# Research of Frequency Multiplexing in 5G Networks

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**Abstract.** Frequency multiplexing techniques for 5G communications include large-scale antenna techniques and frequency division multiplexing techniques such as OFDM and GFDM. Reasonable use and development of these techniques can significantly reduce the cost of 5G technology deployment and improve the spectral efficiency. This paper firstly introduces the current status of multi-input multi-output large-scale antenna technology. This paper then describe the main challenges faced by large-scale antenna technology. Following this, this paper discuss related development and innovation directions, such as the adoption of compact and lightweight radiating devices and high-precision amplitude-phase calibration networks, which are crucial for improving the practicality and efficiency of large-scale antenna systems. Secondly, for OFDM technology, the performance of its improved f-OFDM and CP-OFDM in different situations such as BER is demonstrated. Finally, due to the limitations of OFDM, the SER performance of GFDM is investigated in this paper. To complement these discussions, this paper concludes by exploring the potential synergies between massive MIMO and advanced waveform technologies like f-OFDM and GFDM, highlighting how their integration could further enhance the performance and flexibility of 5G and future wireless communication systems.

**Keywords:** OFDM; Massive MIMO; GFDM; Frequency multiplexing.

## 1. Introduction

Nowadays, the rapid development of the mobile Internet and the Internet of Things, as well as the market's continuous pursuit of high-quality and diverse services, have put forward specific requirements for the next-generation mobile communication system, and 5G networks have emerged. 5G networks need to support higher data rates, more device connections, and faster terminal movement speeds, while providing lower latency and extremely high reliability. And frequency multiplexing technique is an integral part of modern communication network design, which is crucial to achieve efficient and reliable wireless communication. This paper will focus on the large-scale antenna technique and frequency division multiplexing technique in 5G frequency multiplexing technology. By analyzing the advantages and limitations of large-scale antenna and frequency division multiplexing techniques in 5G scenarios, this paper provides suggestions for their future development and innovation. Finally, conclusions are made.

## 2. Massive Antenna Technology

### 2.1. State of the Art in Massive MIMO Research

Massive Multiple Input Multiple Output (MIMO) technology revolutionizes cellular wireless communication by employing an extensive array of antennas, often numbering in the hundreds or thousands, at base stations. This innovative approach seeks to substantially enhance system capacity and energy efficiency. The simplicity and intuitiveness of this method have demonstrated potential improvements in spectral and energy efficiency by several orders of magnitude [1]. Current research trends have shifted towards multi-user MIMO (MU-MIMO), where a multi-antenna base station concurrently serves multiple single-antenna users, allowing them to collectively benefit from multiplexing gains [1]. This strategy concentrates technological advancements at the base station level, increasing antenna equipment costs there while eliminating the need for upgrades to user devices, thus maintaining the efficiency of single-antenna user equipment.

Currently, 5G large-scale antenna technology solutions are capable of meeting the technical demands of 5G network construction. The industrialization process is facilitated by intelligent manufacturing automated production lines, which enhance manufacturing efficiency, and multi-port test matrices, which improve testing efficiency.

### 2.2. Theoretical Benefits of Point-To-Point Massive Antenna Technology

In this initial analysis, this paper focuses on a point-to-point Multiple-Input Multiple-Output (MIMO) configuration. This setup involves a transmission system where the sending device is equipped with Nt antennas, while the receiving end utilizes Nr antennas. Such an arrangement allows for the examination of spatial multiplexing and diversity gains in a direct communication link between two multi-antenna nodes. According to, the main focus will be on narrowband time-varying channels with deterministic and constant channel matrices H The receiver signal vector, $y \in C^{N_r \times 1}$, can be expressed as:

$$y = \sqrt{\rho} H x + n \tag{1}$$

Where $x \in C^{N_t \times 1}$ is the vector of transmit signals and $n \in C^{N_r \times 1}$ represents noise and interferenc2e. When considering the scenario where the aggregate power of transmitted signals is normalized, the noise component is characterized as a circularly symmetric complex Gaussian distribution with zero mean. In this context, the covariance matrix of the noise is represented by the identity matrix I. This formulation provides a standardized framework for analyzing signal-to-noise ratios and system performance in the presence of Gaussian noise. Thus, the scalar $\rho$ is the transmit power [1].

