Abstract—In this paper we present an in–home optical network infrastructure based on 1-mm core diameter plastic optical fibre. Both bus and star topologies based point-to-multipoint (P2MP) infrastructures to deliver ultra wideband (UWB) radio signals are presented. The system complexity and cost are compared and discussed considering real application environments. A detailed experimental study on the performance of the two infrastructures using ultra-wide band signal delivery is carried out, indicating the feasibility of plastic optical fibre solutions for low-cost in-home optical networks.

Keywords: Home communication systems; Optical fibre communication; Plastic optical fibre

I. INTRODUCTION

Now that fibre-to-the-home is becoming a reality in a growing number of cities, the current bottleneck for high capacity communication is the extension of the available bandwidth into the home. The required bandwidth for in-home networks is not exclusively attributed to line capacity of the access network, but also to new bandwidth-hungry services inside the home. The existing in-home network solutions currently consists of a combination of different wired and wireless transport media to deliver different services; e.g. coaxial cable for video broadcasting, twisted pair for wired telephony, and Wireless Local Area Networks (WLAN) for internet access. The complexity of the existing scenario leads to expensive service costs to the home users. Hence, in order to simplify the current situation, a cost-effective universal backbone infrastructure that can carry a plethora of wired and wireless services is becoming of primary importance.

A silica fibre based optical backbone is considered to be future-proof. However, the application of silica fibre for in-home networks leads to increased costs of hardware, installation and maintenance, which are unsustainable for home users. Large-core diameter polymethylmetacrylate (PMMA) plastic optical fibre (POF) is a strong candidate, providing the potential for simple installation and operational complexity hence reducing cost.

To obtain an acceptable bandwidth with the potential for “do-it-yourself” installation, large core POF is an attractive solution [1]. In fact, due to the use of visible light transceivers, high tolerance to misalignment and bending, and very simple or no connectorization, a POF based system can in principle be deployed by the home user without the need of a fibre installer. Moreover, due to its electromagnetic immunity, resistance to high temperatures and small size (2.2 mm cable diameter including external coating), POF can also be deployed in the existing ducts for electrical power cable [2], as well as under existing flooring.

In recent years, a comprehensive study on large core POF (typically 1mm core diameter) systems has been carried out to achieve high capacity transmission [3-5]. However, most studies on POF are based on the point-to-point (P2P) network topology and with the POF market becoming more mature, mass introduction of P2P POF-based in-home networks can be foreseen in the near future. The large size of parallel or an array of P2P links is not preferred because it introduces several disadvantages, such as the big duct diameter and the increased cost of array optical transceivers. Regarding installation and operational costs, point-to-multipoint (P2MP) topology (bus or tree) is recommended because of a larger sharing factor of the fibre cables and smaller duct diameters required [6]. Moreover, from the application point of view, the growth trend of wireless traffic is surpassing that of wireline traffic. Hence smaller radio cells, i.e. femto- and pico-cell radio technologies are required to provide higher bit-rates and lower power consumption. Therefore, to support distributed and compact cells, radio signal distribution over a P2MP POF infrastructure is a potential solution for providing connections to remote antennas in the rooms.

P2P POF systems with target of 50 m transmission distance have been shown as a robust end-to-end solution for both wired and wireless services. Multi-Gigabit Ethernet transmission [4], high definition broadcasting system via ultra wideband wireless technology [5] as well as converged baseband and wireless distribution [7] have been demonstrated recently. On the other hand, for scenarios such as large domotic environments, a large-core POF based tree topology employing 1x2 POF power splitters could provide simultaneous Gigabit wired connectivity as reported recently [8]. In order to further explore the potential of P2MP POF networks with different topologies and study the transport of broadband analogue signals over such infrastructures, UWB signal distribution over POF in-home networks based on bus- and tree topologies are studied in this paper.

As a result, we successfully demonstrated the transmission of an orthogonal frequency division multiplexed (OFDM) 528MHz wide UWB signal using dual-carrier modulation at a data rate of 480Mb/s for P2MP large core POF networks. Employing cascaded of POF splitters, high data rate UWB distribution to multiple end-user mobile ONUs (3 end-users for bus; 4 end-users for tree) is achieved with the error vector magnitude (EVM) of less than 16%. In keeping with CAT-5e industry standards, the total transmission length is up to 55m.
The system performances for both configurations (bus and tree) are compared.

This paper is organized as follows: the introduction is followed by the overview of point-to-multipoint POF based in-home networks, shown in section II. Two topologies (bus and star) are compared. In section III, the employed UWB format is introduced and the setup used for the experimental validation is shown in section IV. Results and discussions for two P2MP topologies are presented in section V. The conclusions will be drawn in section VI.

