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*Research Article*

# User Preference-Based Heterogeneous Network Management System for Vertical Handover

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Vertical handover management plays an essential role in wireless network technologies, mainly due to the rapid development of various radio access technologies (RATs) that require users to connect seamlessly from one RAT to another. However, in multiple RAT environments, vertical handover management encounters different challenges, including unnecessary handovers, handover failures, ping-pong handovers, and unsuitable access network selection. Essential in vertical handover management is maintaining the desired quality of service (QoS) by the mobile device user. The seamless movement of mobile device users as they run various applications depends on a well-performing vertical handover decision-making algorithm. This bears special significance in a heterogeneous network environment. This paper proposes a vertical handover algorithm that considers user preferences (i.e., a vertical handover algorithm that evaluates the application currently running on a user device). The main objective of the algorithm is to determine when it is necessary to perform the handover, depending on the applications running on the mobile device. The proposed algorithm utilizes a fuzzy logic system to assess whether the handover is necessary and a multiattribute decision-making (MADM) method to select the best available radio access network. A simulation scenario involving different applications at various mobile device velocities was developed. The results proved the algorithm's effectiveness compared to some of the earlier proposed vertical handover algorithms. At velocities below 10 m/s and 30 m/s, the proposed algorithm had 0% and 15.02% unnecessary handovers, respectively, while the technique for order preference by similarity to ideal solution (TOPSIS) utility's function-based algorithm obtained 12.38% and 23.24% at the same velocities, respectively. In addition, compared to TOPSIS, the obtained results of the proposed algorithm demonstrated a lower handover failure rate and ping-pong rate for a velocity span of 1–30 m/s for the considered user applications.

## 1. Introduction

Mobile phone usage has exponentially increased in recent years. It was estimated that there were 5 billion smartphone users in the year 2020 [1]. Due to this exponential and rapid growth, new techniques must be used with existing network technologies to create effective network management solutions [2]. One challenge in wireless communication systems is maintaining constant connectivity without service interruptions during mobile device movement [3]. The mobile device experiences a vertical handover procedure as it switches from one access network technology to another. This movement could lead to ping-pong effects and service outages. An effective handover algorithm is necessary for the handover procedure to continue with good quality of service (QoS). A good handover decision in wireless communication should avoid needless handovers, reduce system interference levels, shorten handover times, and ensure QoS during the handover process [4].

Heterogeneous wireless networks combine several access network technologies, such as wireless local area networks (WLANs), fourth generation (4G), fifth generation (5G), and worldwide interoperability microwave access (WiMAX) networks. The main aim of integrating diverse access network technologies is to complement each other [5]. Heterogeneous wireless networks support various forms of traffic, including voice, video, and web traffic. Heterogeneous networks will play a significant role in achieving higher data transmission rates, especially during the development of 5G and other generations or future technologies. More cells, such as picocell and femtocell, are also introduced to support higher data transmission rates [6].

Mobility scenarios, network parameters, decision algorithms, and processes are significant parameters in vertical handover management. Initially, seamless changeover and automatic network switching were vertical handover's main challenges. To solve this, single-criterion methods, including the traditional received signal strength (RSS) techniques, were developed. These techniques rely solely on RSS in the handover decision-making process. Its key objective is to maintain connectivity as the mobile device user traverses across a cell with heterogeneous networks. Functional-based handover decision-making techniques were also created to choose the best access network technology to switch to in a heterogeneous network by utilizing a cost function [7].

Due to the different network users' preferences in a heterogeneous network, users should be able to connect seamlessly to a network that meets their applications' requirements. Therefore, vertical handover management decisions should involve various network parameters, including mobile device velocity, network delay, RSS, data rate, bit error rate (BER), and user preference. This ensures that different network users' needs are met [8]. Most factors related to vertical handover decision-making lack precision because network parameters are constantly changing, impacting the performance of vertical handover. This is most evident in high-mobility scenarios, as accuracy is affected. Furthermore, factors such as user preferences cannot be quantified. The fuzzy logic technique presents an effective way of dealing with such systems due to its ability to manage uncertainty attributes while minimizing complex arithmetic computations in handover decisions. This, in turn, improves the accuracy of the handover decision-making process [9].

Modelling network selection in a heterogeneous network environment can be formulated as a multiattribute decision-making (MADM) problem. This is due to the multiple factors involved in the vertical handover decision-making process, which include network attributes, user preferences, and candidate network, QoS characteristics [5, 10]. The various MADM methods include analytic hierarchy process (AHP) [11], fuzzy analytic hierarchy process (FAHP) [12], simple additive weighting (SAW) [13], multiplicative exponent weighting (MEW) [14], technique for order preference by similarity to ideal solution (TOPSIS) [15], and simple multiattribute rating technique (SMART) [16], and others. Although these methods provide an efficient way of ranking the alternatives, neither has been capable of entirely providing a perfect ranking, from the best to the worst-performing alternatives. Two ways have been proposed to overcome these flaws: improving one method or combining the methods to achieve comprehensive outcomes [17]. Work has been done on intelligent techniques for selecting the best network in a heterogeneous environment, such as neural networks [2] and context-aware decision-making strategies [7]. These methods are effective due to their high accuracy in selecting a suitable network in a heterogeneous environment. However, these strategies may select the unsuitable network if they are not appropriately optimized and produce undesirable results [8].

This paper develops a vertical handover algorithm that initiates the vertical handover, when necessary, by utilizing the fuzzy logic technique. The algorithm also selects the suitable network depending on the user preference using MADM methods. AHP, FAHP, and SMART methods calculate normalized weights that indicate the mobile device user's requirements. SAW and TOPSIS methods are used to rank the available access networks by employing the normalized weights and various normalized network attributes to select the suitable one. This paper's contributions are as follows:

(i) We developed a vertical handover management system that considers network parameters (data rate, delay, BER, mobility, security, and cost of service), mobile device velocity, and applications (conversational, streaming, interactive, and background) in vertical handover decision-making.
(ii) We proposed a QoS-based vertical handover algorithm that determines vertical handover necessity using a fuzzy inference system and network selection using MADM methods.
(iii) We developed an algorithm that considers the existence of a heterogeneous network consisting of four-access technologies (4G, 5G, WLAN, and WiMAX).
(iv) We designed a system that achieves low unnecessary handovers, handover failure, and ping-pong handover rates, which can reduce service interruptions and ping-pong effects and save mobile device power.

The remaining structure of this paper is as follows. Section 2 reviews related work involving vertical handover decision-making methods. Section 3 comprehensively discusses the methodology for developing the proposed user preference-based vertical algorithm. Section 4 details the results and discussion, and finally, the conclusion and future recommendations are discussed in Section 5.

## 2. Related Works

Several approaches for managing vertical handovers have been explored in the literature. Handover decision is the essential part of these techniques. In making the vertical handover decisions, various network parameters are collected and analyzed to determine if the handover is necessary or the best available access network.

In [18], the authors reviewed various past, present, and future RSS-based vertical handover techniques. The review focused on three types of RSS-based handovers: RSS threshold, dwell timer, and prediction technique. The RSS threshold-based vertical handover utilized RSS as its only decision criterion [19]. The main advantage of this method is its simplicity and fast speed in arriving at a decision.

However, the main disadvantage of this method is that it presents high handover rates and unwanted ping-pong effects, making it undesirable for use. In minimizing the high handover rates and the ping-pong effects caused by the ever-changing RSS, authors in [20] suggested the dwell timer-based handover technique as a possible solution. Although this method minimizes the ping-pong effects, it could lead to handover failures at high traveling speeds since the mobile device may be prompted to leave the serving base station before the dwell time elapses. Yew et al. [18] proposed a prediction-based handover technique at high-speeds environment. Although this scheme reduces unnecessary handovers and handover failures in a high-speed environment, its major shortcoming is high power consumption. Also, it needs to be complemented with another method in selecting a suitable access network.

Goatam et al. [21] utilized fuzzy logic to develop a QoS-based vertical handover decision-making algorithm. This method reduced the complexity and time required in the vertical handover decision-making process. Also, the algorithm could be evaluated to accommodate more network parameters. A drawback presented in this method is the occurrence of unnecessary vertical handovers due to the ever-changing network parameters. Research has been done on intelligent algorithms due to their optimization capabilities [2, 22]. In [2], the authors designed a vertical handover algorithm using a back propagation neural network. The algorithm's design considered a heterogeneous network environment comprising UMTS, GPRS, WLAN, 4G, and 5G radio access technologies. Although this method improves the handover success rate, the dynamic network parameters may lead to unreliable prediction if enough data for training is not used. Also, not all mobile user preferences are addressed by a single parameter, i.e., the download rates.

In [5], a network selection algorithm utilized by a multiservice multimode device in a heterogeneous network was proposed. The algorithm addressed the diverse user preferences during the handover. The authors considered three access networks: UMTS, WLAN, LTE-A, and GSM. Although they managed to achieve their key objectives, which were an optimal network selection handover and unnecessary handover avoidance, they did not consider the issue of user mobility and the dynamic network attributes, which are critical factors in analyzing the handover process. Also, the combination of various complex functions may delay the handover decisions.

