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OPTIMIZING 5G+ INFRASTRUCTURE: INNOVATIONS IN OPTICAL TRANSMISSION BASED ON HIGH ORDER QUADRATURE AMPLITUDE MODULATION

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Abstract. This research paper introduces an advanced optical transmission technology for 5G+ networks that uses high-order quadrature amplitude modulation (QAM) to improve data delivery. The system uses coherent optical transmission, dual-polarization, advanced DSP algorithms, and FEC to achieve great spectral efficiency, signal integrity, and resistance against optical defects at 16Tbit/s per channel across 200 kilometers. This study shows that high-order QAM can address future connectivity needs and advances optical network development for 5G and beyond. Based on the system developed by the author with a speed of 1 Tbit/s and the application of the Il'in-Morozov's method, the presented system can be modernized and simplified in its structure, brought to the speeds indicated above due to stream aggregation.

Keywords: optical transmission, high-order quadrature amplitude modulation, spectral efficiency, signal integrity, optical networks, 5G+.

1. Introduction

Optical transmission systems, high-order quadrature amplitude modulation, 5G+ networks, coherent optical communication, high-capacity broadband, digital signal processing, forward error correction, spectral efficiency, fiber-optic networks, dual-polarization techniques, have the great potential to transform communication systems. The capacity to handle bandwidths efficiently with low energy consumption addresses requirements of future networks leading to stronger, more scalable and higher capacity optical infrastructure. Solutions with a high data rate are required to accommodate the expanding global mobile traffic. For networks with brief to medium range, such as automated industrial or residential systems, this will necessitate gigabit-capacity channels. In addition to supporting novel services such as Internet of Things (IoT), 5G technology satisfies this demand [1]. Gigabit service per user, minimal latency, and great spectral efficiency are some of the primary goals of the 5G network, which aims to handle traffic one hundred times faster than 4G networks [2-4]. The optical system must be adapted to handle high-speed and capacity data in order to meet the needs of fifth-generation optical fibers. All areas of digital communication now rely on complex higher-order modulation formats based on quadrature amplitude modulation (QAM) to increase the capacity and efficiency of the spectrum and, by extension, transmission bit rates across existing infrastructures [5]. In comparison to lower-order QAM, higher-order QAM is able to transmit more data [6]. Coherent systems employ spectrally efficient advanced modulation forms to maximize the channel bandwidth. Formats such as 16-32-64-128-QAM and quadrature phase-shift keying are a few examples. Smaller constellations up to 64-QAM may soon be used in practical systems, ones up to 256-QAM becoming feasible in five to ten years, as a result of laser phase noise and OSNR limitations [7]. Improving the capacity, cost-per-bit, and bit rate of coherent optical transmission systems COTS is a top research priority for long-distance communications. The effective technique known as wavelength division multiplexing WDM can solve a broad range of problems. In particular, high-capacity data transmission guarantees coverage across large areas, improved flexibility, and long-distance communication. When building transport domains between the baseband unit BBU and the remote radio heads RRH,

WDM-PON is usually the major framework used by current 5G mobile access networks [8].
Figure 1 shows 5G bandwidth and latency needs [9].

Split	Uplink bandwidth	Downlink bandwidth	One-way latency
1	4 Gbit/s	3 Gbit/s	
2 (F1)	4 016 Mbit/s	3 024 Mbit/s	1—10 ms
3	Lower than option 2		
4	4 000 Mbit/s	3 000 Mbit/s	
5	4 000 Mbit/s	3 000 Mbit/s	
6	4 133 Mbit/s	5 640 Mbit/s	
7a	10.1—22.2 Gbit/s	16.6—21.6 Gbit/s	100 to a few 100 µs
7b	37.8—86.1 Gbit/s	53.8—86.1 Gbit/s	
7c	10.1—22.2 Gbit/s	53.8—86.1 Gbit/s	
8 (CPRI)	157.3 Gbit/s	157.3 Gbit/s	

Fig.1. Requirements for 5G bandwidth and delay

The high-speed transmission system that is shown in this research study is capable of delivering data at a rate of up to 16 Tbit/s. High-order modulation formats and digital optical transmission techniques are utilized by the system, which is scalable across a bandwidth of sixteen channels in the C-band. The 128-256-DP-QAM modulation method is the one that is utilized, where DP – dual polarization.

