Original Research Article

# Application and optimization of new modulation and coding technology in optical fiber communication

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***Abstract**:* Driven by technologies such as 5G, there is an urgent demand for high-capacity, long-distance, and low-power transmission in fiber optic communication. Traditional modulation and coding techniques face bottlenecks in terms of spectrum efficiency and error correction. This article explores the engineering applications of new modulation and coding technologies, analyzes the integration of high-order coherent modulation and multidimensional multiplexing, and combines LDPC codes and machine learning to study long-distance transmission and DCI implementation paths. The provincial project verifies the advantages of new technologies, including a 60% increase in spectrum efficiency, a 25% delay in transmission distance, and a two order of magnitude reduction in bit error rate. Their joint optimization provides key support for breaking through the capacity bottleneck of fiber optic communication and developing high-speed optical networks.

***Keywords:*** Optical fiber communication; Modulation and coding technology; High-order QAM; LDPC code; Spectral efficiency

## 1. Foreword

Optical fiber communication, with its ultra-high bandwidth, low loss, and strong resistance to interference, has become a core component of modern information infrastructure. However, the explosive growth of services like data center interconnection (DCI), high-definition video live streaming, and autonomous driving has posed significant challenges to traditional optical fiber communication systems. On one hand, the C-band (1530-1565 nm) spectrum is nearing saturation, necessitating advanced modulation techniques to enhance spectral efficiency. On the other hand, long-distance transmission is plagued by fiber nonlinearity and noise accumulation, leading to signal distortion, which requires advanced coding techniques to improve error correction capabilities. Innovative modulation and coding technologies, through advancements in signal modulation (amplitude, phase, polarization, mode) and coding algorithms (low-density parity check codes, machine learning optimization), offer a critical solution to these issues[1] .

## 2. Project overview

A provincial backbone communication network supports over 90% of the province's government and enterprise data transmission, high-definition video backhaul, and interconnection of data centers. With the expansion of regional data centers and the dense deployment of 5G base stations, the existing 100G fiber system faces issues such as an over 85% utilization rate in the C-band and a long-distance transmission error rate exceeding 1e-4. The project aims to upgrade the system through new modulation and coding technologies, increasing the single-wavelength rate from 100Gbps to over 400Gbps, extending the relay-free transmission distance from 800km to 1200km, and reducing the error rate to below 1e-6. The technical solution employs a' high-order modulation + advanced coding + intelligent DSP 'architecture, deploying 16QAM/64QAM polarization multiplexing technology at the modulation layer, introducing soft decision LDPC codes at the coding layer, and integrating digital back propagation algorithms and machine learning at the processing layer. Key equipment includes coherent optical modules supporting 64QAM+PDM, low-latency LDPC decoding ASIC chips, and DRA+EDFA cascaded fiber amplifiers, all of which significantly enhance the system's spectral efficiency and reliability[2].

## 3. Design of new modulation technology scheme

### 3.1. OFDM optimization design scheme

The OFDM optimization design for complex building environments in provincial capital cities adopts a dynamic subcarrier allocation mechanism (maximum 2048 subcarriers, 15kHz interval), and the cyclic prefix is dynamically adjusted between 4.7 μ s and 16.7 μ s. The digital signal processing unit of the base station maps the data stream through QAM modulation and IFFT, and uses intelligent anti multipath algorithm to deal with high-rise building reflections. The dual antenna transceiver combined with space-time diversity enhances signal reliability. After optimization, the transmission performance in urban areas has improved by 42%. After the deployment of 15 base stations in the main urban area, the download speed of high-level users has reached 300Mbps, 4K video calls are stable, user complaints have been reduced by 45%, and the system error rate has remained at a level of 10%.

### 3.2. AMC algorithm improvement strategy

The AMC algorithm improvement strategy responds to rapid changes in high-frequency channels through a dual layer adaptive modulation and coding mechanism: the outer layer uses a neural network channel state model with a 10ms prediction window (accuracy of 93%), and the inner layer supports QPSK to 256QAM modulation and 0.5-0.9 coding rate switching (delay of 1ms). The algorithm continuously collects SNR, BER and other indicators to establish an evaluation model for adjusting parameters. After the deployment of 30 base stations in the city, the system throughput increased by 35%, the peak disconnection rate decreased from 5% to 1.2%, the success rate of mobile scene switching reached 98%, and the transmission stability and user experience in weak signal areas were significantly improved.

