OCDMA Indoor Wireless Communications System with Mobile Receiver

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***Abstract*—**In this paper we consider an optical code division multiple access (OCDMA) indoor wireless communication system using spectral encoding and evaluate its performances in cases of classical OCDMA, dynamic OCDMA and OCDMA with deconvolution. We present an analysis of the receiver movement influence on the indoor wireless communications system performances. As the receiver moves increasingly away from transmitter the amount of power received in that place will be getting smaller and system performances are affected. Knowledge of the impulse response in different positions in the room allows calculation of the amount by which power is lower at that point. We showed that increasing the power received in that place with the necessary amount, system performance are maintained at the same values, even if the receiver is moving away from transmitter. The bit error rate (BER) was estimated by means of simulations for several scenarios. The simulation results confirm the fact that using deconvolution in OCDMA systems, the multipath interference is reduced and the BER performances are significantly improved for diffuse configuration, as compared to the case without deconvolution.

***Keywords*—**deconvolution, indoor optical wireless communication, interference reduction, OCDMA, power control.

I. INTRODUCTION

OPTICAL wireless communication techniques are used today in many applications. For wireless systems, infrared (IR) wireless communication systems offer a major advantage over wireless radio systems: the IR spectral region is free from spectrum regulation and offers a virtually unlimited bandwidth. In addition, IR transmission is confined within a room, so the transmissions are secure against casual eavesdropping and they are without interference between links operating in different rooms even if the same optical wavelength is used. Moreover, the components for IR wireless communications can operate at high-speed and are available at relatively low cost.

In this paper, we consider a wireless OCDMA system based on spectral encoding using intensity modulation and direct detection (IM/DD). We evaluate the system performances starting with impulse response of communications channel. For indoor light propagation environments (Fig. 1), especially in the case of diffuse configuration, the multipath dispersion phenomenon exists, which leads to inter-symbol interference. Therefore, the light propagation in these indoor environments is a key issue for obtaining the maximum possible bit transmission rate.

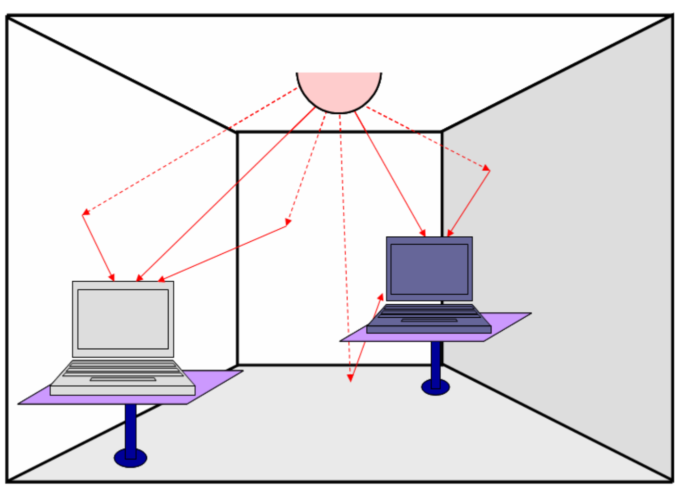

Fig. 1. The light propagation in indoor environments.

Many researchers attempted to determine the impulse response for indoors wireless optical channels. Characterization of this infrared channel was performed using simulation in [1], [2] and experimental measurements in [3], [4], [5], [6]. The light propagation in indoor environments determines a multipath dispersion phenomenon, which decreases the system performances (Fig. 1). We used a procedure, similar to those presented in [1], to determine the impulse response. Using a computer simulation program from [2] we determined the impulse response in an empty room with diffuse reflectors in certain configuration transmitter-receiver for line-of-sight (LOS) and diffuse systems.

For fixed transmitter and receiver locations, multipath dispersion is completely characterized by an impulse response $h(t)$. Mobile transmitters, receivers, and reflectors will result in a time varying channel. In [1] this effect is ignored because they consider that the channel will vary slowly relative to the bit rate for most indoor applications. We consider a variable distance between transmitter and receiver, and we study its influence on system performances.

In the next section, we present an analysis of the OCDMA system. In Section III, we present the results obtained for the simulated system performances. The classical OCDMA, dynamic OCDMA and OCDMA with deconvolution systems performances are compared for different receiver positions. Section IV contains the conclusions drawn from the performance analysis carried out.

II. OCDMA SYSTEM ANALYSIS

In this section we evaluate the performances of an indoor wireless OCDMA system considering that the receiver position is changing during the transmission. The transmission channel is modeled using an impulse response denoted by $h(t)$, obtained by means of simulation. The environment is defined as a room with standard dimensions, i.e., 5m x 5m x 3m used by most authors.

