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REVIEW OF 4G AND 5G WIRELESS COMMUNICATION SYSTEM WITH DIFFERENT TECHNOLOGIES

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***Abstract*—** Wireless communication systems refer to the technology and infrastructure used to transmit information. 4G and 5G wireless communication systems have revolutionized the way we connect, communicate, and utilize mobile data. While 4G offers substantial improvements over previous generations, 5G takes connectivity to new heights with ultra-fast speeds, low latency, massive device connectivity, and support for emerging technologies. These advancements pave the way for transformative applications and innovations across various sectors, driving the evolution of the digital ecosystem. The paper presents the review of 4G and 5G Wireless Communication System using MIMO, Beamforming, and Non-orthogonal Multiple Access (NOMA) Technologies" provides an in-depth evaluation and analysis of the application of multiple technologies in 4G and 5G wireless communication systems. Specifically, the study focuses on the utilization of MIMO, Beamforming, and NOMA techniques. This review aims to assess the strengths, weaknesses, and overall contributions of the research.

Keywords*—MIMO, NOMA, 4G, 5G, Beamforming.*

I. INTRODUCTION

4G and 5G wireless communication systems are the latest generations of cellular network technologies that provide enhanced connectivity, data transmission, and communication capabilities. They offer significant improvements over their predecessors, enabling faster data rates, lower latency, increased capacity, and support for a wide range of applications and devices.

4G Wireless Communication System: 4G, also known as LTE (Long-Term Evolution), represents the fourth generation of wireless communication systems. It introduced several key features and advancements, including:

- Higher Data Rates: 4G networks provide significantly faster data rates compared to previous generations, enabling high-quality streaming, video conferencing, and faster downloads/uploads.
- Improved Capacity: 4G networks offer increased capacity to handle a larger number of users and devices simultaneously, leading to improved network performance and reduced congestion.
- Lower Latency: 4G networks reduce latency, resulting in quicker response times for real-time applications and improved user experience.
- Multimedia Support: 4G supports multimedia applications with enhanced quality, enabling seamless video streaming, online gaming, and other bandwidth-intensive services.
- IP-Based Architecture: 4G is based on an all-IP (Internet Protocol) architecture, enabling seamless integration with existing internet services and facilitating the convergence of communication and data networks.

5G Wireless Communication System: 5G represents the fifth generation of wireless communication systems, offering even greater advancements and capabilities compared to 4G. Key features and enhancements of 5G include:

- Ultra-Fast Data Rates: 5G networks provide extremely high data rates, reaching multi-gigabit speeds, which enable lightning-fast downloads, real-time streaming, and bandwidth-intensive applications.

- Ultra-Low Latency: 5G significantly reduces latency to mere milliseconds, enabling real-time communication, instantaneous response for mission-critical applications, and improved user experiences for emerging technologies like augmented reality (AR) and virtual reality (VR).
- Massive Device Connectivity: 5G supports a massive number of connected devices simultaneously, catering to the requirements of the Internet of Things (IoT) ecosystem. This allows for seamless connectivity and communication between devices, enabling smart homes, smart cities, and various industrial applications.
- Network Slicing: 5G introduces the concept of network slicing, which allows network resources to be dynamically allocated and optimized for different use cases, ensuring tailored connectivity and performance for specific applications or industries.
- Beamforming and Massive MIMO: 5G utilizes advanced antenna technologies such as beamforming and massive MIMO (Multiple-Input Multiple-Output), which enhance signal quality, coverage, and capacity. These technologies enable more efficient spectrum utilization and improved network performance.
- Edge Computing: 5G networks integrate edge computing capabilities, bringing computing resources closer to the network edge. This enables low-latency processing and real-time data analysis, facilitating applications that require immediate decision-making and reduced reliance on centralized cloud infrastructure.
- Enhanced Security: 5G incorporates advanced security measures to protect against potential threats, ensuring secure communication and safeguarding sensitive data.

