Performance Analysis Of Coded Optical Ofdm Over Free Space Atmospheric Link

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Abstract: OFDM is a multicarrier transmission technique where a data stream is carried on many low-rate subcarrier tones. The benefits of OFDM are high spectral efficiency, resiliency to RF interference and lower multi-path distortion. FSO proves to be a cost effective solution for high-rate image, voice and data communication. But atmospheric turbulence can degrade the performance of FSO links, particularly over ranges in the order of 1 km or longer. Inhomogeneities in temperature and pressure of the atmosphere lead to variations of the refractive index along the transmission path. These index inhomogeneities can deteriorate the quality and can cause fluctuations in both the intensity and the phase of the received signal. These fluctuations can lead to an increase in the link error probability, limiting the performance of the communication system. Low-density parity-check (LDPC) coded OFDM is proposed as an efficient coded modulation technique suitable for FSO transmission. LDPC coded OFDM is compared with Convolutional Coded OFDM.

Keywords: Optical Communications; Optical Orthogonal frequency division multiplexing; Atmospheric turbulence; FSO; Modulation

1.INTRODUCTION

Fiber-optics, RF and copper/coaxial lines are the main state-of-the-art technologies to address the high bandwidth requirements. The incompatibility of RF/microwave and optical communication technologies due to large bandwidth mismatch between RF and optical channels may prove to be a limiting factor in efforts to further increase the transport capabilities in the future. Due to this problem, RF/microwave-optical interface solutions, that will enable aggregating multiple RF/microwave channels into an optical channel, are becoming increasingly important. Free-space optical (FSO) links are considered as a feasible solution for the last mile bottleneck problem, because of the following properties: (i) high-directivity of the optical beam - provides high power efficiency and spatial isolation from other potential interferers, (a property not inherent in RF/microwave communications) (ii) the free-space optical transmission operates in unlicensed bandwidth (iii) large fractional-bandwidth coupled with high optical gain- using moderate power permits very high-data rate transmission, (iv) the state-of-the art fiber-optics-communication employs intensity modulation with direct detection (IM/DD), and the components for IM/DD are widely available, and (v) the FSO links are relatively easy to install and easily accessible for reposition when necessary. The FSO communication is considered as an efficient technology to bring different technologies together and to integrate with a variety of interfaces and network elements. However, an optical wave propagating through the air experiences fluctuations in amplitude and phase due to atmospheric turbulence. The intensity fluctuation, also known as the scintillation, is one of the most important factors that degrades the performance of an FSO communication link, even under clear sky condition. The key requirement of FSO is LOS. The LOS problem also exists for most microwave radios but is not as stringent when techniques such as OFDM and MIMO are used. Hence the proposition to integrate optical OFDM with free space optics evolved.

II.OPTICAL OFDM

To enhance the utilization of optical bandwidth more efficiently, new improved transmission technologies are intensively studied. High-speed optical transmission systems are impaired by interchannel and intrachannel nonlinearities. In order to enhance the transmission capacity, narrow channel spacing is pursued and novel modulation formats are investigated [10]. The proposed methodology for long-haul transmission system provides a number of advantages: (i) increase the transmission distance, (ii) improves the spectral efficiency, and (iii) simplifies the dispersion compensation engineering.

III.OPTICAL OFDM OVER FSO LINKS

The free space optics communication is a recent and expanding technology that has found application in many areas of the short and long-haul communications, from intersatellite links to interbuilding links. Atmospheric turbulence impair the performance of free space optical links. A number of phenomena in the atmosphere such as absorption, scattering, and turbulence, can affect beam attenuation, but in case of wavelengths typical of FSO system operation, only scattering and turbulence are appropriate to be taken into consideration. Unitless Rytov variance is used to quantify the strength of the turbulence.

\[ \sigma^2 = 1.23 \frac{C_n^2}{k^7/eL^{11/6}} \]

\( k = 2\beta/\ell \) is the optical wave number, \( \ell \) is the wavelength, \( L \) is the propagation distance, and \( C_n^2 \) is the refractive index structure parameter, which is assumed to be constant for horizontal paths. The refractive index structure parameter \( C_n^2 \) varies from about \( 10^{-17} \) m\(^{-2/3}\) for very weak turbulence to about \( 10^{-13} \) m\(^{-2/3}\) for strong turbulence.
3.1 Coded OFDM

In [1], Low-density parity-check (LDPC) coded optical orthogonal frequency division multiplexing (OFDM) is ensured to outperform standard FEC schemes such as RS and concatenated RS codes, over the atmospheric turbulence channel in terms of both coding gain and spectral efficiency. The design and demodulation of LDPC codes is studied and implemented in [4]. It describes the large-girth binary LDPC design, the min-sum-with correction term, the decoding algorithm and its FPGA implementation.

3.2 Proposed Methodology

The bandwidth of the OFDM signal is set to 2.5 GHz. The number of OFDM sub-channels is set to 64. The OFDM sequence is zero-padded and the 128-FFT is calculated, and a cyclic prefix of 32 samples are added.

3.2.1 Transmitter configuration

The data streams are encoded using an LDPC encoder and then OFDM is performed. The LDPC encoded data stream is then parsed into groups of B bits. The B bits in each group (frame) are subdivided into K subgroups with the i\textsuperscript{th} subgroup containing \( b_i \) bits. The bi bits from the i\textsuperscript{th} subgroup are mapped into a complex-valued signal from a \( 2^{b_i} \)-point signal constellation such as QAM/QPSK. The complex-valued signal points from all K subchannels are considered as the values of the discrete Fourier transform (DFT) of a multi-carrier OFDM signal. After D/A conversion and RF up-conversion, the OFDM signal drives a Mach-Zehnder modulator (MZM) for transmission over the FSO link. Fig shows the transmitter configuration.

3.2.2 Receiver Configuration

At the receiver, an optical system collects the light, and focuses it onto a detector, which delivers an electrical signal proportional to the incoming optical power. After the RF down-conversion, carrier suppression, A/D conversion and cyclic extension removal, the transmitted signal is demodulated using the FFT algorithm. The soft outputs of the FFT demodulator are used to estimate the symbol reliabilities, which are converted to bit reliabilities, and provided as input to an LDPC iterative decoder. Fig shows the receiver configuration. The proposed methodology uses Block Circulant LDPC codes.

IV. PERFORMANCE OF CODED OPTICAL OFDM

To enhance the BER performance of Optical OFDM, Convolutional coding and LDPC coding were implemented. BER performance under strong and weak turbulence were compared for both the FEC schemes.
V. CONCLUSION

The performance of forward error scheme for Optical OFDM over terrestrial links under weak and strong turbulence has been evaluated. To implement Optical OFDM intensity modulation direct detection becomes a prerequisite. The data protection scheme using Convolutional code became worse at lower channel SNR and showed no BER improvement under turbulent condition. The perfect reconstruction of the transmitted data with LDPC coded OFDM indicates that LDPC codes are more robust to atmospheric turbulence than Convolutional codes.

REFERENCES