An Indoor Beamforming Scheme using Optical Signals

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***Abstract*—In this paper, we present a beamforming approach for indoor optical communications. The proposed approach is able to estimate the user's location on a real time basis and maximizes the signal-to-noise ratio (SNR) at the user location. It is demonstrated through simulations that the proposed scheme is capable of providing a high received SNR at the desired user location. The proposed approach requires no pre-processing and less complex.**

***Index Terms*—Beamforming, localization, line-of-Sight communication, ultraviolet communication,**

I. Introduction

An optical wireless communication (OWC) system relies on optical radiation to convey a message in free space. The optical spectrum ranges from infrared (IR) to ultraviolet (UV) including visible light wavelengths. Contrary to radio frequency (RF) communication, the optical communication offers unregulated spectrum and thus provides unlimited bandwidth. In addition, it is a low-cost system with less power consumption than RF systems [1].

Beamforming in wireless communications provides extended communication range, especially with the advent of wave technologies [2, 3]. Beamforming improves spectral efficiency by providing better signal-to-noise ratio (SNR), keeping the total output power constant. One of the advantages of beamforming is that it prevents interference by changing the element weight vector; thus, the transmit pattern has nulls in the direction of interference. This type of process is known as adaptive nulling or batching processing [4, 5]. Beamforming can be dynamic in the sense of continuous tracking of user mobility. This technique enhances spectral efficiency and link quality. Therefore, the transmit power can be optimized with respect to user movement.

Most of localization techniques are based on time of arrival (ToA), time difference of arrival (TDoA), received signal strength (RSS), and angle of arrival (AoA) [6, 7]. ToA, TDoA, and AoA techniques estimate distance using triangulation. Because of the complexity in indoor environments, the above-mentioned techniques may not be suitable for indoor scenarios [8]. In this paper, we propose a beamforming approach using localization. The anchor LEDs are utilized to interactively track the user mobility. The proposed system is validated through simulations.

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II. Proposed Beamforming Approach

A. System Model and Link Analysis

We consider an indoor environment with dimensions 5m $\times$ 5m $\times$ 3m, where four anchors are equipped at the corners of the ceiling as for localization purposes of mobile users and another four LEDs are used as transmitters at the center of the ceiling utilized for beamforming. We consider an environment where both the line-of-sight (LOS) and the diffuse component exist. The impulse response can then be formulated as [9]

$$h_{i,j}(t) = h_{i,j}^{L}(t) + h_{i,j}^{D}(t), \tag{1}$$

where $h_{i,j}^{L}(t)$ denotes the LOS component and $h_{i,j}^{D}(t)$ is the diffuse component.

We consider one PD for each receiver; thereby, the channel matrix for the i^{th} receiver is given by:

$$\mathbf{H}_i = \left[\begin{array}{cccc} h_{i,1} & h_{i,2} & \ldots & h_{i,N_t} \end{array} \right] \tag{2}$$

At the receiver, a PIN photodiode offers a low cost solution with high tolerance to temperature fluctuations and requires low power to operate in comparison to avalanche photodiodes that offer a high gain [10].

The received signal matrix at the i^{th} receiver is given by

$$\mathbf{y}_i = S_i \mathbf{H}_i \mathbf{w}_t x + \mathbf{n} \tag{3}$$

where $\mathbf{n}$ is the AWGN noise vector with independent and identically distributed Gaussian random variables. The given data symbol is denoted by x. $\mathbf{w}_t$ is the transmit beamforming weight vector.

B. Beamforming

For the given $\mathbf{w_t}$, the optimized receive beamforming weight vector, $\mathbf{w_r}$, is obtained as

$$\mathbf{w_r}^* = \frac{\mathbf{H_i w_t}}{\|\mathbf{H_i w_t}\|} \tag{4}$$

The averaged received SNR is then given by

$$\chi = \frac{2\left(S_i \|\mathbf{H_i}\| \mathbf{w_t}\right)^2 \mathrm{E}\left[x^2\right]}{N_0} \tag{5}$$

where E[$\cdot$] denotes the expectation operation. N_0 is the power spectral density of AWGN noise. The optimization problem is to choose $\mathbf{w_t}$ to maximize the received SNR such that

$$\begin{aligned} & \text{maximize} \left\|H_i w_t\right\|^2, \text{subject to} \\ & \frac{E\left[x\right]}{\sqrt{T_s}} \sum_{k=1}^{N_t} w_{t,k} = P_T, \\ & \mathbf{w_t} \geq 0. \end{aligned} \tag{6}$$

III. Results and discussions

An optical light is considered for the communication link. The effective aperture area of the i^{th} receiver, A_i, is set to 1 cm^2. P_T is set to 20 mW. Ray-angle FOV with ψ_{FOV} is set to 85°. We consider a PIN photodiode with S set to 0.6 A/w. An intensity modulation direct detection (IM/DD) on-off keying (OOk) modulation scheme is considered.

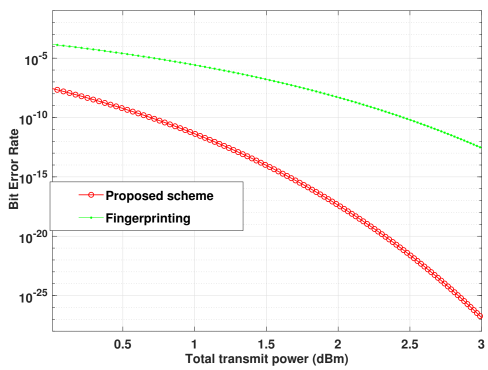

Fig. 1: BER performance comparison.

Fig. 4 illustrates the BER performance comparison in terms of the total transmit power for the same indoor conditions considering one user only. For finger-printing based positioning [11], 10^3 test points are randomly selected from the available coordinates with a step size of 5, to test the localization accuracy. The upper-bound ratio of the variation in amplitude of each transmitted wave is set to 0.05. Moreover, the proposed scheme outperforms the fingerprinting-based indoor localization system.

From Fig. 2, it can be seen that the estimated locations are in good agreement. The mean error estimation is found to be in the range of 6 cm to 9 cm. The transmit beam pattern is directed to the estimated user location.

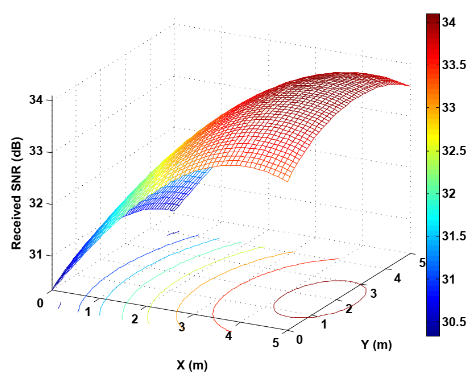

Fig. 2: Beamforming relative to the user's location.

IV. Conclusion

In this paper, a beamforming technique for the indoor NLOS optical communication channel has been proposed. The proposed scheme makes use of the anchor terminals to estimate the user's location. The estimated user location is then used for beamforming. Simulation results have been presented to validate the efficiency of the proposed scheme.

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