A. *Impulse Responses*

Characterization of this infrared channel was performed using a computer simulation program as in [2], to which we added the possibility of calculating the received power coefficient.

For LOS configuration, the transmitter is placed at the coordinate 2.5m x 2.5m x 3m downward and the receiver at the coordinate 2.5m x 2.5m x 1m upward, while in diffuse configuration the transmitter is placed at 2.5m x 2.5m x 2.5m that has upward orientation and the receiver is placed at 2.5m x 2.5m x 1m upward.

The receiver is initially placed just below the transmitter, whether we are in case of LOS configuration or diffuse configuration. Then, the receiver is moved from the initial position, increasing the distance with a step of 0.5 meters. In both configurations, the receiver will pass through the coordinates 2m x 2.5m x 1m, 1.5m x 2.5m x 1m, 1m x 2.5m x 1m and 0.5m x 2.5m x 1m, respectively.

The simulated impulse responses for LOS and diffuse configurations in case of different receiver positions are illustrated in Fig. 2 and respectively in Fig. 3.

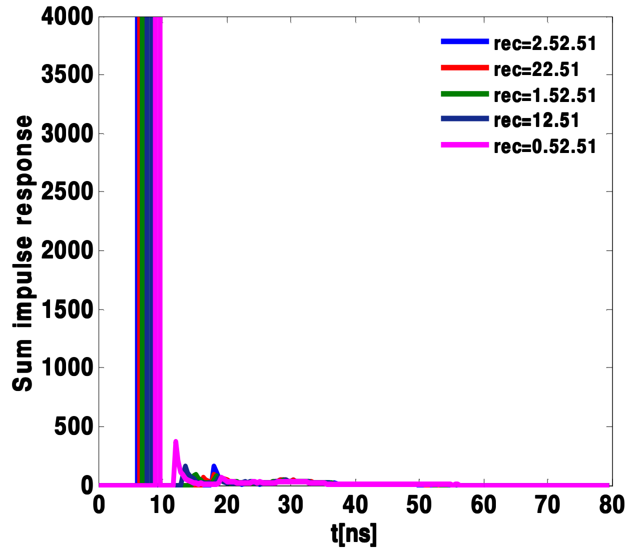

Fig. 2. Impulse response $h(t)$ for LOS configuration

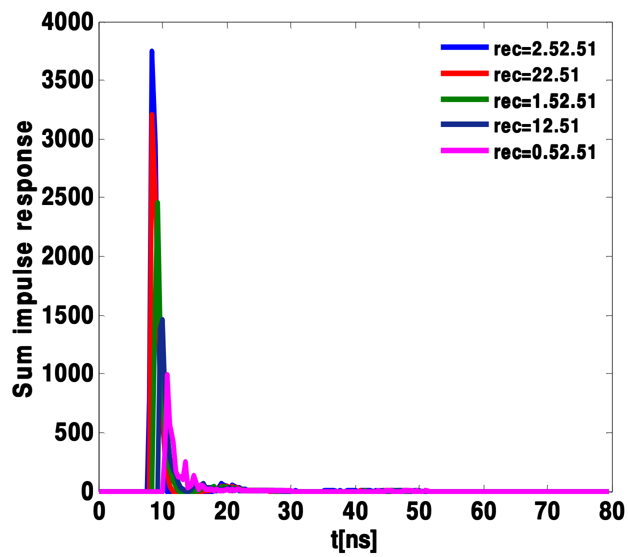

Fig. 3. Impulse response $h(t)$ for diffuse configuration.

As expected, we see that the signal is becoming weaker and more delayed in time, as the receiver moves increasingly away from transmitter.

B. *Classical System Analysis*

We consider a wireless communication system, which uses OCDMA transmission with spectral amplitude encoding. A possible scheme of the system is presented in Fig. 4 [7], [8], [9], [10]. The transmitter utilizes OOK (On Off Keying) modulation.

