A ROF-PON NETWORK SIMULTANEOUSLY PROVIDING BROADBAND 60-GHZ AND BASE-BAND SERVICES

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ABSTRACT

We experimentally demonstrate a RoF-PON system for both wired and 60-GHz wireless services based on heterodyne effect occurring on the photodiode. The system can simultaneously transmit wired and 60-GHz wireless signal at bit rate 2Gbps at BER under 10^{-6}. 2-Gbps data is successfully transmitted through 4.3-km fiber and 1.2-m 60-GHz wireless link.

Keywords: *radio over fiber, passive optical network, 60-GHz radio frequency, optical frequency comb*

1. INTRODUCTION

Wireless communication networks inside rooms are playing an important role in today's society. The increase of mobiles and other wireless devices along with the increasing demand for broadband services are putting pressure on wireless systems to boost their capacity. With the trend to deploy the potential of optical fiber communications, EPON, GPON and WDM-PON have been entering the wire line access market. To make full use of the inherent large capacity fiber communications and mobility of wireless communications, integration of the wireless and optical network has become a promising research direction. There is currently a great interest in studying the integration of existing PON and RoF network.

Access network is expected to carry more data to satisfy the increasing demand of broadband communication. Higher frequency of carrier is indispensable to meet the growing bandwidth of wireless signal. 60-GHz millimeter-wave (mm-wave) RoF system has been widely researched because of its worldwide available unlicensed bandwidth 7-9GHz and huge separation in frequency domain from current low-frequency wireless services [1]. A mass of 60-GHz RoF system schemes have been proposed to realize the seamless integration of the wired and wireless services [2,3]. In order to properly integrate the PON and RoF, OFC (Optical Frequency Comb) is used to provide multiple optical carriers [4-6]. In OLT (Optical Line Terminal), the OFC can be generated in several methods such as using a recirculating frequency shifter [4] or exploiting cascaded intensity and phase modulators driven by tailored radio frequency waveform [5].

In this work, we propose and experimentally demonstrate a RoF-PON full-duplex hybrid system utilizing heterodyne effect on the photodiode (PD). We have realized 2-Gbps OOK signal transmission over 4.3-km fiber and 1.2-m 60-GHz wireless link at BER under 10^{-6}. In the experiment system, we define three optical carriers to carry information for one user. OFC can be used in the system to conduct multi-user transmission. No matter what kinds of all-optical up-conversion schemes, a part of base-band signal still exists in the whole electrical spectrum after all-optical up-conversion [4]. The heterodyne effect occurs in PD mainly produces two components with information loaded on, base-band and 60-GHz mm-wave band. In our system, the base-band and mm-wave band signals are concurrently generated.

2. PRINCIPLE OF THE PROPOSED WIRED/WIRELESS INTEGRATED ROF-PON ACCESS SYSTEM

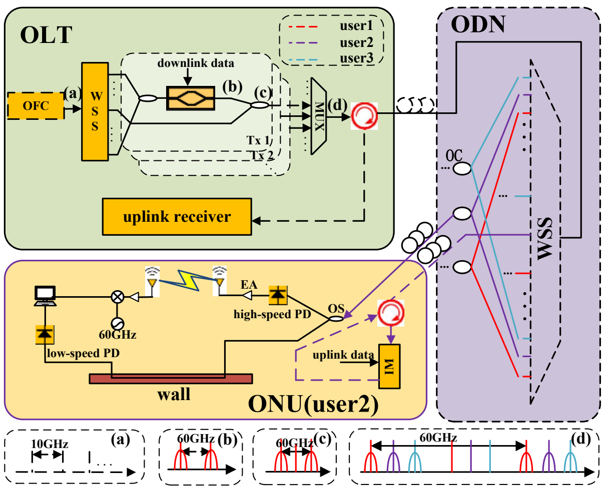

Fig. 1. Schematic of the proposed wired/wireless integrated RoF-PON system using heterodyne effect and OFC

Fig.1 gives the illustration of the proposed wired/wireless integrated RoF-PON system employing heterodyne effect and OFC. OFC is used to generate multiple carriers with frequency interval of 10GHz (shown in Fig. 1(a)). Different from traditional PON, every ONU will occupy three comb lines. In OLT, Tx1 choose three wavelengths to transmit information for one user. In Tx1, the two side wavelengths with frequency interval of 60GHz will be used for downlink

