Secure MDM-OFDM-Ro-FSO System Using HG Modes

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Abstract: Radio-over-free-space-optics (Ro-FSO) is a promising technique to distribute radio frequency (RF) signals over the atmosphere using optical carriers. In this work, we designed a 60Gbps-120GHz OFDM-Ro-FSO transmission system in conjunction with mode division multiplexing. Three independent 40 GHz radio signal are optically modulated at 20 Gbps and transported over a secure free-space link of 50 km by mode division multiplexing of three Hermite-Gaussain modes HG 00, HG 01 and HG 02.

Keywords: Hermite-Gaussian modes, Mode division multiplexing, OFDM, Ro-FSO.

1. INTRODUCTION

The last decade has seen tremendous development in the growth of broadband access networks around the globe. The interest for faster data rates in the evolution towards 5G wireless systems has brought rapid innovation in new optical technologies to accommodate the rise in number of subscribers. The growth of Internet traffic together with an increase in the number and range of new services have placed pressure on legacy low-speed optical networks. This calls for effective modern optical communication systems that support high transmission rates and enhanced coverage. It has been very difficult for the International Telecom Unions (ITU) to allocate the limited RF Spectrum among the operators due to the explosive growth of subscribers every year. The ITU has reported 7.5 billion cellular subscribers in 2013 [1].

Ro-FSO is a promising technology for increasing broadband penetration, enabling transmission of multiple RF signals via a high-speed optical carrier without expensive optical fiber cabling or licensing for RF solutions. Ro-FSO harness merits of both radio-over-fiber (RoF) and free-space-optics (FSO) technologies. In FSO links, transportation of signals is carried out through the atmosphere instead of an expensive optical fiber, thus eliminating the need for costly cabling of fiber optics in sparsely-populated rural areas. Another main advantage of FSO is that contrary to RF communications, no license is required for transmission in FSO [2]. Thirdly, in some rural areas where current wireless radio technology are inaccessible such as hilly terrains and areas far from radio base stations, FSO technology may be integrated with existing mobile cellular radio technology to promote more rapid deployment of a ubiquitous wireless architecture. Although FSO guarantees high speed data rates, there are some challenges such as scintillations, and atmospheric turbulences which need to be addressed in order to improve the signal-to-noise ratio (SNR) of the FSO link [3-4]. Hence by integration of RoF to FSO, referred to as Ro-FSO, a ubiquitous platform for seamless integration with RF wireless networks may extend the achievable capacity of current wireless networks rapidly and cost effectively [5].
OFDM is an established approach for overcoming multipath fading. It works by transporting data over a huge number of sub-carriers separated by precise frequencies with overlapping bands. The orthogonality of the sub-carriers is ensured through Fast Fourier Transform (FFT) calculations. Hence, by adopting OFDM with FSO, long haul transmissions with higher data rates can be achieved [6-11].

Eigenmodes are used in mode division multiplexing (MDM) to drive the propagation of a number of channels on different modes generated by various mechanisms such as spatial light modulators [12-15], optical signal processing [16-18], few mode fiber [19, 20], photonic crystal fibers [21] and modal decomposition methods [22-24]. In this work, we have presented 3 X 20Gbps-40GHz secure OFDM-Ro-FSO channels by adopting mode multiplexing scheme using Hermite-Gaussiam modes, not reported in any prior work.

The remainder of the paper is organized as follows: Section II elucidates the main principles of the MDM-OFDM model and simulation parameters. Section III describes the results and discussions, followed by the conclusion in Section IV.