II. POINT-TO-MULTIPOINT POF NETWORKS

The candidate in-home network topologies are shown in Fig. 1. The residential gateway (RG) connects the access network to the in-home network where POF can provide optical connectivity. The conventional P2P configuration is shown in Fig. 1 (a), with a POF link from the RG to each room. Alternatively, bus- and tree-based P2MP networks (shown in Fig. 1. (b) and (c) respectively) may be more cost-effective for larger buildings. The system cost analyses of the POF solution in comparison to other solutions, such as CAT-5E and silica fibres was carried out recently in [9]. From results of the comparative studies, the duplex POF solution was shown to be cost-competitive with the Cat-5e solution, and clearly outperforms the silica fibres. With the POF market becoming more mature, the cost of the media converters is gradually reducing. The analysis made was with opto-electronic signal conversions in the nodes. With passive optical signal power splitter functions in the node, the power consumption will be significantly reduced for P2MP POF solutions.

For P2MP POF networks, both bus and star topologies could be considered. From the economic point of view, a bus topology is found to yield the lowest installation cost, as the sharing factor of the cable is maximised and the required duct diameter is minimised. On the other hand, the tree topology with a large number of horizontal cables may limit the use of the same ducts for both the fibre cables and the electrical power wires, thus necessitating extra ducts. However, from the practical point of view, asymmetric POF splitters (e.g. 1×3 or 1×7) are preferred for the bus topology in order to ensure that acceptable signal quality for each end-user and transmission distances can be guaranteed. Due to the complex mode coupling occurring in POFs, the required precision for controlling the splitting ratio is difficult to achieve in the fabrication process, especially for asymmetric POF splitters. In comparison, for the tree topology (1×2 or 1×4), with simple symmetric POF splitters the whole POF network is relatively easier to configure and control. This consideration is confirmed by the experimental results, which is shown in the section V.

III. MB−OFDM UWB TECHNOLOGY

Ultra wideband is an emerging technology that offers great promise to satisfy the growing demand for high speed and low-cost short-range wireless networks. Specified and regulated by the Federal Communication Commission in February 2002, the recommended UWB bandwidth of 500 MHz operates in the frequency range between 3.1 and 10.6 GHz where other services are licensed. For this reason, the power spectral density measured in granularity of 1 MHz must not exceed −41.25dBm. UWB systems support two kinds of modulation techniques: the direct sequence and MB−OFDM UWB technologies. MB−OFDM is preferred over other UWB implementations, like impulse−radio UWB, or proprietary UWB solutions, due to the wide commercial availability of low−cost OFDM−based UWB solutions. According to standard ECMA−368 [10], the available spectrum for UWB technology is divided into 14 bands, each with a bandwidth of 528 MHz. The radio signal is based on an OFDM format with 128 subcarriers, spaced by 4.125 MHz. A total 110 subcarriers (100 data carriers and 10 guard carriers) are used per band. In addition, 12 subcarriers, which allow for electrical coherent detection, are used as pilot tones.

Due to the extremely low emitted power, the coverage of wireless UWB is limited within a few meters, which obviously cannot meet the requirements for end-user mobile ONUs. By employing radio-over-fibre (RoF) technology, the transmission distance can be largely extended. Moreover, RoF supports small cell applications with distributed antenna systems, in which the radiation power of the wireless signals can be largely reduced for lower energy consumption. For POF based in-home networks, we employed the RoF technology with the radio frequency shifting technique. Due to the bandwidth limitation of the optical transceiver and POF link, radio frequencies at higher frequency band are converted to a lower intermediate frequency (IF) band before
transmission. An ultra wideband (UWB) wireless signal transmission over 50m P2P POF link has been demonstrated in [5] with an eye-safe laser. Due to the large loss of currently available POF splitters [11], to achieve the required signal quality after 50m transmission distance is challenging for UWB over P2MP POF networks. In this paper, to achieve an acceptable transmission distance, we chose an edge-emitting laser with higher output power that will yield an eye-safe power output after POF transmission.

IV. EXPERIMENTAL SETUP

To study the feasibility of UWB over P2MP POF networks, an experimental setup has been built as in Fig. 2. Employing an arbitrary waveform generator at a sampling rate of 12GSa/s, a WiMedia-compliant 528MHz OFDM UWB signal with a centre frequency of 3.96 GHz (TFC6, 3.696-4.224 GHz) at 480Mb/s is generated. The generated UWB signal is firstly down-converted to an intermediate frequency of 0.69 GHz using a local oscillator at frequency of 3.27GHz to match the low-pass bandwidth profile of the PMMA GI-POF and the response of the optical transceivers (system bandwidth: 1GHz).

An edge-emitting laser (U-LD-651041A) with $\lambda$=650nm is directly modulated by the UWB signals. The bias current of the laser is 30 mA, with an optical power of 8 dBm. The modulated optical power is launched into an Optimedia PMMA GI-POF with optical loss of 0.2dB/m at $\lambda$=650nm. We configured bus- and tree topologies for the P2MP transmission, as shown in Fig. 2 (a) and (b), respectively. For the bus topology configuration, the feeder POF (POF1_bus) is followed by the first 1x2 POF splitter, which gives the drop point (A) with a distribution POF (POF2_bus). POF3 is used to provide the connection between splitters. The POF4_bus and POF5_bus are used for the second and the third drop points (B) and (C) respectively. For the tree topology, after transmission over the feeder POF (POF1_tree), cascaded 1x2 POF splitters split the signal into four ports ((A)-(D)) and the optical signal finally is transmitted over the distribution POF (POF2_tree). The launching condition of the laser into the feeder POF is such that the excited modes constructively interfere to provide an even and stable power distribution at the output ports of the POF splitter. The power splitter [11] splits up the light of the input POF in 50:50 symmetry over the two output POFS with 5 dB insertion loss. A silicon avalanche photodetector (APD) with a photosensitive area diameter of 230$\mu$m followed by a 2-stage electrical amplifier is used to detect the transmitted UWB signal at different drop points. A mixer is employed to recover the UWB signal to its original frequency band. By means of a digital phosphor oscilloscope sampling at 25GSa/s, the received signal is qualitatively analysed.

