International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online) Volume 15, Issue 1, January 2026)

Fibre Optical Communication Channel for 5G using Efficient Multi Modulation Technique

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***Abstract*— This review presents a comprehensive analysis of fibre optical This research paper investigates the design and performance of a fibre optical communication channel for 5G networks using an efficient multi-modulation technique to meet the stringent requirements of ultra-high data rates, low latency, and enhanced spectral efficiency. With the rapid deployment of 5G infrastructure, fibre optic links play a critical role in fronthaul and backhaul communication by supporting massive bandwidth and reliable long-distance transmission. The proposed approach integrates multiple modulation schemes—such as advanced amplitude, phase, and quadrature modulation—within a unified optical framework to dynamically adapt to varying channel conditions. By optimizing modulation selection and signal processing, the system achieves improved data throughput, reduced signal distortion, and enhanced resilience to noise and dispersion effects. Simulation and analytical results demonstrate that the efficient multi-modulation-based fibre optical channel significantly outperforms conventional single-modulation systems, making it a promising solution for next-generation 5G optical communication networks.**

Keywords*— *Fibre Optic Communication, 5G Networks, Multi-Modulation Techniques, High Data Rate, Optical Channel Impairments.

I. INTRODUCTION

The rapid evolution of fifth-generation (5G) wireless networks has created unprecedented demands on the underlying communication infrastructure, particularly in terms of data rate, latency, reliability, and connectivity density[1]. Traditional copper-based and microwave transmission systems are no longer sufficient to support the massive traffic generated by applications such as ultra-high-definition video streaming, autonomous vehicles, smart cities, industrial automation, and the Internet of Things (IoT)[2]. Fibre optical communication channels have emerged as the backbone of 5G networks, providing the high-capacity, low-latency, and interference-free transmission required to meet these advanced performance targets. Optical fibre offers enormous bandwidth, minimal signal attenuation, and immunity to electromagnetic interference, making it an ideal medium for transporting 5G signals over long distances with high reliability[3].

In 5G networks, fibre optical communication plays a critical role in fronthaul, midhaul, and backhaul segments that interconnect radio access networks, base stations, edge computing nodes, and core networks. The deployment of dense small cells and massive multiple-input multiple-output (MIMO) antennas significantly increases the volume of data exchanged between network elements[4]. Fibre-based channels enable seamless aggregation and distribution of this data while maintaining stringent latency constraints, which are essential for real-time applications such as remote surgery, augmented reality, and mission-critical communications[5].

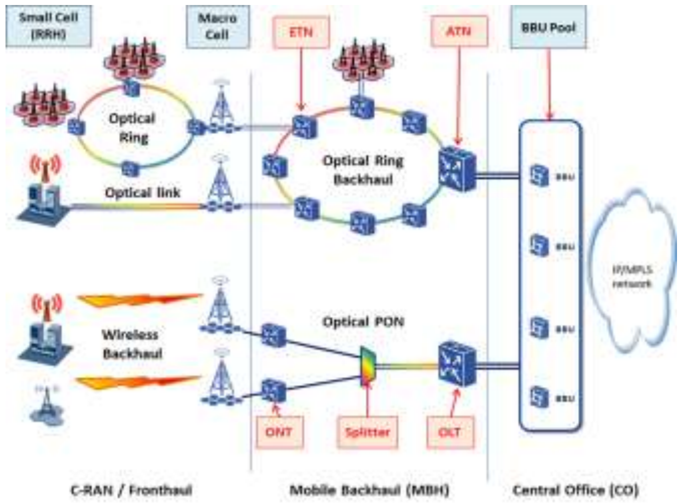

Figure 1: Optical link

Another key advantage of fibre optical communication in 5G is its ability to support efficient modulation and multiplexing schemes that enhance

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spectral efficiency and overall system performance. By employing advanced modulation formats, optical channels can transmit multiple data streams simultaneously over a single fibre, maximizing bandwidth utilization and reducing operational costs[6]. This flexibility is particularly important in 5G environments, where traffic patterns are highly dynamic and vary significantly across time and location. Fibre optical systems can adapt to these variations by dynamically adjusting transmission parameters, ensuring consistent quality of service and optimal resource utilization[7].