II. LITERATURE SURVEY

W. Li et al.,[1] achieve accurate vehicle location without significantly impacting communication capacity. We outline the method for selecting ranging subcarriers and describe the format of the ranging frame carried by these subcarriers. To evaluate the effectiveness of our system, we prove the Cramér-Rao lower bound of this ranging positioning system. The obtained ranging positioning accuracy meets the requirements for vehicle location applications. In our experimental simulations, we compare the performance of our system with other positioning methods, demonstrating its superiority. Additionally, we provide theoretical proofs and simulations that establish the relationship between ranging accuracy and channel parameters in a multipath environment.

H. Al-Obiedollah et al.,[2] Intelligent reflecting surface (IRS) has been recently integrated with emerging communication technologies to meet the demanding requirements of communication systems. This paper investigates the deployment of multi-IRS units in a hybrid time-domain multiple access (TDMA) and non-orthogonal multiple access (NOMA) system, referred to as a multi-IRS-aided hybrid TDMA-NOMA system. In particular, a self-sustainable scenario is proposed, in which the IRS units can harvest energy from the radio frequency signal to feed them-self with the required energy. With this self-sustainable IRS-aided hybrid TDMA-NOMA system, the available time is fragmented into a set of time slots, in which an IRS unit is assigned to serve a cluster of users during each time slot. Meanwhile, the remaining unassigned (i.e., idle) IRS units harvest energy to feed themselves with the required energy, which addresses the energy limitation challenge related to conventional communication systems. Specifically, we propose an efficient algorithm to group the users in clusters and, thus, assign an appropriate IRS unit for each cluster.

H. Choi et al.,[3] WiThRay simulator modifies the RT algorithm to follow the Fermat’s principle, thus, reducing computational complexity, and implements scattering ray calibration providing a precise solution for the analysis of EM propagation. In addition, differently from most of the available RT-based simulators, WiThRay incorporates reconfigurable intelligent surfaces (RISs), which are lately considered as the key technology for RIS-enabled smart wireless communications. We thoroughly show that channel data obtained from WiThRay match sufficiently well with the fundamental EM propagation theory of wireless channels. Furthermore, the proposed simulator was

