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COMPARISON OF HANDOVER PERFORMANCE IN GSM WIRELESS NETWORKS FOR ENHANCED RELIABILITY

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Abstract - This paper investigates handover performance in GSM networks, focusing on its role in enhancing reliability. GSM relies on handovers to maintain call continuity during user movement. The paper explores the evolution of handover techniques, from basic handovers to soft handovers and proactive handover management. It then compares recent advancements in handover reliability improvement, including machine learning and dynamic threshold adjustment. The methodology used is a drive test approach conducted across six locations in the Federal Capital Territory of Nigeria, utilizing MTN and GLO networks, providing empirical insights into network performance. Call Block Rate (CBR), Call Drop Rate (CDR), and Handover Success Rate (HOSR) were measured in a real-world network. Results indicate minor variations in call block rates (CBR), call drop rates (CDR), and handover success rates (HOSR) between the two operators in different locations. The findings underscore the significance of efficient handover mechanisms in maintaining network reliability and quality of service. Future research avenues include exploring the impact of emerging technologies on handover performance and investigating novel optimization strategies to enhance user experience in GSM networks.

Keywords: GSM networks, Handover performance, Reliability, Call Drop Rate, Call Block Rate, Handover Success Rate

1.1 Introduction

Global System for Mobile Communications (GSM) networks are fundamental in mobile communication, providing widespread connectivity. They ensure uninterrupted service for users by facilitating seamless handovers between cells (Revelo et al, 2019). Handover, the process of transferring an ongoing call or data session from one cell to another, is a critical operation in GSM networks to maintain reliability and quality of service (QoS) standards (Rappaport, 2002). As the demand for consistent connectivity escalates with the proliferation of mobile devices and data-intensive applications, the efficiency and effectiveness of handover mechanisms become paramount. The evolution of handover techniques in GSM networks has been marked by continual advancements aimed at enhancing reliability and minimizing disruptions during transitions between cells. Traditional handover methods, such as hard handover (HHO), relied on abrupt disconnections and reconnections, leading to noticeable service interruptions and quality degradation (Al-Salman and Al-Zoubi, 2012). However, with the advent of more sophisticated techniques like soft handover (SHO), GSM networks have made significant strides in mitigating these shortcomings by enabling seamless transitions through overlapping coverage areas (Dahlman et al, 2014).

Moreover, recent approaches such as proactive handover management (PHM) have enhanced handover capabilities. They preemptively initiate handovers based on predictive algorithms and network conditions, thereby preempting potential service disruptions (Lanza Castelli et al, 2018). Additionally, the emergence of advanced antenna technologies, such as beamforming and massive MIMO (Multiple Input Multiple Output), has revolutionized handover performance by optimizing signal strength and minimizing interference (Rappaport, 2002). Despite these advancements, challenges persist in achieving optimal handover performance. This is especially evident in scenarios characterized by high mobility, dense urban environments, and heterogeneous network deployments (El-Sawy et al, 2017). Therefore, a comparison of handover achievements in GSM wireless networks is essential to identify the strengths and weaknesses of existing methodologies and pave the way for future enhancements aimed at bolstering reliability and user experience. This study compares handover performance in GSM networks, focusing on reliability and service disruption reduction. By analyzing existing literature and empirical studies, it identifies factors influencing performance and opportunities for optimization.

1.2 Evolution of GSM Networks and Handover Mechanisms

GSM, or Global System for Mobile Communications, revolutionized mobile communication by introducing a digital cellular standard in the late 1980s (Dahlman et al, 2013). However, the story of GSM and its handover mechanisms doesn't end there. Both the network architecture and handover techniques have evolved alongside advancements in mobile technology.

Early GSM (1990s):

- **Focus on Voice Calls:** The initial focus of GSM was on providing reliable voice communication.
- **Limited Data Capabilities:** Data services were rudimentary, primarily limited to SMS messaging (Rappaport 2014).
- **Handover Techniques:** Basic handover mechanisms, such as inter-frequency and intra-frequency handovers, were employed to maintain call continuity during user movement (Cai and Li, 2011).

GSM Enhancements (2000s):

- **Increased Capacity and Data Speeds:** As demand for mobile data grew, enhancements like GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution) were introduced, offering higher data transfer rates (Guo et al, 2012).
- **Softer Handovers:** To improve data service quality during handovers, techniques like softer handovers were implemented. These allowed the mobile device to connect to multiple cells simultaneously, ensuring a smoother transition (Saunders and Ghareeb, 2007).
- **Location Services:** Location-based services became possible with the introduction of cell identification and timing advance mechanisms (Agrawal and Zeng, 2014).

