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ENHANCEMENT OF CODE DIVISION MULTIPLE ACCESS (CDMA) WITHIN THE GSM SYSTEM IN IRAQ

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ABSTRACT

Despite the widespread adoption of Global System for Mobile Communications (GSM) in Iraq, the network's capacity and performance limitations have become increasingly apparent, particularly in urban areas with high user density. Currently, LTE (4G) is the dominant mobile technology in Iraq, provides faster data speeds, improved coverage, and enhanced features compared to CDMA. GSM network has still function in rural areas with low population density using GSM infrastructure as Time Division Multiple Access (TDMA), and Frequency Division Multiple Access (FDMA). This paper explores the potential of Code Division Multiple Access (CDMA) technology to enhance the GSM system in Iraq instead of TDMA, and FDMA, addressing issues such as limited capacity, interference, and inefficient spectrum utilization. This study conducted a comprehensive simulation of a GSM network integrated with CDMA technology using a state-of-the-art network simulator. The simulation was designed to evaluate the performance of the enhanced system under various traffic loads, channel conditions, and interference scenarios. The integration involved the allocation of specific frequency bands for CDMA operation, the implementation of CDMA spreading codes, and the optimization of power control mechanisms. CDMA is particularly well-suited for the GSM system in Iraq due to its inherent advantages in handling interference and managing spectrum efficiently. Unlike TDMA, FDMA, which are primarily used in GSM in Iraq, CDMA spreads the signal across a wide frequency band, making it more resilient to interference. This characteristic is especially beneficial in Iraq, where the spectrum is congested and interference levels are high. Additionally, CDMA's ability to dynamically allocate resources based on user demand ensures efficient spectrum utilization and improved capacity. The simulation results demonstrate that the integration of CDMA into the GSM system in Iraq can significantly enhance network capacity, reduce interference, and improve overall performance. The enhanced system is

capable of handling higher traffic volumes, providing better quality of service for users, and supporting emerging applications that demand high data rates and low latency.

KEYWORDS

CDMA, GSM, FDMA, OFDMA, TDMA, LTE, Cellular, IF, PSK, PCM, 1G, 2G, 3G,4G, 5G, telecom.

1. INTRODUCTION

Mobile communication networks have developed through ever-higher generations, each offering more speed, capacity, and features than the last (Yrjölä et al., 2023). The first commercial mobile networks used what is now known as GSM, which emerged in the early 1990s (Jiang and Han, 2024). These to meet modern trends in ever-increasing demand for higher data rates and more varied services have limitations in evolving needs for GSM (MPIRICAL, 2024). Code Division Multiple Access (CDMA) emerged as the solution to all the limitations GSM had. Advantages of CDMA over others include better spectrum efficiency, interference immunity, and the possibility of serving multiple users at the same time (Lee, 1998). GSM using CDMA is to be considered as a legacy before the high technology of 4G LTE and 5G. While it was very popular some years ago, it has been mostly replaced by these later standards because they have more capabilities higher data rates and more features. While CDMA has been adopted in many regions, its adoption in Iraq rural area by the GSM system has not thoroughly investigated (Rappaport, 2024). Integration of CDMA techniques into GSM enhances the efficiency of the spectrum as well as the data capacity of the system and makes it easier to move to LTE and 5G. The spread-spectrum technology used with CDMA supplements time division in GSM, realizing higher data rates and better network performance— which further LTE and 5G perfect with ultra-fast, low-lay communication. It was only the growing demands of modern users that, such as Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), have struggled to meet the increasing demands of modern users (Andrew, 1995). This paper investigates the possibility and advantages of adopting CDMA in the existing GSM network in Iraq, as a replacement for TDMA and FDMA. In this paper, we shall discuss the technical challenges and opportunities of the transition and enhancements that can be made in the network performance, capacity, and user experience In other words, CDMA is the most attractive alternative to both TDMA and FDMA since it can deliver added capacity, improved resistance to interference, and higher data rates (Alkasim and Soar, 2021). This paper investigates the potential benefits that could accrue from evolving Iraq's GSM system to incorporate CDMA technology. The underlying principle is the hybridization of GSM and CDMA to exploit the inherent strengths of both in enhancing performance, capacity, and good quality of service. The primary thrust of this research is an investigation into the practicability and potential benefits of adopting CDMA technology on the existing GSM infrastructure in Iraq. I limited to the specific challenges and opportunities that arise due to the prevailing conditions in the country's circumstances. Several other studies have been done on different regions regarding the implementation of CDMA with GSM networks (ITU, 2011).

Certainly, these have addressed different dimensions of planning frequency, power control, and interoperability. However, the peculiar context of Iraq due to its particular geography, demography, and technology parameters warrants just analyses and solutions that are tailored. Even the population in Iraq is able to fully enjoy 4G LTE coverage. It will vary from country to country, but in most countries, it is only the urban areas and some peri-urban areas that have 4G support, whilst large parts of the rural regions will remain on 3G. CDMA system integration Not an easy move for the Iraqi GSM system, which is currently one of the most active in the region. This has both challenges with opportunities. On one side, the already in-place GSM infrastructure and user base shall need a big transformation to embrace CDMA technology. But on the other hand, from the technical point of view, CDMA's potential to improve spectrum efficiency, enhance capacity, and provide advanced features can offer significant benefits. By addressing the challenges and capitalizing on the opportunities, this research aims to provide valuable insights into the feasibility and potential advantages of enhancing the GSM system in Iraqi rural area with CDMA technology.

2. PURPOSE OF STUDY

This study is to consider the possibility of deploying CDMA in Iraq's GSM network as an enhancement for capacity, interference reduction, better spectrum utilization, and most of all user satisfaction, and comparison with LTE techniques using new simulation model. The paper will seek to address the limitations of TDMA and FDMA. Providing valuable insights for network development and optimization in Iraq.

3. LITERATURE REVIEW

The best technologies help in integrating one of their best features with the CDMA in Iraq, as this is key in supporting higher data rates great spectral efficiency and when this brings added value significant implemented convergences system with existing already e- mobile which is platform of GSM in Iraq (Chen and Prasad, 1996). The evolution of mobile communication networks has witnessed a significant shift from traditional multiple access technologies like TDMA and FDMA to more advanced techniques such as CDMA. While GSM networks have been widely adopted in Iraq, the limitations of TDMA and FDMA have become increasingly apparent, particularly in urban areas with high traffic volume (Kim and Lee, 2018). Al-Saffar and Al-Saffar (2015) studied the compatibility of CDMA into the Iraqi GSM network with performance metrics of interference and quality of service. Hussein and Al-Ani (2018) studied optimization techniques of CDMA-based GSM networks in Iraq with power control, frequency planning, and cell sectorization. Al-Tamimi and Al-Zubaidi (2020) a study that compared various interference mitigation techniques between CDMA and GSM networks. It focuses on how effective inter-cell interference is and overall performance. Al-Shami, and Al-Hassani (2022) the simulation-based assessment of the possible quality enhancements in GSM networks due to amalgamation with CDMA under various traffic scenarios and channel conditions. Al-Khafaji and Al-Saidi (2023) presented the results of a field study in Iraq on assessing actual performance benefits of GSM network with CDMA integration in terms of user satisfaction and network metrics. New technological research in the Middle East has generally lagged behind, Including Iraq (Shehadi, 2021). There should be studies to check the long-term effect of integrating CDMA into the Iraqi telecommunications sector on a broad basis— impact on competition, market dynamics, and overall industry growth. Stakeholders lack country-specific, comprehensive cost-benefit analyses to enable them to make informed decisions regarding the adoption of CDMA in Iraq (Communications and Media Commission (CMC) Iraq, 2018). The literature reviewed highlights the potential benefits of integrating CDMA into the GSM system in Iraq. By leveraging CDMA's superior interference resistance, efficient spectrum utilization, and capacity enhancements, it is possible to improve network performance, increase user satisfaction, and support the growing demand for mobile services in the country. Further research and practical implementation are essential to fully realize the potential of CDMA in the Iraqi context.

