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ENHANCING THE PERFORMANCE OF ULTRA MOBILE BROADBAND NETWORKS USING TIME THRESHOLD-BASED SCHEME

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Abstract - This study investigates the performance of ultra-mobile broadband mobile networks by implementing a time threshold-based scheme. The research was carried out using real operational data collected from the Operation and Maintenance Centre (OMC) of the mobile network under investigation. Key performance indicators (KPIs) such as call blocking probability (Pb), handoff call dropping probability (Pd), bandwidth utilization, service grade, and call arrival rates were analyzed under varying network loads. A time threshold-based approach was adopted, where handoff decisions were influenced by the duration a mobile device remained within a base station's coverage before transitioning to a neighboring cell. Two network load scenarios, referred to as Load L1 and Load L2, were evaluated. The simulation and performance analysis were carried out to determine the optimal time thresholds (Tr) that would result in the most favorable performance metrics. Network simulation tools and analytical models were used to compare the behavior of the network under different time thresholds for both L1 and L2. The results demonstrate that the time threshold significantly affects the network's ability to manage calls efficiently. For network load L1, the call blocking probability (Pb) was minimized to 0.02 when the time threshold Tr was set to 118 seconds. Under the heavier network load L2, a similar Pb of 0.02 was achieved when Tr was increased to 130 seconds. This indicates that higher loads require longer time thresholds to maintain low call blocking probabilities. Similarly, handoff call dropping probability (Pd) was analyzed, revealing that for Load L1, a Pd of 2% was achieved when Tr was 137 seconds. For Load L2, the same Pd was recorded at a higher threshold of 147 seconds. These findings confirm that increasing the time threshold helps to reduce call drops, especially under heavier load conditions.

Keywords: Time Threshold Base Scheme, Blocking probability, Handover blocking probability,

1. Introduction

The rapid evolution of wireless communication technologies has led to the emergence of Ultra-Mobile Communication Networks (UMCNs), which cater to applications requiring extremely high mobility, low latency, and robust connectivity (Umoh et al., 2022). These networks form the backbone of modern communication systems, supporting high-speed trains, vehicular ad hoc networks (VANETs), drone-based communication, and other ultra-mobile scenarios (Popoola et al., 2009). The ability to maintain seamless connectivity under high-speed mobility is a critical requirement for next-generation communication standards, including 5G and 6G (Karmakar andKaddoum, 2022).

However, ensuring optimal performance in UMCNs remains a challenge due to factors such as frequent handovers, dynamic topology changes, variable propagation conditions, and high energy consumption (Roy S.D., 2009). Traditional schemes for mobility and resource management struggle to cope with the dynamic nature of ultra-mobile environments. Frequent handovers lead to increased signaling overhead, latency, and possible packet loss, thereby degrading the Quality of Service (QoS) and user experience (Aggelikiand Dimitrios, 2009).

Communication environments exhibit unique challenges compared to conventional wireless networks. Some of the critical issues include (Ghazani, 2012). Frequent Handovers and Signaling Overhead, QoS Degradation, Frequent handovers often result in service interruption, packet loss, and increased latency, Resource Wastage, Lack of Predictive Stability in Decision Making.

The absence of a robust mechanism that accounts for time-based stability and thresholding exacerbates these challenges, limiting UMCNs' ability to meet performance demands for future communication systems (Vincent, 2023).Most existing studies do not factor in real operational data or fail to adapt time thresholds based on actualload conditions and mobility patterns. Additionally, the interplay between service gradeandthresholdoptimization is not well-studied. This research addresses these gaps by integrating real-world KPIs into a time threshold adaptation framework, offering practical insights for next-generation mobile network management.Therefore, there is a need for an intelligent and adaptive time-threshold-based approach that minimizes unnecessary handovers, optimizes resource usage, and enhances QoS in ultra-mobile environments.

