

LITERATURE SURVEY ON ENHANCING 5G PERFORMANCE WITH MIMO-OFDM

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Abstract

MIMO-OFDM is a foundational technology in 5G networks that enables high-speed data transmission and robust connectivity. MIMO employs multiple antennas at both the transmitter and receiver ends to enhance signal quality, data rates, and capacity by exploiting spatial diversity. OFDM, on the other hand, divides data into multiple sub-carriers, each transmitted at different frequencies, which significantly reduces inter-symbol interference (ISI) and enhances spectral efficiency. In the 5G network, MIMO-OFDM works synergistically to meet the demands of ultra-reliable, low-latency communication (URLLC), enhanced mobile broadband (eMBB), and massive machine-type communication (mMTC). The combination allows 5G to achieve higher capacity, better coverage, and greater reliability than previous generations. Advanced implementations such as Massive MIMO leverage large antenna arrays to support multiple users simultaneously, increasing network capacity without additional bandwidth. Additionally, OFDM is adapted to 5G's frequency bands, including mmWave, which brings more bandwidth and higher data rates.

Keywords: MIMO, OFDM, 5G Communications

Introduction:

MIMO-OFDM (Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing) is a core technology in 5G that addresses the growing demand for faster, more reliable, and high-capacity wireless communication. The integration of MIMO and OFDM in 5G allows for efficient use of available spectrum, robust connectivity, and high data rates, making it

well-suited to support a wide range of applications, from high-definition video streaming to real-time IoT communications.

MIMO utilizes multiple antennas at both the transmitter and receiver ends to transmit multiple data streams simultaneously, enhancing signal strength and reliability through spatial diversity. This technique improves capacity and data throughput without requiring additional bandwidth, as it can serve multiple users concurrently. OFDM, meanwhile, divides data into multiple narrowband sub-carriers, each transmitted at slightly different frequencies. This reduces inter-symbol interference (ISI) and enhances spectral efficiency, especially beneficial in high-mobility and high-interference environments.

In 5G, the combination of MIMO and OFDM allows the network to meet the requirements of enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC). Techniques like Massive MIMO further leverage large antenna arrays to support an even higher number of users and data streams, boosting network capacity and coverage. Moreover, OFDM adapts effectively to a variety of frequency bands, including millimeter-wave

(mmWave) frequencies, to achieve extremely high data rates essential for applications like virtual reality, autonomous vehicles, and smart cities.

MIMO Definition: MIMO stands for Multiple Input, Multiple Output. It is a technology used primarily in wireless communication systems to improve the capacity and performance of data transmission. MIMO uses multiple antennas at both the transmitter and receiver ends to send and receive more than one data signal simultaneously over the same radio channel, which enhances data throughput and network reliability.

Types of MIMO:

"MIMO" stands for Multiple Input Multiple Output, and it refers to a technology used in wireless communication systems to improve data transmission rates, reliability, and overall network performance by using multiple antennas at both the transmitter and receiver ends. There are different types of MIMO systems, typically classified based on the number of antennas used and the manner in which the signals are transmitted and received. Here are the main types of MIMO:

- Spatial Diversity MIMO (SD-MIMO)
- Spatial Multiplexing MIMO (SM-MIMO)
- Beamforming MIMO
- Massive MIMO
- Cooperative MIMO

- Polarized MIMO

Spatial Diversity MIMO (SD-MIMO):

Spatial Diversity Multiple Input Multiple Output (MIMO) is a technique in wireless communications that improves signal reliability rather than focusing on data rate increase, which is the aim of spatial multiplexing MIMO. Spatial Diversity Multiple Input Multiple Output (MIMO) is a technique in wireless communications that improves signal reliability rather than focusing on data rate increase, which is the aim of spatial multiplexing MIMO. Spatial diversity MIMO is designed to enhance link robustness and reduce the impact of fading by exploiting the diversity of the multiple antennas.

Key Aspects of Spatial Diversity MIMO:

Enhanced Reliability and Reduced Fading: Spatial diversity transmits duplicate copies of the same data stream over multiple antennas. This approach ensures that if one copy experiences fading or interference, another copy received via a different path is likely to be clearer, thus increasing the likelihood of accurate reception.