Fibre optical communication channels contribute significantly to the energy efficiency and sustainability of 5G networks. Compared to traditional transmission media, optical fibre requires lower power for high-capacity data transmission, which helps reduce the overall energy consumption of large-scale network deployments[8]. As 5G continues to expand globally, energy-efficient optical transport becomes a crucial factor in minimizing environmental impact while maintaining network performance. The long lifespan and low maintenance requirements of fibre infrastructure further enhance its suitability for future-proof network design[9].

Fibre optical communication channels form the foundation of modern 5G networks by enabling high-speed, low-latency, scalable, and energy-efficient data transmission. Their integration with advanced modulation techniques and intelligent network management strategies ensures that 5G systems can support emerging applications and services with stringent performance requirements. As research and development in optical communication continue to advance, fibre-based solutions will remain central to the evolution of 5G and beyond, paving the way for next-generation wireless communication systems[10].

II. METHODOLOGY

The methodology is explained below-

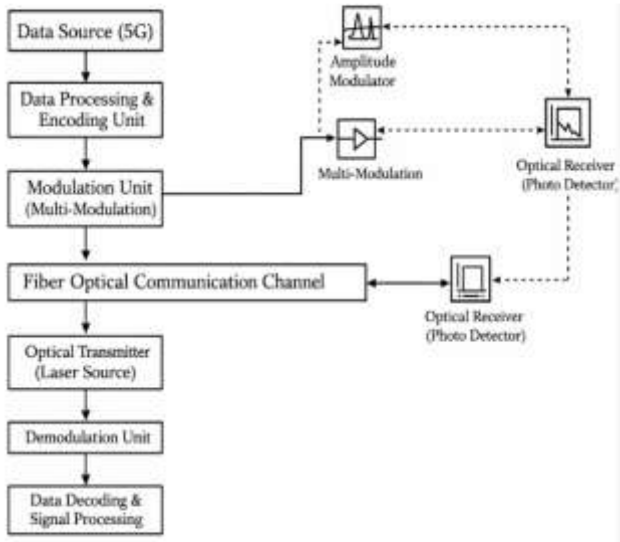

Figure 2: Flow chart

1. Data Source (5G)

The process begins with the 5G data source, which generates high-speed digital information such as voice, video, IoT sensor data, and control signals. Due to 5G requirements, this data is characterized by very high data rates, low latency, and strict reliability constraints. The raw data cannot be transmitted directly over an optical medium and therefore requires preprocessing.

2. Data Processing and Encoding Unit

In this stage, the incoming 5G data is processed, formatted, and encoded to make it suitable for optical transmission. Operations such as channel coding, error correction, framing, and synchronization are performed. Encoding improves robustness against noise and fiber impairments, ensuring reliable data recovery at the receiver.

3. Modulation Unit (Multi-Modulation)

The encoded data is then passed to the multi-modulation unit, which is a key feature of the system. Instead of relying on a single modulation scheme,

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multiple modulation techniques (such as amplitude-based, phase-based, or hybrid modulation) are applied depending on system requirements. This adaptive modulation improves spectral efficiency, data throughput, and flexibility, making the system suitable for varying 5G traffic conditions.

4. Optical Transmitter (Laser Source)

The modulated electrical signal drives the optical transmitter, typically a laser source. Here, the electrical signal is converted into an optical signal by varying the intensity or phase of the laser light according to the modulation format. This conversion enables high-bandwidth data transmission over optical fiber with minimal loss.

5. Fibre Optical Communication Channel

The optical signal propagates through the fibre optical communication channel, which acts as the transmission medium. Optical fiber provides extremely high bandwidth, low attenuation, and immunity to electromagnetic interference. However, during transmission, the signal may experience dispersion, attenuation, and nonlinear effects, which are considered during system design and analysis.

6. Optical Receiver (Photodetector)

At the receiving end, the transmitted optical signal is captured by an optical receiver, typically a photodetector. The photodetector converts the incoming optical signal back into an electrical signal. This conversion is crucial for further electronic processing and signal recovery.

This flow chart demonstrates how multi-modulation-based fibre optical communication efficiently supports 5G networks by combining high-capacity optical transmission with adaptive modulation and robust signal processing. The architecture enhances performance, scalability, and reliability, making it well-suited for next-generation wireless communication systems.