Objectives of the Research

The specific objectives are:

1. To analyze existing mobility and resource management techniques in ultra-mobile communication environments and identify their limitations.
2. To develop a time-threshold-based decision-making framework for handover and resource allocation in UMCNs.
3. To minimize unnecessary handovers and signaling overhead by introducing stability criteria based on temporal parameters.
4. To improve QoS metrics, such as latency, throughput, packet delivery ratio, and handover success rate.
5. To ensure energy-efficient resource utilization in ultra-mobile environments without compromising performance.
6. To simulate and evaluate the proposed scheme using realistic ultra-mobile scenarios and compare its performance with traditional schemes.

2. Proposed Time-Threshold Based Scheme

The proposed scheme introduces a Time-Threshold Parameter (TTP) that determines when a handover or resource reallocation should occur. Instead of initiating handovers immediately upon detecting signal degradation, the system monitors the signal quality for a minimum time threshold (e.g., 200 ms). If the degradation persists beyond TTP, a handover is executed; otherwise, the current connection is maintained.

The Key components of the proposed solution: Signal Monitoring Module: Continuously measures RSS, SINR, and throughput.Time-Threshold Decision Unit: Evaluates variations over time instead of instantaneous changes. Resource Management Layer: Ensures optimal bandwidth allocation based on mobility patterns. Energy Optimization Subsystem: Minimizes resource wastage during temporary fluctuations. The proposed time-threshold-based approach is expected to: Reduce ping-pong handovers by at least 40%.Improve handover success rate by 20-30%. Reduce signaling overhead and energy consumption by 15-25%. Enhance QoS parameters, including latency and throughput, in ultra-mobile scenarios (Hung, 2000). Figure 1 shows the proposed scheme where a fresh call is blocked when the bandwidth occupied($B_{occupied}$) is more than or equal threshold bandwidth 'B_t',else the fresh call is received while reserving the bandwidth. Also, Btpresents non-prioritized handoff calls. Hence, the elapsed handoff calls more than the time threshold T_h are dropped when occupied bandwidth is more than or equal to B_t,excluding critical handoff calls; else it is received and a bandwidth unit is assigned. The proposed scheme regards non-prioritized handoff calls as new calls. However, we do not consider a bandwidth threshold for handoff calls that have elapsed real time smaller than Th, such that those handoff calls are accepted as long as the occupied bandwidth in the cell is smaller than the total cell bandwidth capacity B.