Applications:

Rural or Indoor Environments: Locations where line-of-sight (LOS) conditions are poor benefit greatly from spatial diversity as it mitigates severe fading.

Mobile Networks: Used in both 4G and 5G to maintain connection quality,

especially for users in areas with many obstacles.

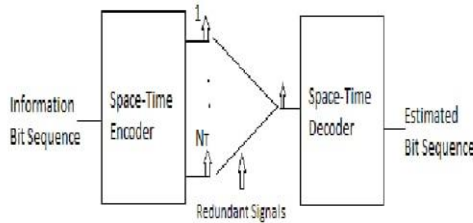


Fig: Spatial Diversity MIMO

Spatial Multiplexing MIMO (SM-MIMO):

Spatial Multiplexing Multiple Input Multiple Output (MIMO) is a wireless technology that enhances data transmission rates by transmitting multiple data streams over multiple antennas simultaneously. This method leverages multiple transmit and receive antennas, utilizing spatial diversity to improve the reliability and capacity of the communication link.

Key Aspects of Spatial Multiplexing MIMO:

Increased Data Rates:

Spatial multiplexing allows the splitting of a data stream into multiple, parallel streams, which are then transmitted simultaneously over separate spatial channels. This means the effective data rate can increase without requiring additional bandwidth or power.

Applications:

4G and 5G Networks: Spatial multiplexing is widely used in 4G LTE

and 5G NR networks to improve data rates and overall capacity.

Wi-Fi: Standards like Wi-Fi 5 (802.11ac) and Wi-Fi 6 (802.11ax) also use spatial multiplexing MIMO to boost performance.

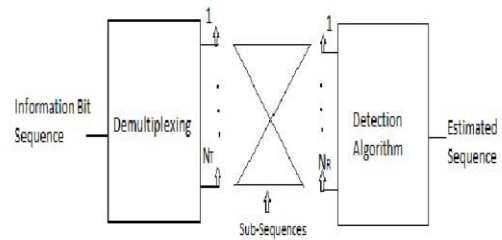


Fig: Spatial Multiplexing MIMO

Beamforming MIMO:

Beamforming MIMO is a technique in wireless communication that focuses on directing signals toward specific receivers, rather than broadcasting uniformly in all directions. Beamforming, combined with MIMO (Multiple Input Multiple Output), creates more efficient, directed transmission paths, which enhances signal strength, reduces interference, and improves overall network capacity.

Key Aspects of Beamforming MIMO:

Directed Signal Transmission:

Beamforming adjusts the phase and amplitude of signals at each antenna in a multi-antenna array. By carefully coordinating these signals, it forms a directed "beam" aimed at a specific user or

group of users, focusing energy in their direction while reducing it elsewhere.

Improved Signal Quality and Reduced Interference: The focused beam increases the signal-to-noise ratio (SNR) for the target receiver, which improves signal quality. By reducing signal spread, it also minimizes interference for other users, making it ideal for densely populated areas with many devices.

Applications:

5G Networks: Beamforming MIMO is central to 5G, particularly in higher frequency bands like mmWave, where signal paths are easily blocked and beamforming helps overcome the limitations of short-range, line-of-sight transmissions.

Wi-Fi: Beamforming is used in Wi-Fi 5 (802.11ac) and Wi-Fi 6 (802.11ax) to boost signal quality and range in home and office networks.

Satellite and IoT Communication: Beamforming improves the reliability and efficiency of satellite communication, while allowing IoT networks to handle more devices with minimal interference.

Massive MIMO:

Massive MIMO (Multiple Input Multiple Output) is an advanced wireless communication technology that uses a large number of antennas at the base station to serve multiple users simultaneously. Massive MIMO is central to 5G and beyond, providing improvements in spectral efficiency,

network capacity, and reliability. By deploying hundreds or even thousands of antennas, it leverages spatial multiplexing at an unprecedented scale, enabling massive throughput gains and reduced interference.