4. CDMA ARCHITECTURE

Multiple mobile network operators (MNOs) like Zain Iraq, Asia Cell, and Korek Telecom provide GSM services nationwide. While GSM offers widespread coverage, variations exist across regions. 3G and 4G/LTE networks, based on Orthogonal Frequency Division Multiplexing (OFDM), support data services to meet growing smartphone demand. Despite progress, challenges persist in infrastructure, security, and regulation (Ipatov, 2005). Despite some achievements, there are still challenges facing the GSM sector in Iraq; some areas lack infrastructure, others suffer from security issues, and there are regulatory complications as well (Ipatov, 2005). CDMA's advanced security features and interference resistance have contributed to its integration into 3G and 4G networks. This has enabled more devices to connect, faster data transfer, and improved call quality compared to other wireless technologies (Abu-Rgheff, 2007). CDMA's unique coding mechanism allows multiple users to share the same frequency band, making it more resistant to interference (Code Division Multiple Access, 2023). See Fig. 1.

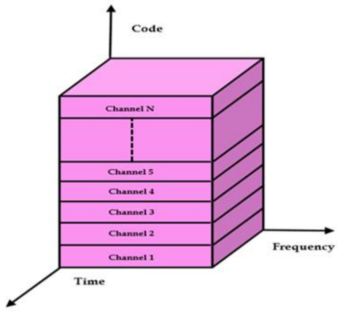


Fig. 1. CDMA channel.

CDMA employs Forward Error Correction (FEC) to detect and correct errors without retransmission (Hossam and Mouftah, 2006). Pseudorandom Noise (PN) sequences, unique to each user, are used for spreading and distinguishing signals. Orthogonal codes ensure signal separation, while soft handoff allows seamless cell transitions (Steele et al., 2001). See Fig. 2 and Table1.

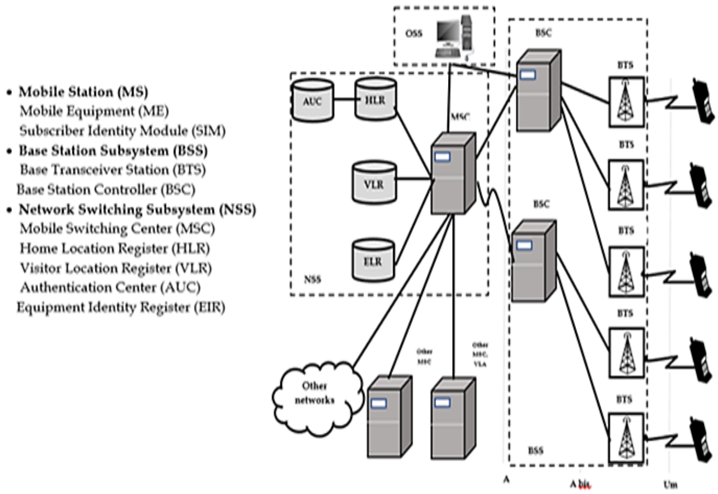


Fig. 2. Cellular Architecture.

Table 1. Comparison between CDMA, GSM, and LTE technologies

Wireless Communication Technology	Network Capa City	Call Quality	Security Features
CDMA	High capacity as a result of spread spectrum technology and the use of various codes.	Improved call quality as a result of sophisticated error-correcting techniques.	Improved security features because every user is given a unique code.
GSM	Because of the dependence on time- and frequency-division multiplexing, this technology has a lower capacity than CDMA.	In places with heavy network traffic or weak signal strength, call quality may deteriorate.	Due to known flaws in GSM encryption techniques, security is poorer than CDMA.
LTE	The use of orthogonal frequency-division multiple access (OFDMA) results in high network capacity.	Enhanced call quality as a result of more effective spectrum uses and additional bandwidth, particularly for data applications.	Robust security measures, such as sophisticated authentication and encryption techniques

CDMA systems use rake receivers to combine signals from multiple paths, improving reception. The orthogonal nature of CDMA codes makes it inherently resistant to interference, allowing more users on the same frequency band (Eberspächer et al., 2008). Capacity is influenced by factors like spreading factor, signal-to-interference ratio, and system design. Power control reduces noise and interference, enhancing network quality. CDMA encrypts transmissions using unique codes, enabling all cells to use the same frequency (Raghunandan, 2022). Pulse Code Modulation PCM-encoded voice signals are multiplied by a unique N-bit chip code and modulated using Phase shift keying (PSK) before transmission. A high-power amplifier boosts the signal for antenna delivery (Chen, 2006). See Fig. 3.

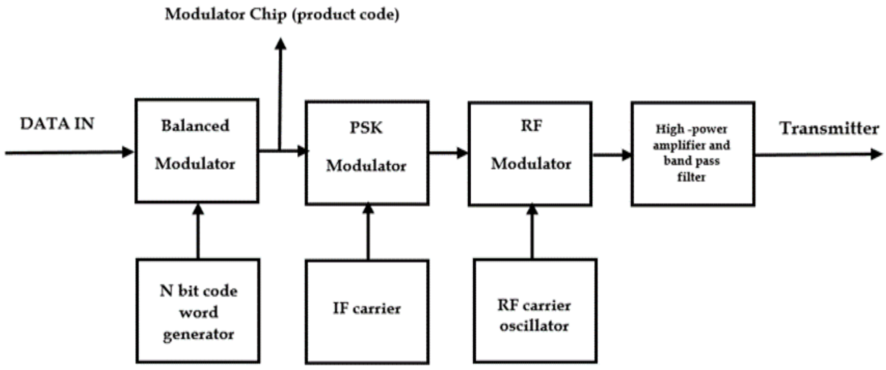


Fig. 3. Encoder for CDMA

The decoder converts the Radio Frequency (RF) signal to Intermediate Frequency (IF), extracting the PSK carrier and chip code. The chip code aids in synchronizing the receiver's code generator. To recover data, the received IF signal is compared to a generated signal containing the chip code and PSK carrier. Key elements include base stations, mobile stations, and spreading codes. The following schematic illustrates the CDMA system architecture (Vanghi et al., 2004). See Fig. 4.

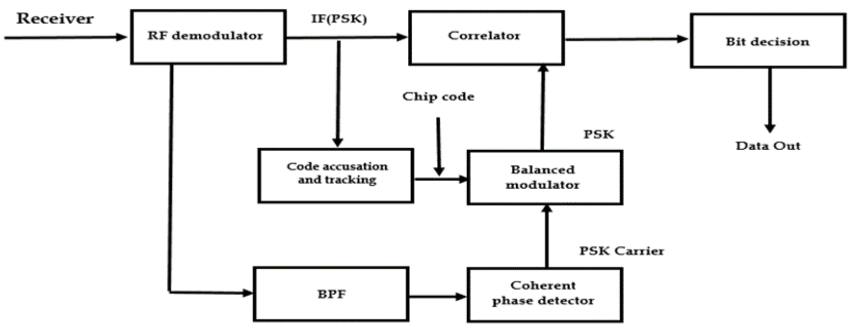


Fig. 4. Decoder for CDMA.

