LETTER

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Transmission of multiband wireless signals over a seamless IM/DD fiber-MMW system

Nguyen Toan Van[1], Pham Tien Dat[2a)], Atsushi Kanno[2], Naokatsu Yamamoto[2], Vo Nguyen Quoc Bao[1], and Tetsuya Kawanishi[2,3]

[1] *Posts and Telecommunications Institute of Technology, Ho Chi Minh City, Vietnam*

[2] *National Institute of Information and Communications Technology, Tokyo 184–8795, Japan*

[3] *Waseda University, Tokyo, Japan*

a) *ptdat@nict.go.jp, Corresponding Author*

Abstract: This paper proposes a high-speed multiband filtered-orthogonal frequency division multiplexing (F-OFDM) signal transmission over a seamless fiber-millimeter-wave (MMW) system at 92.5 GHz. The system employs a frequency and phase stabilized optical MMW signal generation at the transmitter and a simple direct detection at the receiver. We confirm a successful transmission of multiband F-OFDM signal over a seamless 20-km single mode fiber (SMF) and 1-m 92.5-GHz wireless system. Compared to the single-band and multiband OFDM signal transmission, the proposed system can provide a much better performance, particularly at the edges of each band.

Keywords: radio over fiber (RoF), orthogonal frequency division multiplexing, seamless fiber-millimeter-wave systems, mobile fronthaul systems

Classification: Optical systems

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1 Introduction

Fifth-generation (5G) mobile network has attracted growing attention from both industry and the academic community. It is predicted that the capacity of mobile networks will increase approximately 1000 times compared to the current 4G LTE networks [1] and able to provide a ubiquitous communication with much higher data rate, lower latency, and lower power consumption [2, 3]. To achieve the targets of 5G networks, advanced technologies is of particular importance not only for mobile transport networks but also for radio access networks (RANs). For mobile transport networks, mobile fronthaul (MFH) systems that connect a pool of baseband units (BBUs) in a central station (CS) with remote radio heads (RRHs) play a very important role [4]. MFH systems should have high capacity, low-transmission delay, low-power consumption, flexibility, simplicity, and low cost to support different use cases and deployment models.

Recently, the convergence of fiber and millimeter-wave (MMW) systems is considered an attractive solution for MFHs where fiber cables are not available [5, 6, 7, 8]. MMW communications in the W-band (75–110 GHz) is of interest because of its large-available bandwidth and low-atmospheric attenuation. As reported in [5], a seamless convergence of fiber and MMW systems can provide a fiber-like high-capacity transmission. However, the inclusion of complicated digital signal processing algorithms at receivers significantly increases the power consumption and transmission delay. A simple converged system will be more appropriate for an MFH transmission in small-cell-based ubiquitous communications. Intensity modulation and direct detection (IM/DD) seamless fiber-wireless systems have been proposed for simple and low-latency MFHs [6, 7, 8]. Nevertheless, a high-capacity seamless system will be of particular importance to

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facilitate high-data-rate RAN transmission in future mobile networks. Orthogonal frequency division multiplexing (OFDM) is an efficient method for high-capacity IM/DD fiber-wireless systems [5]. However, the performance of a single-band OFDM system might be degraded because of non-flat frequency response. A multiband signal transmission over the converged system can be an attractive alternative to improve the performance.

In this paper, we propose a high-speed fiber-MMW system using multiband OFDM and filtered-OFDM (F-OFDM) signal transmission. We compare the performance of a single-band OFDM (SB-OFDM) signal, a dual-band OFDM (DB-OFDM) signal, and a dual-band F-OFDM (DB-F-OFDM) signal after transmission over a converged 20-km SMF and 1-m 92.5-GHz system. Successful transmission of all signals using 16-quadrature amplitude modulation (16-QAM) is experimentally confirmed. It is shown that the performance of the DB-OFDM signal is better than the SB-OFDM owing to its narrow bandwidth (BW). In addition, the DB-F-OFDM signal outperforms the DB-OFDM signal, especially at the edges of each band, because of its lower out-of-band (OOB) interference. The rest of the paper is organized as follows. In Section 2, we present the experimental setup for the signal transmission. In Section 3, experimental results and discussions are presented. Finally, Section 4 concludes the paper.

