Simultaneous 1.5 Gbps Multilink Indoor Optical Wireless System Using Diffractive Optics

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The shortage of available radio spectrum, catering to the ever increasing bandwidth demand, has impelled many initiatives to look for alternative measures. In the advent of optical wireless systems, high speed networks with vast amount of bandwidth can be realized. Multiple links can be provided to one or more users simultaneously by using efficient beam steering methods. An investigation for indoor optical communication system using diffractive optics has been carried out. This paper demonstrates that up to at least five simultaneous 1.5 Gbps NRZ-OOK links, with BER less than 10^{-9}, can be deployed.

1. Introduction

Many might still recall the arrival of portable devices, especially cell phones and personal digital assistants (PDAs), with embedded Infrared Data Association (IrDA) transceivers in the 90's, for one-to-one short range communication. Then, the first cell phone with Bluetooth arrived in the year 2000, which featured a better coverage of approximately 10m[1]. At about the same time, GPRS was introduced[2]. GPRS is an extension of the GSM network, where users can have access to the internet. This is followed by other technologies that offer better data rates. The Wireless Fidelity (WiFi) technology, which also uses radio signals, is similar to Bluetooth, but constitutes a much greater area. WiFi is by far the fastest and most stable mobile protocol at this point of time[3]. One thing all these technologies have in common is the reliance on radio waves, but is there enough room in the radio spectrum for all? Consider also that Cisco's Internet Business Solutions Group predicts some 50 billion devices that will be connected by 2020. Since year 2008, already more devices are connecting to the internet than people[4]. The radio spectrum is getting congested and devices are interfering with each other. With the explosion of wireless traffic over the next few years, solutions to enable support for the forecasted booming communication traffic are necessary[5][6].

Foreseeing the broad and unregulated bandwidth in the THz frequency, the optical spectrum has much to offer. A considerable amount of research on the visible light spectrum has been carried out. The visible light communication systems (VLC) have a basic system limitation on the bandwidth, i.e. a few 100s of mbps[7][8][9], up to the state of art of 3.22 Gbps, where wavelength division multiplexing (WDM), carrier-less amplitude and phase (CAP) modulation, and RGB light emitting diodes (LEDs) are employed[10]. The infrared communication systems, on the other hand, employ laser diodes, where high bandwidth is achievable due to narrow spectral linewidth. Data rates can go up to terabits per second. Furthermore, ambient light, which is the dominant noise in VLC systems, is eliminated. Since the emergence of fiber-to-the-home (FTTH) technology in 2004, infrared wireless communication is seen as a promising solution to bridge wirelessly the gap to the end user[11].

In this paper, we propose an infrared-based indoor optical wireless solution, employing passive diffractive optics for beam steering. We demonstrate the feasibility of using a passive grating as the beam steering medium for short-range indoor optical wireless communication. Therefore, we have compared the performance of the diffracted beams to the performance of a free space beam, and to the performance of a back-to-back (BtB) measurement with a 2m long single mode fiber(SMF). Subsequently, a multilink free space transmission of 1.5 Gbps, steered over 35cm, with bit error rate (BER) less than 10^{-9}, is demonstrated.

2. Indoor Optical Wireless System

Indoor optical wireless systems can be implemented as line-of-sight (LOS) or non-line-of-sight (NLOS) systems[12][13]. LOS systems are typically suited for point-to-point communication via highly directional power efficient beams, and therefore, require precise alignment. NLOS systems, on the other hand, are appropriate for point-to-multipoint systems via wide angle transmission, and thus, require less critical alignment. In addition, the implementation of a wireless network could be a hybrid of optical and radio links. As uplinks typically do not require as much bandwidth, radio wireless systems could be an option. Intelligence can be added to these systems to enable user localization, and to have a power efficient system, for example, transmission can be turned off when there are no users and only transmits to a particular user when necessary. Fig. 1 shows a typical wireless- equipped building with fibers, such as SMF fiber, multimode fiber or plastic optical fiber[14], as the in-building backbone network. The building is equipped with a central communication controller (CCC), where it will receive traffic from the access network and route it to all the access nodes; in our case, beam steering modules (BSM) in different rooms.

