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Simulation Program for FIR Filter Approximation of Indoor Wireless Optical Channel

Radu Lucaciu, Adrian Mihaescu[1]

Abstract – In this paper we present a performance analysis for an optical code division multiple access (OCDMA) indoor wireless communication system. We described a method based on experimental measurements to obtain the impulse response of an indoor wireless optical channel. The impulse responses used to calculate the system performance are obtained using a simulation program for FIR filters, program based on measured impulse response.

Keywords: indoor optical wireless communication; OCDMA; interference reduction; FIR

I. INTRODUCTION

The emergence of portable devices such as laptops, palmtops and personal digital assistants (PDAs) has increased the demand for mobile connectivity and led to the development of wireless local area networks (LANs). Compared with traditional networks, the wireless offer users increased mobility and flexibility. Optical communications based on infrared (IR) technology are used today in many applications, offering high speed wireless links. 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. However, multipath propagation causes a spread of the transmitted pulse, which leads to intersymbol interference.

In this paper, we consider a wireless optical code division multiple access (OCDMA) system based on spectral encoding using intensity modulation and direct detection (IM/DD). We evaluate the system performances starting with impulse response of the communications channel. Therefore, the light propagation in these indoor environments is a key issue for obtaining the maximum possible bit transmission rate.

Many researchers attempted to determine the impulse response for indoors wireless optical channels. Characterization of this infrared channel was performed using simulation in [1] and experimental measurements in [2]. We measured the impulse response with a model reproducing the actual room using a scale factor, as in [3].

In the next section, we present the OCDMA communication system and we describe the measurement system used to obtain the impulse response. In Section III, we present the results obtained for the simulated system performances. The classical OCDMA and dynamic OCDMA systems performances are compared. Section IV contains the conclusions drawn from the performance analysis carried out.

II. OCDMA COMMUNICATION SYSTEM

We consider a wireless communication system, which uses OCDMA transmission with spectral amplitude encoding. A possible scheme of the system is presented in Fig. 1 [4]. The transmitter utilizes OOK (On Off Keying) modulation. The transmission channel is modeled using an impulse response denoted by $h(t)$. For fixed transmitter and receiver locations, multipath dispersion is completely characterized by an impulse response $h(t)$.

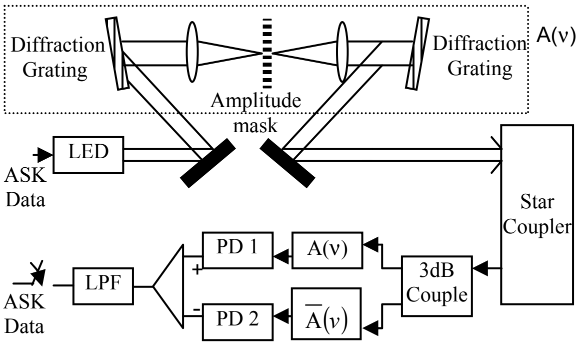

Fig. 1. Block diagram of an OCDMA system with spectral amplitude encoding

A. Measurement system

To measure the channel, spectral method is chosen. This method allows us to directly measure the

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[1] Facultatea de Electronică şi Telecomunicaţii, Departamentul Comunicaţii Bd. V. Pârvan Nr. 2, 300223 Timişoara, e-mail radu.lucaciu@etc.upt.ro, adrian.mihaescu@etc.upt.ro

frequency response of the channel $H(f)$. Therefore, the channel impulse response $h(t)$ is determined by calculating the inverse Fourier transform of frequency response.

Measurements are made starting from a small model of a real room. Scale factor between the actual room size and the model is $S_f = 10$. Using the model, we can estimate the frequency response for a furnished or unfurnished room for a certain position of the transmitter and receiver. Measurement system is illustrated in Fig. 2.

We use a network vector analyzer (HP 8753A). Optical signal source is a laser diode (A1905). The optical signal is modulated at a given radio frequency (RF). The RF output signal of the vector analyzer is swept from 300 kHz to 3 GHz and is applied to an electro-optical modulator. The number of frequencies emitted (measuring points) can be adjusted between 201 and 801.

Modulated signal is divided: 20% of signal strength will go to a PIN photodiode and then to the input A of the vector analyzer, and 80% will be used for transmitter after being amplified.

