A Hybrid TWDM-RoF Transmission System Based on a Sub-Central Station

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Abstract. In this paper, a full-duplex time- and wavelength-division multiplexing -radio-over-fiber (TWDM-RoF) system which can support a hybrid transmission of wired and wireless data is proposed based on an additional sub-central station (SCS). For the downlink, the TWDM technology is employed to transmitted wired and wireless services from a central station (CS) to a SCS with baseband data formats. For the uplink, one upstream optical carrier can simultaneously support both wired and wireless signals to achieve upstream transmissions. Better system compatibility, wavelength utilization and dispersion tolerance for bidirectional transmission links can be achieved in the proposed system. Finally, a demonstrated system with one 10-Gbps wired signal and two 2.5-Gbps wireless signals carried by a 28-GHz radio frequency (RF) signal is established. We validate the feasibility of this system based on the results of the bit error rate (BER) curves for both downlink and uplink.

Keywords: Radio-over-fiber · TWDM · Hybrid transmission · Full-duplex

1 Introduction

The demand of services for terminal users has rapidly increased and the maximum peak rate in the fifth-generation mobile communications system (5G) will be at the Gbps level [1]. Higher radio-frequency (RF) carriers should be employed due to its broad bandwidth and abundant spectrum resources, especially in 5G high-band communications [2]. However, the propagation distance of a high RF signal is significantly limited by atmospheric attenuation, which also means a denser cellular structure (such as microcells and pico-cells) is necessary to ensure requirements of quality of service (QoS) for mobile users [3, 4]. Radio-over-fiber (RoF) technology, which has many advantages, such as low loss, high bandwidth, low cost, simple structure, centralized management and flexible mobility, has been a suitable candidate solution for the enhanced mobile broadband (eMBB) scenario [5–7].

Numerous optical fibre links are required to guarantee the connection between the central station (CS) and a large number of remote base stations (BSs). Since the passive optical network (PON), an optical access network technology, has been used widely and maturely [8]. A hybrid time- and wavelength-division multiplexing PON (TWDM-PON)

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was identified by the full-service access network (FSAN) community in 2012 as the formal standard for the next-generation passive optical network stage 2 (NG-PON2) [9]. The existing optical fiber link resources will be effectively utilized by combining the RoF system with the TWDM-PON [10, 11], which would not only significantly reduce the system costs but also realize a hybrid access network of the wireless (RoF) and wired (NG-PON2) services and thereby satisfy the high bandwidth and mobility requirements of end users.

In this paper, a TWDM-RoF system is proposed based on a sub-central station (SCS), which can realize a hybrid transmission of both wired data and wireless data with an efficient wavelength resource utilization, good system compatibility and dispersion tolerance. A 28-GHz full-duplex TWDM-RoF system with one 10-Gbps wired signal and two 2.5-Gbps wireless signals over a 25-km single-mode fiber (SMF) is demonstrated, and the reliable and practical performance of this system is verified based on results of the bit error rate (BER) curves for both downstream and upstream signals.

2 Architecture of the TWDM-RoF System

The proposed TWDM-RoF system is shown in Fig. 1, where the CS is compatible with the optical line terminal (OLT) and the optical distribution network (ODN) function is included in the SCS. BSs and optical network units (ONUs) are the receiving terminals for the wireless data and wired data signals, respectively. For the downlink, original wireless data is transmitted from the CS to the SCS as a baseband format and centralized modulation of multiple wireless signals are employed at the SCS. Thus the wireless transmitters (TXs) can be effectively compatible with the existing transmitters in the OLT. Moreover, better dispersion tolerance of can be achieved than the RF over fiber system. TWDM technology are employed in this system, which means wired and wireless services can share different time slots at individual wavelengths via medium access control (MAC) layer functionalities in the OLT/CS. Several laser diodes (LDs) are utilized as the upstream optical carriers for each BS to be economic and colorless. All these different wavelengths are combined by a WDM multiplexer (MUX) and transferred to the SCS over a long-distance fiber link.