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deployed to study the performance of uplink channel estimation in orthogonal frequency-division multiplexing systems, downlink multi-user beamforming, and RIS-enabled coverage extension.
M. R. Mahmood et al.,[4] Massive multiple-input multiple-output (mMIMO), assisted by reconfigurable intelligent surface (RIS), can ensure reliable and energy-efficient data transmission. However, the receiver design for large-scale networks based on traditional mathematical approaches requires complex statistics. Therefore, in this paper, machine learning (ML) approaches are investigated to design receivers for the RIS-assisted multi-user MIMO (muMIMO) systems to avoid complicated channel information requirements. Extreme learning machine (ELM) is an effective ML tool for MIMO receiver design because it simplifies the learning process. However, the learning performance of the ELM can get affected by the random choice of its hidden layer size. To address these issues, this paper proposes an incremental ELM (I-ELM) based receiver for the RIS-mu-MIMO system. The proposed receiver computes the weights between the hidden and the output layer based on the automated incremental addition of hidden neurons and provided conditions.
A. S. Rajasekaran et al.,[5] presented a computationally efficient two-stage machine learning based approach using neural networks to solve the cluster assignment problem in a millimeter wave-non orthogonal multiple access (mmWave-NOMA) system where each user's individual successive interference cancellation (SIC) decoding capabilities are taken into consideration. The artificial neural network (ANN) is applied in real time to assign users to clusters taking each user's instantaneous channel state information (CSI) and SIC decoding capabilities as inputs. The algorithm is trained offline on cloud resources, i.e., not using the base station (BS) compute resources. This training is done using a dataset obtained by offline computation of input parameters using the optimization algorithms called NOMA-minimum exact cover (NOMA-MEC) and NOMA-best beam (NOMA-BB) from our earlier work in this area.
L. Pang et al.,[6] presented and compares three channel models for the fifth generation (5G) wireless communications: the quasi deterministic radio channel generator (QuaDRiGa), the NYUSIM channel simulator model developed by New York University, and the more general 5G (MG5G) channel model. First, the characteristics of the modeling processes of the three models are introduced from the perspective of model framework. Then, the small-scale parameter modeling strategies of the three models are compared from space/time/frequency domains as well as polarization aspect.
X. Han et al.,[7] A new framework for CLI management is illustrated along with enhancements for interference identification, spatial domain interference coordination and power domain adjustment. To validate the feasibility and performance of the proposed SBFD methods under indoor and dense urban scenarios, system-level simulations (SLSs) are carried out and a proof-of-concept (PoC) is developed for the purpose of obtaining experimental results.
M. Beshley et al.,[8] Energy-efficient Radio Resource Management (RRM) for 5G and beyond networks has become a key research challenge due to increasing Small Cells (SCs) densities and the high Quality of Experience (QoE) requirements of business users. Ensuring QoE and energy efficiency is essential in mobile networks, but these goals are often opposing and rarely addressed simultaneously in existing solutions. In this paper, we propose to include the QoE criterion in the RRM technique for 5G and beyond multi-layer networks, which will allow ordering individual QoE for business users. We developed a new radio resource allocation and optimization method to address changing user QoE requirements and reduce energy consumption in multi-layer 5G networks. The proposed method differs from the known ones in that it considers the QoE requirements of business users and load localization to optimally distribute the service process between Macro Cells (MCs) and SCs. This method uses a Voronoi diagram to energy-efficiently design the 5G Radio Access Network (RAN) by switching SCs to sleep mode when they are not serving active users.
I. M. Al-Musawi et al.,[9] The former design adopts joint maximum Likelihood (ML) signal detection while the later scenarios utilize integrated receiver designs based on successive interference cancellation (SIC) and ML techniques. For the proposed sNOMA schemes, power control algorithms

are presented to optimize the system performance over constrained total received power and target error rate. Numerical results validate the effectiveness of sNOMA designs compared with the benchmark systems under the worst-case secrecy of unauthorized receiver with complete knowledge of the transmission scheme and associated channel. Valuable tradeoffs are demonstrated between the achieved error rate, connectivity, security gap, and complexity.

M. Rahmani et al.,[10] utilize a learning-based approach to handle the pilot contamination problem by formulating PA as a multi-agent static game, developing a two-level hierarchical learning algorithm to mitigate the effects of pilot contamination, and presenting an efficient yet scalable PA strategy. We first model a PA problem as a static multi-agent game with P teams (agents), in which each team is represented by a specific pilot. We then define a multi-agent structure that can automatically determine the most appropriate PA policy in a distributed manner. The numerical results demonstrate that the proposed PA algorithm outperforms previous suboptimal algorithms in terms of the per-user spectral efficiency (SE).

J. Ghosh et al.,[11] presented power constraint optimization scheme harmonizes conventional total power constraint (TPC) and uniform power constraint (UPC) schemes into a new one called allied power constraint (APC) that can significantly improve the system performance in 5G networks while achieving fairness among users. TPC and UPC have major drawbacks with respect to fairness and achieving quality-of-service (QoS) for users in dense networks. Thus APC aims to harmonize TPC and UPC by adjusting each antenna element’s constraint to adapt for some power resilience to a specific antenna element, hence proposing an intermediate solution between the two extreme case power constraint optimization schemes. Three optimal beam tracking schemes: (i) conventional exhaustive search (CES), (ii) multiobjective joint optimization codebook (MJOC), and (iii) linear hybrid combiner (LHS) scheme, have been provided for the mobile mmWave massive MIMO system with the proposed APC scheme. For the proposed APC scheme a comprehensive performance analysis is provided and compared with TPC and UPC. Spectral efficiency (SE), bit-error-rate (BER), Jain’s fairness index, channel occupancy ratio (COR) and instantaneous interfering power metrics are investigated. It has been shown that the proposed scheme can significantly outperform conventional schemes.