2 Experiment setup

The experimental setup for transmission of wireless signals over the IM/DD seamless fiber-MMW system is presented in Fig. 1(a). We transmit different signals, including a SB-OFDM, a DB-OFDM, and a DB-F-OFDM signal, over the converged system. The signals are generated offline in Matlab and downloaded to an arbitrary waveform generator (AWG). The central frequency of all signals is located at 5.5 GHz. The SB-OFDM signal has a BW of 2.5 GHz while signals in each band of the DB-OFDM and DB-F-OFDM signals spread over a BW of 1.25 GHz. All signals consist of 256 subcarriers, of which 190 subcarriers are used for data 1 modulation, 30 subcarriers are used for data 2 modulation, 8 subcarriers are used for pilots, 1 subcarrier at the center is null, and the remained 27 subcarriers at band edges are used as guard bands. Data 1 and data 2 are located at the center and the edges of each band, respectively. The DB-OFDM signal has an additional 2-MHz guard tone between the first and the second band. Fig. 1(b) shows F-OFDM algorithms at the transmitter and receiver side. The procedures for generating and demodulating F-OFDM signals in each subband are similar to those using OFDM method, excepting that a narrow-band Hann-window-sinc filter is added in each subband to reduce the OOB leakage [9, 10]. F-OFDM signals with different subcarrier spacing, cyclic prefix (CP) lengths, and transmission time interval durations can be contained in different subbands. The subbands do not overlap with each other, and a small number of guard tones, which is much smaller than the guard tone used in 4G LTE, are left to accommodate inter-band interference and allow for asynchronous transmission.

For realizing a seamless fiber and MMW system, we generate a coherent two-tone optical signal using a high-precision optical modulation technology [11]. The

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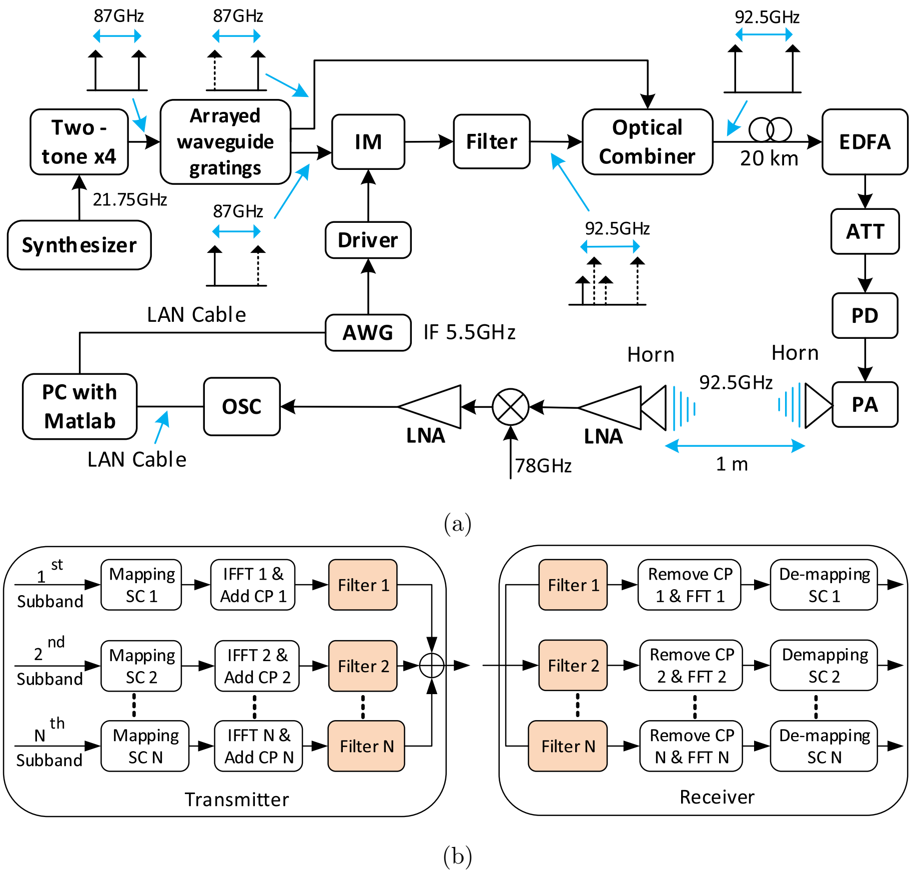

