MIKAILALSYS
Journal of Multidisciplinary Sciences

e-ISSN : 2987-2286
p-ISSN : 2987-3924

Index : Dimensions, Scilit, Crossref, Garuda, Semantic, Lens,Google Scholar,Base, etc

https://doi.org/10.58578/mikailalsys.v3i1.4631

Evaluating Handover Processes in Mobile Networks: Effects on Latency, QoS, and User Experience Across Conditions

Mubarak Abdurrahman[1], Mansur Aliyu Gamawa[2], Abubakar Abdulkadir[3], Bala A. M[4], Jamilu Bala Hamza[5], Abubakar Ahmed[6]

[1,2,3,4]Federal Polytechnic Bauchi, Nigeria; [5]Waziri Umaru Federal Polytechnic, Birnin Kebbi, Nigeria; [6]Hussaini Adamu Federal Polytechnic Kazaure, Nigeria

mabdulrahman.ce@fptb.edu.ng; mgaliyu.ce@fptb.edu.ng

Article Info:

Submitted:	Revised:	Accepted:	Published:
Dec 10, 2024	Dec 27, 2024	Jan 7, 2025	Jan 12, 2025

Abstract

The rapid expansion of mobile networks has revolutionized global communication, enabling seamless connectivity for a growing user base. As networks evolve, efficient handover processes—where mobile devices transition between network cells or base stations—are critical to maintaining uninterrupted service. Poorly optimized handovers can result in increased latency, degraded Quality of Service (QoS), and diminished user experience, especially in advanced networks like 5G that demand low latency and high reliability. This study examines the impact of handover processes on key performance metrics such as latency, QoS, and user satisfaction, analyzing their behavior across urban, rural, and heterogeneous technological environments. In densely populated urban areas, frequent handovers risk creating performance bottlenecks, while rural areas face challenges related to sparse infrastructure. Heterogeneous environments, where legacy and next-generation technologies coexist, further complicate efficient transitions. By identifying these challenges, the study proposes strategies to optimize handover efficiency, ensuring seamless connectivity, enhanced QoS, and reduced latency in advanced networks. These findings contribute to improving mobile communication systems, addressing the dynamic demands of 5G and beyond in diverse operational scenarios.

Keywords: Mobile networks, Handover processes, Quality of Service (QoS)

Introduction

Mobile networks are essential to modern communication systems, with growing user reliance on mobile data services driving demand for improved connectivity. Managing user mobility while maintaining robust connections is a fundamental challenge, particularly during handover processes, where a user's connection transitions between network cells. These handovers, classified as hard handovers and soft handovers, play a pivotal role in ensuring service continuity. Hard handovers, which disconnect the current base station before connecting to the next, can introduce brief service interruptions. In contrast, soft handovers allow simultaneous connections to multiple base stations, minimizing interruptions but increasing network complexity. This paper examines the various factors that influence the effectiveness of handover performance. Key elements analyzed include latency, Quality of Service (QoS) parameters, such as throughput and error rates, as well as the overall user experience. Advanced strategies, including machine learning, proactive decision-making, and network slicing, are explored to enhance handover efficiency. A review of existing literature highlights key advancements and persistent challenges. Studies have demonstrated that proactive approaches using predictive algorithms improve handover reliability (Ahmed & Alzahrani, 2019), while multi-connectivity and network slicing mitigate service interruptions in heterogeneous and dense environments (Fotouhi et al., 2014; Li et al., 2016). However, these solutions face limitations such as computational overhead, integration challenges in legacy systems, and high implementation costs. The findings reveal that while soft handovers are generally more efficient in reducing disruptions, they demand increased resource allocation, which may not be feasible in low-power or cost-sensitive networks. Additionally, external factors such as environmental interference, high-speed mobility (e.g., in vehicular networks), and technological disparities between network types further complicate seamless handover implementation. Addressing these limitations is critical for optimizing handover performance, particularly in 5G and beyond (Sun et al., 2017).

Latency During Handover

Latency, defined as the delay between initiating and completing a communication request, is a critical metric for assessing handover performance. In the context of mobile networks, it significantly impacts Quality of Service (QoS) and user experience. The total latency during a handover process can be mathematically expressed as:

$$L_{Total} = L_{signal} + L_{processing} + L_{coordination} \qquad (1)$$

Where;

L_{signal}: Delay due to signaling exchange between the mobile device and base stations

$L_{processing}$: Delay cause by processing tasksat the base stations and mobile device

$L_{coordination}$: Delay introduce bu inter – cell coordination and resource allocation

Efficiency handovers aim to minimize L_{Total} , for example, in a heterogenous network (e.g. (4G to WI-FI) coordination latency may increase due to additional compatibility checks (Souza et al., 2019).

