has been proposed in the paper to find attenuation [20],

$$\sigma = \frac{3.91}{V}\left(\frac{\lambda}{550nm}\right)^{-q}$$

V = Visibility in Km

λ = Wavelength in nm

q = Size of distribution of scattering particles

Table 2 shows the range of visibility and size of scattering particles with the type of visibility as to be used in the formula [20].

Routing is necessary for good performance so various protocols are used. A method of Adhoc on Demand Distance Vector Hybrid (AODVH) has been proposed and found as better than others in term of packet loss and delays for hybrid FSO/RF links.

The AODVH divides the region into different zones. An intra and inter routing protocol then works to establish routing of aerial vehicles among same zone and different zones. Thus if increase in the signal power and decrease in error rate is required then RF backup is a better solution as FSO is affected by clouds and RF has immunity to cloud blockage but using various frequency division schemes the performance of FSO/RF can be increased [21,22].

Table 2. Values of different parameters in formula

V(km)	q	VISIBILITY TYPE
>50	1.6	High
6<V<50	1.3	Average
1<V<6	0.16+0.34	Haze
0.5<V<1	V-0.5	Mist
<0.5	0	Fog

4.2 Inter and intra airborne communication

Several authors have discussed about various techniques to combat weather affects during inter and intra aerial communication. The major challenge that occurs in the communication between flying vehicle is the atmospheric turbulence. It has 3 post effects which cause laser beam to wander, spread and fluctuate [23].Doppler spread also causes loss in carrier orthogonality and increase in inter carrier interference (ICI). The methods of using mechanical gimbals and two axis scanning mirrors which could make better alignment of link thus reducing shift are utilized [23].The data rate up to 80Gbps has been achieved recently. The better wavelength of 10 µm at altitude of 8 km has been reported. Simulation tools like MATLAB, OptiSystem, Visual C++ and OMNET++ are reported in the literature. In order to have better end to end communication with good coordination and navigation, more than two UAVs are used which in turn increases the range of distance by employing various topologies. It is also observed that affect of fog on laser is more than of turbulent environment. The scintillation in atmosphere is dependent on path length of propagation, which affects its gain. To have high gain different optical amplifiers are used, out of which the probability distribution function of Erbium Doped Field Amplifier(EDFA) at two scintillation indices is more separated than same for Semiconductor Optical Amplifier(SOA) which shows EDFA is much better because SOA has less extinction ratio and more complexity. But SOA is efficient method to decrease scintillation noise and BER where no data transmission is there by observing the results at 1550nm wavelength and 183 cm path length [24, 25].

Moreover the range of coverage can also be increased by dividing the area so that different UAVs could have their own area to work as performed by partitioning a holed rectilinear polygon into n pieces and proposed a new algorithm in time [26]. Using link distance of 400 km and taking different wind speeds the BER and Forward Error Correction (FEC) are checked. It is analyzed that out of two window protocols selective repeat ARQ is better than go back N-ARQ [27]. Further not employing, On-Off Keying (OOK) as done in ARQ, using BPPM in hybrid ARQ gives better results by exploring temporal diversity. The dependence of FSO on beam divergence, power transmitted and distance between transmitter and receiver can be improved by checking point of maximum misalignment using simulation tools [28]. It is also analyzed that as beam divergence increases, error decreases and power increases at receiver. As far as modulation formats are considered it has been observed that direct spread spectrum scheme using [N+1] pseudorandom codes is better as it does not produce false alarms and no tracking is required at receiver as observed at 0.83 cm path length [29]. By monte-carlo simulations the RF link works well for low to mid range thickness using channel shortening equalizer with maximum likelihood sequential detector [30]. In case of disaster area when airborne network has been employed, different routing protocols are used like-proactive, reactive and hybrid in order to solve the difficulties posed by mobility, broadcasting and routing [31]. Using distinct UAV orientation would enhance the performance at the cost of complexity. Some other algorithms are also there namely particle swarm optimization or cuckoo search to find position of connecting nodes [32].

Table 3. Values of attenuation for different weather conditions

Weather conditions	Attenuation to FSO (dB/km)	Attenuation to RF (dB/km)
Haze	2-16	0-1.3
Fog	25-400	1-12
Rain	5-20	10-100
Clear	0-1.5	0-2

It is observed that FSO is operated at 1550nm during rain with offering attenuation level of 5-40 dB/km while in fog it can be operated at any range with attenuation of 20-500 dB/km. RF can be used at 10, 60, 120 GHz in any weather condition but the attenuation caused to RF in rain ranges from 1-50 dB/km while in fog or haze it varies from 0-6 dB/km [33]. There are different attenuation levels of FSO and RF in different weather as shown in table 3.

