POF feeding in Li-Fi systems with MIMO approach

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This work is done in the H2020 project ELIoT - Enhance Lighting for the Internet of Things. ELIoT is an Innovation Action project with strong industrial and academic partners, and aims to introduce Visible Light Communication (VLC) for the realization of dense reliable low-power high-bandwidth connectivity which should bring new features for Internet of Things (IoT) applications.

Introduction

Most in-home, office and even industrial applications require simple maintenance, low-cost installation and upgradability in the future. These scenarios have a heterogeneous network, composed by a mix of wireline and wireless technologies, twisted-pair copper lines for telephones, Wi-Fi, multi-media on coaxial cable (MoCA) etc. Several network infrastructure approaches, based on silica fibers, copper wires and plastic optical fibers (POF) have been proposed and investigated. In the last years the wireless connectivity has become very popular, substituting the wired networks. However, the large amount of wireless devices connected is causing a congestion in the spectrum. Also, the coexistence of different networks increases the cost of installation, maintenance and complicates the upgrade new types of service [1][2].

Optical fiber becomes an ideal option because of its huge bandwidth, low losses, small dimension and insensitivity to electromagnetic radiation. Some types of fiber may be considered: silica single-mode fiber (SMF), silica multi-mode fiber (MMF) and POF. Large core POF is a very promising solution because of the smaller bending radius, low cost, plug and play feature, electromagnetic immunity and easy maintenance. SMF and MMF, require skilled professionals for installation, which increase the costs. Another approach that receives growing attention is visible light communication (VLC) transmission, using light emitting diodes (LEDs), which can be directly modulated and used as wireless transmitters [3]. The main idea is to implement a novel VLC system, which includes a POF backbone, with which it is able to offer a high data bandwidth using advanced signal processing and optical techniques (e.g. multiple input multiple output - MIMO), in order to increase the capacity of the system, in an IoT environment. To implement the multiple MIMO channels efficiently in a single POF, multiple wavelength channels will be used with a compact power combiner made using a single lens, and a wavelength demultiplexer made with thin film filters to separate them.

System concept

The future of IoT is defined by a large number of intelligent devices integrated. The integration of IoT devices can have an important impact on communities such as health care and education, infrastructure and building architectures, manufacturing industries and others. There are several IoT applications that rely on the wireless link as a critical infrastructure for which very high reliability is required. In a near future, billions of IoT devices will use wireless communication, which can be a problem because of the congestion of the spectrum. This demand will increase specially for indoor scenarios, considering that people spend more time inside buildings [1-3].

The light fidelity (Li-Fi) which is a trade name of VLC uses light to transmit data for short distances. Li-Fi is an emerging wireless technology that uses the unlicensed spectrum, being able to use the light for illumination and communication altogether. Li-Fi is gaining attention because it can gradually replace the classical illumination. In order to connect the Li-Fi access point (Li-Fi AP) to the access network (AN) Li-Fi systems require a backhaul link with high bandwidth. POF is an attractive solution for the backhaul link, since it has much higher bandwidth than LEDs. Standard POF has 1mm core diameter and 0.5 numerical aperture, which make splice and alignment an easy task. It also implies more resistance to dust particles and scratches at the end surface [5].
As seen in Fig. 1 we can integrate all the delivered services with a hybrid approach of POF+Li-Fi (with LEDs in visible light or infrared range), for in-home, office and also industrial scenarios.

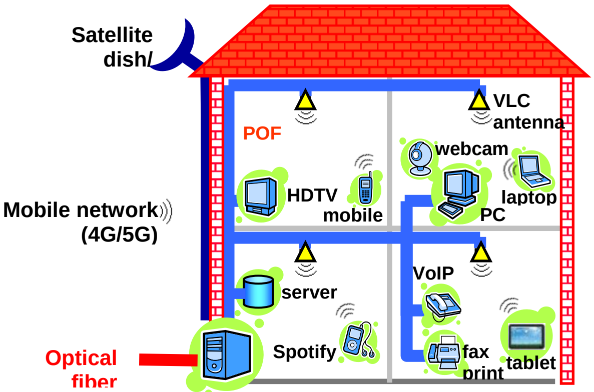

Fig. 1. Converged indoor network.

Despite all the advantages of POF, it also suffers from high attenuation and strong inter-modal dispersion, resulting in lower transmission capacity than silica fibers. One way to increase the capacity of the systems using POF is to implement MIMO technology, which uses multiple optical carriers for parallel transmission of data channels over a single fiber. For these reasons the interest on wavelength division multiplexing (WDM) has been growing in the past years [1]. For the POF, the WDM can have up to 4 channels, which are the transmission windows for POF. The biggest effort is to realize a functional demultiplexer (DEMUX). Some approaches have been studied recently based on filters, gratings and prisms [4][6][7]. For the multiplexer (MUX), in spite of have off-the-shelf products, most of them uses a technique based on an angular sliced POF core or a face coupler principle, which can cause extra losses. We propose a power combiner that can be used as a MUX, which is wavelength independent, using a single lens. The use of a ball lens is necessary to couple light in the biggest area possible as a beam expander, increasing the coupling efficiency. For the DEMUX, the first approach will be realized with thin film filters. The next section will explain the operation of both devices.