Fig. 1. (a) Experimental setup for OFDM and F-OFDM signal transmission over a converged fiber-MMW system. (b) Structures of F-OFDM algorithms at the transmitter and receiver

generated signal consists of two frequency and phase stabilized optical signals with a frequency difference of 87 GHz. The two optical signals are then separated by an arrayed-waveguide grating. The lower-sideband signal is used for data modulation at an intensity modulator (IM), and the upper sideband signal is kept free to work as a reference signal to generate an MMW signal at the optical receiver. The IM is biased at a minimum-transmission point to generate a double-sideband with carrier-suppression signal. To reduce fiber-dispersion induced effects, a narrow-band optical filter is used to filter out the sub-upper sideband. The remained sub-lower sideband signal is amplified by an erbium doped fiber amplifier (EDFA) and combined with the reference signal by a 3-dB optical coupler. The combined signal is transmitted over a 20-km SMF to the optical receiver. At the receiver, the signal is amplified by another EDFA, and power adjusted by a variable attenuator (ATT) before being fed into a high-speed photodetector (PD). At the PD output, a 2.5-GHz MMW signal centralized at 92.5 GHz is generated. The signal is then amplified by a power amplifier (PA) and seamlessly emitted into free space by a 23-dBi horn antenna. After transmission over 1 m in free space, the signal is received by another horn antenna, and amplified by a low-noise amplifier (LNA). The signal is then down-converted to an intermediate frequency at 14.5 GHz by an electrical mixer, amplified by another LNA, and sent to an oscilloscope (OSC). Finally, the signal is demodulated offline in Matlab.

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3 Results and discussions

We first transmit a 2.5-GHz SB-OFDM over the system. Examples of received constellation maps of 16-QAM signals carried by data 1 and data 2 are shown in Figs. 2(a) and (b), respectively. We can observe a clear constellation after the transmission for data 1. The error vector magnitude (EVM) value is much better than the requirement which is determined to be 14.84% for a BER of 10^{-3} for 16-QAM signals [12]. However, the performance of data 2 (edge subcarriers) is degraded and it is difficult to recover successfully the transmitted signal. Multiband signal transmission with a narrow BW in each band can be an alternative to improve the performance. To prove the concept, we generate and transmit a DB-OFDM signal with a BW of 1.25 GHz in each band over the system. Examples of received constellation maps of a 16-QAM signal of data 1 and an 8-PSK signal of data 2 are shown in Figs. 3(a) and (b), respectively. Compared to the SB-OFDM signal, the performance of the DB-OFDM signal is improved. However, the performance of data 2 is degraded because of the OOB interference between the subbands. Figs. 3(c) and (d) show the EVM performance for different subcarrier indexes (data 1 + data 2) for signals in the first and the second bands, respectively. Although the performance is improved compared to the SB-OFDM signal, the performance of edge subcarriers in each band is degraded because of the interference induced from OOB leakage.

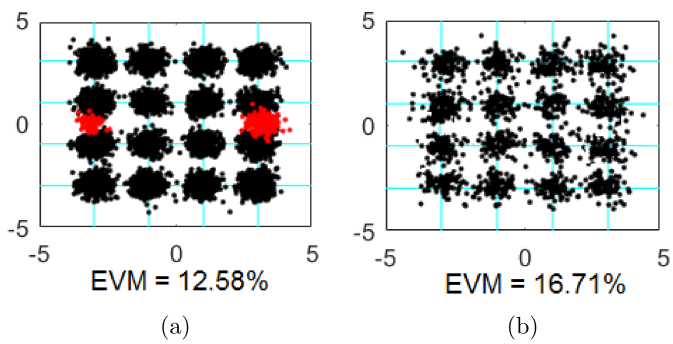

Fig. 2. Constellation of SB-OFDM signal: (a) data 1; (b) data 2

Recently, F-OFDM is proposed as a promising candidate for 5G waveform transmission owing to its advantages of OOB leakage rejection [9]. In this work, we also generate a DB-F-OFDM signal and transmit it over the system. Compared to the DB-OFDM signal, the guard tone between the sub-bands is eliminated. Examples of constellation maps of data 1 and data 2 after transmission over the system are shown in Figs. 4(a) and (b), respectively. An example of the received spectrum of the DB-F-OFDM signal is also shown in Fig. 4(c). Compared to the DB-OFDM signal, the performance of DB-F-OFDM signals is much better, especially for subcarriers at the band edges. With this improved performance, data 2 now can carry 16-QAM signals as data 1. It should be noted that the use of F-OFDM algorithms also helps to improve the spectral efficiency because of the exclusion of an additional guard tone between the subbands. Figs. 4(d) and (e) show the EVM performance for different subcarrier indexes for the signals in the

