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Next-generation bidirectional Triple-play services using RSOA based WDM Radio on Free-Space Optics PON

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ABSTRACT

An innovative low cost reflective semiconductor amplifier (RSOA) based bidirectional Triple-play services (TPS) using wavelength division multiplexed radio on free-space-optics passive optical network (WDM-RoFSO-PON) is proposed and experimentally demonstrated to transmit data, voice and video services simultaneously. In this paper, the TPS (10 Gb/s data/voice and 1.49 Gb/s HDTV signal) are successfully transmitted over a 500 m free-space link in downstream and RSOA is utilized at the receiving site to broadcast 1.25 Gb/s data/voice signal over same free-space link in upstream by reusing the carrier, that makes the system cost-effective. High receiver sensitivity and signal-to-noise ratio (SNR), low bit-error-rate (BER) and low error vector magnitude (EVM), and excellent eye-diagrams in our proposed network build the system more reliable and stable with acceptable performance. Therefore, proposed WDM-RoFSO-PON could be the viable solution for future ubiquitous multiservice wireless network in the scenario of TPS.

1. 1Introduction

Due to advances in optical communication technologies and drastic expanding of multimedia services such as video on demand, high-definition TV (HDTV), video conferencing, Internet Protocol Television (IPTV), interactive games, voice over IP (VOIP) and high speed internet, the next generation wireless access networks have experienced an ultra-high increase in data traffic for everyone at every place during the last decade [1,2]. Convergence of voice, data and video in a single network platform in the form of Triple-play service (TPS) [3–5] has been accepted as a smashing challenge by ubiquitous wireless network providers. Over the last few years, Free-Space Optical (FSO) communications systems have become an efficient alternative to wireless networks for point-to-point long reach communication due to their low implementation cost, high bandwidth, high security and unlicensed spectrum in building, underground and at rural as well as urban area where it is difficult to deploy expensive fibers [6–8]. Radio on Free Space Optics (RoFSO) is a key technology to realize the future networks for heterogeneous wireless services [9,10]. FSO technology is successfully used in a various applications including cellular communication [11], inter-satellite communication [12], deep space, exhibition halls and terrestrial communications [13] etc. However, the main challenge of FSO system is to overcome the performance degradation caused by the atmospheric attenuation and turbulence [14,15]. WDM-PON [16,17] that can provide protocol transparency and network security is a promising technology for the future access TPS in which multiple signals and bandwidths are simultaneously transmitted over a single path. WDM-RoFSO-PON, which is an integration of IP network and heterogeneous wireless networks, could be the ultimate solution of TPS in the wireless networks. For the practical implementation of WDM-RoFSO-PON, it is necessary to construct a low cost WDM source at optical network unit (ONU) and colorless upstream transmission. Reflective semiconductor optical amplifier (RSOA) is promising devices used for reflector, modulator and amplifier simultaneously, and it reuses the downstream source for upstream after remodulation without any additional optical source at ONU, and system makes cost-effective [18–22]. Xiaoyan Wang et al. in Ref. [18] successfully demonstrated and tested the bidirectional single channel FSO system carrying 10 Gb/s DPSK downstream and 1.25 Gb/s OOK upstream data with only a single source using RSOA at the ONU. However, the system was a proof-of-concept demonstration and had a quite high average BER value, resulting into limited transmission distance 0.5 m only and it was only single channel system set-up. Several works [10,23–25] have been proposed and demonstrated successfully to realize WDM-RoFSO-PON for future ubiquitous multiservice wireless networks.

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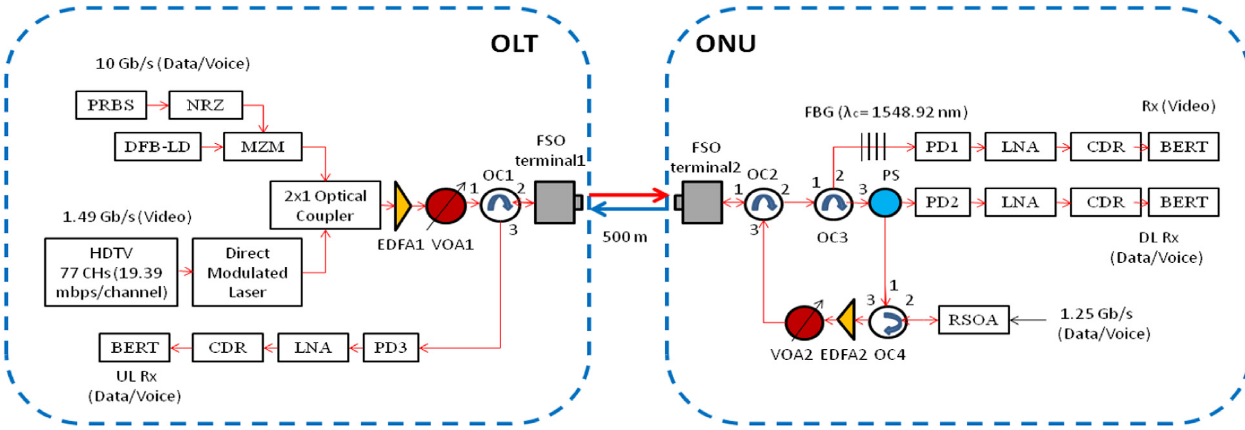

Fig. 1. Experimental setup for next-generation bidirectional Triple-play services using RSOA based WDM-RoFSO-PON.