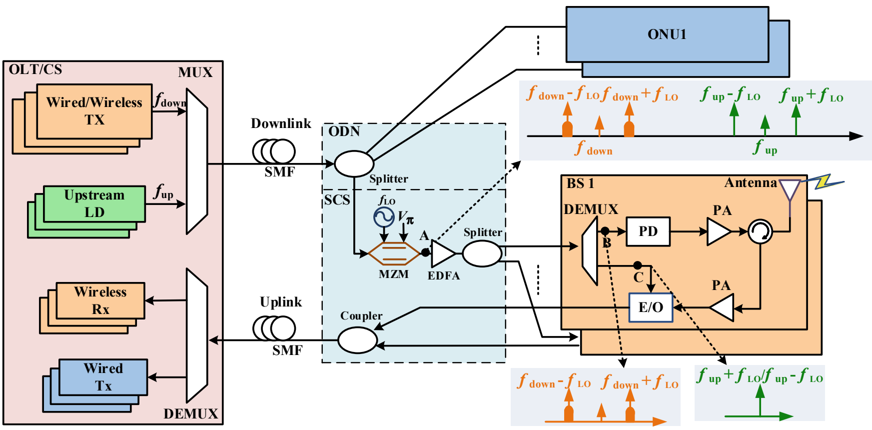

Fig. 1. Architecture of the proposed TWDM-RoF system

At the SCS, the received TWDM signals after an optical splitter are broadcast to each ONU. At each ONU, a de-multiplexer (DEMUX) is tuned to a corresponding wavelength and a wired signal receiver (RX) is employed to realize a downstream transmission, the same as the traditional PON structure. One of the splitter output channels is fed into a MZM biased at V_π and driven by a local oscillator (LO) signals at the frequency f_{LO} to achieve a centralized optical carrier suppression (OCS) modulation. Then each wavelength of f_{down} and f_{up} generates an upper sideband and a lower sideband. The optical spectrum is shown in point A of Fig. 1. To ensure their optical powers of received signals to BSs, these modulated TWDM signals are amplified by an erbium-doped fiber amplifier (EDFA) and broadcasted to each BS after an optical splitter. The modulated RF subcarriers will suffer from a negligible dispersion effect due to the short distance transmission from the SCS to each BS. At each BS, the downstream signal f_{down} is filtered by a programmable wavelength-selective switch (WSS) as a DEMUX. The output spectrum of WSS is shown in point B of Fig. 1. Then, an RF carrier signal with frequency $2f_{LO}$ can be detected by the photo-detector (PD) with its beating function. The detected RF signal is amplified by a power amplifier (PA) and broadcast to mobile terminals by an antenna for a complete downstream transmission of the wireless signals.

For the uplink, the wireless signal received from mobile terminals by each RF antenna is amplified by an electric PA and sent into an external electrical-to-optical (E/O) modulator. The newly generated first-order upper and lower sidebands (with frequencies $f_{up} + f_{LO}$ and $f_{up} - f_{LO}$, respectively), as shown in point C of Fig. 1, can both be used to realize an OCS modulation for the uplink. All the upstream wired signals from different BSs are coupled and transmitted back to the CS.

In this TWDM-RoF system, two new upstream optical carriers are obtained by OCS modulation at the SCS with a single light source at the CS, which supports a higher number of BSs or more upstream traffic. In addition, the optical carrier f_{up} can be reused for wired upstream signals at the ONUs, indicating that the utilizing efficiency of centralized light sources is improved. All upstream signals from BSs and ONUs are separated by the DEMUX in the OLT/CS and then recovered by wired RXs and wireless RXs for a complete upstream transmission.

