2D Beam-steered Indoor Optical Wireless Network with 4- and 8-PAM Modulation

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With the proliferation of connected devices and continuing rise in interconnectivity among people and machines, the radio spectrum congestion is becoming a concern. Optical wireless communication is seen as a potential solution. By means of simple intensity modulation direct detection transceivers, we demonstrate a two-dimensionally steered free-space transmission system with 4- and 8-PAM modulation. We present the measured results of the channel performance which achieved more than 30 Gbps in a 10 GHz bandwidth limited system within FEC-limit.

Introduction

The increasing number of connected devices in relation to the “Internet of Things” phenomena has been received with enthusiasm as technology evolves into more sophisticated forms and functions. However, the ability to get connected at anywhere and anytime has created demands on communication infrastructures to cope with tremendous rise in data bandwidth. Due to heavy traffic, cellular networks operators practices data-offloading to fixed wireless LAN or femtocell networks [4,5] wherever possible. In 2015, mobile offload exceeded cellular traffic for the first time with 51% of total mobile data traffic offloaded. This is a cost effective way for mobile operators while at the same time, mobile users also enjoy the higher speed in LAN networks. At the moment, there are still many efforts in trying to squeeze more and more data onto the available radio bandwidths at the Industrial, Scientific and Medical (ISM) bands centered at 2.4 GHz, 5 GHz and 60 GHz, to improve on spectral efficiency for larger capacity. In short, the radio bandwidth is limited and very costly.

On the other hand, by using optical wireless communication (OWC), bandwidth is aplenty at the optical spectrum with the visible light spectrum extending between 400 nm (750 THz) and 700 nm (430 THz) while in the infrared spectrum, OWC typically centers at 850 nm (353 THz), 1310 nm (229 THz) and 1550 nm (193 THz). At these very high frequencies, OWC can gain from the large bandwidth that the optical spectrum can offer. Optical links are physically secure as light does not penetrate through walls and are also immune towards electromagnetic interference. As such, systems employing OWC have the benefit of an unregulated bandwidth. Interesting works are seen in visible light communication (VLC). VLC introduces the idea of piggy-backing data communication on top of solid-state LED lighting. However, the diffused beams of LEDs lead to lower power per unit area to be captured by the receiving detector. Also, the need for the LEDs to be turned on for providing high speed data communication while illumination is not needed (e.g., in bright daylight conditions) may lead to energy-inefficiency.

In this paper, we propose the use of N-PAM modulation for an infrared narrow beam wireless communication with two-dimensional (2D) beam-steering, for ultra-high speed yet simple receiver hardware. We use a cascade of diffraction gratings to implement the steering module and we further demonstrate a 2 m free-space transmission using the pulse amplitude modulation (PAM) for 4- and 8-PAM signaling.

System Concept

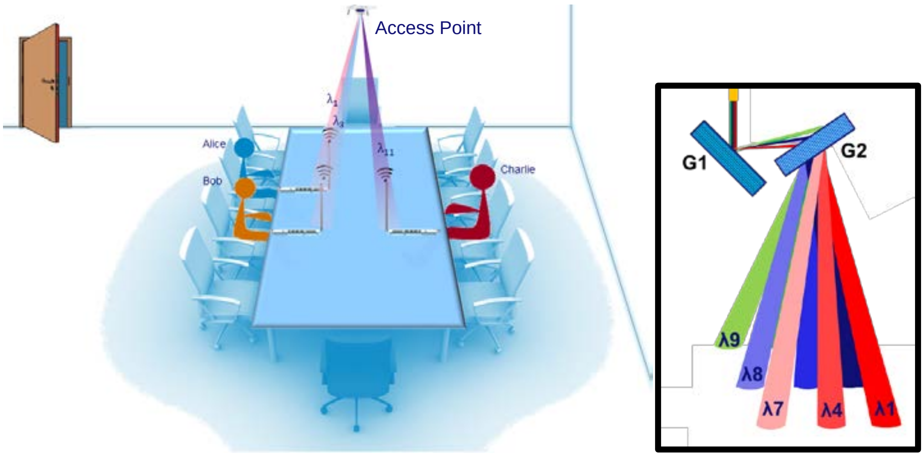

Fig. 1 Hybrid optical-radio wireless equipped in-building network. Subset: 2D steering module with cascaded gratings located at the access point. G1: Reflection grating G2: Transmission grating

The working principle of our proposed OWC system for indoors is illustrated as in Fig. 1 [6,7]. This indoor system interfaces with the access network at the central communication controller (CCC). Therein, a tunable laser provides the wavelengths which act as the carrier wavelengths. Each of the wavelengths is routed accordingly to the different access points (APs) through an optical cross connect (OXC) and single mode fibers (SMFs). At the APs, a pair of crossed gratings, as shown in the subset on the right, is used to direct the different wavelengths in 2-dimensions to different spots in the room [6]. The locations of the diffracted spots can be determined from the grating equation in the x- and y-axis:

$$m\lambda = d(\mathrm{n}_1 \sin\theta_i \pm \mathrm{n}_2 \sin\theta_m) \qquad (1)$$

where m is order of diffraction, λ is the wavelength of the beam, d is the period of the grating, θ_i the angle of incidence measured from grating normal, θ_m is the angle of transmittance or reflectance measured from grating normal, and the variables n_1 and n_2 denote the refractive indices of the medium of incident light and the medium of transmitted or reflected light, respectively.

As each device will be provided with an individual link, the full link capacity can be provided to each device. At the receiver side, the mobile device is equipped with a simple direct-detection photoreceiver. Radio wireless [8] will be used for the uplink, localization and to act as a backup link in case of failure in the optical system. The focus in this paper will be on the optical downlink.