M. Dash et al.,[12] Multiple input multiple output (MIMO) based orthogonal frequency division multiplexing (OFDM) has widely been used in a wireless communications system for its robustness to frequency-selective channels and better spectral efficiency. The introduction of full-duplex (FD) and device-to-device (D2D) communications, which are potential candidates of fifth-generation (5G) and beyond, further improve the spectral efficiency of MIMO-OFDM based systems. This paper proposes a novel MIMO-OFDM based FD Cooperative-D2D (C-D2D) communications system wherein a cellular user (CU) acts as an FD relay to facilitate seamless communications between D2D transmitter and receiver.

A. Nauman et al.,[13] The 5G and beyond-5G (B5G) is expected to be a key enabler for Internet-of-Everything (IoE). The narrowband Internet of Things (NB-IoT) is a low-power wide-area enabling technology introduced by the 3rd Generation Partnership in 5G. The objective of the NB-IoT is to enhance the mobile coverage area by increasing the number of repetitions of control and data packets between user equipment (UE) and the base station/evolved NodeB (BS/eNB). While these repetitions improve data delivery for delay-sensitive applications, they degrade the efficiency of the already resource-constrained IoT system by increasing the system overhead and energy consumption. Moreover, NB-IoT devices in the edge region of the cellular coverage area require more repetitions, which augment energy consumption.

Y. He et al.,[14] presented the integration of D2D and V2X communication from the perspective of SDN. The state-of-the-art and architectures of D2D-V2X were discussed. The similarity, characteristics, routing control, location management, patch scheduling and recovery is described. The integrated architecture reviewed in this paper can solve the problems of routing management,

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interference management and mobile management. It also overcome the disconnection problem between the D2D-V2X in terms of SDN and provides some effective solutions.

III. VARIOUS TECHNIQUES

4G and 5G wireless communication success is depends on the various technology-

Multiple-Input Multiple-Output (MIMO)

MIMO technology plays a significant role in both 4G and 5G wireless communication systems, contributing to their improved performance and capacity. Here's how MIMO is utilized in 4G and 5G:

1. MIMO in 4G (LTE): LTE networks employ MIMO technology to enhance the data rates and spectral efficiency. In 4G LTE, MIMO is typically implemented using two or four transmit and receive antennas, referred to as 2x2 MIMO or 4x4 MIMO, respectively.

a. Spatial Multiplexing: LTE utilizes spatial multiplexing to transmit multiple independent data streams simultaneously using different antennas. This allows for higher data rates and improved spectral efficiency.

b. Beamforming: MIMO in LTE supports beamforming techniques, such as Transmit Beamforming (TxBF) and Receive Beamforming (RxBF), to enhance the signal strength, coverage, and capacity. Beamforming optimizes the signal transmission and reception in the direction of the intended user, improving the overall link quality.

c. Diversity Gain: MIMO provides diversity gain in LTE to combat fading and improve link reliability. By transmitting redundant copies of the same data over multiple antennas, the receiver can combine the received signals, mitigating the effects of fading and improving the quality of the wireless link.

2. MIMO in 5G: MIMO technology has been further enhanced and expanded in 5G networks to meet the increased demands for higher data rates, lower latency, and massive device connectivity. 5G employs advanced MIMO configurations, including massive MIMO, to achieve these objectives.

a. Massive MIMO: 5G networks embrace massive MIMO, where base stations are equipped with a large number of antennas, often ranging from dozens to hundreds. Massive MIMO offers significant gains in capacity, coverage, and interference management.

b. Spatial Multiplexing and Beamforming: 5G utilizes advanced spatial multiplexing and beamforming techniques to maximize the spectral efficiency and enhance the overall network performance. The large number of antennas in massive MIMO systems enables the transmission of numerous independent data streams, improving the data rates and capacity.

c. Beam Management: 5G employs advanced beam management techniques, such as beam tracking and beam switching, to ensure reliable and seamless connectivity as users move within the network coverage. These techniques leverage the MIMO capabilities to track and optimize the beams for improved performance.

d. Multi-User MIMO (MU-MIMO): 5G supports MU-MIMO, enabling simultaneous communication with multiple users, thereby increasing capacity and spectral efficiency. MU-MIMO technology allows the base station to serve multiple users in the same time-frequency resource by forming independent beams towards each user.

