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Relay Assisted Hybrid Free Space Optical Systems : a Survey

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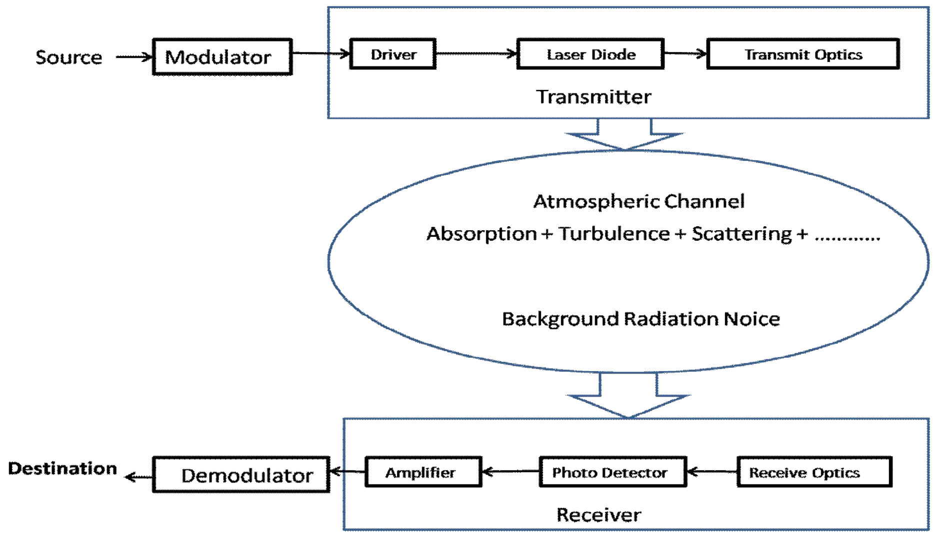
ABSTRACT

The Free Space Optical communication is an ideal solution for exponentially growing demands of high bandwidth and high data rates for modern era communication. In present scenario, its popularity getting momentum because of large bandwidth, license free spectrum, high data rate, absence of radiation hazards, easy and quick installation, immunity to interference and less power requirements. Consequently, it is coming up as an effective option for terrestrial broadband wireless access over short distances. But its performance is limited by some adverse effects of atmospheric channels as well. In present paper we have discussed the relay assisted hybrid free optical systems. The first part consists of introduction to FSO systems along with its applications and limitations. A comprehensive survey on relay-assisted hybrid FSO systems is discussed in second and third part respectively. Fourth part is centralised on the future scope of FSO communication while the fifth part is the concluding one.

Indexing terms/keyword:- FSO, Optical wireless communications (OWC), Radio Frequency (RF), Relay Assisted (Co-operative) Transmission, Hybrid, FSOI

