Chromatic Dispersion Monitoring of Optical OFDM Signals in Flexible Optical Networks

Calvin C. K. CHAN
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., HONG KONG
ckchan@ie.cuhk.edu.hk

Abstract: A chromatic dispersion monitoring scheme for flexible optical OFDM networks is presented. Coded label subcarriers are added to the signal spectrum and dispersion monitoring is performed via direct detection, followed by electronic correlation procedures.
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1. Introduction

Optical orthogonal frequency division multiplexing (OFDM) is a promising and practical signal format to be employed in future high-speed flexible optical networks. Its signal bandwidth is variable so as to realize scalable and spectrum-efficient transport of ultrahigh-speed (say >100 Gb/s) data. It can support segmentation and aggregation of spectral resources, efficient accommodation of multiple data rates, as well as flexible resource allocation [1]. Moreover, it has shown superior tolerance to the chromatic dispersion and polarization mode dispersion in long distance transmission over optical fiber. In order to provision lightpaths which are dynamically reconfigurable according to different demand requests, the accumulated chromatic dispersion on each lightpath would vary. Hence, chromatic dispersion (CD) monitoring is highly desirable to provide the information of accumulated dispersion for each lightpath, so that efficient compensation at the receiving node can be realized. CD monitoring at each intermediate node can further provide information to facilitate impairment-aware routing or scheduling, so as to meet the quality of service requirement.

2. Chromatic Dispersion Monitoring of Optical OFDM Signals

Recently, there have been some interesting schemes proposed for optical performance monitoring of optical OFDM signals [2-3]. However, most of them required a sophisticated coherent receiver with channel estimation. The accumulated signal impairments were estimated via statistical sampling at the destination node of the ligthpath. In this paper, we propose a novel scheme to perform chromatic dispersion monitoring at the intermediate nodes, without the need of expensive coherent receiver. Fig. 1 shows the structure of the proposed transmitter. It follows the conventional coherent OFDM transmitter's structure, but a pair of designated codes, c_1 and c_2, are inserted during the inverse-Fast-Fourier-Transform (IFFT) stage, as label signals. Thus, two more optical coded label subcarriers are generated. Each of them is located at either edge of the signal spectra, and carries the respective designated code, as shown in Fig. 2.

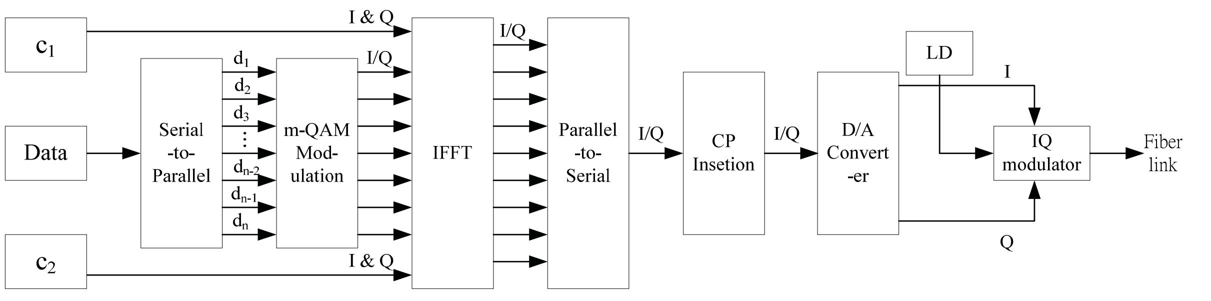

Fig. 1: The block diagram of the proposed CO-OFDM transmitter. (I&Q: inphase and quadrature phase components, IFFT: inverse fast Fourier transform, m-QAM: multilevel quadrature amplitude modulation, CP: cyclic prefix, D/A digital-to-analog, LD: laser diode)

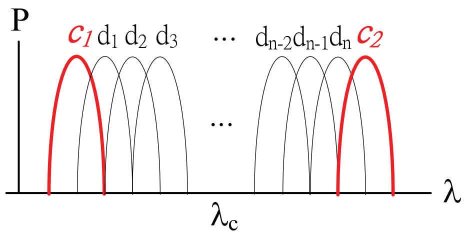

Fig. 2: Optical spectra of the generated optical OFDM signal with two optical coded label subcarriers, c_1 and c_2 (in red).

Each intermediate node is incorporated with a monitoring unit, which comprises a low-speed photo-detector, followed by an electrical low-pass filter, is used to detect the composite signals, comprising all incoming wavelength channels, through direct detection. As the designated labels on all wavelength channels are at relatively much lower data rates than the respective payload data, the low-pass frequency response of the photo-detector and the electrical filter will extract low-pass signal components including the designated coded label spectra, as well as the residual low-frequency components of all payloads from all wavelength channels. Such composite signal is further sampled, quantized and undergone the procedure of autocorrelation so as to extract the individual designated coded label and suppress the unwanted residual payload data. The correlation results are used to estimate the accumulated chromatic dispersion of the optical OFDM signal, via the temporal positions of the correlation peaks. As the code sequences of the first and the last coded label subcarriers (denoted as c_1 and c_2) are different. By correlating the signal with the code sequences c_1 and c_2, we obtain two correlation results, one for each code sequence. As the first and the last coded subcarriers suffer from different amount of walk-off, due to the fiber chromatic dispersion, the code sequences, modulated on those two edge label subcarriers, will experience different amount of temporal spread, accordingly. Such phenomena will lead to larger difference between the temporal positions of the two obtained correlation peaks, when the optical OFDM signal is suffered from a higher value of accumulated chromatic dispersion. Hence, by examining the temporal positions of the correlation peaks of the two edge label subcarriers, the accumulated chromatic dispersion value as well as the dispersion sign of the optical OFDM signal can be derived and monitored.

