V-band Gapless OFDM RoF System with Power Detector Down-conversion and Novel Volterra Nonlinear Compensation

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Abstract: V-band gapless OFDM RoF system with power detector down-conversion is proposed. We propose and successfully employ a novel Volterra nonlinear compensation to mitigate signal-to-signal beating interference, resulting in 22% data rate improvement with bit-loading algorithm.

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1. Introduction

The increasing demand of interactive high-definition video and image services has driven wireless communication to provide multi-Gbps transmission. However, the data rate of the current wireless communication is limited to hundreds of Mbps which are hampered by limited spectra. Recently, the millimeter waves (MMW) with larger bandwidths, such as V-band (57-64GHz), W-band (75-110GHz) and THz-band, have attracted a lot of attention to provide multi-Gbps services [1]. However, higher frequency signals would lead a higher propagation loss. Therefore, the radio-over-fiber (RoF) system with low propagation loss with optical fiber is a promising candidate to extend wireless coverage and reduce the system cost. Moreover, the high modulation format signals such as orthogonal-frequency-division-multiplexing (OFDM) with quadrature amplitude modulation (QAM) format have been utilized to improve spectral efficiency and capacity.

One of the challenges in MMW RoF systems is how to down-convert MMW signals to intermediate frequency or baseband. Electric mixer and power detector are two main approaches to realize MMW signal down-conversion [2-3] as shown in Fig. 1. For the mixer scheme, an additional high power local oscillator (LO) is required. However, as the carrier frequency increases, the power of LO will be limited for mixer down-conversion due to the amplifier, which makes the base station (BS) more complex and expensive. On the other hand, power detector down-conversion doesn’t need the LO in BS and shows phase noise insensitivity. However, only amplitude information can be carried. Recently, voltage signal down-converted using power detector has been proposed as shown in Fig. 1 [4]. To avoid the signal-to-signal beating interference (SSBI), a frequency gap between RF carrier and vector signal is needed, resulting in reduction of spectral efficiency.

In this paper, we propose and experimentally demonstrate V-band gapless OFDM RoF system with power detector down-conversion. In fact, Volterra series have been viewed as a promising technique for modeling and compensation of system nonlinearity [5]. A novel and modified 2nd Volterra nonlinear compensation is proposed to mitigate SSBI. The frequency gap between RF carrier and vector signal is no longer needed. With 7-GHz 16-QAM OFDM signals, the performance can be improved and meet FEC limit of 10⁻³ after modified 2nd Volterra nonlinear compensation. Moreover, we use the Levin-Campello bit-loading algorithm in proposed system, and the data rate can be improved from 24 Gb/s to 29.3 Gb/s in about 22% data rate improvement over 4-km fiber transmission and 3-m wireless transmission.

Fig. 1. Mixer and power detector down-conversion

Fig. 2. Schematic diagram of conventional novel Volterra nonlinear compensation
2. Concept of novel Volterra nonlinear compensation

Fig. 2 shows that a power detector provides a simple approach to realize down-conversion of an RF signal, which is transmitted along with an inserted RF tone as shown in Fig. 2(i). Specifically, the square-law detection creates the beating term ($\Re\{C^*S\}$) at baseband between the RF carrier ($C$) and the RF signal ($S$); i.e., $|C + S|^2 = |C|^2 + 2\Re\{C^*S\} + |S|^2$. However, the procedure is accompanied with undesired SSBI ($|S|^2$), as shown in Fig. 1(ii). If a conventional Volterra nonlinear compensation is applied to the system to remove the 2nd-order nonlinear distortion (i.e., the SSBI), the nonlinear term created by the conventional Volterra for SSBI compensation will be approximately in the form of $\Re\{C^*S\}_{t_1} \times \Re\{C^*S\}_{t_2}$, which cannot compensate the real SSBI. From the aspect of frequency domain, the bandwidth of the SSBI is as wide as the desired signal, but the nonlinear term created by conventional Volterra will have twice bandwidth, as shown in Fig. 2(iii), implying to the failure of SSBI compensation by a conventional Volterra nonlinear compensation. Take the procedure of down-conversion into consideration, a nonlinear term needed for compensation must rely on $S$, instead of $\Re\{C^*S\}$. Thus, we propose to remove the negative spectrum of the received signal ($|C + S|^2$) before creating a nonlinear term for compensation, as shown in Fig. 2(iv). In other words, the elimination of the half spectrum approximately convert the received signal to the form of $S$, such the following novel Volterra nonlinear compensation could reconstruct the nonlinear term $SS^*$ for SSBI compensation.

