Hybrid mm-Wave and for High-Capacity Indoor Communication System

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This work presents the design of a hybrid communication system which combines the strengths of mm-wave and infrared optical wireless communication (IOWC) technologies. A flexible indoor wireless communication network can be achieved with IOWC and 60 GHz radio-over-fiber link, as an alternative to the current Wi-Fi system, to support more devices connected to each other via a wireless network to provide the Internet of Things services. The downstream is deployed with pencil radiation antennas to steer narrow infrared beams establishing wireless optical link between the access point and the user device (UD), thus a high-capacity optical link can be achieved by dedicating one wavelength per UD. The upstream is deployed with phased array antenna at 60 GHz band, beamforming techniques are explored to facilitate user mobility and to maximize system connectivity, counteracting the impact of possible wireless obstructions. Transmission rates of 10 Gbps and 1 Gbps are target for the downstream and upstream, respectively. Indoor optical networks require simple and low-cost systems with binary modulation formats; therefore, the intensity modulation and direct detection is deployed for the radio-optical conversion and on-off-keying for the modulation format.

I. Introduction

The expectation about the Internet of Things is that in the future many devices will be connected via the internet. This will make building and cities increasingly smarter. These developments place very high demand on the network in order to be able to transport large amounts of data efficiently and reliably. The radio frequency ISM spectrum for 2.4 and 5 GHz is already occupied with a large variety of services, introducing new services becomes increasingly impossible. Therefore, solutions are being investigated in order to complement the Wi-Fi network and to develop a high-capacity integrated system utilizing hybrid communication technologies that allow more spectra to be used.

This work investigates two technologies that are getting considerable attention: optical. wireless communication (OWC) and millimeter wave (mm-wave) radio communication. The interest has been rising due to large available bandwidth. The optical spectrum is a key enabler for global internet connection. Extending the optical communication from optical fiber to include free-space optical wireless it is a significant step for future internet communication, making the OWC a promising alternative [1]. Beam-steered infrared light communication (BS-ILC) is one method for OWC that can be applied for indoor use cases, their short wavelength does not penetrate walls can provide high physical security [2]. The mm-wave band is referred in the frequency range from 30-300 GHz in the EM spectrum [3]. The unlicensed spectrum available for the 60 GHz band has gained interest in gigabit-per-second short-range wireless communication. An unlicensed band of 9 GHz around 57-66 GHz were assigned in Europe [4], encouraging commercial applications in the 60 GHz band.

OWC and mm-wave are promising alternatives for future wireless communication networks that relies on higher frequency bands. This work presents a flexible system that combines the strengths of both technologies. It feature the downstream high-capacity optical wireless link, the upstream mm-wave wireless link, and the user localization techniques for establishing the communication link in both directions.

II. Optical Wireless Downstream

The OWC techniques for short range (indoor) communication are mainly: visible light communication (VLC) and beam-steered infrared light communication (BS-ILC) [5]. The BS-ILC technique operates independently from illumination, it is easy to implement since it relies on well-established S+C+L band technologies from fiber optics [6]. The narrow optical beams provided by BS-ILC serves one single user, achieving high security and high-capacity link. BS-ILC could be a complementary technology to support high-speed traffic demand, while Wi-Fi handles low-speed traffic. The implementation of an optical indoor wireless system, illustrated in Figure 1, consists of a residential gateway (RG) which interfaces the outdoor access network and indoor wireless network. The optical cross connect (OXC) is responsible for the dynamic routing of optical wireless signals that are steered to users' devices (UDs). Autonomic network protocols management are deployed at the central communication controller (CCC) [2].