In this paper, we have proposed and experimentally demonstrated a successful application of WDM to the FSO system to support next-generation bidirectional TPS over 500 m free space to transmit 10 Gb/s data/voice and 1.49 Gb/s HDTV signal simultaneously in downlink (DL) and 1.25 Gb/s data/voice in uplink (UL). The transmission performance and channel capacity of FSO system has been improved in our system by deploying WDM technology to the FSO and employing fine tracking technology to each FSO terminal, and with the assist of low noise amplifier (LNA) and clock/data recovery (CDR) scheme at the receiving site comparing with existing architecture [18]. RSOA is employed at the optical network unit (ONU) to remodulate the downstream source as an upstream. The use of single optical carrier for bidirectional transmission makes the system cost-effective. Low BER ($<10^{-8}$) and EVM ($<2.5\%$), high SNR (>28 dB) and clear eye diagrams are achieved with the help of LNA and CDR scheme at the user end. We have plotted log(BER) vs received optical power to validate the feasibility of the system.

2. Experimental set-up

Fig. 1 illustrates the experimental setup of the proposed next-generation bidirectional TPS using RSOA based WDM-RoFSO-PON. The TPS are realized as a combination of data, voice and video signals at the optical line terminal (OLT). The combined data and voice signal (voice over internet protocol) are generated by 10 Gb/s pseudorandom bit sequence (PRBS) generator of word length $2^{31}-1$ and converted into electrical pulses by the NRZ driver. We use distributed-feedback (DFB) lasers with central wavelength 1548.92 nm as a carrier and modulated at 10 Gb/s by a $LiNbO_3$MZM and fed into 2×1 optical coupler. The video signal is generated by a multiple HDTV signal generator with 77 HDTV channels (19.39 Mbps/channel $\times$ 77 channels). The video signal is directly modulated by DFBLD with a central wavelength of 1552.52 nm at 1.49 Gb/s and goes to 2×1 optical coupler. We have chosen wavelengths 1548.92 nm for data/voice and 1552.52 nm for video transmission due to eye safety and to achieve a seamless performance, since such wavelengths experience less free-space attenuation over long free-space link in different meteorological conditions [17]. The multiplexed signals with data, voice and video are amplified to $+20$ dBm by erbium-doped fiber amplifier (EDFA1) as a booster amplifier to improve BER performance of the signal at the receiver. To optimize optical power launched into the free-space, a variable optical attenuator (VOA1) is incorporated after EDFA1 for incurring the best transmission performance. Two identical FSO terminals (FSOT1 and FSOT2) that have special fine tracking optics to directly couple the free-space propagated optical beam to the core of single-mode fiber (SMF), are used to understand FSO communications. Each FSO terminal, shown in Fig. 2 is made of a refractive telescope having aperture of 2.4 cm as an optical antenna, a fast steering mirror to minimize the fluctuation of collimated beam, and a fine tracking system as a fiber coupler. The FSO terminals generate a collimated Gaussian profile beam of approximately 24 mm beam waist that makes the system diffraction limited. The detailed configuration of each FSOT and tracking technology has been reported in [7]. In order to obtain bidirectional tracking the beacon beams of wavelengths 950 nm (FSOT1) and 945 nm (FSOT2) have been multiplexed to the signals from an infrared laser beacon. The power optimized signals are fed into FSOT1 via a three port optical circulator (OC1) which is used after VOA1 to obtain bidirectional TPS through connection SMF. FSOT2 is installed at a free-space distance 500 m away from FSOT1 to couple with connection SMF at the ONU. The output optical signals from FSOT2 are passed through OC2 and then fed into port 1 of OC3 through connection cord. A fiber Bragg grating (FBG) with central wavelength (λ_c = 1548.92 nm) and a reflection ratio of 90% and a loss of 0.1 dB is inserted to the port 2 of OC3 to separate the video signal from data/voice signal and port 3 is connected with a power splitter (PS). After passing through FBG the video signal is detected by photodiode (PD1) and boosted by LNA with a small gain of 20 dB and a noise of 2 dB. The video signal is recovered and regenerated by CDR which is required because of high jitter of the FSO-link and fed into BER tester (BERT) to measure BER value. A functional block diagram of CDR is shown in Fig. 3, which includes amplifier, phase detector, low-pass filter (LPF), voltage-controlled oscillator (VCO) and interleaved data decision circuit. The data/voice is split into two parts by the PS. One part is passed through 10 GHz PD2 as a DL data/voice detector, 10 GHz LNA as a booster amplifier with signal gain of 20 dB, 10 GHz CDR for recovering and regenerating of DL data/voice signal, and BERT respectively to measure signal performance. The other branch of DL data/voice signal is remodulated by the RSOA with 1.25 Gb/s UL pseudo random data/voice signal of word length 2^{31}–1. The optical power injected into the RSOA is -1.75 dBm and the driving current is 55 mA and to reduce backscattering, the RSOA is operated in the saturation region. The UL signal is amplified by 4.37 dB due to the gain of the RSOA and is passed through EDFA2 for boosting the signal and VOA2 for power adjustment from port 3 of OC 4, and fed into port 3 of OC2. The UL data stream is transmitted to FSOT1 through the same free-space path 500 m from FSOT2 which is connected to the port 1 of OC2. Then the UL data/voice signal is fed into PD3 for detection via OC1 and passed through LNA for boosting, CDR as a regeneration of the signal and BERT respectively for UL signal performance.

3. Experimental results and discussions

Fig. 4(a) shows the received optical spectrum of DL data/voice and video simultaneously measured at the output of FSOT2 and the UL received data/voice optical spectrum at the output of FSOT1 is depicted in Fig. 4(b).