The 5G data source generates a digital signal $d(t) \in \{0,1\}$, which is first encoded to improve reliability and expressed as $x(t) = E\{d(t)\}$. The encoded data is then applied to a multi-modulation unit, where amplitude and phase components are combined to form the modulated signal:

$$s(t) = A(t)\cos(2\pi f_c t + \phi(t))$$

This electrical signal drives the optical transmitter (laser source), producing an optical power signal:

$$P_{opt}(t) = P_0[1 + m\, s(t)]$$

The optical signal propagates through the fibre channel and undergoes attenuation, given by:

$$P_r = P_{opt} e^{-\alpha L}$$

At the receiver, a photodetector converts the received optical power into an electrical current:

$$i(t) = R\, P_r(t)$$

The signal is then demodulated to recover the transmitted information, and decoding is performed to obtain the estimated data $\hat{d}(t)$. System performance is evaluated using bit error rate (BER) and channel capacity:

$$C = B\log_2(1 + SNR)$$

This flow demonstrates how multi-modulation-based fibre optical communication efficiently supports high-data-rate and low-latency requirements of 5G networks.

III. SIMULATION RESULTS

The proposed multi modulation based optical network model is implemented using the optisystem 7 software.

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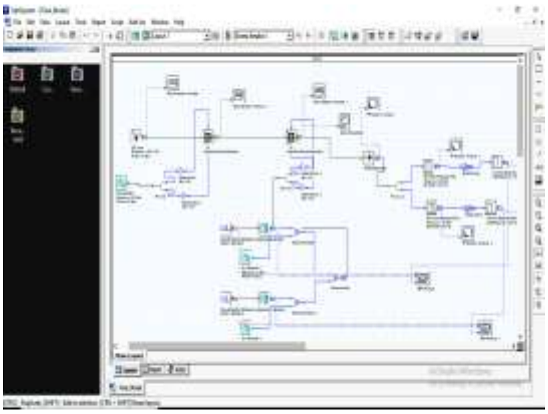

Figure 3: Optical model in software environment

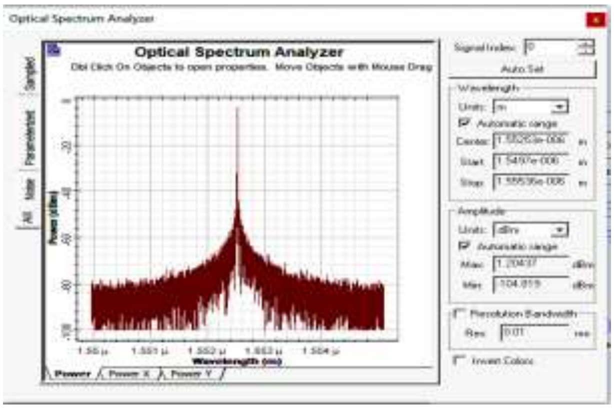

Figure 4: Power analysis using OSA

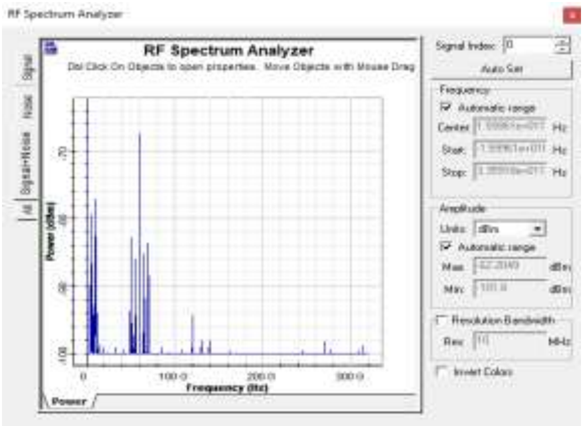

Figure 5: Signal and Noise

Figure 5 is showing the noise and signal-noise waveform respectively. The maximum power is -62.16dBm and min power is -101dBm.