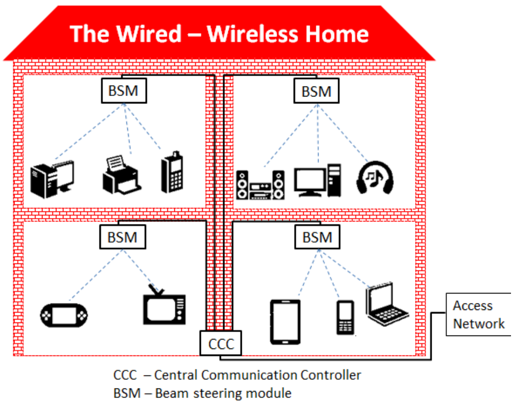

Fig. 1 Wired-Wireless-equipped home with beam steering modules

3. 1D Diffraction for Beam Steering

The novelty of our method for beam steering leads from the principle of diffraction. Diffraction stems from the ability of waves to bend, leading to a divergent profile as it propagates away from its source. At the same time, waves coincide constructively and destructively with neighbouring waves to give rise to interference. This phenomenon results in an array of bright and dark intensity patterns on the screen. These bright patterns are the spots where light beams are formed, as seen in Fig. 2c, which we can use as the medium of transmission in the optical wireless domain. The obvious advantage is that we gain from having multiple spots. These spots translate meaningfully into instantaneous multiple links with the capability of each link to carry the same amount of capacity. This is a win-win power-capacity sharing system, with a gradual power loss as the light intensity falls off towards higher angle diffracted beams. Yet, the same amount of data capacity can be transmitted in each link. As such, this solution is scalable depending on the available power budget of the system.

4. Experiment Setup and Results

The experiments were carried out with a non-return-to-zero on-off-keying direct-modulated 1558.98nm laser diode, with pseudorandom binary sequence of 2^{31}-1 elements. The first experiment is carried out as shown in Fig. 2a. A beam of 3.3mm in diameter is launched through an SMF pigtailed coupler with a lens of 18mm in focal length, for a distance of 25cm, towards a near Littrow-mounted echelle grating. The free space transmission is received by another SMF pigtailed fiber placed at a horizontal distance of 35cm from the grating, attenuated, and finally, evaluated with a BER tester and eye-diagram. In the second experiment, the grating is replaced with a silver coated mirror mounted at 45° from the incident beam, while maintaining the rest of the setup, as shown in Fig. 2b. For the BtB measurement, the Tx and Rx couplers are replaced with a 2m long SMF fiber.

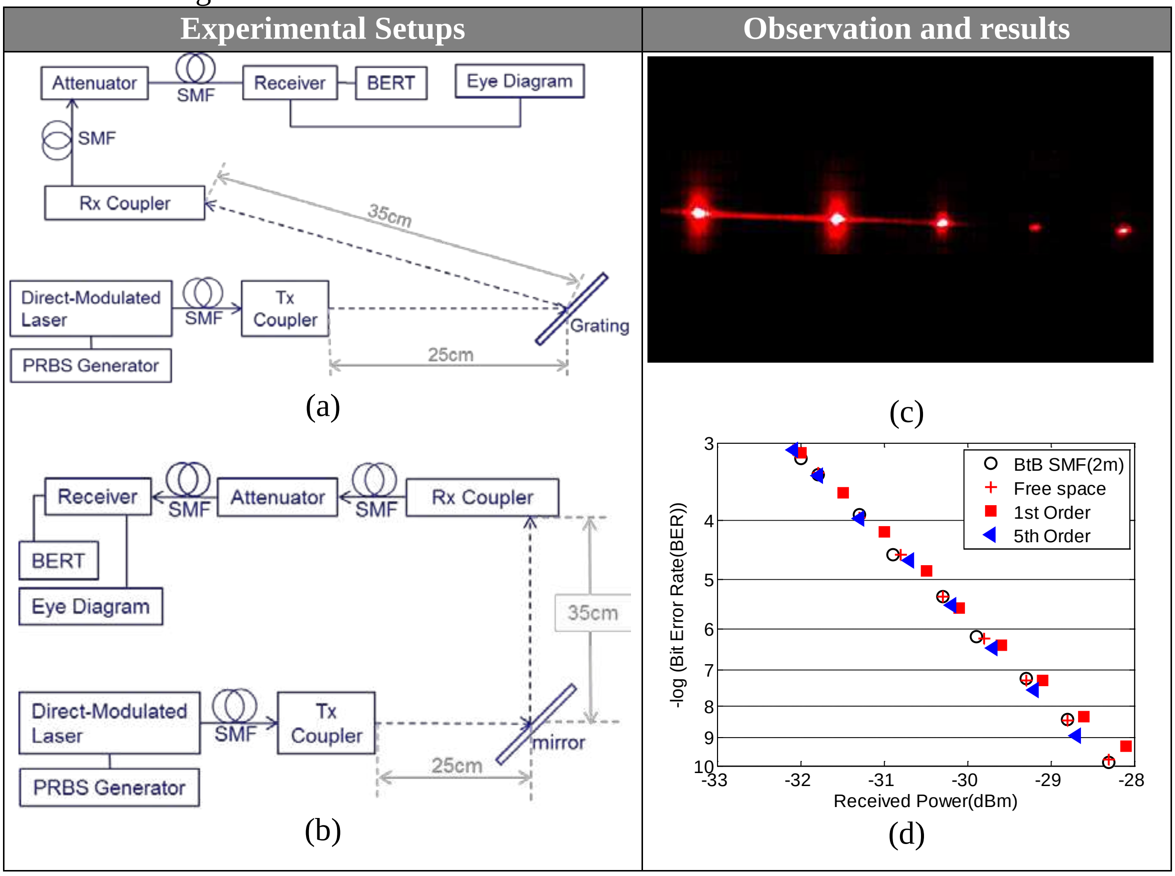

Fig. 2a) Experimental setup for free space transmission with grating b) Experimental setup for free space transmission with mirror c) Bright spots formed after diffraction grating with 657nm laser d) Resultant BER plot for BtB SMF with length of 2m, free space transmission with mirror and transmission of 1st and 5th diffracted orders of an echelle grating.