In [23], an intelligent vertical handover decision-making management system utilizing fuzzy logic was proposed to conserve energy in mobile devices operating in a heterogeneous network. The system demonstrated high efficiency in energy saving and maintaining the quality of experience (QoE) for transmitted videos. However, how the system performs under different network conditions and how changing certain aspects affect it are some areas related to its limitations that the authors could discuss. Gupta et al. [24] addressed the call-dropping problem during vertical handover by proposing a predictive model that utilizes fuzzy logic. Their system achieved lower delay and better bandwidth utilization than earlier proposed fuzzy logic-based algorithms. However, it did not consider mobility scenarios in a heterogeneous environment. Patil et al. [25] proposed a vertical handover technique using fuzzy logic in heterogeneous networks. The system involved three stages: handover decision, network selection, and handover execution. However, in the first stage, the vertical handover decision was solely based on data rate, neglecting other parameters affecting QoS, such as delay.

Alhammadi et al. [26] proposed a mobility management scheme to address handover challenges in 4G/5G networks. Handover parameters were optimized by using a fuzzy weighted self-optimized technique, considering signal-to-interference plus noise ratio (SINR), traffic load, and user equipment velocity. It achieved low radio link failure, handover ping-pong probability, and handover failure rates. Adopting this approach could improve handover procedures' performance in heterogeneous networks. However, further investigation can be done to establish how successful this method performs in real-world environments and compare it to other pre-existing algorithms. In [27], a fuzzy-coordinated self-optimizing handover technique was proposed to address handover problems in 4G/5G heterogeneous networks. The scheme focused on mobility robustness and load-balancing parameters, achieving low handover ping-pong probability, low handover latency, low radio link failure, and low outage probability. Although this approach may work well in some situations, it might not meet the requirements for more sophisticated networks or dynamic surroundings.

In [28], the authors proposed a conflict resolution technique between optimizing mobility robustness and load-balancing functions. The authors used handover attributes such as time to trigger, handover margin, cell load, user speed, and received signal reference power. The proposed system achieved a low handover failure rate, demonstrating its effectiveness. However, exploring the current and recommended future network management strategies could assist readers in getting a more comprehensive outlook into the existing state of research regarding handover management in 4G/5G networks. In [29], the authors used a prediction technique to resolve conflicts in cellular networks when self-optimization functions like mobility load balancing and mobility robustness optimization conflict. The system used a prediction model built with machine learning to determine the best compromise solution. Although this technique demonstrated its efficiency in solving the conflict, the work lacked an exact assessment of shortcomings related to the recommended system and how it could be applied practically. Further investigation is crucial to assess whether the suggested structure performs effectively in real-world scenarios.

Sönmez et al. [30] reviewed the significance of handover in future cellular networks and discussed challenges and expected solutions. They indicated self-organized networks (SON) and machine learning as potential tools to overcome handover challenges. The authors of [31] reviewed different handover decision-making strategies, their input parameters, and performance evaluation. The review outlined challenges and potential solutions related to handovers, including software-defined networks, machine learning, deep learning, dual connectivity, data-driven handovers, and digital twins. As per the authors' recommendations, implementing machine learning technology with deep learning mechanisms can be helpful in optimizing the handover management process within mobile heterogeneous networks to ensure uninterrupted connectivity during the handover.

In [32], the authors surveyed the current mobility robustness optimization (MRO) research in future mobile heterogeneous networks. The reviewed literature focused on mobility robustness optimization, mobility prediction, and network selection techniques. The survey discussed possible research directions for setting handover self-optimization, including optimal handover self-optimization function, utilization of machine learning techniques in handover, dual connectivity, conditional handover, deep reinforcement learning, and data-driven handover optimization.

In [33], the authors analyzed the application of machine learning methodologies to develop advanced MRO models for future mobile networks. The techniques discussed involved supervised, unsupervised, and reinforced learning. Thus, extensive discussion of the potential of machine learning solutions was articulated in the article on creating future mobile network optimization models that focus on improving MRO. Handover control parameters' (HCPs) effectiveness on 5G and beyond mobile network (B5G) handovers was explored by the authors in [34]. The researchers evaluated different system settings with different mobile velocity scenarios to identify their influence on the performance of the network. In addition, the authors presented a comprehensive evaluation of the effects of multiple HCPs on handover performance, including reference signal received power, radio link failure (RLF), handover probability, handover ping-pong, handover failure, and handover interruption time. Although the authors demonstrated the tradeoff between RLF and handover ping-pong with various HCPs settings in B5G mobile networks, their studies solely considered fixed HCPs.

In their study, Wasan et al. [35] examined load-balancing self-optimization (LBSO) in 5G mobile networks. The authors built a simulation model to investigate and evaluate LBSO in various mobile speed scenarios. Optimization techniques, including the cost function, distance, and fuzzy logic techniques, were based on previous studies, and their performance was evaluated based on varying speed scenarios. Furthermore, the authors conducted the network evaluation and analysis regarding spectral efficiency, ping-pong handover probability, and RLF. In addition, the authors examined prospective opportunities for future research and paths to explore in LBSO. Although their results demonstrated that optimizing using the distance technique provided better outcomes in system performance than cost function and fuzzy logic optimization methods when assessed at varying speeds, the article did not give a conclusive performance comparison of its findings with previous studies.

Satapathy and Mahapatro [36] addressed the drawbacks of using a single criterion in the vertical handover decision-making process, such as using RSS in the handover decision-making, in their paper. The authors proposed a two-step execution procedure that first evaluates the handover necessity and generates practicable solutions to formulate the vertical handover as a multiobjective optimization problem. After the initial step, the second step entails using FAHP and TOPSIS methods. Their algorithms had some remarkable improvements over earlier algorithms in terms of low handover rates, delay, cost, and energy consumption. However, limited information was used to determine user satisfaction; the authors used a single criterion, the RSS, to determine if it is necessary to initiate the handover.

The authors of [37] presented a context-aware algorithm adaptable to network specifications and needs variations. They presented a channel allocation method that considers handover call traffic first. Furthermore, they integrated an efficient network scanning technique in the algorithm to reduce energy consumption and maintain uninterrupted service. In their research work, the authors also proposed a utility function-based cell load-balancing mechanism to optimize cell resource allocation. Compared to some existing work, the proposed algorithm shows a notable enhancement in call-blocking probability, channel utilization rate, energy consumption, and handover delay. However, the authors could have demonstrated the applicability of static contextual information's relevance in a real-world scenario heterogeneous network.

The main goal of most of the literature surveyed was to achieve a seamless vertical handover. Nevertheless, existing literature has not exhaustively addressed the vertical handover concerns in a heterogeneous network environment. Factors such as mobile device mobility, diverse mobile device user preferences, and dynamic network parameters present a challenge in maintaining the QoS during the existing vertical handover procedures. Minimizing unnecessary handovers to avoid ping-pong effects, service interruptions, handover failures, and wastage of resources is also a factor that the vertical handover procedures have not fully addressed. Although various user preferences-based vertical handover algorithms, including MADM methods, have been proposed in the literature, most have only focused on the satisfaction of mobile device user requirements during the network selection. Others have utilized a single criterion to determine mobile user satisfaction during the handover initiation. More research needs to be conducted on aspects concerning the necessity of handover and network selection based on user preferences during the vertical handover process. The main contribution of this work is the ability of the proposed algorithm to determine if the user preferences are satisfied before and after the vertical handover. After evaluating various network parameters, the algorithm utilizes a fuzzy inference system to determine if handover is necessary based on the network traffic (application) running on the mobile device. In addition, the algorithm evaluates and selects the suitable access network according to the application running on the mobile device after evaluating the respective network attributes.

## 3. Methodology

*3.1. Algorithm Model Formulation.* In a heterogeneous network environment, vertical handover involves the transfer of the mobile device connection from one access network technology to a different access network technology. This section describes of how the user preference vertical handover algorithm was developed. The handover initiation algorithm is first developed based on a fuzzy inference system, which determines the handover necessity. A network selection algorithm is then created using the MADM method. Finally, the two algorithms are merged to accomplish the user preference vertical handover. Assuming the mobile device possesses a multiinterface capability enabling it to establish connections with various access network technologies.

Figure 1 shows the basic topology of a heterogeneous network. The heterogeneous network comprises of four radio access technologies (RATs): 5G, 4G, WiMAX, and WLAN. The applications considered are Internet protocol-(IP-) based [38]. This means that communication is done over the Internet. According to the Third Generation Partnership Project (3GPP) standards, IP-based network traffic can be classified into four network classes: conversational, streaming, interactive, and background [39]. Each network traffic class is categorized as an application in the development of the algorithm and, therefore, as a user preference. Mobile devices usually contain different applications: conversational application involves real-time communication applications (for example, voice over IP and video calling), streaming application involves the continuous transmission of audio and video services (for example, viewing multimedia), the interactive application involves real-time interactions activities (for example, web browsing and video gaming), and background category involves noninteractive data transfer (for example, WWW and electronic mail) [39].

