Time-sharing Resources for Low Cost and High Performance Indoor Optical Wireless Networks

C. W. Oh, E. Tangdiongga, A. M. J. Koonen

COBRA Research Institute, Eindhoven Univ. of Technology, P.O. Box 513, 5600MB Eindhoven, The Netherlands, C.W.Oh@tue.nl

Abstract Cost, performance and energy consumption are major issues in indoor optical wireless systems. We propose a low cost, energy-friendly and yet high performance solution based on optical beam-steering and time-sharing. This solution also enables unicasting, multicasting and broadcasting of broadband services.

Introduction

The radio spectrum crisis is becoming a major bottleneck to internet traffic in the near future. While the internet traffic is increasing due to the booming rise in interconnected devices, most of the traffic demands will be coming from indoor networks[1]. Many research efforts to mitigate wireless traffic congestion are seen in the optical wireless (OW) domain as it offers several inherent advantages. These include a huge unregulated bandwidth that could support up to terabits/s capacity, physical security, no multipath fading in direct links and insensitivity to electromagnetic interference.

For in-building networks, it is important that the necessary resources are minimized and their usage is maximized in order to optimize the cost, link performance and energy usage of the system. Time-slotted indoor transmission is feasible with OW since most services require less bandwidth than can be delivered. Thus, we propose a low cost yet high performance reconfigurable 2D beam-steered OW system with resource sharing. In our proposed concept using narrow optical pencil beams, which are 2D beam-steered by passive diffractive devices and simple wavelength tuning, we propose sharing of the tunable laser diodes by applying fast switchable wavelength tuning and thus sharing a laser diode among a number of beams. Depending on the number of lasers used, three different supported modes of operation, i.e. unicasting, multicasting and broadcasting, can be implemented.

Indoor Hybrid Optical-Radio Wireless Architecture

Figure 1 shows our proposed architecture for the indoor hybrid wireless system[2]. A central communication controller (CCC) interfaces the access network to the indoor network. Network protocols, management and routing algorithms are located in the CCC. Data is routed through an optical cross-connect (OXC) to different access points known as pencil radiating antennas (PRAs) via single- or multi-mode fibers. Depending on the size of the area coverage needed, one or multiple PRAs can be implemented. In our solution, we propose the use of passive diffractive optics at the PRAs to steer the narrow, therefore termed as pencil, radiating beams only to the necessary spots where a connection is needed. One or more tunable laser sources are placed at the CCC. By tuning the wavelengths of the laser source(s), the room is scanned to locate the wireless

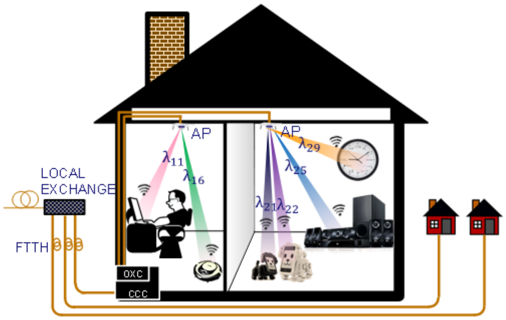

Fig. 1: Hybrid optical-radio wireless system with fiber-within-the-home for indoor wireless communication. FTTH: Fiber-to-the-home, CCC: Central Communication Controller, OXC: Optical Cross Connect, AP: Access Point.

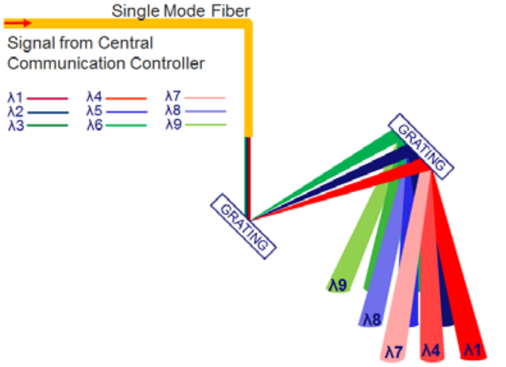

Fig. 2: Illustration of 2D optical beam-steering concept, implemented with a pair of crossed reflective diffraction gratings at the access points.

Oh, C.W.;Tangdiongga, E.; Koonen, A.M.J., "Time-sharing Resources for Low Cost and High Performance Indoor Optical Wireless Networks," Optical Communication (ECOC), 2015 European Conference on, pp.P7.4,27 Sept.-01 Oct. 2015.

