Fully passive user localisation for beam-steered high-capacity optical wireless communication system

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FULLY PASSIVE USER LOCALISATION FOR BEAM-STEERED HIGH-CAPACITY OPTICAL WIRELESS COMMUNICATION SYSTEM

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Abstract

Accurate device localisation within the 10cm pico-cell resolution of a 2D beam-steered optical wireless communication system is achieved by applying a large matrix of miniature corner-cube retro-reflectors. No power-consuming elements are needed at the receiver. Real-time transfer of multiple 10GbE video streams has been demonstrated.

1 Introduction

Optical wireless communication (OWC) provides a great alternative for circumventing the congestion which is arising in the radio spectrum (in particular the 2.5 and 5GHz wifi bands) due to the exploding demand for wireless services. By using narrow infrared (IR) beams, each user can get a personal wireless channel with very high capacity [1]. In contrast to visible light communication (VLC) which makes use of existing illumination facilities to piggy-back data transmission and therefore has a large footprint, the small footprint of each IR beam yields a much larger link power budget and therefore significantly more data bandwidth. Additional power budget is created by using IR wavelengths beyond 1.4µm (notably using well-established 1.5µm fibre communication devices) which allows beam powers up to 10mW according to eye safety standards [2]. The small footprint of the steerable IR beams guarantees enhanced privacy, and better energy efficiency by delivering capacity on-demand when and where needed.
However, for appropriately directing the narrow IR beams the location of the user device needs to be known accurately. Various device localisation techniques employing RF signals emitted or processed by the user have been reported, using triangular algorithms such as RSS (received signal strength), AoA (angle of arrival), TDoA (time difference of arrival) [3]. Also device localisation techniques employing VLC signals have been reported, using multiple luminaires and signal processing at the user device [4]. Localisation by means of a camera which determines the position of user devices by observing active LED tags on them has been reported in [5]. High localisation accuracies within a few mm have been achieved; however, the need for active functions in the user device draws extra power from the mobile device and thus compromises its battery lifetime. In this paper, we propose a novel device localisation concept which only requires a simple fully passive function at the user device, thus not draining the device's battery, while building on our high-capacity IR beam-steered OWC system.

2 IR beam-steered OWC system

Our indoor beam-steered OWC system concept is shown in Fig. 1.

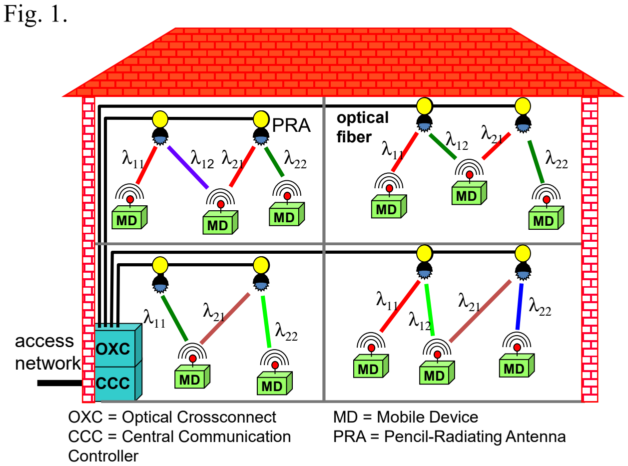

Fig. 1 Beam-steered indoor OWC system

The (FttH) access network is terminated at the entry of the house in a central communication unit, and from there the services are routed to the individual rooms by a fibre network. At the ceiling of each room, pencil beam radiating antennas (PRAs) launch the narrow IR beams to the respective mobile devices. The PRA is fully passive, and contains optical diffractive elements which two-dimensionally direct each beam into a direction determined by the signal's wavelength. We explored two options for implementing such a PRA [1]: by means of a pair of orthogonally-crossed diffraction gratings, and alternatively by means of an arrayed waveguide grating router (AWGR) with a high number of output fibre ports arranged in a 2D fibre array which is put in front of a lens. In our previously reported system demonstrator [6], we deployed the AWGR-based PRA. Device localisation was done by means of a 60GHz beam which was sent by the mobile device and was found by a scanning horn antenna positioned next to the PRA. Reading the mechanical 2D angular coordinates of this scanning antenna enabled to discover the (x,y) position of the user device, and subsequently the IR beam's wavelength was tuned such that it was directed accurately. Obviously, sending of the 60GHz beam draws power from the device's battery.