Under the assumption that the transmitted signals follow an independent and identically distributed Gaussian pattern, and that the receiving end possesses complete Channel State Information (CSI), this paper can articulate the instantaneous achievable rate. This scenario, with perfect CSI at the receiver, allows for the formulation of a mathematical expression representing the system's capacity to transmit information reliably at a given moment:

$$log_2(1 + \rho N_r) \leq C \leq \min(N_t, N_r)\, log_2\left(1 + \frac{\rho \max(N_t, N_r)}{N_t}\right) \tag{2}$$

### 2.3. Main Challenges of Large-Scale Antennas

In massive MIMO systems, as antenna numbers grow, individual user channels maintain spatial uncorrelation, with their vectors becoming asymptotically orthogonal under favorable conditions [2]. While theoretical analyses often assume i.i.d. complex Gaussian (Rayleigh fading) scenarios, these may not always hold in practice. Research indicates that user scheduling plays a crucial role in massive MIMO, surpassing its importance in conventional MIMO systems. Despite discrepancies between ideal assumptions and real-world channels, a substantial portion of the theoretical performance advantages of large antenna arrays remains achievable [2].

Implementing a Base Station (BS) with numerous antennas necessitates the use of cost-effective, energy-efficient Radio Frequency (RF) amplifiers. However, the substantial Peak-to-Average Power Ratio (PAPR) issue can impede optimal Orthogonal Frequency Division Multiplexing (OFDM) performance [2]. In multi-cell massive MIMO setups, the scarcity of orthogonal trials relative to user numbers often forces adjacent cells to utilize non-orthogonal pilots. This practice gives rise to pilot contamination, resulting in directional interference between cells. Notably, this specific form of interference grows more severe as BS antenna count increases, posing a significant threat to overall system performance [2].

### 2.4. 5G Large Scale Antenna

The rapid expansion of 5G networks has introduced new challenges for large-scale antenna systems. As commercial deployment accelerates, the industry faces increasing demands for antennas that deliver consistent performance metrics, maintain robust quality, offer economic viability, and provide enhanced capacity. To meet these evolving needs, continuous innovation in 5G antenna technology and product development is paramount.

This study explores various avenues for advancement in large-scale 5G antenna technology. Key areas of focus include the development of compact, lightweight radiating elements and precision-engineered amplitude-phase calibration systems. Additionally, the research considers integrated high-density radiating arrays, advanced de-reflector configurations, and antennas with built-in filtering capabilities. Other promising directions involve combined antenna-filter modules, hybrid solutions incorporating mechanical phase adjustment and digital beamforming, dual-band 5G antenna designs, and unified 4G/5G antenna platforms.

By pursuing these innovations, the industry aims to achieve superior quality, cost-efficiency, and increased capacity in 5G antenna systems. The subsequent sections of this paper will delve deeper into the first two of these innovation areas, exploring their potential to shape the future of large-scale antenna technology in the evolving 5G landscape.

### 2.4.1 Low-Profile, Lightweight Radiating Unit

The integration of antennas and Remote Radio Units (RRU) in 5G Active Antenna Units (AAU) results in a linear increase in AAU weight. This poses significant challenges for tower load-bearing capacity and construction processes. Large-scale antennas use dozens or hundreds of antenna oscillators, reducing the weight of the antenna oscillator, the design of lightweight radiation unit have obvious benefits; reduce the height of the radiation unit, people can reduce the height of the AAU sealing cover and other components, which can further reduce the weight of the whole machine.