2. SYSTEM DESCRIPTION

The proposed secure OFDM-Ro-FSO transmission system, modeled in OptiSystem™ software, is illustrated in Fig. (1). Three independent four-level quadrature modulation OFDM channels, each carrying 20Gbps-40GHz signal are modulated over an optical spatial carrier by modal multiplexing on three laser modes HG mode 00, HG mode 01 and HG mode 02 and are transmitted over a FSO link of 50km. The HG mode is described mathematically as:

$$\Psi_{m,n}(r,\Phi) = H_m(\sqrt{2x\lambda R_{ox}})exp(-\frac{x^2}{w_{ox}^2})$$

$$\exp(j\frac{\pi x^2}{\lambda R_{ox}})H_n(\sqrt{2y\lambda R_{oy}})exp(-\frac{y^2}{w_{oy}^2})exp(j\frac{\pi y^2}{\lambda R_{oy}})$$

Fig. (1). Proposed Ro-FSO transmission system.
A continuous wavelength (CW) laser and HG mode generator are used to excite HG modes as shown in Fig. (2). A 4-QAM sequence generator is used to generate 20 Gbps of data using 2 bits per symbol which is further modulated using OFDM 512 sub-carriers and 1024 FFT points. These OFDM signals are again modulated at 7.5 GHz using a QM modulator at 40 GHz.

The QM signal is modulated by a LiNb modulator driven by a CW source on HG modes and transmitted over a FSO link. The link equation for the received power is given by [11].

\[
P_{\text{Received}} = P_{\text{Transmitted}} \left( \frac{d_r^2 R}{(d_r + \theta R)^2} \right)^{10^{-\alpha R/2}}
\]  

where \(d_r\) defines receiver aperture diameter, \(d_T\) is the transmitter aperture diameter, \(\theta\) is the beam divergence, \(R\) is the range, \(\alpha\) is the atmospheric attenuation.

At the reception side, the mode is retrieved based on mean-squared error minimization of the optical signal using a mode-indexed semiconductor optical amplifier (SOA) with an injection current of 0.5A. The FSO transmitter aperture and receiver aperture is set to 20 cm and 30 cm respectively. A 40 GHz signal is again added after photodiode for the down conversion of signal. This electrical signal is then fed to a QM demodulator followed by OFDM modulator and QAM decoder for the recovery of data. The atmospheric turbulences emulate clear weather conditions.

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**Fig. (2).** Excited HG Modes (a) HG 00 (b) HG 01 (c) HG 02.
3. RESULTS AND DISCUSSION

In this section, the results from our simulation are presented and discussed. Fig. (3) reveals the SNR and total received power for our proposed Ro-FSO transmission system under clear weather conditions. It is observed from the Fig. (3) (a) that the value of SNR for HG mode 00 is computed as 38.11dB, 36.11dB and 25.11dB; for HG mode 01 as 31.12dB, 17.22dB and 11.16dB and for HG mode 02 as 36.22dB, 26.11dB and 20.34dB at a FSO link of 10km, 40km and 50km respectively. Consequently, the value of total received power for HG mode 00 is computed as -54.11dBm, -68.54dBm and -74.11dBm; for HG mode 01 as -68.12dBm, -82.11dBm and -88.32dBm; for HG mode 02 as -59.43dBm, -73.11dBm and -79.11dBm at the transmission link of 20km, 40km and 50km respectively. This indicates that under clear weather conditions, the channel propagating HG mode 00 prolongs to 50km, the channel propagating HG mode 01 prolongs to 25km and the channel propagating HG mode 02 prolongs to 40km with acceptable SNR and total received power. It also indicates that HG mode 01 is more affected by fading compared to HG mode 00 and HG mode 02. The constellations and RF spectrum at the receiver measured at a distance of

![Fig. (3). Evaluation of SNR and total received power under clear weather conditions.](image)

![Fig. (4). Constellation measured at 50km (a) HG mode 00 (b) HG mode 01 (c) HG mode 02.](image)
CONCLUSION AND SCOPE FOR FUTURE WORK

In this work, mode division multiplexing is adopted for transmitting 3 x 20 Gbps - 40 GHz secure OFDM radio subcarriers using optical HG mode 00, HG mode 01 and HG mode 02 over a FSO link of 50km under clear weather conditions. From our results, it is concluded that HG mode 01 is more affected by severe multipath fading compared to HG mode 00 and HG mode 01. Under clear weather conditions, the achievable distance for the channel propagating HG mode 00 is 50km compared to the achievable distance by the channels propagating HG mode 01 and HG mode 02 which achieve a distance of 25km and 40km respectively with acceptable SNR and total received power.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES


