ANALYTICAL PERFORMANCE EVALUATION OF AN LDPC CODED INDOOR OPTICAL WIRELESS COMMUNICATION SYSTEM

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ABSTRACT

Recently, indoor Optical Wireless (OW) connectivity has gained significant attention as a possible alternative to tackle the problem of bottleneck access and as an improvement to ever more conventional RF / microwave connections. In indoor OW communication, OOK encoding is more widely used owing to its effective usage of bandwidth and robustness to timing errors, given the fact that the power consumption is less than PPM. The modulation format in this research work is Q-array PPM over lasers, with modulation of power. The effects of the analysis are analyzed numerically in view of the amount of bit error (BER). It is shown that, because of coding for 4PPM framework, the bit error performance is increased. For instance, an LDPC-coded device with stable foundation radiation provides a important coding improvement of 5 to 6 dB over uncoded device at BER in the order of 10^{-8} and 10^{-12} respectively.

KEYWORDS

Bit error rate (BER),Indoor optical wireless (IOW), low density parity check (LDPC) code, on-off keying (OOK), signal to noise ratio(SNR) ,Q-ary pulse position modulation (QPPM).

1. INTRODUCTION

Gfeller and Bapst initially introduced indoor optical wireless (OW) communication [1] in 1979, and its implementations have actually reached households, workplaces and factories varying from TV control to IrDA terminals on handheld electronic devices such as cell phones, video cameras, digital assistants, and laptops[2-4]. Indoor OW communication is an attractive solution in the ultraviolet and visible range, particularly in atmosphere settings where radio communication experiences difficulties [5-6]. Modern indoor OW transmission techniques enable data-rates up to 25 Gbit/s [7-9]. LED lights, which are usually used for illumination purposes, relay data concurrently and though handheld terminals do not fit with the connection point [10-11].

In real-world indoor systems, the consumer may travel inside a small coverage range, usually equivalent to the size of a space or an aircraft cabin [12]. This may be difficult to have OW exposure to a traveling user, because the optical rays are obscured by items inside the space [13-14]. For narrower distances safe from environmental pollution such as fog, haze, snow and mist, indoor optical wireless networks are defined as opposed to outdoor models. The failure in the indoor connection only exists because of free space loss [15]. There are two simple wireless optical indoor communication techniques: Direct sight line and diffused setup. The design of the direct line of sight includes synchronization between the transmitter and the receiver in order to maintain contact by transmitting optical signals from the transmitter to the receiver without any reflection [16]. Such a network has greater power efficiency; reduced multipath dispersion and lower path failure, and greater transmission speeds can be obtained.

A potential alternative is to install a narrow-beam and roof-mounted transmitter which is powered by a tracking mechanism. The monitoring system rotates the transmitter and, with appropriate modulation technique, guides the narrow optical beam from the transmitter to the handheld receiver [17-18]. The key goal of this research work is to identify the best implemented modulation method in diffused OW indoor systems. For this research LDPC code is used to locate higher quality signal. The aim of this work is to establish the output analysis for Indoor diffused OW System by defining better performing modulation strategies from OOK and 4-PPM. Eventually, the study aims to increase the reliability of Indoor Diffused Optical Wireless System, and LDPC code is used in comparison to both modulation strategies.

2. SYSTEM MODEL

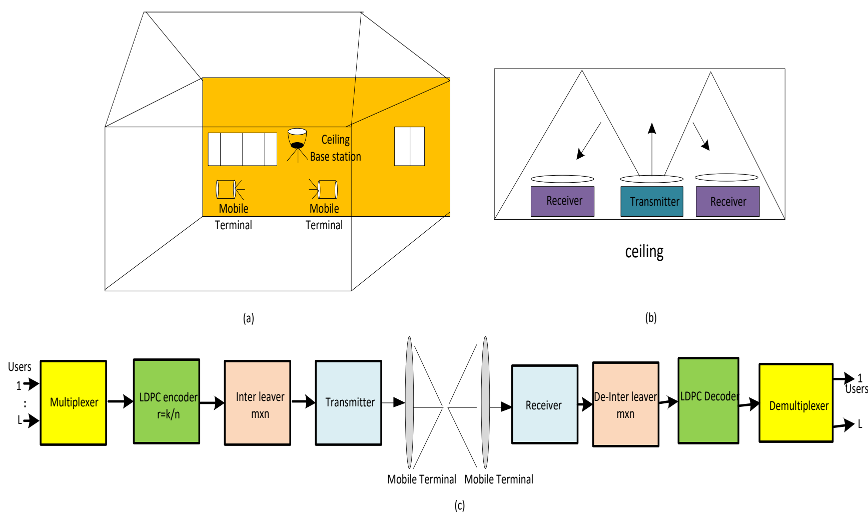

Figure 1: (a) Orientation (b) setup and (c) block diagram of an LDPC coded indoor wireless optical communication system.

Figure 1 provides a schematic of a typical scenario for indoor OW communications. Mobile terminals are permitted to travel within a room and need ties to a base station on the ceiling and other mobile terminals to be created. For certain interfaces the reflective optical force is guided into the receiver, while in others the emitted signal is allowed to bounce off surfaces in the space diffusely. Infrared light sources are the channel's primary cause of noise which must be included in the design of the network.

Moreover, the usable bandwidth may be high in certain guided wireless optical links, which enables massive quantities of information to be transmitted, particularly in short-range applications.

3. THEORETICAL ANALYSIS OF INDOOR OW COMMUNICATION SYSTEM

The principle can be expressed by the following equations for uncoded situation [19]:

$$R_{b=Blog_2 M} \tag{1}$$

$$R_{b=B.\frac{log_2 M}{M}} \text{ [For PPM]} \tag{2}$$

$$BER_{OOK=erfc\left(\frac{M}{2}.Q.\left(\sqrt{SNR\frac{M.log_2 M}{2}}\right)\right)} \tag{3}$$

$$BER_{PPM=erfc\left(2.\frac{M-1}{log_2 M}.Q.\left(\frac{1}{M-1}\sqrt{SNR.log_2 M}\right)\right)} \tag{4}$$

Bandwidth B is the first-null bandwidth, SNR is the electrical signal-to-noise ratio, and M is the number of chips which make up a symbol in PPM or the number of power levels in an ASK. The Q(x) function is set to:

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{\frac{-u^2}{2}}.du \tag{5}$$

To the coded process, the reliability of the bit $L(c_j)$, ($j=1,2, \ldots ,m$) (c_j is the j^{th} bit of the observed symbol q binary representation $c=(c_1,c_2, \ldots ,c_m)$) is calculated from the reliability of the symbol.

$$L(c_j) = \log \frac{\sum_{c:c_j=0} \exp[\lambda(q)]}{\sum_{c:c_j=1} \exp[\lambda(q)]} \tag{6}$$

The N-receiver outputs in response to symbol q, indicated as Z_{nq}(n=1,2,…,N; q=1,2,…,Q), are analyzed to assess authenticity of symbols $\boldsymbol{\lambda(q)}$ (q=1,2,…,Q) denoted by [20]

$$\lambda(q) = -\frac{\sum_{n=1}^{N}\left(Z_{nq} - \frac{\sqrt{E_s}}{M}\sum_{m=1}^{M} I_{nm}\right)^2}{\sigma^2} - \frac{\sum_{n=1}^{N}\sum_{1\neq q}^{Q} Z_{nI}}{\sigma^2} \tag{7}$$

Probability of error is demonstrated as:

$$P(Z_{n,q} \mid \dddot{I}_n) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(Z_{nq} - \dddot{I}_n)^2}{2\sigma^2}\right] \tag{8}$$

4. RESULTS AND DISCUSSION

By applying the analytical method, we try to evaluate the efficiency of uncoded and power-efficient coded modulation scheme based on bit-interleaved coded modulation (BICM) with LDPC code as component code, appropriate for use with OOK and Q-ary PPM in indoor OW communication systems. Perhaps the coded modulation scheme enables very normal integration of RF / microwave signals and translation to the optical domain, which could be a strong choice for RF / microwave hybrid systems. In the presence of background radiation, the output effects of Bit-error rate (BER) are tested with and without LDPC code.

At first the outputs of the bit error rate under uncoded and LDPC coded method have been determined for two separate modulation schemes. Under direct diffuse system, we test the effects of the bit error rate output with Q-ary PP and OOK modulation. The computational analyses are conducted in LDPC decoder for up to 10 iterations, the scintillation effect is based on assuming a diffused channel configuration and the usage of an optimal photon counting receiver. It is found that if we induce Q-ary PPM as a modulation scheme for uncoded and LDPC coding rather than OOk, the device output increases dramatically.

The specifications used for processing in this article are displayed in table 1 for the convenience of the readers.