To enable localisation of the user's device without drawing power from it, we propose to equip the device with a passive retroreflector, e,g. based an optical corner cube (CC). A CC reflects light rays in the same direction as they came from, but there is a displacement between incoming and reflected rays, as is analysed in Fig. 2. The magnitude of this displacement is proportional to the entry aperture of the CC.

As illustrated in Fig. 3, a retro-reflecting CC mounted on the user device's OWC receiver will direct part of the incoming narrow IR beam back to the PRA, into the AWGR output port it came from. From the AWGR's input port, the reflected signal is subsequently returned to the central site, where via an optical circulator it is monitored in the localisation processor. This processor is controlling the wavelength of the tunable laser diode. The device localisation process begins by a command from the localisation processor to the tunable laser diode to start scanning the room with an IR beam by sweeping its wavelength. As soon as the processor detects a returning reflected signal, it halts and stores the actual wavelength of the tunable laser, and thus has found and stored the location of the user device. The laser is then set to this wavelength, and by the correspondingly steered IR beam the system has thus established a high-speed connection to the user.

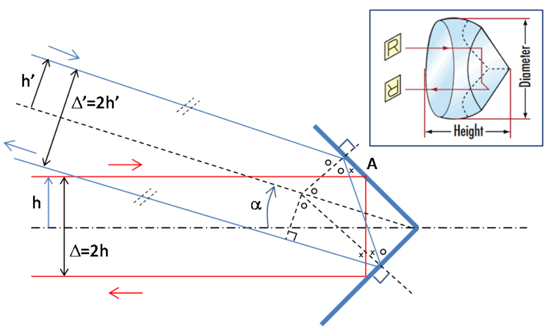

Fig. 2 Ray paths in optical corner cube reflector (inset: 3D view)

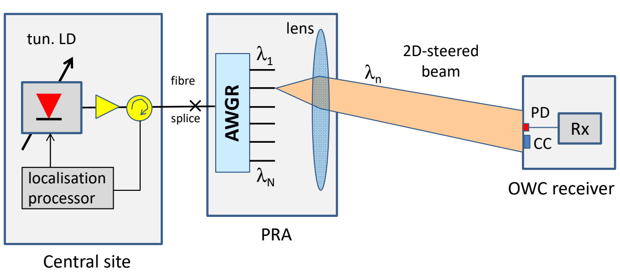

Fig. 3 Localising the user's OWC receiver by means of a retro-reflecting corner cube (CC)

As we have reported before [6], to achieve a compact design of the PRA it is required to position the 2D fibre array of the AWGR outputs not in the focal plane of the lens, but a bit closer to it. Next to a reduction of the PRA's size, this defocusing yields a slight divergence of the beams, which improves the coverage of the user plane and makes the coverage less dependent on the actual distance to the lens; this relaxes the device mobility requirements. But the defocusing makes that the displaced returning beam may not end in the same fibre port as where it came from; see Fig. 4. To minimize this issue, it is preferred that the aperture of the CC is minimized. This implies that only a very small fraction of the beam is retro-reflected, which compromises the detection process. We therefore opted to apply not a single small CC, but a matrix of many miniature CC-s. Such CC arrays are readily available in retro-reflecting foils; these are commercially available and are widely used already, e.g. for road signage. We acquired such a foil containing a fine pattern of miniature molded CC-s (from Orafol [7]); Fig. 5 shows a microscopic view of its structure.