CDMA features, such as spread spectrum, code orthogonality, power control, soft handoff, near-far resistance can be integrated with GSM in Iraq. Signals are spread across a wide frequency band using a unique spreading code, multiple users can share the same frequency band without interfering with each other, transmitters dynamically adjust their power levels to ensure equal signal (Schiller, 2003). CDMA signals are spread across a wide frequency band, making them less susceptible to interference. Multiple users can simultaneously use the same frequency band without interfering with each other due to the use of unique spreading codes (Buehrer, 2006). Transmitters in a CDMA system can dynamically adjust their power levels to ensure that all users receive signals with equal strength. CDMA allows users to seamlessly switch between multiple base stations without interrupting their communication, providing a smooth user experience. CDMA is less affected by interference from nearby strong signals, making it more robust in challenging environments (Viswanath, 2004). CDMA uses Forward Error Correction (FEC) to detect and correct errors, convolutional codes are a common FEC type, and turbo codes offer advanced error correction. Direct-Sequence CDMA (DS-CDMA) spreads data across a wide frequency band, and Multi-Carrier CDMA (MC-CDMA) divides signals into subcarriers for improved frequency diversity (Farhan et al., 2023). CDMA integration with GSM allocate specific frequency bands, upgrade GSM base stations to support CDMA, assign unique spreading codes to users. incorporate CDMA power control algorithms into GSM, and manage interference between GSM and CDMA users. CDMA reduces dropped calls and improves capacity, supports more users on the same frequency band, provides higher data rates and lower latency, and power control optimizes resource allocation (Wang and Poor, 1999).

5. METHODOLOGY

Compatibility of CDMA can be integrated with GSM systems to improve capacity and coverage, by allows multiple users to share the same frequency band, which can significantly increase the network's capacity compared to traditional GSM systems using TDMA, and FDMA, CDMA's spread spectrum technology can provide better coverage, especially in rural and underserved areas. This involves using dual-mode handsets and base stations that support both CDMA and GSM (Hussein and Al-Ani, 2018). Processing interference mitigation techniques such as adaptive multiuser detection can be employed to reduce interference and improve signal quality. Using spatial and temporal filtering methods can help in mitigating co-channel interference, enhancing the overall performance of the CDMA system (Whipple et al., 2023). Implementation of more advanced error-correcting codes not only enhances the reliability and performance of CDMA but also allows the suppressed interference-cancellation technique to further improve interference suppression and network capacity (Zhou et al., 2015).

This is the inherent in CDMA are high security measures because it implements spread spectrum features. Due to these functionalities, failure to permit or provide enough communication to arbitrary users adds reliability to the communication link, particularly under unfavorable environments (Kuznetsov et al., 2024). Challenges Implementation of CDMA by evolving the existing GSM infrastructure to support the technology is very costly and time-consuming. Training and expertise will also be applied to the same level for the operational and maintenance aspects of a hybrid CDMA and GSM network (Sklar, 2021). By enhancing the CDMA on GSM networks in Iraq, it will increase the network's capacity, coverage, and quality, but the improvement is part of a coordinated redesign involving infrastructure modification and relevant technical implementation competencies (Wei et al., 2022). The merging of CDMA into the GSM system in Iraq was done through a comprehensive simulation. The simulation involved setting up a GSM network with a particular number of cells, channel bandwidth, and users associated with their distribution. The GSM network was to be configured to resemble an Iraqi network according to population distribution, geographical terrain, and other infrastructural factors as specified by Al-Hassani (2013). The number of cells was based on the area to be covered, while channel bandwidth conformed to the regulations in force for allocation (Zain Mobile, 2024). User distribution was modeled to simulate real-world traffic patterns, including peak and off-peak hours, then integrate it into the GSM network by allocating specific frequency bands for CDMA operation, assigning frequency ranges that did not overlap with existing GSM channels (Iraq Geography, 2024). In addition, spreading codes for each user to ensure that their signals could be uniquely identified and separated. For simulating the CDMA technology integration with GSM system, a mathematical model for GSM and CDMA Networks must be proposed as described below in Table 2, and 3 (Amaldi et al., 2006).

Table 2. Mathematical model for GSM network

Component	Mathematical Model
Frequency Division Multiple Access (FDMA)	$f_i = f_o + i \,.\, \Delta f$ where: - f_i: Frequency of channel I - f_o: Starting frequency - i: Channel index - Δf: Channel bandwidth
Time Division Multiple Access (TDMA)	$t_i = t_o + i \,.\, \Delta t$ where: - t_i: Start time of time slot i - t_o: Start time of frame - i: Time slot index - Δt: Duration of time slot
Speech Coding	Scoded (t) = F(s(t)) where: - s(t): Uncoded speech signal - Scoded (t): Coded speech signal - F: Speech coding algorithm
Handoff	$P(h) = \frac{P_1}{P_2}$ where: - $P(h)$: Probability of handoff - P_1: Received power from current cell - P_2: Received power from neighboring cell

Table 3. Mathematical model for CDMA network

Component	Mathematical Model
Spread Spectrum	$s_i\,(t) = d\,(t)\,.\,c_i\,(t)$ where: - $s_i\,(t)$: Spread signal for user i - $d(t)$: Data signal - $c_i\,(t)$: Spreading code for user i
Power Control	$P_i\,(t) = P_0\left(\frac{P_{th}}{P_i(t)}\right)^{\alpha}$ where: - $P_i\,(t)$: Transmitter power for user i - P_0: Target received power - P_{th}: Received power threshold - α: Power control exponent
Soft Handoff	$P(h) = \frac{P_1}{P_1 + P_2}$where: - $P(h)$: Probability of handoff - P_1: Received power from current cell - P_2: Received power from neighboring cell

The mathematical model for GSM network simulated as MATLAB code (Appen. A) and plotted in two Fig. 5, and 6 (MathWorks, 2024). Fig. 5 visualizes the number of users assigned to each cell (indexed from 1 to 5). Cell 5 has the highest number of users its 20, while Cell 3 has the lowest its 8. The distribution of users is not uniform, suggesting that certain cells are more popular or overloaded with users (such as Cell 5). Cells with a higher number of users could experience more traffic, potentially leading to higher congestion. Load balancing strategies may be needed if this reflects real-world usage, ensuring no cell is overburdened. Fig.6 shows the received power (measured in dBm) at each cell. Cells 3 and 4 have the highest received power (90 dBm and 85 dBm, respectively), whereas Cell 5 has the lowest received power (70 dBm). There is a visible dip in received power at Cell 5, despite its high number of users, indicating a possible imbalance between power distribution and user load. The cells with the fewest users (Cell 3 and Cell 4) have the strongest signal strength, which could mean these cells are better covered by the base station. The inverse relationship between user load and received power, particularly for Cell 5, suggests that either distance from the base station or network congestion could be reducing signal strength. Cell 5 might require power optimization or additional resources to better handle the user load and improve service quality. For performance mismatch, cells with more users tend to have lower received power (especially Cell 5), indicating potential performance issues, and for optimization need, there may be a need to redistribute users or increase power in high-traffic cells to maintain a balance between capacity and signal strength.

