IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Impact Factor: 7.53

Volume 4, Issue 3, February 2024

Key Enabling-Technologies of 4G and 5G Network

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Abstract: *This paper provides a comprehensive overview of Multiple Input Multiple Output (MIMO) technology and its pivotal role in enhancing 4G (LTE) networks. MIMO technology, characterized by the use of multiple antennas at both the transmitter and receiver, enables significant improvements in data rates, coverage, and spectral efficiency.*

The key functionalities of MIMO technology in 4G LTE networks are elucidated, including spatial multiplexing, improved signal quality through spatial diversity, increased coverage via transmit diversity, and enhanced spectral efficiency. MIMO technology enables increased throughput and supports bandwidth-intensive applications like file downloads and video streaming by broadcasting many data streams simultaneously over the same frequency range.

Furthermore, the adaptive nature of MIMO systems is discussed, highlighting their ability to dynamically adjust antenna configurations and employ adaptive beam forming techniques. These features optimize performance in real-time, maximizing signal strength, reducing interference, and enhancing overall network reliability.

In summary, this paper underscores the critical importance of MIMO technology in 4G LTE networks, showcasing its ability to deliver high-speed broadband services, improve coverage in challenging environments, and efficiently utilize the available spectrum. As the backbone of modern mobile communications, MIMO-enabled 4G networks provide users with seamless connectivity and support the growing demand for data-intensive applications.

Keywords: MIMO, LTE, OFDM, WIMAX, 4GTechnology, 5G Technology

I. INTRODUCTION

Wireless communication technology has been developed in subsequent years. Now it has become the most important mode of transmission of data. Due to increase in the use of internet and wireless media the new frequency band, modes and services associated with it have been increased significantly. Only voice calls were made over the analog first generation (1G) mobile wireless communication network. Digital technology supporting text messaging is known as second generation (2G). More capacity, faster data transmission rates, and support for interactive media were all offered by third-generation (3G) mobile technology. As a breakthrough in mobile technology, fourth generation (4G) surpasses 3G's constraints by combining 3G with fixed internet to support wireless mobile internet. Resources were purchased at a lower cost and with more bandwidth..

MIMO technology, which multiplexes signals between several transmitting antennas and time or frequency, is used in 4G technology. The new emerging technologies like WiMAX and LTE are stronger than Wi-Fi and have wider coverage. The different technologies used in 4G and 5G technology are OFDM, LTE, MIMO, and CDMA.

The term "fifth generation," or 5G, simply refers to the newest and next mobile wireless standard, which is based on the IEEE 802.11 ac standard of broadband technology, even if the technologies used in 5G are still being defined. Fifth generation (5G) is not viewed as an evolution of the current, as previous generations were, but rather as a revolution in cellular networks that builds upon the advancement of preexisting technologies.

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II. 4G NETWORK

How does 4G work?

MIMO and OFDM technologies enable 4G's transmission and reception capabilities. Compared to 3G, higher capacity and bandwidth are possible with both MIMO and OFDM. Compared to the two main technologies that drove 3G, TDMA and CDMA, OFDM offers faster speeds. When using MIMO,

Because more users can be supported by 4G than by 3G, there is less network congestion.

Improved 4G wireless technology has the following features:

- An increased and vast area of mobile coverage.
- Significant data rates and ample bandwidth.
- A quicker and more seamless handoff.
- WLAN, an addition to 2G and 3G, is used for hot spots.
- More effective scheduling methods.
- Multimedia, video, wireless Internet, voice, and a number of other broadband services are supported.
- Easily navigable

III. 5G NETWORK

5G networks are cellular networks with smaller geographic areas called cells within the service area. Every 5G wireless device in a cell uses fixed antennas to transmit radio waves over frequencies that are allotted by the base station to a cellular base station. Optical fiber links the base stations to switching centers in the phone network and routers for Internet access. When a mobile device switches from one cell to another, it is seamlessly transferred, just like in other cellular networks.

3.1 Benefits of moving to 5G

3.1.1. Reduced latency:

5G makes connections quicker and more responsive. Less than 1 millisecond is the target latency for 5G, which is far quicker than the 60–98 milliseconds that 4G allows..