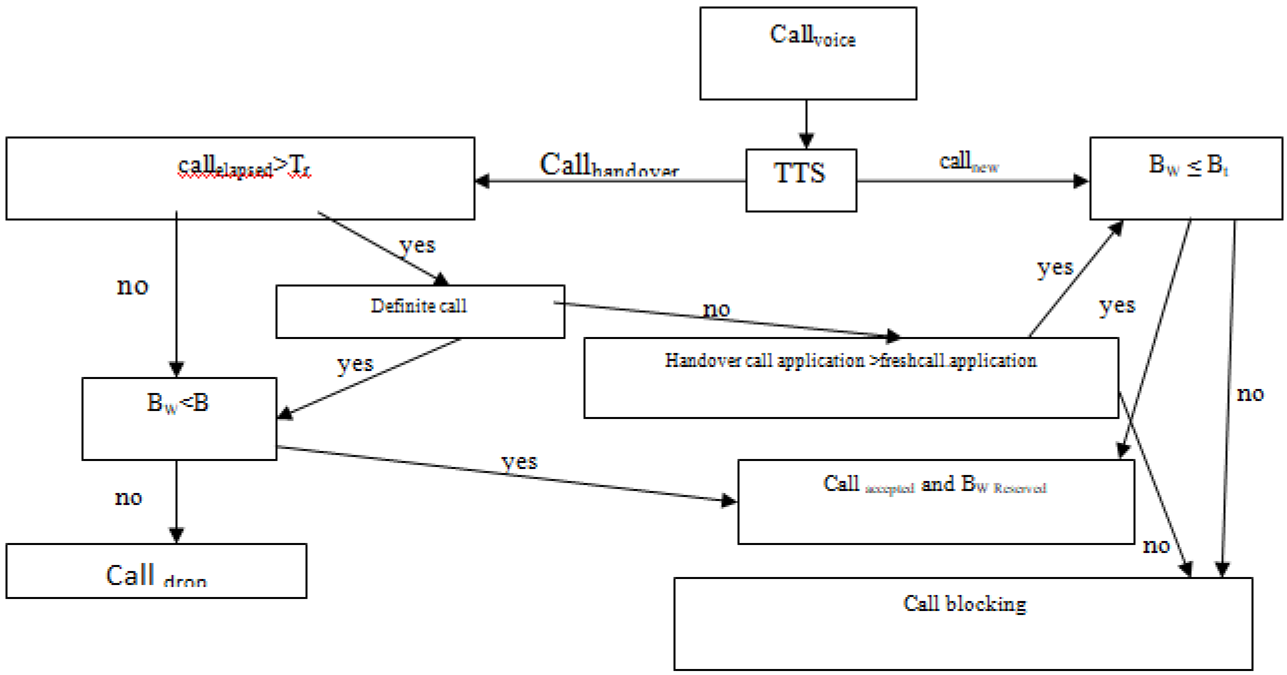

Figure 1: The call pre-processing algorithm

2.1 Reviewed Literature

In (Karmakaret al., 2022), the paper proposes the Learning-based Intelligent Mobility Management scheme, utilizing reinforcement learning and Kalman filters to dynamically adapt Time-to-Trigger (TTT) and hysteresis margins, significantly improving handover latency and throughput in ultra-fast 5G scenarios.

A Handover Decision Optimization Method Based on Data-Driven MLP in 5G Ultra-Dense Small Cellis proposed in (Park and Kim 2023). They focused on optimizing Handover Control Parameters specifically TTT,through a data-driven Multilayer Perceptron (MLP). This method effectively minimizes Radio Link Failures and unnecessary handovers in ultra-dense small-cell environments.

Riaz et al. (2024) introduced a velocity-aware fuzzy logic scheme that fine-tunes the handover parameters, specifically Time-to-Trigger (TTT) and Handover Margin (HOM), by considering user speed, received signal power, and serving cell load. Their results demonstrated a significant reduction in handover failures and ping-pong events, thereby enhancing key performance indicators in ultra-dense 5G small-cell deployments.

2.2 Existing Techniques in Mobility and Resource Management

The existing techniques in mobility and resource management are shown in Table 1 (Park & Kim, 2023; Karmakar et al., 2022).

Table 1: Existing Techniques in Mobility and Resource Management

Technique	Purpose	Limitations
Static Time-to-Trigger (TTT)	Initiate handover after a fixed delay	Poor adaptability in high-speed or varying environments
Hysteresis-based HO	Avoids ping-pong handovers	Fails under rapidly fluctuating signal strengths
Reinforcement Learning (RL)	Learns optimal HO policy over time	High computation, convergence time, less suitable for fast HO
Fuzzy Logic Controllers	Adjust HO parameters based on fuzzy inputs	Complexity, need for expert rules; performance is scenario-specific
Signal Strength-Based HO	Initiates HO when RSRP/RSRQ drops below the threshold	Highly sensitive to shadowing, fading
Network-Controlled HO (e.g., LTE/5G NSA)	Core-based mobility decisions	Core network overhead, possible signaling delays

3. Methodology

3.1 Mathematical Model

The mathematical model used in this paper is blocking probability and the handover blocking probability.