V. RESULTS AND DISCUSSION

Both topologies configured with different POF lengths have been studied, as shown in Table 1 (a). The lengths of the feeder and distribution fibres in both two systems are varied in order to confirm the requirement for in-home networks. The power budget measurements for the longest transmission case (bold in Table 1 (a)) are summarized in Table 1(b). After 55m POF transmission, the received optical powers at the drop point (C) of the bus system and at the drop points (A)-(D) of the tree system are -18 and -17 dBm, respectively. Since we employed 50:50 splitter for the bus topology, a difference in the received power is observed at its drop points.

<table>
<thead>
<tr>
<th>Feeder (m)</th>
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<th>Tree</th>
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<tr>
<td>(POF1_Bus)</td>
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</tr>
<tr>
<td>Conf1</td>
<td>20</td>
<td>15</td>
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<td>25</td>
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Table 1 Bus and Tree topologies based systems with (a) different POF lengths and (b) received power
system, shown in Eqs. (1) and (2), where $P_{\text{max\_bus}}$ and $P_{\text{max\_tree}}$ indicate the maximum received average power, and $P_{\text{min\_bus}}$ and $P_{\text{min\_tree}}$ indicate the minimum received average power for bus and tree topologies respectively. $N$ is the number of splitting nodes.

$$DR_{\text{bus}} = 10 \log_{10} \left( \frac{P_{\text{max\_bus}}}{P_{\text{min\_bus}}} \right) = 10 \log_{10} \left( \frac{1}{2} \right)^{1-N} \quad (1)$$

$$DR_{\text{tree}} = 10 \log_{10} \left( \frac{P_{\text{max\_tree}}}{P_{\text{min\_tree}}} \right) = 0 \quad (2)$$

To evaluate the quality of the received UWB signals, the EVM performance has been studied and is presented in Fig. 3. For a bus topology based configuration, note that the EVM values increase with the transmission distance from Conf1 to Conf3 (see Table 1), which are configured with varied lengths of the feeder fibre, and from the drop point (A) to (C) which are configured with varied distribution lengths in the bus system, shown in Fig. 3 (a). In the maximum reach case in Conf3, the EVM of 15.8% at the drop point (C) can be achieved. In comparison, corresponding to the configuration of a tree based system in Table 1, Fig. 3 (b) shows the EVM simultaneously distributed to multi terminal nodes are achieved. Furthermore, the electrical spectra and the constellation diagrams at the longest reach distance case (55 m) are shown in Fig. 4 (a) and (b), Fig. 5(a) and (b) for the bus and tree systems respectively. The power spectrum density is kept below -41.3 dBm/MHz in order to comply with the FCC requirement for air radiation. The constellation diagrams of the signals exhibit separated constellation points.

From the experimental results shown above, we observed that both bus and tree topologies could be employed for large core POF based P2MP networks. From the transmission point of view, a good quality UWB radio signal transmission can be achieved in both cases. However, note that a significant difference can be found at different drop points in the bus system due to the splitting ratio of the POF splitter, which might be further improved by using emerging asymmetric POF splitters. However, achieving a precise splitting ratio at each node is challenging and may increase system cost and complexity. On the other hand, 50:50 splitters are preferred for the tree system in order to achieve a comparable transmission performance at different end user sites in a home environment. In this experiment, we focused on transmission over 50m POF, which is a typical transmission distance for residential house environment. Considering the power budget of the POF link, a longer reach can be expected if lower losses of the employed
POF splitter and of the connection between splitters and POFs can be achieved.

VI. CONCLUSIONS

We successfully demonstrated P2MP POF networks based on bus and tree topologies using large-core graded-index PMMA POF. High capacity UWBs are distributed over both configurations up to 55m with an EVM performance of less than 16%. Here we use 1×2 POF splitters as the elements for constructing such passive in-home network architectures which connect the residential gateway with the individual rooms. Realistic lengths of feeder and distribution fibres are chosen considering the different requirements for in-home networks.

With the emergence of the lower loss and asymmetric POF splitters, appropriate transmission distances and more flexible configurations could be deployed in the home.

In this paper, the feasibility for high capacity wireless transmission over P2MP POF networks has been validated, thereby showing that the usage of large-core POF is not limited to P2P networks. This low-cost solution for in-home P2MP networks provides a good basis for future low-power broadband communication in the home.

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