BER Performance of Optical Orthogonal Frequency Division Multiplexing in Presence of Shot and Thermal Noises

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Abstract— O-OFDM is an emerging technology in the field of optical wireless communication especially in indoor applications. As in optical wireless VLC the transmission is done in optical domain therefore, photo-detection is performed at the receiver. Therefore it is important to consider, shot and thermal noises in BER analysis. In this work, OOK-SIM (ON –OFF Keying Subcarrier Intensity Modulation) is compared with O-OFDM, and effect of thermal and shot noises is considered in BER analysis.

Key words: O-OFDM, OOK-SIM, Thermal Nose, Shot Noise, VLC

I. Introduction

We can define the orthogonal frequency division multiplexing (OFDM) as another modulation technique that can affectively makes use of the available bandwidth. Figure 1, illustrates the block diagram for an OFDM-based system. It is an extraordinary adaptation of subcarrier modulation examined above in that all the subcarrier frequencies are orthogonal. In the case of an OFDM transmitter, serial data streams are collected and mapped into N_d constellation symbols $\{\{X[k]\}_{k=0}^{N_d-1}\}$ by making use of BPSK, QPSK or M-QAM N_p pilots are embedded into the data symbols prior to transforming into the time domain signal by *N*-orthogonal subcarriers through an IFFT given as

$$m_x(n) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X[k]e^{\frac{j2\pi nk}{N}}, \quad n = 0,1,\ldots,N-1 \qquad (1)$$

We add a cyclic prefix of length G (more noteworthy as compared to the channel length) is joined to the IFFT result to remove multipath-induced ISI.

In the execution of the optical OFDM/DMT, the result of the IFFT blocks nourishes direct into a digital-to-analogue converter (DAC) which interprets the discrete IFFT sample points into continuous time-varying signal. After this, we use this time-varying signal to drive the optical source intensity, regularly LED for this situation. The DAC is additionally typically planned or picked to such an extent that its output is well inside the input dynamic range of the driver–LED mix. This is to stay away from any signal clipping which may then negatively affect the framework execution. At the receiver, subsequent to evacuating the cyclic prefix, y[n] is connected to the FFT. Because of the cyclic prefix, the linear convolution between the transmitted signal and the channel ends up circular convolution; consequently, the output of the FFT can be defined as increase in grid matrix given by

$$Y = \mathrm{diag}(X).H + W \qquad (2)$$

Here, $H = F.h$ defines the frequency response of the channel with length *L*, $[F]_{n,k} = \frac{e^{-(j2\pi kn/N)}}{\sqrt{N}}$ is the FFT matrix, $\boldsymbol{W N\times 1}$ is the white Gaussian noise with $E[WW^H] = \sigma_n^2 I_N$, H is the Hermitian transpose and diag is the diagonal matrix.

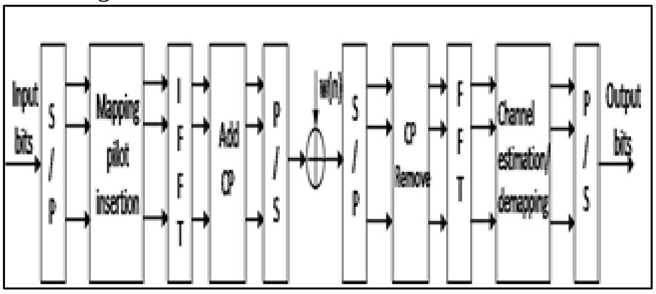

Fig. 1: Block Diagram of OOFDM

In spite of the fact that there are accounted for works which have a tendency to propose that a specific level of clipping can be endured without bringing on an insufferable level of execution corruption, clipping will diminish PAPR and make increment in the average AC control, hence prompting a higher SNR . To specifically modulate the intensity of an optical source (white LED, for example), a genuine, positive signal is needed. An optional method is the application of asymmetrically clipped OFDM (ACO-OFDM). In ACOOFDM, no DC is included at all. The bipolar genuine OFDM signal is clipped at the zero level.

