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Service Multicasting by All-Optical Routing of 1 Gb/s IR-UWB for In-Building Networks

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Abstract: We propose and demonstrate, for the first time, service multicasting by all-optical routing of 1 Gb/s IR-UWB using XGM of SOA. This technique has potential applications for integrating IR-UWB with WDM PON and in-building networks.

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1. Introduction

In recent years, ultra-wideband (UWB) has been considered as one of the most promising techniques for next generation short-range broadband wireless communications and sensor networks. The growing interest in this technique is due to its many features: low power spectral density, tolerance to multipath fading, low probability of interception, co-existence with other wireless services and capability for providing cost effective > 1 Gb/s communications per user [1,2]. However, the main limitation of UWB system is the limited propagation distance (typically < 3 m) over which the expected high data-rate of Gb/s can be realized. This is mainly due to the low power spectral density (PSD) limited to -41.3 dBm/MHz in the frequency range from 3.1-10.6 GHz regulated by the US Federal Communications Commission (FCC). To increase the coverage area, distribution of UWB signals over optical fiber, or UWB-over-fiber, is considered a promising solution [3]. Typically, in the past few years, there has been increasing interest in generation, modulation and distribution of IR-UWB signals over an optical fiber using various modulation formats employing different generation techniques [3-9]. Recently, there is an increasing interest for convergence of IR-UWB over fiber technology with other wired/wireless services over emerging WDM-PON access networks [7-9]. This integration allows generation, modulation and distribution of IR-UWB signals from the central office with potentially low cost.

However, all previously proposed pulse generation concepts and distribution of IR-UWB over fiber focus on a static point-to-point communication links. For increased flexibility, point-to-multipoint using all-optical multicasting is another potentially useful networking function in the optical networks [10]. Multicasting using all-optical wavelength conversion followed by a wavelength selective device can be used for emerging bandwidth-intensive applications (such as video conferencing and video-on-demand services) over high-speed optical networks. Hence, in this paper, to the best of our knowledge, we propose and experimentally demonstrate for the first time, multicasting of IR-UWB by all-optical routing for in-building fiber networks. This centralized optical multicasting aspect provides many features: dynamic adjustment of optical connectivity and capacity, enhanced security, reduction of unnecessary power consumption and flexibility in operation and reconfiguration of the network [11]. Our proposal is a low-cost solution because it used the simplest routing scheme based on the cross-gain modulation (XGM) of a semiconductor optical amplifier (SOA) without any additional assist light apart from the pump and probe signals. This work is supported by the European Commission FP7 ICT-212352 ALPHA project.

2. Experimental Setup

To realize multicasting of IR-UWB over fiber for in-building network application, the proof-of-concept experimental setup is depicted in Fig. 1. A continuous wave (CW) pump signal at 1550.92 nm located in the central office (CO) was externally modulated using LiNbO₃ modulator driven by the electrical IR-UWB signal at 1 Gb/s. The IR-UWB signal was generated based on a pulse generation technique that employed a linear combination of a modified doublet with inverted and delayed forms as introduced in [6]. Then the pulse train was coded with a $2^{13}-1$ PRBS pattern, generated by an arbitrary wave generator. A 20 km standard single-mode fiber (SMF-28) is used to distribute the modulated optical signal from the central office to the residential gateway (RG), which connects the in-building network to the incoming access network. In the RG, the pump signal is boosted by an erbium-doped fiber amplifier (EDFA) in order to compensate the insertion loss of the external modulator and the fiber loss after the 20 km of fiber. Furthermore, the pump signal was filtered using a 1nm tunable optical band pass filter (OBPF) to minimize the ASE noise introduced during the amplification process. Two CW probe signals are generated locally inside the RG using laser diodes (DFB2 and DFB3) at wavelengths of 1541.35 and 1555.75 nm. More wavelengths

are possible because the solution is in principle scalable to include more than two destinations. Then the pump and two probe signals are multiplexed within the RG using multiplexer (MUX) and co-propagated to the input of a SOA for the XGM. To obtain good conversion performance at individual probe signals, the injected powers into SOA for these CW probes and pump signal are set to 0, 4.3 and 6.2 dBm respectively. After the XGM, the data signal is copied to the two probe signals and thus multicasting the service by all-optical routing of IR-UWB is obtained via this process. For routing, the optical signals are de-multiplexed (DMUX) and finally distributed in-building using 6.7 km SMF fiber. Note that both the MUX and DMUX in the RG are based on an arrayed waveguide grating (AWG). Finally, the received electrical signal is analyzed for performance analysis using a DSP based BER measurement.