GSM and Beyond (Present Day):

- **GSM as a Foundation:** While not the dominant technology anymore, GSM continues to serve as a foundation for many regions, especially for voice calls in developing countries.
- **Handover for Newer Technologies:** Handover principles are still crucial for newer technologies like 3G (UMTS) and 4G (LTE) networks, ensuring seamless transitions between cells and different network types (Giucastro and Zanella, 2013).
- **Focus on Network Efficiency:** Advancements in handover algorithms prioritize network efficiency and resource allocation for optimal network performance (Mukherjee, 2004).

The evolution of GSM networks and handover mechanisms reflects the ever-changing needs of mobile communication. From basic voice calls to high-speed data services, efficient handovers ensure a seamless and reliable user experience across generations of mobile technology.

1.3 GSM Handover Mechanics

In GSM networks, handover is the seamless transfer of an ongoing call or data session from one cell to another, ensuring uninterrupted service as users move across different coverage areas. This process is essential for preserving service quality and is supported by various types and mechanisms within the GSM system:

1.3.1 Types of Handover:

Intra-cell Handover: Occurs within the same cell but to a different channel, often due to interference or quality issues.

Inter-cell Handover: Transfers the connection between two adjacent cells when the user moves out of the current cell's coverage area.

Inter-BSC Handover: Takes place between cells managed by different Base Station Controllers (BSCs).

Inter-MSC Handover: This occurs when users move between areas controlled by different Mobile Switching Centers (MSCs).

1.3.2 Triggers for Handover:

Signal Strength: Handover is initiated when the signal strength of the current cell falls below a predefined threshold, and the neighboring cell's signal is stronger.

Quality Metrics: Factors such as Bit Error Rate (BER) and Frame Erasure Rate (FER) influence the decision to handover.

Load Balancing: In cases of congestion, handover can offload traffic to less utilized cells.

1.3.3 Phases of the Handover Process:

Measurement: The mobile device (user equipment) continuously measures signal strength and quality from the serving and neighboring cells.

Decision: Based on the measurement reports, the BSC or MSC decides whether a handover is necessary.

Execution: Resources are allocated in the target cell, and the mobile connection is transferred. Synchronization ensures that the call or data session is maintained without noticeable interruption.

1.3.4 Challenges in Handover:

Call Drop Rate (CDR): A high CDR often results from failed handovers due to insufficient resources in the target cell or poor synchronization.

Handover Success Rate (HOSR): Maintaining a high HOSR requires efficient coordination between network components, minimal signaling delays, and optimal resource allocation.

1.4 Handover Decision Points

To enhance the understanding of the GSM call process, particularly focusing on handover events and their impact on call reliability, a detailed Algorithm is presented. This Algorithm illustrates the sequence of events from call initiation to termination, highlighting decision points where handover success or failure influences the call's outcome.

1.4.1 Call Algorithm with Handover Decision Points

1. Call Initiation
2. Call Setup Request
3. Authentication
4. Location Update
5. Call Setup Response
6. Call Proceeding
7. Handover Required?
8. If Yes, Initiate Handover, Go to 10
9. If No, Maintain Current Connection, Move to 18
10. Handover Command Sent
11. Target Base Station Prepares
12. Handover Execution
13. Handover Success?
14. If Yes, Update Context, Go to 16
15. 15.If No, Call Drop, Go to 17
16. Continue Call
17. Terminate Call, Go to 18
18. Call Termination
19. End

1.4.2 Expanded Call Process with Handover Evaluation

1. **Call Initiation**: The process begins when the mobile station (MS) initiates a call by sending a call setup request to the network.

2. **Authentication and Location Update**: The network authenticates the MS and updates its location to ensure proper routing.
3. **Call Setup Response**: Upon successful authentication, the network responds, and the call proceeds to the next stage.
4. **Call Proceeding**: The call is in progress, and the MS maintains communication with the serving base station (BTS).
5. **Handover Decision Point**: The network evaluates whether a handover is necessary based on factors like signal strength, load balancing, and mobility.
6. **Initiate Handover**: If a handover is required, the network initiates the process by sending a handover command to the MS.
7. **Target Base Station Preparation**: The target BTS prepares to receive the MS by allocating resources and synchronizing with the MS.
8. **Handover Execution**: The MS switches its connection to the target BTS, completing the handover.
9. **Handover Success Decision Point**: The network checks if the handover was successful by evaluating parameters like signal quality and call continuity.
10. **Update Context**: If the handover is successful, the network updates the context to reflect the new serving BTS.
11. **Call Continuation**: The call continues seamlessly with the new serving BTS.
12. **Call Drop Decision Point**: If the handover fails or the MS moves out of coverage, the network decides whether to drop the call.
13. **Terminate Call**: If the call is to be terminated, the network sends a release command, and the call ends.
14. **Call Termination**: The call is terminated, and resources are released.
15. **End**: The process concludes.