2. Design and simulation

The design and simulation of a high-speed optical network that is tailored for 5G applications focuses on utilizing high-order QAM to achieve a transmission rate of 16 Tbit/s across 16 channels over a distance of up to 200 kilometers using single-mode fiber-optic cables. This is accomplished by utilizing the QAM technique. In order to improve the dependability of data transmission by lowering the BER, the transceiver, which is the central component of the system, has been carefully built to contain FEC. During the process of encoding a data sequence consisting of '*k*' bits into a bigger sequence consisting of '*n*' bits, FEC plays a crucial role in guaranteeing that there is a one-to-one mapping between the encoded sequence and the original sequence. In order to establish the code rate, which is symbolized by the symbol '*R*', the ratio of the bit rate without FEC to the bit rate with FEC is the most important measurement.

$$R = \frac{k}{n}. \qquad (1)$$

A block diagram of the 16 Tbit/s coherent WDM-PON scheme over 200 kilometers of single mode fiber (SMF) is presented in figure 2. A symmetric 16-WDM-PON system with 16×1 Tbit/s wavelengths is utilized in the architecture.

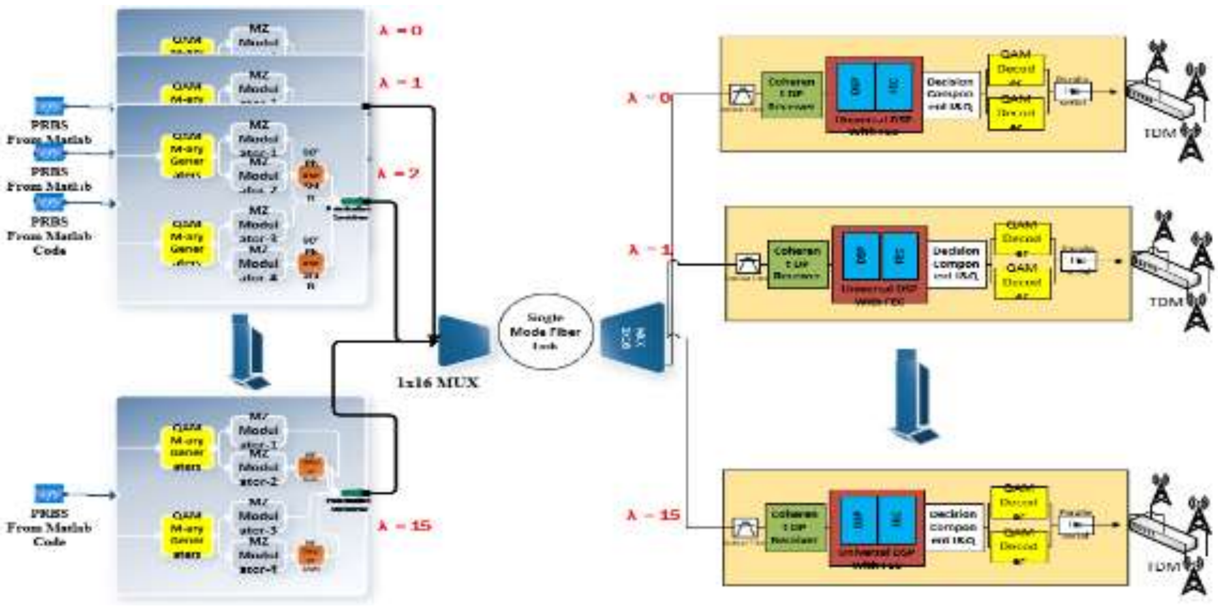

Fig. 2. 16 Tbit/s coherent WDM-PON over 200 km SMF block diagram (adapted from [8])

A coherent M-QAM square DP Receiver, an optical fiber (SMF) with an erbium-doped fiber amplifier EDFA with a gain of 16 dB and a noise figure, and a dual-polarization transmitter with high-order modulation are all components of our system. Additionally, the design that has been proposed postulates the transmission of wavelengths that fall within the C-band, with typical values ranging from 1530 to 1565 nanometers [10]. Constellation diagrams are shown in figure 3.