After the amplifier is positioned an LSD (Light Shaping Diffuser), to obtain a diffuse beam with an opening angle of 60^o (corresponding to a Lambertian source).

To detect the signal we used a photodetector and a lens to enlarge the area of detection. The photodetector is placed in the focal plane of the lens. The opening angle of system lens - photodetector is 40°.

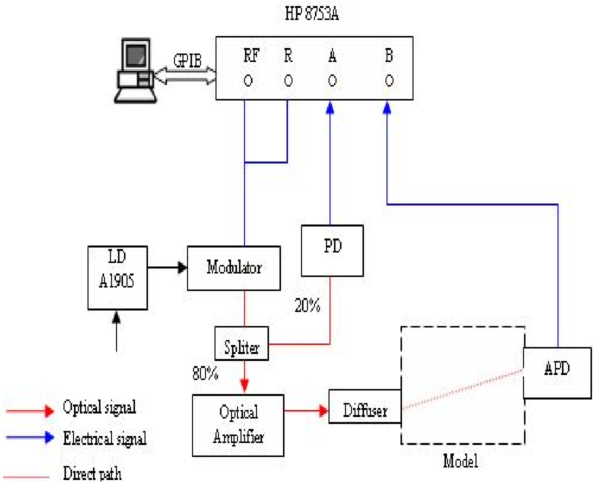


Fig. 2. Scheme for measuring system

Fig. 3 shows a variant of a transmitter-receiver orientation if the model is furnished and Fig. 4 shows the transmitter-receiver orientation if the model is not furnished.

The measured data are acquired and saved on computer to be processed. The vector analyzer is controlled by a HP – VEE (Hewlett Packard – Visual Engineering Environment) program using the available panel driver. Saved data, which represents the channel frequency response will be processed using a Matlab program to obtain the channel impulse response $h\ (t)$.

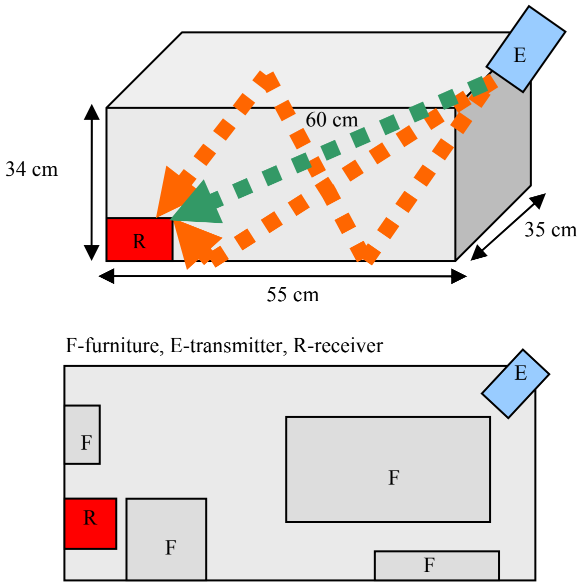


Fig. 3. Transmitter-receiver orientation in furnished room

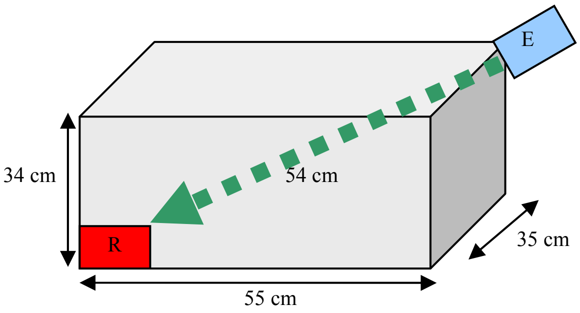
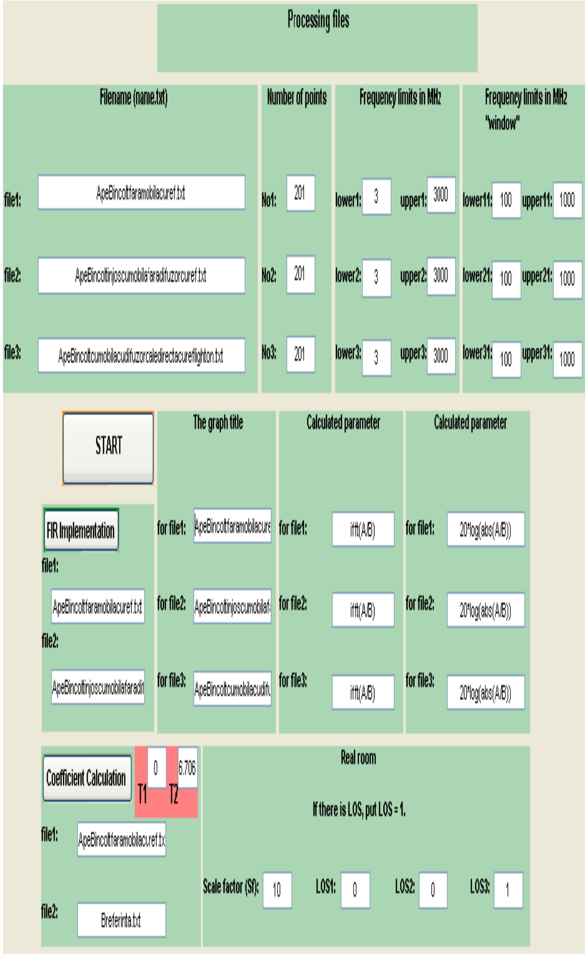


