Research Article

SISO and MISO Architecture Investigation for Wireless Optical OFDM Transmission

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Abstract As the need for demanding communication applications is increasing, the high speed connectivity has become a very significant issue. Thus, the study of optical wireless communication systems can lead to more efficient transmission schemes and techniques that will allow a high capacity bandwidth along with low bit-error-rate (BER). Moreover, the use of a bandwidth efficient signal modulation scheme like orthogonal frequency division modulation (OFDM) has provided the basis to compete with established wireless transmission schemes. In this work, we investigate the performance of an optical wireless link using a visible light laser beam at 680 nm with, both, single-input-single-output (SiSo) and multiple-input-single-output (MiSo) transmission topologies. We evaluate in practice the performance of the link with respect to BER and data rate achieved for an increasing number of subcarriers (64, 128, 256) and with various subcarrier modulation schemes (BPSK, QPSK and 16-QAM). The system gives very good results for non-coded transmission reaching up to 250 Mbit/s with a BER of 10^{-3}. In practice, this value is fully acceptable due to the fact that a BER of up to 10^{-7} in commercial wireless optical systems (e.g., Wi-Fi, WiMAX, etc.) introducing coding at the lower network layer could be thus envisaged.

Keywords wireless optical networks, visible light communications, spread spectrum modulation techniques, orthogonal frequency division multiplexing

1 Introduction

The increase of the number of portable devices has increased the need for wireless connectivity as well as higher data rates per user. This demand has lead to a bottleneck for the entire successful transmission scheme already having a predefined bandwidth (e.g., 2.4 GHz) limiting performance throughout the network layer services. The introduction of new more bandwidth efficient and high-speed transmission schemes is essential in order to overcome the high bandwidth demand of the latest applications offering better quality of services (e.g., Full-HD videos, online gaming etc.). The wireless optical physical layer, based on a digital modulation scheme, has been investigated as an alternative candidate to RF transmission schemes [1,6,7,9,11,12,13,14]. Although transmission quality and capacity metrics are sufficient, the data rates achieved are not able to offer a point-to-multipoint link as 802-11x provides [3] via the use of spread spectrum transmission schemes in RF communication systems. We have investigated the use of an analog modulation scheme, in our case OFDM [17], to increase the capacity of the link and achieve high data rate figures. Spread spectrum schemes offer substantial advantages to the wireless optical links which suffer from fading and the multipath effect degrading their performance. Some other techniques to overcome these effects have introduced different transmission topologies than the standard SiSo used in most of the communication systems. In RF systems, multiple antennas (MiMo) have been proven capable of increasing throughput as well as eliminating the multipath and fading effects. This, in the realm of a wireless optical system, has to be translated to more than one transmitting components, Lasers or LEDs.

In this work, we highlight the importance of implementing and investigating the different topologies of the visible light wireless optical transmission scheme. In Section 2, we analyze the modulation scheme used as well as the advantages expected from the SiSo and MiSo topologies. Section 3 has an extensive description of the components used to implement the wireless optical test bed relating to the results achieved at Section 4. Finally, we will conclude comparing our system performance with other communication systems [16].

2 High data rate wireless scheme

A major role is played by the modulation scheme used for each communication system in relation to the operating environment. Regarding diffuse optical communication systems that operate indoors, the multipath effect can be

very destructive for the link quality. As the power loss with each reflection can vary from 40% to 90% for plaster walls, it is able to desynchronize the transmission.

This work focuses on an OFDM scheme which requires less processing power, with respect to other spread spectrum techniques (e.g., CDMA), and also introduces less complexity to the overall system implementation. OFDM offers immunity to multipath effect and high capacity, commensurable with high data rates.

Although in RF-based OFDM transmission systems both in-phase and quadrature components are transmitted, in optical systems it is not possible to relay phase information. The optical carrier is at THz frequency not allowing the signal demodulation due to technological restrictions.

Because of this physical restriction, we had to apply a modification to the frequency spreading block of the overall system. An IFFT process performs the frequency spreading for the OFDM scheme generating I/Q components. The modification at the IFFT process is a generalized modification of the original function:

$$X(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j(\frac{2\pi}{N})kn}, \tag{1}$$

where $X(k)$ represents the amplitude and phase of the different signal components arriving from the BPSK/QPSK mapping block.