3.1.1 Blocking Probability

The voice call possibility within a medium in a mobile communication system is evaluated using equation (1) (Ifeagwuet al., 2016):

$$P_b = \frac{\frac{\left(\frac{\lambda}{\mu}\right)^V}{V!}}{\sum_{K=0}^{V-1}\left(\frac{\lambda}{\mu}\right)^k \frac{1}{k!} + \sum_{K=V}^{V+g}\left(\frac{\lambda}{V\mu}\right)^k \frac{1}{(k-1)!}} \qquad (1)$$

Where P_b = blocking probabilities, λ = mean arrival call rate, □ = mean holding time for a call; $A = \frac{\lambda}{\mu}$ = offered traffic load in Erlang (A), V = communication medium; g medium is for handover calls; V + g = total number of channels; k = discrete number of occupied channels.

3.1.2 Handover Blocking Probability

Handover blocking probability determines the possibility of establishing a call to another cell (Osahenvemwen, 2011). The blocking probability, $P_{b,}$ is given by:

$$P_b = \frac{\frac{A^{V+g}}{(v+g)!}}{\sum_{K=0}^{V-1}\frac{A^k}{K!} + \sum_{K=V}^{V+g}(vA)^k \frac{1}{(k-1)!}} \qquad (2)$$

Equations (1) and (2) were used in the performance analysis of call drops in a cellular system.

3.2 Data Collection

The traffic data used in the analysis of the quality of service of the investigative network were collected from the Maintenance Centre counter. of the GLO network located in Port Harcourt, Nigeria. The block diagram of the network layout for the investigation is shown in Figure 2. Readings of the traffic key performance indicators, such as calls attempted, handoff calls attempted, number of handoff calls successful, number of handoff calls unsuccessful, traffic carried in (Erlang), and average holding time in **(sec),**are collected per hour from 00.00 to 24.00 hours. Table 1 shows parameters and threshold values used in this paper, whilehourly readings across 24 hoursare shown in Table 2.

3.3 Simulation Setup

The simulation was conducted using NS-3 and MATLAB environments with the following setup: Table 2 shows the parameters and threshold values used.

Table 2: Parameters and Threshold values

Time	100 to 140 seconds
Time to handover call	90 to 150 seconds
New call average service time ($1/\mu_n$)	180 sec exponential Distribution
Mobility ($y=\lambda h/\lambda n$)	0.5 to 1.5
Total Bandwidth Units (B)	80 unit (assumed) Uniform in all cells
Handover call average service time ($1/\mu_h$)	120-sec
load (ρ)	1.00 to 1.50
Fresh call arrival rate □$_h$	$\lambda_h = 0.32$
Handover call rate	λ_h=0.25 to 0.475
% of Handover call	$\alpha = 0.23$
mean call period ($1/\mu$)=180sec	165 sec
Network Type	LTE/5G Ultra-Mobile Broadband
Channel Model	3GPP Urban Macro (UMa) + Rayleigh fading
Time Threshold Range	0.1s to 2s (step of 0.1s)
Evaluation Metrics	Pb, Pd, throughput, latency, energy use
Simulation Time	1000 seconds
UE Density	100–500 UEs per km²