Fig. 6.a shows how the reflected rays from two adjacent miniature CC-s are co-incident when the 2D fiber array is in focus of the lens, and Fig. 6.b shows how they are slightly displaced with respect to each other (i.e. by 20% of the CC's aperture used) when the array is 20% out-of-focus.

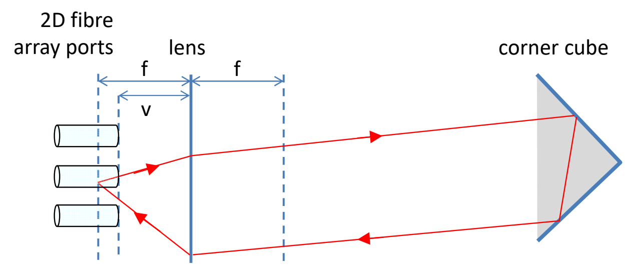

Fig. 4 Operating the retro-reflecting CC in a defocused PRA

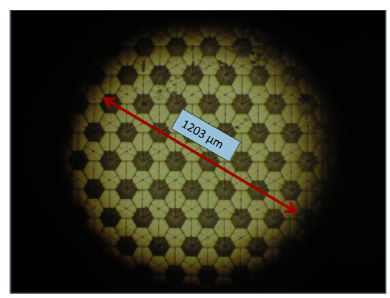

Fig. 5 Foil with many miniature corner cubes, each with a diameter of 100µm (from Orafol)

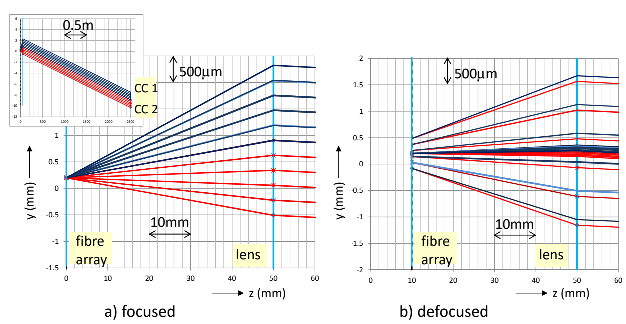

Fig. 6 Ray tracing when 2D fibre array: a) is in focus, b) is 20% defocused w.r.t. lens (red and blue rays are running to/from 2 adjacent small CC-s, respectively; lens f=50mm, CC aperture 700µm; inset: 2 CC-s at distance 2.5m)

3 Passive device localisation - experiments

We have implemented the passive user localisation concept in our AWGR-based beam-steered OWC demonstrator reported in [6] which showed real-time transmission of two independent high-definition video streams in free-space, each embedded in a 10GbE stream. Equipped with a C+L band AWGR with channels spaced at 50GHz and 35GHz bandwidth at -3dB, the PRA can launch up to 129 beams, each with diameter ∅10cm, and cover a user area of ~∅1.3m at a reach of 2.5m. In this setup we have now included the passive localisation by attaching a circular piece of Orafol foil containing the miniature CC-s on an OWC receiver, as depicted in Fig. 7. Due to internal optical reflections in the PRA (we used a commercial 50mm F/0.9 camera lens which was not anti-reflection coated for the λ=1.5µm window, and we used connector joints between the 2D fibre array and the AWGR output fibres), we had to catch the returning rays by a small ∅1cm power detector next to the lens. The optical power launched into the wireless channel was ~ 6dBm in all the measurements. When the beam is scanning the user plane by tuning its wavelength, Fig. 8 shows the reflected power received by the localisation detector for the case of two users, one equipped with a CC sheet with a diameter of 4cm and the other of 5cm. There is a 1-to-1 relation between the beam's wavelength and the device's position; hence the power peaks in Fig. 8 indicate the pico-cells where the devices are located. Scanning the whole user area takes about 15 s; the scan time is limited by the communication links between the power meter and the LABVIEW program running in the laptop which acts as localisation processor. The height of the power peaks is related to the size of the CC sheet, as shown in Fig. 9. An adequate SNR>5dB for the localisation requires a CC foil diameter >4cm. Background noise contributions are coming from the room illumination and from spurious reflections of the demonstrator table's surface. SNR values up to 15dB have been achieved, which enabled localisation clearly within the required resolution of a single pico-cell (diameter 10cm).