To facilitate the vertical handover decision, the mobile device continuously collects the network parameters of the available RATs. The network parameters include RSS, mobile device velocity, and QoS parameters (delay, data rate, and BER). In this work, mobility, security, and cost of service were also considered when selecting the available access network. Figure 2 shows the flowchart of the user preference-based vertical handover algorithm. The development of the algorithm is divided into two phases: handover initiation and network selection.

The handover initiation stage decides when the handover should be conducted. The mobile device collects the network parameters, which are passed through a fuzzy inference system as the inputs. The fuzzy inference system produces a handover factor based on the application running on the mobile device. The handover factor determines whether the handover should be initiated, or whether the mobile device should remain connected to the current network. If the handover factor value exceeds the threshold, vertical handover is initiated; otherwise, the mobile device remains with its ongoing connection. If the handover is initiated, the mobile device advances to stage two. In stage 2, the network selection side decides the suitable access network that meets the device user application's requirements. This decision is based on MADM methods used in both network parameters, weights calculations, and candidate network ranking. Weight calculations involve determining each parameter's requirements for supporting a user application. Network ranking evaluates the instantaneous network parameters' performance and is used to calculate the performance score of the available access networks in conjunction with the parameters' weights. The handover initiation and network selection sides are considered when making a handover decision. The decision is made through iterations performed every 5 seconds [12, 40].

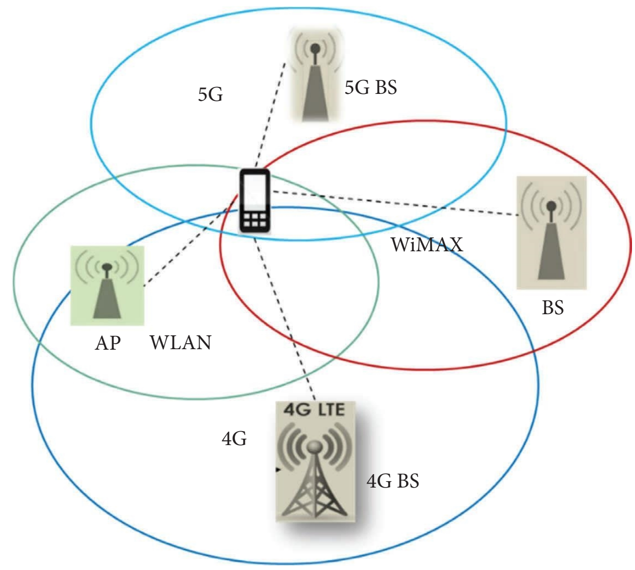


Figure 1: Heterogeneous network topology.

*3.2. Handover Initiation.* The handover initiation algorithm determines when to initiate the vertical handover. The algorithm accepts the network parameters as its inputs. The application running on the mobile device is then determined. A fuzzy inference system is utilized in evaluating the network parameters depending on the application running on the mobile device. The handover factor is obtained as the output crisp value of the fuzzy inference system. In this study, the handover threshold of 0.7 determines whether the mobile device should continue with its current connected network or initiate the handover [41]. The threshold of 0.7 applies to all four applications considered in this study. The handover initiation algorithm developed in this study is detailed below:

**BEGIN**

**Inputs**: Current point of attachment parameters and velocity

**Output:** Handover factor

**Step 1**: The mobile device determines the user application.

**Step 2**: Input the parameters into the fuzzy inference system.

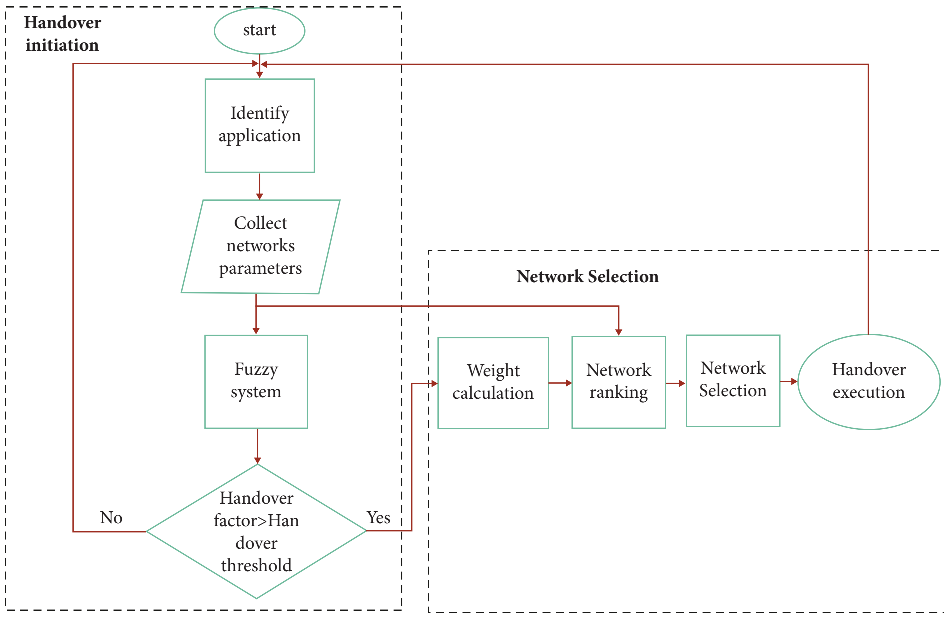


Figure 2: Vertical handover algorithm flowchart.

**Step 4**: If the handover factor is ≤ handover threshold, go to step 5 else go to step 6

**Step 5**: No need to handover

**Step 6**: Initiate Handover

*3.2.1. Fuzzy Inference System for Handover Initiation.* The fuzzy logic technique effectively deals with imprecise and continuously changing network parameters, especially in a high-mobility scenario [42, 43]. The fuzzy mechanism determines the handover necessity. The fuzzy system accepts the network parameters as its inputs, and the application of membership functions and the rules provide an effective way of making the handover necessity decision. Due to its simplicity and fewer calculations, the Mamdani-based fuzzy inference system is utilized to develop the algorithm with the Gaussian membership functions. The input ranges of network parameters to the fuzzy system are shown in Table 1 [44, 45].

Figure 3 shows the established Simulink fuzzy interference system for vertical handover. It consists of two subfuzzy control models. The first submodel accepts the QoS parameters (data rate, BER, and delay), and the QoS factor is obtained as its output. The second submodel inputs are the QoS factor, mobile device velocity, and the RSS mapped into the handover factor as the output.

The QoS factor demonstrates how the currently connected network satisfies the user preference. The input network parameter data rate is essential for the performance of each application. The fuzzy sets for data rate, BER, and delay are represented by linguistic membership labels of *high, medium,* and *low,* while *poor*, *average*, *good,* and *excellent* represent the fuzzy set for the QoS factor. Rules were developed to establish the performance of the QoS factor concerning the QoS network parameters. The rules are based on 3GPP recommendations [39]. The QoS fuzzy inference is developed for every application (conversational, streaming, interactive, and background); for example, the rules for conversational application.

Table 1: QoS application requirements.

| Variables | Data rate (kbps) | Delay (ms) | BER (%) |
|---|---|---|---|
| Conversational | 64–1920 | 0–100 | 0.01 |
| Streaming | 5–700 | 300–400 | 0.01 |
| Interactive | 28.2–500 | 0–200 | 0–0.001 |
| Background | 1–24 | 0–600 | 0–0.001 |

If the data rate is *low*, the delay is *high,* and BER is *high,* then the QoS factor is *poor*.

If the data rate is *high*, the delay is *low,* and BER is *low,* then the QoS is *excellent*.

The inputs to the handover factor fuzzy block are the QoS factor, RSS, and mobile device velocity. The membership functions are developed for these inputs: four for the QoS factor, three for RSS, and four for the mobile device velocity. The linguistic labels adopted to demonstrate the performance of network parameters are *poor, average, good,* and *excellent* for the QoS factor, *weak, average,* and *strong* for RSS, and *low, medium*, *high,* and *very high* for mobile device velocity. The RSS range considered is between −110 and −48 dBm [46]. Also, the mobile device's velocity spans between 0 and 100 km/h [46]. The output value in the form of the handover factor ranges between 0 and 1. The handover factor demonstrates the performance of the current connection in terms of meeting the mobile user requirements. Therefore, the handover factor determines the handover necessity.