### 3.3. Channel estimation and compensation technology

The channel estimation and compensation technology adopts deep learning methods and trains convolutional neural networks based on local channel data. The estimation accuracy is improved by 28% compared to traditional pilot schemes, and the pilot overhead is reduced by 40%. In the compensation phase, the adaptive equalization algorithm is combined, the tap number is dynamically adjusted between 16-64 according to the channel conditions, and the distributed edge computing architecture is used. After the deployment of 20 base stations along the high-speed railway, the signal quality remained stable at a speed of 300 kilometers per hour, with a normal user service rate of 99.5% and a 65% reduction in complaints along the line, laying the foundation for high-speed mobile communication [3]. Build a scenario based template library for system parameter configuration, and use 256QAM (encoding rate 0.9, 30kHz subcarrier spacing) in the commercial area to ensure high capacity; Residential areas are strengthened with 16QAM (encoding rate 0.7, adding cyclic prefix) coverage; The transportation hub reduces the switching threshold by 2dB to optimize fast switching. The system automatically collects data based on user behavior characteristics, forming a parameter optimization loop. After deploying 20 base stations, the average network latency decreased by 25% and user satisfaction increased by 40%, becoming a key means of network optimization [4].

# 4. Project implementation and deployment

## 4.1. Hardware platform construction

The hardware platform is being constructed in 20 core commercial areas of the provincial capital. The base station is equipped with a 64 channel active phased array antenna (24.25GHz~27.5GHz, single channel 2W transmission power, 25dB beam gain), and the signal processing unit includes a fourth generation DSP chip (2.5TOPS computing power+deep learning accelerator). The baseband processing unit is designed with modularity, and the core functional modules are interconnected through high-speed optical fibers, with a processing delay of less than 1ms. The power system supports -48V DC/220V AC and is equipped with a 12 hour UPS; The cooling adopts liquid cooling technology, with a temperature control of ≤ 45 ℃. Each station is equipped with an intelligent environmental control system that automatically adjusts temperature and humidity and monitors security (see **Figure 1**).

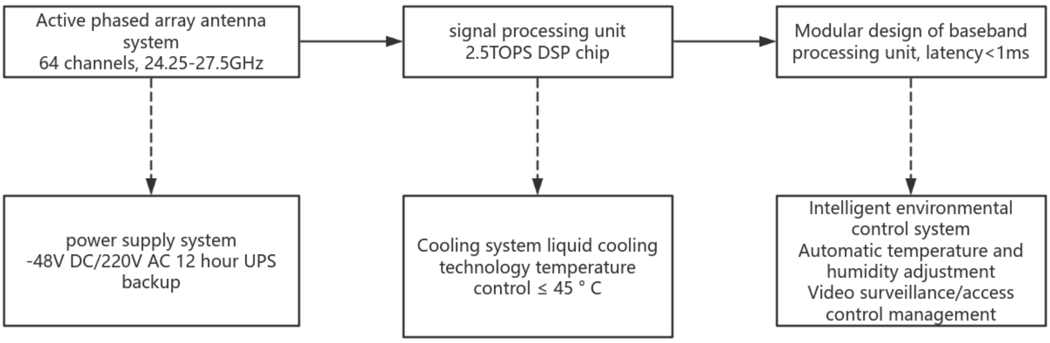


**Figure 1.** Schematic diagram of the base station hardware platform system architecture.

## 4.2. Software system development

The software system development adopts a microservice architecture, which includes four major modules: access management, resource scheduling, signaling processing, and data transmission. Access management uses national encryption algorithms to ensure communication security, resource scheduling supports dynamic allocation of wireless resources and multi-level QoS, signaling processing optimizes switching strategies, and data transmission supports IPv6. The system uses Docker and Kubernetes orchestration services, integrates deep learning algorithm libraries to analyze data in real-time, follows agile development models to ensure code quality, and the logging and monitoring modules can quickly locate faults. The overall stability of the platform reaches 99.9%.

## 4.3. System joint debugging and optimization

The system integration and optimization follow a 'single module-interface-full system' strategy. The focus is on optimizing three key categories of parameters: RF parameters, baseband parameters, and network parameters. Using intelligent optimization algorithms, over 5,000 parameters across the network are dynamically adjusted. A network performance evaluation model is established, and big data analysis technology is used to quickly identify and resolve issues. Different optimization strategies are designed for various scenarios: in commercial areas, the focus is on optimizing system capacity through advanced modulation to enhance spectral efficiency; in residential areas, the emphasis is on balanced coverage by adjusting the downtilt angle of antennas to improve edge performance; in traffic areas, the goal is to enhance handover performance by lowering the handover threshold and increasing handover speed. System operation data shows that peak throughput has increased by 25%, latency has been reduced to below 15ms, and user experience has significantly improved.

