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A Review on FSO and IS-OWC System along with Mode Division Multiplexing

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Abstract—*It is known that 4G and 5G have been evolved in the wireless fields and there is huge growth in IT field, multimedia and data services. But with the excessive demand in the network infrastructure, it is quite difficult to manage the data services. So the technology FSO and IS-OWC has been introduced. Free Space Optics is the alternative solution to replace optical fiber and RF technology. Inter Satellite Optical Wireless Communication is the comprehensive technique in which CW laser has been used for the transmission of data through optical wireless links from source to destination. Usually, WDM and DWDM techniques are used for transmission of multiple data signals over free space. But to improve the capacity of FSO links, the concept of MDM has been introduced. Mode Division Multiplexing is the revolutionary technique that is implemented in FSO to reduce the atmospheric turbulences and improve the capacity of the system. This paper presents a brief overview about Mode Division Multiplexing in FSO and IS-OWC system.*

Keywords*: FSO, Inter Satellite OWC, pointing errors, atmospheric turbulences*

1. INTRODUCTION

There has been massive growth in the field of information and communication technology in the recent few years. This has been possible with the development in the field of light wave technology in the telecommunication field. The transmission of data over longer distances has become possible due to increase in data rates as well as multimedia services. This led to the emergence of the optical wireless communication technology and free space optics [1]. Free Space Optics has been considered as the current edge optical communication technology that contains free space as the medium between the transmitter and receiver. FSO is the alternative to optical fiber and RF technology. The advantages of FSO system are: (1) Strong security features (2) Lower power consumption (3) Huge bandwidth and high speed. But FSO suffers from disadvantage that it has been affected by atmospheric turbulences like absorption, scattering, rain, dust, snow and scintillation effects. One of the major applications of FSO is IS-OWC technology [2].

Inter satellite optical wireless communication is the alternative solution for providing huge data rates, unlimited bandwidth, less power, low antenna size, license free operation and it does not suffer from atmospheric disturbances. IS-OWC system requires the use of optical communication that is guided through wireless links that led to the fusion of optical and wireless transmission. IS-OWC is the bottleneck solution for providing high connectivity and it is considered suitable for indoor and outdoor remote applications. It is used to contain LOS and NLOS propagation [3].Wavelength Division Multiplexing is the technique that is used for the transmission of RF signals over free space. DWDM technique is also used for transmission of RF signals in IS-OWC over range of 2500 km. But the main challenge faced is the huge cost of tunable laser and providing different wavelength lasers which leads to complexity of system. So, the concept of Mode Division multiplexing has been used to decrease the system complexity and improve the capacity of FSO and IS-OWC system.

2. IS-OWC SYSTEM

To establish the optical communication link between two satellites, the line-of-sight link of their optics must be aligned during the time of transmission of signals. A line-of-sight wireless optical communication link is implemented by using the telescope type transreceiver [3]-[4]. The wireless optical communication provides the line-of-sight links with high bandwidth. These systems are now being preferred over radio frequency communication systems because of the high usable bandwidth of optical signals, which increase the transmission capacity that is directly proportional to the carrier frequency and larger difference in wavelength. The RF wavelength is much longer as compared with the LASER light wavelength [4].

Inter Satellite optical Wireless communication system uses a laser beam that is used to provide connectivity between the transmitter and receiver. The satellite itself is called space segment and signal is being transmitted using free space optics and the signal connects two satellites in IS-OWC system. The path of the satellite that revolves another planet is called an orbit. There are various types of satellite orbits: LEO, MEO, HEO and GEO. The transmitting satellite comprises of laser source that is used for generation of light, satellite

transponder, telemetry, tracking and control channel and the optical modulator. The light travels at a speed of $3*10^8$ m/s. So the signals from one satellite to another satellite can be sent without much delay and with minimum distortion and attenuation because the space is considered as vacuum [3]. The Inter-satellite Optical Wireless Communication is shown in Fig. 1.

