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Capacity Optimization with Discrete Multitone Modulation for Indoor Optical Wireless Communication System

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In response to the crisis in shortage of available radio spectrum, research efforts are seen in "small cells" approach and spectral efficiency optimization in order to maximize the usage of available bandwidth. Hereby, we propose the adoption of optical wireless technology, which is capable of providing high capacity narrow pencil beams enhanced with spectrally efficient channels, to service multiple devices within the coverage area. An investigation for such indoor system has been carried out. We demonstrate a free-space channel with an aggregate bitrate of up to 27.4 gbit/s at 8 GHz bandwidth, using bit and power loading discrete multitone modulation.

1. Introduction

The radio spectrum is getting congested with the increasing demand for mobility and high speed connection. This can be seen in the quickly expanding fiber-to-the-home (FTTH) network with the amount of subscribers increasing at 29% per year as shown recently at the European council conference for FTTH in Stockholm [1]. In the Netherlands a quarter of all the households already have a glass fiber connection [2]. The spectrum limitation poses a serious threat to a future traffic bottleneck as more and more devices and applications come to existence. Already today, serious signal interference is occurring among wireless devices due to traffic congestion. However, mobile data traffic is still increasing, and according to Cisco, to a whopping ten-fold between 2014 and 2019 [3]. With the explosion of wireless traffic over the next few years, solutions to support the forecasted booming communication traffic are necessary.

Alternative measures are seen in 60 GHz radio communication, visible light communication (VLC) and infrared free-space optics. The downside of the 60 GHz spectrum is that it is limited to 7 GHz. Interesting works are seen in VLC whereby communication is piggy-backed onto existing lighting infrastructure based on light emitting diodes (LEDs). LEDs, however, have a fundamental limitation of a few tens of MHz bandwidth. Several progress are seen with data rates of 3 Gbit/s with a single microled using OFDM modulation [4] and 3.4 Gbit/s with RGB LEDs using DMT modulation [5], with VLC trending toward LiFi attocells [6]. The infrared communication systems, on the other

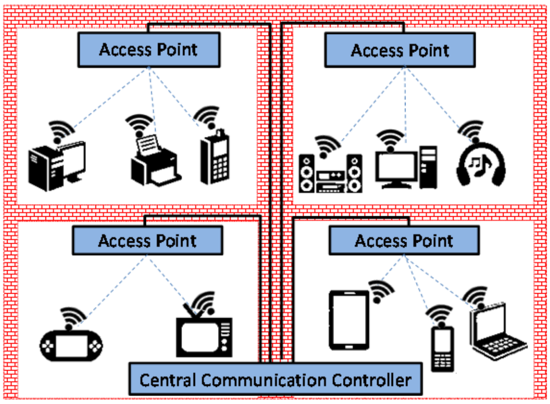


Fig. 1 Hybrid optical-radio wireless communication system with 2-dimensional passive pencil beam-steering.

hand, employ laser diodes, whereby high data rates are achievable easily. More than 10 Gbit/s data rate is achievable by just using energy efficient on-off-keying modulation format [7, 8]. Furthermore, ambient lighting, which is the dominant noise in VLC systems, is eliminated due to the insensitivity of infrared photodetector at the visible light spectrum. The limit to infrared free-space capacity depends on the capacity of the fiber itself. With the emergence of FTTH technology since 2004, infrared wireless communication is seen as a promising solution to bridge wirelessly the gap between the fiber and the end user [9].

In this paper, we experimentally demonstrate an infrared-based indoor optical wireless solution, employing passive diffractive optics for beam-steering over 2.5 m, using discrete multitone modulation (DMT). We report the optimization on the channel capacity to achieve an aggregate bitrate of up to 27.4 Gbit/s.