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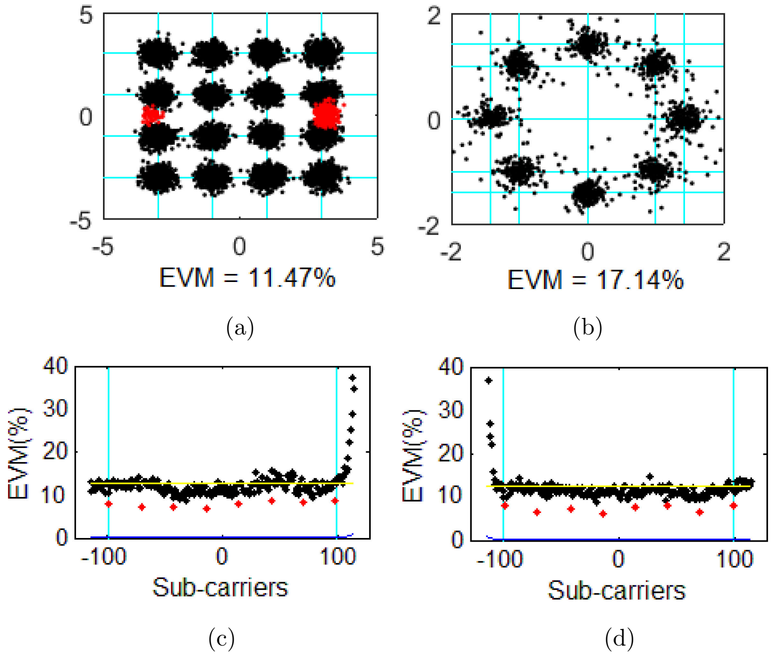

Fig. 3. (a) Example of constellation map of 16-QAM signal of data 1. (b) Constellation map of 8-PSK signal of data 2. (c) EVM for different subcarriers of the first band. (d) EVM for different subcarriers of the second band

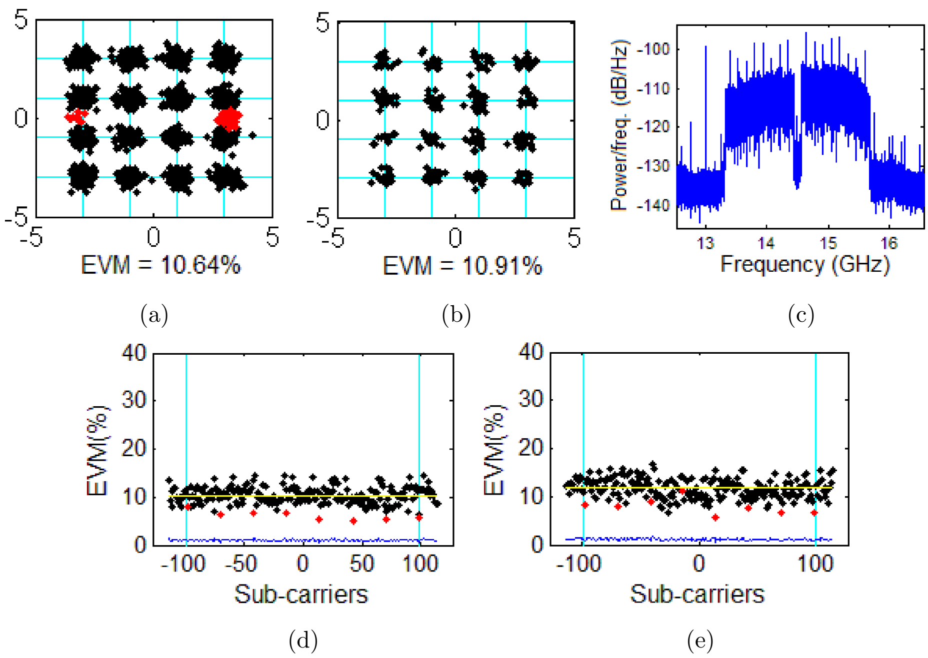

Fig. 4. (a) Constellation of data 1. (b) Constellation of data 2. (c) Received spectrum of the DB-F-OFDM. (d) EVM for different subcarriers of the first band. (e) EVM for different subcarriers of the second band

first and the second band, respectively. It is clearly shown that the performance of the edge subcarriers of the DB-F-OFDM signal is significantly improved compared to the DB-OFDM signals.

