Luminaire-Free Gigabits per second LiFi Transmission employing WDM-over-POF

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Abstract *A transmission link comprising wavelength division multiplexing over 1mm core size step-index plastic optical fibre and up to 1.6m free space is demonstrated for indoor optical wireless communication. Throughputs of more than 2 Gbps has been achieved using 2 wavelengths and discrete multitone.*

Introduction

With the increasing number of wireless devices interconnected, the radio spectrum is becoming congested. One of the main technologies used to ease the pressure on this spectrum is the optical wireless communication (OWC). OWC offers high bandwidth and makes use of unlicensed spectrum. Among the OWC solutions, a promising one is visible light communication (VLC) (a.k.a. LiFi). Usually LiFi considers light emitting diodes (LEDs) installed in the ceiling illumination units ('luminaires') due to their low cost and their capabilities on combining lightning and communication[1]. However, conventional illumination LEDs have narrow bandwidth and high non-linearity which severely limit their application. Another option is to use smaller area LEDs (µ-LEDs) which can provide larger bandwidth[2]. However, µ-LEDs come at the expense of efficiency drop, needing an additional measure to mitigate this, hence increasing the price of LEDs, which undermines the reason to use them. Larger bandwidth laser diodes at the ceiling can technically be a solution. In this paper, we propose not to use separate light sources at the luminaires for data transmission to user devices. Instead, we propose to use large-core optical fibres acting as the light source in the luminaire which are fed by remote light sources, jointly located centrally in the house. Hence no electrical powering and maintenance at the luminaires is needed, which brings considerable operational benefits.

There are several optical network infrastructures that can be considered to carry data from a home central unit to the luminaires. Silica single- and multi-mode fibres have an excellent transmission performance, but they are labour-intensive to install, so costly and not easy to be deployed in-home networking. Plastic optical fibres (POFs) are a very attractive solution for short indoor communication networks due to their do-it-yourself installation options, small bending radius and low cost[3]. Among different types of POFs, the 1-mm core size polymethyl methacrylate step index POF (SI-POF) is the most popular and attractive for indoor communications. This standard POF uses visible wavelengths, enabling visual link testing with naked human eyes, thus easing the installation. A major drawback of SI-POFs is inter-modal dispersion, resulting in a low transmission bandwidth. However, with advances in spectral-efficient modulation formats, multi-Gbps transmission using SI-POFs has been realised[4]. Another solution for increasing POF throughput is to employ wavelength division multiplexing (WDM) where multiple optical carriers are transmitted in parallel within a single POF[5,6]. The WDM solution cannot only be attractive for increasing total throughput on POF links, but also for enabling wireless distributed multiple input multiple output (D-MIMO) techniques[6] which ensure a consistent link performance by supporting mobility and user density variations in the indoor wireless network.

For these reasons this paper demonstrates a novel two-channel WDM transmission over POF enabling source-free luminaries. Our wireless light sources on the ceiling consist only of POF-end faces and a collimating lens, see Fig. 1. We show that this simple structure can result in more than 2Gbps for wireless distances up to 1.6m. We believe that this technique can be scaled up to accommodate more indoor users with higher throughputs and larger coverage areas.

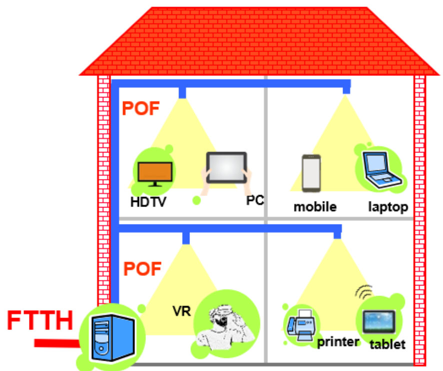
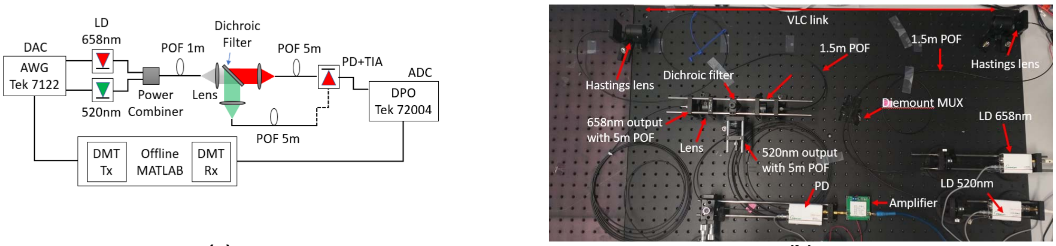


Fig. 1: An in-home network employing luminaire-free LiFi transmission systems.