Fig. 4. Transmitter-receiver orientation in unfurnished room

The corresponding interface of the Matlab program, which we've done for this purpose is shown in Fig. 5. Using the interface we can do the following: enter the name of the file containing the saved data (can be processed simultaneously three different files); enter the number of points in which that measurement was made (eg 201), for each of the files processed; place limits frequencies used for the measurements; we can choose to process data in a specific "window" of frequencies; enter the graph title; we can obtain the impulse response for a normal sized room (real room) depending on the impulse response determined for the model; if there is line-of-sight (LOS), we set LOS = 1, for diffuse configuration LOS = 0; by pressing the button *Coefficient Calculation*, we can get power to the input A taking into account the power of B which is measured; by pressing the button *FIR Implementation*, is activated a part of the Matlab program to produce a impulse response corresponding to that measured.



file1: ApeBincoltfaramobilacuref.txt No1: 201 lower1: 3 upper1: 3000 lower11: 100 upper11: 1000

file2: ApeBincoltinjoscumobila'aradifuzorcuref.txt No2: 201 lower2: 3 upper2: 3000 lower21: 100 upper21: 1000

file3: ApeBincoltcumobilacudifuzorcaledirectacureflighton.txt No3: 201 lower3: 3 upper3: 3000 lower31: 100 upper31: 1000

file1: ApeBincoltfaramobilacuref.txt
file2: ApeBincoltinjoscumobilafaradi

for file1: ApeBincoltfaramobilacure
for file2: ApeBincoltinjoscumobilaf
for file3: ApeBincoltcumobilacudifu

for file1: ifft(A,B)
for file2: ifft(A,B)
for file3: ifft(A,B)

for file1: 20*log(abs(A/B))
for file2: 20*log(abs(A/B))
for file3: 20*log(abs(A/B))

T1: 0
T2: 6.706

file1: ApeBincoltfaramobilacuref.tx
file2: Breferinta.txt

Scale factor (Sf): 10 LOS1: 0 LOS2: 0 LOS3: 1

Fig. 5. Matlab program interface for data processing

Using FIR Implementation, we obtain the impulse responses from Fig.7 and Fig.9. Fig. 6 and Fig. 7 are for the case in which the room is furnished (see Fig. 3). Fig. 8 and Fig. 9 are obtained for unfurnished room (see Fig. 4).