Various methods can be employed to create low-profile, lightweight radiation units. These include using high-quality, lightweight vibrator materials and implementing low-profile designs for PCB radiation units [2].

### 2.4.2 High-Precision Amplitude-Phase Calibration Network

Large-scale antennas require calibration of the amplitude and phase of signals input to the RF port from the transceiver component. This calibration is necessary due to the three-dimensional shaping of the directional map and beam scanning requirements. Improving the amplitude and phase accuracy of the calibration network can greatly improve the communication quality. The amplitude-phase accuracy of large-scale antenna coupling calibration networks is gradually improving. This is due to several factors: the continuous enhancement of PCB raw material processing quality, the introduction of advanced equipment in PCB processing factories, and the ongoing refinement and stabilization of PCB multilayer board processing techniques. These improvements significantly contribute to enhancing network coverage quality.

## 3. Frequency Division Multiplexing Techniques In 5G

### 3.1. OFDM-Based 5G Frequency Division Multiplexing Technique

The emergence of fifth-generation (5G) communication technology introduces three key application domains: enhanced Mobile Broadband (eMBB) for rapid data transfer, Ultra-Reliable Low-Latency Communication (URLLC) catering to critical services, and massive Machine-Type Communication (mMTC) enabling expansive IoT connectivity. Meeting the varied demands of these scenarios necessitates progress in modulation and access techniques, which are fundamental to 5G network evolution. This research explores advanced OFDM-based frequency division multiplexing methods, with particular emphasis on cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) and its filtered counterpart (f-OFDM).

Despite its widespread adoption, CP-OFDM's high out-of-band emissions restrict its utility in multi-digital settings [3]. Conversely, f-OFDM demonstrates superior out-of-band emission suppression, promoting the integration of diverse digital signals. The performance of f-OFDM can be further refined through strategic filtering techniques. In this context, this study evaluates the efficacy of three distinct filters: Hanning, Hamming, and Blackman.

A visual representation of this findings is presented in Fig. 1. The left segment showcases a 64QAM constellation mapping, while the right segment offers a comparative analysis of Bit Error Rate (BER) performance between CP-OFDM and f-OFDM waveforms, utilizing 256QAM modulation [3].