The five linguistic labels assigned to illustrate the performance of the handover factor are *very low, low, average, high,* and *very high*. Rules were formulated to illustrate the performance of the handover factor with respect to the input network parameters. For example, if the QoS is *poor*, the RSS

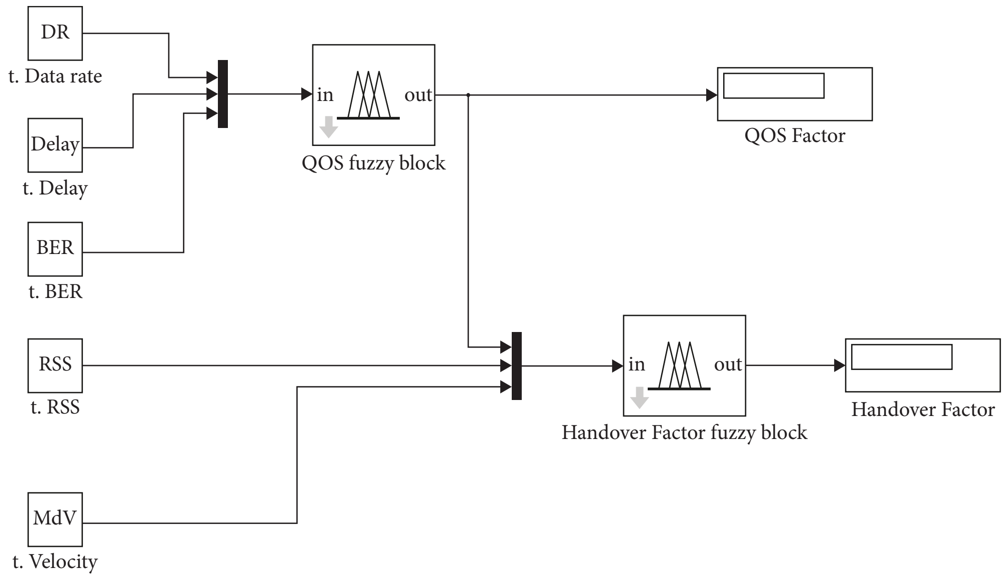


Figure 3: Fuzzy system for handover initiation.

is *weak*, and the mobile device velocity is *high,* then the handover factor is *high*.

If the QoS factor is *excellent*, the RSS is *strong*, and the mobile device velocity is *low,* then the handover factor is *very low*.

The developed handover factor range is between 0 and 1. The handover factor approaches zero for the best network performance scenario and one for the worst network performance scenario. A vertical handover occurs when the handover factor exceeds a threshold of 0.7. After several simulations, the threshold value was established to understand the input parameters' performance.

*3.3. Network Selection.* The network selection problem is classified as a multiattribute decision-making problem whereby various factors are involved in the decision-making process. The developed network selection algorithm evaluates the user preferences and the available access network parameters and selects the access network that best meets the mobile device user requirements. A network selection algorithm is outlined in this section. First, the network parameters are collected, and then the decision matrices are formulated, which depend on the application running on the mobile device. Normalized network parameters' weights are calculated from the decision matrices. The normalized network parameter weights and normalized network parameters are evaluated using MADM methods to rank the performance of the available access network. The ranking is determined in terms of performance scores. The best-performing network is selected, and the vertical handover is executed. The handover is not performed if the current connected network is chosen as the best. The developed network selection algorithm was executed as follows:

**BEGIN**

**Inputs**: Network parameters

**Output**: Network performance score

**Step 1**: Formulate a decision matrix (networks-parameters matrix)

**Step 2**: Calculate normalized parameter weights

**Step 3**: Rank the available networks

**Step 4**: Select the best network

**Step 5**: Perform handover execution

The network selection phase is split into two stages: the parameters weight calculation stage and the network ranking stage. The network parameters weights calculations involve determining parameter requirements in supporting each application. For example, "How much delay is required in supporting conversational application." The network ranking stage involves evaluating each network parameter at any instance and determining the one that best supports the user's requirements.

*3.3.1. Weight Calculations.* Multiattribute decision-making methods calculate the network parameters' subjective weights per application. 3GPP recommendations show that the four applications require different network parameters to meet the end user quality of service satisfaction. Some parameters are given more priority than others to meet the QoS requirements. These network parameters include data rate, delay, and BER [39]. For example, streaming applications need high or medium data rates and a small BER, regardless of the delay. Different MADM methods are used for comparative analyses. The MADM methods considered in network parameter weight calculations include AHP [47], FAHP [5], and SMART [48], as denoted by weights highlighted in Tables 2–4, respectively.

*3.3.2. Network Ranking.* Network ranking involves evaluating the available networks and selecting the one that best meets the user preferences. Network ranking entails making choices between many options using a variety of network

Table 2: AHP importance weights per class.

| | RSS | Data rate | Delay | BER | Mobility | Security | Cost |
|---|---|---|---|---|---|---|---|
| Conversational | 0.35958 | 0.03996 | 0.27983 | 0.03996 | 0.16172 | 0.07875 | 0.04001 |
| Streaming | 0.35958 | 0.2601 | 0.0695 | 0.0299 | 0.16172 | 0.07875 | 0.04001 |
| Interactive | 0.35958 | 0.03946 | 0.1111 | 0.2091 | 0.16172 | 0.07875 | 0.04001 |
| Background | 0.35958 | 0.05438 | 0.01863 | 0.2869 | 0.16172 | 0.07875 | 0.04001 |

Table 3: FAHP weights per class.

| | RSS | Data rate | Delay | BER | Mobility | Security | Cost |
|---|---|---|---|---|---|---|---|
| Conversational | 0.3414 | 0 | 0.3414 | 0 | 0.2368 | 0.0805 | 0 |
| Streaming | 0.3414 | 0.3414 | 0 | 0 | 0.2368 | 0.0805 | 0 |
| Interactive | 0.3414 | 0.0777 | 0.1238 | 0.1399 | 0.2368 | 0.0805 | 0 |
| Background | 0.3414 | 0 | 0 | 0.3414 | 0.2368 | 0.0805 | 0 |

Table 4: SMART weights per class.

| | RSS | Data rate | Delay | BER | Mobility | Security | Cost |
|---|---|---|---|---|---|---|---|
| Conversational | 0.333 | 0.037 | 0.259 | 0.037 | 0.190 | 0.095 | 0.047 |
| Streaming | 0.333 | 0.025 | 0.179 | 0.128 | 0.190 | 0.095 | 0.047 |
| Interactive | 0.333 | 0.208 | 0.042 | 0.083 | 0.190 | 0.095 | 0.047 |
| Background | 0.333 | 0.272 | 0.03 | 0.03 | 0.190 | 0.095 | 0.047 |

variables. In this case, user preference and the network parameters, which include RSS, delay, data rate, BER, security, mobility, and cost, are used in the network ranking decision problem. The network ranked the best in meeting user application needs is selected for vertical handover [35, 37, 49].

In the development of the algorithm, each user preference for QoS satisfaction is addressed in the form of network parameter weights. These network parameter weights depict each application's requirements from the network. These weights and the instantaneous parameters are used to rank the available access networks according to various MADM methods. MADM methods evaluate the influence of each network parameter on the overall decision. Network ranking methods considered in this paper include SAW and TOPSIS. Using SAW and TOPSIS facilitates a comparative analysis of the results provided by the two distinct MADM methods to ensure there is robustness in the decision-making of the algorithm [50]. The network that best satisfies the application requirements is selected for the vertical handover:

(a) Simple Additive Weighting (SAW)

The SAW technique calculates the performance ratings of the available access networks using weighted summation [13]. This method evaluates the available networks and ranks them depending on their individual parameter performance [47, 51]. The best access network in terms of performance has the greatest score among the available access network technologies.

(b) Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

In the TOPSIS ranking method, the best solution is the one that comes the closest to the ideal solution and the furthest from the worst-case solution [10, 47]. The Euclidean model is applied to measure the difference between each alternative and the ideal criteria for performance values. Therefore, TOPSIS evaluates the available network parameters and calculates their performance scores, with the best network having the highest performance score [15].

## 4. Results and Discussion

The performance of the proposed algorithm is evaluated in this section through simulation experiments. The handover initiation algorithm is first tested and evaluated, and its performance is analyzed. The available access networks are evaluated using the network selection algorithm, and the best network is selected for the handover execution. The effectiveness of the proposed network selection algorithm is then verified through the performance rankings of 4G, 5G, WLAN, and WiMAX access networks. To validate the proposed user preference algorithm, a comparison is made with other vertical handover approaches regarding unnecessary handovers, handover failure, and ping-pong rates as the performance metrics. Testing, constructing simulation scenarios, and evaluating the algorithm were conducted using MATLAB 2021a.

*4.1. Fuzzy Inference System Simulation Results.* The fuzzy inference system evaluates the network parameters of the current point of attachment and mobile device velocity. Network parameters and mobile device velocity are collected and assessed after every 5 seconds. Drissi et al. [12, 40] proposed 5 seconds as the optimal time for the vertical handover algorithms to collect and evaluate the network parameters.

Surface plots were generated to demonstrate the mapping of input parameters to the output value using the fuzzy inference system. From the QoS factor versus data rate-delay surface plot in Figure 4, at high data rates and low packet delay, the QoS factor is high, and therefore, the mobile user will be satisfied with the current connection. However, the QoS factor is low at low data rates and high packet delay.