Signal Quality and Handover Probability

Signal strength is a critical factor in handover decision-making within mobile networks. The probability of a successful handover ($P_{handover}$) is influenced by several key parameters, including signal strength (S), user velocity (v), and network load (N). These variables collectively determine the likelihood of maintaining a seamless connection during the handover process. As signal strength decreases or user velocity increases, the success of the handover may be compromised, while network load can impact the available resources for handling the transition efficiently (Ouali et al., 2018). A simplified model is:

$$P_{handover} = e^{-\alpha(S_{threshold} - S)} \cdot e^{-\beta N} \cdot e^{-\gamma v} \qquad (2)$$

Where:

$S_{threshold}$: *Minimum signal strength needed for a successful handover*

α, β, γ: *sensitivity coefficients to signal, load and velocity, respectively*

Impact of Latency on QoS

Latency significantly impacts the Quality of Service (QoS) in mobile networks, influencing metrics such as throughput, packet loss, and user experience. Increased latency results in lower throughput, since the lag in data transfer affects the network's capacity to sustain rapid communication (Tayyab et al., 2019).

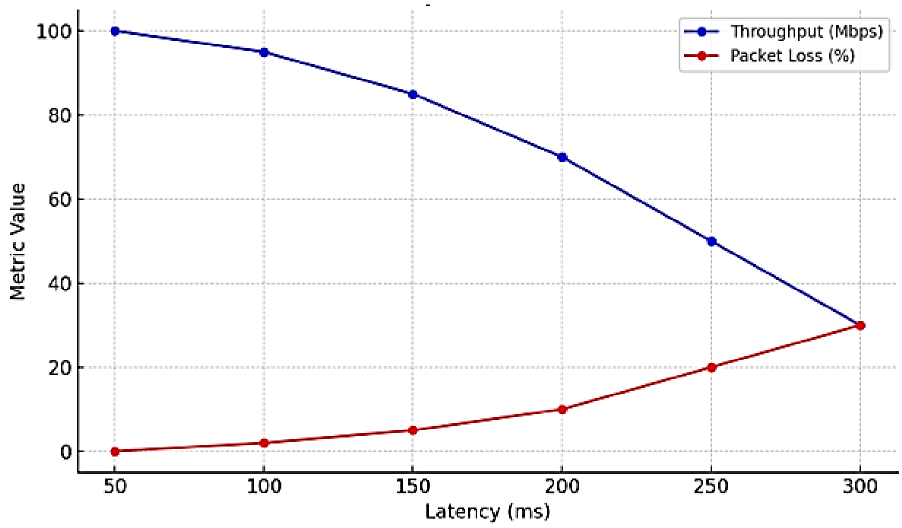

Figure 1: Latency Vs QoS Metrics

Figure 1 illustrates the impact of latency on two critical Quality of Service (QoS) metrics: throughput and packet loss. As latency increases, throughput (blue line) steadily declines from 100Mbps at 50ms to 30 Mbps at 300ms, indicating reduced data transmission efficiency. Conversely, packet loss (red line) rises with increasing latency, from 0% at 50ms to 30% at 30ms, reflecting significant data reliability issues. The inverse correlation between latency and throughput, combined with the direct correlation between latency and packet loss, underscores the negative impact of high latency on network effectiveness. Therefore, achieving low latency is crucial for preserving optimal Quality of Service (QoS), particularly in applications that are sensitive to latency, such as video streaming and real-time communication.

QoS Under Varying Signal Strength

The impact of signal strength on handover success rates is shown in Figure 2. Weak signals below -90dBm, significantly increase the likelihood of handover failures, particularly in congested urban environments.

