Robust BPSK Impulse Radio UWB-over-Fiber Systems Using Optical Phase Modulation

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Abstract: The impact of fiber dispersion on the performance of optical phase modulated impulse-radio-ultrawideband (IR-UWB) signals is experimentally investigated. 2Gbps BPSK IR-UWB over 78km fiber transmission is successfully achieved by using digital coherent detection.

OCIS codes: (060.1660) Coherent communications, (060.5625) Radio frequency photonics.

1. Introduction

With the recent development of integrated electronic circuits and digital signal processing (DSP), optical coherent receivers using DSP are becoming a practical and feasible solution for high speed systems. Digital coherent detection is a dominating approach for long-haul high capacity transmission systems [1]. Recently, it has also been proposed for optical access networks due to its very good channel selectivity, including optical phase modulated radio-over-fiber (RoF) systems which have several advantages compared to intensity-modulated RoF systems, such as no need of bias voltage, no fundamental limit on modulation depth, high linearity [2, 3], and 6 dB receiver performance advantage over intensity modulation counterpart [4].

On the other hand, ultrawideband (UWB) has been considered as a promising technology for short-range, high-speed wireless communication systems [5]. Regulated by the U.S. Federal Communications Commission (FCC), power spectral density of UWB signals is limited below -41.3dBm/MHz. Therefore, wireless transmission distance is very limited. In this context, UWB-over-fiber, similar to radio-over-fiber technology, is a potential technology to extend the reach with assistance of flexible UWB generation and distribution. Several approaches have been proposed to optically generate impulse radio (IR) UWB signals at the central office (CO) and distribute to end-users [6, 7, 8]. Recently, we also demonstrated that UWB-over-fiber could be integrated seamlessly into a WDM-PON that supports both wireline and wireless services [9]. In fact, in such long reach UWB-over fiber transmission systems, fiber chromatic dispersion will critically affect the signal performance, since UWB signals occupy a large bandwidth up to 6.5 GHz. Therefore it is important to conceive a robust IR-UWB optical fiber signal distribution approach with seamless integration with the major trend of employing advanced digital coherent receivers for universal support of several services and modulation formats.

In this paper we consider optical phase-modulated transmission and coherent detection of IR-UWB-over-fiber in a coherent-detection PON scenario. We demonstrate an uplink transmission of 2-Gbps binary phase shift keying (BPSK) IR-UWB signals. The influences of the chromatic dispersion of various single mode fiber links (from 20 km in conventional access networks to up to 78 km in long-reach access networks) are experimentally investigated. The result proves the robustness of our system and its integration capability into a digital coherent receiver structure.

2. Coherent optical access networks

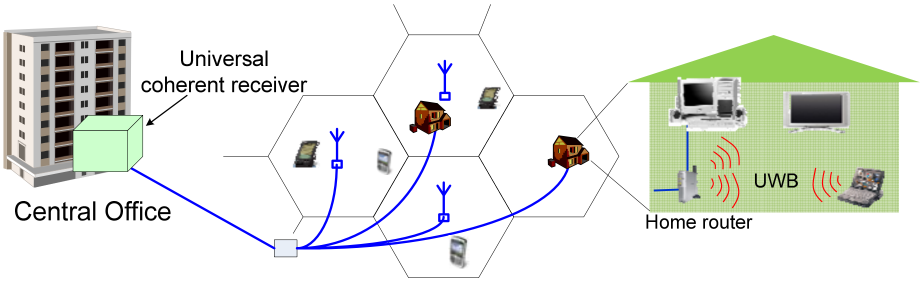
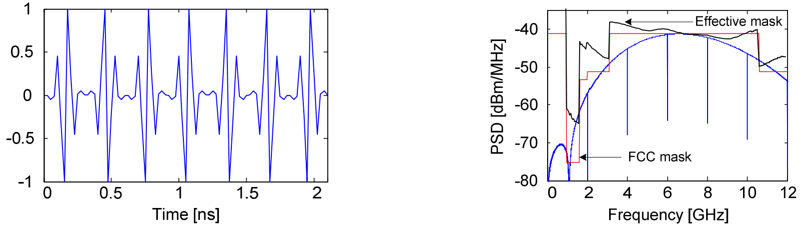


Fig. 1. Hybrid optical-wireless signal transport over optical access network supported by a universal coherent receiver.