Experimental evaluation

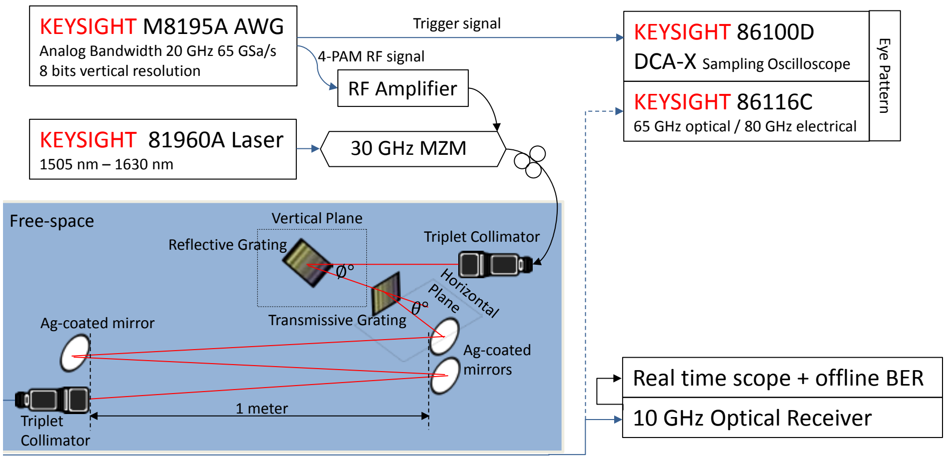

Fig. 2. Experimental setup for free-space passively beam-steered 3 meter links with 4- and 8-PAM signaling.

The system testbed is depicted in Fig. 2. An arbitrary waveform generator (AWG) and a sampling scope are used to set the pre-distortion for the transmission channel. After that, the 4-PAM signals are generated by the AWG. This data signal is amplified and modulated onto an optical beam of 13 dBm, using an external 30 GHz Mach-Zehnder modulator (MZM) with 6-8 dB loss. This 4-PAM signal is then transmitted to free-space through a triplet lens collimator with an opening aperture of 10 mm and a focal length of 18.36 mm. The free-space beam then impinges onto a pair of crossed gratings, steering the beam in a 2-dimensional plane. The first grating is a reflective echelle grating blazed at 80.7° with 13.33 grooves per mm. The second is a transmission grating with 1000 grooves per mm used at an angle of incidence of 49.9°. The beam is then picked up by 4 silver-coated mirrors which extend the free-space distance to over 3 m. An identical triplet lens collimator is used to collimate the propagated beam back into a receiver. Finally, the received signal is analyzed by observing the eye-pattern on a sampling scope while the data is sampled via a real-time scope for offline evaluation.

Results & Discussion

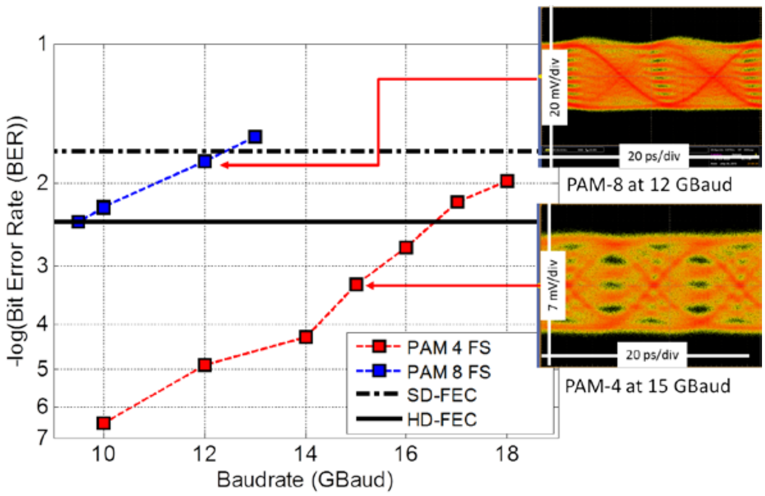

Fig. 3. Achievable baudrates for 4- and 8-PAM with reference to SD and HD FEC-limit.

Channel performance measurements have been carried out at the wavelength of 1550 nm both for 4- and 8-PAM signaling at a received power of -8.5 dBm. The target for error-free performance using hard decision (HD) FEC is BER $\leq 3.8\times10^{-3}$ and soft decision (SD) FEC is BER $\leq 2\times10^{-2}$. Fig. 3 shows the measured performances. With 4-PAM, we achieved up to 16 GBaud (32 Gbps) below HD FEC and 18 GBaud (36 Gbps) below SD FEC. On the other hand, with 8-PAM we achieved approximately 9.5 GBaud (28.5 Gbps) at HD FEC and 12 GBaud (36 Gbps) below SD FEC. The eye diagrams on the right show the eye diagrams for 4- and 8-PAM. The eyes are open and clear for 4-PAM while a slight skew is observed for 8-PAM.

Conclusion

We have demonstrated and measured the performance of free-space communication channel in achieving up to 36 Gbps below the SD FEC limit with 4- and 8-PAM modulation. We have also shown that optical pencil beams can deliver abundant individual high capacity wireless data in an energy efficient way. We believe that these promising results will motivate more efforts as we develop towards ultra-high capacity free-space communication. OWC is a promising alternative to solve the emerging radio communication bottlenecks. It can serve as an alternative or complementary solution for indoor networks to accommodate the increasing indoor traffic.

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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