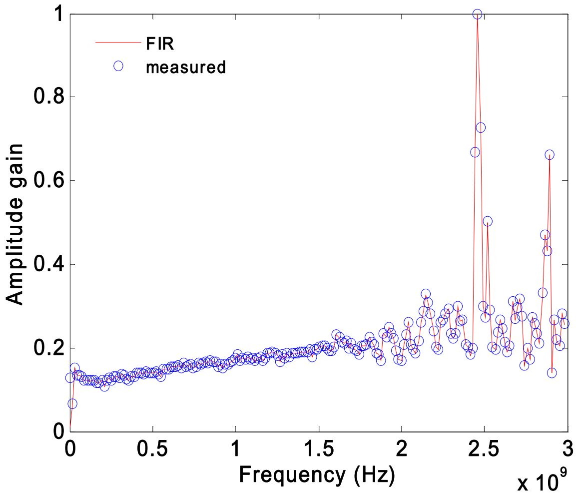


Fig. 6. Desired and adaptive amplitude gains, furnished room

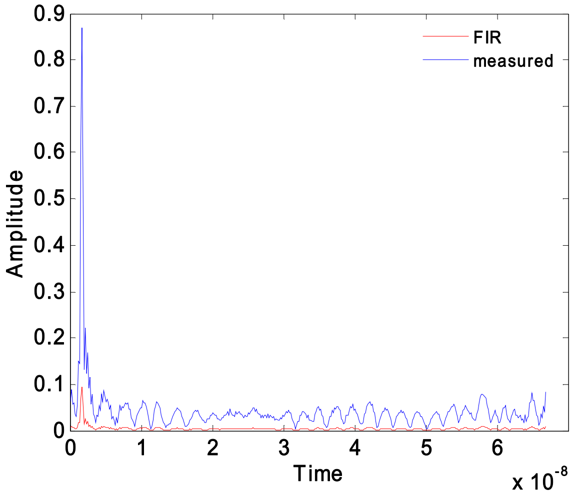


Fig. 7. Impulse response for furnished room

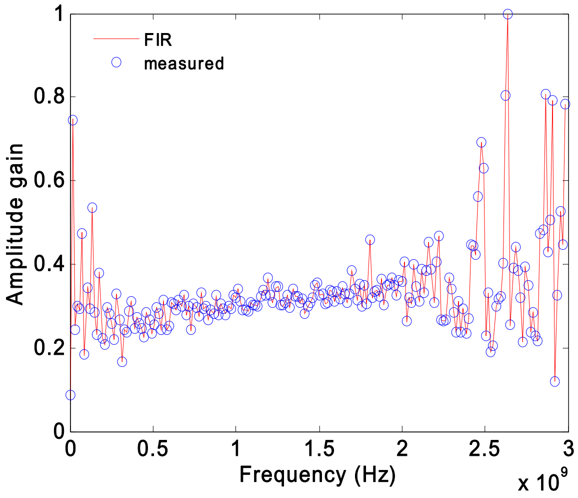


Fig. 8. Desired and adaptive amplitude gains, unfurnished room

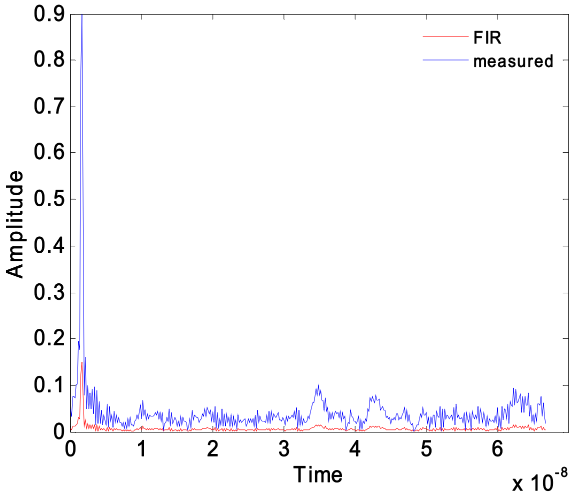


Fig. 9. Impulse response for unfurnished room

B. Considerations on the OCDMA system

If OOK modulation is used, optical pulses with time duration 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 [5]:

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

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

The receiver has the structure presented in Fig. 1. The signal is received over two branches with equal power and the masks in the two branches have complementary patterns. The photocurrent from the two branches of the receiver depends on the intensity of the incident light at the two photodetectors.

We consider both classical OCDMA and dynamic OCDMA. 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 [5] (to reduce the multipath interference) one user transmits the information bits using different code sequences. The first code sequence is used for the first bit, the second code sequence for the second bit, etc. Then, the encoding is continued starting again with the first code sequence.