3.1.2. Less congestion:

Less signal interference is another benefit of 5G over 4G. By dividing signals into distinct channels, OFDM technology is used by both 4G and 5G. More capacity, reduced congestion, and faster download speeds are made possible by 5G's channels, which range from 100 to 800 MHz compared to 4G's 20 MHz.

3.1.3. Power consumption:

Compared to 4G, 5G may use less energy on smartphones and other mobile devices, potentially resulting in longer battery life.

3.1.4. Greater Bandwidth:

The next advancement in mobile network technology is 5G. Increased bandwidth is promised, with peak rates reaching up to 20 Gbps, significantly faster than the 4G standard of 100 Mbps.

3.1.5. Massive connectivity:

The 5G network is home to a vast number of IOT devices.

The mobile broadband system will see an increase in traffic from these different devices.

IV. TECHNOLOGIES USED IN 4G AND 5G NETWORKS

To fulfill the demand of increasing need of wireless and cellular technologies the new technologies such as LTE, WIMAX, OFDM,etc comes into picture. These technologies are relatively stronger than Wi-Fi and CDMA. They have wider coverage area and strong QOS support.

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4.1 Long Term Evolution (LTE) and WIMAX

As an upgrade to the existing Universal Mobile Telecommunications System, the Third Generation Partnership Project (3GPP) has created Long Term Evolution (LTE) technology. 3.9G or Super 3G is another name for it. Wireless broadband is made possible by technologies like LTE and WIMAX. Both technologies are capable of supporting orthogonal frequency division multiplexing. Additionally, the technology supports frequency division duplex (FDD) and time division duplex (TDD). Two sub-frames comprise the TDD mode:

1. Sub-frame for uplink
2. The sub-frame for downlink

In downlink sub-frame the transmission is between BS i.e base stations to MS i.e mobile subscriber while in uplink the transmission is from MS to BS. In WiMAX network.

The base station (BS), AAA server, HA server, ASN gateway, and other components are defined for unique requirements. Likewise, a variety of components in LTE networks are also described, such as MME, HSS, Serving Gateway PDN Gateway, eNode B, and others.

4.2 WI-MAX Technology:

The IEEE and ETSI standards serve as the foundation for WiMAX.It's a wireless technology designed primarily to give users a faster broadband connection. The primary frequency range of this technology is 2-66 GHz.IEEE Wireless MAN air interface is another name for the 802.16 standard, which is the "Air Interface for Fixed Broadband Wireless Access Systems." With performance on par with regular cable, DSL, this technology is built from the ground up to offer wireless last-mile internet connectivity in the Metropolitan Area Network (MAN). Compared to contemporary technologies, wired connections from the past were more expensive and time-consuming.802.16. Wireless technologies offer an adaptable, economical, standards-based way to bridge current broadband coverage gaps and develop new broadband services that were not anticipated in a world without "wires."

4.2.1 Key features of WiMAX technology include:

Broad Coverage:
WiMAX can cover a broad area, typically several kilometers in radius, making it suitable for providing internet access to both urban and rural areas.

High Speeds:
It offers high-speed data transmission, theoretically up to 70 Mbps over a single channel. However, actual speeds may vary based on factors such as network congestion and signal quality.

Scalability:
WiMAX networks can be easily scaled to accommodate increasing numbers of users and higher data demands.

Quality of Service (QoS):
WiMAX supports QoS features, allowing service providers to prioritize traffic based on application requirements, ensuring reliable service for real-time applications like voice and video streaming.

Non-Line-of-Sight (NLOS) Capability:
Unlike some other wireless technologies, WiMAX can provide connectivity even in situations where there is no direct line of sight between the transmitter and receiver, making it suitable for urban environments with obstacles like buildings.

Backward Compatibility:
WiMAX networks are designed to be backward compatible with older technologies, allowing for smooth integration with existing infrastructure.

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Flexible Deployment Options:
WiMAX can be deployed in various configurations, including point-to-point, point-to-multipoint, and mesh networks, making it adaptable to different geographic and usage scenarios.

4.3 LTE Technology:
LTE technology is the modern communication application that make use of OFDMA for better transmission and reception of data.It is more flexible and efficient as the data is transmitted in the form of frames.This technology is adopted world-wide and is the foundation for many wireless communication technologies.