3. Simulation Results

We have studied the proposed optical OFDM signal monitoring scheme via numerical simulation. The optical OFDM system was simulated with 800 quadrature phase-shift keying (QPSK) payload subcarriers. On each subcarrier, 2048 symbols were simulated and thus generating a total of 3.2768x106 data bits. The baud rate of each subcarrier was 32 MHz, thus gave a payload data rate of 51.2 Gbps. 10% of symbol time of the cyclic prefix was inserted into the optical OFDM signal. Orthogonal Gold code sequence was employed. Finally, the generated code sequence was then equally modulated onto the I and Q components of the subcarriers at a symbol rate which is one quarter of that of payload subcarriers. As a result, a time frame of 2048 payload symbols was used to transmit one period of the code sequence without any repetition. The I and Q components of the optical OFDM signal were then modulated onto an optical carrier at 1550 nm.

Fig. 3 shows the simulation results of the temporal difference of the correlation peaks between the two edge coded label subcarriers when the optical OFDM signal passed through a fiber span ranged from 200 km to 3000 km, under different fiber dispersion slopes and signal spectral widths. In the simulation, the single mode fiber was configured to have anomalous dispersion of 17 ps/nm/km, 34 ps/nm/km or normal dispersion of -17 ps/nm/km, -34 ps/nm/km, at signal wavelength of 1550 nm, and zero dispersion wavelength of 1312 nm. From the trace in Fig. 3, which corresponded to a dispersion of 17 ps/nm/km, and a spectral width of 0.23 nm, the absolute value of the temporal difference of the two correlation peaks increased proportionally with the fiber length. Hence, the chromatic dispersion could be estimated by examining the temporal difference of the correlation peaks between the two coded label subcarriers. Moreover, for the case of having a dispersion of -17 ps/nm/km and with the same spectral width of 0.23 nm, the temporal difference of the two correlation peaks exhibited an opposite sign but the same magnitude of the dispersion slope, as compared to the previous case. Thus, the sign of the dispersion coefficient could be monitored. In addition, from the trace in Fig. 3, which corresponded to a dispersion 17 ps/nm/km and a spectral width of 0.46 nm, the 0.46-nm spectrum width was simulated by changing the symbol rate of the optical OFDM signal to 64 MHz, while keeping the number of subcarriers to be 800. As the spectral width was doubled, the slope of the curve thus became doubled. This trace was similar to the trace having chromatic dispersion of 34 ps/nm/km

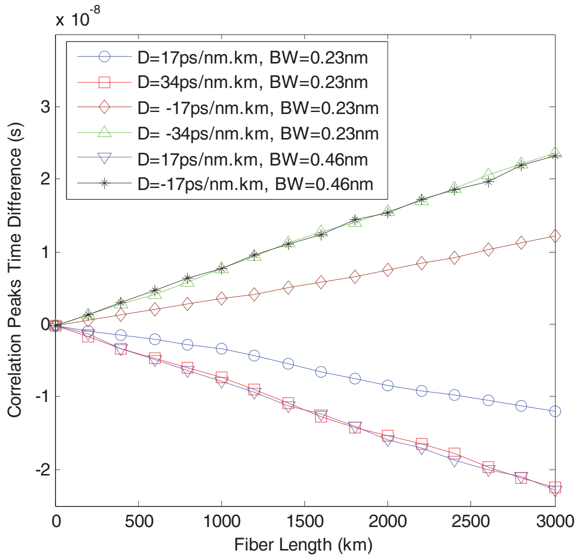

Fig. 3: Temporal difference of the correlation peaks between the two coded label subcarriers at different values of fiber transmission length, fiber dispersion slope and signal spectral width.

and with 0.23-nm spectral width. Similar results were also obtained when signal transmission was in normal dispersion regime of the fiber.

4. Summary

We have proposed a novel technique to realize chromatic dispersion monitoring of optical OFDM signals in flexible optical networks. A pair of coded label subcarriers is added to both edges of the optical OFDM signal spectrum. The signal monitoring is performed via simple direct detection, followed by electronic correlation procedures with the designated code sequences, without using any expensive coherent receiver. The proposed scheme provides a cost-effective monitoring solution for the optical OFDM signals across intermediate nodes in flexible optical networks. This work was partially supported by a research grant from Hong Kong Research Grants Council (General Research Fund: CUHK410512).

5. References

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