Coherent Optical Wireless: Realizing Fiber-like Connections out of Thin Air

Thomas Kamalakis
Department of Informatics and Telematics, Harokopio University/Athens 9 Omirou Street, Athens GR17778, Greece +030-+302109549401
thkam@hua.gr

Panagiotis Kanakis
Department of Informatics and Telematics, Harokopio University/Athens
9 Omirou Street,
Athens GR17778, Greece +030-+302109549433
pkanakis@hua.gr

Adonis Bogris
Department of Informatics, Technological Educational Institute/Athens Ag.Spiridona st, Aigaleo GR122 10, Greece
+302105385312
abogris@teiath.gr

ABSTRACT

In this paper, coherent optical wireless (COWs) technology is proposed for indoor high data rate communication applications. We discuss several design issues and the architecture of the optical wireless coherent transceiver. We also present an initial system demonstrator along with some initial performance results.

Categories and Subject Descriptors

C.2.1 [Computer-Communication Networks]: Network Architecture and Design

General Terms

Design, Performance, Verification

Keywords

Wireless networks, home networks, photonic technologies.

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 bandwidth-hungry applications such as high definition video surveillance, tele-presence and peer-to-peer networking put stringent requirements in the capacity of local area networks. The advent of 4K video distribution will not be fully supported unless multi gigabit data rates become available at these domains. The problem is also highlighted with the advent of Fiber-to-the-home (FTTH) as a dominant last-mile solution [1]. FTTH is being considered for the realization of broadband access networks in many countries around the globe. Passive optical networks (PONs) can support unrivaled access data-rates at the customer premises extending beyond 1Gbps, especially if wavelength division multiplexing (WDM) is applied [2]. The question now becomes how this broadband traffic can be distributed at the user premises, 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 lack of cable installation in existing dwellings. Data center networking is another potential market for such ultra-high speed wireless technologies alleviating the cost associated with fiber cable deployment and management.

In this paper, we discuss the potential of optical coherent wireless systems (COWS) for establishing high data rate, short range optical links. These links can be used to provide fiber-like data rates, essentially realizing fiber connections out of thin air. A number of advantages are associated with the application of coherent detection in the optical wireless domain: These include the achievement of better signal-to-noise conditions, increased coverage and higher data rates, as a consequence of the inherent receiver gain due to the mixing of the incoming signal with a local oscillator [3]. For this gain to be maximized, the spatial phase distribution of the optical field should match that of the local oscillator field. This is perhaps one of the most intriguing aspects of these systems: it implies that communications should rely purely on a line-of-sight component and that unwanted multipath contributions caused by reflections at the walls of the room will be discarded. This is a consequence of the diffuse nature of these reflections. At the infrared or visible wavelengths, most surfaces are considered rough and hence non-specular reflections occur rendering the reflected beam partially coherent. We therefore expect that these components will not match well with the spatially coherent local oscillator field. As a consequence, the coherent channel can be considered flat and largely free from multipath distortion. The same argument applies to ambient light noise. Since the ambient field is incoherent, it will also not mix well with the local oscillator. Ambient light should however contribute to the electrical receiver shot noise in the case where the receiving photodiodes are directly exposed to the indoor environment. If light is coupled to the receiver using a waveguide (e.g. optical fiber), then the ambient light coupling efficiency is determined by the excitation of the waveguide modes. For mono-mode waveguides, the fundamental mode has a smooth profile and hence most of the ambient field will be rejected.

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In this paper, we present a brief overview of COWS for indoor applications. We discuss the system architecture and present some initial experimental results obtained from a demonstrator setup.

2. SYSTEM ARCHITECTURE

Figure 1 shows the COWS system under investigation. In order to limit the number of required optical components the same laser can be used as a source for transmitting the downlink data and as a local oscillator for the uplink signal. In this manner, the light beam of the laser source is divided by a 3dB splitter into two branches. The upper branch is fed to an I/Q modulator [4] which imprints the signal to be transmitted in the optical field. The structure of the modulator is shown in figure 1(b). In the case of PSK modulation, a simpler phase modulator can also be used instead. The field exiting the modulator passes through the transmitter optics consisting of a number of diverging or converging lenses that are used for shaping the beam and achieving the required coverage at the receiver plane at the opposing side. The optical systems of both the transmitter and the receiver comprise of simple lenses. The use of diffusers has been may provide more uniform illumination but it may also degrade the coherence properties of the wave and therefore limit the coupling efficiency at the receiver.

The lower branch acts as the local oscillator of the coherent receiver for the uplink data. The coherent receiver can be heterodyne or homodyne, with the latter providing a 3dB SNR gain compared to the former [5]. The optical field at the receiver side is collected by the receiving lens and is focused on the input port of the coherent receiver. Various implementation strategies can be adopted for the coherent receiver. Figure 1(c) assumes an optical hybrid-based phase diversity homodyne receiver widely used in fiber-optic systems that is depicted in figure 1(c). Figure 1(d) shows the arrangement of a transmitter/receiver pair in a typical indoor scenario. The coverage area is determined by the beamwidth at the receiver plane which should be chosen depending on the required link flexibility and mobility. Depending on the application scenario one must seek a compromise between transmitter and local oscillator power, receiver area and system coverage.