3 Simulation and Results

A hybrid TWDM-RoF system with one wired signal at 10 Gbps and two wireless signals at 2.5 Gbps is evaluated and demonstrated based on the simulation tools of OptiSystem and Matlab to verify the performance of the proposed system. At the OLT/CS, the LD with the central frequency f_1 = 187.1 THz (λ_1 = 1602.31 nm) is used to transmit the 10 Gbps wired downstream signal, and the central frequencies of wireless TX at f_2 = 187.2 THz (λ_2 = 1601.46 nm) and f_3 = 187.3 THz (λ_3 = 1600.60 nm) are chosen for two 2.5 Gbps wireless downstream signals. In addition, another light source with the central frequency f_4 = 187.4 THz (λ_4 = 1599.75 nm) is distributed as an upstream optical carrier. All baseband data signals are modulated to their corresponding optical carriers through direct modulated lasers (DMLs) with 10 dBm output power. The modulated signals and upstream light sources are multiplexed into a SMF via a MUX. The fiber-optic length between the CS and the SCS is 25 km with an attenuation of 0.25 dB/km.

At the SCS, the received signal is divided in two channels by a 1:2 splitter, the first channel signal is sent to ONU1, and the second channel signal is modulated by a 14-GHz LO through a DMZM, whose bias DC voltage is set to $V_{bias} = V_{\pi} = 4$ V. The electric phase shift of inserted LO signals between two arms of the DMZM is 180° to achieve OCS modulation. Figure 2 shows the spectrum of the modulated signal, where the central frequencies of optical carrier signals are suppressed, and the bandwidths between the newly generated first-order upper sidebands and the first-order lower sidebands are 28 GHz. After amplified by an EDFA with a 20-dB gain, the modulated signals are separated by a 1:2 splitter and sent into BS1 and BS2, respectively.

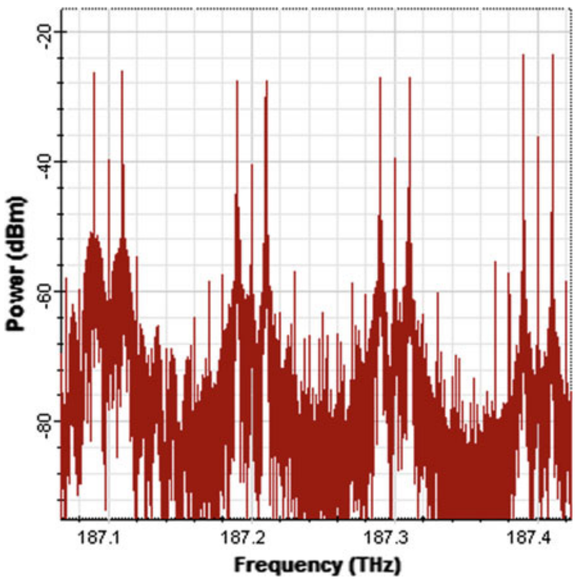

Fig. 2. Optical spectrum after OCS modulation at the SCS

In order to simulate the receiving process for the mobile terminal and verify the quality of the wireless signals received at BSs, a frequency mixer with a 28-GHz LO and a low-pass filter (LPF) are employed to recover the original wireless baseband data and the structure of measured system at the BS is shown in Fig. 3. Taking BS1 as an example, a 1×2 WSS is utilized to separate the downstream data signal and the upstream optical carrier. The central frequency of the output port 1 of WSS is set to 187.2 THz with a bandwidth of 32 GHz, which exceeds the frequency of the necessary RF signal. Then, a PD is exploited to realize the optical-to-electrical conversion and to obtain the 28-GHz RF signal by the beating function of the PD. The generated RF signal is down-converted by a 28-GHz LO. After an LPF, the 2.5-Gbps wireless baseband data can be recovered by a 3R receiver and measured by a BER tester

(BERT). At BS2, by setting the central frequency of the output port 1 of WSS to 187.3 THz, the wireless signal can be recovered and the BER performance can be measured.

