Centralized Digital Self-Interference Cancellation Technique to Enable Full-duplex Operation of Next Generation Millimeter Wave over Fiber Systems

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Abstract: We propose and experimentally demonstrate a centralized digital self-interference cancellation scheme in a mm-wave over fiber system for full-duplex next-generation mobile networks. A 24.1-dB self-interference cancellation over 1-GHz bandwidth is realized with successful signal-of-interest recovery.

OCIS codes: (060.2330) Fiber optics communications; (060.5625) Radio frequency photonics.

1. Introduction

To satisfy the exponential growth of enhanced mobile broadband (eMBB) services such as immersive virtual/augmented reality and cloud based services and applications, orthogonal frequency division multiplexing (OFDM) based fiber-wireless integrated access network attracts tremendous interest because of its inherent benefits including high spectral efficiency, low-latency and simplified remote radio units (RRU) [1]. In the meantime, the next generation mobile networks (NGMN) geographical throughputs supported by distributed units (DU) can be significantly enhanced through exploiting the mm-wave band with enormous available bandwidth and small cells compatibility [2-3]. However, conventional time-division duplex (TDD) and frequency-division duplex (FDD) cannot fully utilize the available spectrum resources. Therewith, Co-time Co-frequency Full Duplex (CCFD) transmission is desired to increase the spectrum usage and increase system capacity [4]. Unfortunately, since the transmit (Tx) antenna and receive (Rx) antenna are collocated at the same cell site, the CCFD transmission will cause severe self-interference (SI) at the Rx antenna due to leakage, reflections, and diffractions of transmitted signals. In this case, the weak signal-of-interest (SOI) from a distant user equipment (UE) will be overwhelmed by the strong SI and the signal quality is degraded severely. Therefore, an efficient self-interference canceller is necessary. SI cancellation can be divided into two major categories, namely, passive suppression and active cancellation. In passive suppression, the SI signal is suppressed while propagating before being processed by the receiver [5]. In active cancellation, the SI signal is cancelled via subtracting a reconstructed SI copy from the fully known Tx signal. Active cancellation includes analog cancellation and digital cancellation, based on the domain (analog or digital) where the SI signal is subtracted. Several analog interference cancellers have been reported [6-7]. In [6], an analog canceller based on fiber optics demonstrated a 30-dB cancellation depth over an ultra-wide 5.5-GHz bandwidth. Nonetheless, since only one variable attenuator and one delay line were used, this scheme cannot mitigate the SI multipath components. An analog multi-tap SI canceller was presented in [7] but it was bulky and costly. Contrarily, digital cancellation is a low complexity active cancellation scheme [8] with efficient SI reconstruction based on channel estimation. The bottleneck of the digital cancellation is the limited quantization dynamic range of an analog-digital-converter (ADC), which requires a low SI to SOI power ratio, otherwise the quantization noise of the SOI will increase dramatically. On the other hand, due to the highly directional beams and reduced signal travel range of mm-wave bands, the SI to SOI power ratio becomes much higher compared to sub-6GHz cases, ensuring a more applicable and reliable digital cancellation for full-duplex NGMN.

In this paper, we propose a centralized digital cancellation scheme integrating with the mm-wave over fiber system to maximize the efficacy of digital cancellation. A proof-of-concept experiment is conducted to evaluate the full-duplex performance of NGMN including both SI cancellation and SOI recovery. We experimentally demonstrate an effective digital cancellation of 24.1-dB over 1-GHz wide bandwidth in full-duplex mm-wave over fiber system.

2. Operation principles and experimental setup

Fig.1 is the experimental setup to verify the feasibility of the centralized digital cancellation. At the DU side, an optical carrier centered at 1565.42 nm generated by an external cavity laser (ECL, PPCL100) is launched to the Mach–Zehnder modulator 1 (MZM1) with 13.5-dBm input power, the optical carrier's spectrum is shown in the inset i. The MZM1 is biased at the null point for optical carrier suppression (OCS), while a 30-GHz RF single-tone signal output from an RF signal generator (Anritsu 68369B) modulates onto the MZM1 to create 60-GHz spacing optical sideband carriers. Inset ii demonstrates the optical spectrum of the MZM1 output. To ensure sufficient power for the signal

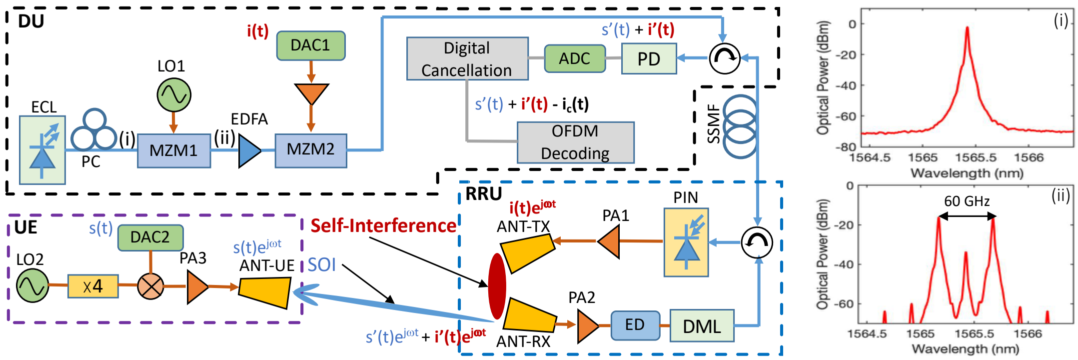

Fig. 1 Experimental setup of the proposed centralized digital cancellation in mm-wave over fiber system; optical spectrum (i) before and (ii) after optical carrier suppression.