Key Aspects of Massive MIMO:

Large-Scale Antenna Arrays: Massive MIMO uses tens to hundreds of antennas at the base station, which is significantly more than traditional MIMO systems. This increase in antenna count allows the base station to send and receive multiple data streams for multiple users concurrently, boosting capacity without additional bandwidth or power.

Spatial Multiplexing: The large number of antennas enables spatial multiplexing for many users at the same time, even within the same frequency band. Each user benefits from a dedicated spatial path, improving data throughput and reducing interference.

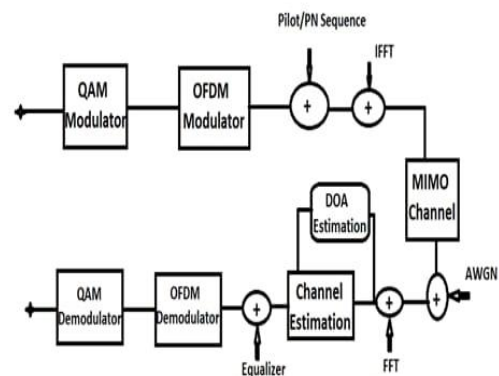


Fig:Massive MIMO

Applications:

5G and Beyond: Massive MIMO is a fundamental technology in 5G, enabling high-speed data, ultra-reliable connections, and low-latency communication for numerous devices in dense urban areas.

Dense Urban Environments: Massive MIMO's ability to serve many users in close proximity with minimal interference makes it ideal for high-density areas like stadiums, airports, and urban centers.

Internet of Things (IoT): With its capacity to handle thousands of connections simultaneously, massive MIMO supports IoT networks, especially in smart cities and industrial applications.

Cooperative MIMO:

Cooperative MIMO (Multiple Input Multiple Output) is a wireless communication technique where multiple devices or base stations work together to create a virtual MIMO system. Unlike traditional MIMO, where multiple antennas are located on a single device, cooperative MIMO uses multiple distributed devices or access points to achieve the benefits of MIMO, such as improved capacity, reliability, and reduced interference. This cooperation is particularly valuable in networks with dispersed infrastructure or in situations where a single device lacks multiple antennas.

Key Aspects of Cooperative MIMO:

Virtual MIMO Arrays: In cooperative MIMO, devices (like cell towers, access

points, or user devices) share their antennas and act as a single, large MIMO system. Each device or node in the network can relay or share information with others, creating a "virtual" MIMO setup even if each individual device has only one or a few antennas.

Increased Coverage and Capacity: By leveraging nearby devices, cooperative MIMO can extend the effective range and capacity of the network. It enables data to reach areas with poor coverage by using other devices to relay signals, effectively overcoming obstacles or interference in the environment.

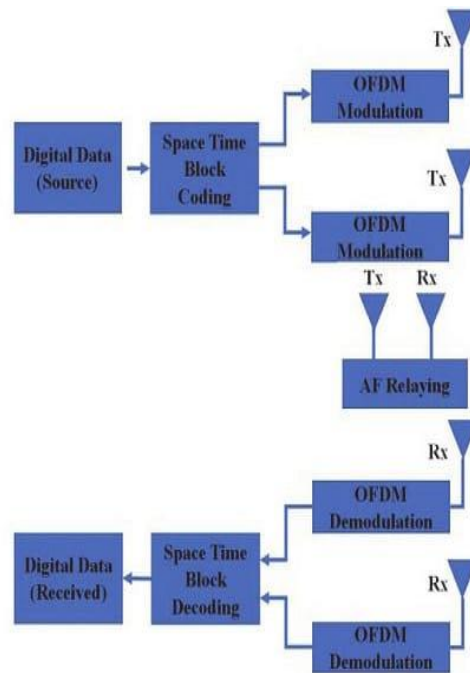


Fig: Cooperative MIMO

Applications:

Cellular Networks (e.g., 4G and 5G): In dense urban areas, cooperative MIMO enables multiple base stations to work together to serve users, especially at cell

edges, where coverage is weaker. It's also valuable for coordinating small cell networks in 5G.

Distributed Antenna Systems (DAS):

Cooperative MIMO is used in large venues like stadiums, airports, and shopping malls, where multiple antennas or access points work together to cover large areas and support many users.