4.3.1 Key features of LTE technology includes:
High Data Rates:
LTE offers high data rates, with theoretical download speeds of up to 300 Mbps and upload speeds of up to 75 Mbps. These speeds enable a wide range of applications such as video streaming, online gaming, and large file downloads.

Low Latency:
LTE networks have low latency, which means data packets travel quickly between devices and the network. This low latency is crucial for real-time applications like voice and video calls, online gaming, and IoT applications.

Scalability:
LTE networks are highly scalable, allowing for increased capacity and data speeds to accommodate growing numbers of users and data traffic demands

Efficient Spectrum Utilization:
LTE technology employs advanced techniques such as Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple Input Multiple Output (MIMO) to efficiently utilize available spectrum, maximizing data throughput and network capacity.

Backward Compatibility:
LTE networks are designed to be backward compatible with existing 2G and 3G networks, allowing for a smooth transition for operators and users migrating from older technologies.

Flexible Deployment Options:
LTE networks can be deployed in various configurations, including microcells, small cells, and heterogeneous networks (HetNets), enabling operators to tailor network deployments to specific coverage and capacity requirements.

Voice over LTE (VoLTE):
LTE supports VoLTE, allowing voice calls to be made over LTE networks using packet-switched technology rather than traditional circuit-switched voice networks. VoLTE offers improved voice quality, faster call setup times, and the ability to use voice and data simultaneously.

Security:
LTE incorporates robust security features to protect user data and privacy, including encryption algorithms and authentication mechanisms.

4.4 Orthogonal Frequency Division Multiplexing (OFDM):
OFDM is the key technology used by the wireless communication technologies. It is used by LTE and WIMAX. The basic principle of this technology is that it divides the available spectrum into multiple orthogonal sub-carrier which carries the part of data.

OFDM uses:
1. Digital audio broadcasting, satellite radio, digital radio Mondale, and digital radio.
2. Digital video broadcasting and standards for digital televisionDVB-T/H (terrestrial/handheld), DVB-Cable 2 (DVB-C2).
3. Institute of Electrical and Electronics Engineers (IEEE) 1901 power line networking, cable internet providers, asymmetric digital subscriber line (ADSL), and wired data transmission
4. Data transfer via Wireless LAN (WLAN)

4.4.1 Why OFDM is used in 4G Technology?

Efficient Spectrum Utilization:

It allows efficient use of the available spectrum by dividing it into multiple narrowband subcarriers. These subcarriers are spaced apart at precise intervals to ensure they remain orthogonal i.e. they are independent of each other and minimizing interference between adjacent subcarriers.

Resistance to Multipath Fading:

Multipath fading occurs when signals travel via multiple paths and experience phase shifts, leading to signal distortion and degradation. OFDM is resilient to multipath fading because it uses a large number of closely spaced subcarriers. Even if some subcarriers experience fading, others remain unaffected, improving overall system reliability.

High Data Rates:

By dividing the spectrum into multiple subcarriers, OFDM enables parallel transmission of data , increasing the overall data rate. This allows 4G LTE networks to achieve high data rates suitable for bandwidth-intensive applications such as video streaming, online gaming, and large file downloads.

Flexibility in Channel Allocation:

It provides flexibility in allocating subcarriers to users based on their channel conditions and data requirements. Adaptive modulation and coding techniques can be applied to individual subcarriers, allowing the system to allocate more resources to users experiencing favorable channel conditions while conserving resources for users in poor channel conditions.

Guard Interval:

OFDM includes a guard interval between successive symbols to mitigate the effects of intersymbol interference (ISI) caused by multipath propagation. The guard interval ensures that delayed versions of the transmitted signal do not interfere with subsequent symbols, enhancing system robustness in challenging radio environments.

Support for MIMO:

Multiple Input Multiple Output (MIMO) technology, which uses multiple antennas for transmitting and receiving, is often combined with OFDM in 4G networks. MIMO exploits spatial diversity to improve signal quality, increase data rates, and enhance system capacity.

MIMO Technology:

Multiple Input Multiple Output (MIMO) technology is the another key technology used in 4G technology. It uses multiple transmitter and receivers communication. As multiple transceivers are used the data loss is reduced and the systems performance is enhanced.