modulation at MZM2, the sideband carriers are boosted by an EDFA (AEDFA13-B-FC) before entering the second MZM. Meanwhile, we implement an OFDM encoder to generate a 16-QAM OFDM baseband transmit signal, denoted as i(t), which is then digital-to-analog converted via an arbitrary waveform generator (AWG, M8195A) operating at 16 GSa/s. The output of the AWG is pre-amplified by a modulator driver (Picosecond 5865) to reach the required peak-to-peak voltage and then modulates onto the MZM2 biased at the quadrature point for optimal optical intensity modulation. The modulated optical signal transmits through a 15-km standard single-mode fiber (SSMF) and is detected by a 60-GHz PIN receiver (XPDV2020R) at the RRU side, where a millimeter-wave OFDM Tx signal with a 60-GHz carrier frequency is produced. A power amplifier (PA) with 25-dB gain and a 15-dBi horn antenna (ATN-Tx) are implemented to establish the mm-wave downlink transmitter of the RRU. The downlink signal is an upconverted version of i(t) denoted as $i(t)e^{j\omega t}$, where ω is 60 GHz. At the UE side, an RF source (E8247C) outputs a 15-GHz RF single-tone signal, which is then quadrupled to 60-GHz frequency serving as the local oscillator (LO) in the mixer. Therewith, we use an independent channel of the AWG to generate a 4-QAM OFDM signal s(t), and the signal is upconverted to the 60-GHz band, denoted as $s(t)e^{j\omega t}$, by mixing with the LO2. Another set of PA and the ANT-UE are employed for uplink mm-wave transmission. The ANT-UE is seated 1.5-m away from the RRU, while the ANT-Tx is collocated with the ANT-Rx. Since the downlink signal from the ANT-Tx and uplink signal from the ANT-UE share the same frequency and are received by the RRU receiver simultaneously, the received downlink signal becomes the SI, while the uplink signal is the SOI. The received interfered mm-wave signal $s'(t)e^{j\omega t} + i'(t)e^{j\omega t}$ is detected by an envelope detector (ED, DET-15-RPFW0). To maximize the digital cancellation efficacy and reduce the cost of computing resources, the baseband interfered signal modulates onto a directly modulated laser (DML, SCMT-100M11G) for being optically delivered to the DU for centralized digital cancellation. The optical signal is detected by a photodetector (PD, SCMR-100M11G) and analog-to-digital converted via an oscilloscope (DSOZ254A) with 20 GSa/s sampling rate. The goal of the digital cancellation is to remove the detected self-interference (SI) i'(t) by subtracting the estimated interference, denoted as ic(t), based on the known baseband Tx signal i(t). The detected signal before cancellation is r(t) = s'(t) + i'(t). By subtracting the $i_c(t)$, the remaining signal is $r_c(t) = s'(t) + i'(t) – i_c(t)$, such that the SI is cancelled and only SOI is left for the subsequent OFDM decoding. Since the interference signal experiences multipath effect while propagating from the ANT-Tx to ANT-Rx, a proper reconstructed copy of the SI can be expressed as $i_c(t) = \sum_{l=-L/2}^{l=L/2} h(l) \cdot i(t-l)$, where h are the estimated channel coefficients and L is the number of taps at the digital canceller. We implement an adaptive filter based on optimized least mean square (LMS) algorithm to derive and track the coefficients to create a matched cancellation signal.

3. Experimental results

The experimental results consist of two parts, SI cancellation and SOI recovery. Firstly, we evaluate the performance of the canceller. Fig.2(a) shows the SI cancellation coefficients of a 128-tap digital canceller derived from the correlation between pilot Tx signal and the SI. As observed, besides the dominant line-of-sight SI, there are multiple notable SI components resulting from multipath effect. Fig.2(b) demonstrates the spectra of the baseband OFDM SI signal before and after digital cancellation. The orange curve is the spectrum of a 1-GHz bandwidth SI signal with 520 efficient carriers over 2048 FFT size, while the blue curve is the 2-GHz bandwidth SI signal with 1040 efficient carriers. After the digital cancellation, both of the SI signals are cancelled completely down to the noise floor as shown by the purple and yellow curves, respectively. The cancellation performance is derived via calculating the difference in dB between the spectra before and after the cancellation. We, for the first time experimentally demonstrate a 24.1-dB digital cancellation over 1-GHz bandwidth and a 19.5-dB cancellation over 2-GHz bandwidth in mm-wave over fiber system, as shown in Fig.2(c). This prominent performance enables full-duplex operations for NGMN over a wide bandwidth. Another essential performance metric is SOI recovery. The SI signal is a 16-QAM OFDM signal with 480