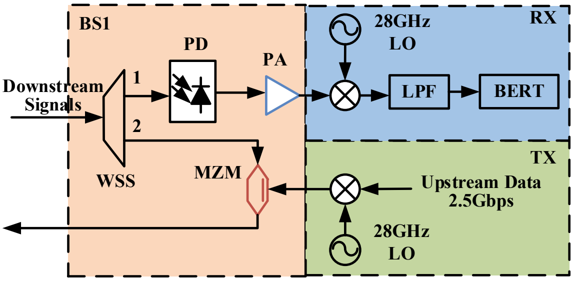

Fig. 3. Structure of measured system at the BS

The measured BER curves of three downstream signals are shown in Fig. 4 and it is shown that a slight power penalty of 0.1 dB is observed between BS1 and BS2. Therefore, the performances of BS1 and BS2 are almost equivalent, and the receiver sensitivities of the two wireless downstream signals are −25 dBm at a BER of 10^{-3}, which can be reduced below 10^{-10} if a forward error correction (FEC) will be exploited. The measured received power of the wired downstream signal in ONU1 is −23.5 dBm at a BER of 1.4×10^{-3}. To achieve the same BER compared with that of the wireless downstream signals a 1.5-dB power penalty for the wired downstream signal is required. This finding is attributed to the higher data rate of the wired signal, which suffers from the impact of chromatic dispersion over a 25-km fiber-optic link.

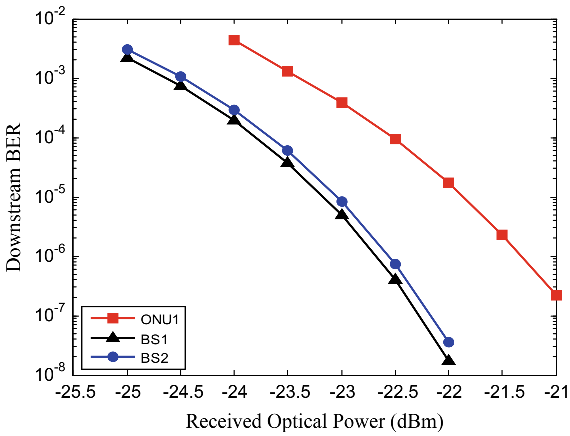

Fig. 4. BER performance of wired and wireless downstream signals

For the upstream transmission, an upstream wired signal at 10 Gbps with a pseudorandom binary sequence (PRBS) for a word length of 2^{31}–1 is modulated by an external MZM and transmitted back to the OLT via a 25-km SMF. At the BSs, two new sidebands with frequencies of 187.414 and 187.386 THz are generated after the OCS modulation. To verify the transmission performance of the first-order sideband signals, the upper sideband at 187.414 THz is filtered by setting the central frequency of the WSS to 187.414 THz. The lower sideband at 187.386 THz is similarly filtered by another WSS in BS2. The wireless data at 2.5 Gbps are mixed with a 28-GHz LO and inserted into an MZM for an O/E conversion. After the 25-km transmission, the wireless signal is recovered in the CS with the same structure as in BS1. The input optical powers of the MZM at two BSs and ONU1 are very important for the reliability of the upstream signals in backhaul. The BER performances of the wired and wireless upstream signals at different input optical power levels are shown in Fig. 5. For a wireless signal received in the CS with a BER below 10^{-3}, the input optical power should be at least −12.5 dBm and the BER for the upstream wired signal is 1.3×10^{-3} when its input optical power is −15 dBm. To obtain the same BER, the input optical powers at BSs must be 2.5 dB higher than the input optical power at an ONU. The communication performance degradation of the wireless system is due to RF transmission in the optical fiber link, which suffers from the dispersion effect of fiber-optic. To solve this issue, the DEMUX at the CS is employed to filter one of two sidebands that contain the original baseband data signal. Then, optical down-conversion is performed to obtain the baseband wireless signal. Since only one sideband is utilized, the power of the other sideband signal is wasted, and a larger input power of the MZM at the BSs is essential to guarantee the received power of single sideband signal.