Figure 5 shows the performance of the QoS factor concerning QoS parameters (delay, data rate, and BER) ranges. For high values of data rate, low values of delay, and low values of BER, the QoS factor approaches 1. This shows the currently connected access network satisfies the mobile device user's QoS requirements. For low values of data rate, high values of delay, and high values of BER, the QoS factor approaches 0. This shows the currently connected network does not satisfy the mobile user's QoS requirements.

In Figure 6, the handover factor versus mobile device velocity—QoS factor surface plot shows that at low velocity and high QoS factor, the handover factor is low. Therefore, the mobile device user is satisfied with the currently connected access network. Also, at high velocity and low QoS factor, the handover factor is high, demonstrating the need for handover since the presently connected network is not satisfying the mobile user requirements.

Figure 7 shows the performance scenario of the handover factor concerning the network parameters in the fuzzy system. The handover factor is low for QOS factor values approaching 1, strong RSS, and low velocities. Therefore, the currently connected network satisfies the mobile user requirements, so there is no need to initiate the handover. The handover factor is high for QoS factor values approaching 0, weak RSS, and high velocities. Therefore, the vertical handover should be initiated since the currently connected network does not meet the mobile user applications' requirements.

After performing various simulations using different values of handover parameters, the handover threshold of 0.7 was computed. If the handover factor is less or equal to the handover threshold, the mobile device continues with the currently connected network; otherwise, the vertical handover is initiated. Higher values prevent necessary handovers. On the other hand, a lower value may lead to unnecessary handovers, wastage of resources, and service interruptions [18, 41].

*4.2. Network Selection.* The developed network selection algorithm selects the best available access network that suits user requirements; that is, the network should provide the best possible user experience to the application running on the mobile device. To verify the algorithm, different MADM methods were used [17]. The algorithm assumes the coexistence of integrating the four-access network technologies in the same environment into a heterogeneous network. This allows the mobile device to use the algorithm to select the best network among the four-access networks based on the application's demands. Table 5 illustrates various handover network parameters employed in verifying the network selection algorithm [2, 52].

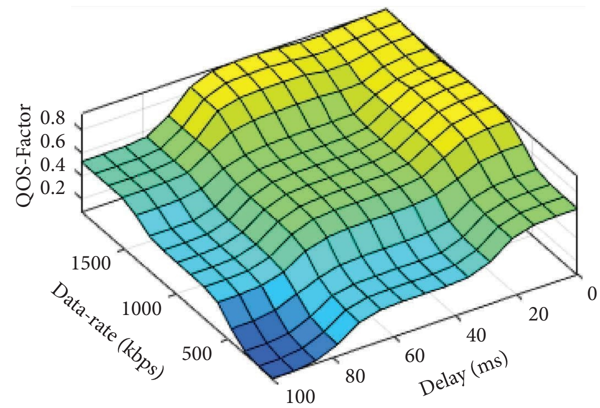


Figure 4: QoS factor versus data rate-delay surface plot.

Figures 8 and 9 show the performance of various combinations of MADM methods employed in network ranking for the four-access network technologies for conversational and interactive applications, respectively. The combined methods used in the network selection algorithm include AHP-SAW, AHP-TOPSIS, FAHP-SAW, FAHP-TOPSIS, SMART-SAW, and SMART-TOPSIS. The network selection algorithm only runs when the handover factor exceeds the threshold. The proposed vertical handover algorithm is based on a make-before-break type of algorithm. The make-before-break algorithm requires that the mobile device must first establish a connection with the new network before disconnecting from the old one [53].

The ranking bar charts in Figures 8 and 9 show consistency in ranking the best network. All the combined methods in the algorithm selected the best access network for conversational and interactive applications as the 5G network. This is justified by Table 5, which illustrates that the 5G network parameter values utilized in the simulation have the best performance compared to the other access networks. Also, consistency is demonstrated in streaming and background applications when ranking the best available networks after employing the combined normalized weight calculations and ranking MADM methods in the network algorithm. This reflects the network selection algorithm's effectiveness in selecting the most suitable network among the available ones.

*4.3. Performance Comparison*

*4.3.1. Simulation Parameters.* The user preference-based vertical handover algorithm considers an environment consisting of WLAN, 4G, 5G, and WiMAX access network technologies. Table 6 illustrates the simulation parameters used in the performance comparative analysis [26, 54], and [55]. To test and evaluate the viability and effectiveness of the algorithm on a small scale, five users were considered. The users are randomly distributed, and only the movement of one user is considered.

Due to the variation of RSS depending on the location of the mobile device user from the base station (BS) or access point (AP), various path loss models were considered. The

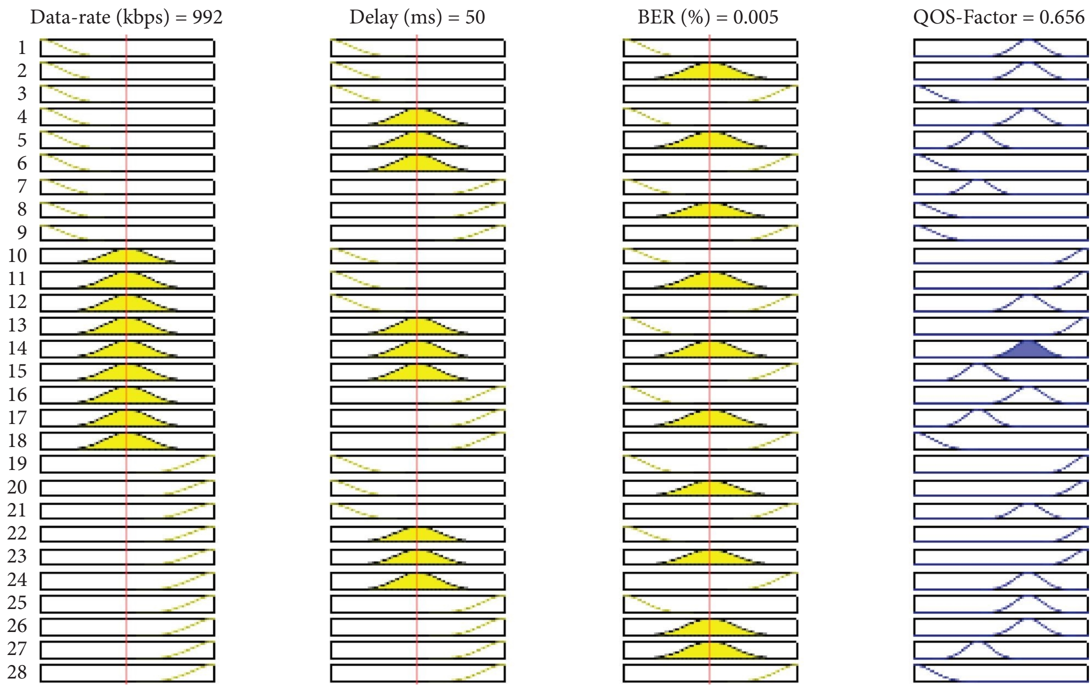


Figure 5: Quality of service parameters performance in fuzzy.

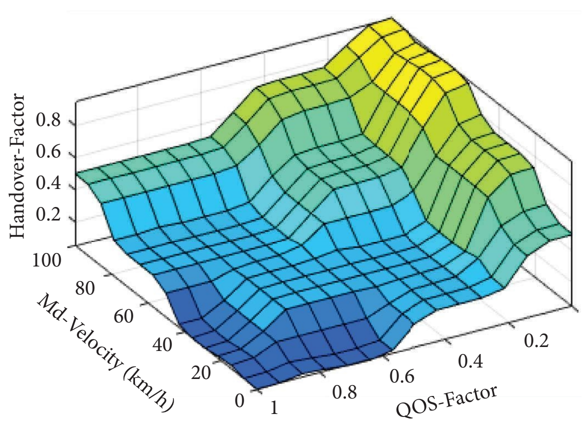


Figure 6: Handover factor versus mobile device velocity—QoS factor surface plot.

access network technologies path loss models for 4G (LTE) [56], WLAN [57], WiMAX [58], and 5G [59] are shown in Table 6. The access networks' propagation channels were modelled in terms of the path loss propagation models. The transmit power and the path loss was utilized in calculating the RSS, as shown in the following equation [54]:

$$\mathrm{RSS}(d) = P_t - \mathrm{PL}(d), \tag{1}$$

where $P_t$ represents the transmit power, and $\mathrm{PL}(d)$ represents the path loss at a distance $d$ between the mobile device and the base station/access point.

