Gigabit-converged wired and wireless networks for simultaneous multi-services transmission

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A novel architecture of converged radio-over-fiber (RoF) and wavelength division multiplexed passive optical network (WDM-PON) system, namely RoF-WDM-PON, is demonstrated. 20-GHz 1-Gb/s radio frequency (RF) signals and 1-Gb/s baseband (BB) signals are simultaneously generated and transmitted using optical carrier suppression (OCS) modulation techniques. The proposed scheme is compatible with the conventional RoF and PON system. 25-km single-mode fiber (SMF) transmission is successfully achieved.

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Access to network traffic has grown exponentially because of the considerable increase in the number of end users and proliferation of emerging applications[1]. Thus, the next generation access network aims to provide high capacity and high mobility in a cost-effective manner. However, the existing wired/wireless service deliveries are realized by a number of dedicated networks. Optical networks provide high bandwidth and proven reliability. Literature has shown that optical networks have provided solid support to data and video applications. On the other hand, wireless networks have provided freedom of movement by fully addressing the constraints of time and place. This has resulted in huge increase in the number of wireless subscribers[2]. The hybrid wireless-optical access network is emerging as a promising technology which can provide economical and scalable broadband access[3].

Passive optical network (PON) has been a prospective approach for fiber-to-the-home (FTTH) communication delivery because it can break through the bottleneck of the "the last mile". A shared network between different users reduces infrastructure and deployment cost. In particular, wavelength division multiplexed (WDM) PON offers high transport capacity, high per-subscriber bandwidth, protocol transparency, line rate independence, high security, and upgradability. Numerous novel schemes have been proposed for WDM-PON[4].

On the other hand, radio-over-fiber (RoF) techniques have become a potential candidate for the future broadband wireless system[5]. RoF has the advantages of low cost, large bandwidth, and high performance among others. Meanwhile, radio frequency (RF) signals can realize long distance transmission using optical fibers to link the central station (CS) and the remote base stations (BSs).

Considerable amount of effort has been dedicated to RoF system design and demonstration[6]. To obtain economically feasible RoF networks, it is vital to support a large number of access points connected to a CS via remote access node[7]. With the introduction of WDM, the wavelength reuse technique can realize cost-effective and large capacity connections by increasing the number of BSs.

In this letter, we propose and demonstrate an integrated RoF-WDM-PON for the seamless convergence of wired and wireless networks. 20-GHz 1-Gb/s RF signals and 1-Gb/s baseband (BB) signals are simultaneously generated and transmitted over a 25-km single-mode fiber (SMF). Optical carrier suppression (OCS) modulation techniques are applied to provide optical sidebands. Bit-error-rate (BER) characteristics are also measured.

The proposed RoF-WDM-PON architecture is illustrated in Fig. 1. The design consists of an optical line terminal (OLT) at the center office, optical network unit (ONU)-BSs at the customer premises, and a remote node (RN) for traffic distribution. OLT provides the interfaces to the backbone network. RN combines/separates signals between the OLT and ONU-BSs to establish point-to-multipoint (P2MP) connections using the WDM technique. The main issue is the simultaneous generation and transmission of RF and BB signals. There are several kinds of ONU-BSs, e.g., ONU for PON customers, BS for RoF subscribers, and hybrid ONU-BS that simultaneously support both wired and wireless services. This architecture can be simplified using ONU-BS. Each ONU-BS has its unique wavelength.

The schematic of the proposed system is illustrated in Fig. 2. Multi-wavelength laser (MWL) is used to provide multiple wavelengths ($\lambda_1\lambda_2\cdots\lambda_N$) for different ONU-BSs. Circulator and fiber Bragg grating (FBG) are used to determine the desired optical sideband.

