Performance of hybrid channel coding in OFDM based FSO communication system during turbulence

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Abstract: In this paper the performance of serially concatenated codes, trellis coded modulation (TCM) with 8-phase shift keying (TCM-8PSK) modulation as inner code and low-density-parity-check (LDPC) (64800, 32400) as outer code, over a free space optical (FSO) communication system, is investigated. The performance is evaluated in terms of bit error rate (BER) for the proposed concatenated codes under various turbulence conditions (weak to strong) for distance of 1 km. The orthogonal frequency division multiplexing (OFDM) is used with FSO link as inspired by the huge demand of bandwidth and optical atmospheric channel is modeled using gamma-gamma fading distribution. Simulation results shows proposed concatenated codes outperform the individually applied LDPC with DVB.S2 standard and TCM codes with same code rate and trellis complexity for OFDM based FSO communication system.

Keywords: low-density-parity-check codes; trellis code modulation codes; atmospheric turbulence; gamma-gamma turbulence

I. INTRODUCTION

Free Space Optics (FSO) communication system provides a tremendous improvement in terms of data rate and cost as compared to optical fibers and Radio Frequency (RF) communication systems [1]- [4]. Recently, researches have shown keen interest in Orthogonal Frequency Division Multiplexing (OFDM) based FSO communication system, as it combines the benefits of both OFDM and FSO, by mitigating the multipath propagation effects and meeting the high bandwidth demand [5]. FSO communication suffers from substantial deterioration due to erratic weather conditions such as fog, rain, humidity etc. causing laser's wave-front spread and on every occasion the visibility in the medium is exaggerated especially during fog and smoke [6]- [7]. Modest fog and a medium rain of 12.5 mm/hr can cause attenuation 40 dB/km and 4.6 dB/km respectively. Extreme weather conditions can make the link completely impractical [9]- [11]. The various models such as lognormal, K, I-K, gamma-gamma, Malaga and normal distribution model are available for defining the atmospheric channels under different conditions [8], [12].

Various channel coding schemes can be used to reduce the bit error rate (BER) during turbulence [13]- [16]. Though channel codes can lead to inefficient utilization of the system and rise in the expenditure of equipment, every time the channel conditions turn out to be normal. In communication systems, the strong point of LDPC codes is their ability to approach the transmission capacity of the communication channel, which shows to be of huge importance with constricted bandwidth efficiency and performance constraints [17]- [18]. The high error-correcting capability arises at the price of high computational complexity and this becomes a critical issue in real life execution of LDPC decoders. Low density parity check (LDPC) codes are suitable choice for many modern communication standards and improves the performance of OFDM based FSO communication system [19]. Trellis code modulation (TCM) codes increases the data rate, adds redundancy by increasing the constellation size, rises throughput (b/s/Hz), decline BER due to decrease in \( d_{min} \). TCM codes achieve higher throughput gain by mutually using the distance properties of the code and the distance properties of the constellation. Coded and uncoded bits are carefully mapped to the constellation points [20]-[21]. The different channel codes can be concatenated serially or in the parallel form. Parallel concatenated code is too complex for decoding whereas serial (inner-outer) codes has greater redundancy and easy to implement as compared to parallel codes [22].

In this paper, LDPC and TCM codes are serially concatenated like inner-outer codes as STBC and TCM codes has been concatenated by Gong et al [23]. Further, a novel coding paradigm named “Hybrid Channel Coding” that completely utilizes the LDPC and TCM codes serially concatenated, to achieve carrier-grade reliability of OFDM-FSO communication.
system, is proposed. This formation of hybrid channel coding has not been previously used anywhere for OFDM based FSO communication system in the studied literature. The remainder of the paper is organized as follows. In Section II, system model is presented with hybrid channel coding. In Section III general assumptions are presented. Next, simulation results and their comparative analysis are discussed in Section IV and V respectively. Finally Section IV concludes the paper.

II. SYSTEM MODEL

The OFDM based FSO technique has brought a revolution because the system data capacity is enhanced by simply adding more number of channels without having the need of more than one FSO link. OFDM is successfully applied with FSO [19], [24] and its detailed explanation is provided by Popoola et al in [8]. Figure 1 illustrates the proposed OFDM-based FSO communication system model with hybrid channel coding considered in this paper.