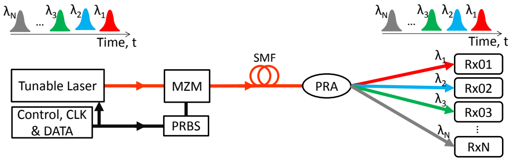

Fig. 3: The concept of time-sharing a tunable laser. MZM: Mach Zender Modulator, PRBS: Pseudorandom Binary Sequence, PRA: Pencil Radiating Antenna, Rx: Receiver.

devices and then, the PRAs will direct the allocated beams according to different positions as illustrated in Fig. 2. For the uplink, radio techniques can be implemented and the RF signals are re-modulated on the downstream optical carriers by means of an RSOA or REAM and sent to the CCC. Optical and radio wireless localization techniques can be used to identify the location of mobile devices.

In order to provide wavelength re-configurability, a fast switchable tunable laser is employed. As the capacity of each line-of-sight optical link can be enormous[3], time-sharing of the tunable laser, as illustrated in Fig. 3, is proposed. In addition, time-slotted transmission allows dynamic resource allocation according to the capacity required by the wireless devices. Finally, the laser sources, together with a crossbar switch[4] and the passive gratings (at the PRA), easily enables unicasting, broadcasting and multicasting schemes, as shown in Fig. 4.

Experimental Setup

The schemes for unicasting and broadcasting have been constructed in an experimental testbed, as shown in Fig. 5. In this experiment, we emulate a tunable laser by utilizing two distributed feedback (DFB) lasers and a 2-by-2 MZI switch, where a switching speed in excess of 1 ns is attainable. This way, the switching of wavelengths as well as the concept and feasibility for broadcasting can be demonstrated.

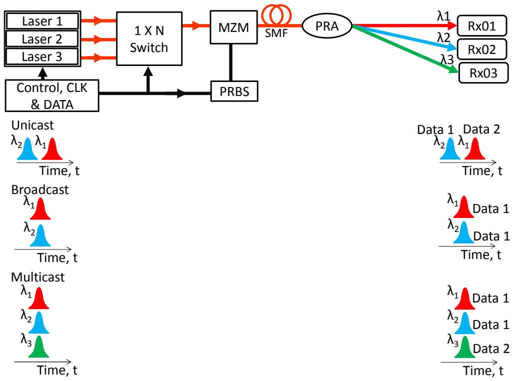

Fig. 4: Optical wireless system architecture with unicasting, broadcasting and multicasting schemes.

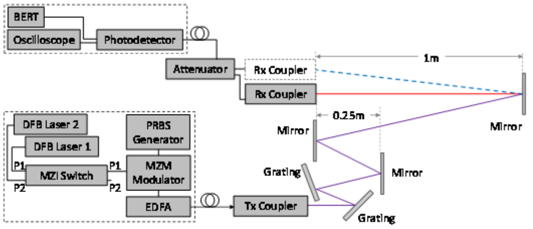

Fig. 5: Experimental testbed setup for a time-slotted optical wireless transmission with 2D beam-steering.

Laser 1 is set to 1549 nm at input port 1 of the switch and laser 2 is set to 1550 nm at input port 2. The optical power of both lasers is set to 10 dBm. An MZM modulator of 10 Gbit/s is used to modulate an OOK-NRZ PRBS pattern of length 2^{31}-1. An EDFA is placed after the MZM to amplify the optical power to approximately 8 dBm, which is within the eye-safety limit (10 dBm at λ>1400nm), for free-space transmission. The data signal is then sent to the (a) back-to-back (BtB) link made up of a 2 m long SMF fiber (b) free-space with 2D optical beam-steering. For the free-space setup, the data signal is then directed accordingly to the receiving coupler positions depending on the wavelengths emitted toward the PRA, which consists of a pair of cascaded gratings. The first echelle grating is blazed at 63° with 31.6 grooves per mm and the second echelle grating is blazed at 75° with 79 grooves per mm. The coupled data beam is then sent to the receiver and analyzed by observing the eye-diagrams via the oscilloscope and the bit error rate via the BERT.

Results and Discussion

The optical output behaviour at port 1 and port 2 of the 2-by-2 MZI switch, as the bias voltage is varied, is shown in Fig. 6. The three points of operation have been identified from the switch characterization. The first is when the switch is biased near 0.5 V and the second at 2.7 V. At these two biases, the input at port 2 (1550 nm) and the input at port 1 (1549 nm) is routed to output port 1, respectively. Unicasting can be used at these biases. For broadcasting, the bias of the switch can be set at 1.6 V such that both input wavelengths are selected and

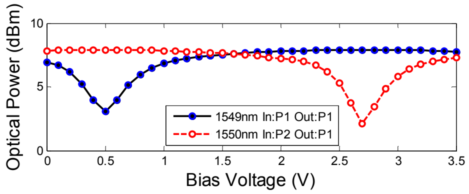

Fig. 6: Switch Characterization measured after EDFA. P1: Port 1, P2: Port 2.

