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POF BASED HOME NETWORKS: FROM ACADEMIA TO INDUSTRY

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Abstract: Thick-core polymethylmethacrylate (PMMA) plastic optical fiber (POF) has been recognized as a strong candidate for future broadband and flexible in-home networks. Economic and technical studies have shown the benefits of a low-cost solution to address the bandwidth or capacity on-demand for wireless and wired services. The current challenges being addressed ensure the evolution from laboratories to field-trial systems, with emerging and maturing POF components. Hence, Gigabit POF solutions either as a stand-alone solution or being integrated in end-user terminals are on the verge of commercialization. This paper gives an overview of the recent activities of POF research in the labs and commercial activities for in-home POF deployment.

Key words: in-building networks, polymer, modulation format, radio-over-fiber, fiber wireless.

1. Introduction

As the main driver, broadband access networks, and in particular fiber-to-the-home (FTTH), are offering abundantly available bandwidth in the local loop with a plethora of services. High-end service bundles readily offer 1 Gb/s and, given a historically sustained annual increase of around 50%, it is expected that 1 Gb/s to the user premises will be a commodity service in 2015 while at 2017 rates up to 10 Gb/s appearing for the high-end could be available to early adopters. The copper solution and wireless PHY cannot meet such high capacity and quality of service (QoS) requirements. Fibre-in-the-home (FITh) is deemed future-proof and promising [1]. However, conventional silicon fibre requires high installation expenses. In comparison, plastic optical fibre (POF) provides distinct advantages for deployment thanks to the cheap transceivers, the connector-less link, and tolerance to bending and the duct sharing with the existing power lines [2].

Recently, the technologies of 1 Gbit/s transmission over a target distance of 50m step-index (SI) POF have been gradually migrated from research to commercialization, driven by the markets of the next generation of in-home networks which require Gigabit optical links [2,3]. Standardization activities on POF are being instigated both in EU and in the worldwide in the main areas of the specification of POF parameters, definition of link parameters and network architectures.

With the relatively maturity in 1 Gbit/s transmission, recent research focus is moving towards multi-gigabit and multi-service transmission. Transmission records are being achieved using a plethora of POF transmission media in combination with advanced DSP techniques and emerging silicon transceivers. Note that a conventional POF network is based on a point-to-point (P2P) configuration, however, FITh networks can be deployed in a point-to-multi-point (P2MP) fashion to offer multiple POF outlets.

Table 1. Main achievements of transmission systems using thick core POFs and different modulation formats.