Experiments and results

Fig. 2 shows the main idea of the system. On the transmitter side up to 4 wavelengths can be transmitted. These wavelengths are coupled into one POF, with the help of one simple ball lens. After transmitting through POF, on the receiver side we have the demultiplexer that will be implemented using thin film filters. The idea is to separate each wavelength and couple it into a POF to feed the Li-Fi luminaires. The length of POF will depend on the application. For example, for in-home networks and industrial applications the length should be around 50m, but for room office applications, 10m is sufficient. The first prototype of the DEMUX still being develop and will be implemented with the Thorlabs' dichroic mirrors, designed for input angle of 45º and cutoff wavelength of 490nm and 605nm. To avoid crosstalk, bandpass filters will be used with cutoff wavelength 405 and 520nm

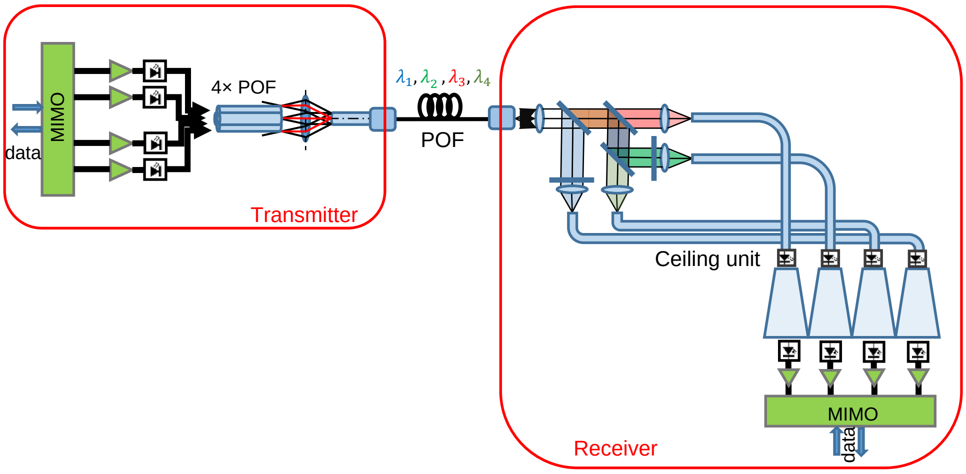

Fig. 2. Principle of operation of the WDM-POF.

A. Multiplexer

The multiplexer is placed on the transmitter side. The principle of the MUX is to combine up to 4 wavelengths in one fiber, where the ball lens will be used to focus the four beams into a single POF. The principle of operation of the MUX is presented at Fig 3.

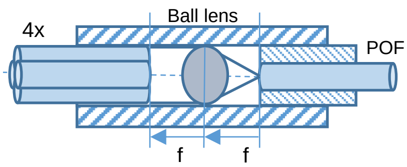

Fig. 3. Principle of operation from the MUX developed.

The components used are all off-the-shelf. The input and output fibers are ESKA MH4001 POF of 1mm core diameter and numerical aperture 0.3. The ball lens used is an Edmund Optics 43711, 3mm BK7, with no coating. To connect the POFs we used the HFBR-4511Z connector. To increase the performance, the input and output POF should be positioned in the focal length of the lens. For characterization of excess loss and power distribution, a red LED (640nm) was used. Two prototypes were developed, the first one with 4.62dB of excess loss and 15% of power spreading. The positioning of the ball lens, input and output fibers in the first prototype was made manually, without a very good precision. For the second prototype, a tube to positioning the ball lens was developed using a high precision machine for improving the performance. We obtained 3.8dB of excess loss and 11% of power spreading. The second prototype is presented in Fig.4. We believe that the performance can be improved using another type of connectors, because the HFBR has 1.5dB typical loss.

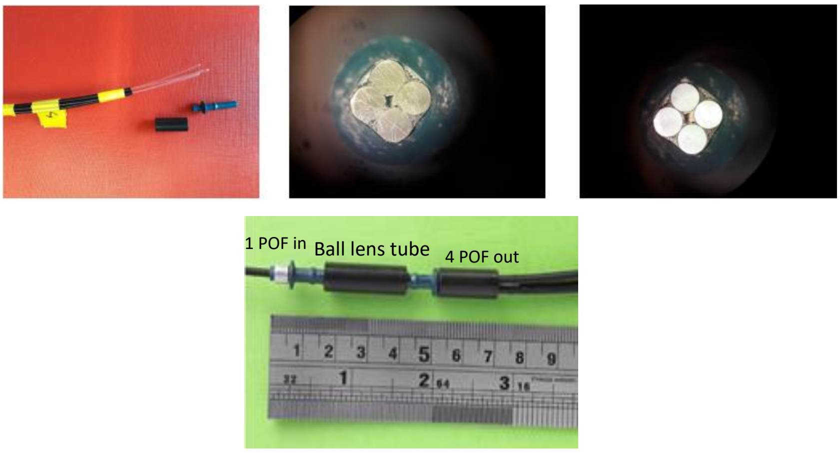

Fig. 4. MUX prototype.

Conclusion

We reported the system concept of POF-LiFi networks employing MIMO functionality using WDM technology. On the transmitter side consisting of LEDs emitting different colors, the MUX will be implemented using a simple lens in order to have a better coupling efficiency. Two prototypes have been made. The first presented 5.6dB excess loss and 15% of power spreading and the second prototype 3.8dB excess loss and 11% of power spreading. The HFBR connector used has a typical loss of 1.5dB. We believe that the excess loss from the WDM MUX can further be reduced using another type but lower loss of connector. The DEMUX will be implemented with thin film filters from Thorlabs and is still being developed. To reduce the crosstalk in the channels, a bandpass filter will be used before coupling light into the output fiber.

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