The establishment of optical link and data transmission between two satellite the angles between the line-of-sight and the transmit beam axis is kept within a traction of the transmitted beamwidth which may be as small as a few micro radians. To maintain the sufficient alignment between the transmitter and receiving antennas, the pointing, acquisition and tracking system is used. The optical beacons signals are used for tracking signals in both directions. The data carrying beams themselves may serve as beacon or separate optical beams may be implemented. The basic and popular method of tracking between satellites is the use of a beacon signal on the one satellite and a quadrant detector and tracking system at the other satellite [3].

IS-OWC system consists of transmitter, transmission channel and the receiver. Transmitter part includes telemetry, tracking and control system. The optical wireless channel takes up the information from Telemetry, Tracking and Control system. The most essential component in the system is the source of light as communication has been possible by the transmission of light. The optical wireless channel acts as the transmission medium between the transmitter and receiver. OWC is the vacuum that is free from losses such as atmospheric losses and the losses related to weather and scintillation. The receiver side on the IS-OWC involves Low pass filter and Avalanche Photo diode. The signal detection is done with the help of photodiode and APD diode is preferred because it contains very high amplification of weak signals. The output of signal is fed to Low pass filter and 3R regenerator that is used for regeneration and amplification of signals. The output is taken at Optical Spectrum Analyzer [4].

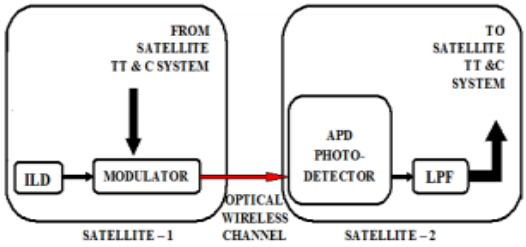

Fig. 1.1: Block Diagram of IS-OWC System [3]

3. RELATED SURVEYS

S. No.	References	Technique Implemented	Comments and Achievements
1	[5]	Integration of FSO-OCDMA was proposed and implemented that had been utilized for the evaluation of the effects of turbulence on OCDMA using temporal encoding method. It uses on off keying and pulse position modulation techniques and chip levels used for detection of error.	Chip level receiver outperforms the correlator receivers in the presence of strong fading environment. PPM modulation provides better results as compared to OOK modulation technique.
2.	[6]	The performance of M-QAM that has been integrated with Wavelength Division Multiplexing had been studied using FSO in the presence of atmospheric turbulences.	The analysis shows that FSO and optical channel non linearity decreases the performance of transmission link and lowers the BER. FSO –WDM provides greater degradation under atmospheric turbulences.
3	[7]	The system was designed and optimized using WDM technique that was integrated with the optical wireless communication. System consisted of 8 channels with LOS propagation using NRZ and RZ modulation format.	The OWC integration with WDM technique leads to improved performance. NRZ modulation format provides provides good performance and improve link distance.
4	[8]	Mode Division Multiplexing had been demonstrated for FSO using orthogonal angular momentum modes. MDM performance of three angular momentum modes from spiral SLM patterns had been evaluated under atmospheric turbulences.	The power penalty has expected to exceed 10 db in the weak to medium turbulence conditions that has resulted in strong crosstalk at the receiver side. Power spread due to turbulence induced crosstalk.
5	[9-10]	The cost effective MDM integrated OCDMA technique was designed at huge data rates of 100 Gbps over the distance of 8 km using free space optics channel. The concept of Laguerregaussian modes LG01 and LG02 was presented.	Under clear weather conditions, FSO links prolongs upto 8 km with the tolerable BER. But when the weather conditions were changed to light fog and medium fog, FSO links provides 1500 m and 1250 m.

4. MERITS IN OWC SYSTEM

FSO communication system provides greater advantages over RF system. The basic difference between RF and FSO system is the huge difference in the wavelength. The atmospheric transmission window of FSO systems lies in the wavelength range that varies between 700 nm to 1600 nm. For RF system, transmission window contains the wavelength range between 30 mm to 3m. The main application of FSO is IS-OWC System. The merits of FSO and Inter satellite optical wireless communication system includes:

(i) Huge Bandwidth: In the communication system, bandwidth of the carrier is in directly relation with the amount of data that has been transported. IS-OWC systems provide unlimited bandwidth and capacity as compared to RF based communication system.