Simulating both mathematical models code using MATLAB shows the code (Appen. B) generated a bar chart comparing four metrics Fig. 7, TDMA capacity, which is calculated as the product of the number of time slots and the number of users per time slot, TDMA shows moderate capacity. It allocates users into time slots, making it efficient in environments where time-sharing is suitable. FDMA capacity calculated as the number of frequency channels multiplied by the users per channel, FDMA is efficient in systems where frequency resources are sufficient but has limitations when many users share limited spectrum. CDMA capacity calculated as the spreading factor multiplied by the number of users; CDMA shows the highest capacity due to its ability to allow multiple users to share the same frequency band simultaneously using different spreading codes. CDMA's capacity scales well with the number of users and performs better in terms of spectrum efficiency. And reduced interference shows how much the interference level is reduced based on the signal-to-interference ratio (SIR), which indicates higher SIR results in lower interference. Fig. 5 shows the total system capacity for TDMA, which should be 8 (time slots) × 10 (users per slot) = 80 users. The bar for FDMA capacity will show the total number of users accommodated by the system, which should be 10 (channels) × 5 (users per channel) = 50 users. The bar for CDMA capacity will represent the number of users in a system using CDMA, calculated as 10 (spreading factor) × 100 (users) = 1,000 users. Capacity comparison show CDMA have a much higher capacity than TDMA and FDMA, as it allows more users due to the spreading factor, and reduced interference, while small in value, is critical for the performance of wireless communication systems, a higher SIR means better quality communication. In Fig. 8, interference levels are inversely proportional to the signal-to-interference ratio (SIR). CDMA generally handles interference better than TDMA and FDMA because of its use of spreading codes that make signals less susceptible to interference. The interference reduction for CDMA is typically higher because its system inherently mitigates interference through code separation. FDMA, on the other hand, may have higher interference levels since users are confined to specific frequency bands. CDMA is the most efficient in terms of system capacity and interference management, making it ideal for high-capacity systems like 3G and beyond. FDMA and TDMA are more suited for earlier-generation networks or scenarios where user density is low to moderate and resource efficiency is less critical. They struggle with interference when user density increases.

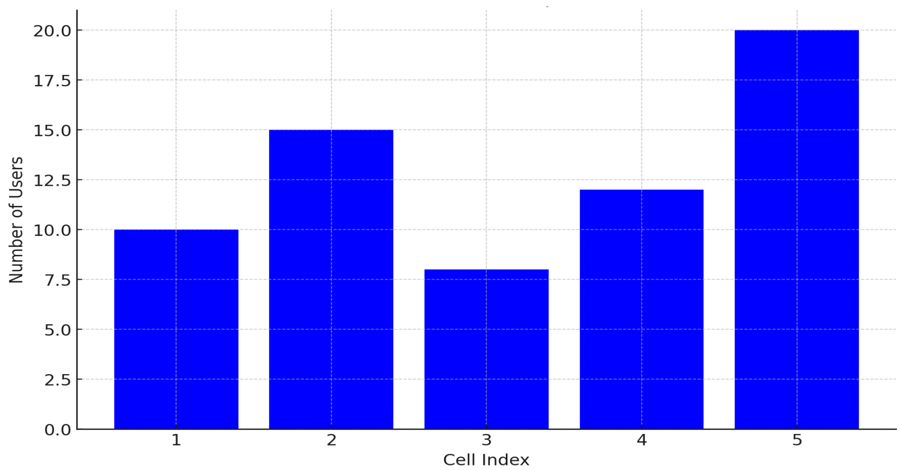


Fig. 5. Number of Users per Cell.

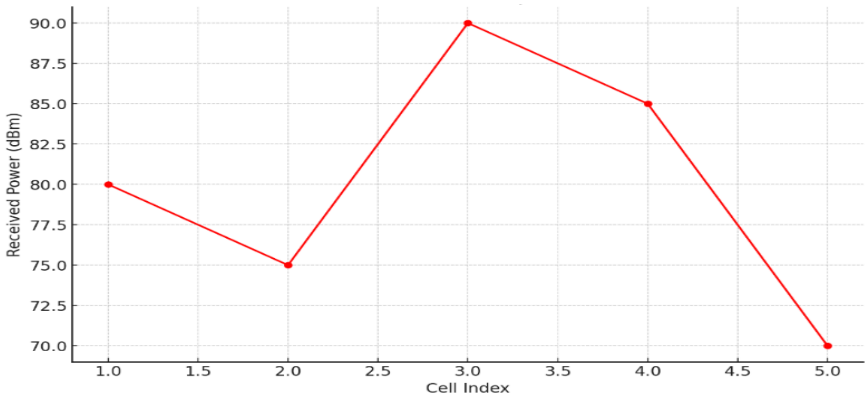


Fig. 6. Received Power per Cell.

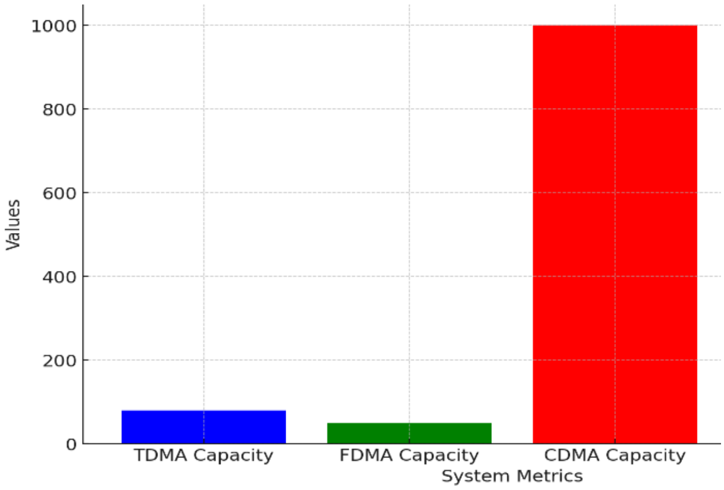
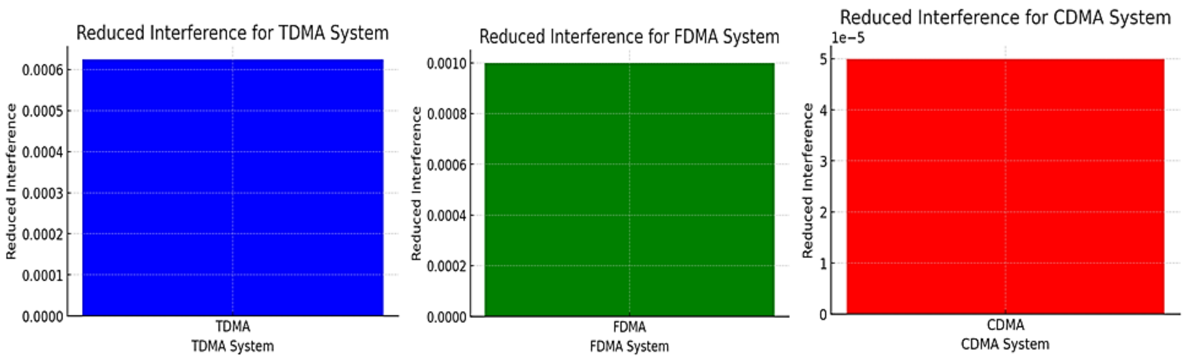


Fig. 7. Comparison of TDMA, FDMA, CDMA in terms of system capacity.



(a) (b) (c)

Fig. 8. Comparison a) TDMA, b) FDMA, c) CDMA performance in terms of system interference.