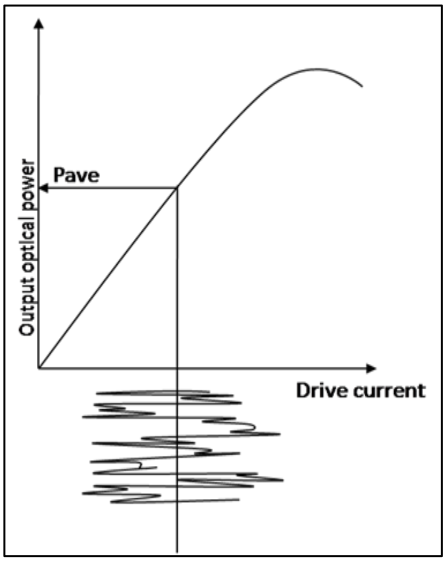

Fig. 2: Real analogue Time Varying Driving an LED

In other words, the whole negative signal is evacuated. It would appear if just the odd-recurrence OFDM subcarriers are nonzero at the IFFT input, the noise brought on by clipping influences just the even subcarrier and the information conveying odd subcarriers are not impaired at all. The spectral effectiveness of ACO-OFDM is although just half of that of DC-OFDM. This is on account of just the odd subcarriers are information conveying in ACO-OFDM while all subcarriers are data conveying in DC-OFDM. After this, the real, unipolar flag is applied to specifically drive the optical source as appeared in Fig. 2.

The LED average driving current (bias point) that corresponds to output optical power Pave in Fig. 2 is elected so as to

1) Give the appropriate level of lighting/illumination for visible light communications
2) Gives permission to the full swing of the input signal
3) Make sure to keep the signal within the linear region of the LED characteristics curve as much as possible.

The OFDM has a disadvantage of high PAPR demanding a high powerful range. As a matter of fact, the OFDM endures most extremely because of the nonlinear distortion by the high PAPR. In OFDM framework, because of multi-amplitude modulation plans, channel estimation is needed for making adjustment and deciphering given that there is no learning of the channel. In the case of one-dimensional channel estimation plans, we can add pilot in the block and comb type. The previous uses the at least block square or the base mean-square blunder (MMSE) to accomplish estimation in a slow fading channel, while the last uses the LS with interpolation and the greatest probability (ML) to perform estimation in a quickly changing channel.

II. RECEIVER NOISE AND BIT ERROR RATIO

The optical receiver converts incident optical power into electrical current through the photo-diode. The relation between the optical power and the photo-current is linear, i.e.

$$I_p = RP_{in} \tag{3}$$

Where R is the responsively of the photo-detector, Ip is the photo-current and P_{in} is the incident optical power. The interaction of photon with the matter in a photo-detector however is a statistical process. That means the linear relationship is valid in an average sense. If we go to micro level there are fluctuations in the photo-current around the mean. These fluctuations are called the noise in the receiver. There are fundamental mechanisms of noise:

A. *Shot Noise*

This is due to statistical fluctuations in the optical signal itself and the statistical interaction process.

B. *Thermal Noise*

This is due to the thermal motion of the electrons inside the electronic circuits and the amplifiers following the photo-detector.

The presence of noise degrades the signal quality. For the analog system the signal quality is measured by the parameter, signal-to-noise ratio (SNR), and for a digital system the signal quality is measured by the parameter, bit error ratio (BER).

The analysis of noise therefore is very important in a communication link. Here first we investigate the properties of the two noises mentioned above and then calculate the BER for the digital signals.

1) Shot Noise

The shot noise is because of the random fluctuation in the photo-carrier generation. The shot noise was first investigated by Schottky in 1918. In the presence of the noise the photo current can be written as

$$I(t) = I_P + i_S(t) \tag{4}$$

Where, $I(t)$ is the instantaneous current of the photo detector, and $i_s(t)$ is current fluctuation due to the shot noise.

The noise current $i_S(t)$ is stationary random process with Poisson statistics.

The spectral density of the shot noise is practically constant over a very wide band and hence the noise is almost white.

The variance of the shot noise is

$$\sigma_S^2 = \left\langle i_S^2(t) \right\rangle = 2\,q\,I_p\,B \tag{5}$$

Where, q is the electronic charge, and B is the effective receiver bandwidth. The variance of the noise essentially gives the rms noise power. The receiver bandwidth depends upon at what location in the receiver the noise is measured. If the noise is measured just after the photo-detector, the bandwidth is equal to the intrinsic bandwidth of the detector. However, if the noise is measured at the end of the receiver, then the transfer function of the receiver $H(f)$ comes into picture and the noise variance is given as

$$\sigma_S^2 = \left\langle i_S^2(t) \right\rangle = 2\,q\,I_p \int_0^\infty |H(f)|^2\,df \tag{6}$$

The integral essentially gives the effective bandwidth of the system.