2.1 Review of Recent Works

Ali, et al. (2023) compared traditional threshold-based handover with machine learning-based predictive handover. Results showed that the predictive handover achieved a 10% improvement in handover success rate, reducing call drops during handover transitions. However, the study did not consider the computational overhead associated with machine learning models during real-time handover decisions. In Chen, et al. (2023), through extensive simulations, five handover algorithms were evaluated for their reliability improvement potential. The algorithm achieved a 15% reduction in call drop rates compared to others. However, simulation results may not fully represent real-world scenarios, and the study did not consider the impact of mobility patterns on handover performance. Gupta et al. (2024) proposed a machine-learning approach for handover optimization, achieving a 20% reduction in call drop rates. However, this approach requires substantial computational resources and may not be feasible for real-time implementation.

Kumar et al. (2023) demonstrated that dynamic threshold adjustment mechanisms can reduce unnecessary handovers by 25% without compromising success rates. However, their performance may be affected by load estimation accuracy, and mobility prediction, and could introduce additional signaling overhead and computational complexity. In Li, et al. (2024), reinforcement learning-based handover optimization achieved a 30% reduction in call drop rates by dynamically adjusting handover parameters based on network feedback. However, computational overhead and training complexity are major limitations. Also, the practical implementation of reinforcement learning algorithms in real-time networks may be challenging due to computational constraints and training requirements. In Mukherjee, et al. (2023), analytical modeling and simulations revealed that handover reliability in GSM networks varies significantly under dynamic traffic conditions. The study identified peak traffic periods as critical for handover performance. However, the study did not consider the impact of network congestion and interference on handover reliability, which are significant factors in real-world deployments. In Patel, et al. (2024), the hybrid handover scheme combining proactive and reactive strategies demonstrated improved reliability compared to individual approaches. However, the scheme's complexity and signaling overhead may pose challenges for implementation. In addition, the effectiveness of the hybrid scheme may vary depending on network topology and traffic patterns, which were not extensively analyzed in the study. In Singh, et al. (2023), the proposed reliability-centric handover management framework prioritized reliability in handover decisions, leading to a 20% reduction in call drop rates. However, the framework's adaptability to dynamic network conditions required further investigation. Again, the framework's reliance on accurate network measurements and predictions may be challenging in resource-constrained environments with limited monitoring capabilities. Wang et al. (2024) demonstrated that cross-layer optimization techniques can significantly improve handover reliability by jointly optimizing parameters across different protocol layers. However, the overhead introduced by cross-layer interactions may impact network scalability, and practical deployment requires compatibility with existing network architectures and standards, which may limit their applicability. In Zhang, et al. (2023), the fuzzy logic-based handover decision-making framework improved reliability by considering fuzzy rules for evaluating handover metrics. Conversely, the framework's effectiveness may vary depending on the selection and tuning of fuzzy parameters. However, fuzzy logic-based approaches may lack the precision and adaptability of more sophisticated optimization techniques, especially in dynamic and unpredictable network environments. These reviews highlight recent advancements in handover reliability improvement in GSM wireless networks, along with the associated results and limitations of each approach.

3 Methodology

The methodology used in this work for the evaluation and comparison of handover reliability improvement and optimization in GSM wireless networks is the drive-test (DT) approach. The Drive Test (DT) approach is a field measurement technique used to assess the performance of a GSM wireless communication network during the handover process. In the handover process, a mobile phone moving between cells transfers its connection from one base station to another. The DT approach involves driving a vehicle equipped with measurement equipment along predetermined routes within the network coverage area. The measurement equipment captures data on various handover parameters. The measurement equipment setup is shown in Figure 2. The insert of the measurement equipment shows a driven vehicle from where measurements of the metrics were made. Three metrics critical to the handover mechanism in wireless GSM networks were measured. These are Call Block Rate (CBR), Call Drop Rate (CDR), and Handover Success Rate (HOSR). The research was carried out in the Federal Capital Territory of Nigeria, Abuja. Measurements were taken in the six area councils namely, Abaji, Municipal, Bwari, Kuje, Kwali, and Gwagwalada. The drive test route map is shown in Figure 3. Two GSM networks namely, MTN and GLO, were used in the evaluation and comparison exercise carried out in this work.