WDM-over-POF concepts for LiFi system

Fig. 1 shows an in-home network, where last meter connectivities are provided by LiFi. Each



(a) (b)

Fig. 2: WDM-over-POF with a VLC link: schematic (a) and experimental setup (b).

room is connected to a central unit by POF and all user devices receive wireless signals from POF-end faces collimated by a lens. The light in the POF consists of multiple WDM channels and each channel represents an in-home service. At a wireless device, a user can select the WDM channel he/she wants to receive. Different in-home services can be stacked in the RF spectrum and be multiplexed to form a WDM channel. By doing so, a variety of in-home services can be transmitted by a single POF. The efficiency of the WDM system is characterized by the performance of the multiplexer (Mux) and demultiplexer (DeMux). The Mux performance is mainly characterised by the insertion loss of each channel. In the DeMux, in addition to the insertion loss, leakage from neighbouring channels may occur due to insufficient channel separation in the DeMux. Such crosstalk effects in the DeMux need to be carefully minimized. Among different approaches for implementing the DeMux, we chose to implement the one based on dichroic separating filters with 45-degree angle of incidence due their low losses, low reflection, and high flexibility for more channels.

The system's diagram can be seen in Fig. 2. The transmitter is composed of two DFB LDs and one 2x1 power combiner from Diemount, that it is used as a Mux, with loss of 1.8dB. The LDs are from Graviton Inc. with visible emitting wavelengths at 520nm (green) and 658nm (red). The LDs are then directly intensity modulated in their linear region and butt-coupled into the POF. The multi-wavelength beam in the VLC channel is collimated by means of triplet achromatic lenses from Thorlabs. In the receiver, after the VLC transmission, the channels are separated in the DeMux, which is implemented with bulk components. The DeMux is implemented using off-the-shelf long pass dichroic filters from Thorlabs, which are designed to an incidence angle of 45º and cut-off wavelength at 605nm. An optical cage system is used for the alignment of the DeMux. The output of the DeMux is coupled into 5m ∅1 mm core SI-POF and then butt-joined and detected by an optical receiver comprising a silicon photodiode (PD) and transimpedance amplifier (TIA). The Graviton receivers are used for both channels and have wavelength dependent detection bandwidth with 1.2GHz at maximum. The receiver sensitivity is also wavelength-dependent with the response to the green light being 50% of that to the red light. Therefore, more optical power is needed for green light to have a similar performance as red light. This paper uses discrete multitone (DMT) modulation with BER of around 1E-3 to determine the link performance.

Results

The WDM-over-POF system is characterized by measuring the crosstalk due to side-channel leakage and losses due to in/out light coupling and beam alignment in the DeMux. To analyse the crosstalk and losses of the system the Yokogawa AQ6374 optical spectrum analyser (OSA) is used. For the green channel a crosstalk level of -13dB and 3.2dB loss is measured and for the red channel -25.7dB crosstalk level and 3.6dB loss. The difference in the crosstalk level for each channel is due to the asymmetric emitted optical power of each LD and lower losses in the reflection path in the long pass dichroic filter. Introducing an extra bandpass filter in the DeMux, the amount of crosstalk filter can be reduced from -13dB to -25dB, but at the expense of 6dB additional loss, hence is not used in this work.

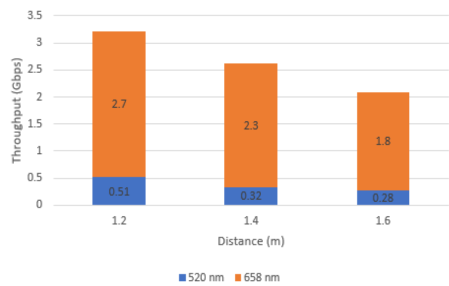


Fig. 3: Link performance of VLC transmission with WDM-over-POF using DMT modulation.

