BER Analysis of Optical Wireless Communication System Employing Neuro-Fuzzy based Spot-Diffusing Techniques

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Abstract—In this paper, Bit-error-rate (BER) performance of Optical Wireless Communication (OWC) System employing Neuro-Fuzzy (NF) based spot diffusion system has been evaluated. The spot-diffusing technique provides performance improvement in compared to conventional diffuse system for indoor OWC system. In order to generate multibeam spot matrix adaptive multibeam transmitter configuration is used and it generates multiple spots pointed towards the different direction in the ceiling. The reflected multibeam spots are received by image receiver employing Maximum ratio combining (MRC). NF controller adaptively control the elevation and azimuth angle of each beam depending on the transmitter receiver position and generate the best spot beam matrix for the receiver’s current position and allocates optimal power to the spots. This adaptive beam position will improve the signal-to-noise plus interference ratio (SNIR) of the received signals and thereby improves BER performance. The proposed OW spot-diffusing communication system is compared with existing spot-beam diffusion method. Numerical results shows that the proposed NF based spot-diffusion system provides better performance compared to other spot-beam diffusion method.

Index Terms—Optical-wireless communication, spot diffusion technique, neuro-fuzzy, imaging receiver, BER.

I. INTRODUCTION

Optical Wireless communication (OWC) have promoted in recent years as an alternative to the conventional radio frequency (RF) approach making the connectivity possible in the indoor environment it can be used to provide flexible interconnection through wireless and distributed data communication systems. Accessing networks for coming days is whistling the needs for the convergence of wired and wireless services to offer end users in an efficient way [1]. There are a number of applications where the data throughput is concern, transmission link based on optical wireless would be one of the best options as outlined in [2], [3], [4], [5]. The performance of OW systems depends on the propagation and type of system used. The basic system types fall into diffuse or line of sight (LOS) systems[6], [7]. In LOS systems, high data rates in the order of Gbit/s can be achieved [8], [11], but the system is vulnerable to blockage/shadowing because of its directionality. In a diffuse OW system, several paths from source to receiver exist, which makes the system robust to blockage/shadowing. However, the path losses are high and multi-paths create inter-symbol interference (ISI) which limits the achievable data rate [8], [11]. There are several advantages of OWC over traditional RF systems, these are: an abundant free spectrum, extremely high communication speed is possible by all network, does not interfere with the over congested RF spectrum. But limitations are: a beam is short ranged, may be harmful for eye. The first limitation can be overcome by wavelength reuse technique, whereas eye safety can be ensured by limiting maximum transmit power. In [9], authors have shown that OFDM-QPSK modulation techniques can improve the bit error rate (BER) in free space communication under stochastic channel fading at low receiver powers. The BER performance for indoor optical communication have been discussed and minimize the overall power penalties [10]. Many researchers have considered diffuse systems for indoor applications. It offered robust link and thereby overcome the problem of shadowing [12], The diffuse system does not require transmitter-receiver alignment and uses the wall or ceiling for multi path reflection [11]. The multipath reflections increased delay spread or inter-symbol interference. Ambient light such as florescent, incandescent light and Compact Florescent Lamp (CFLs) produces channel noise which reduces signal-to-noise plus interference ratio (SNIR). In order to improve the system performance several spot diffusion configuration using multi beam transmitter have been proposed [10]. Multi beam transmitter is place in center of the room and pointed upward. A multi-spot pattern have been generated by the transmitter, illuminated multiple small areas in the ceiling. The reflected multiple spot beams have been received by receivers [12]. Line streaming multi-beam spot diffusion (LSMS) model has been discussed in [12], [13], [14], [15] and authors have shown that a gain about of 32.3 dB SNR at worst communication path can be achieved. But the multi path dispersion reduces the performances due to transmitter power and can be improve using power adaptive system by [12], [13], [14], [15]. User mobility is very important aspect of wireless communication especially with today’s hand hold devices. As the user device can move with the room, thus power adaptation will be a great solution to get higher SNR. A genetic algorithm for multi spot diffuse system have been proposed for indoor wireless communication[15]. But it is noted from different research that if the diffuse system has a predefined spot for a room and use an adaptive power allocation for beam using calculation of delay spread then it can improve the performance of the OWC. Neural network and Adaptive Linear Equalizers can be a solution in this case for adaptive power distribution. In [16] authors presented a comparative study of two equalizers, the adaptive linear and the neural equalizer for indoor optical wireless (OW) links using OOK modulation technique to reduce ISI effect.