MIMO technology, with its spatial multiplexing, beamforming, and diversity gain capabilities, plays a crucial role in enhancing the performance, capacity, and reliability of both 4G LTE and 5G wireless communication systems. Its adoption in 5G, particularly through massive MIMO, significantly contributes to the transformative capabilities of the next-generation networks.

Beamforming

Beamforming is an important technique employed in both 4G and 5G wireless communication systems to enhance the performance and efficiency of the wireless links. While there are similarities in the basic principles of beamforming in 4G and 5G, there are also some differences due to the advancements and capabilities introduced in 5G networks.

1. Beamforming in 4G (LTE): In 4G LTE networks, beamforming techniques are primarily implemented at the base station (eNodeB) to optimize the transmission towards the intended user. Here's how beamforming is utilized in 4G:

a. Downlink Beamforming: LTE employs downlink beamforming, also known as Transmit Beamforming (TxBF), to enhance the signal strength and coverage for individual users. The base station utilizes multiple antennas to transmit focused beams towards the desired user, improving the received signal quality and mitigating interference.

b. Channel State Information (CSI): To achieve effective beamforming, the base station requires accurate Channel State Information (CSI) about the wireless channel conditions. CSI feedback from the user equipment (UE) is used to estimate the channel characteristics, enabling the base station to adapt and optimize the beamforming accordingly.

c. Precoding: Precoding techniques are used in 4G beamforming to optimize the transmit signal at the base station. Precoding algorithms utilize the CSI feedback to determine the appropriate precoding matrix, which applies specific weights to the signals transmitted from different antennas to maximize the desired signal power at the user's location.

2. Beamforming in 5G: Beamforming techniques in 5G networks are further advanced compared to 4G, leveraging the capabilities of massive MIMO and improved beam management. Here's how beamforming is utilized in 5G:

a. Massive MIMO Beamforming: 5G networks deploy massive MIMO, where base stations are equipped with a large number of antennas. This enables advanced beamforming techniques to form highly focused beams towards specific users or groups of users. Massive MIMO enables precise spatial filtering, improving signal quality and reducing interference.

b. Beam Tracking and Switching: 5G introduces dynamic beam management techniques to track and optimize the beams as users move within the network coverage. Beam tracking continuously adjusts the beam direction based on the user's location, ensuring reliable and uninterrupted connectivity. Beam switching enables seamless handover between adjacent beams or base stations, maintaining high-quality communication.

c. Hybrid Beamforming: 5G utilizes hybrid beamforming, which combines analog and digital beamforming techniques. Analog beamforming is performed at the radio frequency (RF) level, while digital beamforming is applied at the baseband level. Hybrid beamforming enables efficient beamforming with reduced complexity and power consumption, particularly in massive MIMO systems.

d. Multi-User Beamforming: 5G networks support multi-user beamforming, allowing the base station to form independent beams towards multiple users simultaneously. This enables efficient spectrum utilization and increases the capacity of the network.

Beamforming in 4G and 5G networks improves signal quality, coverage, and capacity by focusing transmission in specific directions and adapting to channel conditions. While 4G LTE primarily utilizes downlink beamforming, 5G takes advantage of advanced techniques like massive MIMO, beam tracking, and hybrid beamforming to further enhance the performance and capabilities of wireless communication systems.