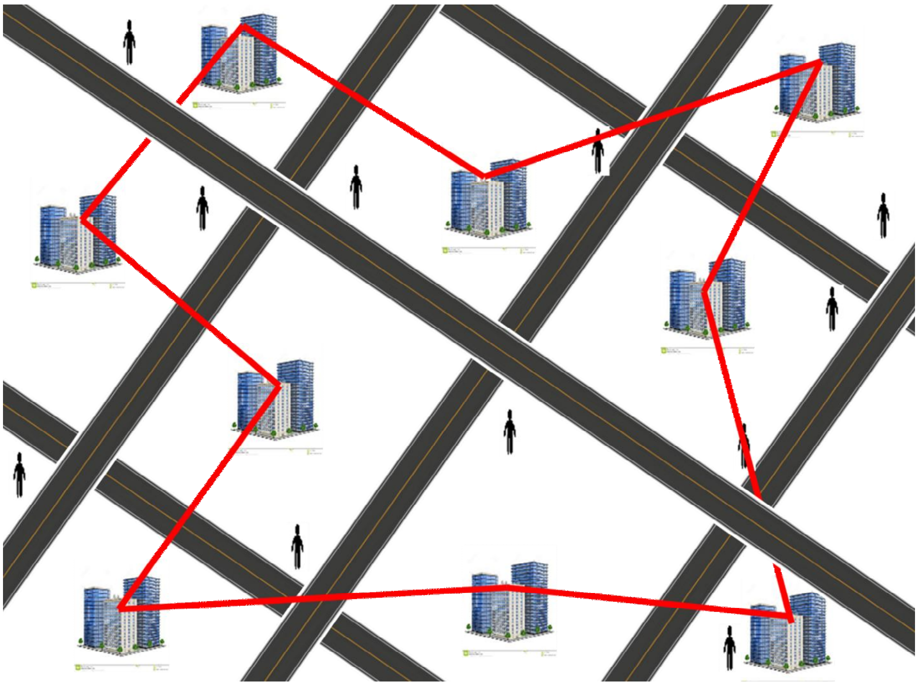
1.INTRODUCTION

Really, wireless communication is among the technology's miraculous boon for modern urban life. The expansion of wireless devices and technologies is very fast and dynamic even than expectations, and hope it will be continue, as it is a key element for upcoming generations and modern urban society. Conventionally, Wireless is associated with Radio frequency technologies. As RF band of electromagnetic spectrum is limited and exclusively licensed through government. So, time has arrived to consider the viable options for wireless communications by exhausting the upper bands of electromagnetic spectrum to cope the exponentially growing need of high date rate and high bandwidth as well.



Block Diagram of FSO System

Optical wireless communications (OWC) is a form of optical communication in which unguided visible, infrared (IR), or ultraviolet (UV) light is used to carry a signal. Optical wireless communication is a potential solution, especially in atmospheric turbulence where radio communication encounters difficulties. Terrestrial point-to-point OWC systems, also known as the Free Space Optical (FSO) systems, operate at the near IR frequencies (750–1600 nm). These systems typically use laser transmitters and offer a cost-effective with high data rates, i.e., 10 Gbit/s per wavelength, and provide a potential solution for the backhaul bottleneck. Free Space Optics (FSO) communications, is a transmission of modulated visible or infrared (IR) beams through the atmosphere to obtain optical communications. Like fiber, Free Space Optics (FSO) uses lasers to transmit data, but instead of enclosing the data stream in a glass fiber, it is transmitted through the air. Free Space Optics (FSO) transmits invisible, eye-safe light beams from one telescope to another using low powered infrared laser in the teraHertz spectrum. The beams of light in Free Space Optics (FSO) systems are transmitted by laser light focused on highly sensitive photon detector receivers. These receivers are telescopic lenses able to collect the photon stream and transmit digital data containing a mix of Internet messages, video images, radio signals or computer files.



Although, Free Space Technology is not new technology but in recent time FSO communication has attracted significant attention of researchers, as an potential alternative option for terrestrial broadband wireless access for short distances. Signalling through beacon fires, smoke, ship flags and semaphore telegraph are the examples of OWC in ancient world [2]. Polished shields used to send signals by reflecting sunlight By Greeks and Romans [3]. To direct a controlled beam of sunlight to a distant station, Carl Friedrich Gauss invented the heliograph in 1810, which served significantly for battles in late nineteenth century. The voice- generated vibrations on a mirror at the transmitter, reflected and projected by sunlight and converted back into voice at the receiver by means of Photophone, the world's first designated wireless telephone system [2] invented by Alexander Graham Bell in 1880. Until 1950, American and German army used high pressure arc lamps for optical communication [4]. After the introduction of laser in 1960, Bell Labs scientists have used a ruby laser to transmit signals upto 25 miles [5]. A exhaustive elaborations of OWC affirmations realized during 1960–1970 using various types of lasers and modulation can be found in [6]. However, due to enormous diversity limitations of laser beams to cope with atmospheric turbulence, the results were not up to the expectations.