The effect of fog in the said system is considered and the attenuation due to fog is given by equation 1 [9].

\[ \alpha_{\text{atten}} = e^{\sigma_{fog}^2L} \]  

\( \sigma_{fog} \) is the attenuation coefficient and L is the link distance assumed as 1000 m in the said system. The system performance is upgraded by raising the number of subcarriers but at the same time, this requires more SNR for achieving the targeted BER [8]. In the proposed system, 4 subcarriers are used for OFDM modulator. The random interleaver is also applied which rearranges the elements of its input vector using a random permutation and minimize the effect of burst errors.

III. GENERAL CONSIDERATIONS

LDPC codes are suitably represented in the form of a bipartite graph and have codeword of length N fully defined by a sparse parity check matrix H having dimensions M * N. The codeword bits and parity checks bits are represented by bit (variable) nodes and parity (check) nodes respectively, with their interconnections mapped directly from the parity check matrix. The decoding process of LDPC codes can be observed as iterative message passing between adjacent variable and check nodes, which process the incoming messages. The correct codeword ‘G’ is obtained, if equation 2 is satisfied [25].

\[ GH^T = 0 \]  

In this work, irregular LDPC code of sparse parity check matrix (64800,32400) is considered in the proposed system and the codeword is obtained by satisfying equation 2.

TCM code with 8-PSK modulation is taken into consideration having ½ code rate. TCM codes are concatenated with LDPC codes to provide good coding gain as well as low decoding complexity and low latency. The benefits of both the codes are taken into consideration and used for concatenation.

Among various models the gamma-gamma (ΓΓ) distribution have been successfully used by Odeyemi et al [26], and Badar et al [27] for defining weak to strong all turbulence conditions. Thus, this model is opted in the considered system and all turbulence conditions, weak to strong, are taken into consideration. The probability density function (pdf) of the received irradiance fluctuation, as per ΓΓ model, considering both the small and large-scale effects, is represented using equation 3 [8], [25], [28].

\[ p(I) = \frac{\alpha^{\alpha+\beta}}{\Gamma(\alpha+\beta)} I^{\alpha-1} K_{\alpha+\beta} (2\sqrt{\alpha\beta I}) \quad I > 0 \]  

where \( \alpha \) and \( \beta \) denote the efficient number of large-scale and small-scale eddies of the scattering process given by equation 4 and 5 respectively, I is the intensity of the signal.

\[
\alpha = \exp \left( \frac{0.49 \sigma_0^2}{(1+1.11 \sigma_0^2)^{1/6}} \right) - 1^{-1}
\]  

\[
\beta = \exp \left( \frac{0.51 \sigma_0^2}{(1+0.62 \sigma_0^2)^{1/6}} \right) - 1^{-1}
\]
σₙ² = Raytov Variance or variance of light intensity
K₉(⋅) = modified 2nd order Bessel function
Γ(⋅) = the gamma function.
\[ \sigma_n^2 = 1.23 C_n^2 k^{3/6} L^{11/6} \]

Cₙ² = refractive-index structure parameter
k = wave number
L = the distance between transmitter and receiver

Raytov variance values for different weather conditions under gamma-gamma distribution model is given in table 1.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Weather turbulence conditions</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weak (maritime or light fog)</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>Moderate (continental fog)</td>
<td>1.6</td>
</tr>
<tr>
<td>3</td>
<td>Strong (dense fog and dense haze)</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 1: Raytov variance (σₙ²) values [8]

The results attained from the various channel codes for different weather conditions are validated using MATLAB. In the simulation, the Monte Carlo Method is adopted for the verification of results by random attempts. The single-input/single-output (SISO) OFDM-FSO is preferred for simplicity and compactness. The simulation parameters considered in the proposed SISO model as depicted in figure 1 are given in table 2.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Weather turbulence conditions</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coding Rate</td>
<td>1/2</td>
</tr>
<tr>
<td>2</td>
<td>Coding Scheme</td>
<td>LDPC, TCM, Hybrid</td>
</tr>
<tr>
<td>3</td>
<td>Modulation scheme</td>
<td>8-PSK</td>
</tr>
<tr>
<td>4</td>
<td>Wavelength (λ)</td>
<td>1550 nm</td>
</tr>
<tr>
<td>5</td>
<td>Range</td>
<td>1000 m</td>
</tr>
<tr>
<td>6</td>
<td>Transmit Power</td>
<td>30 dBm</td>
</tr>
<tr>
<td>7</td>
<td>No. of Subcarriers</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2: Computation Parameters used in proposed system model

The various channel coding schemes under different turbulent conditions are analyzed in the following sections.