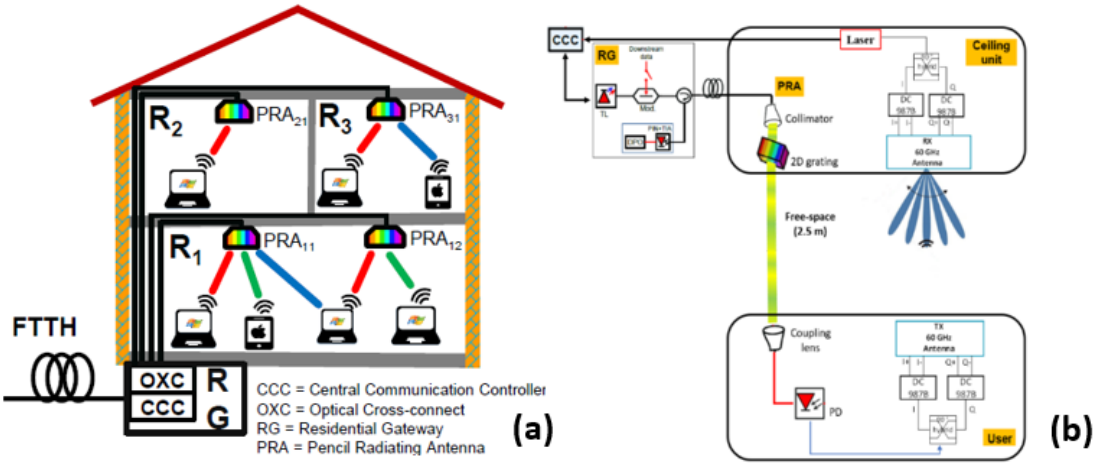

Fig. 1. (a) Indoor optical/radio network architecture [4], (b) Hybrid wireless system: mm-wave upstream at 60 GHz and optical downstream.

A key challenge for this system is to support user mobility. Figure 1(b) illustrate the hybrid wireless system. At the ceiling unit a pencil radiating antenna directs the beams to the users according with the wavelength selected at the RG, each wavelength corresponds to a location in the room. The phased-array antenna scans the room searching for the UD using beam steering, for a RSSI value above a certain threshold the user is localized. This localization information is shared with the optical network so the optical downstream can also be adjusted. At the user side the optical signal is coupled by lens to a photodetector (PD), which is converted to the radio domain to be transmitted by the mm-wave upstream in the 60 GHz carrier.

III. mm-Wave Upstream

The mm-wave upstream system designed is based on the radio-over-fiber technology. To implement the wireless path operating at high frequency bands, phased-array antennas are considered. These antennas are able to perform beam steering for user localization. Figure 2(a) illustrates the EVK06002 from *Sivers* used as transmitter and receiver modules

with an antenna array optimized for operation in 57-71 GHz band, beamforming transceivers for radio beam-steering and compatible with IEEE 802.11ad standard. The module operates with baseband I/Q differential signals.

The mm-wave uplink will be integrated with an optical network. Figure 2 (b) illustrate the mm-wave upstream system design. At the user side the data stream comes from the photodiode PD as baseband OOK modulated signal. The *Interface 1* converts the NRZ signal to I/Q signals to be transmitted by the antenna module. The 90°-hybrid split the signal into I/Q. The DC987B-A differential amplifier boards convert the input into two differential outputs (180° out of phase) therefore *Interface* 1 converts one single input into 4 differential I/Q outputs (I+, I-, Q+ and Q-). The baseband signal is upconverted to 60 GHz carrier by the antenna module to be transmitted. The signal is transmitted wirelessly to the access point (AP)/PRA at the ceiling.

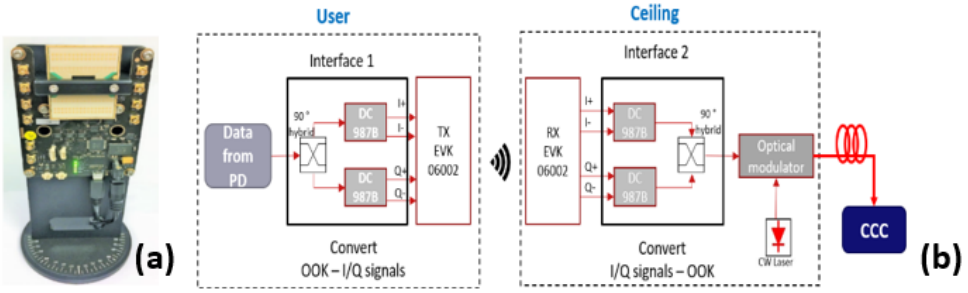

Fig. 2. (a) EVK06002 TX/RX antenna module for 60 GHz, (b) mm-Wave upstream schematic.