This paper introduces Bit-error-rate (BER) performance of
Multi-beam Optical Wireless Communication (OWC) System employing Neuro-Fuzzy (NF) based spot diffusion system considering Doppler shift.

The paper is organized as follows: the system model is presented in section II; power allocation algorithm is explained in section III; Section IV presents discussion and results. The concluding remarks and future work is included in section V.

II. PROPOSED SYSTEM MODEL

Consider an empty room with floor dimensions of $8 \times 4$ $m^2$ and ceiling height of $3m$ as shown in Figure 1. The reflection coefficient of the ceiling is considered to be 0.8. Their are eight spot lights on the ceiling. In the Figure, $\delta$ is the elevation angle, $\alpha$ is the azimuth angle, $d = 8$, $w = 4$ and $h = 3$, $x_0$ and $x$ are the position of the imaging receiver and $v$ is the velocity. Neuro-Fuzzy (NF) adaptive multibeam transmitter is located at the center of the room whereas a imaging receiver is placed at $x_0 = (1,1,0.5)$. The transmitter generates multi spot beam matrix on the ceiling where beam power and beam angle $(\alpha, \delta)$ are adapted and the reflected beams are received by the imaging receiver. The transmitter learns receiver position, mobility through the low rate diffuse channel. At low data rate, the beam maintains the fixed power.

![Figure 1. System Model for OWC based on spot-diffusing technique. Here $\delta$ is the elevation angle, $\alpha$ is the azimuth angle, $d = 8$, $w = 4$ and $h = 3$.](image)

A. Signal to Noise Plus Interference Ratio

In indoor optical-wireless communication, the ambient light affects signal-to-noise-plus interference (SNIR) at the receiver. Many researchers have considered intensity modulation with direct detection (IM/DD) as most viable approximation. The received signal, denoted by $y(t)$, can be expressed as

$$y(t) = \sum Rx(t) * h(t, \alpha, \delta) + \sum n(t, \alpha, \delta) + I(t, \alpha, \delta) \tag{1}$$

where $R$ is the receiver responsivity, $x(t)$ is the instantaneous optical transmitted power, $h(t, \alpha, \delta)$ is the impulse response of the OW channel, $n(t, \alpha, \delta)$ is the ambient light noise, $I(t, \alpha, \delta)$ is the instantaneous interference power.

The SNIR, denoted by $\gamma$, of the received signal can be calculated by [9]

$$\gamma = \frac{R^2(P_{s1} - P_{s0})h^2}{(\sigma_{s1} - \sigma_{s0})^2} \tag{2}$$

where $P_{s1}$ and $P_{s0}$ are the optical power associated with the binary 1 and binary 0 respectively, $\sigma_{s1}$ are $\sigma_{s0}$ are the shot noise variation component with $P_{s1}$ and $P_{s0}$ respectively.

B. Bit Error Rate

For the uncoded system with binary phase-shift-keying (BPSK), the BER expression can be given by

$$\psi_{b_{psk}}(\gamma) = \frac{1}{\pi} \int_{0}^{\pi/2} \exp \left( - \frac{b_{psk} \gamma}{\sin^2 \phi} \right) d\phi \tag{3}$$

where $b_{psk} = \sin^2(\pi/2)$. Using Equations (2) and (3), we can write

$$\psi_{b_{psk}}(\gamma) = \frac{1}{\pi} \int_{0}^{\pi/2} \exp \left( - \frac{\sin^2(\pi/2)(R^2(P_{s1} - P_{s0})h^2)}{\sin^2 \phi(\sigma_{s1} - \sigma_{s0})^2} \right) d\phi \tag{4}$$

