End-to-End Demonstration based on hybrid IFoF and Analogue RoF/RoMMF links for 5G Access/In-Building Network System

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Abstract *An end-to-end mobile fronthaul system based on hybrid IFoF and analogue Radio-over-fibre /Radio-over-multi-mode-fibre (RoF/RoMMF) links is demonstrated for the first time. With the capacity of 25.65 Gbps, the transmission link complies the required peak data rate of 5G vision of IMT-2020.*

Introduction

With the explosively increasing demand on the capacity of mobile communication, the upcoming 5G mobile service is launched for providing enhanced mobile broadband (eMBB) services, ultra-reliable, and low latency communication (URLLC) services, and massive machine type communication (mMTC) in the wireless network system. According to IMT-2020, low latency of <1 ms and a peak data rate of 20 Gbps should be achieved in the 5G system at its final stage [1]. Up to now, the common public radio interface (CPRI) has been widely employed for the mobile fronthaul (MFH), which covers the transport span from baseband units (BBUs) at the central office (CO) to remote radio heads (RRHs) at the antenna site in the current 4G system. However, the CPRI requires optical bandwidth about 16-times larger than that in the wireless domain owing to the quantisation process. To solve this issue, several approaches on MFH system have been studied to accomodate the large data rate of 5G eMBB services [2, 3]. The intermediate-frequency-over fibre (IFoF) system based on analogue optical transmission has been regarded as a high spectral efficiency solution to reduce the bandwidth requirement [4-6]. For practical demonstration on IFoF-based MFH, a 16-QAM OFDM transmission including both 7-km single-mode fibre (SMF) IFoF and millimetre wireless link was achieved to reach up the data capacity at 24 Gbps [6]. In 2018, Sung, *et al*. proposed a real-time 1-GHz IFoF transmission over 20-km SMF with 28-GHz millimetre-wave (MMW) [4].

In our previous work [7], an off-line MFH system consisted of cascaded IFoF links, frequency converters, and channel selector over 20-km SMF was demonstrated by applying dual stages optical links and digital signal processor (hereafter” the DSP equipment”). To discuss the transmission link from remote antenna site to spot cells, the SMF is traditionally adopted for longer distance applications in the radio-over-fibre (RoF) link. In contrast, the RoF transmission based on multi-mode fibre (MMF) and direct modulation of vertical cavity surface emitting laser (VCSEL) might be a cost-effective solution to extend the coverage of the wireless system for short distance application such as in-building networks [8-10]. To the best of our knowledge, this is the first demonstration of hybrid IFoF and analogue RoF/radio-over-MMF (RoMMF) link with wireless transmission for mobile fronthaul.

In this work, we enhanced our previous work [7] involving a high capacity hybrid IFoF and analogue RoF/RoMMF link for evolving 5G MFH system. We demonstrate the end-to-end downlink system, including the RoF/RoMMF link from DSP equipment to an antenna and wireless transmission of 28-GHz MMW from the antenna to the air. To further verify the MFH system, both the standardized 5G new radio (NR) waveform and on-line OFDM demodulator are applied to perform a real-time transmission performance evaluation.

Architecture of RoF/RoMMF and Hybrid IFoF MFH

In Fig.1, the architecture of analogue RoF

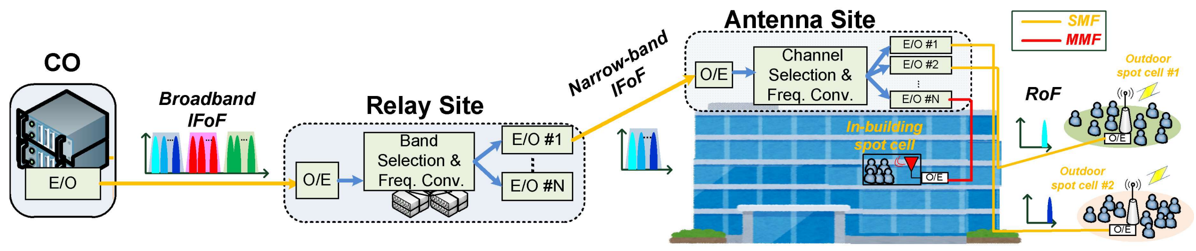

Fig. 1: Architecture of IFoF and A-RoF / A-RoMMF hybrid MFH.

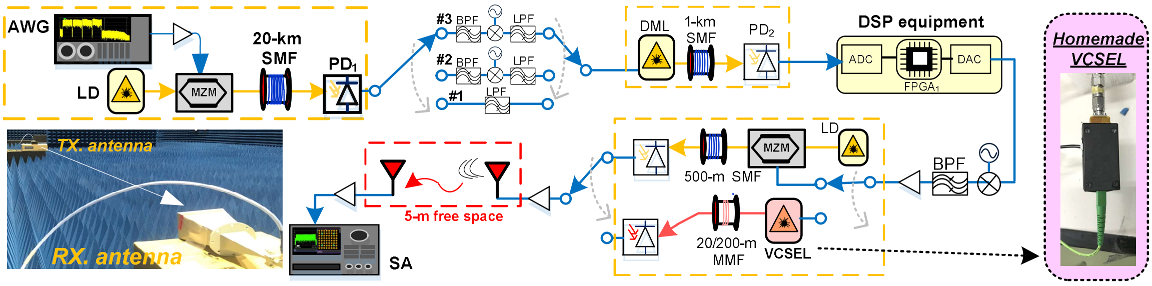

Fig. 2: Experimental setup of the real-time hybrid IFoF and RoF/RoMMF wireless system.