Fig. 1 shows a schematic diagram for a prospective converged wireless-optical network. Both wireline and wireless services are transported in the same fiber infrastructure. With the advantages of DSP, a universal and reconfigurable coherent-detection based DSP receiver can be employed in the CO to detect all types of signals. Moreover, the utilization of the universal receiver allows the CO to adaptively tackle the requirements for large number of users, diversity of services and reach extension, as it has potential to support large number of channels with very close channel spacing and increased receiver sensitivity.

3. Experimental setup



a) b)

Fig.2. a) BPSK-modulated UWB sequence (1 0 1 1 0 0 1). b) Spectrua of the 2Gbps BPSK-UWB signals.

To emulate a UWB wireless signal generation terminal, an arbitrary waveform generator (AWG) with a 24-GSa/s sampling rate was used. The generated UWB pulse is a 5th derivative Gaussian shape for its good compliance with the FCC mask [6]. In the experiment, a pseudo-random bit sequence (PRBS) at a bit rate of 2 Gbps with a word length of 2^{11}-1 was used. Bipolar modulation is employed for the UWB signal in order to avoid spectral lines at multiplication of pulse repetition frequency for on-off-keying modulation [10], and thus to be able to radiate further wirelessly. Fig. 2 shows an example of UWB sequence and the UWB spectra generated by the AWG. We can see PI phase shift is perfectly introduced between bit ‘1’ and ‘0’, and no spectral spike lines are observed. The effective mask is the allowed mask when the frequency response of the transmitting antenna is taken into account.

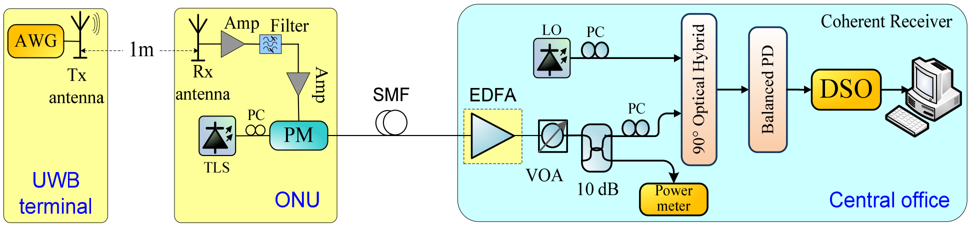


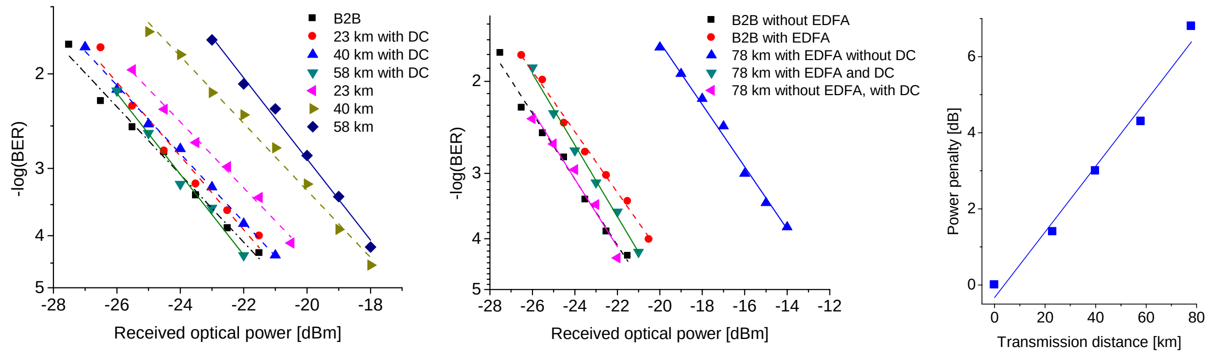
Fig. 3. Experimental setup. AWG: arbitrary waveform generator, TLS: tunable laser source, PM: phase modulator, EDFA: Erbium doped fiber amplifier, SMF: single mode fiber, VOA: variable optical attenuator, LO: local oscillator, DSO: digital storage oscilloscope.

Fig. 3 shows the experimental setup. The UWB signal from the AWG was transmitted wirelessly through an Omni-antenna (SMT-3TO10M-A) and received by a directive antenna (AU-3.1G10.6G-1). The wireless transmission distance was set at 1 m. The received UWB signals from the receiver antenna were amplified and filtered out by a high-pass filter, to remove frequency components below 3.1 GHz before driving an optical phase modulator (PM). The lightwave launched into the PM with 4 dBm power was emitted from a tunable laser source (TLS). The modulated optical signals were then transmitted over a spool of single mode fibers (SMF) with different length (23, 40, 58 and 78 km fiber). The 78-km long link is a deployed fiber; in this case an erbium doped fiber amplifier (EDFA) was used as pre-amplifier to compensate 25 dB losses of the optical link.