The performance for each channel is asymmetric due to the differences in wavelength characteristics of the POF transceivers, emitting power and receiver sensitivity. This results in a different link budget and bandwidth for each channel. The emitted optical power for the green and red laser are -1.8dBm and +2dBm respectively. Both lasers are biased at 80mA. A DMT modulation format is used to provide higher spectral efficiency within the two channels. DMT modulation is a baseband version of orthogonal frequency division multiplexing (OFDM) with bit and power loading. Parallel passband signals are transmitted with quadrature amplitude modulation (QAM). The signal is generated using a Tektronix arbitrary waveform generator (AWG) 7122, that is used as a digital-to-analog converter (DAC). After the signal being generated it goes through the Mux and then after transmission through the POF and lens into a collimated VLC channel. For the VLC channel performance measurements were made at several distances, from 1.2m up to 1.6m VLC. At detection the signal enters the analog-to-digital converter (ADC) and sampled by a 50 GSa/s digital phosphor oscilloscope (DPO). An offline signal processing is subsequently deployed and throughputs, signal-to-noise ratio (SNR) and BER counting are proceeded.

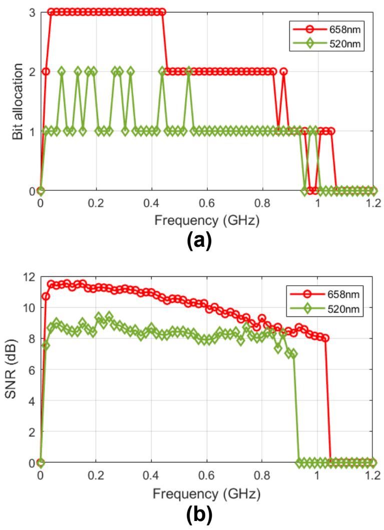


Fig. 4: Bit allocation (a) and received SNR (b) for 1.2m VLC transmission.

To estimate the channel and then to allocate the number of bits per subcarrier a pilot signal with 64 subcarriers loaded with 4-QAM is transmitted. For both channels the use of 64 subcarriers is adequate to maximize the throughput and to allow BER values to be around 1E-3. To reduce the peak power and to limit the dynamic range of the DMT signal we clipped the signal. For the green channel a clipping of 9dB is used and for the red one of 10dB. In this paper we define clipping as the ratio of the maximum allowed peak amplitude over the root-mean-square amplitude of the original DMT signal. In Fig. 3 the total throughput per distance of the VLC transmission with WDM-over-POF for each channel is presented. All the measurements were performed with ambient light on. No noticeable change in the performance was observed when ambient lights were turned on/off. In Fig. 4 the received SNR variation and bit allocation for the 1.2m wireless length is presented as a function of frequencies. The difference between the received bandwidth, SNR and throughput of each channel is related to the asymmetric link budget and frequency response of each channel. For the red channel the increase of the distance is not so substantial. However, for the green channel, it causes a drop in the received power which is close to the receiver sensitivity for this wavelength, resulting in a significant performance reduction. The constellation for the received green and red channels for the shortest link (1.2m VLC) modulated with 4-QAM can be seen in Fig. 5(a,b). We can see a clear separation between constellation points, indicating an excellent transmission performance. These constellations are very similar to the case of 1.6m VLC. Longer POF and wireless distances will deteriorate the link performance, but we believe that longer links are possible by making a dedicated signal processing circuit to increase SNR values, especially around the high frequencies.

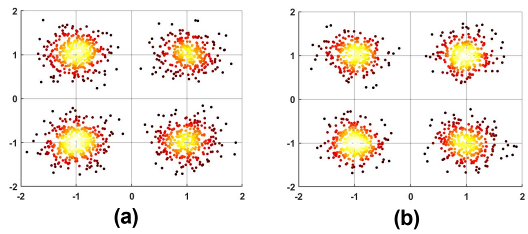


Fig. 5: Received constellation for the green channel (a) and for the red channel (b) considering 1.2m VLC transmission.

Conclusions

We presented an indoor communication system combining POF and wireless link without using separated luminaires. Experimental results based on proof-of-principle are given for downstream employing two wavelength channels (520 and 658nm). Each wavelength channel can be used to serve a mobile user device. Different lengths of wireless transmission were presented, reaching a total throughput of >2Gbps using DMT. The asymmetric performance of the red and green channel is largely attributed to the differences in emitting power, RF bandwidth and the sensitivity of the POF transceivers. Further work will include the return path and distributed MIMO to ensure high performance wireless links. We believe that the proposed POF-LiFi system is an attractive simple and potentially low-cost technique for high-capacity indoor communication.

Acknowledgements

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