<table>
<thead>
<tr>
<th>Data rate</th>
<th>POF type</th>
<th>Tx</th>
<th>Rx</th>
<th>Format</th>
<th>Length</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time Gigabit</td>
<td>SI-POF</td>
<td>Eye-safe RCLED</td>
<td>Large area receiver</td>
<td>OOK</td>
<td>50 m</td>
<td>2010</td>
</tr>
<tr>
<td>4.7 Gb/s</td>
<td>MC-POF</td>
<td>Eye-safe VCSEL</td>
<td>APD</td>
<td>DMT</td>
<td>50 m</td>
<td>2010</td>
</tr>
<tr>
<td>5.3 Gb/s</td>
<td>GI-POF</td>
<td>Eye-safe VCSEL</td>
<td>PIN+TIA</td>
<td>DMT</td>
<td>50 m</td>
<td>2010</td>
</tr>
<tr>
<td>10 Gb/s</td>
<td>MC-POF</td>
<td>High power laser</td>
<td>PIN+TIA</td>
<td>DMT</td>
<td>25 m</td>
<td>2011</td>
</tr>
<tr>
<td>10 Gb/s</td>
<td>GI-POF</td>
<td>High power laser</td>
<td>PIN+TIA</td>
<td>DMT</td>
<td>25 m</td>
<td>2011</td>
</tr>
<tr>
<td>5.8 Gb/s</td>
<td>GI-POF</td>
<td>High power laser</td>
<td>PIN+TIA</td>
<td>DMT</td>
<td>75 m</td>
<td>2011</td>
</tr>
<tr>
<td>4x2.5 Gb/s</td>
<td>Ribbon</td>
<td>VCSEL array</td>
<td>PIN Diode array</td>
<td>OOK</td>
<td>25 m</td>
<td>2011</td>
</tr>
<tr>
<td>3 Gb/s (wired)</td>
<td>GI-POF</td>
<td>VCSEL</td>
<td>APD</td>
<td>DMT/OFDM</td>
<td>50 m</td>
<td>2011</td>
</tr>
<tr>
<td>7.3 Gb/s</td>
<td>mPOF</td>
<td>High power laser</td>
<td>APD</td>
<td>DMT</td>
<td>50 m</td>
<td>2012</td>
</tr>
<tr>
<td>10.7 Gb/s</td>
<td>SI-POF</td>
<td>WDM high power lasers</td>
<td>PIN+TIA</td>
<td>DMT</td>
<td>50 m</td>
<td>2012</td>
</tr>
<tr>
<td>2.2 Gb (withwire) +480Mb/s (wireless)</td>
<td>SI-POF</td>
<td>High power laser</td>
<td>PIN+TIA</td>
<td>DMT</td>
<td>50 m</td>
<td>2012</td>
</tr>
<tr>
<td>10.7 Gb/s</td>
<td>GI-POF</td>
<td>VCSEL</td>
<td>MSM PD+TIA</td>
<td>NRZ+MLSE+PLL</td>
<td>5m</td>
<td>2012</td>
</tr>
<tr>
<td>2 Gb/s</td>
<td>500um POF</td>
<td>VCSEL</td>
<td>MSM</td>
<td>NRZ</td>
<td>15m</td>
<td>2013</td>
</tr>
<tr>
<td>34 Gb/s</td>
<td>GI-POF</td>
<td>VCSEL</td>
<td>MSM+TIA</td>
<td>PAM4</td>
<td>5m</td>
<td>2013</td>
</tr>
</tbody>
</table>
2. POF transmissions

In recent years, comprehensive research activities on large core POF (typically 1mm core diameter) systems have been carried out to achieve high capacity transmission, including both baseband and RF signals. The capability of a single POF backbone to support converged wired and wireless services employing advanced modulation formats (PAM, DMT and OFDM) has been demonstrated. Table 1 summarizes the achievements using the thick core POFs for different modulation formats, lengths and years [2]. Different system parameters will result in different link performance. Table 1 indicates that POF can accommodate various signal formats for wired and wireless applications. With the increasing maturity of POF devices, the performance can further be improved to deliver bandwidth-on-demand for home networks. There has been many transmission experiments conducted during the EU project POF-PLUS [3] and EURO-FOS [4]. Beyond these projects, national level pilot projects have been initiated to bring the POF system to residential homes. This paper will present only two examples of our recent POF activities regarding convergence between traditional FTTH and emerging FITH networks and convergence between wired and wireless signal transmission over large core POFs. It should be noted here that once in-home optical communication infrastructure has been installed, other emerging wireless transmission such as pico/femtocell radio at 60 GHz (via up-down frequency shift) and visible light communication can be incorporated for more bandwidth and flexibility.

2.1. Recent technical achievements

To demonstrate a like FITH architecture, an all-optical P2MP POF topology employing passive POF splitters was validated. A novel POF-PON architecture is proposed to cover larger areas with an advanced network concept. In such POF-PON networks, the passive splitting nodes can largely reduce the number of required POF cables. Multiple-services can be simultaneously distributed to each end user with all available system capacity without any medium access control (MAC) issues as every user terminal can be assigned an optical channel.

![Figure 1. Triple-play and bidirectional service delivery over FTTH SMF and FITH POF network: the schematic of the networking scenario and the trial setup with POF PON.](image)

The concept of offering multi-services was validated in a transmission trial involving bidirectional P2P topology utilizing ITU-T G.hn technology. This demonstration comprised of step-index plastic optical fibre for the in-home network and single-mode fibre for the access network constituent [2]. In Fig. 1, SI-POF links are used at the FITH wide area and local area network (WAN; LAN) interfaces, namely duplex SI-POF PTP and simplex 1:2 SI-POF passive optical network.