Non-Orthogonal Multiple Access (NOMA)

NOMA is a technique used in both 4G and 5G wireless communication systems to enhance spectral efficiency and increase the number of users supported in a given frequency resource. NOMA allows multiple users to share the same time-frequency resource by allocating different power levels or codebooks to individual users. While NOMA has gained significant attention in 5G, it has also been studied and applied to some extent in 4G systems.

1. NOMA in 4G (LTE): In 4G LTE networks, NOMA has been explored as a means to increase the system capacity and improve the overall spectral efficiency. Here's how NOMA is used in 4G:

a. Power Domain NOMA: In power domain NOMA, different power levels are allocated to users sharing the same time-frequency resource. Users with good channel conditions are allocated higher power levels, while users with poorer channel conditions are assigned lower power levels. This allows for simultaneous transmission and reception at the base station, enabling multiple users to share the same resource.

b. Successive Interference Cancellation (SIC): SIC is an essential component of NOMA in 4G. At the receiver, users with higher power levels are decoded first, and their signals are subtracted from the received signal to mitigate interference. This process is repeated successively until all users' signals are recovered.

2. NOMA in 5G: NOMA has gained increased attention and adoption in 5G networks due to its potential to improve spectral efficiency and support massive connectivity. In 5G, NOMA techniques are further advanced and integrated into the system design. Here's how NOMA is utilized in 5G:

a. Multi-User Shared Access (MUSA): MUSA is a NOMA-based scheme introduced in 5G that allows multiple users to share the same time-frequency resource. Users are separated in the power domain, enabling simultaneous transmission and reception. MUSA offers higher spectral efficiency and supports a large number of connected devices.

b. Dynamic Clustering: In 5G, NOMA is often combined with dynamic clustering, where users with similar channel conditions are grouped together. Each cluster is assigned a different power level or codebook, allowing users within the same cluster to share the same resource. Dynamic clustering optimizes resource allocation based on the users' channel conditions, further improving the overall system performance.

c. Enhanced SIC: 5G enhances the SIC process used in NOMA to handle interference and decode multiple user signals. Advanced receiver techniques, such as successive cancellation list decoding or parallel interference cancellation, are employed to mitigate interference and efficiently decode user signals.

d. Non-Orthogonal Multiple Access Modulation (NOMA-M): NOMA-M is a modulation scheme introduced in 5G, specifically designed for NOMA transmission. It enables multiple users to share the same resource using different modulation schemes and power levels, enhancing the system capacity and spectral efficiency.

NOMA in 4G and 5G wireless communication systems improves spectral efficiency, enables more users to share the same resource, and enhances the overall system capacity. While NOMA was primarily explored in power domain in 4G, it has been further advanced and integrated into the design of 5G networks, utilizing techniques such as dynamic clustering, enhanced SIC, and NOMA-specific modulation schemes.

IV. CONCLUSION

The MIMO, beamforming, and non-orthogonal multiple access (NOMA) technologies in 4G and 5G wireless networks has revolutionized the way we connect, communicate, and utilize wireless data. MIMO technology, with its use of multiple antennas, has enabled higher data rates, improved link reliability, and enhanced spectral efficiency in both 4G and 5G networks. It leverages spatial multiplexing and diversity gain to transmit multiple data streams simultaneously and combat fading effects. Additionally, beamforming techniques have been instrumental in optimizing signal transmission, improving coverage, and increasing network capacity. By focusing signals in specific directions, beamforming enhances the overall system performance and user experience. Furthermore, NOMA has emerged as a promising technology for maximizing spectral efficiency and supporting a large number of connected devices in both 4G and 5G networks. By allowing multiple users to share the same time-frequency resource through power domain allocation or dynamic clustering, NOMA significantly increases system capacity and improves resource utilization. However, challenges such as infrastructure deployment, spectrum allocation, network coverage, security, and cost remain important considerations in the widespread implementation of these technologies. Addressing these challenges requires ongoing research, industry collaboration, and regulatory support to ensure the efficient and secure deployment of MIMO, beamforming, and NOMA in future wireless networks.

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