5.1. Evaluation Metrics

To evaluate an enhanced network system, it's crucial to define key performance metrics that reflect its overall efficiency and performance. Higher spectral efficiency allows more data to be transmitted within the same frequency bandwidth, improving network capacity and supporting more users without additional spectrum, focuses on optimizing bandwidth usage (Andrews, 2024).

$$\text{Spectral Efficiency} = \frac{\text{Data Throughput (bps)}}{\text{Bandwidth (Hz)}} \quad (1)$$

Higher data throughput indicates better performance and a higher capacity to handle larger volumes of data traffic, which is crucial for applications like video streaming, cloud services, and IoT devices, ensures higher data transmission rates (Code Division Multiple Access, 2018).

$$\text{Data Throughput} = \frac{\text{Total Data Transferred (bits)}}{\text{Time (seconds)}} \quad (2)$$

Low latency is critical for real-time applications such as online gaming, video conferencing, and autonomous driving, where fast data transmission is essential for performance (Shukla et al., 2023).

Total Delay=Transmission Delay+Propagation Delay+Processing Delay+Queuing Delay (3)

As networks grow in size and complexity, energy efficiency is vital to reduce operational costs and environmental impact, minimizes power consumption while maximizing data transfer, especially for large-scale deployments like 5G and IoT networks (Maiti and Juneja, 2023).

$$\text{Energy Efficiency} = \frac{\text{Data Transmitted (bits)}}{\text{Energy Consumed (joules)}} \quad (4)$$

These metrics, when monitored and optimized, provide a comprehensive view of the system's performance, helping to identify bottlenecks and areas for improvement, and evaluate many facets of the system's dependability, effectiveness, and service quality, so among the important metrics are, Signal-to-Noise Ratio (SNR), which is a measurement of the targeted signal's power divided by the power of interference or background noise, so higher SNR indicates better signal quality and less interference (Rajab and Cinkler, 2023).

$$SNR = \frac{Psignal}{Pnoise} \quad (5)$$

The measurement of the rate at which bits are received in error due to noise, interference, distortion, or bit synchronization errors is called the Bit Error Rate (BER), which is the ratio of erroneous bits to total transmitted bits, reflecting the system's susceptibility to noise, interference, and distortion. Throughput is a measure of data transfer efficiency over a network, influenced by factors like system capacity, coding schemes, and channel conditions., and CDMA capacity can support within a given bandwidth. It is determined by system architecture, interference, and spreading factors, and is calculated using the Shannon capacity formula (Rajab and Cinkler, 2023):

$$C=B\times\log_2 (1+SNR), \quad (6)$$

Where B is the bandwidth and SNR is the signal-to-noise ratio.

These metrics help optimize network design, allocate resources efficiently, and ensure high-quality service for mobile consumers in Iraq. By analyzing factors such as multipath environments, transmitter/receiver parameters, and path loss, network operators can make informed decisions about network optimization, spectrum allocation, and technology upgrades. Incorporating CDMA technology into Iraq's GSM network, including deploying base stations alongside GSM infrastructure, would enhance mobile broadband services, improve network capacity, and extend coverage to rural areas. Higher SNR indicates better signal quality, lower BER suggests greater reliability, increased throughput reflects improved data transfer efficiency, and higher capacity shows better scalability and resource management (Halonen et al., 2004). In Fig. 9, Signal-to-Noise Ratio (SNR) fluctuates over time due to factors such as environmental interference, signal fading, and network congestion leading to variations in signal quality and reliability in communication systems. Monitoring SNR trends helps identify periods of high interference, allowing for adjustments in network settings to maintain optimal signal quality and minimize data transmission errors (Ramakrishnan et al., 2023).

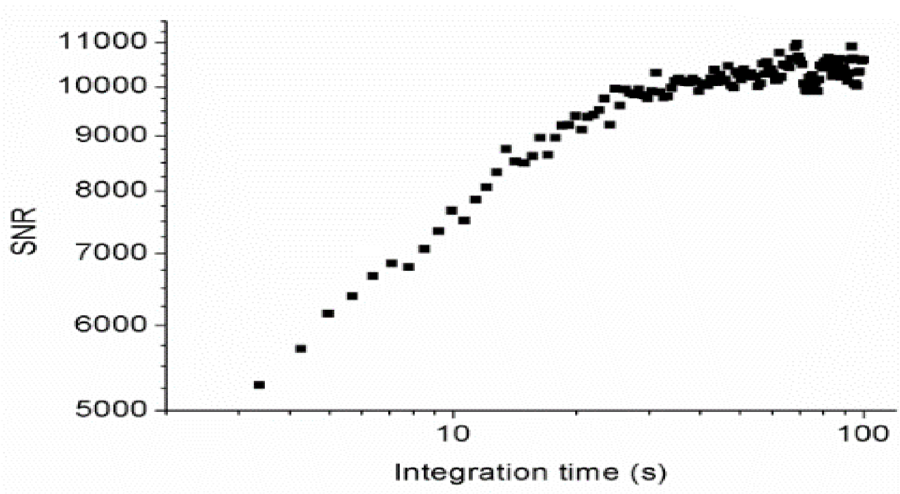


Fig. 9. Signal-to-Noise Ratio (SNR) overtime.

In Fig. 10, Bit Error Rate (BER) analysis assesses transmission accuracy by measuring the ratio of erroneous bits to total bits transmitted, high BER indicates signal degradation due to noise or interference, affecting data reliability. Reducing BER through error correction and network optimization enhances overall system performance and data quality (Khalil et al., 2017).

The integration of CDMA technology into Iraq's GSM-based network faces challenges such as compatibility issues, high costs for hardware and network upgrades, limited spectrum, and regulatory hurdles. These factors could delay implementation, impact efficiency, and require careful technical planning to ensure seamless operation with existing 4G/LTE technologies (Al-Shami and Al-Hassani, 2022). The enhancement of CDMA performance in Iraq’s GSM network involves strategies such as frequency reuse, dynamic spectrum sharing, and smart antenna systems with beamforming to reduce interference and multipath fading. Quality of Service (QoS) and traffic management algorithms help reduce congestion and maximize

CDMA resource utilization. Interference mitigation techniques, such as adaptive filtering and frequency hopping, improve signal quality. Dynamic power control algorithms optimize spectral efficiency and network capacity. Collaboration with regulatory bodies simplifies licensing and ensures sufficient spectrum allocation. Overall, performance improvements require a combination of infrastructure upgrades, algorithm optimization, and strategic alliances between stakeholders (Torlak, 2008).

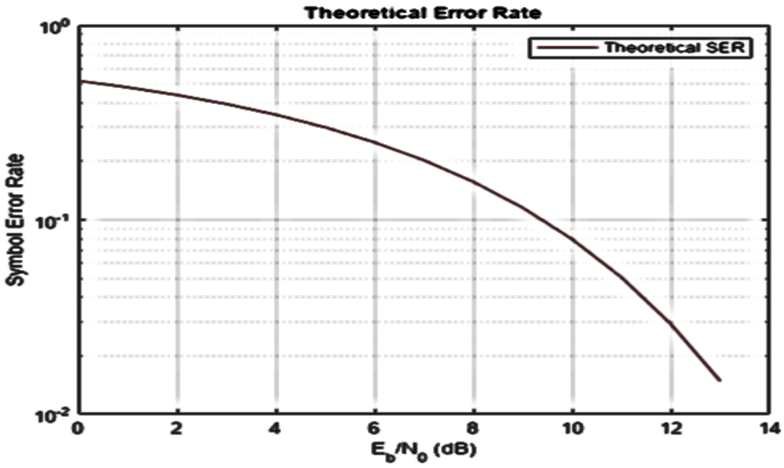


Fig. 10. Bit Error Rate (BER) Analysis.