(ii) Unlicensed Spectrum: Optical wireless communication system contains FSO and Inter satellite links. These optical systems do not require license spectrum. But RF systems require licensing due to congestion of spectrum [11].

(iii) Small Size of Antenna and High Security: FSO signals are useful in prevention of eavesdropping and provide huge security. FSO and IS-OWC systems are detected by optical spectrum analyzers and RF meters. Due to large carrier frequency, the size of antenna is reduced in optical wireless communication system. Thus the reduced weight of satellite minimizes the consumption of power in the communication system.

(iv) Huge Data Rates: Optical wireless communication systems are useful to provide huge data rates upto Gbps and provide faster communication, immunity towards interference and high power efficiency [12].

5. APPLICATIONS OF FSO AND IS- OWC SYSTEM

Inter satellite communication has been used for networking of group of satellites that contain huge data rates upto Gbps. There are currently systems like NASA's Tracking and Data Relay satellites that use RF Inter satellite links for these purposes. The major applications in the field of optical wireless communication include:

(i) Long Range OWC Applications

FSO systems are the effective solution for the problem of last mile access. Free Space optical systems are basically used in cellular backhauls, Wireless LAN to Wireless LAN connectivity in the campus environments, wireless MAN, broadband access to the undeserved areas. FSO contains easy installation and it is quite advantageous in disastrous areas where infrastructure is not available. FSO system is used in tactical field and it has been preferred by researchers in the military organizations and defense companies. FSO links are used for aircraft to ground, aircraft to aircraft and aircraft to HAP [13].

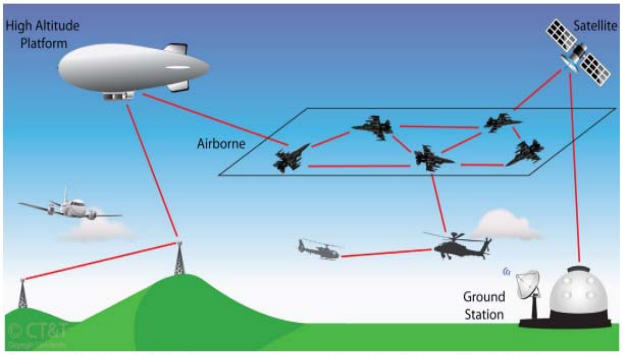

Fig. 1.2: FSO deployment for HAP, aircraft to aircraft, aircraft to HAP and HAP to ground communication [13]

(ii) Ultra Long Range OWC Applications

Free space optical system is also used as ultra-long range connectivity solution for Inter Satellite and ground to satellite communication. The European Data Relay System is the satellite system that is used to relay the data from the spacecraft, Earth stations and non-geostationary satellites. This data relay system contains three LEO satellites that contain OWC Inter-satellite links as well as Ka-band links [14]. NASA's Lunar Laser communication link had been established in 2013 that contains high data rate upto 622 Mbps. It has shown that OWC will prove to be the best emerging technology in the future [15].

6. CHALLENGES IN OWC SYSTEM

But there are certain challenges that are faced in Optical wireless communication systems:

(i) Atmospheric Turbulences: The major factor that is responsible for atmospheric turbulence is the fog that would lead to scattering and absorption. Background noise and sky radiance are other factors that can affect the FSO system. So to control it, there is need to limit the optical bandwidth of receiver.

(ii) Transmitter and Receiver Pointing Errors: The major challenges in IS-OWC system involve the beam divergence, pointing errors in receiver that further decrease the capacity and transmission distance of OWC link. When there is no proper alignment of transmitter and receiver, then there is reduction of power at the output [16].