Table 1: Nominal Parameters for indoor OW Communication link

Parameter Name	***Value***
Bit Rate, B_r	10 Gbps
Bandwidth, *B*	20 GHz
Modulation	OOK and Q-PPM
Order of PPM, Q	4
Code word length	2048
Channel Type	Diffused
PIN photodetector responsivity, R_d	0.7
Rytov variance, σ	0.1-0.8
Quantum efficiency, η	0.5
Operating wavelength, λ	1.55µm

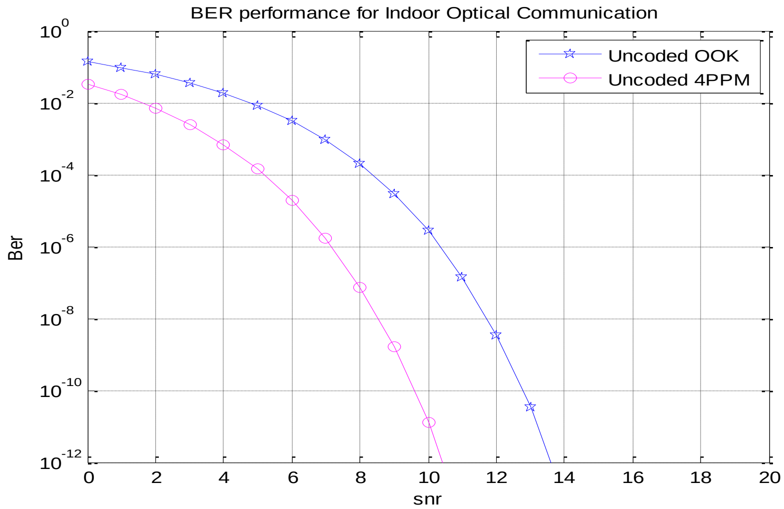

Figure-2: BER against SNR plots for the indoor OW connectivity network with OOK and 4PPM modulation.

Figure-2 reveals the BER against SNR plots for the indoor OW connectivity network with OOK and 4PPM modulation. From the evaluation of the figure, it is evident that PPM is advantageous over OOK for low-rate systems because it needs lower average power and is more reliable towards optical noise, particularly near-baseband noise components.

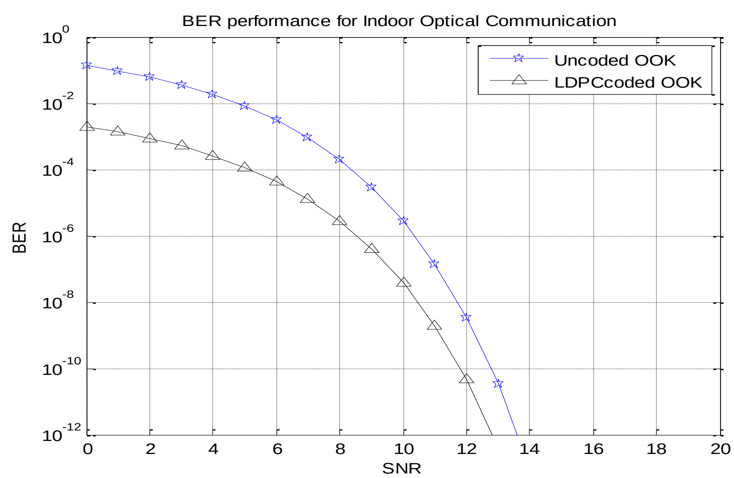

Figure-3 BER versus SNR plots for indoor OW connectivity network with OOK modulation for both uncoded and LDPC coding schemes.

Figure-3 demonstrates the plot of indoor OW connectivity network BER versus SNR with OOK modulation under uncoded and LDPC coded condition. It is noted that the BER performance under coded condition is much better than uncoded system.

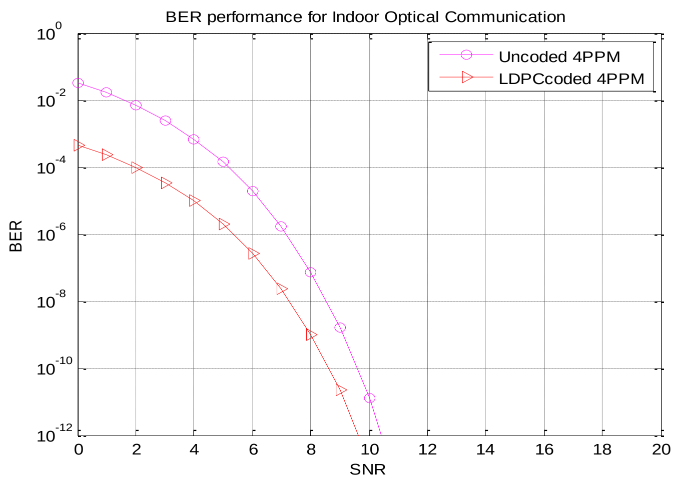

Figure-4: BER against SNR plots with 4PP modulation for indoor OW communication networks for both uncoded and LDPC coded application.