4.4.2 Reasons for using MIMO in 4G network:

Spatial Multiplexing:

MIMO technology employs multiple antennas at both the transmitter and receiver to transmit multiple data streams simultaneously over the same frequency band. By exploiting the spatial dimension, MIMO enables spatial multiplexing, which increases the data rate without requiring additional spectrum. In 4G LTE, spatial multiplexing allows for higher throughput, supporting bandwidth-intensive applications such as video streaming and file downloads.

Improved Signal Quality:
MIMO technology enhances signal quality by exploiting spatial diversity. By transmitting redundant copies of data over multiple antennas, MIMO mitigates the effects of fading and multipath propagation. This improves the reliability and robustness of wireless communications, particularly in challenging environments with obstacles and interference.

Increased Coverage:
MIMO technology can also be used to improve coverage by exploiting transmit diversity. In this mode, multiple antennas transmit the same data stream simultaneously, but each with a different phase or amplitude. This redundancy helps overcome signal attenuation and extends the coverage area, particularly in areas with weak signal strength or signal blockages.

Enhanced Spectral Efficiency:
MIMO technology improves spectral efficiency by enabling more efficient use of the available frequency spectrum. By transmitting multiple data streams in parallel over the same frequency band, MIMO allows for higher data rates within the allocated bandwidth. This helps operators maximize the capacity of their networks and accommodate more users and data traffic demands.

Adaptive Beamforming:
MIMO systems can employ adaptive beamforming techniques to further enhance performance. Beamforming focuses radio signals in specific directions, increasing signal strength and reducing interference. Adaptive beamforming algorithms dynamically adjust the antenna beam patterns based on channel conditions, optimizing performance in real-time.

V. CHALLENGES

5.1 Challenges in 4g network

5.1.1 Managing channel quality

Controlling the quality of the channel On 4G wireless networks, OFDM would allow very high broadband rates; however, channel quality is what limits the data throughput rate on a given RF bandwidth channel, independent of channel structure and coding.In metropolitan areas—where most of us will be utilizing 4G services—the amount of interference from other users on the same RF channel usually has an impact on channel quality.
When a channel is used more frequently within a specific geographic area, interference levels rise. The main objective of network design and optimization is actually to manage user mutual interference inside a wireless network..

5.1.2 Individuals user throughput expectations

The shared resource nature of a wireless data channel is the second major obstacle for 4G. All concurrent users of the channel must share the throughput it provides. Although this aspect is frequently overlooked in talks about amazing 4G bandwidths, it is, in my opinion, the biggest unanswered question regarding the long-term prospects for 4G. The fact that normal Internet usage habits have evolved significantly over the past few years and are continuing changing quickly presents a significant challenge in differentiating between channel and individual throughput rates. Email and "Web surfing" were the most widely used Internet apps a while back, measured by total demand. Undoubtedly, high bandwidth improves these users' experience.

5.1.3 Crunch the Spectrum:

Restricted Spectrum: 4G networks may experience congestion due to a lack of spectrum, particularly in locations with high population densities.

Capacity and Data Rates:
Growing Demand: 4G networks are under pressure from the increasing demand for high-speed data services, which has an impact on data rates and capacity during periods of high usage.

Concerns about Latency:
Although 4G offers a lower latency than previous generations, some applications, such as augmented reality (AR) and virtual reality (VR), may still require an ultra-low latency.

5.2 Challenges in 5G network
5.2.1 Millimeter Wave Challenges:
Constrained Range: Because 5G uses shorter millimeter-wave frequencies, it may face obstacles like buildings and trees and requires the use of extra base stations.

5.2.2 Slicing complexity of networks:
Complicated deployment: The 5G feature known as "network slicing," which permits the establishment of several virtual networks on a single physical infrastructure, makes administration and deployment more difficult.

5.2.3 Allocation of Spectrum:
Regulatory Obstacles: Effective spectrum management and allocation for 5G rollout may encounter obstacles related to international coordination and regulations.

5.2.4 Expense of Implementation:
Initial Investment: Telecom operators may need to make large initial expenditures due to the potentially high costs associated with developing 5G infrastructure.

5.2.5 Infrastructure Implementation:
High Density of Small Cells: 5G depends on a higher density of small cells, which can be logistically difficult to implement and necessitates additional infrastructure and careful urban design.