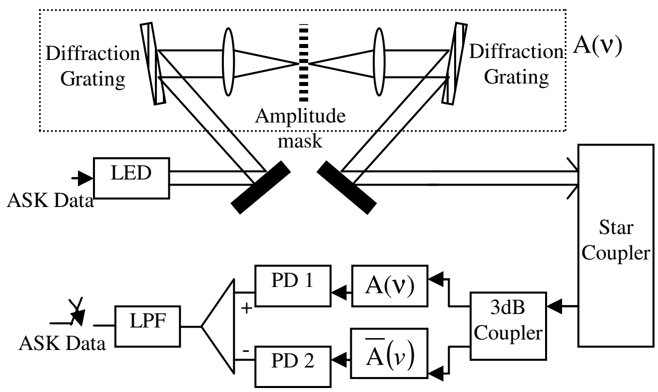

Fig. 4. Block diagram of an OCDMA system with spectral amplitude encoding

If OOK modulation is used, is considered that optical pulses with time duration of T seconds are transmitted. The transmitted pulse $x(t)$ is:

$$x(t) = \begin{cases} 1, \text{ if } 0 < t < T \\ 0, \text{ elsewhere} \end{cases} \tag{1}$$

The received pulse when sending the pulse $x(t)$ over the channel with impulse response $h(t)$ can be expressed using formula:

$$R(t) = x(t) * h(t) \tag{2}$$

The spectral shape of the optical source is considered Gaussian [6]:

$$z_i = \frac{1}{\sqrt{2\pi}\sigma} \cdot \int_{(-B/2\alpha + i \cdot B/N\alpha)}^{(-B/2\alpha + (i+1) \cdot B/N\alpha)} e^{-f^2/2\sigma^2} df \tag{3}$$

where B is the 3dB bandwidth of the source, N is the code sequence length, and α denotes the encoded bandwidth factor. Therefore, $\alpha = 1$ when the whole 3dB bandwidth of the source is encoded, and if α is increased the encoded bandwidth will be reduced.

The receiver has the structure presented in Fig. 3. The signal is received over two branches with equal powers and the masks in the two branches have complementary patterns. The photocurrents from the two branches of the receiver depend on the intensity of the incident light at the two photodetectors.

The variance of the decision variable for classical OCDMA is given by [11]:

$$\sigma_z^2 = N_0 d_1^l a + \frac{N_0 a}{2} \sum_{n=1}^{L-1} \frac{S_n}{S_0} + \frac{N_0}{2} \sum_{n=0}^{L-1} \frac{S_n}{S_0} \sum_{k=2}^{K} (b_k + c_k) + \\ + \left(\frac{N_0 a}{2}\right)^2 \sum_{n=1}^{L-1} \left(\frac{S_n}{S_0}\right)^2 + \left(\frac{N_0}{2}\right)^2 \sum_{n=0}^{L-1} \left(\frac{S_n}{S_0}\right)^2 \sum_{k=2}^{K} (b_k - c_k)^2 + \\ + \sigma_{th}^2 \tag{4}$$

In (4) the following notations were made: N_0 is the number of detected photons; d_1^l is the l-th transmitted bit by the user number 1; L is time extent of $R(t)$; a, b and c are correlation coefficients.

$$S_n = \int_{nT}^{(n+1)T} R(t) dt, \qquad n = 0, 1, \ldots, L-1 \tag{5}$$

The thermal noise has the following variance expression:

$$\sigma_{th}^2 = \frac{2 \cdot K_B \cdot T_0 \cdot T}{R_i \cdot q^2} \tag{6}$$

where K_B is the Boltzman constant, T_0 is the temperature in Kelvin degrees, T is the bit transmission time, R_i is the input resistance.

The bit error rate can be written as [11]:

$$P_e = \frac{1}{2} \operatorname{erfc}\left(\frac{N_0 a}{2\sqrt{2}\sigma_z}\right) \tag{7}$$

C. *Dynamic OCDMA Analysis*

The multipath dispersion implies that the bits of the same user transmitted before the l-th bit influence the detection of l-th bit. One method for reducing this intersymbol interference effect due multipath dispersion consists in the use of more different code sequences by a user to transmit his bits.

In contrast with the classical OCDMA systems, where one user transmits all the information bits using the same spreading code sequence, in the dynamic case [11] we can transmit dynamically a certain number of bits (2, 3, ...) of a user with a code sequence, and thereafter, for the next bits (2, 3, …) we use other code sequences. This will determine a reduction of intersymbol interference due to multipath propagation of the signal. In a more general approach, a user can select a different code sequence for transmission of each of his bit. In this last case, because the received pulse $R(t)$ has a time extent LT, a user will have assigned L different code sequences and not one as yet. The encoding is made using a different code sequence for each transmitted bit in case of first L bits (the first code sequence for the first bit, the second code sequence for the second bit, etc.). Then, when all available spreading codes are used, the encoding is continued by reusing codes in the same order (as we can see in Fig. 5.).