Figure-4 depicts BER against SNR plots with 4PP modulation under uncoded and LDPC coded conditions for the indoor OW communication network. It is evident from the close examination of the figure that the output of the BER is improved under a coded condition. It is also shown that bit error is almost zero at a bit rate of 10^{-4} under coded condition.

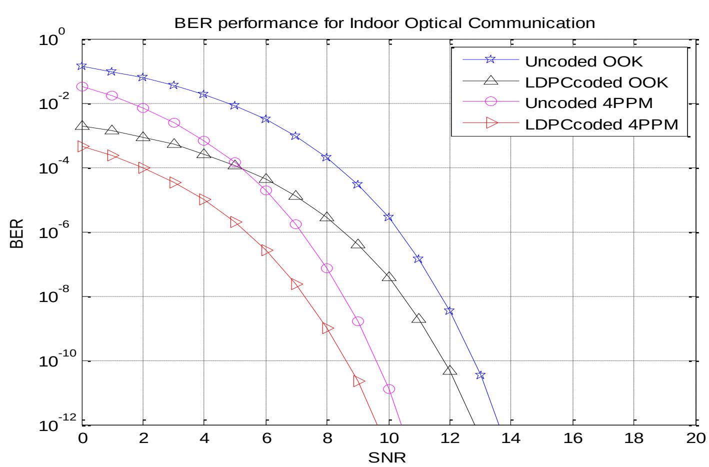

Figure-5 BER toward SNR modules with OOK and 4PP modulation for indoor OW communication for both uncoded and LDPC coded networks.

Figure-5 illustrates the BER versus SNR plots with OOK and 4PP modulation for the indoor OW communication network. It is clear from the study of the figure that PPM is advantageous over OOK for low-rate systems for both uncoded and coded conditions under the diffuse connection channel model. Analysis shows that in this combination, we find a coding gain of almost 5 dB at BER in the range of 10^{-12}.

5. CONCLUSIONS

Indoor OW networking has evolved as a technology that has the potential to bridge the last-mile barrier of high-speed Internet access separating households and businesses. A comprehensive analytical approach to analyze the degradation of the reliability of wireless optical links with OOK and Q-ary PPM schemes is presented. Analysis reveals that PPM is advantageous over OOK for low-rate systems, as it needs lower average power and is more resilient against optical noise, particularly near-baseband noise. Elsewhere we introduce an analytical approach for determining the efficiency of an uncoded and energy-efficient coded modulation scheme based on bit-interleaved coded modulation (BICM) utilizing LDPC codes as component codes, suitable for use in Q-ary PPM and OOK indoor OW networks. The results of the performance are assessed numerically in terms of bit error rate (BER). It is observed that, due to coding for 4PPM framework, the efficiency of bit error is increased. For reference, an LDPC-coded system with constant background radiation provides a noticeable coding gain of 5 to 6 dB over uncoded system at BER in the range of 10^{-8} and 10^{-12} respectively. Eventually, energy-efficient encoded modulation mechanism focused on bit-interleaved coded modulation (BICM) for LDPC codes offers excellent efficiency and seems to be easier to implement, as it includes only one LDPC encoder / decoder. Overall the design and analysis proposed can solve the connectivity problem of high speed indoor communication connections.

