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Multi-standard Transmission of Converged Wired and Wireless Services over 100m Plastic Optical Fibre

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Abstract The first multi-standard transmission consisting of 6 Gbit/s DMT baseband and 200 Mbit/s MB-OFDM UWB radio signals over 100m perfluorinated graded-index plastic optical fibre is demonstrated. Transmission performance indicates $BER < 10^{-5}$ and $EVM < -22\text{dB}$ respectively.

Introduction

Fibre-to-the-home (FTTH) techniques and passive optical networks (PONs) have been widely deployed to enable the transportation of broadband services to the residential home or the multi-dwelling units (MDU). As the capacity bottleneck of the broadband access is now shifting towards the in-building network, challenges related to the delivery of next-generation broadband services with cost-effective solution are gradually being addressed. To improve the data capacity of the in-building infrastructure, plastic optical fibre (POF) has been proposed to replace the copper twisted pair or CAT-5 cable in order to provide multi-Gbit/s data rates for in-home end users [1]. The easy installation and maintenance of POF due to its smaller bending radius (5 mm), better tolerance to tensile stress and simpler connectorisation, makes POF-based infrastructure more suitable for in-building networks compared to standard single-mode fibre (SMF).

One of the desired benefits of POF backbone for in-home environments is to enable simultaneous multi-standard transmission of both wired and wireless services over one physical infrastructure, as shown in Fig. 1. The POF backbone is connected to external access networks via a residential gateway (RG), and deliver, for example, both baseband xDSL or HDTV services together with WiFi or other short-range wireless services to end users by employing the same POF link [2].

Recently, the increase in applications for personal area networks (PANs) is fuelling the development of ultra-wide-band (UWB) communications for wireless high data rate short-range networks. This type of so called "wireless-USB" standard provides data-rates up to 480 Mbit/s for personal area communications, by employing multi-band orthogonal frequency division multiplexing (MB-OFDM) to combat impairments from multi-path fading. In the POF backbone proposed in Fig. 1, the coexistence of

Fig. 1: In-building POF infrastructure for converged wired and wireless services

UWB and other baseband services is particularly challenging and interesting to investigate due to its wide bandwidth ($> 1.6\text{ GHz}$) and low power spectral density ($< -41\text{ dBm/MHz}$).

UWB radio-over-fibre (RoF) transmission has been successfully demonstrated using perfluorinated POF with single UWB services [3]. Meanwhile, multi-standard RoF systems have also been shown over glass multi-mode fibre (MMF) or SMF [4]. This paper presents the first demonstration of a multi-standard POF transmission system of baseband signals at data-rates of 6 Gbit/s and UWB radio signals, thereby full utilising the full-bandwidth available within the POF (from 0 to 5 GHz).

Experimental Setup

The experimental setup is shown in Fig. 2. We chose the cost-effective intensity modulation and direct detection (IM/DD) approach to deliver

Fig. 2: Experimental setup: multi-standard POF system for baseband DMT and UWB radio signals

both baseband and radio signal. A WiMedia-compliant UWB transmitter is used to generate the MB-OFDM signal centred at 3.96 GHz with 3 sub-bands (TFC1: 3.168 – 4.752 GHz). In the baseband region, we employ the discrete multi-tone (DMT) modulation format with bit-loading to maximise the data rate. We use off-line processing to generate the DMT signal employing an arbitrary waveform generator (AWG) sampling at 3 GHz. After electrically combining the baseband DMT signal and the UWB radio signal, a DFB laser at 1302 nm wavelength is directly modulated to transmit both signals over 100m $\varnothing 50\mu\text{m}$ perfluorinated graded-index POF (GI-POF). The received optical signal is detected by a $\varnothing 25\mu\text{m}$ photo-detector with a $\varnothing 62\mu\text{m}$ multi-mode pigtail. After amplification, the two signals are separated respectively using a UWB band-pass filter (BPF) and a 3 GHz low-pass filter (LPF). Then the two signals are analyzed and demodulated by a real-time oscilloscope (DPO). The employment of the DMT format enables the efficient utilization of the POF bandwidth up to 1.5 GHz, which is limited by the AWG sampling rate. Beside the baseband DMT band in Fig 3, the UWB radio signal from 3.1 GHz until 4.8 GHz can be seen.

Experimental Results and Discussions

The spectrum of the received electrical signal is shown in Fig. 3. We employ the Chow's bit-loading algorithm to efficiently utilise the spectrum. At the beginning of the algorithm, a DMT signal with a uniform bit allocation is sent to evaluate the channel response. Depending on the received signal-to-noise ratio, bit allocation is executed accordingly to maximise the bit assigned for each sub-carrier. Due to the channel response at the DMT receiver, DMT signal experiences low-pass filtering until 3 GHz. Centered at 4 GHz, the UWB spectrum consists of 3 sub-bands, corresponding to the time-frequency code one (TFC 1) of the WiMedia

Fig. 3: Received electrical signal after 100m POF transmission

Fig. 4: Bit-loading parameters and the BER values of the DMT signal vs. frequencies, after 100m POF (when DMT and UWB signals coexist in the system)

standard.