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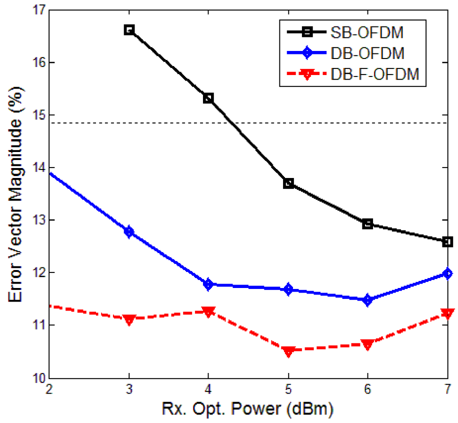
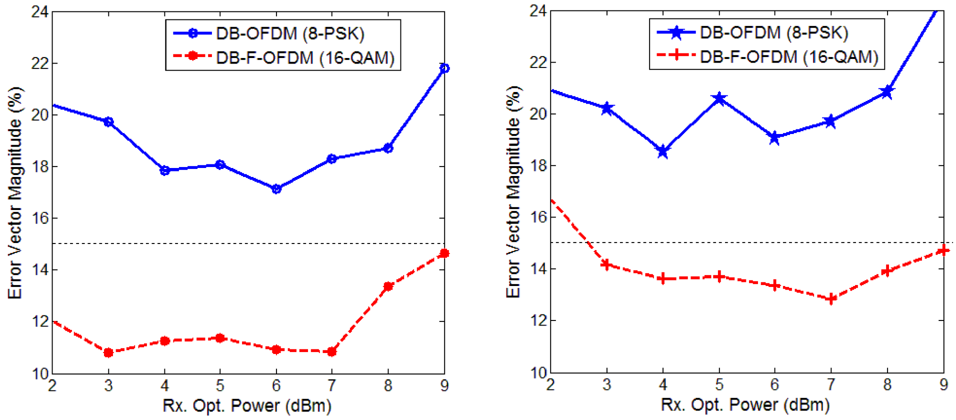


Fig. 5. Performance of the SB-OFDM, the DB-OFDM (first band), and the DB-F-OFDM (first band) signals for different received optical powers



(a) (b)

Fig. 6. Performance of data 2 for different received optical powers: (a) first band; (b) second band

We then measure the EVM performance for different received optical powers. A performance comparison of data 1 of the SB-OFDM, the DB-OFDM (band 1), and the DB-F-OFDM (band 1) for different received optical powers is shown in Fig. 5. We can observe that the performance of multiband signals is much better than the single-band signal. The F-OFDM signal also outperforms the OFDM signal because of its better OOB leakage rejection. We also compare the performance of data 2 (edge subcarriers) of the DB-OFDM and the DB-F-OFDM signals for different received optical powers. Figs. 6(a) and (b) show the performance for signals in the first and the second band, respectively. As mentioned previously, because the performance of edge subcarriers of DB-OFDM signals is degraded, 8-PSK signal is generated and transmitted over the system instead of 16-QAM signals. For DB-F-OFDM signals, owing to the performance improvement, we can transmit 16-QAM signals at the edge subcarriers. The figures show a significant improvement of the F-OFDM signals compared to the OFDM signals.

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4 Conclusion

We have proposed a high-speed IM/DD seamless RoF-MMW system using multiple-band F-OFDM signal transmission. Compared to the conventional single-OFDM and dual-band OFDM signals, the use of dual-band F-OFDM signal helps to improve significantly the performance, especially at the edge subcarriers. The F-OFDM method also helps to improve the spectral efficiency owing to its better out-of-band leakage rejection. The system can be an attractive solution for future high-capacity mobile fronthaul systems in 5G networks.

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