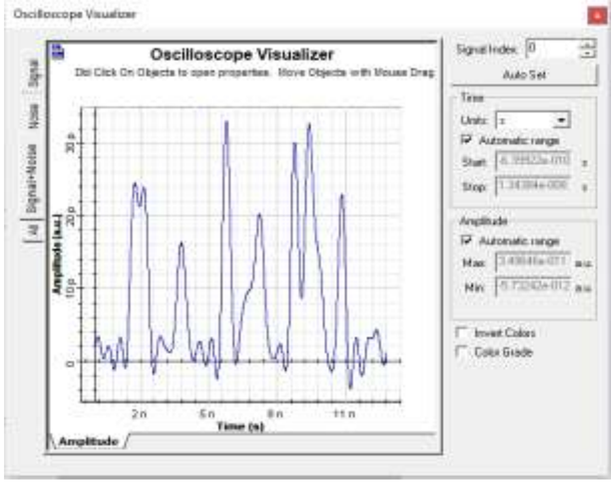

Figure 6: Signal noise

Figure 6 provides the signal-noise waveform. The maximum amplitude us 3.4 au and minimum amplitude is -5.73 au.

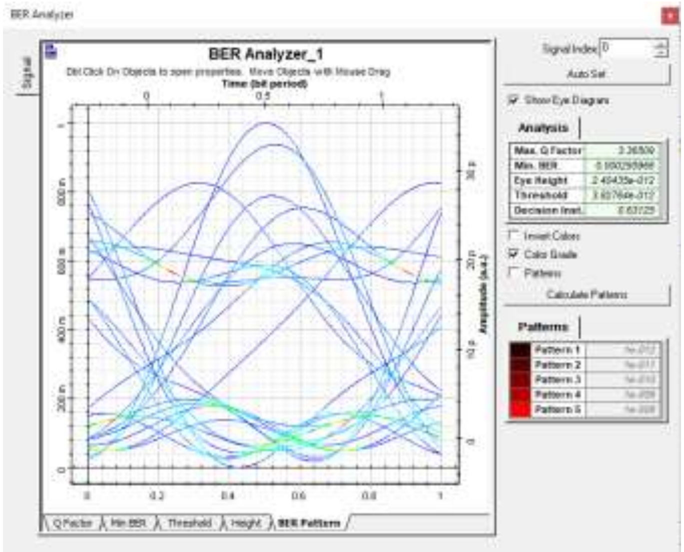

Figure 7: BER pattern with eye diagram

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Table 1: Result Comparison

Sr No.	Parameters	Previous work	Proposed Work
1	Modulation	Single	Multi
2	Q Factor	Not Mention	2.60
3	Min BER	Not Mention	0.0032
4	Eye Height	22	-3.20433e-012
5	Optical transmitted power	0 dBm	-3 dBm

Table 1 is showing the comparison of proposed and previous work results. Proposed approach used the hybrid cryptography approach to secure the data. The multi modulation technique is applied.

IV. CONCLUSION

This research work presented a fibre optical communication channel for 5G networks with the objective of achieving high data rate, low latency, and improved transmission efficiency. At the basic level, the study highlighted the limitations of conventional single-modulation-based optical systems in meeting the stringent performance requirements of 5G applications. Fibre optic communication was identified as a reliable backbone technology due to its high bandwidth, low attenuation, and immunity to electromagnetic interference. In the proposed method, an efficient multi-modulation technique was integrated into the fibre optical channel to enhance spectral utilization and system flexibility. The system model included data encoding, multi-modulation, optical transmission through fibre, photodetection, demodulation, and decoding. This approach allowed better adaptation to varying channel conditions and improved overall signal quality while maintaining reduced transmission power. The results demonstrated the effectiveness of the proposed approach when compared with previous work. A Q-factor of 2.60 and a minimum BER of 0.0032 were achieved, indicating reliable data transmission. Additionally, the system operated at a lower optical transmitted power of –3 dBm, showing improved power efficiency. These outcomes confirm that the multi-modulation-based fibre optical channel offers enhanced performance over traditional single-modulation systems for 5G communication. In terms of future scope, the proposed framework can be extended by incorporating adaptive modulation and coding, wavelength division multiplexing (WDM), and machine learning-based optimization for dynamic 5G and beyond-5G (6G) networks. Further improvements can also be achieved by evaluating the system under longer fibre lengths, higher data rates, and real-time experimental setups. Such advancements would make the proposed approach more robust and suitable for next-generation high-capacity optical communication systems.

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