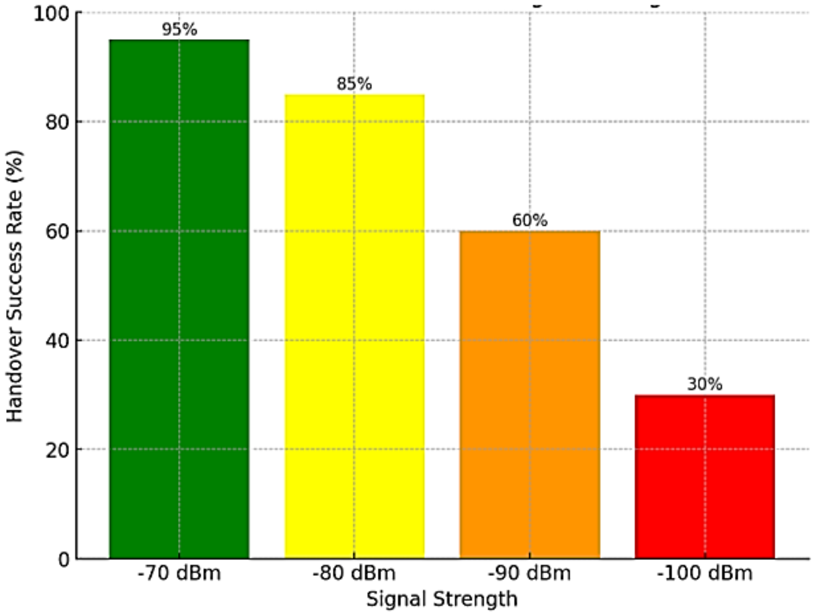

Figure 2: Handover Success Rate Vs Signal Strength

Figure 2 depicts the relationship between signal strength (measured in dBm) and handover success rate (measured in percentage). As signal strength weakens (moving from -70 dBm to -100 dBm), the handover success rate declines significantly. At -70 dBm, the success rate is highest at 95%, but it drops progressively to 85%, 60%, and finally 30% at -100 dBm. This trend highlights the critical role of strong signal strength in maintaining efficient handover processes, with weaker signals leading to reduced reliability. The bars are color-coded (green to red) to visually emphasize this decline.

User Experience in Real-Time Applications

Applications like voice-over-IP (VoIP) and video streaming are sensitive to even minor disruptions caused by handovers. Table 1 summarizes the user experience impact for different latency thresholds.

Table 1: The impact of different latency thresholds during handovers

Latency (ms)	VoIP MOS Score	Streaming Buffering Time (s)
≤ 100	Excellent (4.5)	< 0.5
100 - 200	Good (4.0)	1.0
≥ 200	Poor (2.5)	> 2.0

Table 1 illustrates the impact of different latency thresholds on user experience during handovers. If Latency ≤ 100ms is considered excellent, causing minimal disruption, and ensuring a smooth experience for VoIP and video streaming applications, where users typically experience no noticeable delays or quality degradation. The latency between 100ms and 200ms still results in a good experience, though users may notice slight delays or echoes in VoIP calls and brief buffering or stuttering in video streaming. Latency ≥ 200ms is deemed poor, leading to significant disruptions such as noticeable call delays, poor audio quality for VoIP, and frequent buffering or reduced resolution in video streaming, which severely impacts the user experience (Martin et al., 2019).

Challenges in Urban vs. Rural Environments

Urban environments are characterized by high user densities and significant signal interference, resulting in frequent handovers between cells and an elevated risk of "ping-pong" effects, where mobile devices repeatedly switch between adjacent cells. These frequent handovers can degrade network performance, cause latency spikes, and disrupt the seamless experience that users expect from their mobile services. The complexity of managing network resources increases in urban settings due to high traffic volumes and environmental factors such as tall buildings and other physical obstacles that can obstruct signals (Özkoç et al., 2021).

Conversely, rural regions, despite having a lower population density, encounter a distinct array of challenges. Sparse infrastructure and fewer cell towers in these regions lead to wide-coverage cells with larger gaps between coverage areas. As users move between these areas, they are more likely to experience dropped connections, especially in the absence of robust handover mechanisms. The lack of nearby towers also means that network resources can be strained when users move over long distances, as the nearest cells may be located far apart, leading to slow handover processes and degraded service quality (Vasudeva et al., 2016).

To address the challenges faced in both urban and rural environments, multi-connectivity solutions—such as combining LTE and Wi-Fi networks—offer significant advantages. For instance, proactive handover mechanisms that utilize user mobility patterns can reduce latency by up to 30% (Palas et al., 2021). These solutions enable devices to maintain connectivity through multiple access points simultaneously, enhancing network reliability and minimizing the risks associated with coverage gaps or signal interference. For example, if one connection deteriorates due to interference or network congestion, the device can seamlessly switch to an alternative connection without causing noticeable disruptions for the user. This approach ensures consistent performance, whether the user is in a crowded urban area or a sparsely connected rural location.