C. Adaptive Power Allocation

The achievable data transmission rate, denoted by $b$, of the OWC system is given by

$$b = \frac{1}{M} \sum_{i=1}^{M} \log_2 \left( 1 + \frac{R^2 \times (P_{s1} - P_{s0})h^2}{(\sigma_{s1} - \sigma_{s0})^2} \right) \tag{5}$$

The optimization problem and constraint of the power allocation can be written as

$$\max \quad b \tag{6}$$

$$s.t. \quad \sum_{j=1}^{\bar{J}} P_j \leq \bar{P} \tag{7}$$

where $\bar{P}$ is the average power. We can use the Lagrange multiplier method to analyze the above optimization problem and the Lagrangian function is defined as

$$L = b + \mu_j \sum_{j=1}^{\bar{J}} (P_j - \bar{P}) \tag{8}$$

where $\mu_j$ is the Lagrange multiplier. After solving the Eqn. (8), we can write

$$P_j = \left[ \frac{P + \sum_{j=1}^{\bar{J}} \frac{1}{h_i}}{C} - \frac{1}{h_i} \right] \tag{9}$$

$$= \max \left[ \lambda(C) - \frac{1}{h_i}, 0 \right] \tag{10}$$

D. Delay Spread

The Doppler spread of an impulse is expressed as rms value by,

$$D = \sqrt{\frac{\sum (t_i - \mu)^2 P_r^2}{P_r^2}} \tag{11}$$

where $\mu = \frac{t_r P_r^2}{P_r}$ and $t_i$ is the delay time and $P_r$ is the received power.


E. Doppler Shift

Light waves require no medium and being able to travel even through vacuum. Let $\vec{v}$ is the relative velocity between transmitter and receiver, the proper frequency of the transmitted information signal from the optical transmitter is $f_0$. Let $f$ is the frequency of the received signal accepted by the moving receiver with a velocity $\vec{v}$, then

$$f = f_0 \times \sqrt{1 + \frac{\beta}{1 - \beta}}$$  \hspace{1cm} (12)

where $\beta = \vec{v}/c$, $c$ is the speed of light. For low speed, i.e., $\beta << 1$, and in this case the above eqn. (12) is reduced to

$$f = f_0(1 - \frac{\beta}{2})$$

$$f = f_0(1 - \beta + \frac{1}{2} \beta^2)$$  \hspace{1cm} (13)

F. ANFIS Model

Neuro-fuzzy inference system is consider if learning capabilities are required. In this paper, we consider the adaptive neuro-fuzzy inference system (ANFIS) for the implementation of the spot beam matrix selection as shown in Fig. 2. Based on the signal to noise ratio, i.e., $\gamma$, and link delay, i.e., $\Delta \tau$, ANFIS decides a spot is eligible for selection or not. The ANFIS is trained iteratively to achieve the desired output for the input parameters and their membership functions. This can be done by back propagation gradient descendnet which evaluates the parameters and their membership functions. This can be done by back propagation gradient descendnet which evaluates the error signals recursively from the output layer backward to the input nodes. In this way, ANFIS learns the behavior of the system. Mamdani ANFIS model contains if and then rules, e.g., If $x$ is $A_i$ and $y$ is $B_i$ then $z$ is $C_i$. Fig. 2 shows ANFIS model for spot beam matrix selection. It consists of five layer: input layer, output layer and three hidden layers. Each adaptive node in the input layer generates membership grades. The input layer converts crisp set into fuzzy set. If bell shape membership functions are considered, output of this node, denoted by $O_i^1$, can be written as

$$O_i^1 = \mu_i(x_i) = \frac{1}{1 + \left|x_i - \alpha_iight|^{2b_i}}$$

where $\alpha_i \in \{A_i, B_i\}$ is the input vector.