The variance of the decision variable for classical OCDMA is [5]:

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

and for dynamic OCDMA is [5]:

$$\begin{aligned} \sigma_z^2 = {} & N_0 d_1^l a + \frac{N_0}{2}\sum_{n=1}^{L\text{-}1}\frac{S_n}{S_0}(b_{1n} + c_{1n}) + \\ & + \frac{N_0}{2}\sum_{n=0}^{L\text{-}1}\frac{S_n}{S_0}\sum_{k=2}^{K}(b_{kn} + c_{kn}) + \left(\frac{N_0}{2}\right)^2 \sum_{n=1}^{L\text{-}1}\left(\frac{S_n}{S_0}\right)^2 (b_{1n} - c_{1n})^2 + \\ & + \left(\frac{N_0}{2}\right)^2 \sum_{n=0}^{L\text{-}1}\left(\frac{S_n}{S_0}\right)^2 \sum_{k=2}^{K}(b_{kn} - c_{kn})^2 + \sigma_{th}^2 \end{aligned} \tag{5}$$

The thermal noise has the variance $\sigma_{th}^2 = \frac{2\cdot K_B \cdot T_0 \cdot T}{R_i \cdot q^2}$, 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 [5]:

$$P_e = \frac{1}{2}\operatorname{erfc}\left(\frac{N_0 a}{2\sqrt{2}\sigma_z}\right) \tag{6}$$

We use the impulse responses presented in Fig. 7 and Fig. 9 to calculate the OCDMA system performances. The results are presented in Section III.

III. SIMULATIONS RESULTS

The code sequences used in these simulations are m-sequences with length N.

In Fig. 10 the bit error rate (BER) for K active users with sequences of length $N = 511$ is depicted in the cases: classic and dynamic with 4 code sequences. For dynamic case, one code sequence for each bits from the first four bits. The transmission bit rate is 100 Mb/s. We used the impulse response obtained for furnished room.

BER shown in Fig. 11 is for unfurnished room. We have K active users. The code sequences length is $N = 511$, the bit rate that we use is 1 Gb/s.

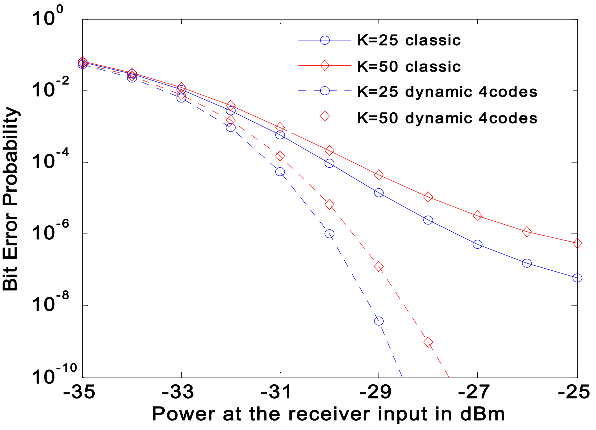


Fig. 10. BER for furnished room, $N = 511$, α=1.

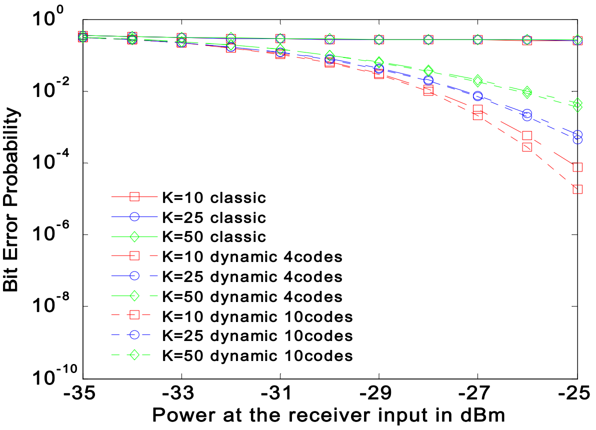


Fig. 11. BER for unfurnished room, $N = 511$, α=1.

In Fig. 11 are shown comparatively the BER for the cases: classic, dynamic with 4 code sequences and dynamic with 10 code sequences. For dynamic cases we used: one code sequence for each bits from the first four bits, respectively one code sequence for each bits from the first ten bits. Then, the encoding is continued in the same manner.

IV. CONCLUSIONS

As expected, BER is worse when the number of simultaneous users increases. By using dynamic OCDMA the multipath interference will be reduced, the BER performances are improved as compared to the classic case. For a transmission bit rate of 100 Mb/s, $R(t)$ has a time extent due to multipath propagation of about 4 bits. If the transmission bit rate is 1 Gb/s, $R(t)$ has a greater time extent. In this case by increasing the number of used code sequences, BER will be improved. It was assumed that ambient noise was filtered, and only multiple access interference, shot noise and thermal noise affect the system performances.

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