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Advanced Modulation/Demodulation Technologies for High-Speed Optical Transmission Systems

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Abstract
This paper reviews advanced modulation and demodulation technologies to increase the channel bit rate in optical transmission systems.

Introduction

Practically all commercial optical transmission systems with bit rates up to 10 Gbit/s are realized with intensity modulation direct detection (IM-DD). The main advantage of IM-DD is that the least components are required at transmitter and receiver. For bit rates of 40 Gbit/s and higher, however, a large signal-to-noise ratio (OSNR) is required for error-free operation and expensive electrical and optical components with high bandwidth are needed at the transmitter and receiver. In addition, accurate compensation for chromatic dispersion and polarization-mode-dispersion (PMD) is required for long-haul transmission systems with a bit rare of 40 Gbit/s and higher.

Most of these difficulties can be solved by reducing the symbol rate of the high speed signal by using an advanced modulation format. In this paper, promising advanced modulation formats for next generation transmission systems are reviewed.

DQPSK

Phase-shift keying (PSK) in combination with balanced detection is an attractive technology to improve the sensitivity of high speed transmission systems with respect to IM-DD. Recently, differential quadrature phase-shift keying (DQPSK) has been intensely studied [1]. DQPSK carries two bits information per symbol and therefore has a narrower spectral bandwidth at the same data rate (shown in Fig.1). The reduction of the symbol rate brings other benefits as well: The bandwidth requirement of the components in the transmitter and receiver is reduced by a factor of two and the tolerance towards chromatic dispersion and PMD is enhanced. The narrow spectral width of DQPSK enables WDM transmission with a high spectral efficiency. With 80-Gbit/s RZ-DQPSK, 1.6 bit/s/Hz [2] and 3.2 bit/s/Hz [3] spectral efficiency have been achieved using polarization interleaving and multiplexing, respectively. In [3], the record capacity of 25.6 Tbit/s has been demonstrated with C- and L-band EDFA amplifiers.

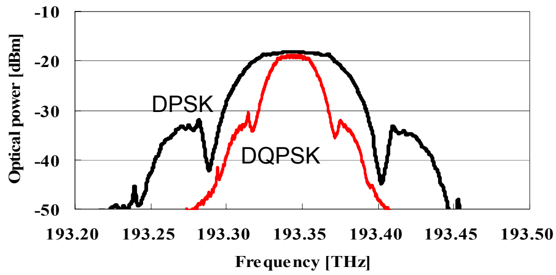

Fig.1 Optical spectra of 40 Gbit/s RZ-DPSK and RZ-DQPSK signals.

The use of DQPSK signals is also effective to increase the channel bit rate to 100 Gbit/s and higher. With a combination of RZ-DQPSK signals and optical time-division-multiplexing (OTDM) technologies, 2.56 Tbit/s transmission has been demonstrated [4]. This is the highest single-channel transmission experiment demonstrated so far. However, OTDM systems are not cost effective as they require many components and complex optical signal processing. Without OTDM, the highest bit rate ever achieved is 200 Gbit/s. To investigate the applicability of DQPSK in 100-Gbit/s transmission without OTDM, we conducted a DQPSK transmission experiment over 2-km of standard SMF (SSMF) without chromatic dispersion compensation [5]. In this experiment, a BER of 1 x 10^{-9} was obtained with no sign of an error floor. After 2 km transmission only a 6-dB penalty was observed for the 37-ps/nm uncompensated chromatic dispersion. Long-haul 100 Gbit/s-based WDM transmission experiments have been also demonstrated with DQPSK [6, 7]. In [6], 200-GHz spaced 10 x 100-Gbit/s RZ-DQPSK signals have been transmitted over 2000 km. These results indicates that the DQPSK modulation format is a promising candidate both for short reach uncompensated transmission and long-haul transmission at 100 Gbit/s.

DSP-aided technologies

Coherent detection using digital signal processing (DSP) [8, 9] is an attractive method to increase the number of levels in multi-level (M-ary) signals. In such a system, the carrier phase is recovered after homodyne or heterodyne detection by means of DSP. Various experiments have been reported with multi-level (M-ary) signals. 8-PSK signal transmission with a symbol rate of 10 GSymbol/s (bit rate of 30 Gbit/s) has been demonstrated [10]. DSP has also enabled 32-level signal transmission with incoherent detection using delayed interferometers [11]. In this demonstration, a combination of quaternary amplitude-shift keying (QASK) and 8-PSK has been utilized to obtain 50-Gbit/s signal at a symbol rate of 10-Gsymbol/s.

DSP aided coherent detection can be employed as well to increase the robustness of the transmission system. By using DQPSK and polarization multiplexing in combination with a polarization diverse receiver, the symbol rate can be reduced by a factor of four. Recently, this technology has been employed to demonstrate 40-Gbit/s and 100-Gbit/s long-haul transmission [12-15]. In these systems digital equalization is used to significantly increase the chromatic dispersion and PMD tolerance.

Orthogonal frequency division multiplexing (OFDM) is a frequency efficient form of subcarrier multiplexing (SCM) in which subcarriers partly overlap. Recently OFDM, which is widely used in wireless communication, has been proposed for high speed optical transmission [16] and we have conducted OFDM transmission experiment at a bit rate of 20 Gbit/s [17]. The configuration of the transmitter and receiver, used in the demonstration, is shown in Fig. 2. In this case, DSP is used in both transmitter and receiver. The 20-Gbit/s OFDM signal was transmitted over 4160 km SMF without dispersion compensation. The main advantage of OFDM is that unlike pre-distortion [18], the signal is continuously detectable along the whole transmission link. Such a large dispersion tolerance is attractive for high speed transmission systems as it eliminates the necessity of inline dispersion compensation even in dynamically reconfigurable networks.

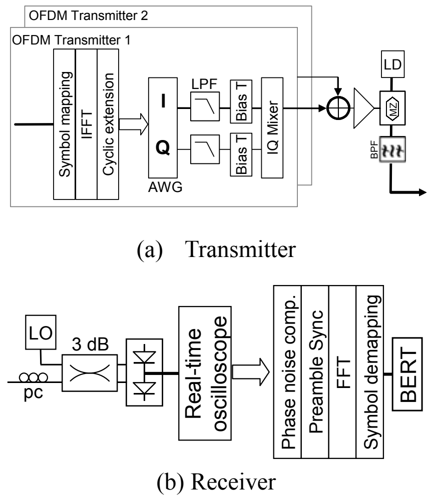

Fig. 2 Configuration of transmitter and receiver for 20-Gbit/s OFDM transmission

Conclusion

Advanced modulation and demodulation technologies to increase the channel bit rate are discussed. One of the main goals for advanced modulation formats is to reduce the symbol rate, since this relaxes the requirements for the bandwidth of optical and electrical components and enhances the robustness against the chromatic dispersion and PMD. The use of DQPSK is considered to be the current most promising method. To increase the robustness, DSP-aided technologies are attractive and further progress is expected.

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