Hybrid CPFSK/OQPSK modulation transmission techniques’ performance efficiency with RZ line coding based fiber systems in passive optical networks

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ABSTRACT
This study shows hybrid continuous-phase frequency shift keying (CPFSK)/optical quadrature-phase shift keying (OQPSK) modulation transmission techniques’ performance efficiency with return-to-zero (RZ) line coding scheme based fiber systems in passive optical networks. Max. Q factor/min. bit error rate variations versus modulation frequency and fiber length are studied in detail for various bits/symbol, based on hybrid proposed modulation transmission techniques. Also, optical power and received electrical power variations are simulated with fiber-length variations at a specified modulation frequency of 300GHz. Max. Q Factor, min. BER, max. signal power, and min. noise power variations are based on hybrid modulation techniques for CPFSK/OQPSK of 32 bits/symbol and a modulation frequency of 500GHz through a fiber length of 30km.

Keywords:
CPFSK
Fiber system
OQPSK
Passive optical networks
RZ line coding

1. INTRODUCTION
Equalization can significantly help increase the overall communication bandwidth over copper channels with a severe frequency-dependent loss [1-5]. As the communication distance grows while the bandwidth requirement keeps scaling [6-8], equalized channels exceed the power envelope and become inadequate for delivering the required data in a power-efficient manner [9-13]. The optical transmitter and receiver electronics’ power consumption and area can limit the number of possible on-chip interconnections. An example of such limitation is board-to-board communication in data centers and high-performance computers [14-19]. A promising solution to this IO bandwidth requirement is the use of optical signaling [20-23].

The primary motivation for such a radical input/output architecture modification as optical signaling is the magnitude of potential bandwidth that occurs with an optical channel. In conventional optical data transmission, data is transmitted by modulating the high-frequency optical carrier signal’s optical intensity or amplitude. In order to achieve high fidelity over the most common optical channels that is, optical fiber high-speed optical communication systems typically use infrared light from source lasers with wavelengths ranging from 850nm to 1.550nm [24-34].

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2. MODEL DESCRIPTION AND RESEARCH METHOD

Figure 1 shows the basic simulation model for the proposed model. The electrical modulators namely, electrical CPFSK/OQPSK are combined together to modulate the user-defined data generators’ two stream bits sequences. CPFSK is employed with different bits per symbol: 8 bits/symbol, 16 bits/symbol, and 16 bits/symbol, respectively. The carrier signal is generated from a directly modulated laser measured with a frequency of 193.1 THz, a power of 10 mW, and an extinction ratio of 10 dB. Data sequences’ stream bits are encoded with an RZ coding line. The modulated electrical signal with the modulated carrier signal is injected into LiNbO$_3$ electro-optic modulators.

The modulated electro-optic signal is injected into a fiber cable with a length of 30 km. An optical power meter is used to show the total power through the fiber cable. Signal power levels versus time/wavelength are shown using optical time domain/optical spectrum analyzers. The Bessel light filter is used to filter the modulated light signal from the ripples, which are then converted to the electrical signal form through APD photo-detectors. The low-pass Bessel filter is used to show the modulated electrical signal from the noise (unwanted signals with high frequencies). The signal is modified (retiming, reshaping), and the max. Q factor and min. data error rate can be calculated through eye diagram analyzers.

![Proposed simulation model description](image)

3. PERFORMANCE ANALYSIS WITH DISCUSSIONS

The optical power and received electrical power variations are simulated with fiber length variations at a specified modulation frequency of 300GHz. Max. Q Factor, min. BER, max. signal power, and min. noise power variations are based on hybrid modulation techniques for CPFSK/OQPSK of 32 bits/symbol and a modulation frequency of 500GHz through a fiber length 30km. All the results are assured, depending upon the variables in Table 1.