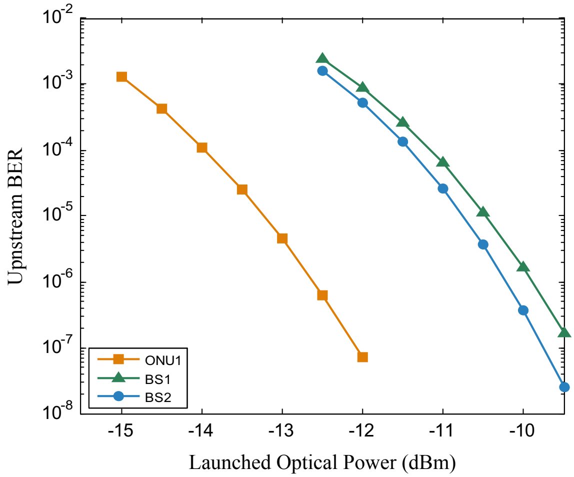

Fig. 5. BER performance of wired and wireless upstream signals

4 Conclusions

In this paper, we propose a full-duplex TWDM-RoF system that can provide a hybrid transmission of wired and wireless signals based on the SCS structure. Compared with a traditional RoF system, this system has many advantages such as a seamless fusion between the CS and OLT, a reduction of CS cost because of the sharing of optical fiber links and transceivers in the existing optical network. The impact of the chromatic dispersion effect on RF signals caused by the long-distance transmission in an optical fiber can be eliminated by using the baseband data format. Bidirectional communication is implemented in the TWDM-RoF system by the upstream optical carrier centralized allotment in the CS. The light sources provided for the ONUs and upper/lower sideband signals generated by OCS modulation are adopted by the BSs in the RoF system, which can support more BSs and improve the utilization of the central light sources. Finally, a 28-GHz TWDM-RoF system with two wireless signals at 2.5 Gbps and one wired signal at 10 Gbps for the bidirectional transmission over 25 km is experimentally demonstrated via our simulation. The reliability and practicality of this system is verified based on the results of the BER curves of the bidirectional transmission of wired and wireless signals, which makes this system highly practical for future 5G mobile communications.

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References

1. Soldani D, Manzalini A (2015) Horizon 2020 and beyond: on the 5G operating system for a true digital society. IEEE Veh Technol Mag 10:32–42
2. Alliance N (2015) 5G white paper. Next generation mobile networks, white paper, pp 1–125
3. Li R, Zhao Z, Zhou X et al (2017) Intelligent 5G: when cellular networks meet artificial intelligence. IEEE Wirel Commun 24(5):175–183
4. Chen H, Li Y, Bose SK, Shao W, Xiang L, Ma Y, Shen G (2016) Cost-minimized design for TWDM-PON-based 5G mobile backhaul networks. J Opt Commun Netw 8:B1–B11
5. Sauer M, Kobyakov A, George J (2007) Radio over fiber for picocellular network architectures. J Lightwave Technol 25:3301–3320
6. Ying C, Lu H, Li C, Chu C, Lu T, Peng P (2015) A bidirectional hybrid lightwave transport system based on fiber-IVLLC and fiber-VLLC convergences. IEEE Photon J 7:1–11
7. Mahmood NH, Lauridsen M, Berardinelli G et al (2016) Radio resource management techniques for eMBB and mMTC services in 5G dense small cell scenarios. In: Vehicular technology conference, Montreal, Canada, pp 1–5

8. Mitchell JE (2014) Integrated wireless backhaul over optical access networks. J Lightwave Technol 32:3373–3382
9. Luo Y, Zhou X, Effenberger F, Yan X, Peng G, Qian Y, Ma Y (2013) Time- and wavelength-division multiplexed passive optical network (TWDM-PON) for next-generation PON stage 2 (NG-PON2). J Lightwave Technol 31(4):587–593
10. Nesset D (2015) NG-PON2 technology and standards. J Lightwave Technol 33:1136–1143
11. Wey JS, Nesset D, Valvo M, Grobe K, Roberts H, Luo Y, Smith J (2016) Physical layer aspects of NG-PON2 standards—part 1: optical link design. J Lightwave Technol 8:33–42