(iii) Beam Divergence: Beam Divergence defines the spreading of beam from transmitter to the receiver during the propagation. These are some of the challenges that are found by the researchers when the IS-OWC system has been designed [5] [17].

7. MODE DIVISION MULTIPLEXING IN OWC SYSTEM

The optical wireless communication system contains the use of lasers as signal carriers. Earlier if we want to transmit distinct signals then we require different wavelength lasers (i.e. no. of lasers are required), due to which cost of system increases to very large extent. In addition, system complexity increases. One solution to this problem will be use of tunable lasers. Definitely, system complexity reduces to large extent but cost of tunable laser is very high. So this method is not considered effective and efficient. Another solution to the reported problem will be the use of LP modes concept. As with the use of this concept, we transmit distinct signals with same laser (i.e. only one laser is required). Hence, cost and complexity both reduces at the same time. Sofor enhancing the capacity of Optical wireless link, the concept of Linear Polarized modes has been introduced. Light has been propagated in the form of linearly polarized modes known as LP modes. These modes are used to contain light intensity profiles that usually propagate with the help of OWC transmission channel that is used to maintain the transverse field shapes. The LP modes have been normally defined by the two parameters: one contains radial mode number denoted by m and other contains azimuthal mode number denoted by n. Every mode corresponds to beam of light that travels with different angles [18]. The LP modes have been achieved by changing the size and refractive index of core. It can be obtained by setting the Eigen value and changing the core's refractive index. LP modes consist of degeneration of three modes: TE02, TM01 and HE21. HE11 is the dominant mode that is already a linearly polarized mode. It consists of two types of polarization: Horizontal and Vertical Polarization [19].

With the increasing bandwidth demand for future wireless network, the concept of Radio over Free Space Optics has been used that contains the combination of FSO and Radio over fiber. DWDM scheme has been employed to carry the RF signals over the FSO links having the range of 1km. OFDM scheme has also been used for short range applications. Mode Division Multiplexing is another scheme that is used to increase the capacity of RO-FSO systems. MDM has allowed the transmission on different modes of large number of channels that is generated with the help of various mechanisms like by the use of spatial light modulator. It basically uses LG modes LG00 and LG10 that has been multiplexed over free space [20]. Mode Division Multiplexing has been used to reduce the MAI effects and increase the capacity of optical networks. Users basically allocate the different modes that transmit over the single channel using Mode Division Multiplexing, thus it has reduced the bandwidth issues and spectrum.OCDMA is the technique that has done immense development in optical communication systems [21]. MDM has been integrated with OCDMA using FSO channel that is used to transmit the data rates at 100 Gbps[22].

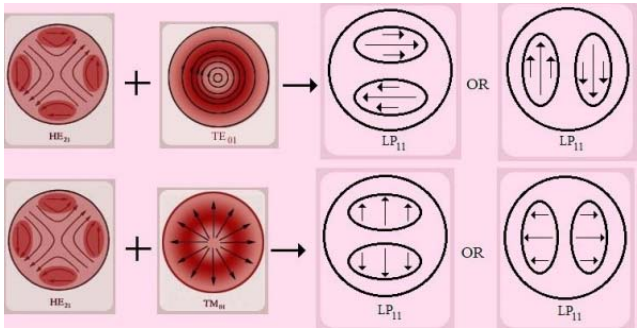

Fig. 1.3: Formation of LP_{11} modes from TE_{01}, TM_{01} and HE_{21} modes [19].

8. CONCLUSION

The rapid growth in the multimedia users and the unlimited Internet access has put stress on the RF systems that has been operating at low data rates. Due to high explosion in IT field that has been driven to high data rates, there is need to switch from RF technology to optical technology. So the concept of FSO and Inter satellite communication has been introduced that is the promising technology in the future to meet very huge speed and high capacity needs. The concept of linearly polarized modes has been introduced to increase the capacity of free space optics and adopt the use of single laser instead of different wavelength lasers. But in the future, there is the requirement to adopt Mode Division multiplexing in Inter Satellite OWC systems at higher data rates and huge distances.

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