System characterization of optical ASK/DPSK orthogonal modulation for supervisory information dissemination

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ABSTRACT

Recently, optical differential phase shift keying (DPSK) has attracted much interest in high-speed optical transmission systems. It features constant intensity and thus is less vulnerable to the fiber nonlinearities. In addition to high-speed data transmission, it is desirable to carry relatively low-speed supervisory information simultaneously to facilitate the system monitoring and network management. In this paper, we propose and investigate an orthogonal modulation scheme for carrying relatively low bit-rate supervisory amplitude shift keying (ASK) data on a high-speed (10-Gb/s) optical DPSK data stream. The supervisory data is amplitude-modulated onto the constant intensity optical DPSK signal, thus no dedicated time slots are needed and this eliminates the bandwidth overhead. We investigate both experimentally and numerically the optimized operation conditions for such orthogonal modulation. The results suggest the design guidelines of the proposed ASK/DPSK orthogonal modulation for supervisory information dissemination.

Key words: optical supervisory information, orthogonal modulation.

1. INTRODUCTION

Nowadays, various internet applications, such as electronic commerce, video-on-demand (VOD), video phone and conferencing, etc. are emerging and are becoming very popular. In order to support these bandwidth-hungry services, networks which are broadband, easy to manage, secure and transparent to the end users are highly desirable. One promising solution is to employ wavelength-division multiplexing (WDM) technique to unleash the enormous bandwidth offered by the optical fiber. In conventional optical fiber transmission systems, intensity modulation is often employed. Recently, optical differential phase-shift keying (DPSK) has attracted much interest for WDM systems because of its high robustness in the presence of fiber nonlinearities [1]. To facilitate the network management, supervisory schemes are required to monitor the working status and performance of all network elements. The obtained status information has to be disseminated to the major router nodes for control and management decisions. Previously proposed approaches include using optical subcarriers [2,3] and pilot-tones [4,5] or a separate control channel. Instead of using a separate wavelength or subcarrier channel, we may employ an orthogonal modulation scheme in which the relatively low-speed supervisory data can be superimposed onto the high-speed payload data. In this way, we can save the network resources. In most of the previously proposed approaches to realize such orthogonal modulation scheme for optical label encoding [6-8], the high-speed payload data was encoded in amplitude shift keying (ASK) format while the relatively low-speed label data was in constant intensity modulation format, such as optical DPSK [6,7] or optical
frequency shift keying (FSK) [8]. However, it required more complicated label transmitter circuits at each router node and it was not practical to implement relatively low-speed optical DPSK demodulators.

In this paper, we proposed to employ a simpler scheme using ASK/DPSK orthogonal modulation, where the high-speed payload data are encoded in the optical DPSK format while the supervisory information is directly intensity (ASK) modulated onto the constant intensity profile of the payload. As the supervisory data is usually of much lower bit rate (<1-Gb/s), the high-speed (~10-Gb/s) optical DPSK payload signal may suffer from slow amplitude fluctuation. One feasible solution is to reduce and optimize the extinction ratio of the supervisory ASK signal in such a way that both the high-speed optical DPSK payload signal and the low-speed supervisory ASK signal can still achieve error-free performance with minimal induced power penalty to each other. As the supervisory ASK signal is of low bit-rate and thus its intrinsic low receiver sensitivity can provide large tolerance to its degraded extinction ratio. We assume the high-speed optical DPSK signal is operating at 10-Gb/s and its performance is examined in the presence of the supervisory ASK signal under different bit rates and extinction ratios.

The paper is organized as follows. In section 2, the proposed ASK/DPSK orthogonal scheme will be described. In section 3, simulation results will be presented to assess the performance. Section 4 presents the experimental demonstration and characterization of the proposed scheme. Section 5 concludes this paper.

2. PROPOSED ASK/DPSK ORTHOGONAL MODULATION SCHEME

Fig. 1 shows the block diagram of the proposed ASK/DPSK transmitter. An optical phase modulator and an optical intensity modulator are employed. The CW light is first modulated with the 10-Gb/s payload data in optical DPSK format, via the optical phase modulator. The resultant payload signal, which exhibits a constant intensity profile, will then be modulated with the lower-speed ASK supervisory data via the optical intensity modulator. As a result, both the high-speed payload and the supervisory data can be transmitted over the WDM network simultaneously.
3. NUMERICAL SIMULATIONS

In this section, we study the mathematical model of the ASK/DPSK orthogonal modulation format. Moreover, we have performed simulation using a commercial simulation software, OptSIM\textsuperscript{TM} to investigate and optimize the performance of such orthogonal modulation scheme under different operating conditions.

