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Designing coherent optical wireless systems for high speed indoor telecom applications

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ABSTRACT

This paper focuses on several design issues of coherent optical wireless systems as a means of providing high data rate optical links in indoor environments enabling the realization of ultra-broadband wireless local area networks. We show how the performance specifications can be translated into signal-to-noise ratio requirements inside the coverage area, taking into account the laser phase noise mitigation scheme. We then discuss the power budget details using Gaussian beam optics incorporating the transceiver positioning and the optical systems used at the transmitter and receiver side. We also treat the influence of ambient light noise. We show that coherent optical wireless systems are characterized by excellent signal-to-noise performance enabling networking at very high data rates. Our results indicate that 2 Gb/s and 10 Gb/s data rates can be easily sustained at 3 m distances over a circular coverage area of 1 m radius using Class-1 lasers for the transmitter and the local oscillator. We also discuss the power gain compared to intensity modulated/direct detection optical wireless and show that it can be as high as 20 dB, especially near the edge of the coverage area.

1. Introduction

The distribution of online content through the world-wide web is expected to dominate video entertainment offering in the years to come. Various applications such as high-definition video surveillance, tele-presence and peer-to-peer networking put stringent requirements in the capacity of access and home/office networks. The advent of 4 K video distribution will not be fully supported unless multi-gigabit data rates become available at these domains. Fiber-to-the-home (FTTH) [1,2] is already being considered as a technology of choice for the realization of broadband access networks in many countries around the globe. Passive optical networks (PONs) [3] can support unrivaled access data-rates at the customer premises extending beyond 1 Gb/s, especially if wavelength division multiplexing (WDM) is applied [4,5]. The question now becomes how this broadband traffic can be distributed inside the home/office environment. Optical wireless may hold the key for overcoming this obstacle combining fiber-like data rates and the merits of wireless solutions including flexibility, mobility and cable-free installation in existing dwellings [6,7]. Data center networking [8] is another potential market for such ultra-high speed wireless technologies [9] alleviating the cost associated with fiber cable deployment and management. Optical wireless systems mainly rely on intensity modulation/direct detection (IM/DD) using either the infrared or visible spectrum [10]. Such links are shown to provide high data rates but can be impaired by ambient light noise and the multi-path nature of the optical wireless channel with direct detection.

In this paper, building on the existing know-how of IM/DD optical wireless, we investigate the potential of coherent optical wireless systems (COWS) [11–13] for establishing a multi-gigabit short range optical link and present a detailed system design framework covering various aspects of the system. The primary motivation behind our study is the inherent power gain of a coherent receiver which may lead to reduced transmission power requirements. Our results demonstrate the suitability of COWS for establishing ultra-broadband wireless local area networks intended for data center and local area networking. Compared to previous studies in the area of indoor COWS, the paper contributes in the following points: first, we include the effect of laser phase noise mitigation using digital signal processing and how it impacts the power budget of the link through the required receiver signal-to-noise ratio (SNR). Second, we highlight several aspects of the nature of the coherent optical wireless channel, which unlike conventional IM/DD is practically immune to multipath interference. We show that in integrated or fiber-coupled coherent

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receivers, ambient light does not couple well with the input waveguide mode or the local oscillator field and provide equations for the ambient light coupling efficiency. Using Gaussian optics, that are arguably more suitable for laser beam propagation than simpler Lambertian radiation patterns, we provide a detailed framework for the power budget analysis using ABCD matrix theory. We pay particular importance to transmitter and receiver optics. We show that a wide enough area can be covered using a two lens system at the transmitter and determine the required receiver optical system parameters. We highlight the relation between the transmitter power receiver area product $P_T A_r$ and the overall system performance and discuss the influence of residual ambient light noise. In addition we compare the performance of coherent and IM/DD optical wireless and show that the former requires much less power to achieve the same error rate and that the corresponding gain may be as high as 20 dB depending on the position inside the coverage area and the data rate. Our results indicate that 2 Gb/s and 10 Gb/s data rates can be easily sustained at 3 m distance over a circular coverage area of 1 m radius using Class-1 eye safe lasers for the transmitter and the local oscillator. Such a system therefore fulfills many of the requirements posed by next generation local area networks. The results of the paper indicate that although IM/DD optical wireless is cost-effective, coherent optical wireless requires much less power, no equalization scheme to mitigate the frequency dependence of the channel while at the same time provide the well-known spectral efficiency of coherent detection enabling dense wavelength division multiplexing in order to meet data rate requirements imposed in large server farms [14].