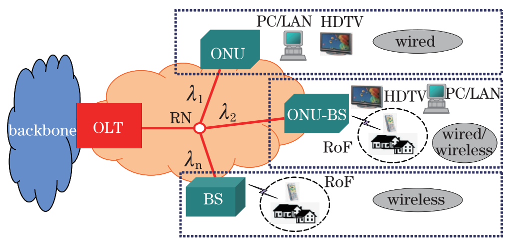

Fig. 1. RoF-WDM-PON prototype architecture. OLT provides P2MP connections over PON to ONU (for BB signal); BS (for RF signal); ONU-BS (for both BB and RF signals).

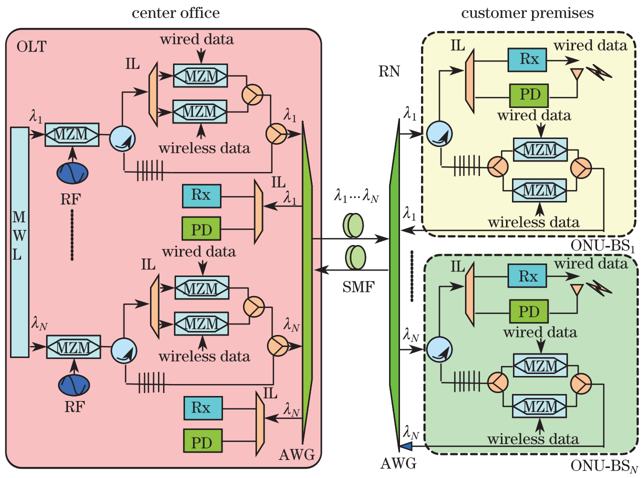

Fig. 2. Schematics of the proposed RoF-WDM-PON access network.

RN multiplexes and de-multiplexes the wired and wireless signals before distributing the wired signals to serve a number of ONUs and RF signals for the wireless subscribers[8]. Arrayed waveguide grating (AWG) is used for channel multiplexing and de-multiplexing.

Optical millimeter-waves can be generated by several all-optical up-conversion schemes[9]. Among the modulation methods, the schemes based on the double sideband (DSB) have a critical drawback, which is caused by the chromatic dispersion. Similarly, single sideband (SSB) methods have become less preferred because of their low signal-to-noise ratio (SNR) characteristics.

On the other hand, OCS modulation techniques have been applied to many RoF systems by the help of its dispersion-tolerant and high SNR characteristics for the carrier[10]. We use modulators to get OCS signals.

At the ONU-BS side, we separate the BB/RF signals first and subsequently amplify and detect the signals. The recovered wired and wireless signals are used for PON and RoF subscribers.

For the uplink transmission, wavelength reuse technique is utilized to achieve full-duplex operation. The upstream signal is modulated onto the same downstream wavelength by the Mach-Zehnder modulator (MZM).

Downstream transmission is experimentally demonstrated and illustrated in Fig. 3.

At the transmitter side, continuous wave (CW) light source is modulated by the optical intensity MZM to obtain OCS signals. The CW light output power is 5 dBm centered at 1 549.72 nm. Polarization controller (PC) is used to align the polarization state and improve the coupling efficiency. The local oscillator (LO) signal is 20 GHz with the power of 20 dBm. Two optical sidebands are produced by the MZM which are 40 GHz apart and characterized with suppression of the center carrier. Figure 3 shows that the suppression ratio of the OCS signal is approximately 20 dB. Subsequently, the two sidebands are divided through the 3-port optical circulator and FBG to carry downlink data 1 and data 2. The lower sideband is used for the RF signal and the upper one is used for the BB signal.

The BB signal (1 GHz with a data pattern of pseudorandom pattern bit stream (PRBS) $2^{23}-1$) in the upper sideband is upconverted to RF frequency by the 20-GHz LO signal. The RF signals in the lower sideband are modulated by the MZM and combined with the signal in the upper sideband via a coupler before transmission to the SMF. Erbium-doped fiber amplifier (EDFA) is used to adjust the optical power injected in the MZM or photo-detectors (PD). The DC bias voltage of the MZM is 6 V.