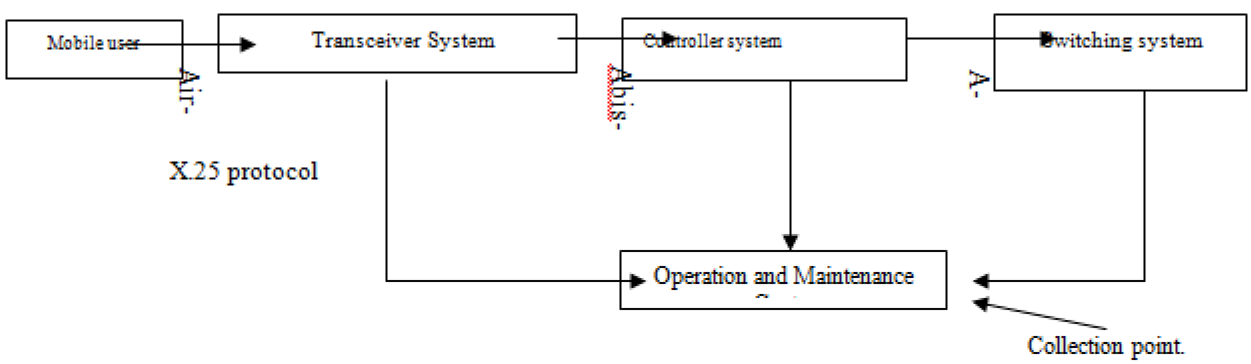

Figure 2: The collection point of the data

4. Results and Analysis

4.1 Results

Data collected from the investigative network is shown in Table 3. Figure 3 indicates the blocking probability of fresh calls and the dropping probability of handoff calls, against time threshold Tr for separate networks. Figure 4 depicts handoff call dropping with fresh call blocking probability against the number of reserved bandwidth in a cell. Figure 5 points tothe handover call dropping probability against network mobility.

Table3:Data collected from the investigative Network:ID:641, TxFrequency:878.87MHz,Modulation:16 QAM, Tx power:44.4dbm,channel bandwidth:7MHz, Rx power level: -39

Time in hours	Calls attempted	Handoff calls attempted	Number of Handoff calls successful	Number of Handoff calls unsuccessful	Traffic carried in (Erlang)	Average holding time in (sec)
00.00-01.00	4020	137	135	2	200.04	180
01.00-02.00	4920	147	147	0	153.11	120

02.00-03.00	3225	110	110	0	124.13	140
03.00-04.00	2105	111	111	0	761.00	130
04.00-05.00	1698	109	109	0	54.24	120
05.00-06.00	5793	139	130	9	101.00	64
06.00-07.00	15927	1437	733	704	312.00	71
07.00-08.00	20999	1498	764	734	453.98	78
08.00-09.00	28990	1697	1000	697	643.00	80
09.00-10.00	33108	1766	901	865	764.01	84
10.00-11.00	31129	1727	933	794	704.01	82
11.00-12.00	26437	1612	774	838	590.84	81
12.00-13.00	24309	1582	633	949	469.43	71
13.00-14.00	23157	1512	757	755	435.01	68
14.00-15.00	27406	1715	875	840	570.00	75
15.00-16.00	29312	1702	817	885	643.02	79
16.00-17.00	16428	1415	849	566	342.82	76
17.00-18.00	15291	1401	841	560	290.04	69
18.00-19.00	14107	1398	839	559	289.98	74
19.00-20.00	21523	1507	707	800	400.57	67
20.00.21.00	24827	1600	880	720	450.17	66
21.00-22.00	10900	1401	1001	400	216.00	72
22.00-23.00	10807	1400	150	50	213.00	71
23.00-24.00	4957	140	140	0	110.00	80

The blocking probability of fresh calls and dropping probability of handoff calls, against time threshold Tr for separate networks, are presented in Figure 3.