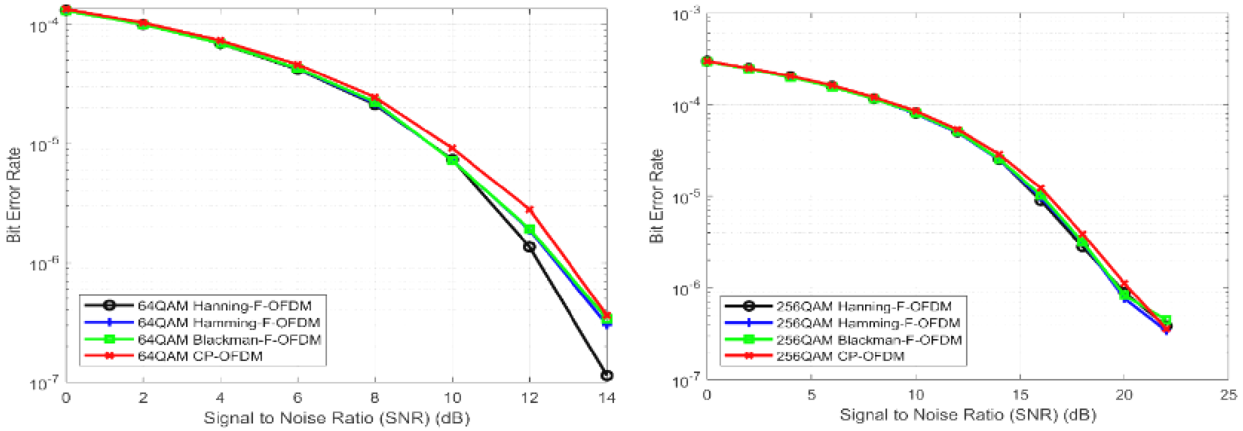

**Fig. 1** Comparative analysis of Bit Error Rate (BER) performance [3]

An analysis of the Bit Error Rate (BER) curves depicted in Fig. 1 reveals that the Hanning-filtered signal exhibits superior performance compared to other waveforms, which demonstrate performance characteristics nearly identical to the CP-OFDM signal. Interestingly, when examining the BER performance of waveforms utilizing higher-order constellation mapping, as illustrated in Fig. 1, the differences become negligible [3]. This observation suggests an inverse relationship between baseband mapping order and BER variation magnitude.

To ensure a comprehensive comparison, it is essential to consider Error Vector Magnitude (EVM) and Modulation Error Ratio (MER) metrics. Such analysis indicates that the Blackman-filtered f-OFDM demonstrates enhanced performance relative to other waveforms when compared against the CP-OFDM signal [3]. These findings underscore the importance of considering multiple performance indicators when evaluating the efficacy of different filtering techniques in OFDM-based systems. This study demonstrates an improvement in the throughput of filter-based waveforms, particularly f-OFDM, when compared to CP-OFDM. However, this analysis reveals that baseband constellation mapping does not significantly limit the performance of f-OFDM based signals. This suggests that f-OFDM can maintain its advantages across various constellation mapping schemes.

### 3.2. Development and Applications of GFDM

While Orthogonal Frequency Division Multiplexing (OFDM) has been widely adopted in current communication systems due to its resilience against multipath channels and ease of implementation via Fast Fourier Transform (FFT), emerging 5G network scenarios present new challenges. For instance, telematics and tactile Internet applications demand low-latency communications for bursty situations, where OFDM signals may result in unacceptably low spectral efficiency. Moreover, OFDM's high out-of-band emissions complicate dynamic spectrum access. Consequently, alternative waveforms are being explored for next-generation networks.

### 3.2.1 Introduction of GFDM

In the evolving landscape of 5G technology, Generalized Frequency Division Multiplexing (GFDM) stands out as a compelling contender for physical layer implementation. Its adaptable framework accommodates a wide array of requirements, making it particularly suited for next-generation communication systems. The distinctive architecture of GFDM, comprising MK samples with K subcarriers each transmitting M sub-symbols, enables the creation of customized time-frequency configurations. This structural flexibility proves advantageous in addressing the stringent timing demands of applications requiring minimal latency, positioning GFDM as a versatile solution for the diverse needs of 5G networks. GFDM's subcarriers can be filtered using various impulse responses, impacting out-of-band transmissions and Symbol Error Rate (SER) performance. This adaptability in frequency and time characteristics preserves OFDM's key advantages while introducing additional implementation complexity.

### 3.2.2 Comparison of SER for GFDM

A comparative analysis of SER performance between Space-Time Coded (STC) OFDM and STC-GFDM was conducted, utilizing system parameters and frequency-selective channel delay profiles (Table 1). The simulation employed two transmitting and two receiving antennas, with each antenna transmitting half of the available power to maintain constant total transmit power [4].

Results indicate that STC-GFDM and STC-OFDM achieve equivalent diversity gains. In practical setups, a small roll-off factor (α) is preferable as it minimizes noise enhancement factor (NEF) and allows more efficient use of the cyclic prefix (CP). Consequently, STC-GFDM outperforms STC-OFDM at low α values. However, high α values lead to increased NEF, degrading performance [4]. Fig. 2 illustrates that STC-GFDM attains a diversity gain of 2I for both analyzed transmit pulses. The steeper slope of the STC-GFDM curve compared to STC-OFDM demonstrates the benefits of more precise equalization. Notably, at high SNR levels (>18dB), STC-GFDM exhibits superior performance to STC-OFDM, even with raised cosine (RC) filtering at α=0.9.