By parallelizing the complex components carried out from the mapping block (e.g., QPSK 16-QAM) we mirror them, introducing DC components for separation, by reversing the complex-conjugated symbols. As a result a stream of real-valued samples is generated, corresponding to an intensity modulation at the optical source allowing the fast and accurate demodulation of the transmitted signal (Figure 1),

$$X(k) = DC, a+bi, c+di, \ldots, DC, \ldots, c-di, a-bi,$$
$$Y(k) = A, B, C, \ldots, S. \tag{2}$$

Suitable optoelectronic components, based on a simple LED or Laser diode, can emit the signal. On the other hand, the use of a low cost, off-the-shelf APD (Avalanche photodiode) offers a large area of reception with minimum noise figures for the optical-to-electrical conversion [4,5,15].

Such modulation scheme can be enhanced using a different transmission topology than the ordinary SiSo. Especially, the MiSo scheme can also provide, for the wireless optical links, better SNR figures [10].

3 The wireless optical OFDM system

The orthogonal frequency division multiplexing is widely used in wireless RF communication systems and our goal is to adapt and investigate the performance of such a modulation scheme to the wireless optical physical layer.
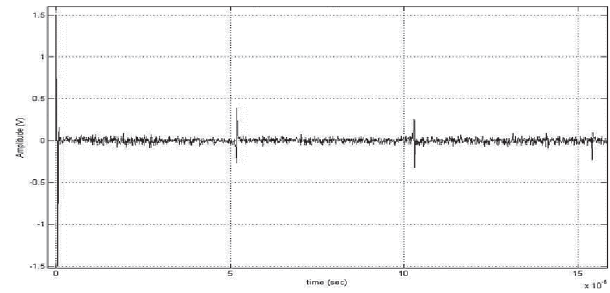

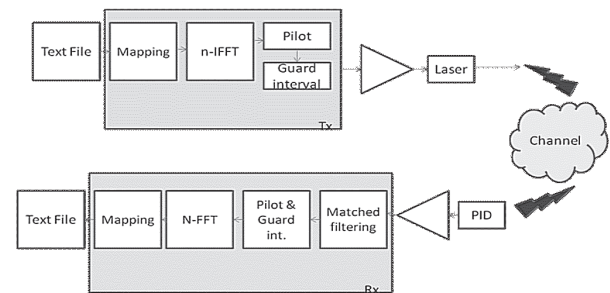**Figure 1:** Wireless optical OFDM transmitted frame.

Figure 2: Wireless optical OFDM system block diagram.

An optical test bed has been implemented in order to allow further evaluation of the simulated system in real conditions. For this reason, we have integrated optical components in an optical laboratory bench as an optical interface and furthermore we have emulated the entire system with a vector signal generator from Agilent technologies (E8267D). The wireless optical system is designed to explore, mainly, the physical layer performance of the transmission rather than the actual protocol stack of a network. In Figure 2, the full block diagram of the evaluated system is presented. For the transmission part, a text file was chosen, broken-up in bits and mapped to subcarrier modulation schemes according to transmission requirements. The subcarriers modulation schemes can be BPSK, QPSK or 16-QAM in every number range from 4 to 512. After the mapping process, the symbols are driven to a serial-to-parallel block and introduced to the IFFT spreading process, as explained in Section 2. The result of this process is amplitude modulation transmission as we are not able to have coherent schemes in wireless optical systems. All this process is driven by custom software and the samples are downloaded to the Agilent vector signal generator where we can introduce the desired sampling rate and also further amplification if necessary. Once the samples are loaded to the generator, we are choosing the sampling rate, in our case 10 MHz. The output of the signal generator is interfaced to a laser driver which biases the 650 nm laser diode. In order to stabilize the laser diode, we have used temperature controllers keeping the temperature at 25 degrees centigrade.