3. COWS DEMONSTRATOR AND PRELIMINARY RESULTS

Figure 2 shows the COWS demonstrator implemented at the telecom and electronics laboratory of the Department of Informatics and Telematics. The system is based on commercially available components operating at 1550nm. There are two reasons behind this wavelength choice in the wireless domain. First of all, the majority of the required components (narrow-linewidth lasers, I/Q modulators, integrated coherent receivers, etc) are already commercially available in integrated form at λ=1550nm, which may significantly simplify the implementation of the system. At the time of this writing, such components were not readily available at other wavelengths, say at λ=800nm which is popular band for IM/DD optical wireless systems. The second reason is that at the infrared spectrum, ambient light noise from sunlight or artificial lighting generally decreases with increasing wavelength, implying that larger wavelengths are generally more favorable in terms of the SNR. Figure 3 shows the block diagram of the COWS demonstrator. Light from a commercial narrow linewidth external cavity laser pass from a polarization controller and is then modulated by a $LiNbO_3$ modulator with a half-wave switching voltage of about ~6.2V. The polarization controller is used in order to control the polarization of the incoming light so that optimum modulation performance is obtained. Light is then fed to a collimator and propagates in free space. At the receiver side, light is collected from a fiber port and then passes through a polarization controller. Light is then coupled to a commercially available homodyne coherent receiver, along with the local oscillator field. An additional polarization controller is used in order to match the polarizations of the signal and the local oscillator. Preliminary results indicated a path loss of ~12dB at ~50cm, mainly caused by coupling losses at the collimator and the fiber port. Excellent performance was obtained even at low AC driving voltages. When a binary phase shift keying modulation format is used at the transmitter with a low driving of 2Vpp, the receiving signal-to-noise ratio per symbol was measured at about 10dB and the bit error ratio was measured of the order of 10^{-4}. The results demonstrate the potential of COWS for high-speed local area network implementations.

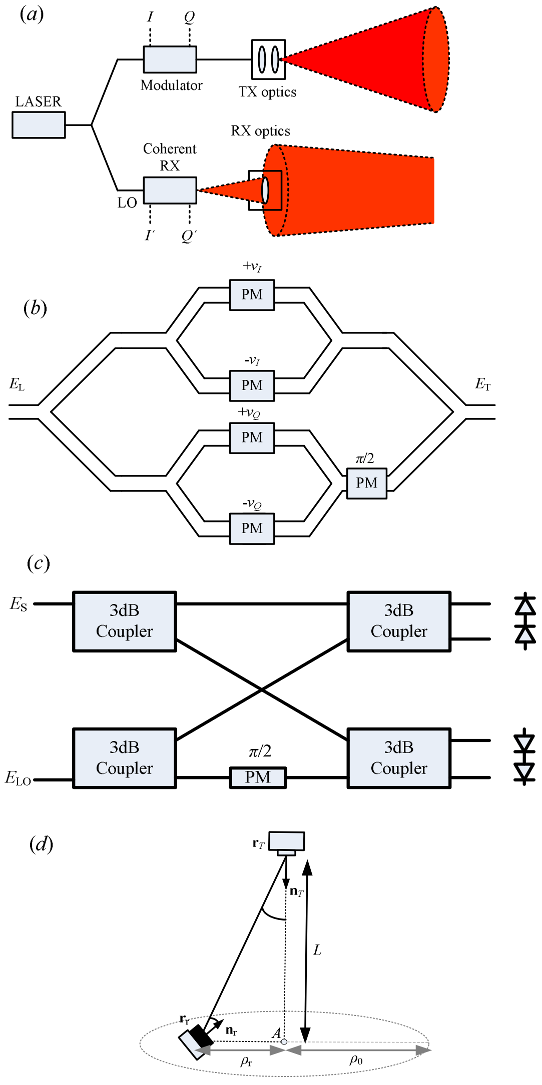

Figure 1. System architecture

Figure 2. COWS demonstrator realization

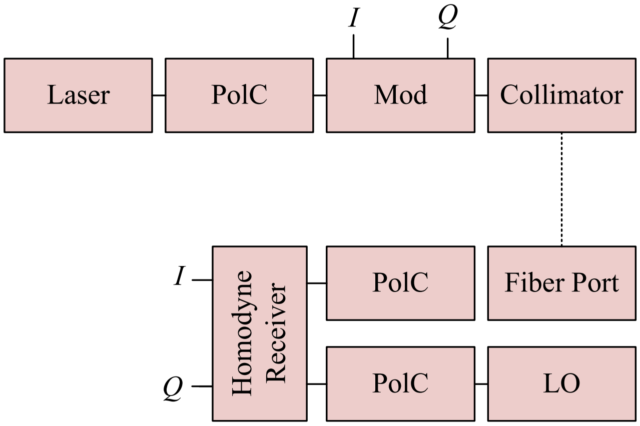

Figure 3. COWS demonstrator block diagram

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5. CONCLUSIONS

We have discussed the potential of coherent optical wireless systems for establishing ultra-broadband point-to-point local area network connections. We have analyzed the architecture of the system and presented an initial implementation along with some preliminary performance results.

6. ACKNOWLEDGMENTS

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