IV. SIMULATION RESULTS

Simulation results presented in this paper evaluate the performance of the proposed Hybrid coding scheme in terms of BER as a function of signal to noise ratio (SNR) under diverse turbulence conditions. The system is evaluated for information (frame length) of 32400 bits. It is presumed that the receiver has complete channel state information (CSI). For proposed system, the LDPC and TCM codes are also applied independently for comparison purpose with same code rate and trellis complexity.

A. WEAK TURBULENCE CONDITIONS

The value of σₙ² is considered as 0.2, characterizing weak turbulence, such as maritime or light fog. The BER performance for various channel coding schemes such as LDPC, TCM, and their Hybrid blend is presented in figure 2. The results validate that beyond 20 dB, the proposed hybrid scheme shows better performance as compared to their individual performance and gives least BER. As compared to LDPC it gives an improvement of 5 dB, whereas as compared to TCM, hybrid coded system shows an improvement of 3-4 dB beyond SNR of 20 dB.

B. MODERATE TURBULENCE CONDITIONS

The value of σₙ² is considered as 1.6 characterizing moderate turbulence, like advection or continental fog. Like weak turbulence condition, the BER performance for various channel coding schemes such as LDPC, TCM, and their hybrid combination is presented in figure 3. As compared to LDPC it gives an improvement of 2-3 dB, whereas as compared to TCM, hybrid coded system shows improvement of 4.5 dB. The proposed hybrid coding scheme shows better performance as compared to their individual performance and gives least BER.
C. STRONG TURBULENCE CONDITIONS

The value of $\sigma_n^2$ is considered as 3.5 characterizing strong turbulence, like dense fog and dense haze. The BER performance for various considered channel coding schemes are presented in figure 4. The results validated that the proposed hybrid coding scheme shows better performance and shows an improvement of 5 dB and 4 dB as compared to individual performance of LDPC and TCM codes respectively:

![Gammathe model for Strong turbulence](image)

Figure 4. Performance of various coding schemes during strong turbulence (dense fog and dense haze)

V. COMPARATIVE ANALYSIS UNDER DIFFERENT TURBULENCE CONDITIONS

The BER performance comparison of the proposed hybrid coded OFDM based FSO system under various turbulence conditions has been illustrated. From the results it is proven that the proposed hybrid coding scheme outperforms the individual LDPC and TCM coding schemes for OFDM-FSO system over gamma-gamma turbulence model with atmospheric fading conditions. Simulation run time in MATLAB for TCM is 0.388 sec., for LDPC is 15.344 sec. and for hybrid scheme the time required is 17.544 sec.

Comparing LDPC, TCM and Hybrid coding schemes from SNR perspective with $\frac{1}{2}$ code rate for achieving BER of $10^{-7}$, the proposed hybrid coding scheme outperformed all. During weak turbulence condition with $\sigma_n^2 = 0.2$, the hybrid coding scheme shown an improvement of 5 dB and 2-3 dB as compared to LDPC and TCM codes respectively. In moderate as well as strong turbulence conditions both with $\sigma_n^2 = 1.6$ and 3.5 respectively, hybrid coding scheme has shown an improvement of 4 dB and 2 dB as compared to LDPC and TCM codes respectively. From the above said results, it is concluded: a) for a given code length, the performance of OFDM based FSO system with hybrid channel coding is healthier as compared to individual performance of LDPC and TCM codes for $\frac{1}{2}$ code rate; b) the improved performance is achieved at the cost of acceptable delay latency; c) it has been observed from the simulation results not presented here that due to TCM encoder the bit rate degradation is not severe.

VI. CONCLUSION

In this paper, a novel scheme that serially concatenated the LDPC using the DVB-S2 standard and TCM codes with random interleaver for an OFDM-based FSO communication system has been evaluated under weak to strong turbulence conditions. The proposed hybrid channel coding scheme has reasonable complexity and delay latency and the results indicated that performance of the OFDM based FSO communication system along with 8-PSK modulation has been upgraded when combined with the proposed LDPC -TCM concatenated codes. LDPC and TCM codes has been opted because of their pros for novel hybrid (inner-outer) combination to improve the BER performance of the optical signal through atmospheric turbulence channel. The performance gain of the LDPC, TCM and Hybrid coding schemes is simulated and analyzed for $\frac{1}{2}$ code rate and with same trellis structure. Simulation results show that proposed encoding method can significantly reduce the BER as compared to their individual performance under all turbulence conditions such as weak, moderate and strong.

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