The performance of the developed algorithm is evaluated in terms of the following parameters:

(1) Unnecessary Handovers

Vertical handover is essential in maintaining the quality of service to the mobile device user only if necessary. However, if not necessary, it may lead to ping-pong effects, interruption of service, and wastage of power. For this reason, unnecessary handovers are used as a critical handover parameter for assessing the user preference for vertical handover performance. An unnecessary handover is defined as a handover that is not beneficial to the mobile device user [60]. The number of unnecessary handovers was computed using the following equation:

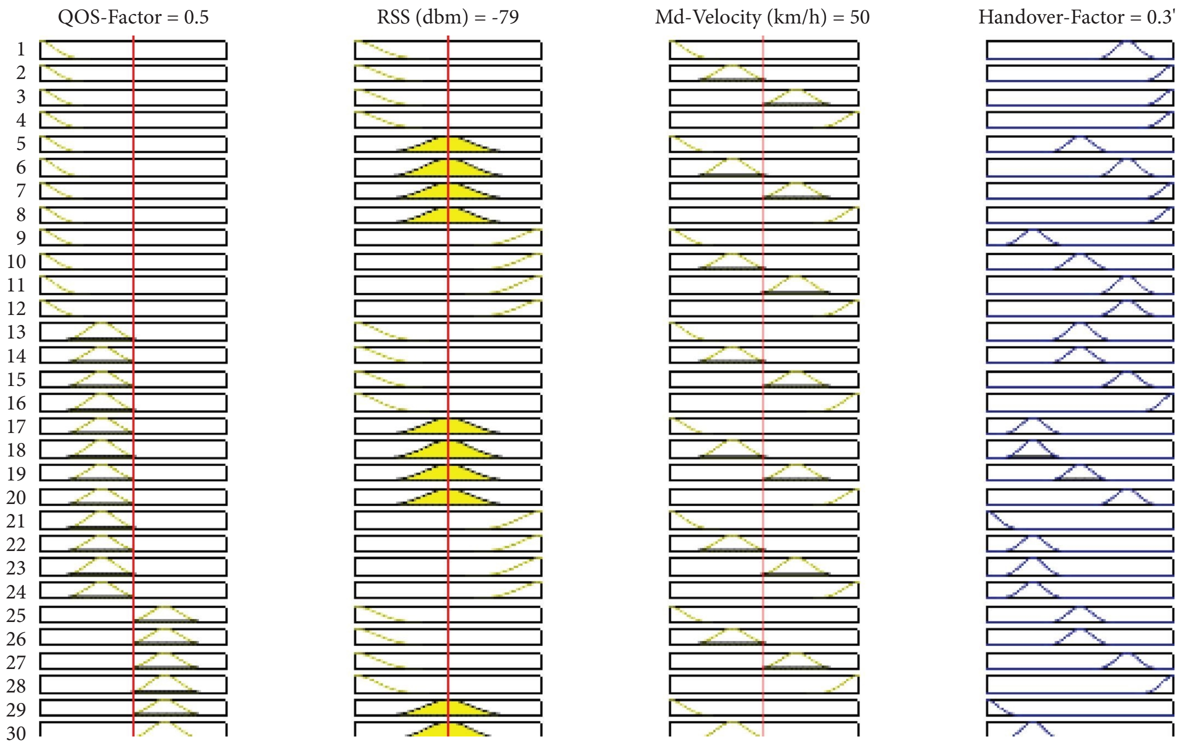


FIGURE 7: Vertical handover parameters performance in the fuzzy system.

TABLE 5: Network selection simulation data.

| Network parameters | WLAN | WiMAX | 4G | 5G |
|---|---|---|---|---|
| RSS (dBm) | −75 | −77 | −82 | −82 |
| Data rate (Mb/s) | 50 | 20 | 20 | 100 |
| Delay (ms) | 10 | 20 | 15 | 1 |
| BER (%) | 0.002 | 0.003 | 0.001 | 0.0001 |
| Mobility | 2 | 7 | 4 | 3 |
| Security | 5 | 5 | 6 | 6 |
| Cost | 3 | 4 | 7 | 8 |

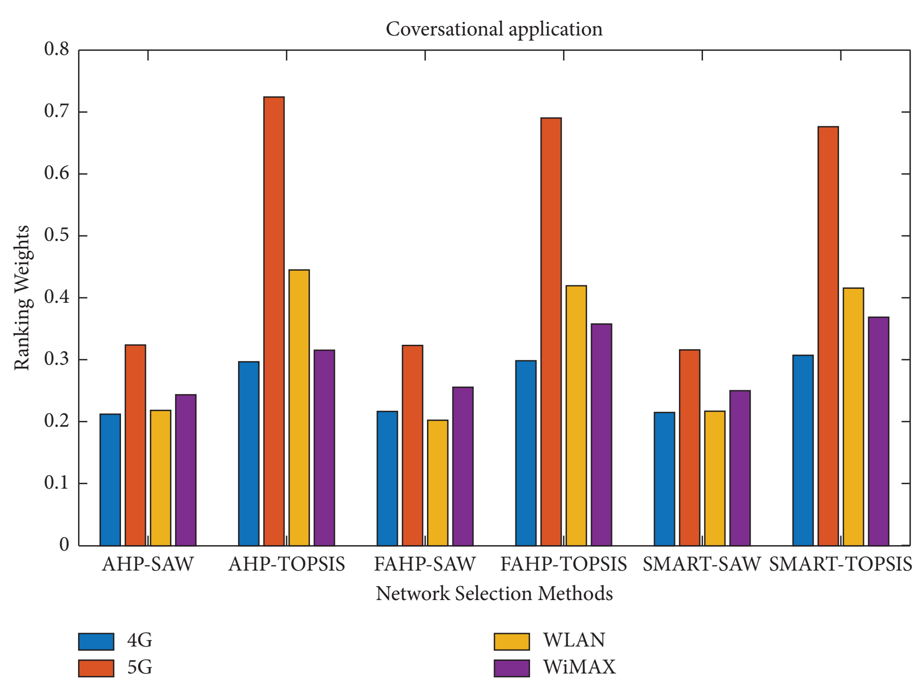


FIGURE 8: Conversation application ranking.

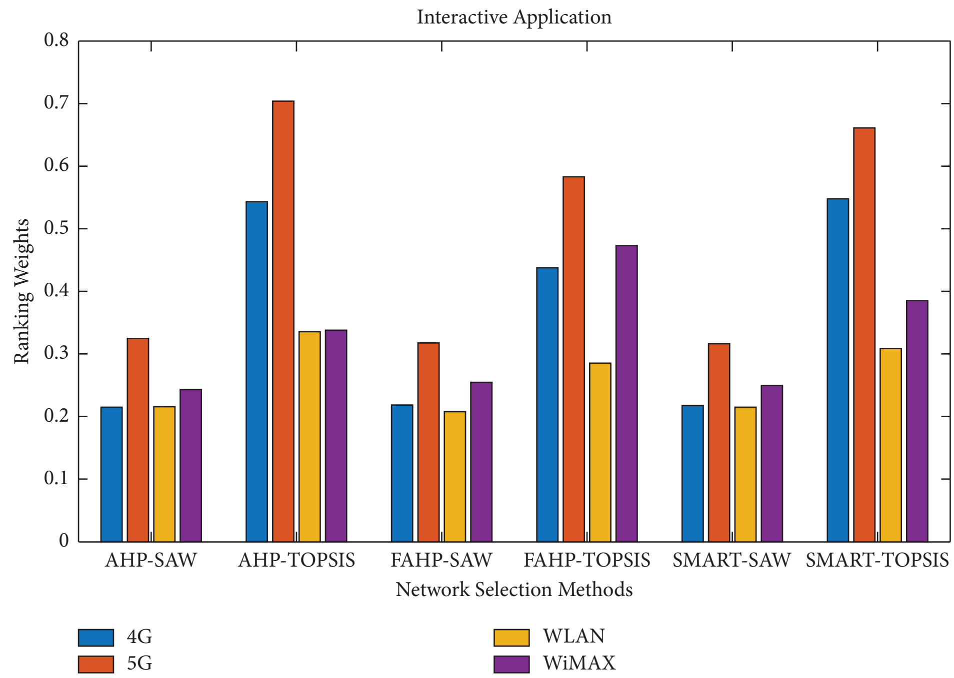


FIGURE 9: Interactive application network ranking.

$$\text{No of unnecessary handovers} = \text{No of handovers} - \text{No of necessary handovers}. \tag{2}$$

(2) Handover Failure Rate

The handover failure rate is significant in demonstrating the effectiveness of a vertical handover management system. In the proposed algorithm, handover failure means the vertical handover is initiated, but the execution step, which is the last step, does not occur. The handover failure rate is calculated using the following equation [61]:

$$\text{Handover failure rate} = \frac{\text{Number of failed hadovers}}{\text{Number of attempted handovers}}. \tag{3}$$

(3) Handover Ping-Pong Rate

In the proposed algorithm, handover ping-pong occurs when the mobile device immediately reconnects to the same previous access network in the subsequent iterations after 5 seconds. The average number of ping-pong handovers is calculated using the following equation [61]:

$$\text{Average pingpong handover rate} = \frac{\text{Number of ping pong handovers}}{\text{Number of attempted handovers}}. \tag{4}$$

*4.3.2. Simulation Environment.* The proposed user preference-based vertical handover is tested and evaluated in this section to validate the algorithm's effectiveness. A heterogeneous simulation environment was built using MATLAB 2021a. The proposed algorithm is compared with the TOPSIS utility function-based algorithm [55]. The authors of the TOPSIS utility function-based technique considered similar heterogeneous network composition and similar handover performance metrics, making it suitable for the comparative analysis with the work addressed in this paper. In addition, the utility function and MADM methods have been demonstrated to perform a similar function in addressing mobile device user satisfaction in network selection algorithms [62]. In [55] and the proposed algorithm, the degree of user satisfaction is expressed in terms of network ranking to determine the best network that satisfies the user's requirements. SAW and TOPSIS ranking methods are straightforward, and their simplicity makes them suitable for integrating with the proposed algorithm and in network selection.