2. Hybrid Optical-Radio Wireless System

Figure 1 illustrates the concept of the proposed indoor optical wireless communication system. The system is interfaced to the access network via the central communication controller (CCC) which also stores routing information and executes an autonomous network management. The building is equipped with single- or multi- mode fibers for the in-building backbone network. An optical cross-connect then routes the signals, carried by different wavelengths provided at the CCC, to the respective fibers to transport them to the corresponding rooms and eventually to the access points. At the access points, a pencil radiating antenna (PRA) is employed. The PRAs are composed of a pair of crossed gratings for a two-dimensional dispersion effect, which then determines the position of the narrow beams of different wavelengths. As we can deduced from the figure, this architecture is based on line-of-sight systems which are typically suited for point-to-point communication via highly directional power efficient beams, and therefore, require precise alignment. As uplinks typically do not require as much bandwidth, 60 GHz radio wireless technology is foreseen. The uplink effort is currently work-in-progress and therefore, will not be reported in this paper. In order to locate the mobile devices, optical and radio localization techniques are foreseen.

3. Discrete Multitone modulation (DMT)

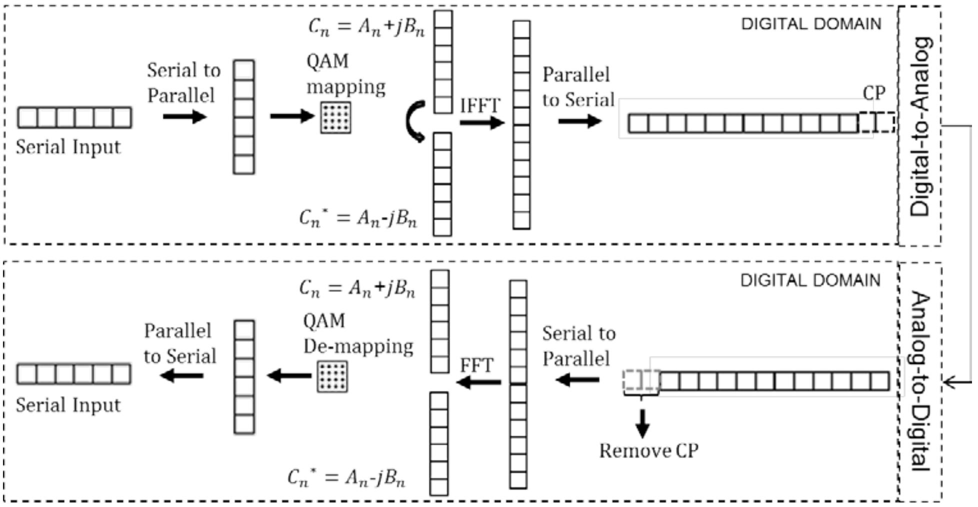


Fig. 2 Schematic block diagram showing the DMT process.

The basic principle of DMT is to divide a high data rate signal into smaller, lower data rate subcarriers that are simultaneously transmitted. Fig. 2 shows a high data-rate bit stream which is divided for each subcarrier and mapped into complex values according to the quadrature amplitude modulation (QAM) technique. The QAM level is dynamically allocated according to the signal-to-noise ratio (SNR) of the channel. Through IFFT, the data is now mutually orthogonal and is then converted from parallel to serial again. The real-valued digital data is converted to an analog signal and sent through the channel. On the receiver side, FFT is performed to retrieve the data.

4. Experiment Setup

The experiment is carried out on a testbed as shown in Fig. 3. A 1550 nm wavelength laser is set at 9.5 dBm. The beam, directly-modulated with DMT signal using the array waveform generator, is launched from the laser. It is sent to free-space through a fiber-pigtailed lens collimator with 18.36 mm focal length. The beam has a waist diameter of 3.33 mm. The beam then travels toward two cross-mounted echelle gratings. The first is an echelle grating blazed at 63° (31.6 grooves-per-mm) and the second is an echelle grating blazed at 75° (79 grooves-per-mm). The transmission distance for the diffracted beam is set to approximately 2.5 m. The free space transmission is received by another fiber-pigtailed lens collimator and sent to an optical receiver. The signal is then sampled on a real-time scope and processed offline on Matlab.