Figure 2 shows the max. Q Factor variations based on hybrid modulation techniques for CPFSK/OQPSK of 16 and 32 bits/symbol with modulation frequency variations through a fiber length of 30km. The max. Q factor is 18.12 with CPFSK/OQPSK of 16 bits/symbol and 24.65 with CPFSK/OQPSK of 32 bits/symbol at a modulation frequency of 300MHz. Moreover, the max. Q factor is 24.12 with CPFSK/OQPSK of 16 bits/symbol and 22.14 with CPFSK/OQPSK of 32 bits/symbol at a modulation frequency of 400MHz. Additionally, the max. Q factor is 32.97 with CPFSK/OQPSK of 16 bits/symbol and 32.675 with CPFSK/OQPSK of 32 bits/symbol at a modulation frequency of 500MHz. The max. Q factor is 10.14 with CPFSK/OQPSK of 16 bits/symbol and 20.15 with CPFSK/OQPSK of 32 bits/symbol at a modulation frequency of 600MHz.
Table 1. Variables used in this work

| Variables                        | Values/Units                  |
|----------------------------------|-------------------------------|
| Laser Source Specifications      |                               |
| Frequency                        | 193.1 THz                     |
| Power                            | 10 mW                         |
| Extinction ratio                 | 10 dB                         |
| Bit rate                         | 10 Gb/s                      |
| Threshold current                | 20 mA                         |
| Electrical Modulators Specifications |                           |
| Modulation frequency            | 300 GHz-600 GHz               |
| Bits/symbol                      | 8, 16, 32                     |
| Frequency separation             | 1 MHz                         |
| Fiber Specifications             |                               |
| Loss                             | 0.2 dB/km                     |
| Length                           | 30 km                         |
| Wavelength                       | 1550 nm                       |
| Dispersion                       | 16.75 ps/nm.km                |
| Differential group delay         | 0.2 ps/km                     |
| Receiver Specifications          |                               |
| APD photodetector                |                               |
| Ionization ratio                 | 0.9                           |
| Responsitivity                   | 1 A/W                         |

Figure 3 depicts the max. Q factor variations based on hybrid modulation techniques for CPFSK/OQPSK of 8, 16, and 32 bits/symbol with a modulation frequency 300GHz through fiber length variations. The max. Q factor is 13 with CPFSK/OQPSK of 8 bits/symbol, 24 with CPFSK/OQPSK of 16 bits/symbol, and 40 with CPFSK/OQPSK of 32 bits/symbol at a distance of 5km. The max. Q factor is 12.32 with CPFSK/OQPSK of 8 bits/symbol, 21 with CPFSK/OQPSK of 16 bits/symbol, and 30 with CPFSK/OQPSK of 32 bits/symbol at a distance of 20km. The max. Q factor is 11.79 with CPFSK/OQPSK of 8 bits/symbol, 18 with CPFSK/OQPSK of 16 bits/symbol, and 24.74 with CPFSK/OQPSK of 32 bits/symbol at a distance of 30km. The graph shows that the max. Q factor degrades with an increase in distance.

Figure 4 indicates the optical power variations based on hybrid modulation techniques for CPFSK/OQPSK of 8, 16, and 32 bits/symbol with a modulation frequency of 300GHz through fiber length variations. The optical power is 0.668 mW with CPFSK/OQPSK of 8 bits/symbol, 0.6mW with CPFSK/OQPSK of 16 bits/symbol, and 0.56mW with CPFSK/OQPSK of 32 bits/symbol at a distance of 5km. The optical power is 0.342mW with CPFSK/OQPSK of 8 bits/symbol, 0.312mW with CPFSK/OQPSK of 16 bits/symbol, and 0.3mW with CPFSK/OQPSK of 32 bits/symbol at a distance of 20km. The optical power is 0.1986mW with CPFSK/OQPSK of 8 bits/symbol, 0.19mW with CPFSK/OQPSK of 16 bits/symbol, and 0.18mW with CPFSK/OQPSK of 32 bits/symbol at a distance of 30km. The graph confirms that the optical power degrades with an increase in distance.