3.1 Mathematical model of ASK/DPSK signal

The low-speed ASK signal will definitely degrade the signal-to-noise ratio (SNR) of the high-speed optical DPSK payload. Therefore, the extinction ratio of the ASK signal has to be controlled so as to limit the possible intensity fluctuation induced to the constant intensity profile of the optical DPSK payload, which may, in turn, induce the system degradation. On the other hand, in order to ensure that the ASK supervisory signal can be detected by an ordinary optical receiver, the extinction ratio of the ASK signal should be large enough. Assume that the DPSK data is 10-Gb/s, and the ASK data bit rate is \((10/k)\text{Gb/s}\), where \(k\) is a positive non-zero integer. Equation (1) expresses the ASK/DPSK orthogonal modulation signal, \(S(t)\), with a finite ASK extinction ratio \([-10\log_{10}(\varepsilon)] (0<\varepsilon<1)\), where \(\varepsilon\) is defined as the optical power ratio of the zero level to the one-level of the ASK signal after being superimposed onto the high-speed optical DPSK payload.

\[
S(t) = \sum_{n=0}^{+\infty} \{\varepsilon + (1 - \varepsilon)q_{s,n}g_s(t - nT_s)\} \cdot \sum_{m=1}^{k} \exp[i \cdot \pi \cdot q_{d,n+m}g_d(t - (kn + m)T_d)]
\]

(1)

where \(q_{s,n}\) and \(q_{d,n}\) are the \(n\)th bit value of the ASK supervisory data and the optical DPSK payload, respectively; \(T_s\) and \(T_d\) are their respective bit periods while \(g_s(\cdot)\) and \(g_d(\cdot)\) are their respective pulse shape. The ASK pulse shape, \(g_s(\cdot)\), is assumed to be non-return-to-zero (NRZ). The intensity level of the optical DPSK payload is normalized to 1. Table 1 lists the possible cases and the intensity levels of the demodulated output of the optical DPSK payload.

<table>
<thead>
<tr>
<th>10Gb/s Data</th>
<th>Supervisory Data</th>
<th>Intensity level of the demodulated optical DPSK payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>(q_d)</td>
<td>(q_{s,n}, q_{s,n+1})</td>
<td>(2)</td>
</tr>
<tr>
<td>0</td>
<td>1,1</td>
<td>(2)</td>
</tr>
<tr>
<td></td>
<td>1,0 and 0,1</td>
<td>(1 + \varepsilon)</td>
</tr>
<tr>
<td></td>
<td>0,0</td>
<td>(2 \varepsilon)</td>
</tr>
<tr>
<td>1</td>
<td>0,1 and 1,0</td>
<td>(1 - \varepsilon)</td>
</tr>
<tr>
<td></td>
<td>0,0 and 1,1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1
From Table 1, it can be deduced the worst case eye-opening of the demodulated optical DPSK payload is \((3\varepsilon - 1)\), as illustrated in Fig. 2 (a). Fig. 2(b) shows the relation of the eye-opening of the demodulated optical DPSK payload against different values of the ASK extinction ratio of the supervisory data.

![Figure 2](image)

**Fig. 2.** (a) Definition of eye opening; (b) the eye-opening of the 10-Gb/s optical DPSK payload vs the extinction ratio \([-10\log_{10}(\varepsilon)]\) of the ASK supervisory data

### 3.1 Simulation model

We have used a commercial simulation software, OptSIM™, to investigate and optimize the performance of the proposed ASK/DPSK orthogonal modulation scheme under different operating conditions. Fig. 2 shows the simulation model. The CW light at 1550nm was modulated by an optical phase modulator with the 10-Gb/s pseudo-random bit sequence (PRBS) to generate the optical DPSK payload signal. It was then modulated with a lower-speed ASK signal,
via a Mach-Zehnder modulator (MZM), whose driving voltage was controlled by the modulator driver. By appropriately setting the driving voltage levels for “1” and “0” bits, different extinction ratios for the ASK signal could be achieved. The resultant ASK/DPSK orthogonal modulated signal was then split into two streams. For the upper arm, the DPSK signal was demodulated by a 10-ns delay-interferometer and was detected by a high speed receiver, followed by a 10-Gb/s Bessel filter before measuring the bit error rate (BER). At the lower arm, the ASK supervisory signal was directly detected by an optical PIN receiver, followed by a RF Bessel filter before measuring the BER. The bandwidth of the Bessel filter was chosen to match the bit-rate of the ASK signal so as to limit the receiver noise. The optical powers of the signals at both arms were adjusted, via the optical attenuators, for BER measurements.