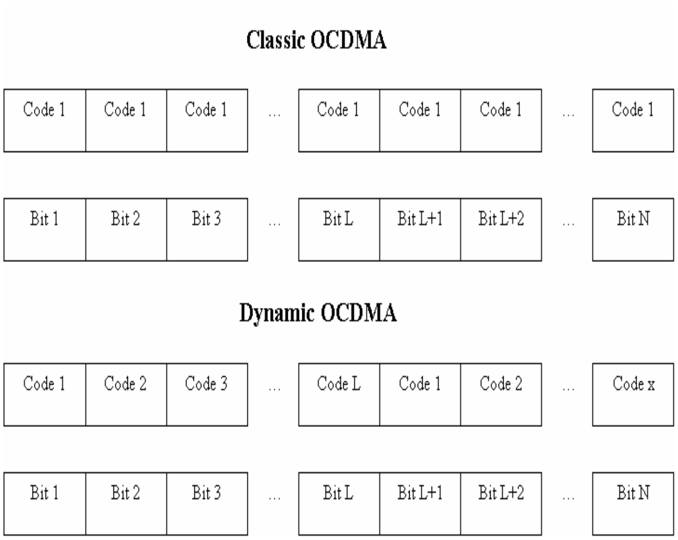

Fig. 5. Classical and dynamic OCDMA

The variance of the decision variable for dynamic OCDMA is given by [11]:

$$\sigma_z^2 = N_0 d_1^l a + \frac{N_0}{2}\sum_{n=1}^{L-1}\frac{S_n}{S_0}\left(b_{1n}+c_{1n}\right) + \frac{N_0}{2}\sum_{n=0}^{L-1}\frac{S_n}{S_0}\sum_{k=2}^{K}\left(b_{kn}+c_{kn}\right) + \left(\frac{N_0}{2}\right)^2\sum_{n=1}^{L-1}\left(\frac{S_n}{S_0}\right)^2\left(b_{1n}-c_{1n}\right)^2 + \left(\frac{N_0}{2}\right)^2\sum_{n=0}^{L-1}\left(\frac{S_n}{S_0}\right)^2\sum_{k=2}^{K}\left(b_{kn}-c_{kn}\right)^2 + \sigma_{th}^2 \qquad (8)$$

D. Deconvolution OCDMA Analysis

Because the signal is received over different propagation paths, we have the multipath dispersion phenomenon, which decreases the system performances. To improve system performance we make a deconvolution of the signal obtained after crossing the wireless channel. We used a method inspired by [12], to calculate the inverse of the channel impulse response $h^{-1}(t)$. The used signal processing algorithm is described below [13], [14].

Knowing the channel impulse response $h(t)$ we obtain discrete-time response $h(n)$. Then, we calculate the corresponding frequency response of $h(n)$ in N_h point:

$$H(\omega) = fft\left[h(n), N_h\right] \qquad (9)$$

For each of the N_h values of ω, the inverse frequency response $H_{inv}(\omega)$ is calculated using formula:

$$H_{inv}(\omega) = \frac{H'(\omega)}{H'(\omega)\cdot H(\omega)+\beta} \qquad (10)$$

where $H'(\omega)$ is the complex conjugate transpose of $H(\omega)$, β is a regularization parameter, (β = 0.0001 [12]). Using inverse Fourier transform we calculate $h_{inv}(n)$:

$$h_{inv}(n) = ifft\left[H_{inv}(\omega), N_h\right] \qquad (11)$$

We implement the modeling delay, as in [12], by cyclic shift of $N_h/2$ of each element of $h_{inv}(n)$ and obtain the desired $h^{-1}(n)$.

The received pulse when sending the pulse $x(t)$ over the channel with impulse response $h(t)$ after the deconvolution process can be expressed using formula:

$$U(t) = x(t) * h(t) * h^{-1}(t) \qquad (12)$$

The variance of the decision variable z^l in this case can be rewritten, based on [11], as:

$$\sigma_z^2 = N_0 d_1^l a + \frac{N_0 a}{2}\sum_{n=1}^{L-1}\frac{W_n}{W_0} + \frac{N_0}{2}\sum_{n=0}^{L-1}\frac{W_n}{W_0}\sum_{k=2}^{K}\left(b_k+c_k\right) + \left(\frac{N_0 a}{2}\right)^2\sum_{n=1}^{L-1}\left(\frac{W_n}{W_0}\right)^2 + \left(\frac{N_0}{2}\right)^2\sum_{n=0}^{L-1}\left(\frac{W_n}{W_0}\right)^2\sum_{k=2}^{K}\left(b_k-c_k\right)^2 + \sigma_{th}^2 \qquad (13)$$

where W_n:

$$W_n = \int_{nT}^{(n+1)T} U(t)dt, \qquad n = 0,1,...,L-1 \qquad (14)$$

The computer simulation program of the impulse response also allows us to determine the coefficient of received power for the actual receiver position. Dividing each of these coefficients of received power by its maximum value, we determine some coefficients of "normalization".