Then, the signal 60 GHz signal is down converted to baseband and in an analogous way the *Interface 2* converts 4 differential I/Q signals to one single output. Then, the baseband (radio) signal is modulated by an optical modulator to be transmitted over a short-length fiber to be processed at the CCC.

a. User Localization

The quasi-optical nature of mm-wave results in sharp and narrow beamwidth radio signals. These narrow beams, generated by phased-array antennas, can gather accurate angle information such as angle of arrival (AoA), angle of departure (AoD) and the received signal strength information (RSSI) [7]. RSSI values are simpler to obtain in a wireless network. To estimate the UD location only from RSSI values, it's necessary to determine the dependence between RSSI values and the distance between AP and UD choosing a suitable propagation model. Eq. 1 describes the propagation model or path loss model. The signal attenuation between transmitter and receiver to be inversely proportional to the distance between them to the path loss factor [8].

$$P_R = \alpha - 10\,.\,n\,.\log_{10}(d) + X \qquad (1)$$

where d is the distance between AP and UD and the term X denotes Gaussian random variable with zero mean caused by shadowing. The term α depends on the factors of fast and slow fading, antenna gains G_t and G_r, and transmitted power P_t, often this value is known [8].

b. Antenna Module Analysis

To avoid the saturation of the received antenna module the transmitter module gain must be adjusted for a certain distance. Figure 3(a) shows the relation between the maximum transmitter module gain and distance between the antennas.

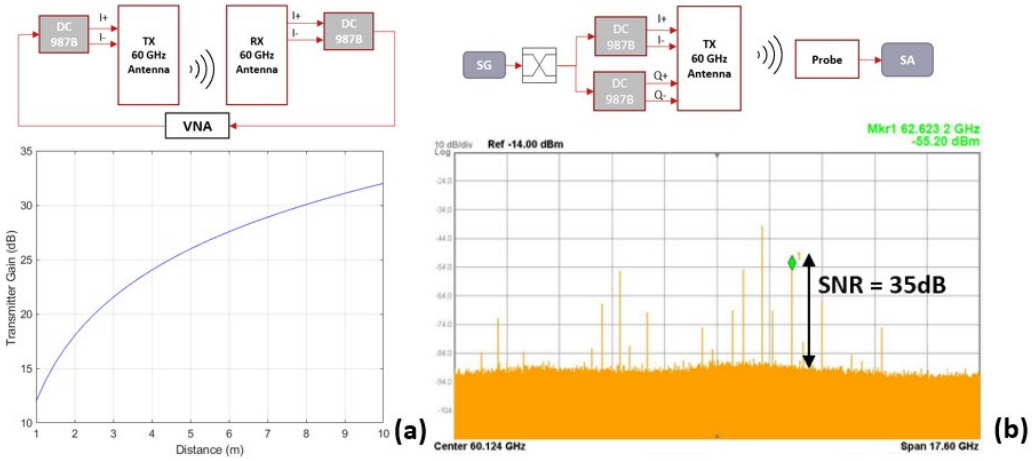

Fig. 3. (a) Gain of the transmitter over distance between transmitter and receiver, (b) Spectrum analysis of the received signal.

During the transmission the signal is affected by random noise, signal to noise ratio (SNR) indicates how strong the signal is compared to the channel noise. Figure 3(b) shows a SNR value above 20 dB, which is recommended for wireless data links.

V. Conclusion

Due the growing demand for internet services and the rising number of connected devices, the demand for wireless bandwidth is getting beyond the current indoor wireless network capacity. A logical way to tackle this bandwidth crunch is to combine the best aspects optical/radio wireless technologies. This work proposes a flexible hybrid wireless network which combines mm-wave for upstream and infrared optical wireless for downstream for an indoor use case. The system dynamically routes one wavelength per user providing high-capacity and unshared link. The radio beam steering is used to scan the room and provide to the network user localization. Steered infrared optical beam and mm-wave radio beam are promising future solution to the increasing demand in indoor wireless services.

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