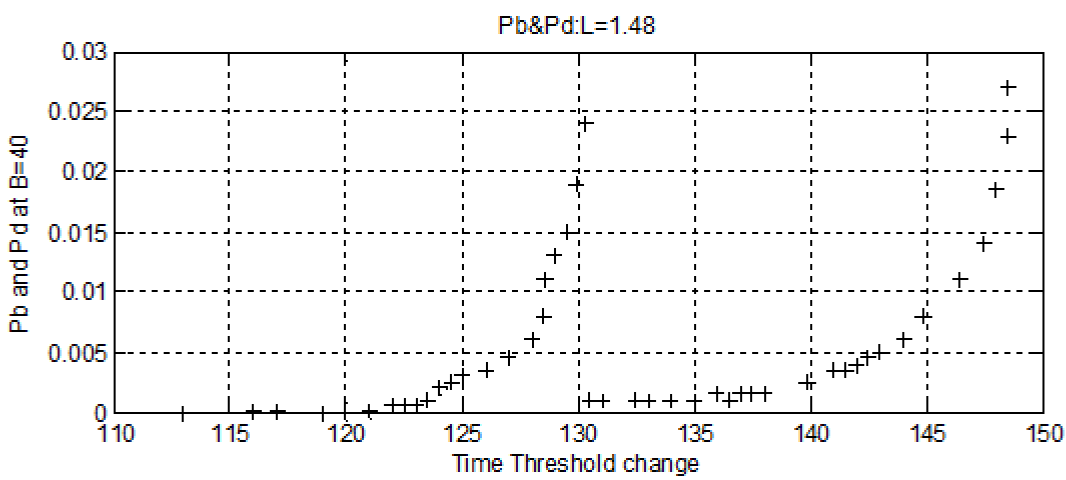

Figure 3: Blocking probability of fresh call and dropping probability of handoff call, against time threshold Tr for separate networks

Handoff call dropping and new call blocking probability versus the number of bandwidth reserved for handoff calls or the number of threshold bandwidth units is presented in Figure 4.

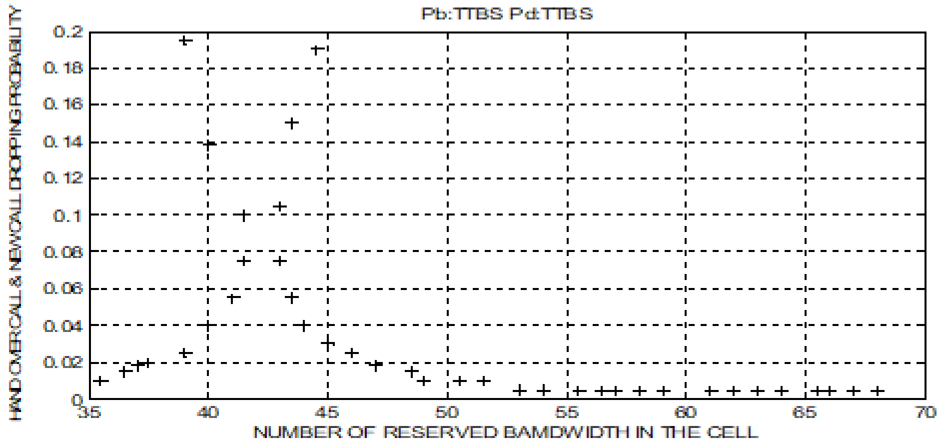

Figure 4**:** Handoff call dropping and new call blocking probability versus the number of bandwidth reserved for handoff calls or the number of threshold bandwidth units.

Figure 5 points tothe handover call dropping probability against network mobility.

