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OFDM Radio-over-Fibre Systems Employing Routing in Multi-Mode Fibre In-building Networks

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Abstract
We report a radio-over-fibre system for all-optical routing OFDM signal at 18.3 GHz over 950 m multi-mode fibre, with error vector magnitude penalty < 3%.

Introduction
With the evolution of high data rate broadband access networks, high carrier frequencies of 10 GHz and above are required for in-building broadband wireless services, resulting in the reduction of wireless cell size and the increase of the cost for antenna site (AS). The emerging radio-over-fibre (RoF) technology potentially provides a low-cost solution to wireless access network, by centralizing microwave signal processing in the central office (CO) and delivering radio frequency (RF) signal to AS via optical fibre, hence simplifying the antenna [1]. In RoF systems, orthogonal frequency division multiplexing (OFDM) attracts lots of interests due to its dispersion robustness [2]. This is especially beneficial when deployed in multi-mode fibres (MMFs), which are easily installed in in-building access networks.

In this paper, we demonstrate a RoF link for in-building access networks using MMF to transport OFDM signal above 10 GHz with the functionality of optically routing the RF signals for different end-users, as shown in Fig. 1. The building may be a residential area, an office building or an airport lounge, etc. The CO connects the in-building network to the outside access network, delivering one or more RF signals at different RF carriers with certain optical wavelength ($\lambda_1$) over MMF and routed to another wavelength ($\lambda_2$ or $\lambda_3$) by the routing device (denoted as “R” in Fig. 1), followed by another length of fibre transmission to different AS, where the RF signals are radiated. Creating the possibility of inter-room wireless communications by means of the routing in “R”, this structure brings more flexibility in operating, maintaining and reconfiguring the network as well as adapting the coverage area.

Experimental setup
Among various RoF transmission techniques reported, optical frequency multiplication (OFM) proposed in [3] has shown to be a low-cost and effective method to generate highly pure microwave frequency carrier and to transport RF data beyond the fundamental bandwidth of MMF [4]. This experiment employs OFM technique to transport the RF signal, and wavelength conversion and filtering to realize all-optical routing, see Fig. 2.

A continuous wave (CW) pump signal at 1552 nm wavelength is phase modulated (PM) by an electrical sweep signal at 9 GHz. The OFDM RF data signal with a central carrier frequency of 300 MHz is then put onto the optical carrier by a Mach-Zehnder modulator (MZM). The electrical input of MZM is labelled “A”. The OFDM signal is 16-quadrature amplitude modulation (16-QAM) with the data rate of 36 Mbit/s and 52 frequency sub-carriers. After amplification, a Mach-Zehnder interferometer (MZI) with a free spectral range of 40 GHz converts the phase modulated signal into intensity modulation (IM). The PM-IM conversion through the MZI generates several harmonics in the frequency domain, each of which is separated from the adjacent harmonic by the sweep frequency 9 GHz [3]. By using this effect, the harmonic frequency is up-converted to the multiple of 9 GHz. The output of the OFM transmitter is labelled “B”, and after 750 m MMF transmission “C”. After that, the wavelength conversion employing a semiconductor optical amplifier (SOA) is performed. Another CW light (acting as probe) at 1535 nm is injected into the SOA. From the cross gain modulation (XGM) effect in the SOA, the OFDM data at 1552 nm is copied to the target wavelength of 1535 nm, which is aligned to one of the pass-bands of the filter. The converted signal, labelled “D”, is sent to the second MMF span of 200 m before reaching the AS. At the AS, we employ a photo-detector with 25 GHz bandwidth, followed by an electrical band-pass filter at 18.3 GHz for the optical carrier by a Mach-Zehnder modulator (MZM). The electrical input of MZM is labelled “A”. The OFDM signal is 16-quadrature amplitude modulation (16-QAM) with the data rate of 36 Mbit/s and 52 frequency sub-carriers. After amplification, a Mach-Zehnder interferometer (MZI) with a free spectral range of 40 GHz converts the phase modulated signal into intensity modulation (IM). The PM-IM conversion through the MZI generates several harmonics in the frequency domain, each of which is separated from the adjacent harmonic by the sweep frequency 9 GHz [3]. By using this effect, the harmonic frequency is up-converted to the multiple of 9 GHz. The output of the OFM transmitter is labelled “B”, and after 750 m MMF transmission “C”. After that, the wavelength conversion employing a semiconductor optical amplifier (SOA) is performed. Another CW light (acting as probe) at 1535 nm is injected into the SOA. From the cross gain modulation (XGM) effect in the SOA, the OFDM data at 1552 nm is copied to the target wavelength of 1535 nm, which is aligned to one of the pass-bands of the filter. The converted signal, labelled “D”, is sent to the second MMF span of 200 m before reaching the AS. At the AS, we employ a photo-detector with 25 GHz bandwidth, followed by an electrical band-pass filter at 18.3 GHz for
Fig. 3: Spectrum of 16-QAM OFDM signal at point “B”
detecting the 2\textsuperscript{nd} harmonic frequency of 18 GHz plus
the RF sub-carrier 300 MHz, labelled “E”.