/RoMMF and IFoF hybrid MFH is illustrated. As described in [5], IF band signals which are transmitted to different antenna sites, are firstly frequency multiplexed at a central office (CO) and later propagate through a broadband IFoF link. After passing O/E in the relay site, the IF bands signal in the high frequency are extracted and down-converted to the same frequency range as the lowest frequency band by applying the analogue frequency-converter. Then, each band is transmitted to a narrow-band IFoF link for the respective antenna site. Each IF channel signal is extracted and converted to the desired frequency by the digital frequency-converter. Subsequently, the baseband IF channels are transmitted to spot cells through RoF/RoMMF links after up-converting to radio frequency and finally transmitted out to the air by an antenna for access/in-building wireless communication.

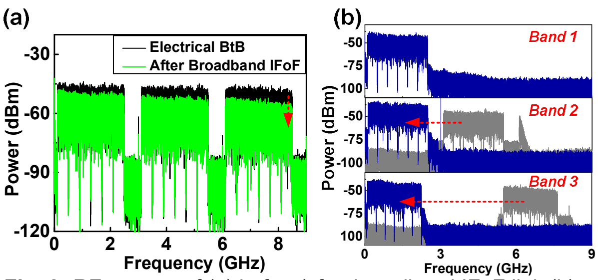

Fig. 3: RF spectra of (a) before/after broadband IFoF link (b) after IF bands selection.

Experimental Setup and Result

Figure 2 illustrates the experimental setup for real-time hybrid IFoF and RoF/RoMMF based with a cascaded frequency selector/converter. Generated from Keysight studio 5G-NR commercial software, the 64-QAM OFDM signal with the bandwidth of 380.16 MHz for each IF channel was utilized in the proposing 5G MFH Due to the bandwidth limitation of arbitrary waveform generator (AWG), 18 IF channels were generated with the total configure bandwidth of 6.84 GHz. The first IF band composed of 8 IF channels located ranging from 100 to 2500 MHz with the guard interval of 19.84 MHz between two adjacent IF channels. Similarly, both second/third band contain 6 IF channels occupying the frequency from 3.1 to 5.5 / 6.1 to 8.5 GHz, respectively. The exported 18 IF channels OFDM electrical data stream from AWG were amplified and injected into a Lithium Niobate Mach-Zehnder modulator (LN-MZM). A distributed feedback laser diode (DFB-LD) operating at 1550 nm was used for an optical light source. For the broadband IFoF link, the optical signal with carried 5G signal of 18 IF channels propagated over 20-km SMF was received by a photodetector (PD) at the received power of 2 dBm. The received RF spectra of before/after broadband IFoF link are illustrated in Fig. 3(a). After 20-km SMF transmission, a degradation larger than 10 dB is occurred in second and third bands due to the frequency response of PD and dispersion induced RF power fading effect which induces the SNR degradation. The average error vector magnitudes (EVMs) also deteriorated from 1.78%/1.69%/2.02% to 2.53%/3.52%/3.87% for first/second/third band, respectively. A pre-emphasis technique that redistributes the power allocation of each channel is employed after broadband IFoF link to compensate for the RF throughput in high-frequency channels and improve the EVM to 3.03%/3.43%/3.31%. The related RF spectra for analog frequency conversion and narrow-band IFoF optical link for all three bands are shown in Fig.3 (b).

To conduct the band selection in analog process, one LPF and two BPF with the frequency ranging from 0 to 3, 3 to 6, and 6 to 9 GHz, respectively, were employed to extract six successive 5G OFDM IF channels. For the second and third IF bands, additional analog processing was performed for down-converting the narrow IF bands to a frequency below 3 GHz by using mixer and LO at 3 and 6 GHz, respectively. For the narrow-band IFoF link of 1-km SMF transmission, one of the extracted narrow IF band was encoded to directly modulated laser diode (DML) with the optimized bias at 35 mA. The optical narrow-band signal was detected by the second PD with the received power of 2 dBm. Suffering from the relative intensity noise (RIN) and intermodulation distortion (IMD) from DML, the average EVM increases to 3.98% /3.99%/3.94% after narrow-band IFoF optical link for first/second/third band, respectively. The electrical narrow IF band signal was subsequently sent into a DSP equipment consisting of FPGA and DAC for conducting real-time IF channel separation and frequency conversion in the digital process. The RF spectra of the six IF channels in the third band before/after DSP equipment are illustrated in Fig. 4(a) as an example. In this stage, the EVMs was slightly increased to 4.31%/4.31%/4.25%, indicating degradation of <0.4% after the DSP equipment for the first/second/third band, respectively. The measured EVM performance of all 18-channel in different IF links are compared in Fig. 4(b) with the related constellation plots.