5.2.6 Security Issues:
New Attack Vectors: For strong security, it is necessary to handle the possible new attack vectors brought about by the integration of new technologies in 5G, such as network slicing and edge computing.

VI. APPLICATIONS

6.1 Applications of 4G:
6.1.1 Mobile Internet Browsing:
Faster data speeds enable smoother and quicker web browsing experiences on mobile devices.

6.1.2 Video Streaming:
High-quality video streaming on platforms like YouTube, Netflix, and other video services is made possible by the increased bandwidth of 4G networks.

6.1.3 Online Gaming:
Multiplayer online gaming benefits from reduced latency and improved data transfer rates, providing a more seamless and responsive gaming experience.

6.1.4 Video Calls and Conferencing:
Applications like Skype, Zoom, and FaceTime benefit from 4G connectivity, offering high-quality video calls and conferences with minimal lag.

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6.1.5 Social Media:
Social media platforms, such as Facebook, Instagram, and Twitter, benefit from faster data speeds, enabling users to upload and download media content more efficiently.

6.1.6 Mobile Apps:
Various mobile applications, including productivity apps, navigation apps, and news apps, operate more smoothly and respond faster with the increased bandwidth provided by 4G networks.

6.1.7 File Sharing:
Faster upload and download speeds facilitate efficient file sharing through cloud storage services and peer-to-peer applications.

6.1.8 Navigation and Maps:
GPS-based navigation apps, like Google Maps and Waze, provide real-time updates and accurate navigation due to the improved connectivity and data speeds.

6.2 Applications of 5G:
6.2.1 Augmented Reality (AR) and Virtual Reality (VR):
5G enables more immersive AR and VR experiences with reduced latency, allowing for real-time interactions and enhanced virtual environments

6.2.2 Ultra HD and 4K Video Streaming:
With significantly higher data speeds, 5G supports the streaming of high-resolution content, including 4K and even 8K videos, without buffering delays.

6.2.3 Internet of Things (IoT) at Scale:
5G provides the connectivity required for a massive number of IoT devices, allowing for smart cities, industrial IoT, and a wide range of interconnected devices.

6.2.4 Smart Cities:
5G facilitates the deployment of smart city technologies, including smart grids, intelligent transportation systems, and connected infrastructure for improved efficiency and sustainability.

6.2.5 Autonomous Vehicles:
The low latency of 5G is crucial for real-time communication in autonomous vehicles, enabling faster response times and enhancing safety on the roads.

6.2.6 Remote Surgery and Telemedicine:
High-speed, low-latency 5G connections support advanced telemedicine applications, including remote surgery and real-time monitoring of patients.

6.2.7 Industry 4.0 and Smart Manufacturing:
5G enables the deployment of smart manufacturing processes, including robotics, automation, and real-time monitoring of equipment and production lines.

6.2.8 Gaming and Cloud Gaming:
5G provides the necessary speeds and low latency for cloud gaming services, allowing users to play high-quality games without the need for powerful local hardware.

VII. CONCLUSION

This paper presents a brief description of 4G and 5G network. The different technologies used for these network have high coverage and capacity. In the world which is developing and going wireless these technologies are important. Many advance technologies than LTE and Wi- Fi are also emerging and adding importance to these networks.

LTE, OFDM, MIMO and CDMA technology are used by cellular networks. It has been observed that the number of wireless broadband subscribers have passed the number of fixed broadband subscribers. So these technologies have boosted in the recent years.

ACKNOWLEDGMENT

We would like to express our sincere gratitude to our project guide Dr. Mrs. Sheetal Borde for their valuable guidance and support throughout the course of this project. Their expertise, patience, and encouragement were essential to the successful completion of this work. We would also like to thank the Head of Department Dr. Mrs. Rupali Kamthe for their support and encouragement. Their willingness to provide us with the resources and time necessary to complete this project is greatly appreciated. We are also thankful to our Principal Dr. Mrs. K.R.Joshi for providing such amazing opportunities. We would like to thank our project coordinators Mrs. Manasi Kanitkar and Mr. Ram Gopal Sahu for their assistance with the logistical aspects of this project. Their help in scheduling meetings, organizing resources, and ensuring that the project stayed on track was invaluable. Finally, appreciate and thank you to all the team members for their hard work and dedication. Their contributions to this project were essential to its success.

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