**Table 1.** Impulse Response and Delay Spread [4]

| Channel | Impulse Response | Delay Spread |
|---|---|---|
| AWGN | $\vec{h} = (1)$ | $N_{ch} = 1$ |
| FSC | $\vec{h} = (10^{\frac{-i}{N_{ch}-1}})^{T}_{i=0,\ldots,N_{ch}-1}$ | $N_{ch} = N_{CP}$ |
| TVC | $\vec{h} = (h), h \sim CN(0,1)$ | $N_{ch} = 1$ |

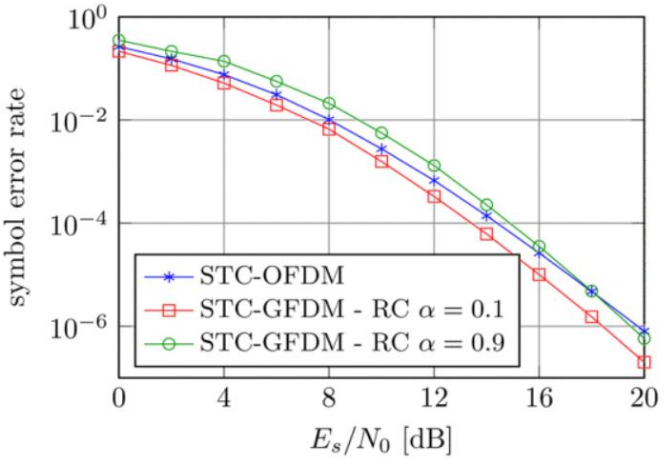

**Fig. 2** SER performance [4]

### 3.3. Summary

This research presents Generalized Frequency Division Multiplexing (GFDM) as a compelling candidate for waveform modulation in upcoming 5G network air interfaces, based on its demonstrated performance advantages. This investigation delves into GFDM's Bit Error Rate (BER) performance under diverse channel conditions, particularly in scenarios employing iterative receivers. Comprehensive analysis has revealed several GFDM configurations that exhibit comparable or superior performance to established techniques such as Orthogonal Frequency Division Multiplexing (OFDM) and Single-Carrier Frequency Domain Equalization (SC-FDE) [4]. These results underscore GFDM's versatility in meeting the multifaceted demands of next-generation wireless communication systems. The adaptability and robustness of GFDM position it as a strong contender for incorporation into emerging 5G standards, potentially offering solutions to the complex challenges faced by future wireless networks [5,6].

## 4. Conclusion

This paper focuses on the large-scale antenna technology and frequency division multiplexing technology among the key frequency multiplexing technologies for 5G. Among them, the large-scale antenna technique with multiple inputs and multiple outputs can significantly reduce the user-end deployment cost of 5G technology. However, at the same time, the large-scale antenna technology still has some challenges, such as Propagation Models, Modulation. to address these challenges, this paper proposes the corresponding technology development methods and innovation directions. For frequency division multiplexing in 5G networks, this paper discusses the BER performance of OFDM and its improved technologies, CP-OFDM and f-OFDM. This analysis shows that Blackman-based f-OFDM is superior to other waveforms, including CP-OFDM signals, due to its better spectral containment and lower out-of-band emissions. However, due to the limitations of OFDM in terms of efficiency, this paper also discusses the more advanced GFDM technique and proposes GFDM as a candidate waveform modulation scheme for the air interface of future 5G networks.

Implementation of these technological advances and innovative strategies will significantly enhance 5G frequency multiplexing technology, leading to improved spectral efficiency, reduced interference, and more cost-effective network deployments. Large-scale antennas will offer superior technical parameters, including higher consistency and integration. These improvements will lead to more compact and lightweight designs, higher production efficiency, and ultimately, lower deployment costs. And the 5G system will have faster data transmission rates, and higher spectral efficiency obviously, which will greatly enhance the build quality of the fifth-generation mobile communication network.

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