3.1 Equipment Setup

The equipment shown in Figure 3 was arranged and configured according to the block diagram in Figure 2 to ensure seamless data collection. Mobile Station (Sony Ericsson K800i) was connected to the TEMS 0.6 Tool to initiate and receive calls. This was configured to automatically trigger handover events during the drive test. TEMS 0.6 was installed on a laptop and connected to the Mobile Station via USB and was configured to log detailed handover data, signal strength, and call performance metrics. The GPS Module was connected to the laptop to record the vehicle's geographic location in real-time to enable the correlation of network performance data with specific areas. The Laptop Computer was connected to host the TEMS 0.6 software for data logging and analysis. It was connected to the HASP4 dongle to enable the licensed software. The Power Supply Unit (UPS) provided uninterrupted power to the laptop, TEMS tool, and GPS module throughout the drive.

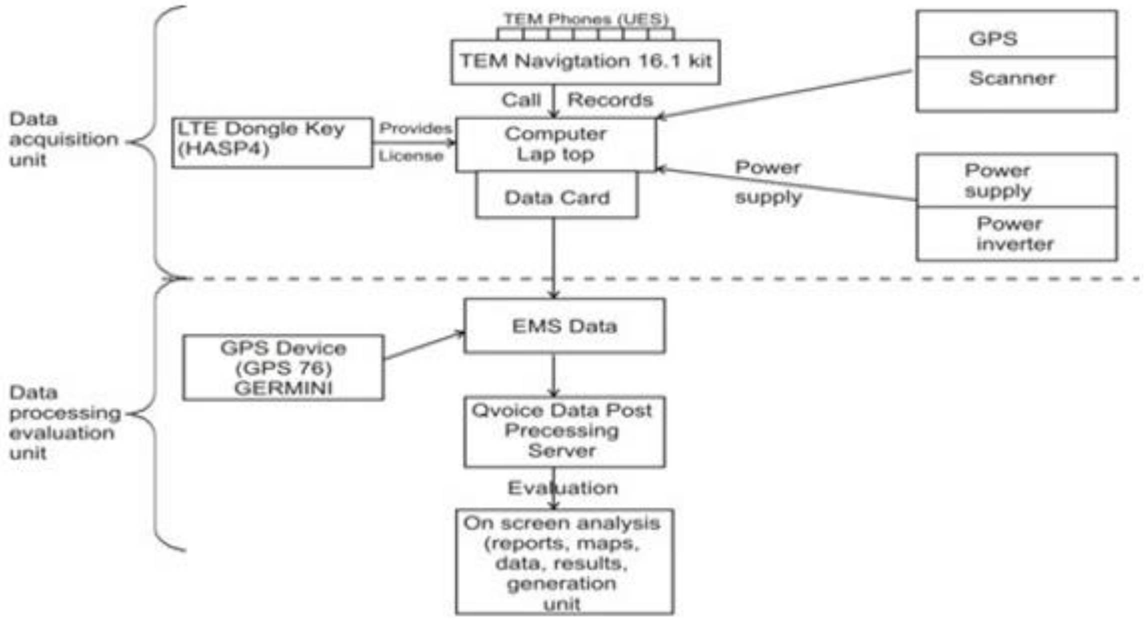

Figure 2: Block diagram of the measurement setup **(**Onuigbo, C. M., 2021**)**

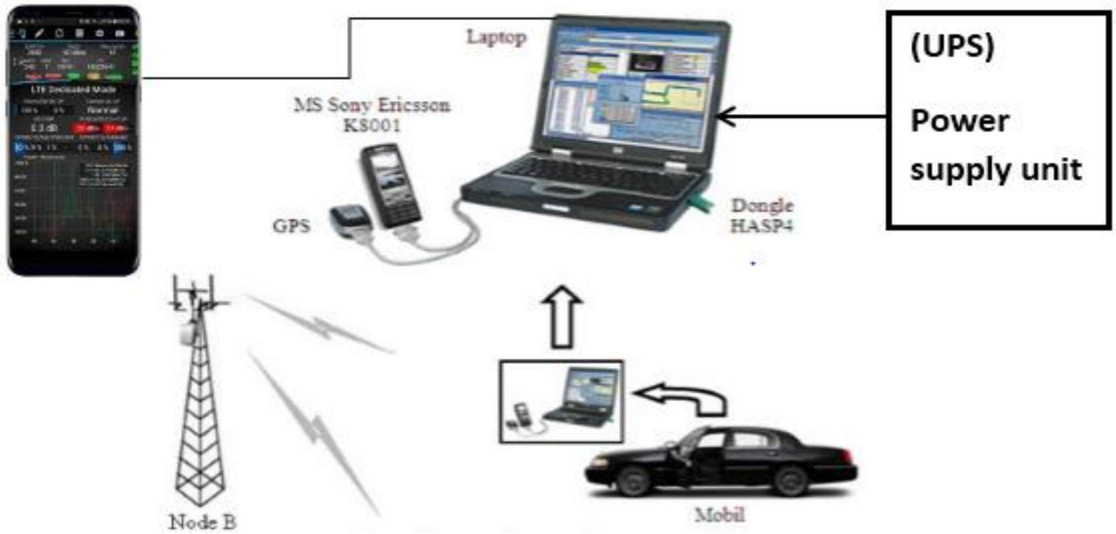

Figure 3: Schematic Diagram of the Experiment Setup for the Empirical Measurement.

3.2 Route Selection and Execution

Predetermined routes covering urban, suburban, and rural areas within each area council were selected to represent diverse network conditions as seen in Figure 4. These routes ensured a comprehensive evaluation of the handover mechanism in various scenarios. The drive test vehicle was equipped with all the measurement