Measurement results
First, we present the spectrum of the signal generated
by the OFM transmitter in Fig. 3. Five harmonics are
displayed in the plot, where the power of the second
harmonic at 18 GHz is optimized. The inset plot shows
the spectrum of OFDM signal around 18.3 GHz.

Second, we investigate the effect of parameters in the
wavelength conversion in order to find an optimum
system performance. The results in the averaged error
vector magnitude (EVM) are taken at point “E”. In
Fig. 4(a), EVM values are plotted versus the probe
power, for three different pump powers. For each pump
power, we find an optimum probe power. Results left
from the optimum value are caused by low optical
signal-to-noise ratio; while those rights from the
optimum are due to the deep gain saturation of the SOA.
The optimum probe power shifts to the larger value for
larger pump powers. We observe that the system can
handle 8 dB probe power fluctuations within an EVM
increase of less than 1%.

In Fig. 4(b), EVM values are shown versus pump
powers for different probe powers. We observe that to
keep EVM low for larger probe powers, larger pump
powers are needed. As an example, for 3 dBm probe
power, 9 dBm pump power is necessary while for −3 dBm probe power, only 5 dBm pump power is
needed for the same EVM.

Finally, we report the EVM value at different
measurement points (“A”, “B”, “C”, “D” and “E”), as
shown in Fig. 4(c). The pump power and probe power
are set to 6 and 0 dBm, respectively, according to
Fig. 4(a, b). It is seen that even though 52 sub-carrier
OFDM signal is transmitted over 950 m MMF and is
converted to another wavelength in the link, the
measured EVM value is only around 3%, with the total
system penalty less than 3%. For comparison, in IEEE
802.11a standard, the required EVM is 11.2% for
16-QAM. It is also seen from “B−C” and “D−E” in
Fig. 4(c) that the MMF gives negligible EVM penalty in
the system, due to the robustness of the OFM
technique to the modal dispersion [4]. Fig. 4(d) shows
the constellation diagram of the demodulated 16-QAM
signal at point “E”. In Fig. 5, we also show the EVM vs.
the index of sub-carrier of the OFDM signals, at three
measurement points “A”, “B” and “E”, by using the
same parameters as Fig. 4(c, d).

Conclusions
By employing OFM we have successfully demonstrated
the feasibility of transporting 18.3 GHz 52 sub-carriers
OFDM signal of 36 Mbit/s data rate over 950 m MMF
link. We have also shown a mid-span all-optical routing
with EVM less than 3%. We observed that the penalties
induced by the MMF modal dispersion are negligibly
small, thanks to the OFM technique, enabling large
operational flexibility for in-building broadband access
networks.

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