Nodes in the first hidden layer calculates the firing strength of a rule via multiplication. The output of the each node, denoted by $O_i^2$, can be written as

$$O_i^2 = w_i = \prod_{i=1}^{2} O_i^1$$

Nodes in the second hidden layer computes the normalized value of the firing strength. The output of the each node, denoted by $O_i^3$, can be written as

$$O_i^3 = \frac{O_i^2}{\sum_{i=1}^{5} O_i^2}$$

Nodes in the third hidden layer computes the contribution of $i$-th rule towards the overall output. The output of the each node, denoted by $O_i^4$, can be written as

$$O_i^4 = \sum_{i=1}^{3} O_i^3$$

A signal node in the output layer computes the overall output, denoted by $O_i^5$, as follows:

$$O_i^5 = f(O_i^4)$$

The center of area (COA) defuzzification method is considered at the output layer. The linguistic terms for input and output membership functions are \{Low, Medium, High\}

III. Adaptive Spot-Beam Selection Algorithm

Fig. 3 shows the block diagram of the adaptive spot-beam selection algorithm. In the first step the beam hologram or matrix generates $40 \times 20$ equal powered spot-beams in the ceiling. The BER and Doppler spread for each beam have been calculated by the image receiver. The receiver periodically evaluates the BER after 1 second interval whereas the Doppler spread for each beam is same if the receiver is not moving. In the second step, the receiver sends the spot-beam information which contains BER and Doppler spread to the transmitter. Based on the minimum SNIR and maximum BER and maximum delay spread, transmitter select the spot-beam matrix by NF based algorithm in the third step. The transmitter allocates the power for each selected beam adaptively using eqn. (8) in the forth step. Finally based on the velocity of movement of the receiver, transmitter moves spot-beam matrix for the receiver.

Fig. 3. Spot beam selection algorithm in the presence of Doppler shift due to receiver movement
The algorithm is summarized as follows:

Step 1: A spot beam scans the ceiling, SNIR, γ and delay spread, Δτ for each beam have been calculated by the image receiver using Eqs (2) and (9).

Step 2: Based on the required minimum SNIR, i.e., γ_{min}, and maximum delay spread, i.e., Δτ_{max}, transmitter selects the spot-beam matrix (H) by NF controller.

Step 3: The transmitter allocates the power for each selected beam adaptively using Eqn (7).

Step 4: Based on Doppler shift, the transmitter adapts the beam angles α and δ.

Step 5: Multi-spot optical transmitter further reduce the Δτ by scheduling.

Step 6: Finally, Multi-spot optical transmitter transmits the spot-beam matrix to receiver via ceiling.

Step 7: Go to Step 1 if transmitter gets receiver’s position update.

IV. NUMERICAL ANALYSIS

In this section, Neuro-Fuzzy based multibeam system (NFMS) is investigated with diversity receiver configuration. It is compared with other spot-beam diffusion method. The ANFIS model, adaptive power allocation and multi-spot diffuse pattern formation are implemented in MATLAB/SIMULINK. ANFIS consider two input such as SNR and delay.

Simulation parameters considered for the analysis are: length, width and height of the room are 8m, 4m and 3 m; the reflection coefficient of the ceiling is ρ = 0.8; there is one transmitter which is located at (2, 4, 1) location; there is also one receiver; the area, acceptance semi-angle of the each photo-diode are 2cm^2 and 65° respectively. The number of pixel at the receiver is 200 (with area of 0.01cm^2) Pedestrians move typically at the speed of 1 m/s. If the SNIR is computed after 10 µs; there are 8 lamp in the room which are located at (1, 1, 1), (1, 3, 1), (1, 5, 1), (1, 7, 1), (3, 1, 1), (3, 3, 1), (3, 5, 1), and (3, 7, 1); and the wavelength of the light is 850nm.

The 80 ms adaptation time will give overhead of 8%. Adaptation time depends on environment. Receiver computes the SNIR and delay spread and sends these information via a low rate channel to the transmitter.

ANFIS consider two inputs. Iterative training of the ANFIS has been done to achieve the desired output. After a predefined simulation time to obtain the simulation result and use them to train. Based on the training data set, ANFIS

REFERENCES


