Employing DDQPSK in Optical Burst Switched Systems to Enhance Throughput

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Abstract *We demonstrate that doubly differential decoding can demodulate phase shift keyed data much faster after the switching event of a tunable laser than usual mth power single differential decoding. This technique can significantly improve throughput of optical burst switched networks.*

Introduction

As demand for bandwidth increases[1] and the limits of the Non-linear Shannon capacity are reached[2], it will be necessary to investigate new ways of increasing throughput in the optical internet. Optical burst switching (OBS)/ Optical packet switching (OPS) provides a way of improving network resource utilization by using sub-wavelength grooming and statistical multipliplexing[3] while simultaneously removing expensive optical-electrical-optical conversions[4]. Also, using coherent modulation formats, with spectrally efficient modulation formats and digital signal processing can results in a large improvement in capacity[4].

When using coherent modulation formats it is necessary to compensate for frequency offset (FO) between the transmitting laser and the local oscillator (LO). Performing this task can be problematic in an OBS environment where fast switching tunable lasers can exhibit large, time-varying frequencies[5], as well as time-varying linewidths[5], specifically immediately after a wavelength switching event. In addition, it is necessary to consider that in order to maximize utilization of bandwidth resources, it is important to start successfully transmitting information as quickly as possible after switching wavelength in an optical burst/packet switched network. Hence, it is important to determine which FO compensation schemes can handle the severe frequency fluctuations.

One of the most common techniques for performing FO compensation and phase estimation is to use the m^th-power operation[6]. This raises the received complex field to the power of m, where m is the number of phases in the phase shift keying format being used, and compares the present m^th-power value with the previous value in order to determine the FO. After FO compensation, the m^th power of the FO compensated field can be tracked in order to perform phase estimation. One key limitation of this FO compensation scheme is that the range of FO must be less than $\pm(\text{Baud Rate})/2/\text{m}$[7]. This limitation may be problematic for coherent optical burst switching as the FO of the switching laser may drift outside the tolerance range before it settles to its steady-state value.

Another method of dealing with frequency offset is to use doubly differential decoding which was simulated in the optical domain[8] and experimentally implemented in the optical domain for fixed FO's[9]. This modulation format has a very large FO tolerance range and was shown to demodulate FOs approaching the symbol rate[9].

In this paper, doubly differential binary phase shift keying (DDBPSK) will be compared with single differential binary phase shift keying (SDBPSK) in an experiment with a fast switching tunable laser where the FO is both large and quickly varying, to show that DDBPSK can demodulate data sooner after the switching event of a wavelength tunable laser than SDBPSK. The use of BPSK maximizes the range of m^th power FO compensation, while using 2.5GBd set a very strict limit on the linewidth/phase noise of the tunable laser.

Theory

Doubly differential decoding is where the differential operation on the received phase is repeated twice. This results in the following decoding equation[9]:

$$\Delta^2\theta_{rec}(i) = \theta_{rec}(i) - 2\theta_{rec}(i-1) + \theta_{rec}(i-2), \bmod 2\pi, i \geq 3 \quad (1)$$

where θ_{rec} is the received phase and i is the index of the received phase. In order to encode phase data for doubly differential decoding, the following equation can be used[10]:

$$\theta_{en}(k) = \theta_{data}(k) + 2\theta_{en}(k-1) - \theta_{en}(k-2), \bmod 2\pi, k \geq 3 \quad (2)$$

where $\theta_{en}(k)$ is the encoded phase, $\theta_{data}(k)$ is the phase data and k is the index of the phase data. It is clearly illustrated that in the noise free case the doubly differential decoded phase is independant of the FO and initial phase9,10. This enables DDBPSK to have a very large FO tolerance range. As illustrated in [9] doubly differential decoding can maintain a very large FO tolerance in the presence of amplified spontaneous emission noise, approaching FOs equal to the symbol rate. However, doubly differential decoding suffer from a power penalty when compared with single differential schemes as discussed in [10].

For single differential decoding using the mth power operation, this FO compensation scheme and phase estimation scheme used in the experiment is similar to the implementation described in [9] except that here m=2 whereas in [9] m=4.

Experimental Setup

The experimental setup is shown in figure 1. A sampled grating distributed Bragg reflector (SG-DBR) tunable laser was switched between two 1547nm and 1559nm by switching the voltage of the back-section. Figure 2 plots two sample frequency fluctuations from a tunable sampled SG-DBR laser immediately after a switch, and shows the frequency offset from the target frequency as a function of time after the switch (note that this was taken from a different experiment to the one described here). The output of the SG-DBR laser was fed into a polarization controller (PC) which in turn fed into an intensity modulator which was setup to perform binary phase shift keying (BPSK) by setting its DC bias to the null point of the modulator's transfer function. An arbitrary waveform generator (AWG) then provided a 2.5GBd 2^7-1 PRBS7 signal to an electrical amplifier with the output of the electrical amplifier driving the modulator to produce the optical BPSK signal. The output of the modulator was fed into variable optical attenuator (VOA) which also acted as a power meter. The power reading on this VOA was taken as the received power. The output of this VOA was then fed into a two-stage amplification process with two optical filters with bandwidths of 5nm for the first stage and 2nm for the second stage. An output from the first stage optical amplifier was coupled out using a 50/50 coupler in order to observe the optical eye diagram so that the modulator could be optimized. The output of the second filter was then passed through another VOA, with the output of this VOA being fed into the signal port of a coherent receiver after another PC. The output power of this second VOA was kept constant during measurements in order to keep the signal power going to the coherent received constant. A tuneable laser source (TLS) was then used as a local oscillator (LO) for the coherent receiver.