Figure 5 demonstrates the received electrical power variations based on hybrid modulation techniques for CPFSK/OQPSK of 8, 16, and 32 bits/symbol with a modulation frequency of 300GHz through fiber length variations. The electrical power is 10μW with CPFSK/OQPSK of 8 bits/symbol, 9.23μW with CPFSK/OQPSK of 16 bits/symbol, and 8.65μW with CPFSK/OQPSK of 32 bits/symbol at a distance of 5km. The electrical power is 5.54μW with CPFSK/OQPSK of 8 bits/symbol, 4μW with CPFSK/OQPSK of 16 bits/symbol, and 3μW with CPFSK/OQPSK of 32 bits/symbol at a distance of 20km. The electrical power is 0.633μW with CPFSK/OQPSK of 8 bits/symbol, 0.6μW with CPFSK/OQPSK of 16 bits/symbol, and 0.5μW with CPFSK/OQPSK of 32 bits/symbol at a distance of 30km. The graph shows that the electrical power degrades with an increase in distance.

Figure 6 depicts the max. Q factor and min. BER values based on hybrid modulation techniques for CPFSK/OQPSK of 32 bits/symbol and a modulation frequency of 500GHz through a fiber length of 30km. The max. Q factor is 32.675 with a min. bit error rate of 1.74 x 10^{-234}. Figure 7 illustrates the max. signal power and min. noise power variations with wavelength variations based on hybrid modulation techniques for CPFSK/OQPSK of 32 bits/symbol and a modulation frequency of 500 GHz through a fiber length of 30km. The max. signal power is -6.798dBm, and the max. noise power is -104.438dBm. Figure 8 indicates the max. signal power and min. noise power variations with time variations based on hybrid modulation techniques for CPFSK/OQPSK of 32 bits/symbol and a modulation frequency 500GHz through a fiber length of 30km. The max. signal power is 0.0010494, and the min. noise power is -4.977 x 10^{-4}.
Figure 2. Max. Q Factor variations based hybrid modulation techniques CPFSK/OQPSK (16, 32 bits/symbol) with modulation frequency variations through fiber length (30km)

Figure 3. Max. Q Factor variations based hybrid modulation techniques CPFSK/OQPSK (8, 16, 32 bits/symbol) with modulation frequency (300GHz) through fiber length variations

Figure 4. Optical power variations based hybrid modulation techniques CPFSK/OQPSK (8, 16, 32 bits/symbol) with modulation frequency (300GHz) through fiber length variations
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Figure 5. Received electrical power variations based hybrid modulation techniques CPFSK/OQPSK (8, 16, 32 bits/symbol) with modulation frequency (300GHz) through fiber length variations

Figure 6. Max. Q Factor and min. BER values based hybrid modulation techniques CPFSK/OQPSK (32 bits/symbol) and modulation frequency (50GHz) through fiber length (3km)

Figure 7. Max. signal power and min. noise power variations with wavelength variations based hybrid modulation techniques CPFSK/OQPSK (32 bits/symbol) and modulation frequency (50GHz) through fiber length (3km)
CONCLUSION
This study has demonstrated the positive engagement between the CPFSK/OQPSK modulation transmission techniques for upgrading fiber systems in passive optical networks. The max. signal power, max. Q factor, and min. noise power variations with time/spectral wavelength variations are simulated and estimated based on hybrid modulation techniques for CPFSK/OQPSK of 32 bits/symbol and a modulation frequency of 500GHz through a fiber length of 30km. As well as optical power, received electrical power variations are simulated and studied based on hybrid modulation techniques for CPFSK/OQPSK of 8, 16, and 32 bits/symbol with a modulation frequency of 300GHz through fiber length variations. Max. Q factor variations have been studied and sketched based on hybrid modulation techniques for CPFSK/OQPSK of 16 and 32 bits/symbol with a modulation frequency/fiber length variation at a specified modulation frequency/fiber length. The max. Q factor is enhanced with a modulation frequency of 500MHz and a 32 bits/symbol CPFSK modulation transmission technique.

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