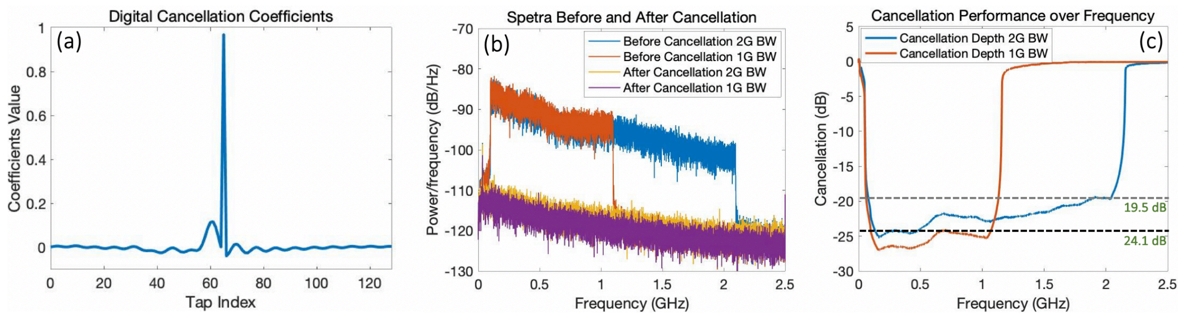

Fig. 2 (a) Digital cancellation coefficients over tap index; (b) self-interference signal spectra before and after SI cancellation; (c) cancellation performance over frequency range.

efficient subcarriers, 480-kHz subcarrier spacing and 200-MHz intermediate frequency (IF), while the SOI is a 4-QAM OFDM signal with 120 efficient subcarriers. Fig.3(a) is the spectra of the baseband interfered signal detected at the DU. The orange curve is the spectrum before cancellation. The SOI is seriously contaminated by the in-band SI signal and cannot be recovered through spectral filtering. However, with digital cancellation, the SI is completely removed and the SOI is recovered from the spectrum as shown by the blue curve for the subsequent OFDM decoding. Fig.3(b) shows the constellation of the recovered SOI after zero-forcing equalization. The left-side constellation without digital cancellation is blurred because of the strong SI, while the right-side constellation with digital cancellation is clearly displayed. The EVM is improved from 102.23% to 16.33% correspondingly. To further verify the robustness of the proposed centralized digital cancellation scheme, we perform a BER of the recovered SOI over received optical power (RoP) measurement at the DU side. As shown in Fig.3(c), the sensitivity reaches -10.1 dBm based on the HD-FEC threshold. By taking the difference between the DML's 5.5-dBm output power and the sensitivity, the link budget is 15.6 dB. Since most of the DU to RRU connections are logically point-to-point (P2P) in WDM-based MFH, the centralized digital cancellation scheme should possess a sufficient power margin for link degradation due to aging, instable temperature, etc. The constellation diagrams at reference points are also shown correspondingly.

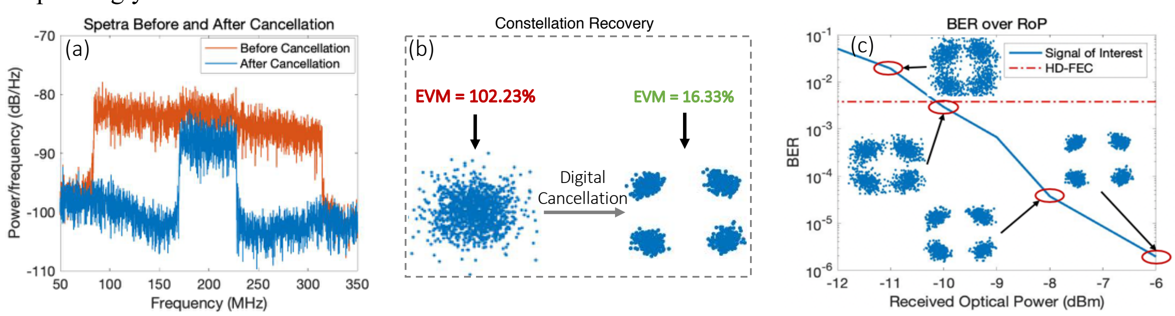

Fig. 3 (a) Interfered signal spectra before and after cancellation; (b) constellation diagrams with and without digital cancellation; (c) BER over received optical power (RoP) at the DU.

4. Conclusions

We propose a centralized digital cancellation scheme in a mm-wave over fiber system and experimentally verify the full-duplex performance of preeminent SI cancellation and efficient SOI recovery. A digital cancellation performance of 24.1-dB over 1 GHz and 19.5-dB over 2 GHz are firstly demonstrated in a mm-wave over fiber system. The EVM of the decoded SOI is improved from 102.23% to 16.33% with the help of digital cancellation. Besides, the BER over RoP measurement is conducted to evaluate the scheme's robustness with a -10.1-dBm sensitivity. Our scheme offers a promising solution to enable wideband full duplex operation in 5G and beyond NGMN.

5. References

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