The frequency of the LO was setup so that the FO of the beat signal from the coherent receiver was minimized for the end of the burst (i.e. after the tunable laser had settled to its target frequency). This minimization was done by observing the reduced periods of the beat signal at the end of the bursts on the real time scope. The first VOA was set to a particular received power with the second VOA at the signal being optimized in order to ensure the optimum signal power going into the coherent receiver. The beat signal from the coherent receiver was saved on a real time scope for each received power. The polarization for the signal going into the coherent receiver was also optimized during the experiment.

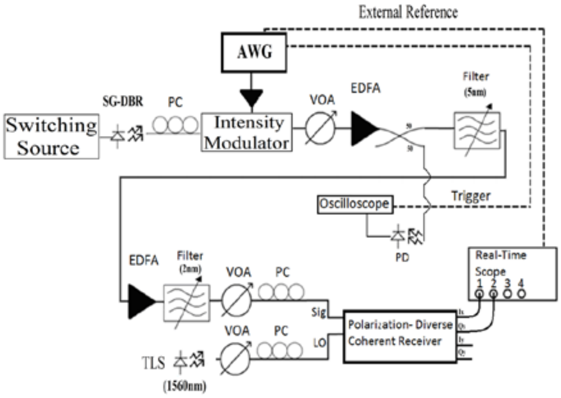

Figure 1: Experimental setup for determining the BER versus received power measurements (PD= "Photodiode")

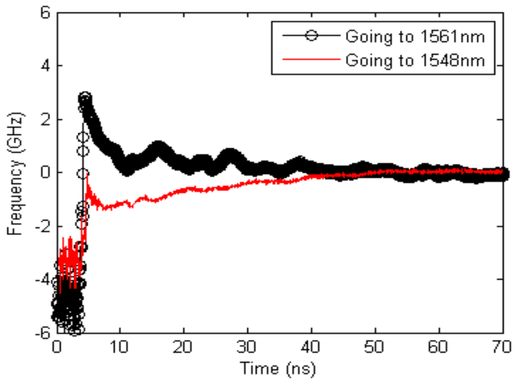

Figure 2: Frequency Variation of Fast Switching SG-DBR

The saved waveforms were decoded as either SDBPSK or DDBPSK. The data decoded at the receiver for each modulation format was compared with the decoded transmitted data. The BER was calculated as the ratio between the number of errors found during the times when a signal was present divided by the total number of bits during the time when a signal was present. Note that at least 70,000 samples were used for each BER value shown in figure 3 which means that we could measure BER of values of 10-4 reasonably accurately.

Results and Discussion

Figure 3 below presents the performance of both modulation formats during the switching case where the blue dots indicate when data was decoded starting only 2ns delay after the switch while the red dots indicate performance when the data was decoded starting 50ns after the switch. It is evident from figure 3 that the performance of SDBPSK is greatly degraded during the start of the burst due to the larger FOs from the tunable laser immediately after a wavelength switching event. When the data is decoded 2ns after the wavelength switch the SDBPSK data has an error floor around 10^{-1}, but the DDBPSK data shows no error floor and can achieve a BER of 10^{-3} at -35 dBm. To obtain good performance using SDBPSK it is necessary to wait about 50ns after the switching event of the tunable laser to start decoding the data. At this stage the tunable laser frequency has settled down close to its target frequency, and in this case the performance of the SDBPSK is better than the DDBPSK. DDBPSK is able maintain good performance immediately after the wavelength switch, and SDBPSK cannot, since DDBPSK can tolerate FOs up to the symbol rate but SDBPSK with the mth power law can only deal with FOs within $\pm(\text{Baud Rate})/4$ (using formula from [7]) which in this case is $\pm 0.625\text{GHz}$.

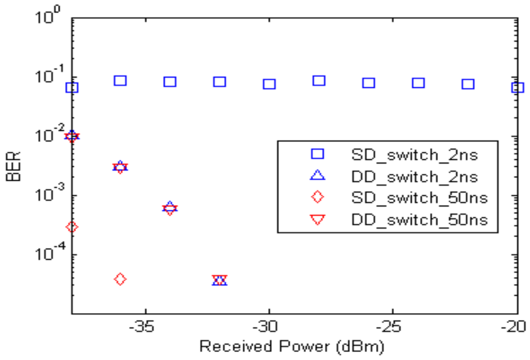

Figure 3: Plot of decoded switching data, where the single differentially decoded data, the doubly differentially decoded data, the points that are for BERs 10ns after the switch and 50ns after the switch are all marked in the legend.

The result shown is in agreement with the prediction made in [9] where it was stated that a larger FO range would allow data to be decoded sooner after the switching event of a wavelength tunable laser, which has been shown here. Noting that the LO at the coherent receiver was optimized to match the frequency of the SG-DBR at the end of the burst (when it had settled close to its target frequency), it is clear that doubly differential decoding can operate correctly even if the LO is not precisely optimized. Therefore, this results in a relaxing of the precision constraints put on the frequency accuracy of fast switching tunable lasers.

Conclusions

It has been shown the doubly differential decoding is able to demodulate phase shift keyed data much faster after the switching event of a tunable laser than the usual mth power single differential decoding. This technique can significantly improve the throughput of optical burst switched networks as it will allow advanced modulation format data signals to be successfully transmitted much faster after a wavelength switching event. This will significantly enhance both the temporal and spectral efficiency of these optical burst switched networks.

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