3. Experiment setup and result

Figure 3 depicts the experimental setup of 60-GHz RoF system employing power detector down-conversion and Volterra nonlinear SSBI compensation. The OFDM 3.5-GHz I/Q baseband signals with FFT size of 512 and 298 subcarriers are generated by arbitrary waveform generation (AWG) with 12G-Sample/s. An electric I/Q mixer is used to up-convert the baseband OFDM signal to 7-GHz signal centered at 21 GHz. The driving signals for single-electrode Mach-Zehnder modulator (SD-MZM) are composed of the OFDM-modulated signal at 21 GHz, a RF tone at 39.5 GHz, and a RF carrier at 17.5 GHz as shown in Fig. 3(i). The SD-MZM biased at null point to achieve optical double sideband with carries suppression as shown in Fig. 3(ii). In order to overcome fading issue from fiber dispersion, a 33/66 interleaver is utilized to remove one OFDM-modulated sideband and one optical subcarrier as shown in Fig. 3(iii). The frequency difference between optical RF tone and optical signal is 60.5 GHz. Hence, the electrical OFDM signal and RF tone are generated at 60.5 GHz and 57 GHz by photo detector as shown in Fig. 3(iv), respectively. After 3-m wireless transmission, the OFDM signal is down-converted to 3.5 GHz with square-law power detector as shown in Fig. 3(v) and received via scope to be demodulated in off-line MATLAB® DSP program.

To investigate the SSBI effect from power detector down-conversion, the OFDM bandwidth increases from 3.5 GHz to 7 GHz in Fig. 4(a). It can be observed that SSBI will not be in down-converted OFDM signal when the bandwidth is 3.5 GHz. When the bandwidth increases to 7 GHz, SSBI will occupy whole 7-GHz bandwidth as shown in Fig. 4(a)-(b). In other words, the larger signal bandwidth is, the more SSBI would be in down-converted OFDM signal. Hence, the carrier-to-signal power ratio (CSPR) of the generated 60-GHz OFDM signal is a crucial parameter in optimizing the performance of proposed system. Fig. 5 shows the SNR versus different CSPR and constellations with and without Volterra nonlinear compensation. Without Volterra nonlinear compensation, the SNR increases as CSPR value increases because the effect of SSBI decreases. With the Volterra nonlinear compensation, the optimal CSPR of the OFDM signal with highest SNR can be decreased. It can be seen that the constellations of 16-QAM OFDM signals have been obviously improved and there is 1.8dB SNR improvement in optimal CSPR value of 7dB.
Figure 6 shows BER curves of 16-QAM OFDM signal. Without Volterra nonlinear compensation, the performance of 6-GHz OFDM signal can meet the FEC limit of $10^{-3}$. After Volterra nonlinear compensation, the performance can be greatly improved. Even the whole 7-GHz bandwidth OFDM signal can meet the FEC limit.

Because the 60-GHz channel response is uneven and the SSBI has more interference on lower frequency band of OFDM signal, we apply Levin-Campello bit-loading algorithm to find maximum data rate with various signal bandwidth. Fig. 7 presents the attainable data rate with a given target BER of $10^{-3}$. Notably, as the OFDM signal bandwidth increases, the improvement of attainable data rate can be obviously enhanced. For 7-GHz OFDM signal, the data rate can be improved from 24 Gb/s to 29.3Gb/s resulting in about 22% data rate improvement. Moreover, after 4-km fiber transmission, there is no penalty of the maximum data rate with various signal bandwidth.

5. Conclusion

In V-band gapless OFDM-RoF system employing power detector down-conversion, we successfully utilize novel Volterra nonlinear compensation to mitigate SSBI. With 7-GHz 16-QAM OFDM signal, the BER can be improved and achieves FEC limit of $10^{-3}$. Moreover, we use the Levin-Campello bit-loading algorithm in proposed system, and the 22% improvement of data rate can be achieved.

6. References