All photo-diodes generate a small amount of current even in the absence of optical signal. This is due to the stray light falling on the detector and also due to thermal generation of the carriers. This current is called the dark current, I_d.

The total current in the presence of signal then is the sum of the signal photo-current and the dark current. In a binary digital signal the dark current is generally negligible for bit 1. For bit 0 however, since the optical signal is very low (ideally zero), the dark current is to be taken into account.

Since variance of the shot noise is proportional to the average signal current, the shot noise essentially is a multiplicative noise. The shot noise therefore is a multiplicative white noise.

2) Thermal Noise

The thermal noise is because of the random thermal motion of the electrons inside a conductor. The thermal is added in the load resistor connected to the photo-diode.

The thermal noise also has constant spectral density over a very wide frequency range and consequently, thermal noise is also white.

The thermal noise is modeled by Gaussian process. Since this noise is added externally to the photo-current, this noise is additive in nature.

The variance of the thermal noise is given as

$$\sigma_T^2 = \left\langle i_T^2(t) \right\rangle = \frac{4\,K\,T\,B}{R_L} \qquad (7)$$

Where K Boltzmann is constant, T is the temperature of the receiver, and R_L is the load resistor connected to the photo-diode. The variance gives the thermal noise power.
The thermal noise does not depend on the signal. Hence it is same for both 1 and 0 bit of the binary signal. The amplifier following the load resistor also adds the noise. The character of this noise is similar to the thermal noise. The contribution of the amplifier noise can be accounted for by a parameter called the Noise Figure F_n of the amplifier.
The variance of the thermal noise in presence of amplifier is

$$\sigma_T^2 = \left\langle i_T^2(t) \right\rangle = \frac{4\,K\,T\,B}{R_L} F_n \qquad (8)$$

It may be noted that the thermal noise can be reduced by using high load resistance.

This indeed gives loading problem for the following amplifier. However, that is an independent issue. Generally high input trans-conductance amplifiers are used after the photo-detectors.

3) SIGNAL–TO-NOISE RATIO (SNR)

The SNR is a ratio of the signal power to the total noise power. To get total noise power, we assume that the shot noise is approximately Gaussian with of course mean equal to the average photo-current. Then since the shot and thermal processes are independent Gaussian random processes, the variance of the total noise is equal to the sum of the variances of the two noises.

The average mean square value of the photo-current fluctuation is therefore [51]

$$\sigma^2 = \left\langle \Delta I^2 \right\rangle = \sigma_S^2 + \sigma_T^2 = 2\,q\,I_p\,B + \frac{4\,K\,T\,B}{R_L} F_n \qquad (9)$$

The signal to noise ratio is

$$SNR = \frac{\text{Average signal power}}{\text{noise power}} = \frac{I_p^2}{\sigma^2}$$

(10)

$$SNR = \frac{\Re^2 P_{in}^2}{2\,q\,I_p\,B + \frac{4\,K\,T\,B}{R_L} F_n}$$

Depending upon the optical signal the thermal noise may dominate over the shot noise and vice versa. Since shot noise is proportional to the signal, the shot noise is dominant at high signal levels, typically higher than -20 dBm.

4) BIT-ERROR RATIO (BER)

The performance of digital receiver is measured by a parameter called the Bit-Error Ratio (BER). The BER tells the fraction of the bits which are wrongly detected,
For a satisfactory performance the BER has to be less than 10-9.

5) Probability of error, Pe

Pe is normally expressed in terms of the bit error rate (BER). This depends on the SNR at the receiver. The BER requirement and the magnitude of noise power at the receiver thus set a lower limit on the optical signal power that is required to be incident on the photodiode (receiver sensitivity).
In most famous Q (error function) the error probability is also defined as

$$P_e = \frac{1}{2}\left[Q\left(\sqrt{\frac{S}{N}} \right) \right] \qquad (11)$$

List of Parameters	Value
Number of Sub-carrier	256
Number of Symbols	256
Guard interval	64
Modulation	BPSK
Channel Length	2 and 4
Number of iterations	10000
Signal to noise ratio	1 to 12