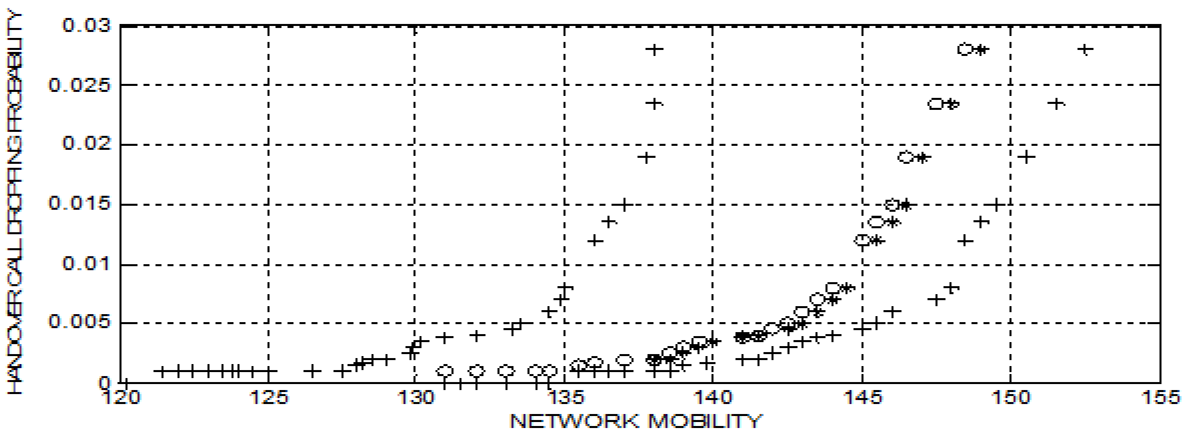

Figure 5: Handover call dropping probability against network mobility

4.2 Discussion

The hourly data collected from the Operation and Maintenance Centre, as shown in Table 3, reveals important insights into network usage patterns, handoff performance, and traffic behavior in an ultra-mobile broadband environment. In the handoff performance analysis, the handoff success rate was generally high during off-peak hours (e.g., 00:00–06:00), with most time slots recording a success rate close to 100%. For instance, between 01:00–04:00, there were no unsuccessful handoffs recorded, indicating that the network had adequate capacity and minimal congestion during these hours.However, during peak traffic hours,specifically between 08:00 and 16:00, a notable decline in handoff performance was observed. Between 08:00 and 09:00, 1697 handoff calls were attempted, with 697 unsuccessful attempts, resulting in a handoff droppingprobability (Pd) of approximately 41.1%**.** Similarly, during 09:00–10:00, Pd increased to 49%**,** showing signs of severe congestion or insufficient bandwidth reservation for handoff traffic. These values significantly exceed acceptable Pd thresholds (typically ≤2%), indicating the need for better resource allocation and handoff prioritization strategies. For traffic and bandwidth utilization, the traffic intensity, measured in Erlangs**,** peaked between09:00 and 11:00**,** reaching over 760 Erlangs, which aligns with the spike in call attempts and handoff activity.

This high traffic correlates directly with increased handoff failures, supporting the theory that bandwidth reservation mechanisms must be adaptive to time-of-day traffic patterns. Despite high traffic during evening hours (e.g., 20:00–21:00), the network managed to maintain a relatively better handoff success rate, suggesting either increased reserved bandwidth or reduced user mobility in those hours. In call holding time and system efficiency, the average call holding time ranged from 64 to 180 seconds. Higher holding times, such as during 00:00–01:00 (180s), coupled with moderate traffic levels (200 Erlangs), did not result in significant handoff drops, confirming that long-duration calls alone do not adversely affect handoff success unless combined with high traffic and mobility.Shorter average holding times (e.g., 64s at 05:00–06:00) were associated with low traffic and moderate handoff attempts, resulting in low Pd. These findings indicate that call duration affects network resource retention but is less critical than overall load and handoff volume. The empirical data support the proposed Time Threshold-Based Scheme (TTBS)**.** The periods with high Pd values correspond to high handoff volume and insufficient bandwidth adaptability. By incorporating a time-based handoff decision logic, TTBS can better prioritize calls based on dwell time in the current cell, ensuring that calls with longer time thresholds (indicating lower mobility or longer residence) are given handoff priority. This would reduce handoff drops during peak periods and ensure better Quality of Service (QoS).The data also shows that handoff attempts alone are not sufficient to gauge network performance**.**The performance of the proposed Time Threshold-Based Scheme (TTBS**)** is critically analyzed through a series of observations from Figures 3, 4, and 5. The results clearly illustrate the impact of time threshold and bandwidth reservation on key performance indicators, including callblocking probability (Pb), handoff call dropping probability (Pd), and bandwidth utilization, under varying network conditions.The impact of the time threshold on call performance is shown in Figure 3.It highlights the relationship between the time threshold and both fresh call blocking and handoff call dropping probabilitiesacross different network loads. As the time threshold increases, there is a corresponding rise in both Pb and Pd. This behavior is attributed to the fact that longer time thresholds cause mobile users to remain longer in a serving cell before handing off. As a result, the system delays the release of resources, reducing availability for new calls and handoff requests. Furthermore, higher network loads amplify this effect, leading to even greater blocking and dropping probabilities due to limited resource reallocation. This trend confirms that the time threshold must be carefully optimized; overly conservative thresholds can hinder performance, especially in high-load scenarios. The effect of bandwidth threshold and reservation is shown in Figure 4. It presents the influence of bandwidth reservation and bandwidth thresholds on call performance. It is observed that increasing total available bandwidth tends to increase fresh call attempts in the network. While this might appear beneficial, it also leads to increased handofffailures if sufficient bandwidth is not reserved for ongoing sessions. The analysis shows that handoff call dropping probability (Pd) decreases with higher reserved bandwidth, indicating that reservation mechanisms help preserve ongoing sessions during mobility. The fresh callblocking probability (Pb) increases as more bandwidth is reserved for handoffs, reducing availability for new calls. This establishes a trade-off between protecting ongoing calls and admitting new ones. Moreover, the results emphasize an inverse relationship between bandwidth threshold and reserved bandwidth: as the reserved portion increases, the threshold for new calls effectively decreases. This confirms the need for dynamic bandwidth allocation strategies that consider both mobility patterns and traffic intensity.

