Gigabit/s Optical Wireless Access and Indoor Networks

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Abstract: Optical wireless networks are being explored as a wireless alternative for provision of multi gigabits/second wireless and this paper presents an overview of recent progress and outstanding challenges. and technologies.

1. Introduction

The increasing adoption of interactive applications coupled with the increasing demand for consumption of dynamic content such as 4K videos have become a strong driver for worldwide search for suitable technology solutions for wireless connectivity in our personal spaces. In such indoor settings, ultrabroadband short-haul wireless connectivity with guaranteed latency has become a major focus for research [1]. Among the key technology contenders, optical networking based on visible light communications and optical wireless communications as well as the electronic networking based on millimeter-wave and terahertz communications have attracted widespread attention [1-4]. Many of these technologies do require the communication link between the transmitter and the receiver often needs to be line of sight if one wishes to achieve multi gigabits/second connectivity. In this paper, we present a review of the research conducted in the optical approaches for full duplex optical wireless access for indoor applications given their advantage of relatively unrestricted bandwidth available, the ability to provide additional physical layer security and the potential advantage in where radio frequency approaches are either denied or restricted.

2. Optical Wireless Access Network (OWAN)

Figure 1 presents a simplified schematic of the OWAN that seamlessly integrates fiber based local area network with an optical wireless delivery within the last few meters of the end-user's personal areas. While it is possible to realise the OWAN without the fiber feeder network, we consider this configuration as more applicable. In this configuration, optical wireless access point for duplex transmission is realized by optical assemblies integrating the optical fiber with wireless interface supporting up and downlinks as well as the corresponding architecture for the customer equipment is shown in Fig 1b [4]. The downlink in this configuration is realized by a pair of steering mirrors assembled at the lensed fiber interface to generate a cone of light forming steerable beam at the ceiling top transmitter and a lens arrangement integrating a parabolic concentrator focuses this beam on to a photodetector to complete the receiver. In the uplink configuration a similar arrangement is used.

2.1. Localization of users for supporting mobility

The steerable beams with variable beam widths provides us with the ability to deploy 'search and scan' to allow registration

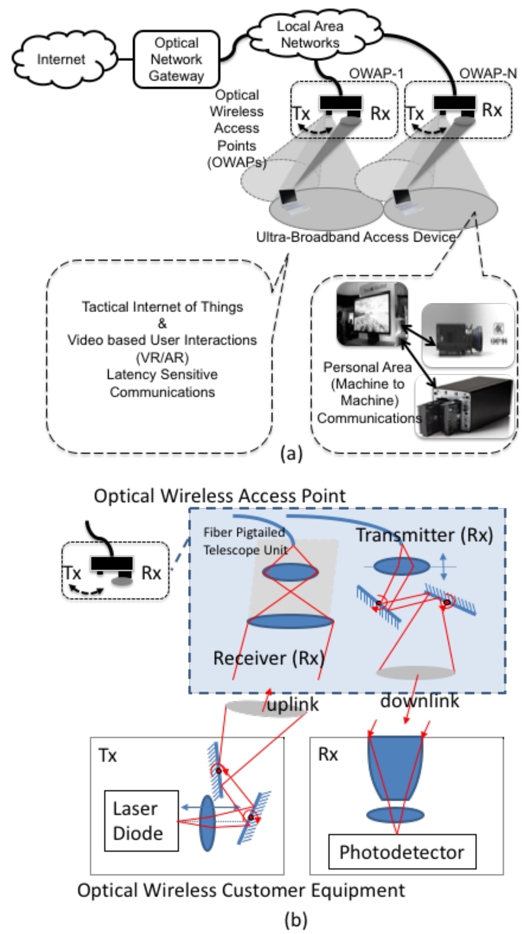

Fig 1 (a) optical wireless network architecture (b) optical transmit and receive assemblies used in the access point and customer equipment

of customers within the given coverage zone and also with certain coordination with the customer equipment, it also provides a framework to use the duplex transmission to localize individual customers within the specific coverage zones.

We have developed a localization algorithm that allows us to divide the coverage area by fixed number of cells and then use a “search and scan” method. Once the beam width is adjusted such that it could cover all the cells, downstream transmitter can send a request to respond to all customer equipment terminals and then follow a search and scan by reducing the beam width so that each user terminal in different cell areas can be discovered and their cell location registered. In addition, by taking a coordinated beam scanning method, it is possible to extend the algorithm to achieve accuracies better than 5 cm in height and better than 10 cm accuracies on the horizontal plane [5]. With the localization approaches developed, the network can support limited mobility of users within the indoor access.