Fig. 1: Experimental setup

Fig. 2: Optical spectrum after SOA

3. Experimental Results and Discussions

Fig. 2 presents optical spectra of all optical channels and the products from four-wave mixing (FWM) at SOA output. The FWM products are produced from the high optical signals and the SOA nonlinear effects. These unwanted products are about 30 dB or more weaker than the desired converted channels and are filtered out by the AWG. Several modulation formats can be used for IR-UWB [1], however for simplicity and low-cost reason we use on-off keying (OOK) of PRBS $2^{13}-1$ pattern length. Fig. 3a-3c shows received IR-UWB signal from the pump signal as well as multicasted probe channels. The results clearly show an OOK IR-UWB signal without any significant impairments except for the inversion of the IR-UWB pulses from the probe channels due to the XGM effect. The PSD of the received IR-UWB from the main pump channel after 26.7 km SMF-28 fiber is fully compatible with FCC mask as shown in Fig.4a. Note that the noise floor is above -75 dBm outside the assigned band for UWB this is mainly attributed to the noise floor of the spectrum analyzer and amplification of signal. The PSD of the multicasted IR-UWB from both the probe signals during optical back-to-back case are shown in Fig. 4b and Fig. 4c respectively. Due to the on-off keying modulation scheme, all the PSD show a discrete spectral line called comb-lines where the spacing between each comb lines is 1 GHz and exactly equal to the bit-rate of the transmission system. The PSD of the multicasted signals after the distribution fiber of 6.7 km SMF are shown in Fig. 5a and 5b respectively fits FCC mask requirements. However, the degradation caused from ASE noise of the SOA, wavelength conversion penalty and the non-linearity of the SOA gain profile is noticeable.

Fig. 3a: IR-UWB from pump signal after transmission

Fig. 3b: IR-UWB from probe1 after transmission

Fig. 3c: IR-UWB from probe2 after transmission

Fig. 4a: PSD of IR-UWB from pump after transmission

Fig. 4b: PSD of IR-UWB from probe1 under optical back-to-back case

Fig. 4c: PSD of IR-UWB from probe2 under optical back-to-back case

Fig. 5a: PSD of IR-UWB from probe1 after transmission

Fig. 5b: PSD of IR-UWB from probe2 after transmission

Fig. 6: BER performance under back-to-back and transmission case for all channels

We measured the BER performance to evaluate the quality of the multicasted signals, as shown in Fig. 6. The BER is subsequently computed using a DSP algorithm in a bit-for-bit comparison between the transmitted and received data. The DSP algorithm distinguished between binary “1” and “0” by comparing the average power within the central window of each bit slot to an adaptive decision threshold. The measurements are performed for the pump signal at 1550.92 nm, two other probe signals at 1541.35 and 1555.75 nm respectively. The BER measurement considers both optical back-to-back and transmission scenario. The results show that the probes are successfully modulated with a power penalty of 2 and 4 dB compared to pump signal. The penalties come from ASE noise of SOA, the cross-gain competition between the probe channels, wavelength-conversion penalty and the nonlinearity of the SOA gain profile. In general, the BER results are below a forward error free (FEC) limit (10^{-3}) for successful routing of IR-UWB over a standard SMF-28 fiber transmission for in-building network application.

4. Conclusion

With the experimental results presented in this paper, we demonstrate, for the first time, service multicasting by all-optical routing of 1 Gb/s of IR-UWB based on multi-wavelength conversion using XGM in a single SOA. Whilst remaining within the stringent FCC mask requirements for wireless transmission, the BER performance of optical multicasting exhibited a FEC error-free 1Gb/s IR-UWB transmission over the 26.7 km feeder and 6.7 km distribution SMF fiber. This proof-of-concept experiment shows that centralizing key features such as signal generation, modulation and distribution is feasible to achieve low cost and highly flexible in-building networks.

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