Clean open-eye diagrams are observed indicating negligible dispersion. The BER performance of the transmitted links, against the received power in dBm, is presented in Fig. 2d. The good overlap of the plot for BtB, free space, 1st order and 5th order links show that the grating induced negligible power penalty. We observe ≤ 1dB, for up to the 5th order diffraction, compared to BtB. The distance of measurement and the number of links are scalable depending on the available power budget; therefore, measurements for a longer distance as well as more links can be measured if there is enough space on the testbed.

5. Conclusion

We have demonstrated, for the first time, a simultaneous multilink carrying 1.5 Gbps each, with a free space transmission of over 60 cm, by which 35 cm between grating and receiver plane are diffracted links. Additionally, a BER of $<10^{-9}$ has been achieved. In short, these results are promising for the deployment of gratings as the beam steering medium for indoor optical wireless system. The system complies with the eye-safety regulations) formulated in the ANZI Z-136 in the US and the international IEC 60825 specifications.

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7. References

[1] "History of Bluetoth Special Interest Group," Bluetooth® [Online]. Available: http://www.bluetooth.com/Pages/History-of-Bluetooth.aspx, 2013 [Oct. 14, 2013].

[2] R. Keller,"General Packet Radio Service (GPRS)" [Online]. Available: http://misnt.indstate.edu/harper/Students/GPRS/GPRS.html [Oct. 14, 2013].

[3] "Mobile Marketing 101: Chapter 4: Mobile Technologies: SMS, MMS, USSD & Bluetooth/Wireless/Infrared," Quirk eMarketing [Online]. Available: http://www.quirk.biz/cms/3188.quirk_emarketing_mobile_marketing101_ch4.pdf [Oct. 14, 2013].

[4] "The internet of things," Cisco [Online]. Available: http://share.cisco.com/internet-of-things.html, 2011[Oct. 14, 2013].

[5] G. Parodi, "Radio spectrum shortage prompts a growing number of initiatives," LÁtelier [Online]. Available: http://www.atelier.net/en/trends/articles/radio-spectrum-shortage-prompts-growing-number-initiatives_422770, July 15, 2013 [Oct. 14, 2013].

[6] E. Savitz, "The solution to the wireless spectrum shortage: more wires," Forbes [Online]. Available: http://www.forbes.com/sites/ciocentral/2012/03/23/the-solution-to-the-wireless-spectrum-shortage-more-wires/, March 23, 2012 [Oct. 14, 2013].

[7] Y. Wang, Y. Shao, H. Shang, X. Lu, Y. Wang, J. Yu, and N. Chi, "875-Mb / s Asynchronous Bi-directional 64QAM-OFDM SCM-WDM Transmission over RGB-LED-based Visible Light Communication System," Proceedings of the Optical Fiber Communication Conference and Exposition (OFC) National fiber optic engineers conference (NFOEC), 18–20, 2013.

[8] G. Cossu, A. M. Khalid, R. Corsini, and E. Ciaramella, "Non-Directed Line-of-Sight Visible Light System providing High-Speed and Robustness to Ambient Light," Proceedings of the Optical Fiber Communication Conference and Exposition (OFC) National fiber optic engineers conference (NFOEC), 2–4, 2013.

[9] W. Joachim and C. Technology, "Light LEOs OSC Colour Filter LED lamp," vol. 1, no. 1, 3–4.

[10] F. Wu, C. Lin, C. Wei, C. Chen, Z. Chen, and H. Huang, "3.22-Gb / s WDM Visible Light Communication of a Single RGB LED Employing Carrier-Less Amplitude and Phase Modulation," Proceedings of the Optical Fiber Communication Conference and Exposition (OFC) National fiber optic engineers conference (NFOEC), 22–24, 2013.

[11] T. Koonen, "Fiber to the home/fiber to the premises: What, where, and when?," Proceedings of the IEEE, vol. 94. No. 5, 911–934, 2006.

[12] J. M. Kahn and J. R. Barry, "Wireless Infrared Communications," Proceedings of the IEEE, vol. 85, No. 2, 265-298, 1997.

[13] H. Elgala, R. Mesleh, and H. Haas, "Indoor optical wireless communication: potential and state-of-the-art," IEEE Communications Magazine, vol. 49, no. 9, 56–62, 2011.

[14] A. M. J. Koonen, H. P. a van den Boom, E. Ortego Martinez, a Pizzinat, P. Guignard, B. Lannoo, C. M. Okonkwo, and E. Tangdiongga, "Cost optimization of optical in-building networks.," Optics express, vol. 19, no. 26, 399–405, 2011.