Future studies should inspire the development of adaptive algorithms that harness real-time data to elevate handover decision-making effectiveness. These innovative algorithms can seamlessly monitor network conditions, user mobility, and traffic patterns, allowing for dynamic adjustments in handover strategies. By optimizing these essential transitions, they can significantly reduce latency and enhance overall network performance.

Conclusion

In conclusion, the handover process is vital for ensuring smooth connectivity and delivering a positive user experience, especially for real-time applications like VoIP and video streaming. Latency during handovers directly impacts how users perceive the quality of service, with latency below 100ms providing an ideal experience with minimal disruptions. However, as latency increases, even slightly, users may start to notice delays, poor call quality, or buffering, which can detract from the overall experience. Managing handovers effectively, by considering factors like signal strength, user movement, and network load, is key to reducing these issues. The potential of emerging technologies, such as machine learning and context-aware handovers, offers promising solutions to improve this process, especially in the evolving 5G networks, ensuring users enjoy consistent, high-quality service.

References

Ahmed, A. A., and Alzahrani, A. A. (2019). A comprehensive survey of handover management for vehicular ad hoc networks based on 5G mobile networks technology. *Transactions on Emerging Telecommunications Technologies, 30*(3), e3546.

Abraham, J., Kannampallil, T., and Patel, V. L. (2014). A systematic review of the literature concerning the evaluation of handoff tools: implications for research and practice. *Journal of the American Medical Informatics Association, 21*(1), 154-162.

Fotouhi, H., Alves, M., Zamalloa, M. Z., and Koubâa, A. (2014). Reliable and expedited handoffs in low-power wireless networks. *IEEE Transactions on Mobile Computing, 13*(11), 2620-2633.

Li, Y., Cao, B., and Wang, C. (2016). Handover schemes in heterogeneous LTE networks: challenges and opportunities. *IEEE Wireless Communications, 23*(2), 112-117.

Mardis, M., Davis, J., Benningfield, B., Elliott, C., Youngstrom, M., Nelson, B., et al. (2017). The effects of shift-to-shift handoffs on patient safety and outcomes: a systematic review. *American Journal of Medical Quality, 32*(1), 34-42.

Martin, G., Khajuria, A., Arora, S., King, D., Ashrafian, H., and Darzi, A. (2019). The impact of mobile technology on teamwork and communication within hospitals: a systematic review. *Journal of the American Medical Informatics Association, 26*(4), 339-355.

Özkoç, M. F., Koutsaftis, A., Kumar, R., Liu, P., and Panwar, S. S. (2021). The impact of multi-connectivity and handover constraints on millimeter-wave and terahertz cellular networks. *IEEE Journal on Selected Areas in Communications, 39*(6), 1833-1853.

Ouali, K., Kassar, M., and Sethom, K. (2018). Handover performance analysis for managing device-to-device mobility in 5G cellular networks. *IET Communications, 12*(15), 1925-1936.

Palas, M. R., Islam, M. R., Roy, P., Razzaque, M. A., Alsanad, A., AlQahtani, S. A., and Hassan, M. M. (2021). Multi-criteria handover mobility management in 5G cellular networks. *Computer Communications, 174*, 81-91.

Shayea, I., Dushi, P., Banafaa, M., Rashid, R. A., Ali, S., Sarijari, M. A., et al. (2022). Handover management for drones within future mobile networks: a comprehensive survey. *Sensors, 22*(17), 6424.

Sönmez, Ş., Shayea, I., Khan, S. A., and Alhammadi, A. (2020). Handover management for next-generation wireless networks: a succinct overview. *2020 IEEE Microwave Theory and Techniques in Wireless Communications Conference (MTTW), 1*, 35-40.

Souza, D. D. S., Vieira, R. F., Seruffo, M. C. D. R., and Cardoso, D. L. (2019). A novel heuristic for prioritizing handover in mobile heterogeneous networks. *IEEE Access, 8*, 4043-4050.

Sun, Y., Feng, G., Qin, S., Liang, Y. C., and Yum, T. S. P. (2017). The SMART handoff policy for millimeter-wave heterogeneous cellular networks. *IEEE Transactions on Mobile Computing, 17*(6), 1456-1468.

Tayyab, M., Gelabert, X., and Jäntti, R. (2019). A survey of handover management: spanning from LTE to NR. *IEEE Access, 7*, 118907-118930.

Vasudeva, K., Simsek, M., López-Pérez, D., and Güvenç, I. (2016). An analysis of handover failures in heterogeneous networks under fading conditions. *IEEE Transactions on Vehicular Technology, 66*(7), 6060-6074.