Table 1: List of Parameters and Values

III. RESULTS

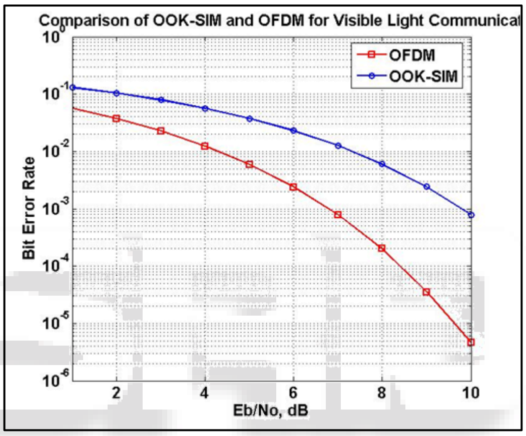

Fig. 3: Comparisons of OOK-SIM and OOFDM

In Fig. 3, OOK-SIM and OOFDM is compared, it is clear from the figure that, the performance of OOFDM is much better in comparison to OOK-SIM. It can also be observed that as SNR increases the gap in improvement is wider. Comparing the results at SNR level of 8, the BER for OOK-SIM is 6×10-3 while for OOFDM is 2×10-4. This improvement in result is observed due to better transmission capability of O-OFDM.

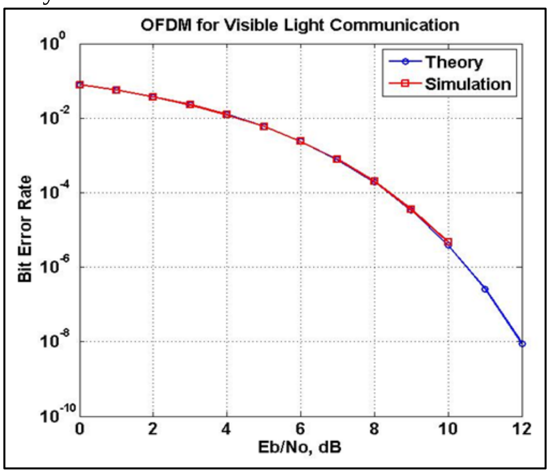

Fig. 4: Comparisons of OOFDM Simulation and Theoretical Results

In Fig. 4, comparisons of O-OFDM simulation and theoretical results are presented, and they are in well agreement with each other. In the simulation 1000 iterations are considered.

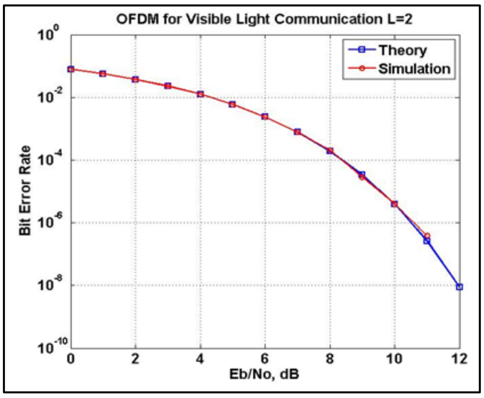

Fig. 5: Comparisons of OOFDM Simulation and Theoretical Results for Channel Length L=2

In fig. 5, comparisons of OOFDM simulation and theoretical results for channel length L=2 is presented while considering 10000 iterations. It is shown in the figure with more number of iterations a better and deeper analysis is possible, as simulation covers lower ranges of BER.

In Fig. 6, comparisons of OOFDM simulation and theoretical results for channel length L=4 is presented while considering 10000 iterations. As the channel number increases a faster information transfer takes place while performance in terms of BER remains the same.

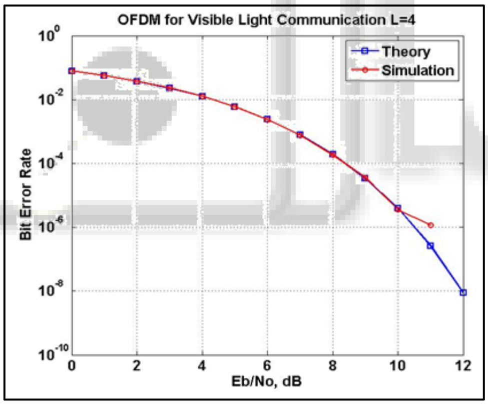

Fig. 6: Comparisons of OOFDM Simulation and Theoretical Results for Channel Length L=4

IV. CONCLUSIONS

This paper discusses the effect of shot and thermal noise on the BER analysis of O-OFDM and OOK-SIM methods. It is found that in terms of BER, the performance of O-OFDM is much superior to OOK-SIM. Moreover, thermal and shot noises have very little effect on BER analysis in case of indoor applications.

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