2.2. Simple multi-user access with optical time slot coding method

OWAN can use both time, frequency, wavelength and code domains to provide multiple user access frameworks. While optical transmitter technologies can easily support tens of Gb/s data rates, it is important to reduce the required bandwidth to achieve cost-effectiveness and thus optical wireless links employing advanced modulation methods such as quadrature amplitude modulation (QAM) have been demonstrated [6]. We have also developed a simpler time slot coding as a multiple access method where each user is given unique code which provides them a unique period to transmit their specific QAM data symbols, leveraging simpler signal processing while achieving improved spectral efficiency. In addition, as the beams produced directly from the most laser diodes will suffer from variable beam intensity due to the gaussian like beam profiles. In these contexts, modulation formats could be adjusted from 4QAM to 16 QAM when considering a user at the edge of the bean in comparison to the one in the middle of the beam. The time slot coding easily supports multiplexing of data streams with the adaptive loading. In the case of k users sharing a downlink beam, the timeslot coding can be represented by a kxk identity matrix. The data symbols from each user is then multiplied by the matrix to determine the symbol and the slot in which it will be transmitted. We have shown that it is possible to 4-16 QAM with the time slot coding to provide different users with different throughput depending on their channel conditions. The multiplexing method was also shown to be tolerant to some imperfections in the time alignment of codes [7].

2.3. Adding a physical layer security to the OWAN

Optical approaches with smaller coverage areas do offer an added physical layer security as a direct channel access is often required. This has already been shown to be improved by adding chaotic sequences to VLC to improve the security of such links [8]. We have also taken advantage of this simple time slot coding method to realise a secure communication channel by adding phase noise terms based on a chaotic logistic map determined by the iterative relationship with bifurcation profile. Using these phase noise terms, we have shown that eavesdroppers need very precise estimate (better than 10^{-10} accuracy) to have any chance of decoding the channel. We have used this method to demonstrate 4 QAM and 16 QAM transmissions using time slot coding based multiple access to illustrate the physical layer security feature [9].

2.4. Spatial diversity to overcome blocking of optical beams

Optical beams within the OWAN could be either partially or fully blocked by objects in the personal area as well as movement of users. Signal processing techniques exploiting redundancy in time and space through methods such as space-time-block-coding (STBC) are known to be effective in responding to such challenges using different realisations of multiple input multiple output (MIMO) architecture. An indoor OWAN link utilizing STBC system had been previously demonstrated with preliminary experimental results demonstrating robustness to physical shadowing [10]. Likewise, another coding approach – repetition coding (RC) was also considered for overcoming such challenges [11]. We have extended these ideas by demonstrating an optical wireless link with STBC and RC and verified their effectiveness [13]. Our results show that up to 10Gb/s data transmission can be achieved with results showing RC outperforms the STBC system by about 1.5 dB under perfect synchronization. In addition, results have shown that both RC and STBC systems are robust against possible channel blockage.

2.5. Dynamic tuning of contention window to optimize throughput and latency

Having demonstrated an ultrabroadband wireless connectivity directly exploiting duplex optical layer wireless transmission, we have realized the performance of the most commonly used wireless medium access control protocol demonstrate poor performance in guaranteeing the latency and throughput when a mix of services are supported – such as real-time video or latency guaranteed tactical internet of things. Noting the limitation of the IEEE 802.11 where contention window (CW) is always reset to the minimum specified CW (CWmin) after a successful transmission, we proposed an algorithm for dynamic tuning of CW that dynamically changes the CWmin so that it is suitable for the congestion level of the network given specific mix of services being offered[13].

2.6. Towards a universal architecture

It is clear from looking at different wireless alternatives, each technology options – mm-wave, THz, VLC or OWA, all could potentially have applicability in specific areas and many challenges of working with these technology options remain similar. With this background, we have been investigating an universal architecture with fiber feeding and highly centralized network controller with the most of the processing applications. In addition such controller needs to manage beam forming and steering as these technologies would demand such capacbility to effectively offer ultrabroadband wireless connectivity. With the complexity of balancing channel access and high speed data transmission, these will need to adopt a framework for having separate control and data plane. Integrating these concepts, we have developed a universal architecture for such future heterogeneous wireless networks [14].

3. Summary

In this paper we present an overview of our proposed optical wireless architecture delivering multigigabit/s connectivity. We provide further insight into key functionalities needed to realise optical networking in a wireless network by investigating multiple access, enhancing security at the physical layer, exploiting spatial diversity to overcome beams being blocked as well as dynamically optimized MAC protocols for improved performance. We articulate framework towards an universal architecture that can be applied across all competing technology fabrics.

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