The coefficient of normalization will tell us how much of the power obtained with the receiver in the first position (closest to the transmitter) will be received at other positions where the receiver will be. Thus, for a given power at the input of the receiver closest to the transmitter, we can determine received powers for the other receiver positions.

The received powers in those positions will be different and therefore will vary the number of photons, N_0, which reach the receiver. For this reason, as we shall see in the next figures, the bit error rate (BER) will not remain the same when the receiver moves.

III. Simulations Results

We considered for simulations the classical OCDMA, dynamic OCDMA and OCDMA with deconvolution systems. In the sequel, we compare the BER performances obtained by means of simulations for these three cases.

In Fig. 6, Fig. 8, and Fig. 10 the bit error rate for K = 25 active users is depicted, for LOS configuration, according to the power at the input of the receiver closest to the transmitter.

The code sequences used in simulations are m-sequences with length $N = 127$, the transmission bit rate is 100 Mb/s.

We plotted in Fig. 7, Fig. 9, and Fig. 11 BER depending on receiver position at a certain power at the input of the receiver closest to the transmitter (-37 dBm, -35 dBm, -33 dBm, -31 dBm, -29 dBm, -27 dBm), for a fixed number of $K = 25$ active users. The transmission bit rate is 100 Mb/s, the code sequences length $N = 127$.

In Fig. 6 and Fig. 7, the performances for the classical and dynamic OCDMA cases are compared; in Fig. 8 and Fig. 9, classical OCDMA and OCDMA with deconvolution systems are compared; in Fig. 10 and Fig. 11 we compared all three OCDMA cases.