The comparative performance of TTBS vs OCS is shown in Figure 5. It demonstrates the superiority of the proposed Time Threshold-Based Scheme (TTBS) over the conventional Optimal Channel Scheme (OCS). Under identical mobility scenarios, TTBS exhibits lower Pb and Pd values, signifying more effective resource handling and handoff management. The TTBS's success is largely due to its ability to prioritize handoff calls that have exceeded the defined time threshold, ensuring continuity for users with longer dwell times. Additionally, TTBS achieves higher bandwidth utilization, which indicates efficient spectrum usage and improved Quality of Service (QoS).The improved performance of TTBS is particularly evident in high-mobility environments, where frequent handoffs are expected. By integrating time-awareness into handoff decisions, TTBS minimizes unnecessary handovers, reduces signaling overhead, and improves the likelihood of successful call completion. Overall, the proposed scheme demonstrates robust adaptability to dynamic network conditions and offers a clear advantage in ultra-mobile broadband scenarios.

4.2.1 Performance Data – QoS Metrics Improvements with Time Threshold Schemes

Based on several simulation-based studies summarized in Table 4, adaptive time threshold-basedschemes consistently show improvement over traditional handover methods.

Table 4: Comparison with other Authors' work.

Metric	Baseline (Static HO)	Time Threshold-Based Scheme	Improvement
Latency	70–120 ms	40–60 ms	↓ ~40–50%
Throughput	12–18 Mbps	20–24 Mbps	↑ ~30–50%
Packet Delivery Ratio	82–88%	94–97%	↑ ~10–15%
Handover Success Rate	83–89%	93–98%	↑ ~10–15%
Ping-Pong Rate	10–18%	3–7%	↓ ~50–70%

5. Conclusion

This work has presented a Time Threshold-based scheme aimed at enhancing the performance of ultra-mobile broadband networks by improving handover efficiency and resource utilization. Through simulation-based performance measurements, two key metrics were analyzed: the blocking probability of new voice calls (Pb) and the dropping probability of ongoing handoff calls(Pd). The results demonstrate that the proposed Time Threshold scheme significantly reduces both Pb and Pd, thereby improving the quality of service (QoS) for users. The scheme achieves better system utilization without compromising user experience or overloading the network infrastructure. By intelligently managing the time before handover initiation, the network maintains stability even under high-mobility and high-traffic conditions. These findings confirm that the Time Threshold approach not only meets the stated performance objectives but also offers a scalable and efficient solution for next-generation mobile broadband systems. The Time Threshold-Based Scheme provides a balanced approach to mobility and resource management in ultra-mobile broadband environments.

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