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REFERENCE

[1] Gfeller, F.R. and Bapst, U., (1979) “wireless In-house Data Communication via Diffused Radiation,” Proceeding IEEE.
[2] Komine, T. and M. Nakagawa, (2004) “Fundamental analysis for visible light communication system using LED lights,” IEEE Trans. OnConsumer Electronics, vol. 50, no. 1, pp.100–107.
[3] Bobby Barua, Tanzia Afrin Haque and Md. Rezwan Islam, (2012) “Error Probability Analysis of Free-space Optical Links with Different Channel Model under Turbulent Condition”, International Journal of Computer Science & Information Technology (IJCSIT) ,vol. 4, no. 1, pp.246-258 .
[4] Gonz´alez, O., S. Rodrguez, R. P´erez-Jim´enez, B. R. Mendoza, and A. Ayala, (2005) “Error analysis of the simulated impulse response on indoor wireless optical channels using a Monte Carlo-based ray-tracing algorithm,” IEEE Trans. on Communications, vol. 53, no. 1, pp. 199–204.
[5] Chen, C. H., C. L. Liu, C. C. Chiu, and T. M. Hu, (2006) “Ultrawide band channel calculation by SBR/Image techniques for indoor communication,” J. of Electromagn. Waves and Appl., vol. 20, no. 1, pp.41–51.
[6] Havran, V., J. Bittner, and H.-P. Seidel, (2005) “Ray maps for global illumination,” Eurographics Symposium on Rendering, pp.43–54.
[7] Chao Li, Xuebing Zhang, Eduward Tangdiongga, Xiaoyu Dai, Cheng-Ting Tsai, Huai-Yung Wang, Yuanjiang Xiang, Gong-Ru Lin, Zizheng Cao, and Ton Koonen , (2019)”Cost-efficient half-duplex 10 Gbit/s all-optical indoor optical wireless communication enabled by a low-cost Fabry–Perot laser/photodetector” Opt. Lett. vol.44, no. 5, pp. 1158-1161.
[8] A. T. Hussein, M. T. Alresheedi, and J. M. H. Elmirghani, (2015) “20 Gb/s Mobile Indoor Visible Light Communication System Employing Beam Steering and Computer Generated Holograms,” J. Light. Technol., vol. 33, no. 24, pp. 5242– 5260.

[9] A. T. Hussein, M. T. Alresheedi, and J. M. H. Elmirghani, (2016) “25 Gbps mobile visible light communication system employing fast adaptation techniques,” in International Conference on Transparent Optical Networks.
[10] Cocheril, Y. and R. Vauzelle, (2007) “A new ray-tracing based wave propagation model including rough surfaces scattering,” ProgressIn Electromagnetics Research, PIER 75, pp. 357–381.
[11] Liang, C., Z. Liu, and H. Di, (2008) “Study on the blockage of electromagnetic rays analytically,” Progress in Electromagnetics Research B, vol. no. 1, pp.253–268.
[12] F. E. Alsaadi, M. A. Alhartomi, and J. M. H. Elmirghani, (2013) “Fast and efficient adaptation algorithms for multi-gigabit wireless infrared systems,” J. Light. Technol., vol. 31, no. 23, pp. 3735–3751.
[13] A. T. Hussein and J. M. H. Elmirghani, (2015) “10 Gbps Mobile Visible Light Communication System Employing Angle Diversity, Imaging Receivers, and Relay Nodes,” J. Opt. Commun. Netw., vol. 7, no. 8, pp.718.
[14] S. H. Younus and J. M. H. Elmirghani, (2017) “WDM for high-speed indoor visible light communication system,” in International Conference on Transparent Optical Networks.
[15] Ke Wang, Ampalavanapillai Nirmalathas, Christina Lim, and Efstratios Skafidas , (2015) “Experimental demonstration of a novel indoor optical wireless localization system for high-speed personal area networks” Opt. Lett. vol. 40, no. 7, pp. 1246-1249.
[16] Feng Feng, Paramin Sangwongngam, Grahame Faulkner, and Dominic O’Brien , (2019). “Wide field-of-view optical broadcasting for bi-directional indoor optical wireless communications employing PAM-4 modulation” Opt. Lett. vol. 44, no. 24, pp. 6009-6012.
[17] Dima Bykhovsky , (2018) “Coherence distance in indoor optical wireless communication channels” Opt. Lett. vol. 43, no. 10 , pp.2248-2251.
[18] Jiayuan He, Jeonghun Lee, Tingting Song, Hongtao Li, Sithamparanathan Kandeepan, and Ke Wang (2019), “Recurrent neural network (RNN) for delay-tolerant repetition-coded (RC) indoor optical wireless communication systems” Opt. Lett. vol. 44, no. 15, pp. 3745-3748.
[19] Bobby Barua, and S. P. Majumder,(2010) "Performance analysis of a LDPC coded multiple input/multiple output free-space optical system with Q-ary pulse-position modulation", International Conference on Electrical & Computer Engineering (ICECE 2010).
[20] Bobby Barua, and S. P. Majumder,(2018) " Analytical Performance Evaluation of a MIMO FSO Communication System with Direct Detection Optical Receivers Under Turbulent Condition", Integrated Optics and Lightwave:An International Journal(OPTLJ), vol. 1, no.1, pp. 27-33.

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