The rest of the paper is organized as follows: in Section 2, we present the architecture of a coherent optical wireless link, highlighting various components that play an important role in the design procedure including the modulator, transmitter optics, free space propagation, receiver optics and the achieved SNR at the coherent receiver. In Section 3, we examine the receiver SNR requirements imposed by phase modulation schemes such as

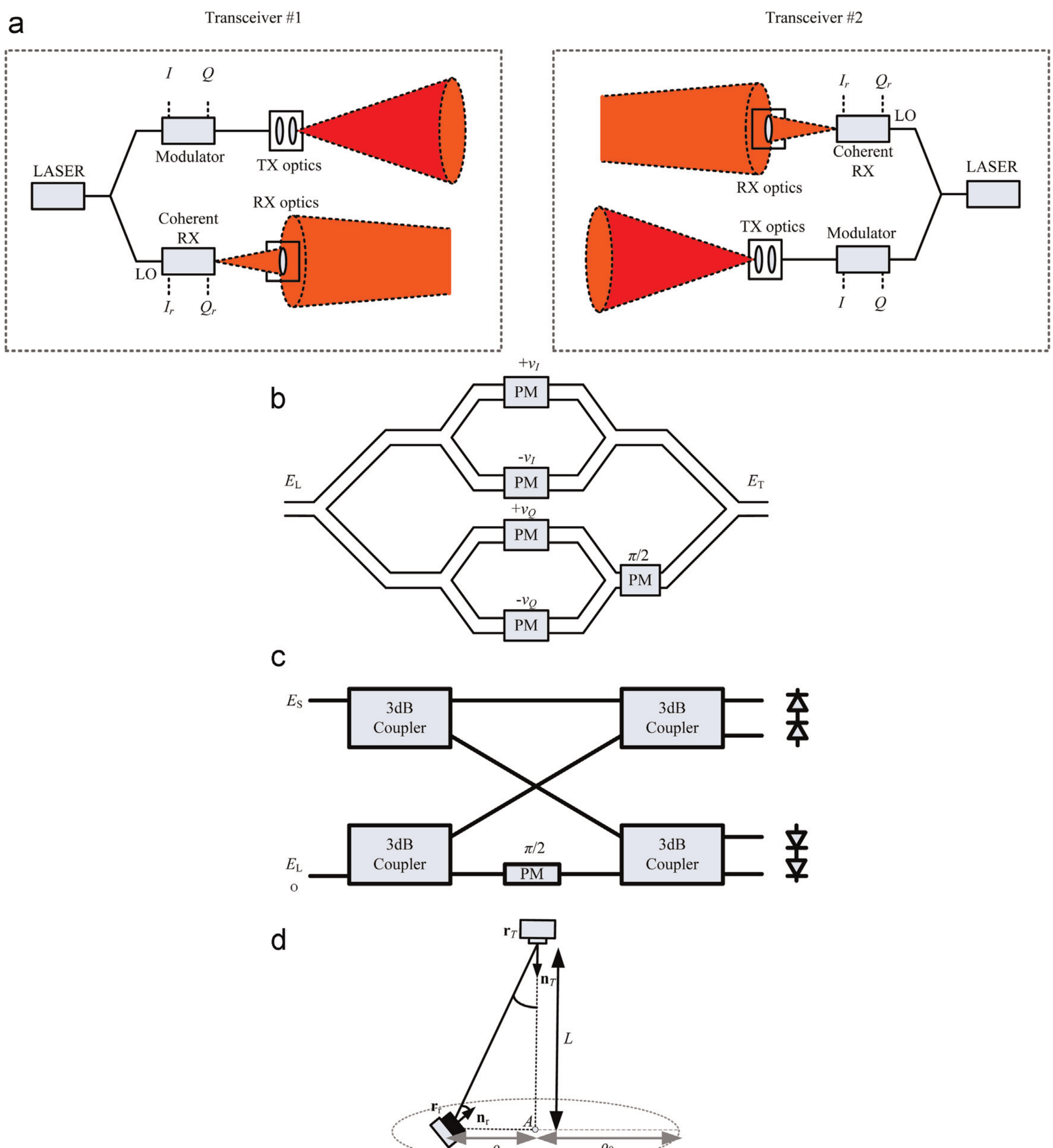

Fig. 1. System under consideration: (a) coherent transceivers possibly employing a single laser at each side, (b) an I/Q modulator, (c) a coherent receiver based on a 90° optical hybrid and (d) transceiver placement.