To reduce co-channel interference and enhance CDMA performance, sophisticated techniques like Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) should be employed. Frequency hopping minimizes narrowband interference, while dynamic and closed-loop power control algorithms optimize CDMA power levels and maintain target Signal-to-Interference-plus-Noise Ratios (SINR). Power control algorithms help in governing the received signal power PRx in order to maintain the SINR level at a required level (Rouwet, 2022).

$$P_{Rx} = P_{Tx} \times \text{Path Loss} \times \text{Fading Margin} \times \text{Power Control Factor} \tag{7}$$

Where PTx is the transmitted power.

Upgrading base station infrastructure is essential for advanced CDMA features. Distributed Antenna Systems (DAS) enhance capacity and coverage, while QoS methodologies and admission control improve service reliability and user experience (Rouwet, 2022).

$$\text{QoS} = \frac{\text{Resources Allocated}}{\text{Resources Requested}} \times 100\% \tag{8}$$

Operators can improve both network performance and user perception by adopting these CDMA improvement recommendations into the GSM system in Iraq. It will also increase network capacity as well as efficiency, reliability, and quality of service.

5.2. Simulation For (LTE) And (CDMA)

This study compares the capacity performance of LTE and CDMA technologies, focusing on data throughput and user capacity. LTE, with its higher spectral efficiency and MIMO technology, supports more users and high-bandwidth applications. CDMA excels in noisy environments and handoff performance but faces capacity challenges in densely populated areas. Through simulations using spreading code, random data, and Gaussian noise, performance metrics like SNR, BER, throughput, and capacity were analyzed. The findings provide insights for Iraqi telecommunications operators to choose the most suitable technology, optimize network performance, and meet increasing data demands. MATLAB code sets up 4G/LTE parameters, generates spreading codes, generates data, spreads data, adds noise, performs decoding, detects data, calculates performance metrics, and visualizes the results using line charts. The spreading codes include orthogonal codes (Walsh-Hadamard codes) and pseudo-random codes (pseudorandom sequences) see Appen. C. The performance metrics calculated include BER and throughput, which are plotted against SNR and the number of users, respectively, as shown in Fig. 11, and 12. Fig. 11 shows high throughput and capacity stem from advanced modulation and MIMO, supporting more users and high data rates. Low BER and high SNR ensure reliable communication, minimizing errors and improving overall network efficiency and performance.

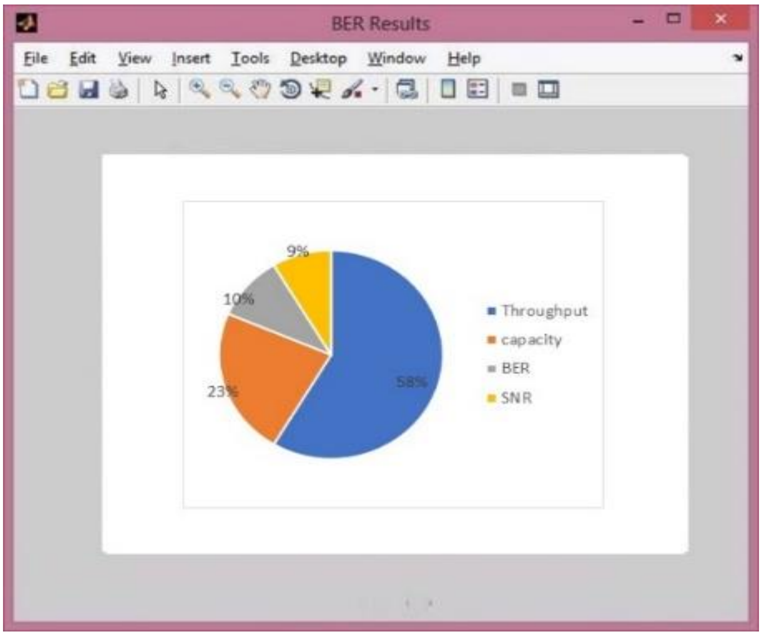


Fig. 11. LTE capacity performance parameters.

MATLAB code sets up CDMA parameters, generates spreading codes, generates data, spreads data, adds noise, performs decoding, detects data, calculates performance metrics, and visualizes the results using line charts. It includes orthogonal codes (Walsh-Hadamard codes) and pseudo-random codes (pseudorandom sequences) for spreading, view Appen. D. The performance metrics calculated include BER and throughput, which are plotted against SNR and the number of users, respectively, as shown in Fig. 13, and 14.

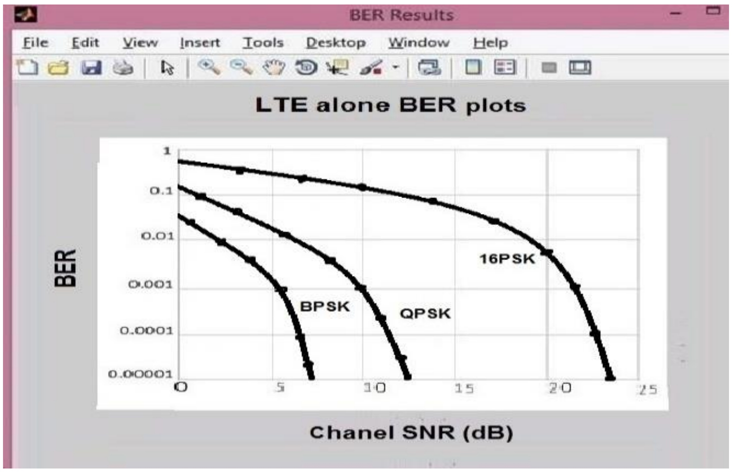


Fig. 12. BER verses channel SNR by MATLAB in 4G/LTE.

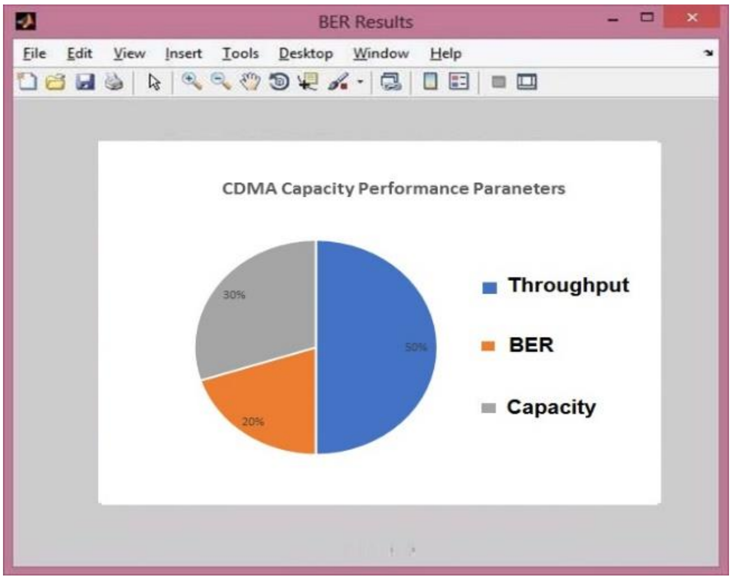


Fig. 13. CDMA capacity performance parameters.