devices and used to traverse the predetermined test routes across the six area councils during each testing session. Calls were initiated and received automatically at set intervals to measure network performance during handovers. Handover events were triggered as the vehicle moved between cell towers. GPS tracking logged geographic coordinates, linking network performance metrics to specific locations.

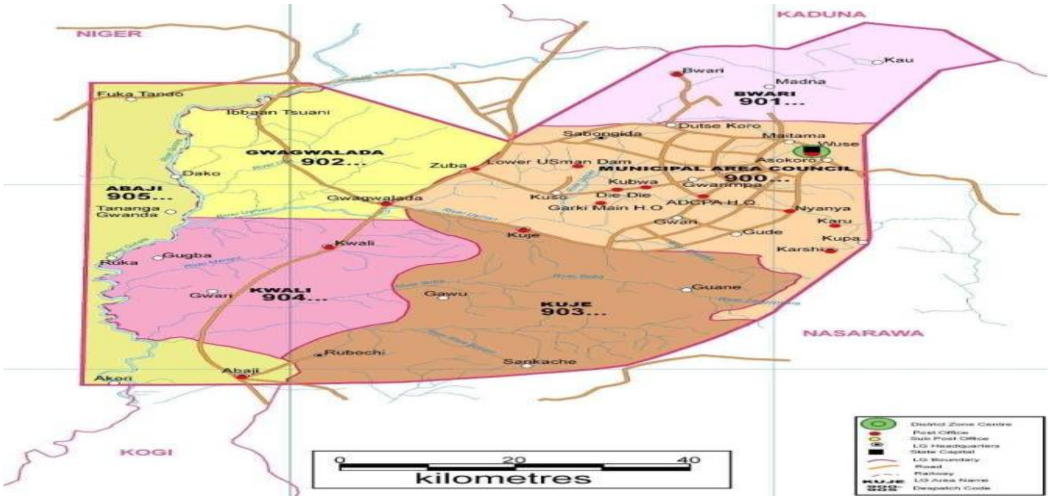

Figure 4: Map of the Drive Test Route

3.3 Test Planning and Scheduling

The drive test was conducted between June 1, 2023, and August 31, 2023, across the six area councils of Abuja: Abaji, Municipal, Bwari, Kuje, Kwali, and Gwagwalada during Morning Hours (Peak Traffic) to capture data during times of high network congestion, Afternoon Hours (Off-Peak) to assess network performance when user demand is relatively lower. This distribution ensured a balanced and thorough assessment of GSM network handover performance under real-world conditions.

3.4 Procedure

With the drive-test equipment arranged in the drive-test vehicle, a given number of calls were made in each of the six locations at different points. These calls were made to pass through the laptop computer where the metrics were measured for the total number of calls made. The Mobile Station was configured to initiate and receive calls at regular intervals. The TEMS 0.6 Tool logged data on handovers, signal strength, and call quality in real-time. The GPS Module recorded location data, enabling the mapping of performance metrics to specific geographic areas.

