Modeling of Mode Division Multiplexing for High-Capacity Ro-FSO Transmission

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Mini Review

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ABSTRACT

The demand for ubiquitous connectivity, high data capacity, faster data speed, low latency, and reliable services increases day by day with the persistent growth of mobile users and new technologies. The stringent requirements for 5G heavily rely upon the interconnected backbone network. Thus, in order to achieve the requirements of 5G, fiber-wireless integration is inevitable. Radio-over-Free-Space-Optics (Ro-FSO) is a promising technology for future wireless networks. The capacity of the channel is increased by using Mode Division Multiplexing (MDM) which entails launching several propagation modes, each carrying different information into FSO channel and demultiplexing them at the other end to obtain a separate data stream from each. In this work, a hybrid Orthogonal Frequency Division Multiplexing (OFDM) Ro-FSO system for transmission of independent channels by Mode Division Multiplexing (MDM) was designed and analyzed.

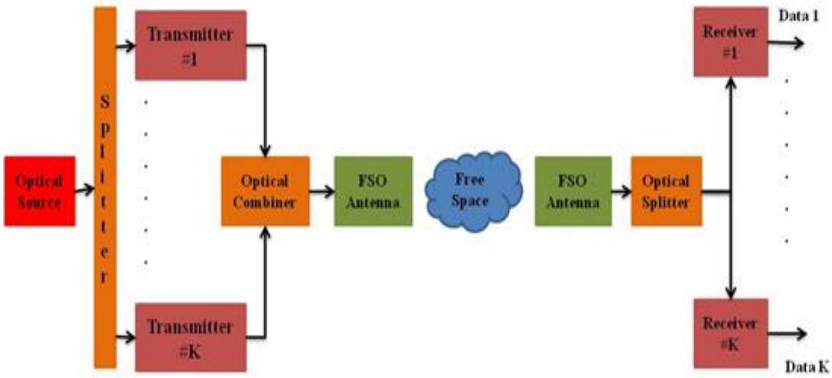
Keywords: Mode division multiplexing; OFDM; Spatial demultiplexing; Radio-over-Free-Space-Optics (Ro-FSO); Technologies.

INTRODUCTION

The amount of information transmitted through the web has grown exponentially within the previous couple of decades. It is predicted in, that there will be more than 15 billion connected machine to machine and consumer electronic devices by 2022 which creates the need to extend the capacity of optical fibers [1]. The transmission capacity can be increased by using many transmission techniques like Wavelength Division Multiplexing (WDM), advanced digital signal processing and higher-order modulation formats. In recent years, Space Division Multiplexing (SDM) has gained momentum as it utilizes extra spatially isolated channels to increase the transmission capacity on top of wavelength division multiplexing [2]. WDM transmits separated channels at different wavelengths in the same optical fiber. Parallel fibers are a type of SDM. However, Few Mode Fibers (FMFs) and Multimode Fibers (MMFs) are used in modern and adaptive systems, where there is possible to combine components like amplifiers for all channels directly [3]. FSO links are a very cost-effective way to provide high bandwidth links over short distances. By using Mode Division Multiplexing (MDM), the capacity of the channel is increased without the need of multiple laser arrays [4].

The RoFSO system is implemented by simply combining a new generation FSO system with Radio-over-Fiber (RoF) technology as shown in Figure 1 [5]. RoF is a technique of modulating RF subcarriers onto an optical carrier for distribution over fiber network. Using Orthogonal Frequency Division Multiplexing (OFDM) appears to be very attractive since the low bandwidth occupied by a single OFDM channel increases the robustness towards dispersion, drastically allowing the transmission of high data rates of 40 Gb/s and hundreds of kilometers without the need for dispersion compensation [6]. A. Amphawan et al,proposed 2 × 20 Gbps and 4 × 20 Gbps Ro-FSO system using two LG modes and a combination of a Donut mode, LG mode and two HG mode in which they achieved a distance of up to 65 km and 20 km respectively when scintillations are considered [7].

Figure 1. Schematic diagram of Ro-FSO system.



The most important properties of modes are coherence and orthogonality. There are two types of modes:

- Spatial modes (based on divergence) and
- Temporal modes along the direction of propagation (based on time and frequency).

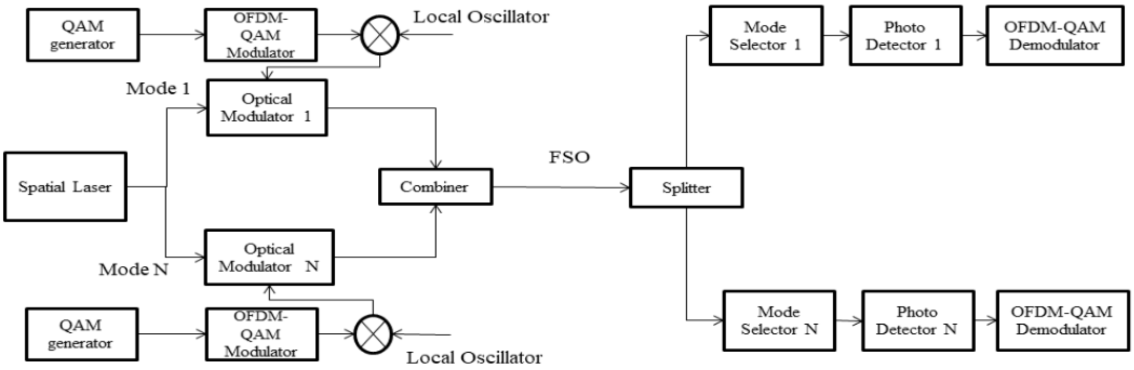
The MDM is a strategy which is applied in some cutting-edge frameworks for optical fiber communications to increment the data limit [8]. Basically, the idea depends on utilizing diverse guided methods of a multimode fiber for different transmission channels. In this work modelling of 8 × 20 Gbps Ro-FSO system is proposed for eight LG and HG modes considering the scintillation factors. The system description and result analysis are given below [9].