In the beginning, the only defence and space were two major deployment domains for OWC [7], [8]. Capable and adequate wireless technologies for a variety of transmission link for disparate communication networks for distinguish services with different constraints to exponentially growing need for greater data rates is the necessity of time. OWC/FSO provides high speed diverse range of communication from few cms up to few meters/kms i.e. right from integrated circuits over outdoor inter-building links to satellite communications means the communication range may be ultra short (in cms) to ultra long.

Plethora of uncontrolled bandwidth, No usage fees, no multipath fading, secure connectivity, cost effective, no interference, no digging, easy installation, minimum absorption, lower power consummation and Immunity to the electromagnetic interference are some of the key features of FSO in comparison to its RF counterpart. FSO is an efficient elucidation for the "last mile" issue to fill the space between the end user and the fiber optic infrastructure. The FSO systems can ideally exploit the capacity of fiber tenacity through a growth at the network edge. Enterprise/campus connectivity, Video surveillance and monitoring, Back-haul for cellular systems, Redundant link and disaster recovery, security and broadcasting are some of the application domain for FSO in recent times [9-12]. There are many world class companies in different countries, working on the design and production of FSO systems as effective and capable outdoor wireless transmission solutions.

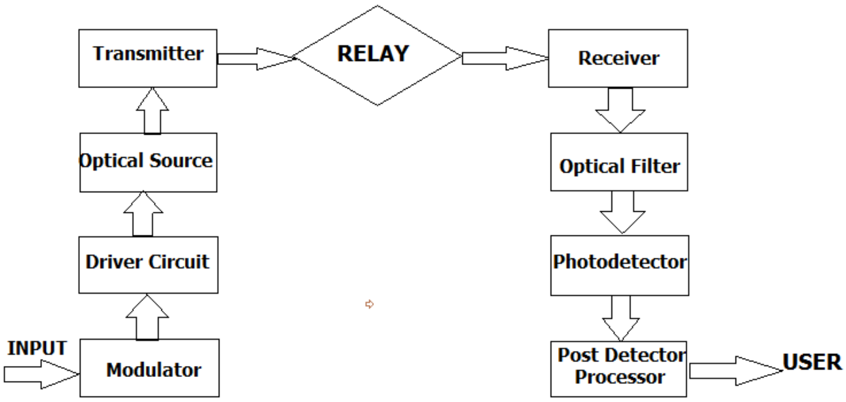
Relay-Assisted (Co-operative) Transmission

To realize spatial diversity advantages, Cooperative diversity has been suggested as an effective and promising option for RF wireless communication [13-15]. In conventional communication, signal is transmitted between the source and destination, without any assistance. However, in a RF wireless communication network, when source node transmits signals, all the nearby nodes overheard its transmission which may be called as relays. Cooperative Communication aims to process and forward this overheard information to the respective destination to create spatial diversity, which can in result increase the system performance. It extends the benefits of MIMO systems towards single-antenna mobiles as they can share their antennas as a virtual MIMO system. There are a number of fundamental relaying techniques such as amplify-and-forward (AF), decode and-forward (DF), detect-and-forward (DetF) and Compress and Forward (CF). Multi-hop relaying is a effective and significant flavour of relay-assisted transmission [16], [17]. However, these policies are only to improve the signal indemnity without any improvement in fading effects [18].

Cooperative diversity approach is a cost-effective choice to improve FSO system realization. If the FSO base station transmits cooperatively with another FSO base station with better weather conditions, the channel degradation can be minimised. In literature, Acampora and Krishnamurthy [1] were the first, who proposed the Relay-assisted FSO transmission, emphasis only on networking perspective [19]. Authors in [20] and [21], elaborated K and Gamma-Gamma fading channels and derived the outage probability for a multi-hop FSO system, without path-loss consideration. They highlighted the significance of relay-assisted transmission only towards improvement of the coverage, without considering its fading-mitigation capabilities. In [22], outage probability is evaluated after due consideration to both path-loss and fading effects. It is also observed that the multi-hop FSO transmission is efficient with reduced hops and improves performance as fading variance is distance vulnerable in FSO systems. It is altogether distinct if we compare it with its RF counterpart, where multi-hop transmission extends the range without diversity gain. It is shown in [24] that the outage probability can be reduced, if the successive nodes are at the same distance on the path from transmitter to receiver. In [25] the performance of multi-hop relaying over Gamma-Gamma channels is analysed.