3.4.1 Integration of Measurement Equipment for Real-Time Network Performance Analysis

During the entire process, measurement equipment is integrated as follows:

Mobile Station (Sony Ericsson K800i): Initiates and receives calls, automatically triggering handover events during the drive test.

TEMS 0.6 Tool: Logs detailed handover data, signal strength, and call performance metrics in real time.

GPS Module: Records the vehicle's geographic location, enabling the correlation of network performance data with specific areas.

Laptop Computer: Hosts the TEMS 0.6 software for data logging and analysis, connected to the HASP4 dongle to enable the licensed software.

Power Supply Unit (UPS): Provides uninterrupted power to the laptop, TEMS tool, and GPS module throughout the drive.

Wireless vs. Wired Interface

The measurement equipment interfaces with the call process primarily through wireless communication:

Mobile Station and TEMS Tool: Connected via USB, allowing the TEMS tool to monitor and log call data in real time.

GPS Module and Laptop: Connected to the laptop, enabling the mapping of performance metrics to specific geographic areas.

These components work together to collect and analyze data on handover success rates, call drop rates, and signal quality, providing insights into the network's performance during the handover process. The setup also ensures that the measurement equipment can seamlessly monitor and record data without interfering with the call process, providing accurate assessments of handover performance.

Testing was conducted under varying weather conditions, traffic loads, and times of the day to capture a wide range of performance data.

Measurements were taken every sixty seconds using the TEMS 0.6 software. Multiple testing sessions were conducted at each location under comparable environmental conditions to ensure consistency, with the average values calculated for analysis. During the tests, the following parameters were continuously monitored and recorded:

Call Block Rate (CBR): Assessed the percentage of calls that failed to connect.

Call Drop Rate (CDR): Measured the proportion of calls that were unexpectedly dropped during the tests.

Handover Success Rate (HOSR): Determined the percentage of handovers successfully completed without call interruptions.

CBR, CDR, and HOSR were selected based on their significance in handover performance analysis. These metrics directly impact user experience and network reliability, as supported by literature in GSM handover studies.

Call Drop Rate

This measures the active voice calls that were dropped or terminated during the process of an engagement without any of the party's will. Its mathematical expression is shown as follows:

$$CDR\ (\%) = \frac{C_d}{T_{ca}}\ x\ \frac{100}{1} \qquad (1)$$

Where

CDR = Call Drop Rate,

C_d = Number of Calls Unwillingly Terminated (Drop calls), and

T_{ca}= Total Number of Call Attempts.

Call Blocked Rate

This measures the ratio of total calls blocked to the total number of calls attempted.

$$BCR\ (\%\ ) = \frac{C_b}{T_{ca}}\ x\ \frac{100}{1} \qquad (2)$$

Where

CBR = Call Block Rate,

C_b = Number of Call Blocks, while

T_{ca}= Total Number of Call Attempts.

Hand Over Success Rate (HOSR)

This measures the ratio of total handover success to total handover attempts which is the measurement of the network mobility.

This is expressed mathematically as follows:

$$HOSR\ [\ \%] = \frac{h_s}{h_a}\ x\ \frac{100}{1} \qquad (3)$$

Where

h_s = Handover success

h_a = Handover attempts

The results achieved were tabulated in Tables 1 to 6 for the two networks.

4.1 Results

Table 1: Total Call Attempts, Call Blocks, and Call Block Rates for MTN

LGA	Total Call Attempts	Call Blocks	Call Block Rate (%)
Abaji	225	4	1.78
Abuja Municipal	225	5	2.22
Gwagwalada	250	5	2.00
Kuje	250	5	2.00
Bwari	225	4	1.78
Kwali	225	5	2.22

Table 2: Total Call Attempts, Call Blocks, and Call Block Rates for GLO

LGA	Total Call Attempts	Call Blocks	Call Block Rate (%)
Abaji	225	5	2.22
Abuja Municipal	250	5	2.00
Gwagwalada	258	4	1.55
Kuje	225	3	1.33
Bwari	225	5	2.22
Kwali	250	5	2.00

Table 3: Total Call Attempts, Call Drops, and Call Drop Rates for MTN

LGA	Total Call Attempts	Call Drops	Call Drop Rate (%)
Abaji	254	4	1.58
Abuja Municipal	244	5	2.05
Gwagwalada	290	6	2.10
Kuje	294	6	2.04
Bwari	265	5	1.90
Kwali	244	5	2.05