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transmission (shown in Fig. 1(b)) and they will beat in high-speed PD to produce 60GHz wireless signal. The middle pure carrier in Fig. 1(c) will be used for uplink transmission. Fig. 1(d) shows the optical spectrum after multiplexer (MUX). Colors red, purple and blue represent the signal provided for user1, user2 and user3, respectively. The signal generated from OLT will be transmitted to the ODN (Optical Distribution Network) through SMF (Single Mode Fiber). In ODN, a WSS (Wavelength Selective Switch) is used to filter out the signal of different comb lines. OC (Optical Combiner) can combine the two modulated side-bands of one user, and the combined light signal will be sent to ONU (Optical Network Unit). The center unmodulated carriers will also be sent to ONUs to complete uplink transmission. Thus ONUs can be released from laser source and the cost of the whole system can be reduced.

In each ONU, e.g. in user2, heterodyne effect will occur in PD. After the heterodyne effect in PD, the two optical carriers will produce an electrical signal including two parts, base-band and mm-wave band, respectively. Both of them carry the information for user2. VPI transmission-Maker is used to demonstrate and verify the result of this heterodyne effect. Fig. 2 shows the electrical spectrum after all-optical up-conversion.

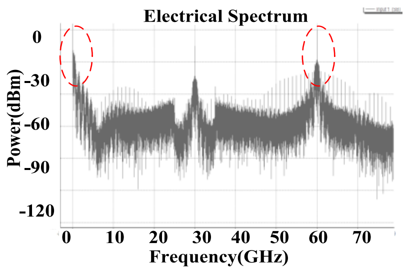

Fig. 2. Frequency spectrum of the received electrical signal after PD.

The light signal arrived at ONU will be split into two parts by an OS (Optical Splitter). The first part will be directly detected by a high-speed PD. The mm-wave band component of the electrical signal will be detected and transmitted through 60-GHz antennas in air, and then the received mm-wave signal will be demodulated by a local oscillator. The second part of the light signal will be sent to the plugs on building wall via SMF. After transmitting through the wall, the wired light signal will be directly detected by a low-cost low-speed receiver and the base-band component of the signal can be produced. In such method, we can simultaneously provide the wired and wireless services in access networks.

3. EXPERIMENT SETUP AND RESULTS FOR ROF-PON FULL DUPLEX HYBRID SYSTEM

A proof of concept experimental setup for the proposed bi-directional full-duplex fiber-wireless link in RoF-PON system with 4.3-km SMF transmission and 1.2-m 60-GHz wireless delivery is shown in Fig. 3. For the lack of equipment to make optical comb, we only produce three coherent wavelengths for one user. Fig. 4(a) and (b) show optical spectrum (0.16-pm resolution) after phase modulator (PM) and after intensity modulator (IM), respectively, when the laser center wavelength and power are at 1552.08nm and 10.02dBm.