In the coherent receiver, a tunable external cavity laser with a linewidth of 100 kHz was used as local oscillator (LO). The in-phase and quadrature signals after a 90° optical hybrid were detected by two pairs of balanced photodiodes with 7.5 GHz full-width-half-maximum (FWHM) bandwidth. The detected photocurrents were digitized by a sampling scope at 40 GSa/s for offline digital signal processing (DSP). The employed single digital receiver included a digital dispersion compensation module, which is followed by an optical carrier-recovery digital phase-locked loop (PLL) [9] and a linear signal demodulator. In the digital linear demodulation module, the DSP algorithm performs functions of high-pass filtering, matched filtering with the original UWB pulse, synchronization and threshold decision [10]. The dispersion parameter for dispersion compensation (DC) module was 17ps/nm/km.

4. Experimental results

In the experiment, 70,000 UWB bits were used to assess the performance of the UWB signals in each case. Fig. 4a shows the BER curves in cases of back-to-back (B2B), after 23, 40 and 58 km fiber transmission, with and without dispersion compensation as well. As illustrated in the figure, 23, 40 and 58 km fiber without DC caused approximately 1.4, 3.1 and 4.3 dB power penalties at a BER of 10^{-4}, respectively. When digital DC was applied in the digital domain, power penalties were then less than 0.5 dB for all the transmission cases. Fig.4b shows the comparison of the measured BER performance between B2B and 78 km fiber transmission cases. The use of the EDFA introduced about 1 dB power penalty while 78-km fiber caused about 7 dB. However, similar to the shorter transmission distances, this power penalty can also be compensated completely by using digital dispersion compensation. Fig. 4c simply summaries the measured power penalties caused by the chromatic dispersion.



a) b) c)

Fig. 4. BER performance of the UWB signals with and without dispersion compensation after (a) 23km, 40km and 58km and (b) 78km fiber transmission, c) Summarized power penalties caused by chromatic fiber dispersion.

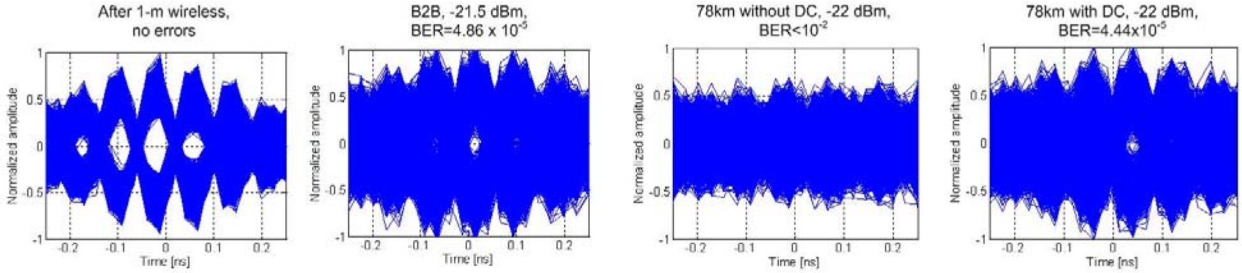


Fig. 5. Eye-diagrams of the received BPSK UWB signals

Fig. 5 illustrates the eye-diagrams of 10,000 UWB bits at different positions in the 78-km transmission system. The eye diagram after wireless transmission but before fiber transmission was clear and open. After 78-km fiber transmission, the eyes at -22-dBm optical power were completely close due to the chromatic dispersion. However, after using digital dispersion compensation, the eye-diagrams and the transmission performance were similar to B2B.

5. Conclusions

We experimentally demonstrated an optical phase modulated UWB-over-fiber system using digital coherent detection for the transport of 2-Gbps BPSK IR-UWB signals in a coherent detection PON. Our experimental results indicate that a DSP receiver has the capability of overcome fiber transmission impairments, and the power penalty caused by the chromatic fiber dispersion is completely compensated in the digital coherent receiver. Therefore, it can be foreseen that a universal, reconfigurable DSP receiver will make it possible to seamlessly integrate also IR-UWB into the diverse services supported in next generation high capacity optical access networks.

6. References

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