Polarized MIMO:

Polarized MIMO is a wireless communication technique that uses antennas with different polarizations to improve network capacity, reduce interference, and enhance signal quality. In polarized MIMO, each antenna is polarized differently, typically in orthogonal directions (e.g., vertical and horizontal or $+45^\circ$ and -45° orientations), which allows multiple data streams to be transmitted over the same frequency channel with reduced crosstalk.

Key Aspects of Polarized MIMO:

Polarization Diversity: By using antennas with orthogonal polarizations, polarized MIMO creates separate channels for each polarization, which effectively doubles the capacity without needing extra spectrum or increasing the antenna count. The two polarized channels are less likely to interfere with each other, allowing independent data streams over the same frequency.

Increased Capacity and Throughput:

Polarized MIMO doubles the potential

data rate by enabling two data streams in the same frequency band. This is particularly useful in environments where adding more antennas for traditional MIMO is challenging due to space constraints or design limitations.

Reduced Interference and Improved Reliability:

Orthogonal polarization reduces interference between channels, enhancing the signal-to-noise ratio (SNR) and leading to more stable and reliable connections. This approach is beneficial in dense environments where interference from nearby devices is a concern.

Applications:

Cellular Networks: Polarized MIMO is widely used in 4G and 5G base stations. By using dual-polarized antennas, networks can improve capacity and coverage without significantly increasing tower hardware.

Wi-Fi Access Points: Many modern Wi-Fi routers use polarized antennas to improve data throughput and connectivity, especially in homes and offices with many overlapping networks.

Mobile Devices: Polarized MIMO is used in smartphones and other compact devices to improve signal quality and maintain reliable connections without needing extra physical space for more antennas.

OFDM Definition: In 5G technology, Orthogonal Frequency Division Multiplexing (OFDM) is used in different forms to meet the diverse requirements of various use cases, including high-speed data transfer, low latency, and efficient

spectrum utilization. The main types of OFDM used in 5G include:

1. Cyclic Prefix OFDM (CP-OFDM)
2. Filtered OFDM (F-OFDM)
3. Universal Filtered OFDM (UF-OFDM)
4. Generalized Frequency Division Multiplexing
5. Orthogonal Time Frequency Space (OTFS)
6. Single Carrier Frequency Division Multiple Access
7. Multicarrier code Division Multiple Access

1. Cyclic Prefix OFDM (CP-OFDM)

This is the most commonly used form of OFDM in 5G. It includes a cyclic prefix (CP) at the beginning of each symbol to combat inter-symbol interference (ISI) caused by multipath propagation.

Key Characteristics:

Cyclic prefix acts as a guard interval, ensuring that the symbols are orthogonal despite the delay spread.

It provides robust performance in a wide range of conditions, especially in scenarios with multipath propagation and frequency-selective fading.

Applications: Used in the downlink and uplink of 5G NR (New Radio) networks, including both sub-6 GHz and mmWave frequencies.

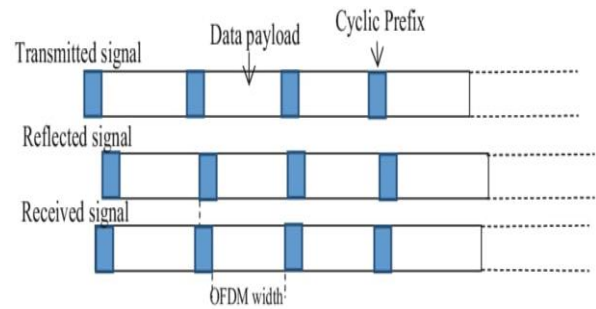


Fig: Cyclic Prefix OFDM

2. Filtered OFDM (F-OFDM)

F-OFDM is a variant of OFDM where filters are applied to each sub-carrier to reduce out-of-band emissions. This improves spectrum efficiency and reduces interference with neighboring bands.

Key Characteristics:

The subcarriers are shaped using filters to limit the signal's bandwidth and reduce adjacent channel interference.

F-OFDM is particularly useful in scenarios where the spectrum is scarce or when there is a need to co-exist with other communication systems.