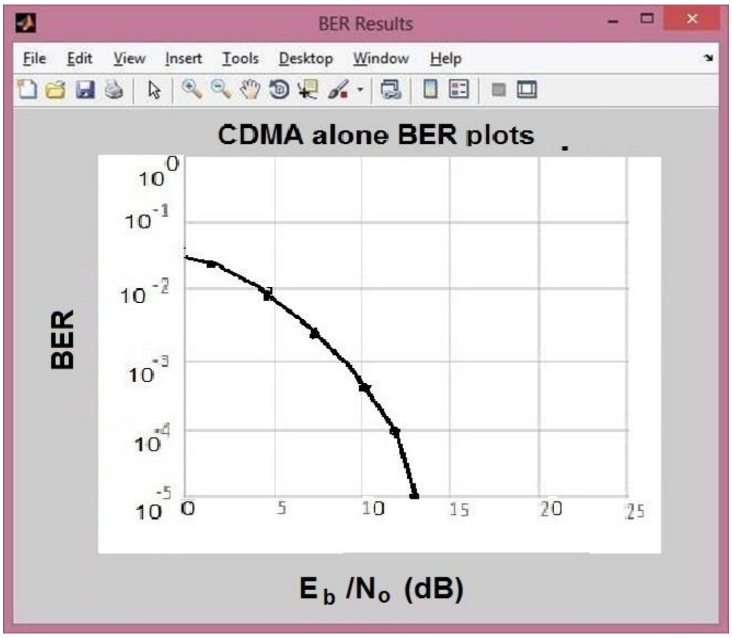


Fig. 14. BER result by MATLAB in CDMA.

CDMA capacity performance Fig. 13 is characterized by moderate throughput and capacity, limited by spectrum efficiency. It excels in noisy environments with robust error correction, achieving low BER and stable communication. However, SNR fluctuations can impact performance, especially in densely populated areas, reducing overall data rates and network capacity. In Fig. 12, and 14, LTE typically achieves lower BER using different techniques, such as BPSK (Binary Shift Keying), QPSK (Quadrature Phase Shift Keying), and 16-PSK compared to CDMA due to its advanced modulation schemes, error correction techniques, and higher spectral efficiency. CDMA, while robust in noisy environments, experiences higher BER under heavy load or interference, particularly in dense areas, making LTE more reliable for data-intensive applications. CDMA networks efficiently use bandwidth and support many users but offer slower data speeds than modern LTE, which delivers in urban and suburban area faster speeds, lower latency, and improved user experiences for tasks like video streaming. In Iraq, implementing CDMA faces challenges due to spectrum constraints and compatibility issues, as the technology is becoming obsolete. Improving spectrum management and network optimization could enhance rural Iraq's GSM network by integrating CDMA, boosting capacity, signal quality, and coverage in underserved areas according TDMA, and FDMA. This would improve connectivity, reduce call drops, and increase data rates, enhancing overall user experience and network performance.

5.3. Enhanced CDMA Architecture

Enhancing CDMA within the GSM system, particularly in the context of Iraq, involves addressing specific challenges such as coverage, capacity, and quality of service while also considering the evolving landscape of mobile communication technologies like LTE, by a conceptual design that could enhance CDMA within the GSM system and a comparative analysis with LTE. Implementing adaptive power control algorithms that adjust the transmission power based on real-time channel conditions. This reduces interference and enhances the overall quality of service. Advanced Error Correction can use Turbo codes or Low-Density Parity Check (LDPC). They are better at error correction in very noisy channels. By doing this, the reliability of the CDMA system is enhanced, especially in areas with high interference. Developing more sophisticated interference cancellation algorithms for distinguishing and canceling signals from other users. In other words, this would enable an increased number of users to share the same frequency band without any resultant degradation of quality of service. Introducing multi-carrier CDMA for increasing the data rate by distributing user data on many carriers as well to improve spectrum efficiency and system performance. It involves dynamic spectrum allocation, which will enable the CDMA system to utilize the spectrum more efficiently by instantiating an assignment of frequencies according to demand at each particular time, hence decreasing the chances of congestion and bettering the network capacity. Developing a seamless handover mechanism between CDMA and GSM/UMTS to allow users to move between different networks without dropping calls or data sessions. This could involve using IP-based handover techniques. Using software-defined radios (SDR) to enable flexible reconfiguration of base stations to support both CDMA and GSM/UMTS standards, allowing for efficient use of infrastructure. The implementation of enhanced CDMA within the existing GSM infrastructure in Iraq would require significant investment in upgrading base stations, deploying new technologies like SDR, and developing advanced algorithms for interference management. In Iraq might benefit more from focusing on expanding LTE coverage, given its superior performance in terms of data rates, spectrum efficiency, and latency. The gradual phase-out of CDMA in favor of LTE could be considered as a long-term strategy. The cost of enhancing CDMA may be justified in areas where GSM coverage is strong, and LTE deployment is not feasible due to economic or logistical reasons. LTE, while requiring higher initial investment, would offer better long-term benefits in terms of performance, capacity, and support for future technologies like 5G.

6. CONCLUSION

CDMA technology has shown to be a crucial component of cellular communication in the current day, compared to TDMA and FDMA wireless communication technologies, it offers superior coverage, higher network capacity, greater call quality, and improved security features because to its unique code-division multiple access. FDMA and TDMA are more suited for earlier-generation networks or scenarios where user density is low to moderate and resource efficiency is less critical, they struggle with interference when user density increases. Replacing TDMA and FDMA with CDMA in Iraq's rural GSM networks could enhance spectrum efficiency, network capacity, and signal quality. CDMA's ability to handle more users and provide better coverage in noisy or challenging environments would improve connectivity, reduce call drops, and enhance data services in underserved areas. CDMA is the most efficient, while there are commonalities between most academic writing standards and citation system implementation requirements scenarios such as differentiating CDMA technology from LTE technology in terms of fitting Iraq's GSM system, this choice would depend on the specific needs of the application, deployment scenario, and other factors as mentioned above. It is important to evaluate these factors based on a proper analysis before making any decisions.

Expanding CDMA under the GSM system can bring some short-term advantages in enhancing coverage and capacity, under consideration that LTE deployment would not yet be feasible for all regions in Iraq while for the Long-Term Evolution LTE and increasing demand for high-speed data services it may be more strategic to focus on LTE deployment, and the two systems can coexist. LTE typically achieves lower BER compared to CDMA due to its advanced modulation schemes, error correction techniques, and higher spectral efficiency. which delivers in urban and suburban area faster speeds, lower latency, and improved user experiences for tasks like video streaming. Implementing enhanced CDMA architecture in Iraq could significantly improve network capacity, spectrum utilization, and signal quality, especially in rural or underserved areas. Key considerations include optimizing spectrum management, integrating with existing GSM infrastructure, and addressing compatibility challenges. Enhanced CDMA would boost connectivity, reduce interference, and improve user experience through better data rates, reduced call drops, and wider coverage. Future work could explore advanced CDMA algorithms, improved spectrum management techniques, and seamless integration with 5G technologies to further enhance capacity, coverage, and data performance in Iraq's GSM network.

