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LTE-A compliant multi-band radio and gigabit/s baseband transmission over 50 m of 1 mm core diameter GI-POF for in-home networks

F. Forni, Y. Shi, H.P.A. van den Boom, E. Tangdiongga and A.M.J. Koonen

The transmission of multiple standard-compliant long-term evolution advance (LTE-A) bands together with a 4-pulse amplitude modulation (PAM) baseband signal over 50-m-long 1 mm core diameter polymethyl methacrylate graded-index plastic optical fibre is demonstrated. Transmission of eight LTE-A 64-QAM bands and a 1.2 Gbit/s 4-PAM baseband signal over the fibre was achieved resulting in an error vector magnitude <8% and pre-forward error correction (FEC) BER < 10^{-9}, respectively.

Introduction: The deployment of long-term evolution advance (LTE-A) access of the third generation partnership project (3GPP) and its evolution towards 5G presents a number of challenges. Network densification by means of spatial densification (e.g. femto-cell architecture) and spectral aggregation (i.e. intra- and inter-band carrier aggregation) are pursued as solutions. Network densification implies that new in-home networks are needed for an extensive low-cost broadband wired backbone connecting all the femto-cells and supporting the spectral aggregation and the data traffic from the fixed-wired network [1]. Plastic optical fibres (POFs) with their easy ‘do-it-yourself’ installation capability are an attractive medium to transport 3GPP and other wired and wireless signals simultaneously, as shown in Fig. 1.

Fig. 1 POF network for multi-standard wired and wireless fibre in home applications

Our previous work has shown that a cost-effective solution is the use of multiple LTE bands in parallel with a pulse amplitude modulation (PAM) baseband signal [2], in an in-home scenario transmitted over graded-index (GI) polymethyl methacrylate (PMMA) POF. However, only a limited distance of 20 m link length was reached and strict spectrum allocation is required [3]. Compared with [3], here we report the achievement of a significantly longer distance, hence more suitable for in-home applications, and we increased the LTE-A total throughput using a low-cost laser diode (LD) and a standard receiver. The following signal processing steps are required: first, digital filtering allows us to allocate the baseband and LTE-A spectra with a minimum separation, in order to decrease the mutual interference and to relax the spectrum allocation. Secondly, digital equalisation is applied to the LTE-A bands for optimising the individual LTE-A band performance. Finally, the combination of the higher output power of the LD, optimised at the operating wavelength of 650 nm, and higher receiver sensitivity, allowed the link length to be increased to 50 m.

Experimental setup: The proposed system is based on a simple intensity-modulated direct-detection optical link. The transmission tested is shown in Fig. 2. We aimed to maximise the number of transmitted LTE-A bands within the available link bandwidth, in a format-transparent way without any spectrum shifting. Following these criteria, eight widely deployed bands Bi (where i = 1, ..., 8) with the downlink channel carrier frequency (f_{\text{Bi}}) allocated between 450 MHz and 1 GHz are studied, as listed in Table 1. To ensure a standard-compliant signal, the LTE-A bands were generated in accordance with the 3GPP defined test model (E-TM) 3.1 using the highest standardised modulation order (i.e. 64-QAM) [4]. Following the E-TM 3.1, the LTE-A signal power is related to the channel bandwidth, hence the equalisation of the individual channels was performed in order to flatten the power spectrum and avoid driving the laser into saturation. The equalisation was carried out employing digital signal processing of each band by allocating the gains Gi (where i = 1, ..., 8), as listed in Table 1. Thereafter, the equalised LTE-A bands are combined, as shown in Fig. 2b.

Table 1: LTE-A bands and main parameters used in experiments

According to the LTE-A frequency allocation, the frequency range from DC to 450 MHz is unused. In this frequency range a baseband signal is transmitted. Accordingly, a pseudorandom binary sequence (PRBS) 2^{31}–1 baseband signal is encoded off-line in the 4-PAM format. The symbol sequence is filtered by a 430 MHz digital lowpass filter (LPF), as shown in Fig. 2b. Consequently, the LTE-A and baseband signals are generated by two arbitrary waveform generators working as DACs. The DAC output signals are combined and amplified by 10 dB and the resulting signal drives the low-cost LD operating at 650 nm. The LD emitted an optical output power of 5.7 dBm at a wavelength of 650 nm and it was coupled into the fibre by using a ball lens. The optical signal is then transmitted over 50 m of Ø1 mm core PMMA GI-POF, with the fibre loss of 0.2 dB/m at 650 nm [5]. The optical receiver was a Graviton SPD-2 module, consisting of a pin photodiode followed by a transimpedance amplifier. The SPD-2 has an FC connector in which the bare fibre is plugged. The received optical power is equal to ~5 dBm, in order to safeguard the p-i-n, and ~10.7 dBm for optical back-to-back (oB2B) and 50 m transmission. As shown in Fig. 2c, the output signal of the optical receiver was amplified with a

