Evaluation of FSK Light Labels Superimposed on 112 Gbps DP-QPSK Signal with Real-time Coherent Receiver and Optical Filter Based Decoder for Light Path Tracing

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Abstract: We experimentally evaluate the feasibility of FSK light labels superimposed on 112 Gbps DP-QPSK signals using real time digital coherent receiver and optical filter based light label decoder.

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1. Introduction
Future reconfigurable optical add/drop multiplexer (ROADM) networks should be growing faster, more efficient, and more flexible to support dynamic services, such as large bulk data transfer between large data centers. Colorless, non-directional, contention-less and grid-less (CNCG) ROADM node architecture is attractive for such flexible network to setup arbitrary light paths between any pairs of transponders. One of the issues of such ROADM nodes is the detection and isolation of misrouting of lightpath because these nodes can receive/send the same wavelength but with different data. Light path tracing is one of the most promising schemes for identifying each add/drop port and transceivers in these ROADM nodes and networks. Several path tracing techniques such as AM pilot-tone base [1, 2], non-AM approaches (frequency shift keying [3, 4], polarization shift keying [5], and so on) have been reported so far. We previously proposed the FSK light labels scheme for embedding a path-ID into the main signal and its detection in which the in-band frequency modulated (FM) tone is imposed to the main signal by transmitter-side DSP, and the path-ID can be detected by a narrow optical band-pass filter and a low speed photo-diode (PD) [6].

In this paper, we further extend this previous work and demonstrate the first real-time FSK light labeling for light path tracing superimposed on 112 Gbps dual-polarization (DP)-quadrature phase shift keying (QPSK) signal using real time digital coherent receiver and optical filter based decoder. The impact on the main signal quality caused by the superimposed FSK tone is experimentally investigated for the effective FSK parameter in the flexible ROADM network.

2. Principle of light label superimposition and detection scheme
In Fig. 1, we recall the block diagrams of the light label superimposition and detection scheme under this study [6, 7]. Here the transmitter is assumed to be based on a DSP for waveform pre-processing (Tx-DSP), DAC's and an IQ optical modulator [8, 9] where a light label is encoded as the carrier frequency within Tx-DSP (Fig. 1(a)). It should be noted that such a carrier frequency modulation impacts the main signal performance if digital coherent detection receivers are applied: the frequency modulation is equivalent to additional fluctuation in transmitter laser frequency that is anyway removed by the laser frequency offset compensation (FOC) algorithm built-in to typical Rx-DSPs. At the light label detector (Fig. 2(b)), which will be placed at input, output and add/drop port of ROADM node, the signal spectrum with FSK light label is filtered by a narrow optical band-pass filter that serves as a frequency discriminator and hence converts the FM light label into of the optical intensity that can be detected by low-speed PD.

Fig. 1 Principle of light label superimposition and detection scheme. DAC: digital to analogue converter, LD: laser diode, PD: photo diode.
3. Experimental setup

In order to experimentally evaluate the feasibility of FM imposition scheme, we prepare the transmitter generates 28 Gbaud DP-QPSK signals with pseudo random binary sequence (PRBS) pattern with a $2^{15}-1$ sequence length, as shown in Fig. 2. To emulate Tx-side DSP for light label insertion, we used laser diode (LD) source emitting wavelength at 1546.119 nm which contains function of frequency modulation with quasi-sinusoid at 21 kHz. No residual AM fluctuation was observed in this source. The polarization multiplexing (PM) was performed by dividing the signal into two, adding subsequent delay to one signal, and recombining them. Optical signal with light label was coupled to ASE light source, and then divided into 10 to 1 optical splitter for simultaneous measurement on both main signal and light label.

In order to extract the light label from the main signal after the transmission, the output of a low speed PD after a narrow optical band-pass filter was measured by an RF spectrum analyzer. The transmission characteristic of the optical band-pass filter (3 dB bandwidth: 5 GHz), optical spectra of the main signal, and decoded optical signal through the filter after the alignment with respect to the target signal spectrum are shown in Fig. 3. The signal-to-noise ratio (S/N) of the received tone signal at 21 kHz was measured as the ratio of the carrier power at 21 kHz to the total noise power over the assumed 100 kHz bandwidth for this light label signaling. The total noise power was obtained based on the noise power density measured over the range from 18 kHz to 100 kHz. The signal qualities of the 28 Gbaud DP-QPSK was checked by a digital coherent receiver using the ADC/DSP LSI [10]. The pre-FEC bit error ratio (BER) is evaluated by an external error detector.

4. Results and discussion

In order to estimate the optimal parameters [7] for FM tone superimposition, we evaluated the S/N of the decoded (i.e. pass band filtered) light label signal and the quality of the main signal as a function of the frequency deviation for the FM light label modulation in back-to-back situation. Figure 4 shows the typical result of RF response spectra of the detected signal with the frequency deviation of 0.6 GHz. The definition of carrier power and noise power for the calculation of S/N is also indicated in this figure.

Figure 5 shows the Q-penalty of the main signal and S/N of the embedded FM tone as a function of the frequency deviation of the FM tone. Q-penalty in this figure was defined as the Q-difference between the cases with and without the FM light label modulation at each OSNR in back-to-back condition. S/N of the embedded tone monotonically increased as the frequency deviation increases, and the frequency deviation of the FM tone exceeds...
around 0.4 GHz, S/N reached to 12 dB which correspond to the BER of $10^{-9}$ in the NRZ signal. On the other hand, the Q-penalty of the main signal was negligibly small enough up to 0.6 GHz. Therefore, we still have sufficient margin for increasing the bit rate of the FSK light labels.

![Frequency deviation of embedded tone (GHz)](image)

![Q penalty of main signal (dB)](image)

![S/N of embedded tone (dB)](image)

Fig.5 Q-penalty of the main signal and S/N of the embedded FM tone as a function of the frequency deviation of the FM tones.

Next we measured the Q-penalty of the main signal through a CNCG-ROADM node (from optical line to drop-line) as a function of the frequency deviation of the FM tones as shown in Fig.6 (a). Q-penalty in Fig.6 (b) referred to the Q-value without the FM light label modulation at each OSNR in back-to-back condition. Inset of Fig.6 (b) shows the FM tone spectrum of decoded light label signal for the corresponding frequency deviation at 21 dB OSNR. The CNCG-ROADM node mainly consists of wavelength selective switches (WSSs), Erbium doped fiber amplifiers (EDFA), and multicast switches (MCSs). In the flexible ROADM node network transmission study we first confirmed that the Q-penalty due to the embedded tone through the CNCG-ROADM node is small less than 0.2 dB.

![Light path used for experiment](image)

Fig.6 (a) Configuration of a CNCG-ROADM node and (b) Q-penalty of the main signal thorough the node (Inset: FM tone spectrum of decoded light label signal). R-WADD: Reconfigurable wavelengths add/drop devices, R-LADD: Reconfigurable local add/drop devices [11].

5. Conclusion

We experimentally, for the first time, clarified the relationship between Q-penalty of the main signal and S/N of the embedded tone as a function of frequency deviation of FM light label embedding with 112 Gbps DP-QPSK signal using real time digital coherent receivers. We have experimentally confirmed that there is no significant impact with this light path tracing scheme applying to CNCG-ROADM network.

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6. References