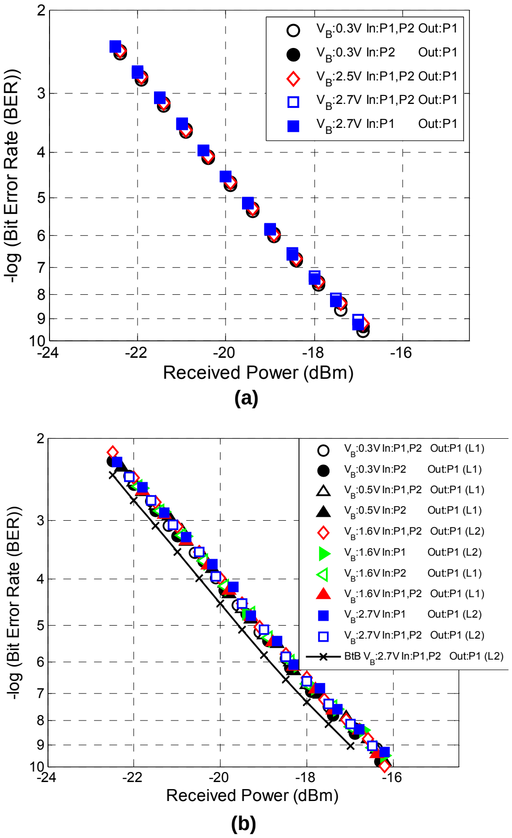

Fig. 7: 10 Gbit/s transmission performance for **(a)** back-to-back (BtB) and **(b)** Free-space with 2D beam-steering. P1: Port 1, P2: Port 2, L1: Laser 1 (1549 nm), L2: Laser 2 (1550 nm).

transmitted to the PRA.

As the switch and modulator contribute optical power losses of up to 5 dB and 8 dB respectively, an EDFA is added to the output of the modulator to keep the free-space transmission power to approximately at ≤ 8 dBm. The crossed gratings contribute at max 15 dB of optical power loss collectively. These gratings are not selected for optimal power efficiency but they provide the optical beam-steering needed for our proof-of-concept demonstration.

The BER performance for BtB measurement and for the free-space transmission is shown in Fig. 7. Both systems show a consistently good performance. The power penalty of the free-space transmission compared to BtB is negligible at less than 1 dB. The corresponding eye-diagrams are shown in Fig. 8. The eyes are open with negligible distortions observed.

Conclusion

Time-slotted transmission with fast switchable tunable laser(s) enables time-sharing of resources among users and is a viable method to lower the system cost for high-performance indoor OW networks. On top of that, this system can be configured to support dynamic resource allocation according to the capacity required. Also, unicasting, broadcasting and multicasting schemes can be implemented. We have emulated such a scheme in an experimental testbed for 10 Gbit/s OOK-NRZ signal over 2.5m with measurements showing good performance, and therefore, the feasibility of implementing the proposed time-sharing system for in-building OW networks.

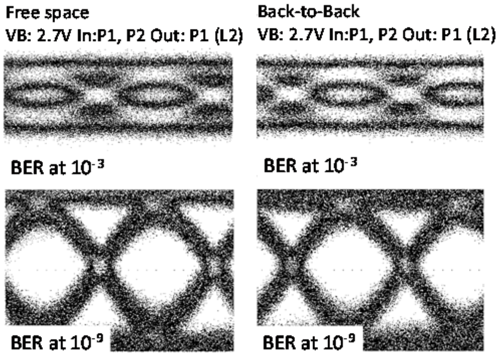

Fig. 8: Eye-diagrams of 10 Gbit/s links.

Acknowledgement

This work is part of the Beam-steered Reconfigurable Optical-Wireless System for Energy-efficient communication (BROWSE) project, funded by the European Research Council within the FP7 program.

References

[1] *Cisco Service Provider Wi-Fi: A Platform for Business Innovation and Revenue Generation*, Cisco Solution Overview (2012).

[2] A. M. J. Koonen et al., "Reconfigurable free-space optical indoor network using multiple pencil beam steering," Proc. OECC/ACOFT, p. 204, Melbourne (2014).

[3] C. W. Oh et al., "42.8 Gbit/s Indoor Optical Wireless Communication with 2-Dimensional Optical Beam-steering," Proc. OFC, M2F3, Los Angeles (2015).

[4] A. R. Dias et al., "Fiber-Optic Crossbar Switch with Broadcast Capability," Opt. Eng., Vol. 27, no. 11, p. 271155 (1988).