Fig. 3 Spectrum at receiver amplifier output during simultaneous transmission
gain of 29 dB and acquired by either the baseband 4-PAM or the LTE-A receiver, as shown in the spectrum Fig. 3. For the oB2B test an extra 10 dB attenuator was used before the amplifier, to avoid the amplifier saturation. For the baseband receiver, a digital sampling scope is employed as ADC, a digital LPF with the same bandwidth as in the transmitter, and the 4-PAM receiver, both implemented by MATLAB. For simplicity, no equalisation or precoding was used. The LTE-A signals are received and processed by a vector signal analyser consisting of a spectrum analyser and a Keysight LTE-A software receiver.

**Table 2: 4-PAM transmission experimental results**

<table>
<thead>
<tr>
<th>Link</th>
<th>Bit rate, Gbit/s</th>
<th>BER (×10⁻¹⁰)</th>
</tr>
</thead>
<tbody>
<tr>
<td>oB2B</td>
<td>1.54</td>
<td>3.6</td>
</tr>
<tr>
<td>4-PAM over 50 m</td>
<td>1.4</td>
<td>3.4</td>
</tr>
<tr>
<td>4-PAM + LTE-A over 50 m</td>
<td>1.2</td>
<td>8.7</td>
</tr>
</tbody>
</table>

**Fig. 4 LTE-A EVM results, with and without 4-PAM transmission, bands are according to Table 1**

**Experimental results:** The LTE-A signal is evaluated in accordance with [6] by taking the error vector magnitude (EVM) value of 8% as threshold. The 4-PAM signal is required to have a pre-FEC BER value of <10⁻³. Initially, the performance of the 4-PAM and LTE-A signals are separately measured as a reference.

Let us consider the 4-PAM performance first. As depicted in Table 2, the 4-PAM transmission over the oB2B is feasible up to a bit rate of 1.54 Gbit/s. When increasing the link to 50 m, the achievable bit rate drops to 1.4 Gbit/s. Moreover, when also the LTE-A signal is co-transmitted, the bit rate decreases further to 1.2 Gbit/s. In case of only 4-PAM transmission, the signal amplitude can be adjusted to optimise the throughput. However, when co-transmitting with LTE-A, the 4-PAM amplitude increment can severely affect the LTE-A performance through the non-linearity of the light source. Consequently, during the simultaneous transmission we had to decrease the 4-PAM amplitude, causing the PM throughput to be lower than the case without the LTE-A bands. Our results show that a minor impairment on the baseband signal bit rate is caused by the LTE-A signals.

Next, the LTE-A multi-band transmission is considered for the electrical back-to-back (eB2B), oB2B, and 50 m link. As depicted in Fig. 4, the eB2B EVM is, in general, below 2.4%. Similar performance among all the LTE-A bands is achieved, thanks to the equalisation technique used. The outermost bands 8 and 31 have the best performance. Moving to oB2B, the EVM increases to values of ~2.9%.

Employing 50 m POF makes EVM to increase to <4%. When also the 4-PAM signal is present in the link, the EVMs become <7.4%, which are still better than the 8% allowed EVM. In general, the presence of 4-PAM signal causes an increase in EVM values of LTE-A signals, especially the innermost bands. The lowpass filtering does not necessarily lead to degradation of LTE-A bands spectrally located close to the 4-PAM signals. The nearest-neighbour LTE-A band to the 4-PAM spectrum (i.e. band 31) has the lowest EVM increase, as also shown by the constellation diagram in Fig. 5. Better EVMs can be achieved by decreasing the 4-PAM power, hence limiting interference within the LTE-A bands, albeit the 4-PAM performance decreases. Therefore, for in-home networks, a cost-effective technique for mitigating non-linearity effects on light sources is necessary to further improve the throughput and performance of wired and wireless signals.

**Conclusion:** In this Letter, we achieved the successful transmission of multiple LTE-A bands and baseband signals over 50 m of thick-core PMMA GI-POF. We have performed the simultaneous transmission of eight LTE-A compliant 64-QAM bands with a total throughput of 478.8 Mbit/s, together with a 1.2 Gbit/s 4-PAM baseband signal. Furthermore, only low-cost components were used without complex digital signal processing and 50 m distance was reached, which could be considered as a good reference length for short distance applications (e.g. single-detached dwelling and apartment). This Letter has demonstrated the feasibility of using POF as in-home network backbone for the LTE-A-based future 5G wireless and wired technologies, which enables a cost-effective approach for supporting the network densification and baseband communications.

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One or more of the Figures in this Letter are available in colour online.

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**References**