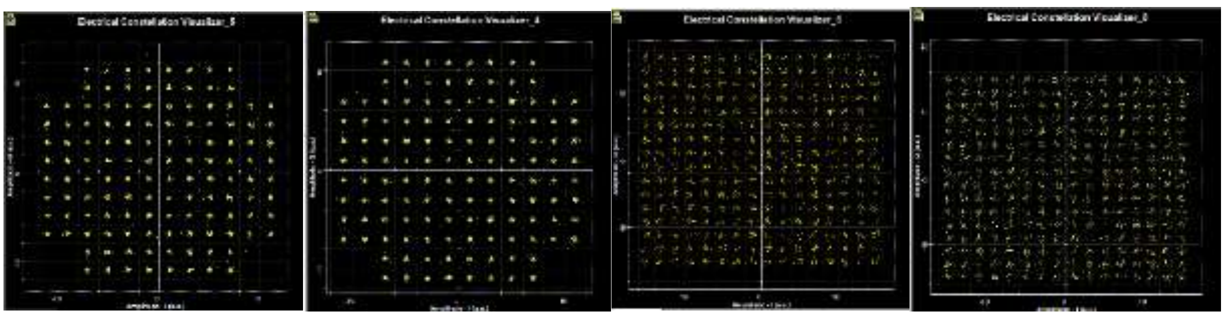

Fig. 3. Constellation diagram of 1550 nm channel frequencies with C-band:
128-QAM with distance (160, 200) km, (a) and (b) respectively;
256-QAM with distance (100, 120) km, (c) and (d) respectively

Utilizing a spacing of 50 GHz, it is possible to make more efficient use of the transmission channel from 191.560 to 195.910 THz, which is 88 channels. Recommendation G-694.1 of the International telecommunication union ITU for the year 2020 specifies optical channel operating frequencies for C-band dense WDM [11]. In figure 4, we can see that the transmission loses via the SMF was measured to be 0.2 dB/Km. A non-repeated optical communication system is limited in its ability to achieve its maximum range because to the phenomenon known as attenuation.

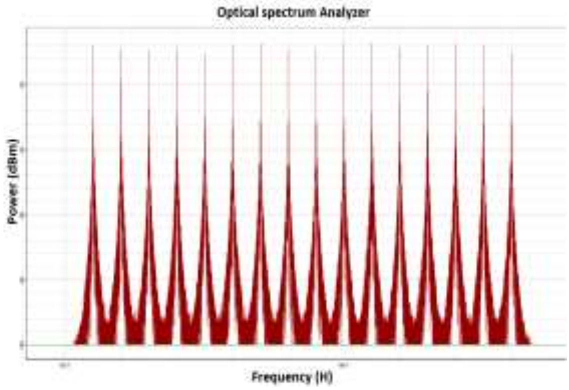

Fig. 4. Optical signal spectrum of 128- DP-QAM DWDM system

Principles of dual polarization formats carriers getting are shown in fig. 5. They are very closed to Il'in-Morozov's method, which can be used for simplification.

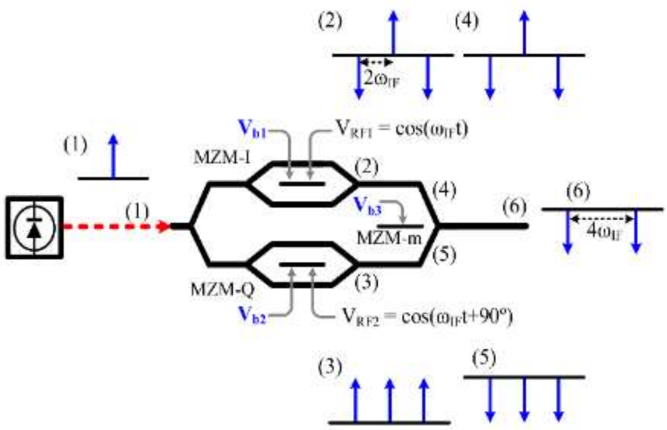

Fig. 5. Dual-polarization Mach Zehnder Modulator

For demonstrating how the signal-to-noise ratio (SNR) increases with increasing receiver power, several different exercised receiving powers were investigated. Evaluation of COTS with higher-order modulation formats is accomplished through the utilization of EVM (%) and BER. Optical signal-to-noise ratio (OSNR), laser linewidth, launched optical power, received optical power, and transmission distance all have an impact on system performance. The general equation for OSNR:

$$\mathrm{OSNR} = \frac{P_{\mathrm{signal}}}{P_{\mathrm{noise}}} \quad , \tag{2}$$

where P_{signal} is the optical power of the signal and P_{noise} is the optical power of the noise within a 0.1 nm bandwidth. Within the range of optical signal to noise ratio (20–50) dB, the modulation type 128-QAM demonstrated a different response. This reaction was observed with distances of approximately 100, 120, 160, and 200 kilometers. In contrast, the modulated type 256-QAM demonstrated a satisfactory response within the range of 20 to 30 dB of OSNR. BER for different distances are shown in table 1 with −10 dBm input power. The EVM% analogy shown in table 2.

Table 1. BER for variance distance and order modulation

QAM Modulation Order	BER With Distance 100 Km	BER With Distance 120 Km	BER With Distance 160 Km	BER With Distance 200 Km
128 bit/s	2.888×10^{-3}	2.955×10^{-3}	4.652×10^{-3}	7.775×10^{-3}
256 bit/s	3.572×10^{-3}	6.978×10^{-3}	2.231×10^{-1}	1.242×10^{-1}

Table 2. EVM% values for different modulation types

Modulation Type	EVM%			
	100Km	120Km	160Km	200Km
DP-128-QAM	2.88%	3.85%	4.01%	5.12%
DP-256-QAM	5.70%	7.33%	9.52%	11.01%

3. Conclusion

Using high-order QAM from 128- to 256-QAM in COTS allows data transfer speeds of 16 Tbit/s per channel across 200 km.

Author examines how dual-polarization, contemporary DSP algorithms, and forward error correction (FEC) might improve signal transmission efficiency and quality. These innovations ensure the system can survive optical difficulties, enabling reliable and rapid data transfer, which is essential for 5G+ networks. This is important to the digital developments that will transform telecoms. High-order QAM's capacity to meet future connection needs marks a major step forward in optical network development for 5G and beyond, advancing global digital connectivity.

The future way of such system modernization is to use Il'in-Morozov's method, which can be used for simplification [12-13].

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ОПТИМИЗАЦИЯ ИНФРАСТРУКТУРЫ 5G+: ИННОВАЦИИ В ОПТИЧЕСКОЙ ПЕРЕДАЧЕ ДАННЫХ НА ОСНОВЕ КВАДРАТУРНОЙ АМПЛИТУДНОЙ МОДУЛЯЦИИ ВЫСОКОГО ПОРЯДКА

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Аннотация. В этом исследовании представлена передовая технология оптической передачи для сетей 5G+, которая использует квадратурную амплитудную модуляцию (QAM) высокого порядка для улучшения доставки данных. Система использует когерентную оптическую передачу, двойную поляризацию, усовершенствованные алгоритмы DSP и FEC для достижения высокой спектральной эффективности, целостности сигнала и устойчивости к оптическим дефектам при скорости 16 Тбит/с на канал на расстоянии 200 километров. Это исследование показывает, что QAM высокого порядка может удовлетворить будущие потребности в подключении и способствовать развитию оптических сетей для 5G и за его пределами. На базе разработанной автором системы со скоростью 1 Тбит/с и применении метода Ильина-Морозова представленная система может быть модернизирована и упрощена в своей структуре, доведена до скоростей, указанных выше за счет агрегации потоков.

Ключевые слова: оптическая передача, квадратурная амплитудная модуляция высокого порядка, спектральная эффективность, целостность сигнала, оптические сети, 5G+.

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