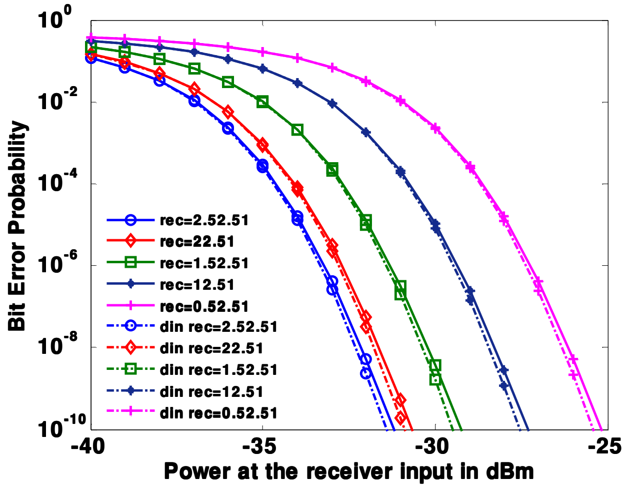

Fig. 6. BER for LOS configuration, $N = 127$, $\alpha = 1.15$

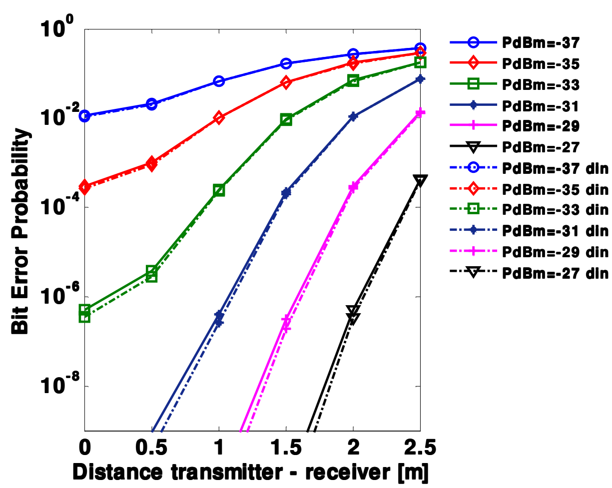

Fig. 7. BER for LOS configuration, $N = 127$, α=1.15

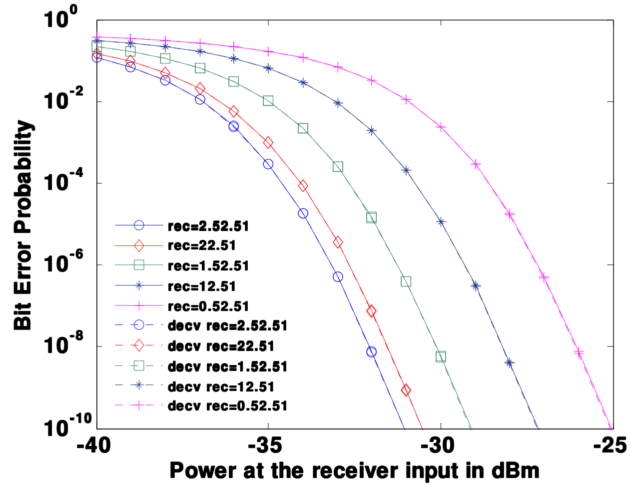

Fig. 8. BER for LOS configuration, $N = 127$, $\alpha = 1.15$

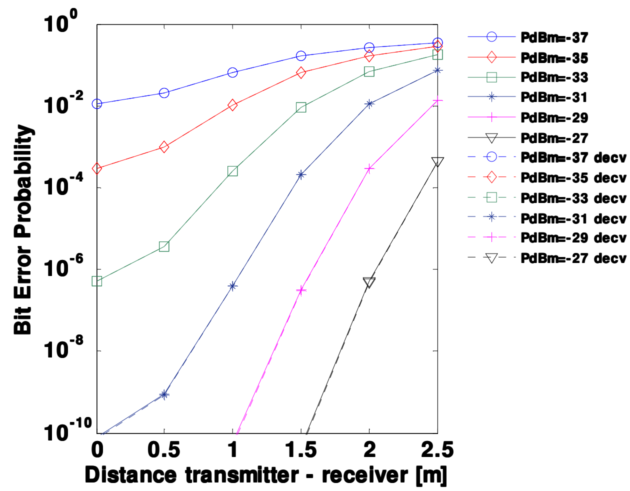

Fig. 9. BER for LOS configuration, $N = 127$, $\alpha = 1.15$

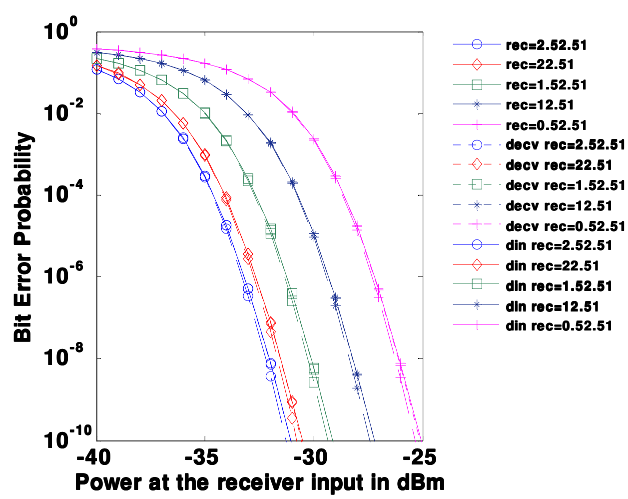

Fig. 10. BER for LOS configuration, $N = 127$, $\alpha = 1.15$

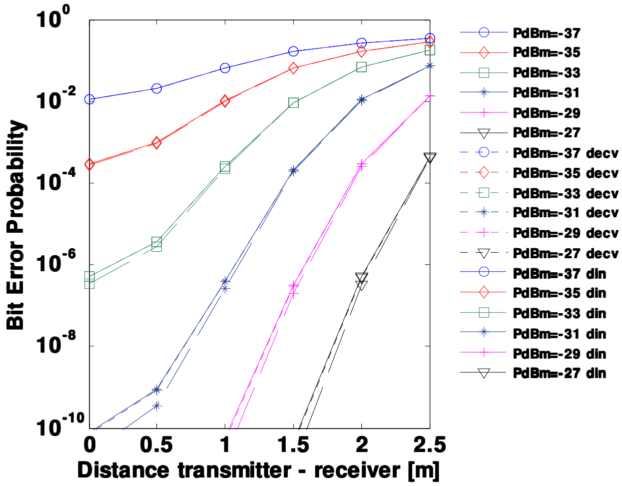

Fig. 11. BER for LOS configuration, $N = 127$, $\alpha = 1.15$

Fig. 12 - Fig. 17 shows BER for diffuse configuration. In all these figures, the parameters that were considered are: fixed number of active users $K = 25$, the code sequences length N = 127, a transmission bit rate of 100 Mb/s.

The BER as function of the power at the input of the receiver closest to the transmitter is depicted in Fig. 12, Fig. 14, and Fig. 16. BER depending on receiver position at a certain power at the input of the receiver closest to the transmitter (-37 dBm, -35 dBm, -33 dBm, -31 dBm, -29 dBm, -27 dBm) is plotted in Fig. 13, Fig. 15, and Fig. 17, respectively.