APPENDICES

A- MATLAB code for GSM using TDMA, FDMA.

import numpy as np import matplotlib.pyplot as plt # Parameters for GSM system using FDMA and TDMA num_cells = 5 users_per_cell = [12, 18, 10, 14, 22] # Number of users per cell (different from previous) frequency_channels = 8 # Number of frequency channels (FDMA) time_slots = 8 # Number of time slots per channel (TDMA) total_capacity = frequency_channels * time_slots # Total capacity per cell received_power_per_cell = [-85, -80, -75, -90, -70] # Received power (dBm) per cell (different from previous) # Create frequency and time slot matrix for FDMA and TDMA fdma_tdma_matrix = np.zeros((num_cells, frequency_channels, time_slots)) # Simulate the GSM system: Distribute users into FDMA channels and TDMA slots for i in range(num_cells): users = users_per_cell[i] capacity = 0 for ch in range(frequency_channels): for ts in range(time_slots): if capacity < users: fdma_tdma_matrix[i, ch, ts] = 1 # Allocate user capacity += 1 # Data for the bar chart (number of users per cell) and line chart (received power per cell) cell_index = range(1, num_cells + 1) # Plot 1: Number of users per cell (bar chart) fig1, ax1 = plt.subplots() ax1.bar(cell_index, users_per_cell, color='g') ax1.set_xlabel('Cell Index') ax1.set_ylabel('Number of Users') ax1.set_title('Number of Users per Cell (GSM with FDMA/TDMA)') ax1.grid(True) # Plot 2:

Received power per cell (line chart) fig2, ax2 = plt.subplots() ax2.plot(cell_index, received_power_per_cell, '-o', color='m') ax2.set_xlabel('Cell Index') ax2.set_ylabel('Received Power (dBm)') ax2.set_title('Received Power per Cell (GSM with FDMA/TDMA)') ax2.grid(True) # Show the two separate plots plt.show()

B- MATLAB code for TDMA, FDMA, CDMA capacity and reduced interference.

import matplotlib.pyplot as plt # Define the functions def calculate_tdma_capacity(num_time_slots, num_users_per_slot): return num_time_slots * num_users_per_slot def calculate_fdma_capacity(num_channels, users_per_channel): return num_channels * users_per_channel def calculate_cdma_capacity(spreading_factor, num_users): return spreading_factor * num_users def calculate_interference(interference_level, signal_to_interference_ratio): return interference_level / signal_to_interference_ratio # Example usage values num_time_slots = 8 num_users_per_slot = 10 num_channels = 10 users_per_channel = 5 spreading_factor = 10 num_users_cdma = 100 interference_level = 0.5 signal_to_interference_ratio = 10 # Calculate capacities and interference tdma_capacity = calculate_tdma_capacity(num_time_slots, num_users_per_slot) fdma_capacity = calculate_fdma_capacity(num_channels, users_per_channel) cdma_capacity = calculate_cdma_capacity(spreading_factor, num_users_cdma) reduced_interference = calculate_interference(interference_level, signal_to_interference_ratio) # Plot the capacities and interference labels = ['TDMA Capacity', 'FDMA Capacity', 'CDMA Capacity', 'Reduced Interference'] values = [tdma_capacity, fdma_capacity, cdma_capacity, reduced_interference] # Plot the 2D chart plt.figure(figsize=(10, 6)) plt.bar(labels, values, color=['blue', 'green', 'red', 'purple']) plt.xlabel('System Metrics') plt.ylabel('Values') plt.title('Comparison of TDMA, FDMA, CDMA Capacities and Interference') plt.grid(True) # Show the plot plt.show()

C- MATLAB code for 4G/LTE.

% LTE Simulation Parameters spreading_factor = 128; % Spreading factors num_users = [5 10 15 20 25]; % Number of users SNR_values = [0, 5, 10]; % SNR values in dB % Generate spreading codes % Orthogonal codes (Walsh-Hadamard codes) walsh_hadamard_matrix = hadamard(spreading_factor); orthogonal_codes = walsh_hadamard_matrix(1:num_users(end),:); % Pseudo-random codes (Pseudorandom sequences) rng(0); % Seed for reproducibility pseudo_random_codes = randi([0,1], num_users(end), spreading_factor)*2-1; % Initialize performance metrics storage bit_error_rates = zeros(length(num_users), length(SNR_values)); throughputs = zeros(length(num_users), length(SNR_values)); % Simulation loop for user_index = 1:length(num_users) for snr_index = 1:length(SNR_values) % Generate data user_data = randi([0, 1], 1, spreading_factor*num_users(user_index)); % Spread data if user_index <= size(orthogonal_codes, 1 spreading_code =orthogonal_codes(user_index, :); else spreading_code = pseudo_random_codes(user_index, :); end spread_data = user_data .* spreading_code; % Add noise noise_power = 10^(SNR_values(snr_index)/10); noise = sqrt(noise_power)*randn(1, length(spread_data)); received_signal = spread_data + noise; % Perform decoding correlation_result = abs(conv(received_signal, spreading_code(end:-1:1), 'valid')); % Detect data decoded_data = correlation_result > 0; % Calculate performance metrics num_errors = sum(decoded_data ~= user_data); bit_error_rates(user_index, snr_index) = num_errors / length(user_data); throughputs(user_index, snr_index) = (length(user_data) - num_errors) / (spreading_factor * num_users(user_index)); end % Visualization figure; subplot(2,1,1); plot(SNR_values, bit_error_rates', '-o'); xlabel('SNR (dB)'); ylabel('Bit Error Rate'); legend(cellstr(num2str(num_users', 'Users = %d'))); title('Bit Error Rate vs. SNR');subplot(2,1,2); plot(num_users, throughputs', '-o'); xlabel('Number of Users'); ylabel('Throughput (bps)'); legend(cellstr(num2str(SNR_values', 'SNR = %d dB'))); title('Throughput vs. Number of Users');

D- MATLAB code for CDMA.

% CDMA Simulation Parameters spreading_factor = 32; % Spreading factor num_users = [5 10 15 20 25]; % Number of users SN values = [0, 5, 10]; % SNR values in dB % Generate spreading codes % Orthogonal codes (Walsh-Hadamard codes) walsh_hadamard_matrix=hadamard(spreading_factor);orthogonal_codes = walsh_hadamard_matrix(1:num_users(end), :); % Pseudo-random codes (Pseudorandom sequences) rng(0); % Seed for reproducibility pseudo_random_codes = randi([0,1], num_users(end), spreading_factor)*2-1; % Initialize performance metrics storage bit_error_rates = zeros(length(num_users), length(SNR_values)); throughputs = zeros(length(num_users), length(SNR_values)); % Simulation loop for user_index = 1:length(num_users) for snr_index = 1:length(SNR_values) % Generate data user_data = randi([0, 1], 1, spreading_factor*num_users(user_index)); % Spread data if user_index <= size(orthogonal_codes, 1 spreading code=orthogonal_codes(user_index, :); else spreading_code = pseudo_random_codes(user_index, :); end spread_data = user_data .* spreading_code; % Add noise noise_power = 10^(-SNR_values(snr_index)/10); noise = sqrt(noise_power)*randn(1,length(spread_data)); received_signal = spread_data + noise; % Perform decoding correlation_result = abs(conv(received_signal, spreading_code(end:-1:1), 'valid')); % Detect data decoded_data = correlation_result > 0; % Calculate performance metrics num_errors = sum(decoded_data ~= user_data); bit_error_rates(user_index, snr_index) = num_errors / length(user_data); throughputs (user_index, snr_index) = (length(user_data) - num_errors) / (spreading_factor * num_users(user_index)); end % Visualization figure; subplot(2,1,1); plot(SNR_values, bit_error_rates', '-o'); xlabel('SNR (dB)'); ylabel('BitErrorRate');legend(cellstr(num2str(num_users', 'Users = %d')));subplot(2,1,2); plot(num_users, throughputs', '-o'); xlabel('Number of Users'); ylabel('Throughput (bps)'); legend(cellstr(num2str(SNR_values', 'SNR = %d dB')));

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