LITERATURE REVIEW

System description of high-capacity Ro-FSO transmission with MDM

The block diagram for high capacity Ro-FSO Transmission with MDM is shown in Figure 2.

Figure 2. High capacity Ro-FSO transmission with mode division multiplexing.



In the proposed system, Laguerre-Gaussian/Hermitte-Gaussian was multiplexed through free-space. Two independent 40 GHz radio signals were modulated using a 4-level Quadrature Amplitude Modulation (QAM) followed by modulation by 512 OFDM subcarriers [10]. The purpose of the OFDM modulation is to reduce the multipath fading effect incurred during the transmission through FSO link. The OFDM approach divides the data over a huge number of sub-carriers, which are separated from each other at narrow frequencies. The OFDM signal was then modulated at 7.5 GHz by using Quadrature Modulator (QM) [11].

This OFDM-QM modulated signal was then fed to a lithium niobate modulator which modulated the experimental LG/HG modes at 40 GHz. The modulator is assumed to preserve the modal stability of the channels. The output from the channels was transmitted over the FSO link. The modes were demultiplexed using a spatial photodetector wherein an inner circular aperture of 5 cm was used to extract the modes [12]. The received power between the apertures was adjusted such that the intensities on both the circular and outer apertures were equal. A 40 GHz was applied after the photodetector using a mixer in order to recover the SCM signal. Finally, the output signal after the mixer was fed to the OFDM demodulator followed by the QM demodulator in order to recover the original data.

RESULTS AND DISCUSSION

The simulation is done by using OptiSystem. A Pseudo–Random Bit Sequence (PRBS) Generator was taken and encoded with NRZ pulse. The encoded signal is then fed to a 4-level Quadrature Amplitude Modulation (QAM) followed by modulation by 512 OFDM subcarriers. The optical carrier signal used here is CW laser which gets modulated with binary signal using Mach–Zehnder modulator. The simulation parameters are shown in Table 1.

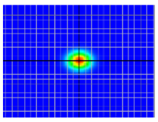
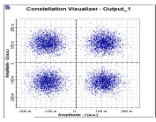
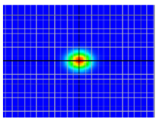
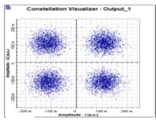
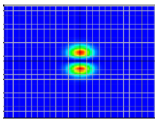
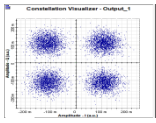
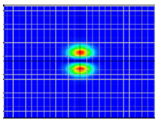
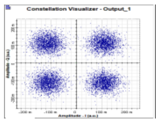
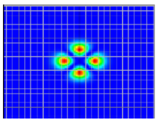
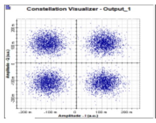
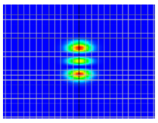
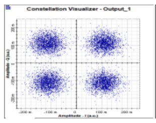
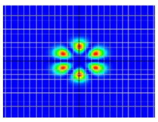
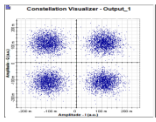
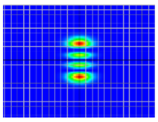
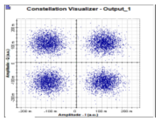
Table 1. Simulation parameters.

Parameters	Values
Data rate	20 Gbps
Wavelength used	1550 nm
Laser power	10 dBm
Line width	10 MHz
Attenuation (FSO)	25.5 dB/km
PIN Responsivity	1 A/W

Constellation diagram of Ro-FSO OFDM (4 LG modes and 4 HG modes)

From the Figure 3, it is inferred that even with the worst case attenuation of 25.5 dB/Km, the system is capable of transmitting 20 Gbps of data through the FSO channel for up to 1 km for HG/LG modes. The simulation is carried out for up to 8 LG/HG modes. Under clear sky condition, the system is capable of transmitting data up to 12 kms.

Figure 3. Constellation diagram of Ro-FSO DD-OFDM (4 LG modes and 4 HG modes).

LG Modes	Constellation diagram	HG Modes	Constellation diagram
 (0, 0)		 (0, 0)	
 (0, 1)		 (0, 1)	
 (0, 2)		 (0, 2)	
 (0, 3)		 (0, 3)	

CONCLUSION

A high-capacity Ro-FSO transmission with mode division multiplexing architecture is designed and analyzed for various LG and HG modes under various atmospheric conditions. Optical LG modes and HG modes were multiplexed for transmitting 40 GHz radio QAM-OFDM signals through free space at a data rate of 20 Gbps for long haul communication. At receiver, the modes containing the data are retrieved successfully. It is discovered that a high-capacity front haul for realizing centralized processing can be achieved by fiber-wireless convergence through RoF technology. RoF approach not only increases the capacity but also reduces the, latency, cost and complexity. The achievable distance is 12 km under clear weather condition. When scintillation (α=25.5 dB/km) is considered, the achievable distance is 1 km. On comparison with A. Amphawan, et al., work, the capacity of the channel is further increased and even with the worst case attenuation factor the system is still transmitting data at 20 Gbps for each mode with better efficiency as shown in Figure 3. As a future work, the proposed front haul design will be implemented and experimentally evaluated with various application scenarios using different data modulation formats and MIMO configurations.

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