In Fig. 12 and Fig. 13 the performances for the classical and dynamic OCDMA cases are compared; in Fig. 14 and Fig. 15 classical OCDMA and OCDMA with deconvolution systems are compared; in Fig. 16 and Fig. 17 we compared all three OCDMA cases.

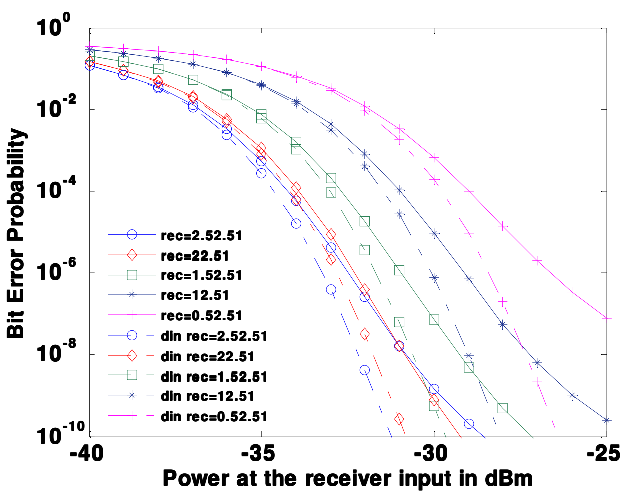

Fig. 12. BER for diffuse configuration, $N = 127$, $\alpha=1.15$

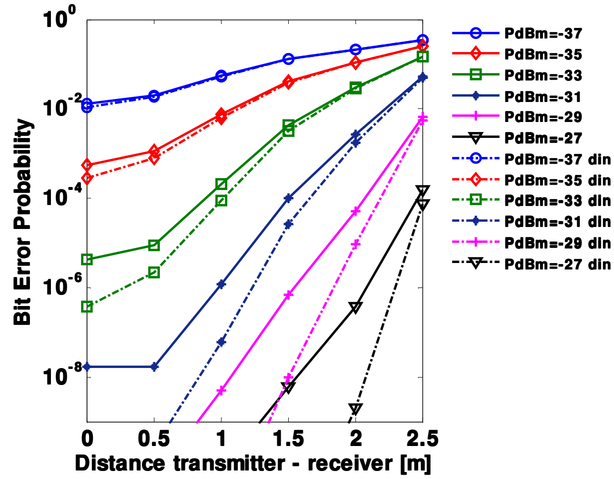

Fig. 13. BER for diffuse configuration, $N = 127$, $\alpha=1.15$

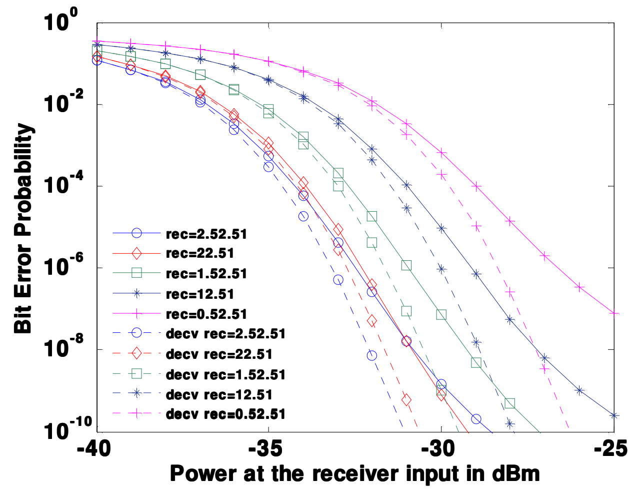

Fig. 14. BER for diffuse configuration, $N = 127$, $\alpha=1.15$

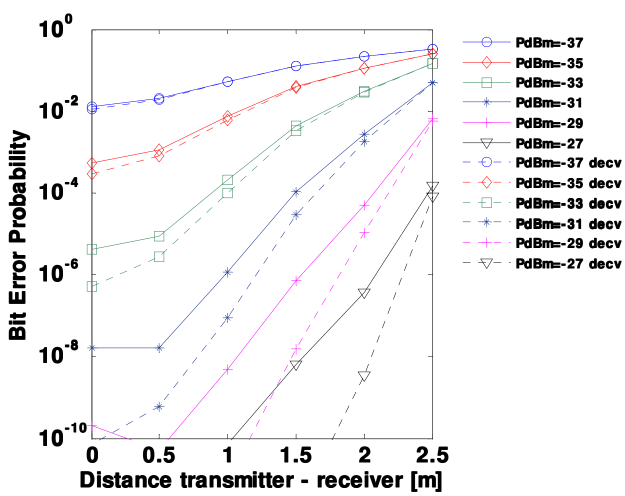

Fig. 15. BER for diffuse configuration, $N = 127$, $\alpha=1.15$

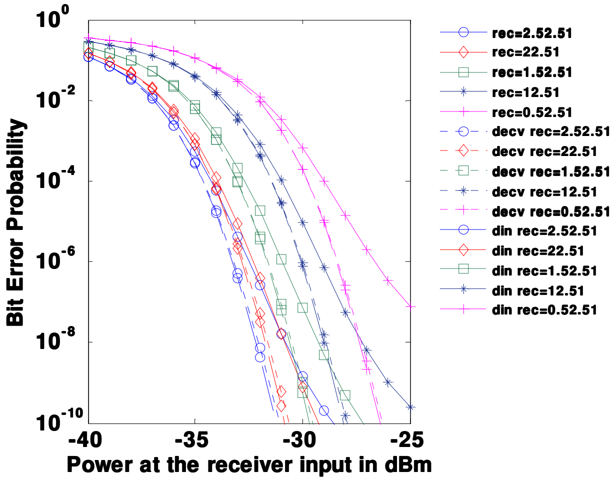

Fig. 16. BER for diffuse configuration, $N = 127$, α=1.15

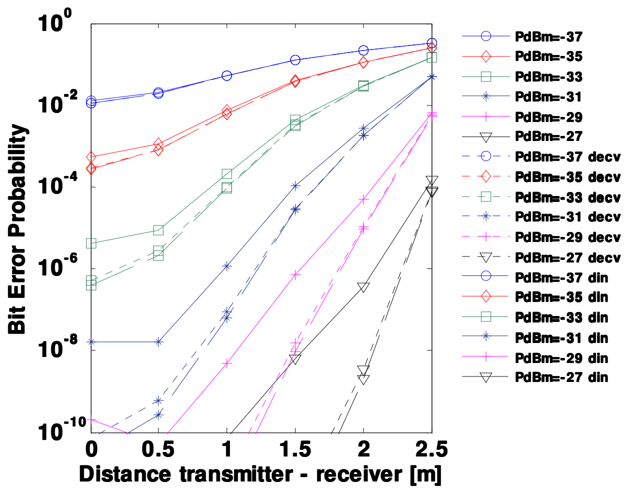

Fig. 17. BER for diffuse configuration, $N = 127$, α=1.15

As expected, we can see in Fig. 7, Fig. 9, Fig. 11, Fig. 13, Fig. 15 and Fig. 17 that the probability of error will be larger if the transmitter - receiver distance increases. We have the lowest probability of error for the transmitter - receiver distance 0, i.e. the receiver is located just below the transmitter in the middle of our room having dimensions 5m x 5m x 3m. When the receiver moves, reaching a distance of 2.5 meters from the transmitter located in the middle of the room will have a high error probability.

As we can see in Fig. 8 and Fig. 9, the BER performances improvement using deconvolution, in OCDMA indoor wireless system, is very low for LOS configuration. In the case of diffuse configuration, the BER performances are significantly improved using deconvolution but are still slightly lower than in dynamic OCDMA system (Fig. 16 and Fig. 17).

IV. Conclusions

As the receiver moves increasingly away from transmitter the amount of power received in that place will be getting smaller.

A movement of 0.5 meter has no an important influence, but as the distance increases influence on performance will be more significant. Using the data obtained (eg Fig. 6, Fig. 8, Fig. 10, Fig. 12, Fig. 14, and Fig. 16) we can see and calculate how much should amplified signal to have the same BER when moving from one position to another. Thus knowing the impulse response at different positions in the room, if we could increase the power received in that place with the necessary amount the error performance could be maintained at the same values.

By using dynamic OCDMA the multipath interference will be reduced, the BER performances are improved as compared to the classic case mainly for diffuse configuration (Fig. 12) and therefore less power is needed to achieve desired performance.

We showed that using deconvolution in OCDMA indoor wireless communication system, the multipath interference is reduced and the BER performances are significantly improved for diffuse configuration, as compared to the case without deconvolution (see Fig. 14).

For LOS configuration most of the optical power reach the receiver on direct path. The influence of the multipath dispersion in this case is less important and therefore the gain obtained, by using dynamic OCDMA and OCDMA with deconvolution systems, is lower.

It was assumed that ambient noise was filtered, and only multiple access interference and thermal noise affect the system performances.

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