Applications: Used for applications requiring strict spectral containment, such as dense urban deployments or when operating in frequency bands near other services.

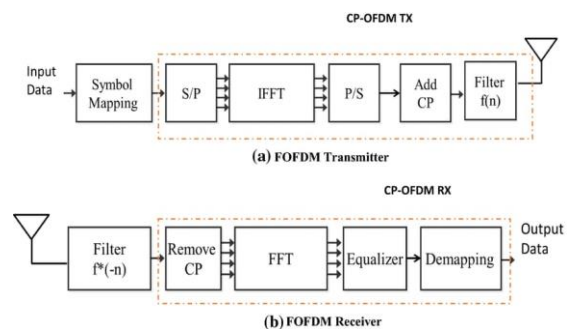


Fig:Filtered OFDM

3. Universal Filtered OFDM(UF-OFDM)

This type of OFDM uses a universal filter applied to the entire signal rather than just individual sub-carriers. The main goal is to reduce the out-of-band emissions even further.

Key Characteristics:

It improves the spectral efficiency while maintaining low out-of-band interference.

UF-OFDM can be more flexible in terms of the filter shape and frequency band used.

Applications: UF-OFDM is considered for higher-frequency bands, particularly in mmWave, to ensure efficient use of spectrum and reduce interference.

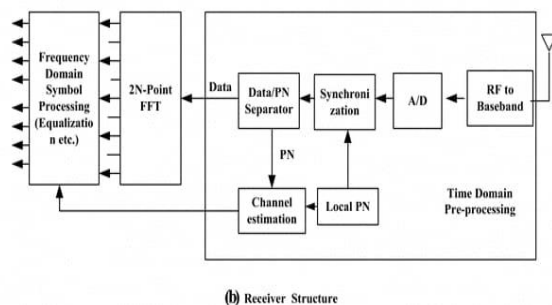
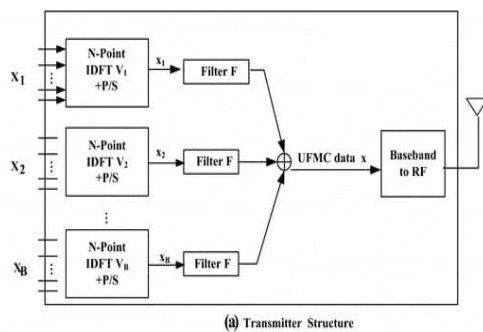


Fig:Universal Filtered OFDM

4. Generalized Frequency Division Multiplexing

GFDM is a multi-carrier modulation technique that can be considered an extension of OFDM. It generalizes OFDM by introducing more flexibility in how the subcarriers are spaced and how data is mapped onto them.

Key Characteristics: GFDM uses flexible symbol shapes and subcarrier arrangements, which makes it well-suited for highly dynamic environments like 5G.

Unlike traditional OFDM, GFDM doesn't use a strict orthogonal structure for subcarriers, allowing for better handling of non-contiguous spectrum.

Applications: GFDM can be useful in scenarios where bandwidth is fragmented or irregular, such as in ultra-dense networks and when operating with non-contiguous frequency bands in 5G.

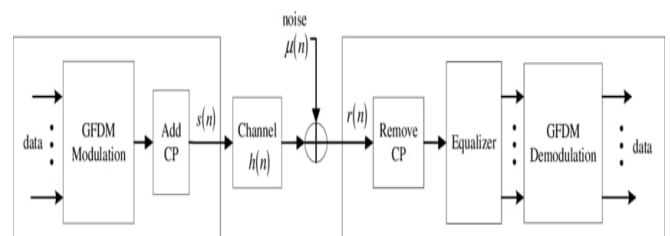


Fig: Generalized Frequency Division Multiplexing

5. Orthogonal Time Frequency Space(OTFS)

OTFS is a relatively new modulation scheme that is being investigated for 5G and beyond. It combines time, frequency, and space domain multiplexing to improve

robustness in high mobility and non-line-of-sight (NLOS) conditions.