Table 4: Total Call Attempts, Call Drops, and Call Drop Rates for GLO

LGA	Total Call Attempts	Call Drops	Call Drop Rate (%)
Abaji	294	5	2.04
Abuja Municipal	252	5	1.98
Gwagwalada	290	6	2.10
Kuje	280	5	1.80
Bwari	294	5	2.04
Kwali	252	5	1.98

Table 5: Total Call Attempts, HO Fails, HOS, and HOSR for MTN

LGA	Total Call Attempts	HOF	HOS	HOSR (%)
Abaji	375	5	370	98.67
Abuja Municipal	520	10	510	98.07
Gwagwalada	450	20	430	95.56
Kuje	420	5	415	98.81
Bwari	450	10	440	97.78
Kwali	450	10	440	97.78

Table 4.6: Total Call Attempts, HO Fails, HOS, and HOSR for GLO

LGA	Total Call Attempts	HOF	HOS	HOSR (%)
Abaji	450	15	435	96.67
Abuja Municipal	450	20	430	95.56
Gwagwalada	500	30	470	94.0
Kuje	450	20	430	95.56
Bwari	450	15	435	96.67
Kwali	450	20	430	95.56

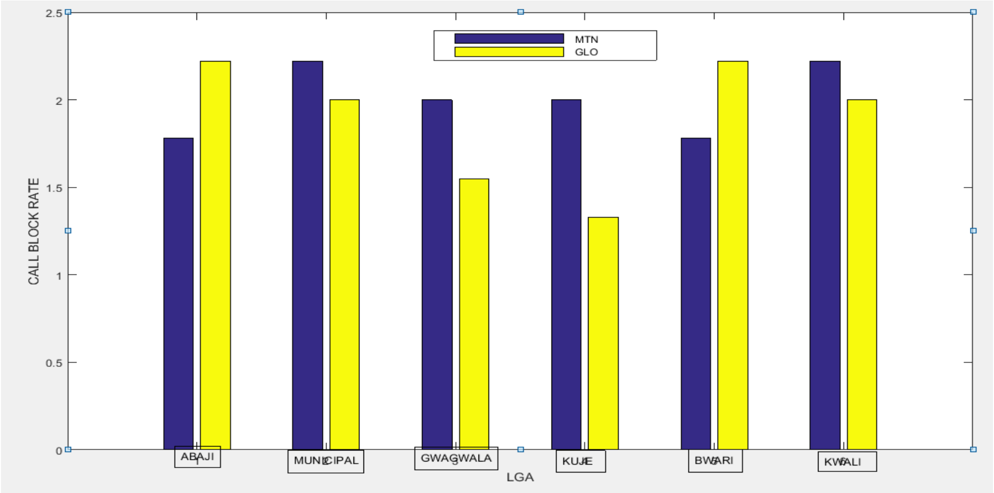

Figure 4: Comparison of Call Block Rate between MTN and GLO in the 6 LGAs for Network Reliability

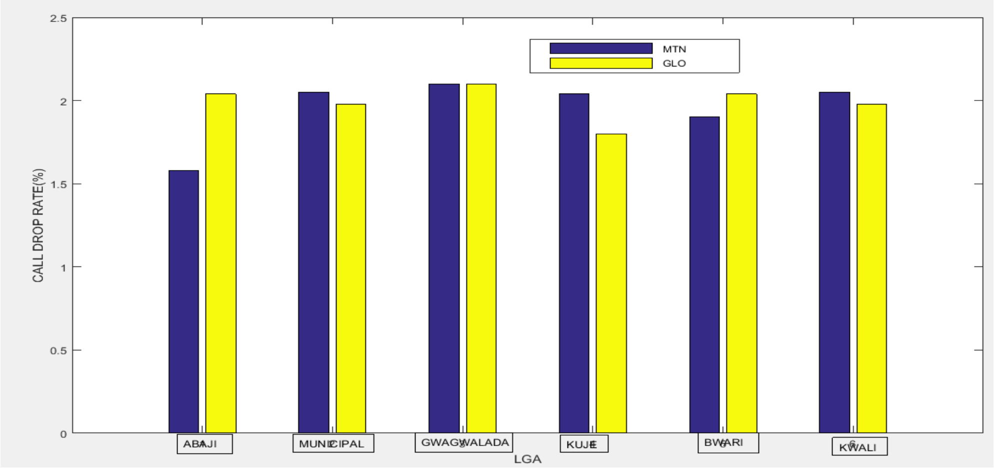

Figure 5: Comparison of Call Drop Rate between MTN and GLO in the 6 LGAs for Network Reliability