The considered heterogeneous network environment in the simulation is dynamic, meaning network parameters

Table 6: Simulation parameters.

| Variables | 4G | 5G | WLAN | WiMAX |
|---|---|---|---|---|
| Carrier frequency ($f_c$) (GHz) | 2.1 | 28 | 2.4 | 3.5 |
| System bandwidth (MHz) | 10 | 500 | 20 | 20 |
| Base station/Access points | 1 | 1 | 1 | 1 |
| Path loss model | $103.8 + 20.9\log_{10} d\,(\text{km})$ | $28 + 22\log_{10}(d) + 20\log_{10}(f_c)$ | $34.48 + 32.79\log_{10} d\,(m)$ | $130.62 + 37.6\log_{10} d\,(\text{km})$ |
| Transmit power (dBm) | 46 | 30 | 13 | 47 |
| Number of cells | 10 | 10 | 1 | 1 |
| Cell radius (km) | 0.75 | 0.5 | 0.25 | 0.7 |
| Thermal noise density (dBm/Hz) | −174 | | | |
| Noise figure | 9 | | | |
| Area ($m^2$) | $2000 \times 2000$ | | | |
| Number of users | 5 | | | |

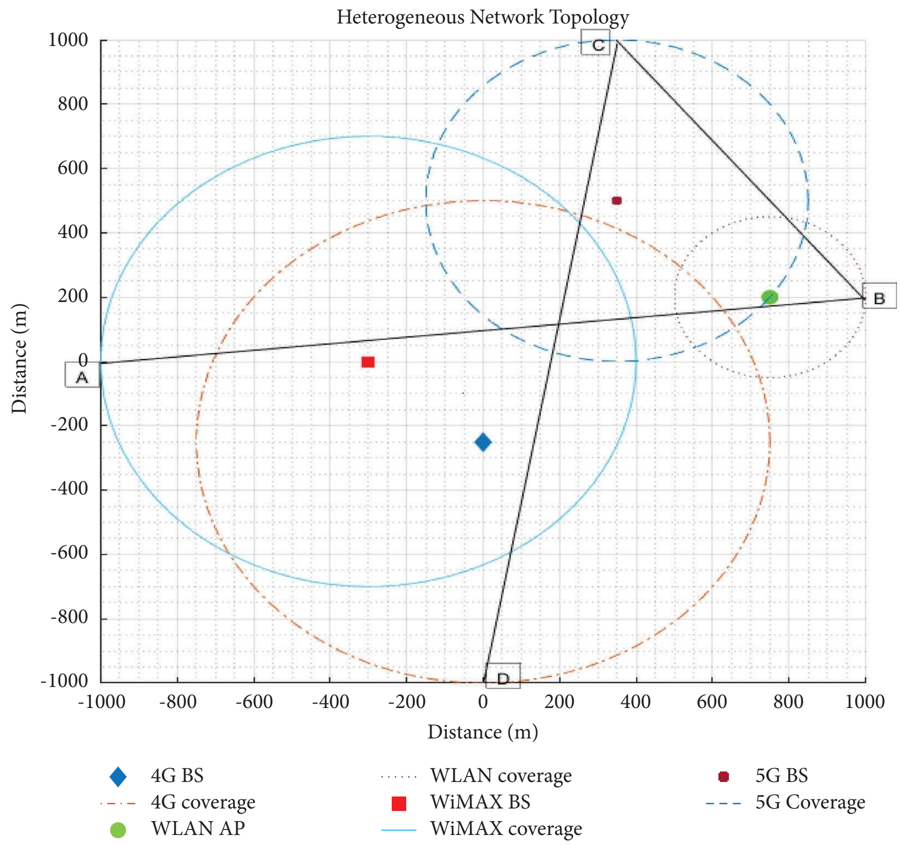


FIGURE 10: Heterogeneous network environment with a defined path.

change depending on the mobile device user's location. The random waypoint mobility model represents how mobile devices move within the heterogeneous network [63]. When traveling, the mobile device's direction and time are randomly chosen, but the velocity is assumed to be uniform. Figures 10 and 11 show the mobile device user movement simulation scenarios in a heterogeneous network environment. The heterogeneous environment integrates the four-access network at random locations, the WiMAX, 4G, and 5G base stations, and the access point for WLAN. Also, the simulation scenario demonstrates each access network coverage area. Table 6 indicates the parameters used in the simulation. This region considers the parameters: mobile device velocity, RSS, data rate, and delay dynamic. The parameters mobility, security, and cost are considered static, as shown in Table 5.

To validate the algorithm's effectiveness, it is assumed that the mobile device user moves on the fixed paths A-B, B-C, C-D, and D-A, as shown in Figure 10, experiencing vertical handover at various locations. The direction of this path was randomly chosen. In addition, to test and validate the algorithm performance, 10 random locations were generated to create the random paths shown in Figure 11. The mobile device experiences vertical handovers at various locations as the user moves on these paths.

As the user moves on the path, the network parameters are collected and evaluated after every 5 seconds. Therefore, the algorithm's performance does not change regardless of the user's movement or velocity. Four mobile device velocities are considered to compare the algorithms' performance. They include 1 m/s, 10 m/s, 20 m/s, and 30 m/s.

*4.3.3. Comparison Results.* Following the simulation of heterogeneous network environments, utilizing the random paths, the obtained results for the unnecessary handovers, handover failure rate, and handover ping-pong rate are presented in this section. Figure 12 shows the percentage of unnecessary handovers of the proposed algorithm and the TOPSIS utility function-based algorithm that occurs as the mobile device user traverses the heterogeneous network environment.

The results show that the proposed algorithm achieves a low unnecessary handover rate compared to the TOPSIS utility function-based algorithm. There are no unnecessary handovers for the proposed algorithm at low velocities (1 m/s and 10 m/s), even if the other parameters are unstable. Vertical handovers only occur when the current point of access cannot support the application running on the mobile device, which is determined by the fuzzy inference system. At higher velocities (20 m/s and 30 m/s), the mobile tends to switch the connection to a more reliable and stable access network if the current point of access is unstable. This causes unnecessary handovers.

Figures 13–16 show the handover failure rates of the proposed algorithm compared with the TOPSIS utility

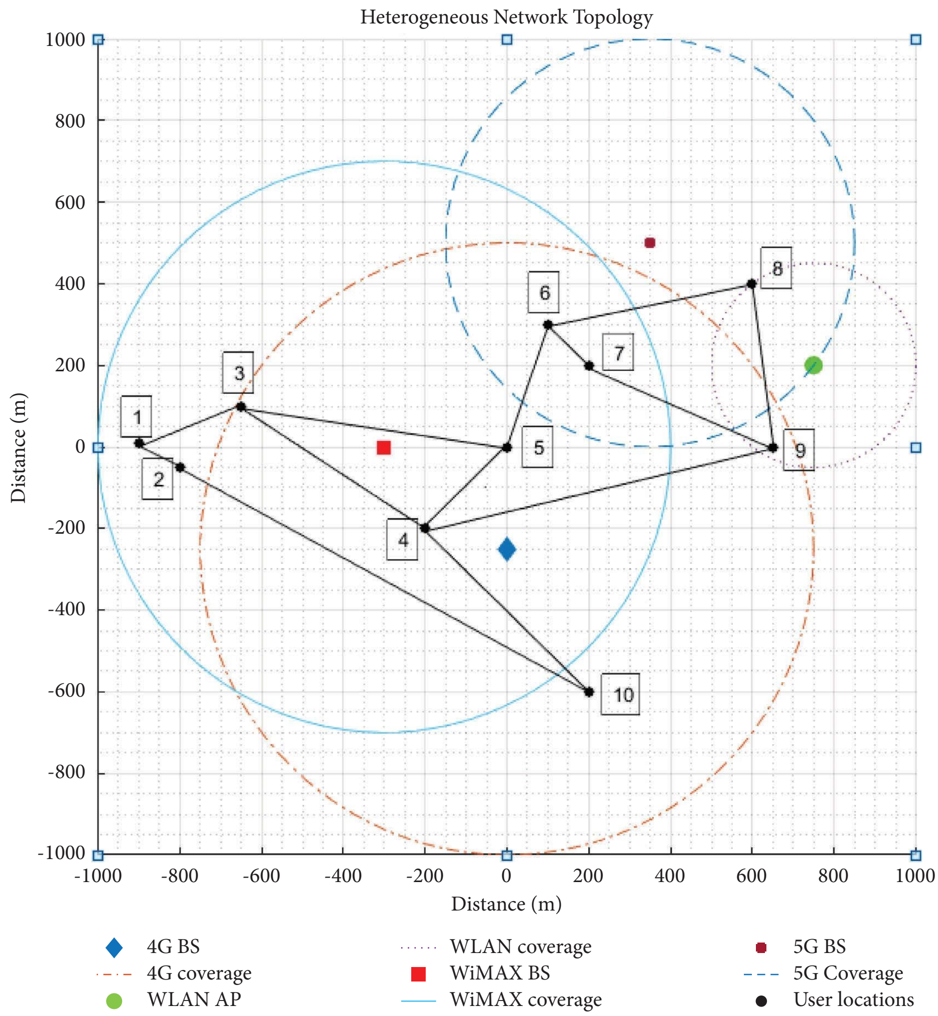


Figure 11: Heterogeneous network environment with random paths.