Fig. 4 presents the detailed measurement results for DMT signal using bit-loading. Fig. 4a shows the bit allocation parameters used in the DMT modulation after 100m transmission with the received optical power of 0 dBm. In this experiment we chose 256 sub-carriers, ranging from 0 to 1.5 GHz. It is seen in Fig. 4a, that the 5 bits are allocated for most of the sub-carrier till the 130th. From the 130th sub-carrier above, the bit allocation is set as 4 for most carriers. It should be noted that until the highest sub-carrier index, there are always more than 2 bits allocated. Therefore, the power distribution from 1.5 GHz to 3 GHz shown in Fig. 3 is actually the aliasing signal, which will be filtered out in the demodulation process. Fig. 4b presents the measured bit error rate (BER) as a function of sub-carrier index. The advantage of the DMT format is shown in Fig. 4b, indicating that although some of the sub-carriers degrades due to the channel, the signal quality depends on the averaged BER over all the sub-carriers. Therefore, the overall BER is measured as 4×10^{-5} in Fig. 4b, which falls within the forward error correction (FEC) limit of 1×10^{-3} .

We measure the influence of the multi-standard transmission on each signal in the following figures. In Fig. 5 the transmission performance measurement is shown with respect to the baseband DMT signal. BER is shown using the logarithm scale as a function of the received optical power. The yellow curve shows the back-to-back (B2B) measurement with only DMT signal in the transmission system. Similarly in the B2B case, the green curve presents the BER performance when both DMT and UWB signals co-exist in the system. A 1 dB penalty in receiver sensitivity is shown compared with single signal B2B case. In contrast, after 100m POF transmission with only

Fig. 5: BER performance of DMT signal; only DMT and DMT together with UWB, for both back-to-back and transmission cases

DMT signal existing, a penalty of 2 dB is observed compared with the B2B measurement where also only the DMT signal is present (yellow curve). Finally, the blue curve presents the BER performance after 100m POF transmission consisting of both UWB and DMT signals. Compared with the B2B case when both signals exist in the system (green curve), a penalty of 4 dB is measured. This penalty can be attributed to the modal dispersion in the POF. Further, the cross-talk between UWB and DMT adversely influences the quality of the DMT signal. In Fig. 5, a BER of 10^{-3} is labelled as the FEC limit.

Fig. 6 shows the error vector magnitude (EVM) of the MB-OFDM UWB signal as a function of the received optical power. Compared with the DMT signal shown in Fig. 5, UWB signal is more sensitive to POF transmission, than the crosstalk between DMT and UWB. As seen in Fig. 6, for the same received optical power, the EVM penalty from the crosstalk is less than 1 dB for both back-to-back and transmission cases. However, 100m

Fig. 6: EVM performance of UWB signal; only UWB and UWB together with DMT, for both back-to-back and transmission cases

(a) DMT

(b) UWB

Fig. 7: Constellation diagrams of the received signal after simultaneous transmission over 100m POF.

POF transmission introduces an EVM penalty of approximately 4 dB. This is because the central frequency of UWB signal at 4 GHz approaches the spectral limit while the DMT signal is transmitted at a lower frequency band. In Fig. 6 we also show the WiMedia standard requirement (-16 dB) as well as the measured electrical back-to-back EVM value. With more than -1 dBm received optical power, the overall EVM penalty of UWB signal after transmission is only around 3 dB.

Finally, in Fig. 7 we show the received constellation diagrams after 100m POF with a received optical power of 0 dBm. For the DMT format, the constellation is obtained for 50 to 60 sub-carriers; while the UWB constellation is an overlap of all 128 sub-carriers indicating low deviation in the EVM value.

Conclusions

By employing DMT and MB-OFDM modulation formats, we have experimentally demonstrated for the first time a multi-standard transmission system of both baseband and radio signals over 100m POF. We efficiently exploit the POF bandwidth using the DMT format, thus achieving bit-rates of 6 Gbit/s with $\text{BER} < 10^{-3}$. Using the same POF link, 200 Mbit/s WiMedia-compliant UWB signal has also been delivered in coexistence with 6 Gbit/s DMT signal with only 3 dB EVM penalty.

We believe that this experiment demonstrates the feasibility of a POF backbone as a low-cost infrastructure for converged wired and wireless services in future broadband in-building networks.

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