The CC foil preferably surrounds the detector of the lens-based OWC receiver, which has an aperture of ∅3cm. Hence we also measured the returned localisation power for a ∅4cm CC foil with a central hole of ∅3cm hosting the receiver's detector, and a ∅4cm foil without hole. As shown in Fig. 10, the central hole caused a reduction of returned power of about 3.2dB (theoretically 3.6dB when uniformly illuminated).

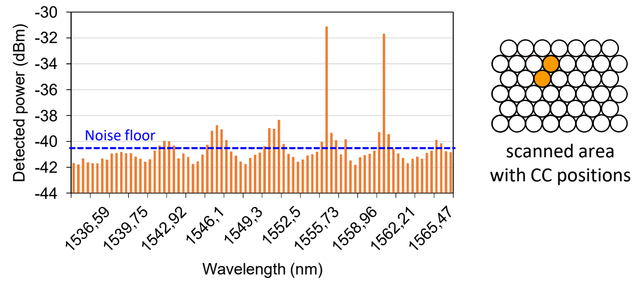

Fig. 8 Power received by localisation detector when scanning across the system's pico-cells (for CC sheet diameter ∅ 4cm)

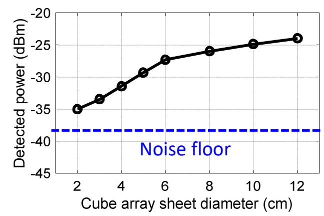

Fig. 9 Detected peak localisation power vs. diameter of circular CC sheet

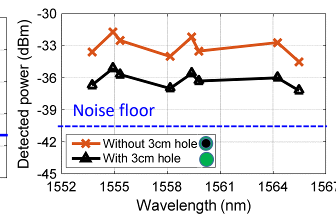

Fig. 10 Detected peak power vs. wavelength, for ∅ 4cm CC foil with ∅ 3cm hole, and ∅ 4cm CC foil without hole

4 Concluding remarks

Applying passive retroflection by means of a foil containing many miniature corner cubes enables device localisation within the pico-cell resolution of our 2D beam-steered high-capacity optical wireless system setup. Real-time 10GbE video streaming to mobile devices has been demonstrated.

5 Acknowledgements

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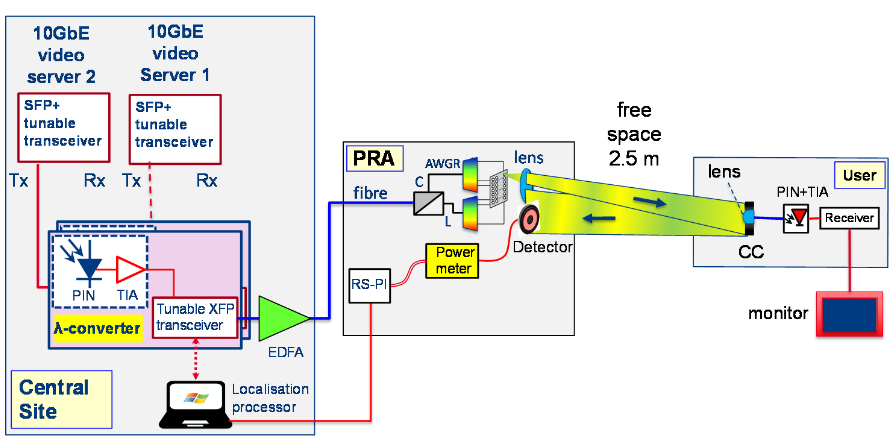

Fig. 7 Experimental setup for the passive device localisation

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