3.3 Simulation results
We have performed the simulation of the ASK/DPSK signal when the ASK supervisory data was at three different bit rates: 622-Mb/s, 1.244-Gb/s and 2.488-Gb/s. NRZ pulse shape was used for both ASK and DPSK modulations. The receiver sensitivities (at BER=10⁻⁹) of both the 10-Gb/s optical DPSK payload and the ASK supervisory signal were obtained, under different extinction ratios (ER) of the ASK supervisory signal. The results are shown in Fig. 3. With the increase of the ER, the receiver sensitivity of the optical DPSK payload decreases, due to the increased intensity fluctuation, while that of the ASK supervisory signal increases. At different bit rates of the ASK signal, its receiver sensitivity curves are spaced apart, about 1.5-dB difference is observed between two adjacent curves. It was due to the fact that the receiver noise has been limited by the matched receiver filter. Higher bit rate results in higher required minimum received power to achieve the BER=10⁻⁹. On the contrary, the variation of optical DPSK signal sensitivity is small under different bit rate. There exists a cross-point for each DPSK-ASK pair, where the receiver sensitivities for both the optical DPSK signal and the ASK signal are at the minimum simultaneously. The corresponding value of the ASK extinction ratio is chosen as the optimum ASK extinction ratio. At higher bit rates, the optimum ASK extinction ratio is getting larger.

![Fig.4: Simulation results: receiver sensitivity of the 10-Gb/s optical DPSK signal with the ASK signal at various bit-rates against different ASK extinction ratios [-10log₁₀(ε)].](image)
**4 EXPERIMENTAL DEMONSTRATION**

### 4.1 Experimental setup

Fig. 4 shows the experimental setup which is similar to the simulation model presented in section 3.2. A 1550nm CW laser was used as the light source. Two polarization controllers (PC) are used to align the polarization of the carrier with the principle axis possessing maximum modulation response in the optical phase modulator (PM) and the optical intensity modulator. The PM was driven by a 10-Gb/s NRZ $2^{31}-1$ pseudo random binary sequence (PRBS), while the optical intensity modulator was driven by a lower bit-rate NRZ $2^{31}-1$ PRBS. From the simulation results in section 3.3, the range for ASK extinction ratio (ER) was about 1-2dB. To achieve such a small value of ER, an electrical tunable attenuator was used to adjust the driving voltage level of the ASK signal. The resultant ASK/DPSK optical signal was then fed into a piece of standard single mode fiber (SMF) for transmission experiment (to be presented in section 4.2).

To minimize the possible phase-to-intensity conversion induced by the fiber chromatic dispersion, a piece of dispersion compensating fiber (DCF) was also used. In the inset of Fig. 4 shows the waveform of the ASK/DPSK signal. At the receiving side, it was fed into two receiver circuits, one for optical DPSK demodulation via a delay-interferometer, while the other one for direct detection of the ASK signal. If only intensity modulation (ASK) was performed, its receiver sensitivity (at BER=$10^{-9}$, 2.5-Gb/s) was measured to be -26 dBm. Similarly, when there was optical DPSK signal only, its receiver sensitivity (at BER=$10^{-9}$, 10-Gb/s) was measured to be -21.4 dBm.

Fig. 5 shows the experimental results of the receiver sensitivities of both the 10-Gb/s DPSK payload signal and the ASK signal under different ASK extinction ratios and different ASK bit rates. The trend of the curves agrees well with the simulation results presented in section 3.3. When the ASK signal was at 622-Mb/s and 1.244-Gb/s, the receiver sensitivities were less than -18 dBm for both the 10-Gb/s optical DPSK payload and the ASK supervisory signal at their respective optimum ASK extinction ratios. When the bit rate of the ASK signal was increased to 2.5-Gb/s, the phase noise induced by the optical DPSK signal became grievous and thus further degraded the system performance. Fig. 6 shows the eye diagrams of the 622-Mb/s ASK signal and the corresponding demodulated ASK/DPSK signal.
4.2 Transmission experiment

We have also performed the transmission experiment for the ASK/DPSK signal over a 40-km standard single mode fiber (SMF). A piece of 8-m dispersion compensating fiber (DCF) was used to compensate the fiber chromatic dispersion. The bit rate of the ASK signal was chosen to be 1.244-Gb/s while that of the optical DPSK payload was 10-Gb/s. The optimal ASK extinction ratio (~1.3 dB) was chosen. BER performance of the optical DPSK data and the ASK data after transmission are depicted in Fig. 7 and Fig. 8, respectively. The receiver sensitivities (at BER=10^{-9}) for both signals were measured and the power penalties were 0.7 dB and 0.45 dB for the ASK signal, and the optical DPSK payload, respectively, after the transmission. Clear eye opening, shown in the insets, was obtained for both the 1.244-Gb/s ASK and 10-Gb/s optical DPSK signal.
5 SUMMARY

In this paper, a new scheme using orthogonal modulation for supervisory information dissemination is presented. By superimposing the lower-speed ASK supervisory data onto the constant intensity profile of the high-speed optical DPSK payload, the supervisory information can be disseminated without requiring an extra dedicated control channel. The characteristics of the scheme have been studied and characterized both numerically and experimentally. It is found that the supervisory data has good performance when the bit rate is below 1.244 Gbit/s when it is operated at the respective optimum ASK extinction ratio. The results suggests that the ASK/DPSK orthogonal modulation scheme is a feasible solution for supervisory dissemination in WDM networks.

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