Moreover, studies on the emerging POF transceivers, integrated circuits with RF distributions (e.g. DVB-S and DVB-T) are carried out [5]. The RF distribution of standard DVB-satellite second-generation signals in 950-2150 MHz and DVB-terrestrial signals in 470-790 MHz over GI-POF is shown in Fig. 2. The DMT signals exhibit 3 Gb/s and the DVB signals (31.67 Mb/s each) has complied with the standard for error-free reception. More DVB signals or other wireless standards can be included here as long as the total signal bandwidth can be accommodated by the POF system bandwidth.
in-home network solutions. Recent studies indicate that POF technology is an emerging transmission technology which is already cost-competitive with matured and widely-deployed cabling solutions such as CAT-5, in particular, currently estimated to reach 100 million users in 2015 [7].

P2P topology is preferred. In this case, individual user terminals such as STBs are generally installed at a different location and by technicians different from the fiber termination point. The optimal location of the RG inside the customer premises can be further from the ONT and can change with time. For example, some FTTH customers may request an OTP reinstallation to a different room. This can lead to cabling difficulties, leading to higher costs when using copper-based cables to connect the ONT and the RG. A POF in-home network solves this restriction as it saves cable cost, reduces installation time, and allows self-installation and reconfiguration by the customer.

The topologies applied to residential homes depend on the actual application conditions. Considering a small residence, typically in The Netherlands or in Switzerland, a P2P topology is preferred. In this case, individual cables run from the residential gateway to individual rooms. For big dwelling houses with several floors, a local WAN topology is needed in order to keep the deployment and the maintenance easy for the framework providers and the service operators. The ONT can be placed in one centralized place and using P2MP topology to provide the services to individual apartment where the RG is placed.

Many Tier-1 European operators have experienced that POF is much faster and thus cheaper to install than Ethernet cable [6]. Hence contributing to the total addressable consumer market for growth in Gigabit POF market, currently estimated to reach 100 million users in 2015 [7].

2.3. POF standardizations

An important part for making wide deployment of POF possible is standardization. The standardization of the POF systems has been pushed to migrate from 100 Mb/s towards 1 Gb/s. In Europe, the Gigabit POF standards VDE-DKE 0885-763-1 and ETSI TS 105 175-1 have been published. Recently, an IEEE 802.3 Gigabit Ethernet Over Plastic Optical Fiber Study Group (GEPOF) [8] has been approved at the IEEE 802 plenary meeting in Beijing, March 2014. At the IEEE 802 plenary meeting in San Diego, USA, July 2014, the technical solutions with respect to transmitter, receiver, cabling and channel, and the market potential and requirement were discussed.

In addition, VDE-DKE 0885-763-1 standard is one of the proposals discussed in the GEPOF Study Group. Its physical coding sub-layer overcomes the bandwidth limitation of standard SI-POF, which is about 50 MHz@50 m. A combination is used of pulse amplitude modulation, Thomlinson-Harashima precoding, and multi-level coset codes for error correction is used to transmit 1 Gb/s error-free with sufficient operating margin. Furthermore, the standard defines a mode of operation denoted adaptive bit rate, where the system gradually and dynamically reduces the link speed to maintain error-free performance with respect to level of signal to noise ratio required for Gigabit operation.

3. Conclusions

We have described the recent efforts from both academia and industry on the thick-core POF based broadband in-home network solutions. Recent studies indicate that POF technology is an emerging transmission technology which is already cost-competitive with matured and widely-deployed cabling solutions such as CAT-5, in particular when duct sharing is employed at deployment. The research and the field trial achievements have shown
that the demand of capacity, QoS diversity and flexibility can be addressed by the POF solutions, evolving from the P2P to P2MP architecture, single to multi services, uni to bi-directional transmission.

Standardized Gigabit over POF is promising and quickly becoming the preferred solution for short-reach in-home networks. Smooth evolution of the transmission media is foreseeable from copper-base to fiber-base with high data rate capacities. After the successful field-testing of the commercial fully integrated FTTH and FITH links, a wide deployment of POF for broadband in-home communication networks can be expected in the near future.

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