In [22], [25]–[29] parallel relaying is considered with multi-hop relaying. We know that the FSO is planted on LOS transmission over directional beams, so there is very less probability that the transmitted signals is received by other than destination nodes, which is quite significant in wireless RF transmission. In parallel relaying, multiple transmitter apertures directed to relay nodes and all relays should be located at the same place, closer to the source and on the direct link between the source and the destination. Exact location of this place is significant towards the SNR, the number of relays, and the end-to-end link distance [24]. Parallel relaying with a direct link as a three-way cooperative scheme has been studied in [30], [26], [27], [31]. If the SNR is high, then only the cooperation through relay nodes is favourable, otherwise, there is performance degradation as relays are with noisy signal.

Several signalling policies have been suggested for relay-assisted FSO communications on the basis of its RF counterparts. The classical methods includes amplify-and-forward [20], [22], [26], [32], decode-and-forward [22], [28], [31], and detect-and-forward [26] approaches. Adaptive decode-and-forward and adaptive detect-and-forward also has been proposed, in some special cases [27]. When Channel State Information is available at the source and relays, it is suggested in [29], [31], [33] to activate only a single relay in each communication slot. A easier way out given in [33], if two relays are deployed is to switch the activated relay for too low link SNR [33]. The authors M. Safari and M. Uysal in [22] shown the substantial improvements in power margin when one or two (equidistant) relays are placed between the source and the destination using serial/parallel relaying in DF and AF mode. The work in [22] is extended in [23] with an interesting diversity gain analysis.



Block diagram of relay assisted FSO system

Conventionally, on amplify-and-forward relaying in FSO systems, the relays use optical-to-electrical and electrical-to-optical convertors. The amplify-and-forward relaying skips the need for high-speed electronics and electro-optics in comparison to decode-and-forward relaying. So, to control and adjust the gain of amplifiers with all-optical AF relaying, the relay needs only low-speed electronic circuits. Consequently, optical-to-electrical and electrical-to-optical transformations were omitted, for effective applications. All-optical amplify-and-forward relaying has been discussed in [34]–[36]. In [34], authors have assumed either fixed-gain optical amplifiers or optical regenerators, and BER performance with Monte Carlo simulations is given. In [35], all-optical relays using EDFAs and an outage probability analysis is given for a dual-hop system considering the effect of ASE noise. In [36], the outage performance is re-analysed considering effect of optical degree-of-freedom.

Some efficient algorithms have also been given for the joint relay selection and power allocation in cooperative FSO in [37],[38]. A one relay cooperative diversity method was studied to mitigate turbulence induced fading in [39]. In [40] authors studied cooperative FSO systems with multiple relays and an optimal power allocation policy to improve the diversity order and error probability. The author in [41] studied a comparative analysis of various diversity policies in FSO systems including relay-assisted transmission system. The author also discussed the advantages of using additional relay nodes with necessary design issues under different turbulence regimes with the help of diversity and coding gain analysis.

Hybrid RF/FSO Systems

The FSO was introduced and evolved for wireless communications as a efficient option for present RF system to fulfil the data rate demands of next upcoming generation. Since FSO is an optical communication technology in which data is transmitted by propagation of light in free space allowing optical connectivity in which channel beam-width is adjustable so, inter-FSO communication interference can be controlled effectively. Above all, FSO has huge usable bandwidth along with inherent security and energy efficiency.

