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Circumventing LoS Blocking in Beam-Steered Optical-Wireless Systems with Real-time Tracking and Handover

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Abstract: This paper demonstrates a real-time user tracking and handover mechanism for indoor ultrahigh-speed beam-steered optical-wireless systems implementing a low-cost camera. This allows us to tackle LoS blocking by switching to a secondary beam-steering device automatically.

OCIS codes: (060.2605) Free-space optical communication; (050.0050) Diffraction and gratings; (100.2000) Digital image processing; (100.4999) Pattern recognition, target tracking

1. Introduction

Optical-wireless communication (OWC) has been proven to be a very promising alternative to radio access techniques such as WiFi and millimeter wave to combat the looming capacity crunch and interference problems in the radio frequency regions due to the ever growing demand for higher speed wireless services. The visible and infrared regions have been under intense investigation [1,2]. Visible light communication (VLC) uses light emitting diodes (LEDs), which are optimized for illumination, to piggy-back data transmission. Therefore, due to limited modulation bandwidth of LEDs and their large beam footprint, 10Gb/s and higher transmission speeds per user are beyond the capability of VLC. By using steerable narrow infrared beams, each user can get an unshared wireless channel with larger link power budget, enhanced privacy, and better energy efficiency [3]. In particular, IR wavelengths beyond 1400nm, which allow beam powers up to 10mW according to eye safety standards [4], also enable us to deploy the mature and widely available high-speed components in conventional optical fiber communication systems.

However, most of the research on narrow beam based OWC so far focused on establishing the point-to-point communication link, without giving much emphasis on user mobility. In order to appropriately direct the narrow IR beams to moving users accurate localization, real-time tracking, and proper hand-over to a secondary steering device are essential. Various user localization techniques have been reported for optical-wireless communication [5,6]. However, none of these techniques tackled the issues of precise real-time user tracking and hand-over needed in steered IOWC, where line-of-sight (LoS) blocking is a major issue. In this paper, we demonstrate a narrow beam based IOWC system with real-time user tracking and proper hand-over in order to support continuously moving users. These functionalities are enabled by image processing where the user plane is captured by low-cost cameras installed together with the beam steering devices. It is demonstrated here that connection to a secondary beam steering device can be established within 40ms when there is LoS blocking from the beam steerer currently serving the user. Moreover, by anticipating where the user could be at any time, change of the steering direction, or proper hand-over to another steering device can be performed without significant delay (signal drop) in the wireless signal.

2. Indoor infrared OWC demonstration

Our indoor beam-steered demonstrator system is depicted in Fig. 1. Pencil-beam radiating antennas (PRAs) which each can steer multiple optical pencil beams into directions determined by the wavelengths of the signals are installed at the ceiling of each room. These PRAs are fully passive, and are constructed by means of arrayed waveguide grating routers (AWGRs) with high number of output ports. The output ports are then arranged in a 2D fibre array and put in front of a camera lens. The defocussing technique described in [7] allows us to provide improved coverage at any free-space distance. With this design, femto-cells of diameter ~10cm have been formed at a free-space distance of ~2m, each addressed by a specific wavelength. A central communication controller at the residential gateway takes care of the dynamic routing of signals to where they are needed using tunable transmitters. In order to determine the accurate position of the users for the beam steering, localization of the user devices using a passive retroreflector (a retroreflector reflects light rays to where they came from) was demonstrated in our previous work [8]. The localization process starts with scanning the coverage area by sweeping the wavelength of an IR beam by means of a tunable laser diode. When the localization processor at the central site detects a reflected signal (from the user equipped with a retroreflector), it stops and stores the current wavelength of the tunable laser. This way the device is located precisely and without requiring any active component at the user terminal. Though this novel technique is simple and energy efficient, it is not possible to track the user device in real-time given the presently used laser tuning control.

In order to support user mobility, real-time user tracking is essential, whether to anticipate the movement and

Fig. 3. (a) Captured image where the coverage area appears black, except when there is a user with infrared LEDs (inset: the user image after thresholding); (b) Different eye diagrams captured by a 150MHz receiver; (c) Real-time user tracking at a speed lower than the camera frame rate.; (d), Delay of handover to a secondary PRA during LoS blocking.

for the localization and tracking. Fig. 3a shows the captured image by the camera at the start of the communication. The individual LEDs are clearly visible on the image which can then be processed to determine the location of the user. The communication is started with the appropriate wavelength obtained from a table that contains the a priori stored calibrated cell vs wavelength information. Note that the camera captures an image of the user plane at a rate of 100fps, and the image is processed within this 10ms. Hence, when the user starts moving, the camera can track its movement in real-time (the central controller knows its location at all times; its position is updated every 10ms). When the user enters into another cell the wavelength has to be changed to the one corresponding to the new cell. Since all this information is automated using LABVIEW, the total time needed to establish this new connection (or the signal delay/drop) is mainly limited by the laser tuning process using Arduino, and it is $\leq 10\text{ms}$ as shown in Fig. 3b (note that the user is moving continuously). If the user is in the overlap region as shown in Fig. 2a, we can also circumvent LoS blocking. When the camera captures the image of the user plane the user's location is determined with respect to the two PRAs. Hence, when the communication link is blocked, the controller immediately switches to the second PRA (a.k.a. handover) to return the connection with a new wavelength. In this case the total time taken to re-establish the communication link is also affected by the switching time (each PRA is connected to an output port of the MEMS switch), in addition to the laser tuning process. This time is $\sim 40\text{ms}$ as shown in Fig. 3d. Note that the received power may fluctuate a little at different locations, and when using different PRAs due to the limited FoV of the receiver.

4. Conclusion

We demonstrated a real-time user tracking and handover mechanism for high-speed indoor beam-steered optical wireless system using accurate user localization and tracking by deploying a low-cost camera (near IR range). Although we used a lower speed optical-wireless receiver (which is capable of receiving $\sim 400\text{Mb/s}$ OOK signal) because of its wide FoV, the mechanism is applicable to Gb/s transmission speeds using a receiver with larger bandwidth and wide FoV, which we are working on currently.

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