Pilot signal 10-samples	Data Load N-samples	Guard interval 16-samples

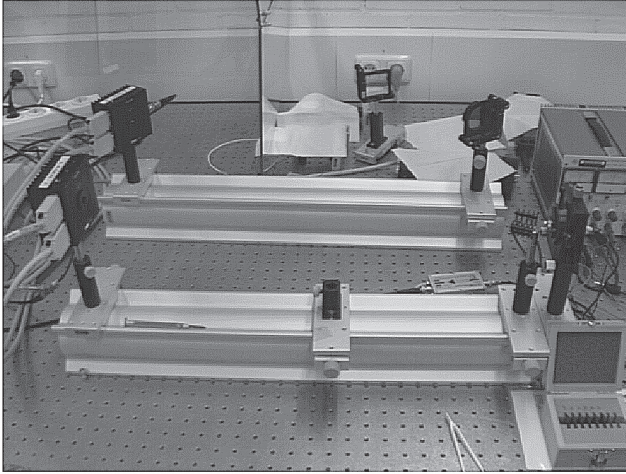**Figure 3:** Generic wireless optical OFDM transmitted frame.

Figure 4: Wireless optical transmission test bed for SiSo and MiSo schemes.

Regarding the MiSo transmission case, we have split the output signals from the generator to two optical configurations, including the laser driver and the temperature controller. The secondary transmission is towards the photodiode at an angle of 45 degrees and with an optical power drop up to 3 dB.

On the receiver side, a small area silicon photodiode (BPX65) is collecting the light emitted by the laser diode and converts the optical power to electrical current. An amplification stage is required in order to amplify the signal above the noise levels. A standard 500 MHz wideband amplifier was used. The next stage is the offline recording and processing stage where we introduce the signal from the amplifier to a highly accurate oscilloscope (Agilent Infinium DS0813048) which we have used as a measurement recorder, allowing us to vary the sampling rate and increase precision. Using the Agilent oscilloscope, we record the received signal and introduce it to Matlab for demodulation and further processing.

Using Matlab, we can identify the beginning of the transmitted frame. Each transmitted frame (Figure 3) contains a pilot signal, the data load, and a guard interval, which we have chosen as a maximum value of the ratio of 1/5 of the total frame load. The synchronization phase is done by auto correlation of the recorded with the already known pilot sine signal. Once we have identified the beginning of the frame, we can extract the data load and introduce it to the FFT block

Modulation scheme	64-subcarriers	128-subcarriers	256-subcarriers
BPSK	38.75 Mbit/s	43.05 Mbit/s	45.5 Mbit/s
QPSK	77.5 Mbit/s	86.1 Mbit/s	91.17 Mbit/s
16-QAM	310 Mbit/s	344.4 Mbit/s	364.7 Mbit/s

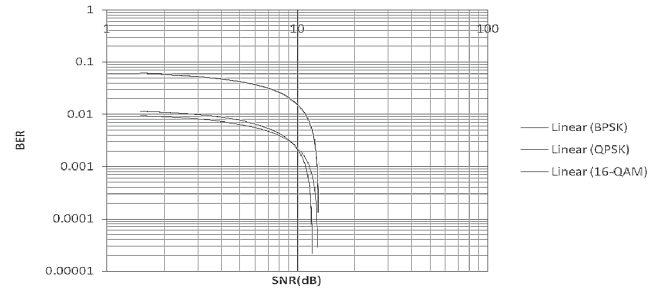**Table 1:** Wireless optical transmission data rate per number of subcarriers

Figure 5: OFDM transmission with 64-subcarriers for SiSo scheme.

in order to generate the mapped symbols. Consequently, the bit-stream is reproduced generating the original text file.

By comparing, both, the original and the regenerated text files, we are able to calculate the transmission bit-error-rate and further evaluate the system figures of merit (transfer functions, constellation diagrams, data rate, etc.). Finally, with this procedure we are able to investigate all transmission possibilities with different attributes and obtain a clear overview of a real system performance in fairly short time.

4 Link analysis and result exploitation

Since we would like to investigate the performance of the system in different channel cases, we have used optical attenuators in order to degrade the signal power from 1.5 dB up to 15 dB. The wireless optical system is mounted on an optical bench with the aid of rails (Figure 4).

The system transmission has reached high data rates (Table 1) proving that such technology can be an alternative to the RF wireless communication technologies. Although the maximum data rate achieved is 364.7 Mbit/s, the BER was of order of 10^{-2} not really allowing quality of service. It is worth mentioning that the entire system does not incorporate any physical coding scheme. Introducing further coding could enhance the system BER performance by at least two orders of magnitude.