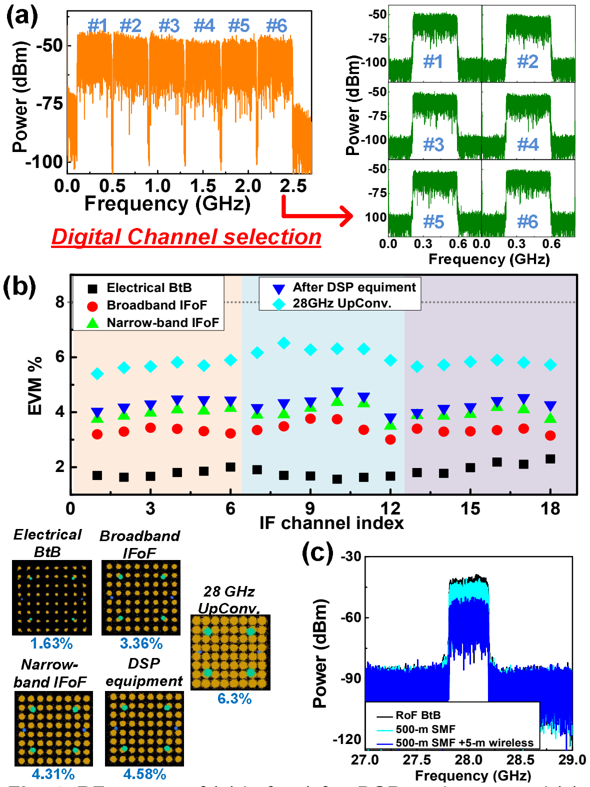

Fig. 4: RF spectra of (a) before/after DSP equipment and (c) RoF and wireless transmission. (b) The EVM performance and related constellation plots in IF transmission.

Later on, the output of the single IF channel was amplified and up-converted to the millimeter-wave frequency at 28 GHz. Noted that the mixing process during 28-GHz MMW up-conversion induced a significant EVM degradation of >1.5% for all three RF bands. To implement the RoF/RoMMF link, the single RF channel conveying the 5G OFDM data stream was injected to another C-band LN-MZM/850-nm VCSEL, and later detected by high-speed PDs after transmitting 500-m SMF/ 20~200-m OM4 MMF, respectively. For wireless transmission, the horn antenna pairs were applied to enable a 28-GHz OFDM millimeter-wave transmission through free-space at a distance of 5 m. At the wireless received part, a high-speed spectrum analyzer (SA) was used to analyze received real-time EVM, RF spectrum and related constellation plot by the built-up software program. The RF spectra of before/after 500-m SMF RoF transmission and 5-m wireless link of the first IF channel in the third band are compared in Fig. 4(c). The decreasing OFDM power of 3 dB and 7 dB are observed during 500-m RoF and 5-m wireless transmission with the related EVM of 5.97% and 6.05%.

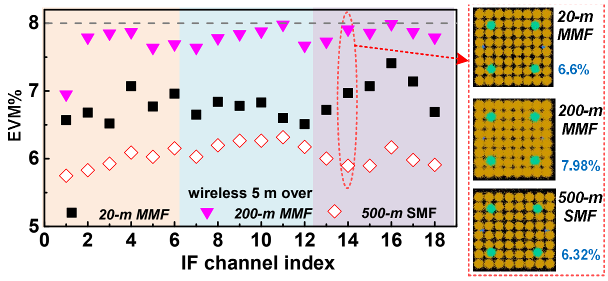

Fig. 5: End-to-end EVMs and related constellation plots of OFDM channels after 5-m wireless transmission.

The end-to-end EVM performances of all 18-channel for different fibre types and distances in RoF/RoMMF link including 5-m free-space transmission are compared in Fig. 5 with the related constellation plots. In the RoMMF link, the total average EVMs increase from 6.82% to, 7.98% with increasing the length of the OM4 MMF from 20 m to 200 m due to the increased propagation loss and somewhat chromatic/modal dispersion. The propsed VCSEL exhibted the low slope efficiency and nonlinearity in the light-to-current (L-I) response, which inevitably distorted the OFDM waveform during the RoMMF transmission. As a result, the the RoMMF link reveals a worse performance when copmared with the RoF link. Finally, all 18-channels successfully meet the 3GPP specification of required 8% with a capacity of 25.65 Gbps (18×0.38 GHz×3.75 bps/Hz) after IFoF, RoF/RoMMF and 5-m wireless transmission.

Conclusions

A proof-of-concept experiment has been successfully demonstrated to show the scalability of end-to-end MFH system for 5G based on hybrid IFoF, analogue RoF/RoMMF and wireless links. The EVMs performance in IFoF, RoF/RoMMF and wireless link are below the required EVM threshold of 8%. A total capacity of 25.65 Gbps was achieved based on 18×0.38 GHz IF channels after 20-km broadband IFoF, 1-km narrow band IFoF, 500-m RoF/ 20~200-m RoMMF and 5-m wireless transmission.

Acknowledgments

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