Today, maximum wireless networks are set up in the RF domain, as natural support for radial broadcast activities. But some of prominent technical limitations of RF includes the bandwidth insufficiency, high intrusion, and susceptibility to eavesdropping. All of these can be reduced by the deliberately integrated fusion of FSO communications. Although, in FSO the requirement of line of sight (LOS) between the transmitter and the receiver during the communication is essential, and FSO link can be disgraced by unavoidable weather conditions like fog, rain, snow, and haze. A hybrid approach is that which uses RF and FSO communication optimally, with the strengths and weaknesses of both. In a hybrid RF/FSO system, the RF link provides connectivity to mobile user with the nearest base station where a direct LOS path may not be feasible, while the FSO technology provides the last mile connectivity.

As per previous sections discussions, the performance of FSO links adversely affected by atmospheric turbulence, and unpredictable connectivity and temporary link outages due to visibility limiting conditions including snow, fog, and dust, along with misalignment and pointing errors etc. [42] [43]. These can be responsible for the frequent link failures, and so, there is a need to increase the reliability of these links. One efficient solution for this is to use a hybrid approach, which uses RF and FSO communication optimally, one channel can serve as the backup channel of the other. Comparatively, RF systems are more reliable for preserving connectivity at the lower data rates against the unpredictable connectivity of FSO systems. Therefore, hybrid RF/FSO systems, where a RF link is used to support the FSO link, have been proposed for the benefits of both i.e. high data rate is provided by FSO link while reliability assured by the RF link [44],[45]. The RF link is less sensitive towards atmospheric turbulence, pointing errors [46]. Actually, fog and rain affect FSO and RF links respectively, but they rarely occur at the same time. Consequently, the two links operates in interdependently. Generally, the RF link is designed either in the unlicensed bands or in MMW range because of larger bandwidth availability. The authors in [47] studied the LOS propagation signalling and fading with the Rice fading model. In [48] the RF link used for beam procurement, pointing and even for purpose of link control due to its reliability for RF/FSO long span links.

Optical beams are highly susceptible to dense fog, mist, snow, and dust particles, but are comparatively less effected by rain on the other hand radio frequency signals, suffer from drastically effected by rain but lesser effected by snow [49]. Several scenarios [49],[50],[51] have been studied where both channels RF and FSO working in parallel. Smadi et al. improving the capacity and reducing the radio interference by introducing the FSO links selectively at critical locations [52], [53]. Lee et al., have combined hybrid FSO/RF systems at the macro-cellular level for power efficient and high capacity wireless backhauling [54]. Demers et al. investigated the positive aspect of combined use of RF and FSO for data transmission on single media, because of the interdependent nature of both in capacity and coverage [55]. In [56], RF frequency used to keep FSO links connected and radio channel used as control channel in the process of pointing, acquisition, and tracking.

Liang Yang, *et al.* in [57] proposed a FSO communication scheme with a variable gain relay and links from the source to the relay are RF while the links from the relay to the destination are FSO with M-distribution. Goran T. Djordjevic, *et al.* in [58] studied the outage probability and the average bit error rate BER performance of a dual-hop amplify-and-forward relaying system, of a mixed RF/FSO link, when simultaneously outdated channel state information CSI is assumed at the relay and there is a misalignment between transmitter and receiver apertures in FSO link. A multiuser decode-and-forward (DF) based dual-hop cooperative system over mixed RF/FSO links is studied in [59]. The information theoretic study of decode-and-forward based mixed radio frequency-free space optical (RFFSO) cooperative communication system is proposed in [60].

An asymmetric RF-FSO cooperative communication system has been proposed in [61], with AF relay, receives signal from the Rayleigh fading RF link, amplifies it and then forwards the received signal over the Gamma-Gamma fading FSO link, by using the SIM modulation scheme. The work in [61], extended in [62], the performance analysis of a dualhop relay composed of asymmetric RF/FSO links with pointing errors have been studied. The dual hop hybrid RF/FSO system using AF relay [63] and DF relay [64] have been studied, where the RF link was Nakagami-m distributed and the FSO link was characterized by path loss, Gamma-Gamma turbulence, pointing errors.