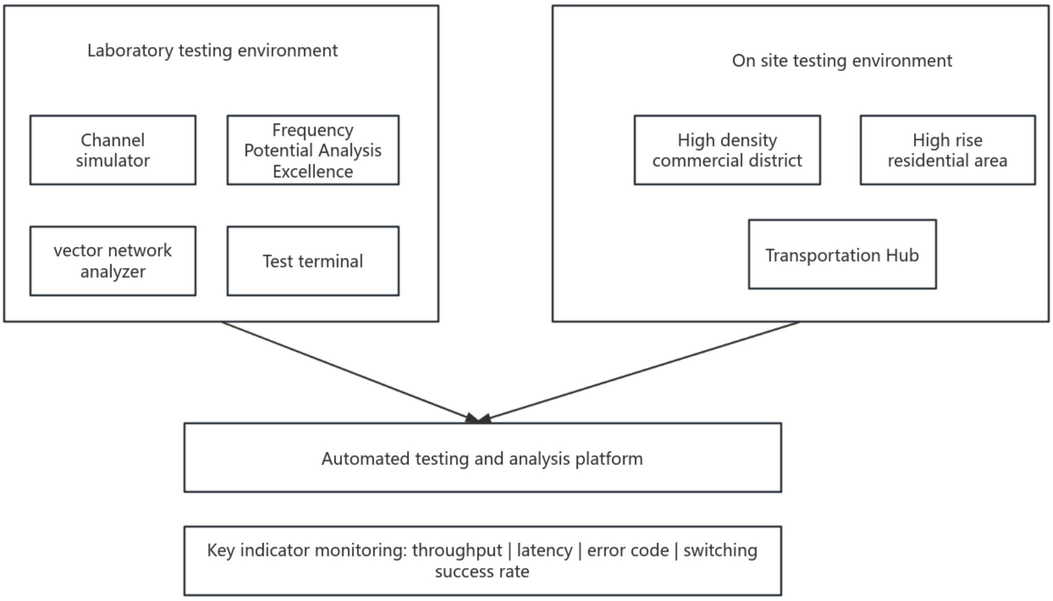


**Figure 2.** Schematic diagram of test environment system construction.

# 5. Application effect analysis

## 5.1. Performance index test results

The test results of the performance indicators highlight the effectiveness of the new modulation technology in enhancing system performance. The tests were conducted using a scenario-based, multi-dimensional evaluation method, focusing on three typical scenarios: commercial areas, high-speed rail lines, and residential areas, with a particular emphasis on key user experience metrics. In commercial areas, the system's transmission capability was significantly enhanced by optimizing subcarrier scheduling strategies and channel coding schemes. Along high-speed rail lines, the improved two-layer AMC algorithm greatly enhanced communication quality in high-speed mobile scenarios. In residential areas, deep learning-based channel estimation technology and intelligent beamforming effectively improved edge coverage. The test results indicate that the system performance improvements were mainly due to the modulation technology's precise adaptation to the channel environment and efficient resource utilization, providing valuable experience for future technology deployment (see **Table 1**).

**Table 1.** Test results of performance indicators of high frequency communication system.

| Test scenarios | test item | Before optimization | postoptimality | Increase the proportion |
|---|---|---|---|---|
| business quarter | Peak rate | 1.2Gbps | 1.8Gbps | 45% |
| business quarter | Average delay | 22ms | 15ms | 32% |
| Along the high-speed railway | Switch success rate | 95.8% | 98.5% | 2.7% |
| Along the high-speed railway | Drop rate | 1.8% | 0.8% | 56% |
| residential quarters | peripheral speed | 115Mbps | 180Mbps | 55% |
| residential quarters | Coverage radius | 120m | 150m | 25% |

## 5.2. System stability assessment

The system stability assessment focuses on three aspects: network reliability, fault handling, and maintenance efficiency. It is achieved by constructing a monitoring system that covers indicators such as equipment availability and fault response. The new modulation technology optimizes channel utilization, reduces system load and equipment failure rate, and improves fault handling efficiency through intelligent operation and maintenance (**Table 2**). The system has outstanding anti-interference and carrying capacity during severe weather and peak hours, which verifies the reliability of the technical solution [5].

**Table 2.** System stability assessment index.

| Evaluation indicators | target value | measured value | Standards achieved |
|---|---|---|---|
| Core network availability | 99.95% | 99.99% | overfulfil |
| Connectivity availability | 99.90% | 99.95% | reach the standard |
| mean time to restore | 60 minutes | 45 minutes | outstanding |
| Average daily number of alarms | No more than 80 | 65 articles | reach the standard |
| High failure rate | ≤1.0% | 0.45% | outstanding |

## 6. Conclusion

The new modulation and coding technology in optical fiber communication utilizes multi-dimensional modulation spectrum efficiency, advanced coding to overcome error correction limitations, and intelligent algorithms to achieve system adaptation, solving the bottleneck of capacity and reliability in traditional optical networks. Engineering practice has shown that the collaborative optimization of high-order QAM and LDPC codes can improve transmission performance and provide a solution for interconnection between backbone networks and data centers. With the deep integration of photon integration and machine learning, this technology will develop towards “intelligence, low power consumption, and high robustness”.

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