Key Characteristics:

Unlike OFDM, OTFS maps symbols in the time-frequency domain and applies a two-dimensional grid over the entire communication channel.

It offers higher robustness to high Doppler shifts and signal fading, especially in mobile environments.

Applications: OTFS is being considered for 5G applications where mobility and high-speed transmission are critical, such as vehicular networks.

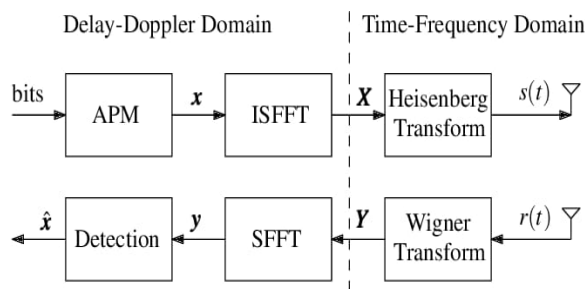


Fig:Orthogonal Time Frequency Space(OTFS)

6.Single Carrier Frequency Division Multiple Access

C-FDMA is a variant of OFDM designed to address the high Peak-to-Average Power Ratio (PAPR) problem inherent in traditional OFDM. It is mainly used in the uplink of 5G networks.

Key Characteristics:

SC-FDMA uses a similar structure to OFDM but with single-carrier processing, reducing the PAPR.

It provides better power efficiency, which is important for mobile devices with limited battery life.

Applications: SC-FDMA is primarily used in the uplink of 5G NR networks due to its improved power efficiency, particularly in mobile devices.

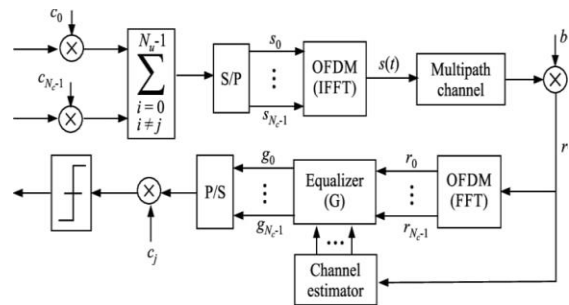


Fig:Single Carrier Frequency Division Multiple Access

7. Multicarrier code Division Multiple Access

MC-CDMA is another extension of OFDM that combines the principles of CDMA with OFDM to offer multiple access for several users within the same frequency band.

Key Characteristics:

MC-CDMA uses code sequences to distinguish between users while maintaining the advantages of multi-carrier modulation.

It provides a good balance of robustness against fading and efficient spectrum usage.

Applications: MC-CDMA is investigated for 5G for scenarios where multiple users need to share the same spectrum

efficiently, particularly in crowded environments.

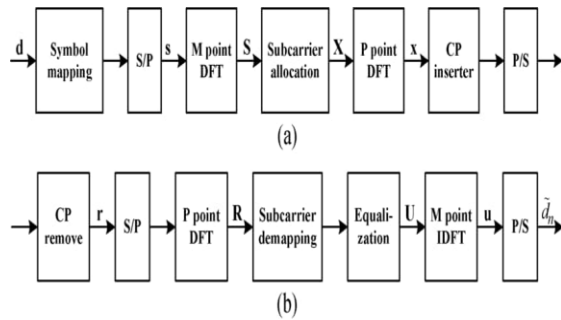


Fig: Multicarrier code Division Multiple Access

CONCLUSION:

In 5G technology, MIMO-OFDM (Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing) plays a critical role in achieving the high data rates, capacity, and reliability required by modern communication systems. MIMO leverages multiple antennas at both the transmitter and receiver to improve signal quality and spectrum efficiency, while OFDM divides the signal into multiple subcarriers to reduce interference and enhance data throughput. MIMO-OFDM is a foundational technology in 5G, providing the framework for high-speed, low-latency, and highly reliable communication.

These techniques are employed on downlink of LTE. A MIMO system utilizes numerous antennas at both the transmitter and receiver to work on the performance of the correspondence framework using diversity and multiplexing methods. MIMO framework gives higher phantom effectiveness,

further develops unwavering quality, decreases fading and further develops protection from interference.

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