In a simple approach, the same data transmits on two channels, and perform signal detection for each frame at the receiving end for more reliable channel has been suggested in [65], [66]. Some papers have considered the efficient use of RF/FSO in parallel and transmission can progressively switched to one link to another as per channel condition deterioration [67]. An experimental setup has been proposed in [68] where hybrid LDPC coding is performed on a wire line low bandwidth link used in alliance with an FSO link. To exploit the channel diversity optimally, hybrid channel coding was considered in [69], as data is encoded on two channels. In [70], joint FSO/RF channel coding using Raptor codes was considered. A similar work in [71] considered hybrid rate less Raptor encoding practically. A bit interleaved coded modulation scheme using a convolution code is proposed in [72]. Lately, adaptive modulation and coding applied to hybrid RF/FSO channels has been considered in [73].

Recently, Behrooz Makki at al. [74] studied the performance of hybrid radio-frequency (RF) and free-space optical (FSO) links assuming perfect channel state information (CSI) at the receiver. Hassan K. Al-Musawi et al. [75], demonstrates a hybrid radio over multi-mode fibre and free space optics (RoMMF-FSO) system that can be used to extend the transmission range of the 4th generation long-term evolution (4G-LTE) signal in access networks. A single mode filtering technique (SMFT) is used to enhance 4G-LTE performance so far bandwidth and optical power is concern.

Future Scope of FSO Communication

FSO communication is a economical and potential connectivity option for upcoming next generation wireless communication system as it offers effective solution for high data rate, free license, last mile access, cell cite back haul, fibre backup, quick deployment, and many others. It has experienced exponential growth in revolutionary manners in communication technology. Easy availability of components, quick deployment, no licensing and low cost with tremendous returns are the key features of this. It is an effective alternative for backup protection for fibre based system that provides high speed data connectivity for distance ranging from ultra short up to ultra long distances.

Today, FSO technology is capable of providing promising gigabit Ethernet access for intra campus connections. It provides good solution for cellular carriers using 4G technology to cater their large bandwidth and multimedia requirement by providing a back haul connection between cell towers. It is proved that, FSO technology is an ideal remedy for high capacity last mile connectivity for end user. FSOI technology offers the potential to build interconnection networks with higher speed, lower power dissipation and more compact packages than electronic VLSI technology.

The FSO technology can be utilized in such organisations where highly secured communication is expected as in armed force. Intelligence, Surveillance, and Reconnaissance platforms may use this technology as they are expected to deal with large amount of images and videos. Above all, this technology can be a good option to aural and tethered underwater communications for short distances. FSO underwater technology has the calibre of delivering high data rates for real time applications. In the future, these underwater sensor nodes can use FSO technology to wirelessly off load their data to an interrogating underwater vehicle equipped with an optical modem. [76]

2.Conclusion

Optical wireless communication is one of most secure transmission technology. The requirement of higher and higher bandwidth will grow in future to meet the organizational and individual needs. The demand of higher and higher bandwidth, compel to switch towards optical communication. FSO communication is a vital potential technology for coming generation to meet the demand of high bandwidth and capacity. The utilization of the capability and capacity of the technology, efforts are to be put forth towards the challenges due to heterogeneous nature of atmospheric channels, as it is very sensitive towards the atmospheric phenomenon as absorption, scattering, atmospheric turbulence and negative weather conditions. A number of techniques have been implemented either at physical layer or at network layer to reduce the effect of atmosphere on the quality of the laser beam. The fading mitigation techniques of RF as diversity, adaptive optics, error control codes and modulation works well for FSO communication too. The RF/FSO system ensures carrier class availability for almost all weather conditions. The modifications in the upper layer of TCP model like application, transport and link layer with appropriate protocols and algorithms improve the reliability of FSO system. Hence, FSO communication has very high growth potential in future. A number of commercial products for FSO terrestrial and space links are available in the market. In such environment, the technology may very soon bring revolution in telecommunication worldwide. There is a tremendous scope of further research in this field that will overcome a large number of problems faced in communication links presently. [77]

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