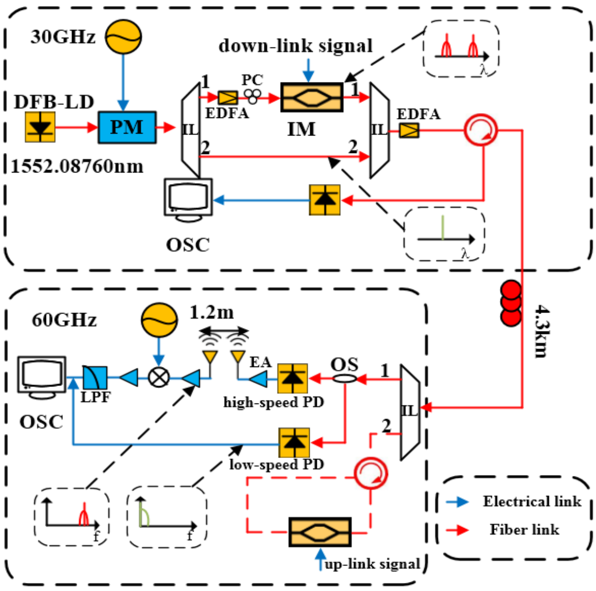

Fig. 3. Experiment setup

The PM is driven by a microwave source at frequency 30GHz to produce the two sidebands. The IM is driven by 1-Gbps or 2-Gbps electrical rectangular NRZ signal with a PRBS (Pseudo-Random Binary Sequence) length of 2^{15}-1, which is generated from signal quality analyzer. The amplitude of the electrical signal is adjusted to accommodate the linear zone of the intensity modulator. The IL (Interleaver) can separate the center carrier and two sidebands of the light signal. Port 1 of the IL will put out the two side bands for downlink communication. Port 2 will put out the center carrier for uplink communication. At receive point, the center carrier will be directly modulated by uplink signal and travel back through SMF. The data capture is realized in serial data analyzer. Limited by the bandwidth of the devices, the analyzer is not able to recognize the 60-GHz mm-wave high speed component before down-conversion. The data analyzer can act as a low-pass filter. So, we can get wired-link signal through directly detecting the electrical signal after low-speed PD. For wireless-link, after the two sidebands detected by a high-speed PD, we use two rectangular horn antennas with a gain of 20dBi, frequency range of 50-70GHz to broadcast the mm-wave component of the electrical signal. The two antennas can also act as two band-pass filters to remove the base-band component. Two amplifiers are utilized before transmitting antenna and after received antenna respectively to compensate the great loss of the 60-GHz wireless signal in air. Limited by the gain of 60-GHz radio amplifiers, the transmission distance of 60-GHz wireless signal is only 1.2m. If high-efficiency amplifier is available, the

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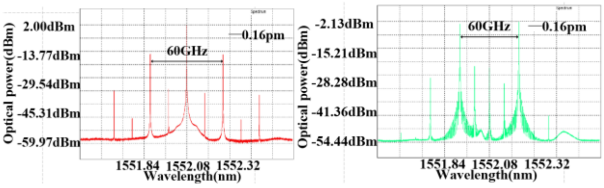
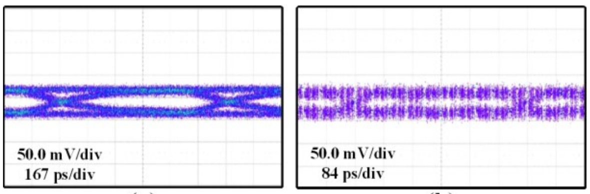
distance can be greatly extended. The received signal will be demodulated by the local oscillator. LPFs with bandwidth of 1GHz and 2GHz are needed to reduce the huge AWGN (Additive White Gaussian Noise) before detected by signal quality analyzer. The local oscillator is produced by frequency multiplication of the 30-GHz signal emitted from microwave source.



(a) (b)

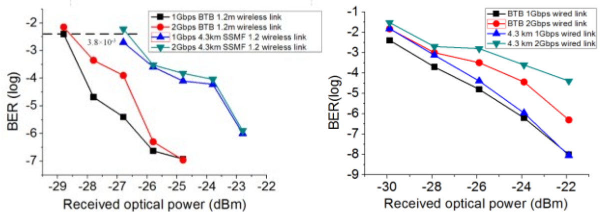
Fig. 4. Optical spectrum of the lightwave signal. (a) after PM, (b) after IM when the wavelength and power of the laser are 1552.08nm and 10.02dBm.

Fig. 5 gives the B2B eye diagrams of the 1-Gbps and 2-Gbps wireless signals after 1.2-m wireless delivery. Fig. 6(a) illustrates the BER curves versus received optical power launched into the high-speed PD for the 1-Gbps and 2-Gbps signal carried by 60-GHz mm-wave carrier in wireless delivery. It can be found that the BER performances of all the conditions are smaller than the threshold of FEC (Forward Error Correction) 3.8×10^{-3} when the received optical power is larger than -26.6dBm. With received power increasing, the performance of the signal can be improved. Fig. 6(b) gives the BER curves for the 1-Gbps and 2-Gbps wired link. Without 60-GHz wireless delivery and limitations of high-speed devices, the performance of wired signal is much better than 60-GHz wireless one.



(a) (b)

Fig. 5. B2B eye diagrams of the (a) 1Gbps wireless signal and (b) 2Gbps wireless signal after PD and down-conversion.



(a) (b)

Fig. 6. BER performance of the experiment system versus received optical power driven by 1-Gbps and 2-Gbps signal in (a) 60GHz wireless link and (b) wired link.

4. CONCLUSIONS

We have proposed and experimentally demonstrated a full-duplex wired/wireless RoF-PON system exploiting heterodyne effect on PD. The system can simultaneously transmit wired and 60-GHz wireless signal at bit rate 2Gbps at the BER under 10^{-6}. The center carrier can be used for up-link communication. Moreover, OFC can be applied to extend the system to serve multiple users. The experiment results verify the feasibility of the proposed RoF-PON system.

5. ACKNOWLEDGMENTS

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