In Figures 5 and 6, the BER performance versus the signal-to-noise ratio (SNR) is depicted for MiSo and SiSO transmission schemes. The BER at the MiSo scheme has been enhanced by nearly 5% compared to the SiSo results. This small enhancement is due to the increase of the overall SNR which is slightly better for the MiSo case.
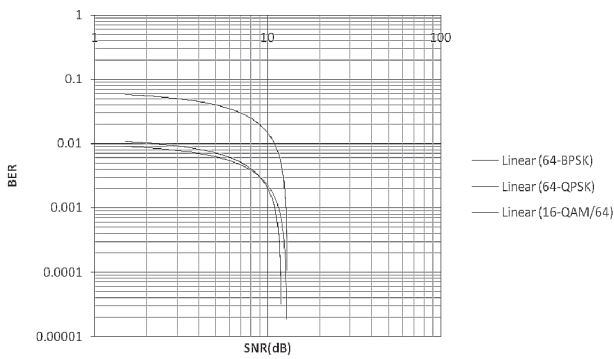
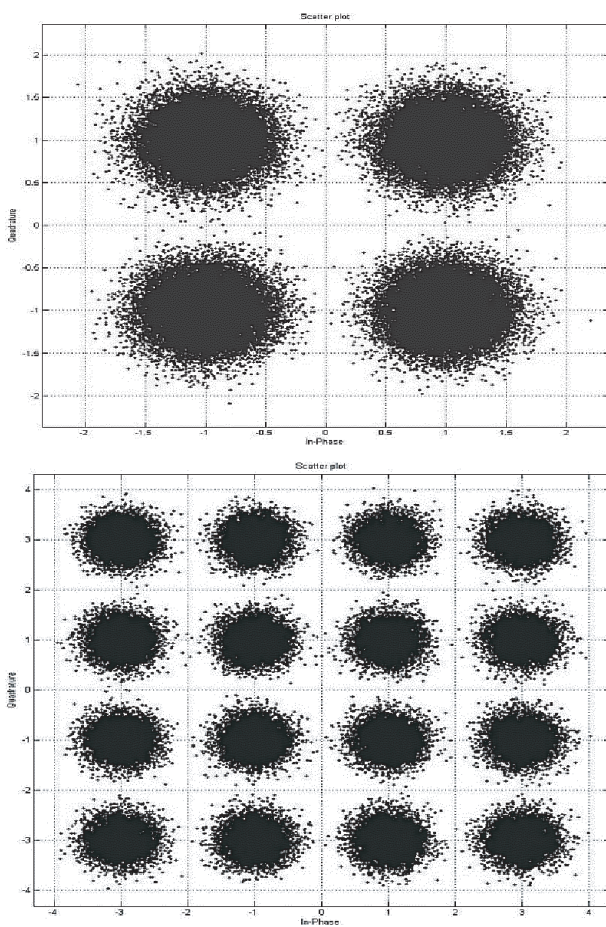**Figure 6:** OFDM transmission with 64-subcarriers for MiSo scheme.

Figure 7: Constellation diagram for 64-subcarriers transmission QPSK and 16-QAM for MiSo architecture.

To further investigate and analyze the subcarriers performance, we have calculated the constellation diagram of the transmission. In Figure 7, a QPSK and 16-QAM constellation with low BER figures shows clearly that the symbols, especially for the QPSK case, can be identified and the overall OFDM frame can be reconstructed to represent the original data with minimum loss.

Such results allow the introduction of such technologies into the future household "visible light" communication links where high power ultra bright LEDs will provide illumination as well as data transmission from the same source.

5 Conclusions

An extensive investigation of a high data rate transmission scheme for wireless optical communication links has been carried out in order to identify the proof of concept as well as the capabilities and challenges in such a system. Spread spectrum modulation schemes are already used in systems incorporating RF technologies with exceptional results. This work proves that it is possible at a minimum cost to implement a wireless link with data rates over 150 Mbit/s with low BER figures. As an improvement to the system, further line coding could be integrated decreasing the BER figures by another two to three orders of magnitude [2, 8].

Finally, such technology can offer a solution for several environments where RF technologies are prohibited such as hospitals, factories, and aircraft cabins in case of sensor networks or plain data links.

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