In addition to this intra-airborne network is also gaining importance i.e. in-flight communication network to provide Wi-Fi access in airplanes for videos, songs. For high data rate, control of surface illumination and FOV of receiver improves bandwidth to at least 100MHz. To distinguish users in the same cell, Walsh-Hadamard codes are used for 'movies on demand'. A method of using optical codes in FSO and indoor Visible Light communication (VLC) gives better BER and SNR [34, 36].

5. TECHNIQUES TO ENHANCE SYSTEM PERFORMANCE

There are different ways to increase the functionality in the long run as the use of multiple trans-receivers would help to find an acceptance level for switching links and can thus help to increase the coverage area also. Dividing the coverage area would also serve as a good measure to increase gain as a particular vehicle would work in that area only and no interference from others would be there. Using EDFAs, MRR, hybrid codes are good choice to increase the performance of ground station to aircraft and inter-intra airborne link in FSO. However, they are not efficient in longer path links as it needs more precise and accurate system. For ground station to aircraft communication, different error correcting codes can be used which could decrease BER and scintillation effects. Instead of RF/FSO another such link which can be used is WCDMA technology since RF range is limited up to 450 KHz to 420 MHz but using R-o-FSO the range is extended up to GHz and operating wavelength is also 1550nm instead of 785 nm.

6. PROPOSED SOLUTION

As shown in fig. 5 different UAVs and HAPs can interact with each other and with geostationary satellite using FSO link and if more bandwidth is required same can be done using R-o-FSO. The communication between ground station and HAPs can be hybrid. The algorithm to be used is:

- Generate the signal from transmitter.
- Check the attenuation level and use switching for particular channel either FSO or RF.
- Use Dense Wavelength Division Multiplexing (DWDM) with Multiple Input Multiple Output (MIMO) at the transmitter end. The corresponding output from transmitter can be

$$Y = [x1 \quad x2 \ldots \quad xn]$$

- Send the message using different hybrid codes.

6.1. Merits of the proposed solution

1.Using RF link along with FSO link would give better performance in rain and increase the range where there would be no line of sight and using RoFSO gives good results than FSO on clear weather.

2.The interference would be reduced since different wavelengths are used.

3.The efficiency would be more than existing solutions

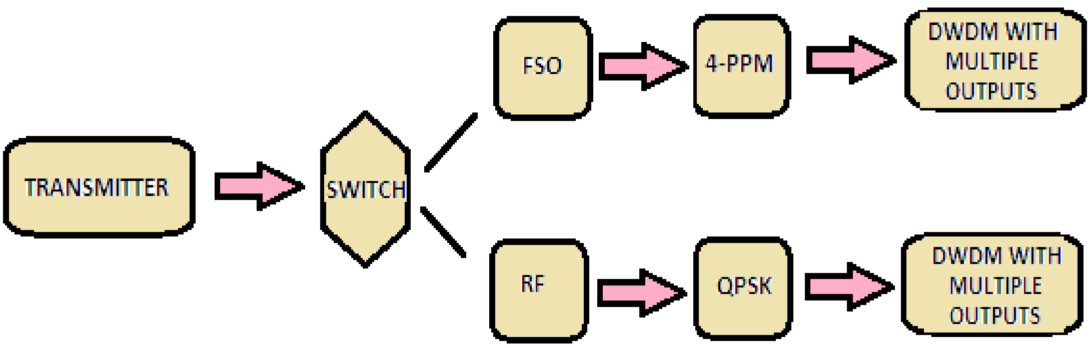

Fig 5: The basic working blocks of the proposed system

7. CONCLUSION

The increase in the demand of high data rates has focused the attention towards hybrid FSO/RF link. In this paper, the various aspects of FSO and RF are discussed with its implications in airborne communications. It has been reported that hybrid FSO/RF link helps to provide high bandwidth with FSO link and short range limited bandwidth with RF as per requirement. Moreover, it provides better performance in all weather conditions. A number of models with various routing protocols, hybrid codes, diversity receivers and spread spectrums are discussed which give efficient results. So a method of using either Hybrid FSO/RF or RoFSO with the existing technology has been suggested which could enhance the performance of the system by curing the limitations of FSO and RF both.

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