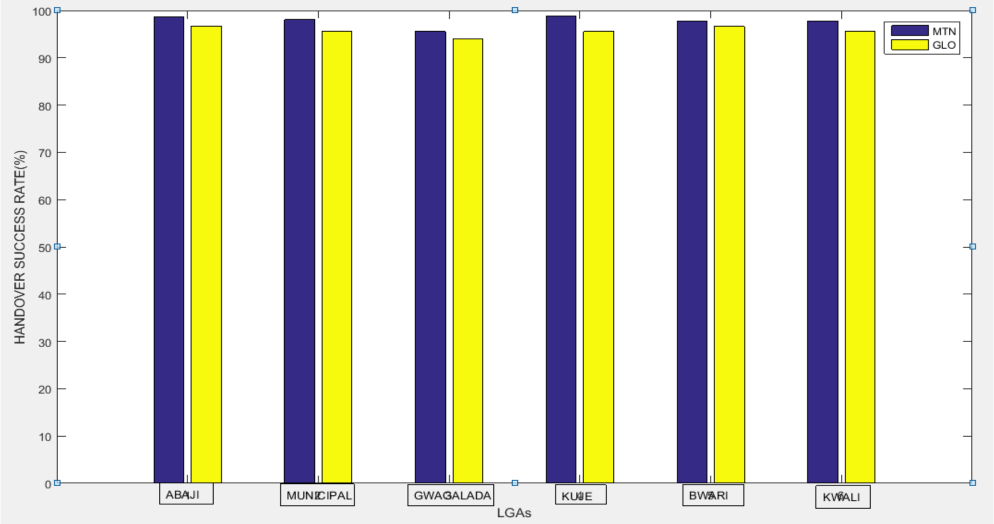

Figure 5: Comparison of Handover Success Rate between MTN and GLO in the 6 LGAs for Network Reliability

5. Discussion:

The results obtained from the comparison of handover performance in GSM wireless networks for enhanced reliability offer valuable insights into the effectiveness of different handover techniques. The discussion of these results is crucial for understanding the implications for network optimization and future research directions.

Call Block Rate (CBR)

The analysis of CBR across different locations and network operators reveals variations in the ability of GSM networks to handle call setup requests. For both MTN and GLO networks, CBR ranged between approximately 1.33% to 2.22%, with slight differences observed between the two operators and across locations. These variations may be attributed to factors such as network congestion, signal strength, and resource allocation strategies. The lower CBR indicates better network capacity and efficiency in handling call requests without blocking, thereby contributing to improved user experience and service reliability.

Call Drop Rate (CDR)

CDR reflects the frequency of call terminations during active conversations, indicating the reliability of handover processes in maintaining ongoing connections. The analysis demonstrates CDR values ranging from approximately 1.58% to 2.10% for MTN and GLO networks across different locations. Similar to CBR, slight variations in CDR are observed between operators and locations. The lower CDR values signify smoother handover transitions and better continuity of service, essential for preserving user satisfaction and network reliability.

Handover Success Rate (HOSR)

HOSR measures the effectiveness of handover processes in ensuring seamless transitions between cells, particularly during mobility scenarios. The comparison of HOSR between MTN and GLO networks reveals high success rates ranging from approximately 94.0% to 98.81%. These results indicate robust handover mechanisms deployed by both operators, resulting in minimal disruptions and high reliability during user movement. However, slight differences in HOSR across locations and operators may be attributed to network topology, infrastructure deployment, and handover algorithm optimizations.

Conclusion and Future Directions

The findings underscore the importance of efficient handover mechanisms in maintaining network reliability and quality of service in GSM wireless networks. While both MTN and GLO networks demonstrate high levels of performance in terms of CBR, CDR, and HOSR, there are minor variations observed between operators and locations. These variations highlight the influence of factors such as network infrastructure, traffic patterns, and optimization strategies on handover performance.

Further research is warranted to delve deeper into the factors influencing handover performance and to identify opportunities for optimization. Future studies could explore the impact of emerging technologies, such as 5G and beyond, on handover reliability and efficiency. Additionally, investigating novel handover algorithms, optimization techniques, and network configurations could lead to enhanced performance and improved user experience in GSM networks.

The results of the comparative analysis provide valuable insights into the performance of handover mechanisms in GSM wireless networks. By understanding the implications of CBR, CDR, and HOSR variations, network operators can implement targeted strategies to optimize handover performance and ensure continued reliability and quality of service for mobile users.

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