At the receiver side, the signal is filtered out and amplified before detection by the PD in each ONU-CS. The RF signal is downconverted to recover the wireless data.

In Fig. 3, insets (a) and (b) indicate the measured optical spectra before and after the MZM. The filtered-out spectrum and boosted spectrum are shown in insets (c) and (d). The upper sideband is suppressed by almost 28 dB lower than the lower sideband. Inset (e) represents the spectrum modulated with RF signal. Insets (A1) and (A2) show the recovered B2B signal and its eye diagram, respectively. Insets (B1) and (B2) present the recovered RF signals for the back-to-back (BB) and 10-km transmissions. It should be noted that the signals are received well.

The BER characteristics of the downlink transmission for B2B and 10- and 25-km SMF transmissions are also measured and plotted in Fig. 4. The BER of 10^{-7} is obtained at the received Rx powers of approximately 6.3 and 7.8 dBm for B2B and 10-km transmissions, respectively.

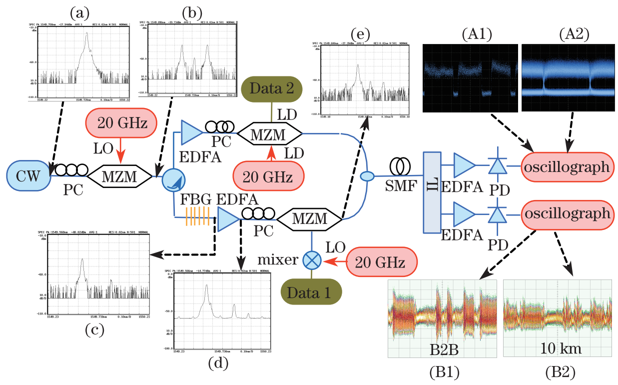

Fig. 3. Experimental setup and the results of the RoF-WDM-PON system. Insets (a)–(e) Measured optical spectra; (A1) and (A2) recovered signal and measured eye diagram of the wired downlink transmission; (B1) and (B2) recovered wireless signal of the B2B and 10-km downlink transmissions.

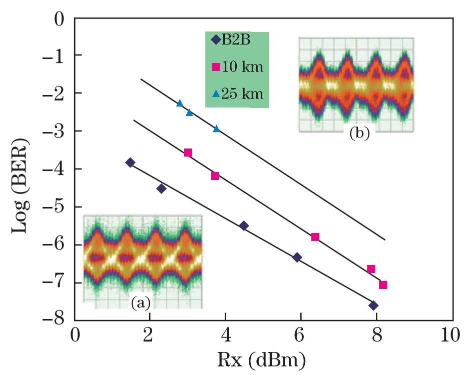

Fig. 4. BER curves and eye diagram of the RF signal transmission for the downlink. The insets are the eye diagrams at the receiver. (a) B2B and (b) 10-km SMF transmissions.

The BER of 10^{-8} can also be obtained for the B2B and 10-km transmissions. These results indicate that for the proposed system, we can transmit 1-Gb/s signals over a 25-km SMF with acceptable performance. The eye diagrams for the B2B (inset (a)) and the 10-km transmissions (inset (b)) of the RF signal after demodulation are shown in Fig. 4 as well.

The introduction of WDM-PON was effective in extending the transmission distance of the RoF system. In our experiment, 25-km transmission is achieved. Furthermore, the capacity of RoF is extended by the use of WDM. Meanwhile, the hybrid access network improves the efficiency of optical fibers and infrastructures.

In conclusion, we propose and experimentally demonstrate a novel integrated RoF-WDM-PON network to enable the coexistence of two different technologies in a single network. The integrated RoF-WDM-PON network is a promising choice for future multi-service access network. With the introduction of the OCS modulation method, 25-km downlink transmission of 20-GHz 1-Gb/s RF signal and 1-Gb/s BB signal is achieved. However, the physical layer platform for wired/wireless connections has been the main consideration of the present study. Thus, in future studies, we intend to focus on the medium access control (MAC) layer.

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