4. Results and Discussions

The received optical power of the free-space transmission has a measured power of only -5 dBm. Since the output optical power of the laser source was set to 9.5 dBm, the total loss of the system is then 14.5 dB which could be explained by the two gratings which divide the optical power in a matrix of beams, the polarization controller, coupling losses from free-space to fiber and from fiber-to-fiber connections. Since the output RF signal from the receiver is insufficient to be viewed on the scope, an electrical amplifier was added after the receiver to amplify the signal. A gross and net bitrates of up to 27.3 Gbit/s and 24.2 Gbit/s (BER = 1.02×10^{-3}), were measured, respectively. Alternatively, an EDFA with a bandpass filter were added before the optical attenuator and re-

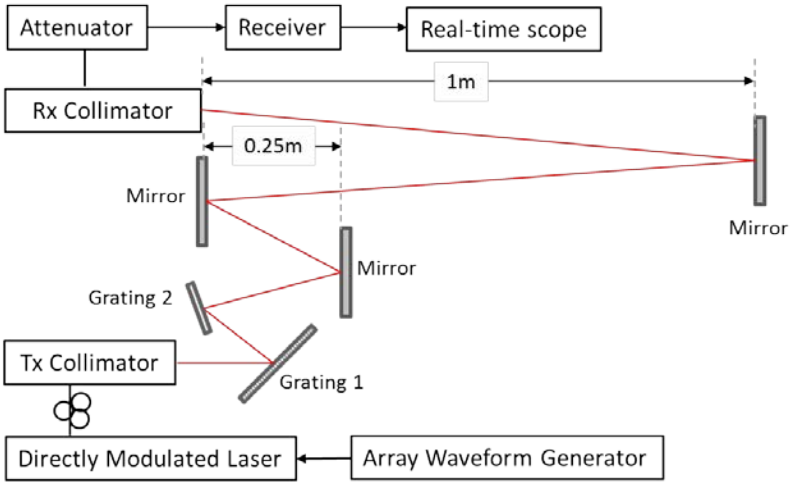
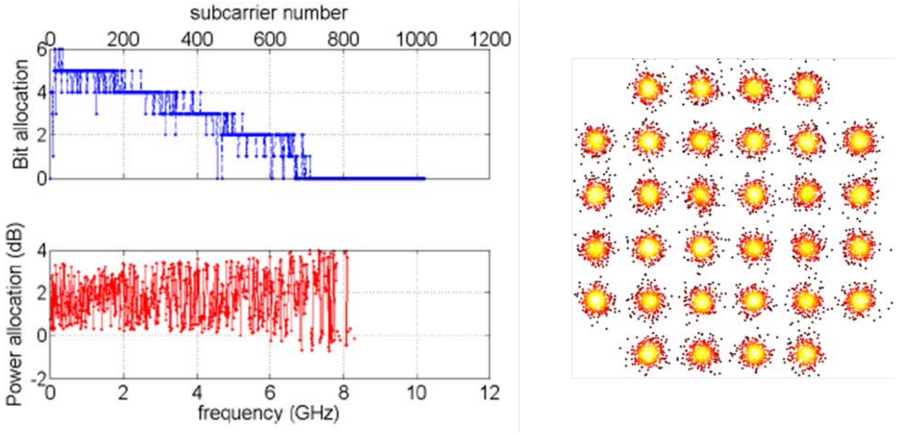


Fig. 3. Experimental testbed for a 2-dimensionally steered infrared optical wireless system



(a) Bit and power loading b) 32-QAM constellation

Fig. 4 Experiment Results for free-space 27.4 Gbit/s

measured. However, with 4 dBm optical input power, a gross and net data rate of only 27.4 Gbit/s and 24.3 Gbit/s (BER = 9.18×10^{-4}), were achieved, respectively, not significantly more compared to without EDFA.

5. Conclusion

We have experimentally demonstrated free-space channel performances of up to 27.4 Gbit/s and 24.3 Gbit/s, aggregate and net bitrates respectively, with DMT modulation on a two-dimensionally steered free-space optical wireless system of over 2.5 m. Additionally, BERs < 3.8×10^{-3} are achieved, therefore, the links are FEC correctable to achieve error-free transmission.

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