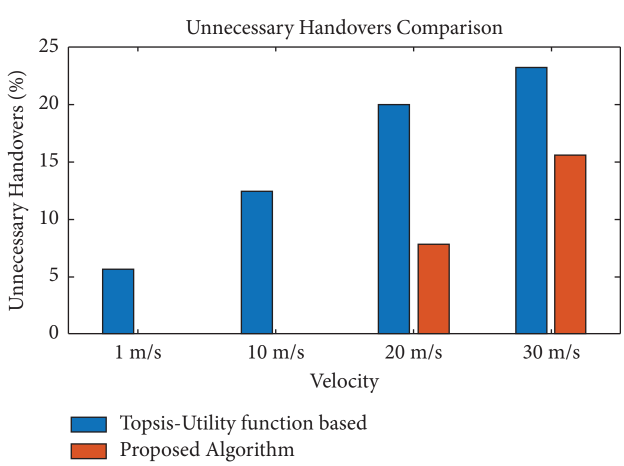


Figure 12: Unnecessary handovers comparison.

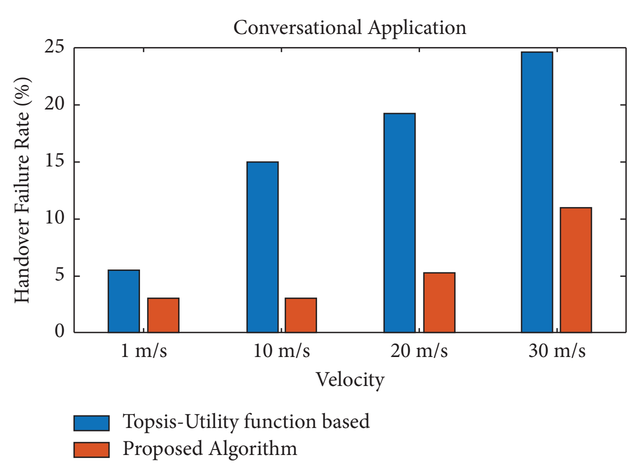


Figure 13: Conversational application handover failure rate.

function-based algorithm considering various mobile device applications. The figures show that the proposed algorithm achieves lower handover failure rates at all velocities compared with the TOPSIS utility function-based algorithm. In addition, the figures show that as the mobile device's velocity increases, the proposed system's handover failure rate increases.

Figures 17–20 show the average number of handover ping-pong rates demonstrated by the proposed algorithm and the TOPSIS utility function-based algorithm

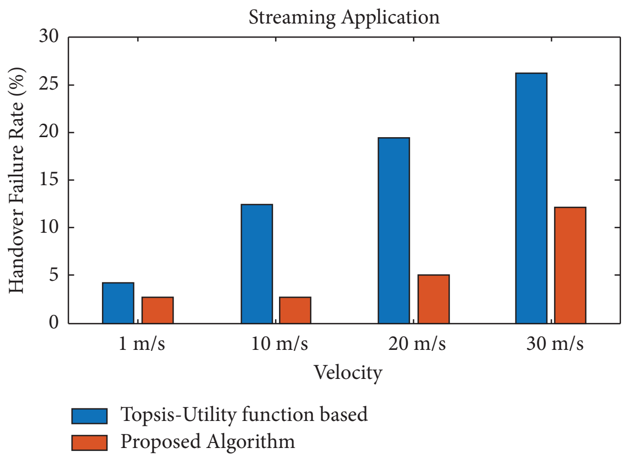


Figure 14: Streaming application handover failure rate.

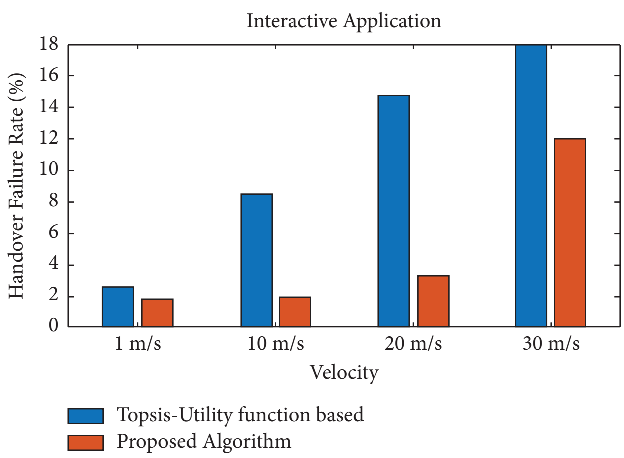


Figure 15: Interactive application handover failure rate.

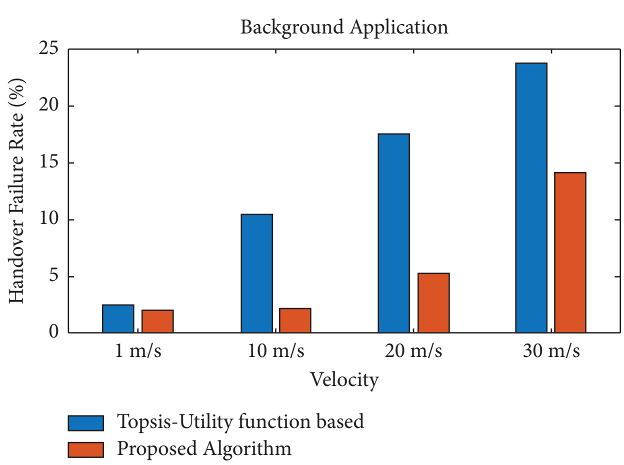


Figure 16: Background application handover failure rate.

considering different mobile device applications. It can be observed that at velocities below 10 m/s, the handover ping-pong rate of the proposed algorithm is zero. The handover ping-pong rate is observed at higher velocities (20 m/s and 30 m/s) and increases as the velocity increases. In addition,

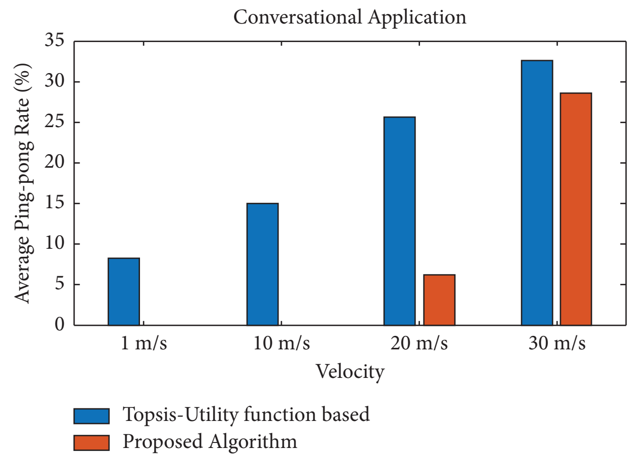


Figure 17: Conversational application average handover ping-pong rate.

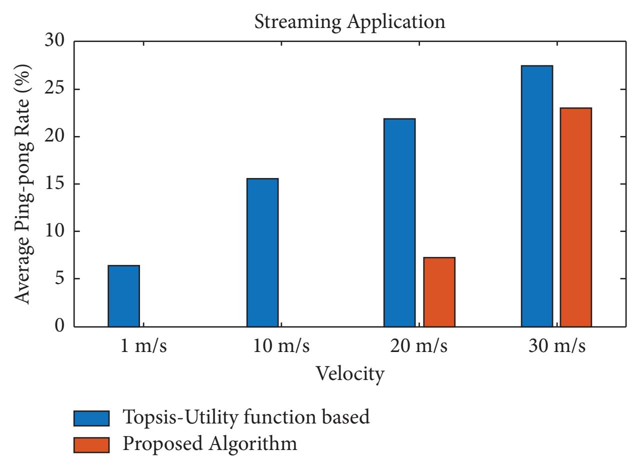


Figure 18: Streaming application average handover ping-pong rate.

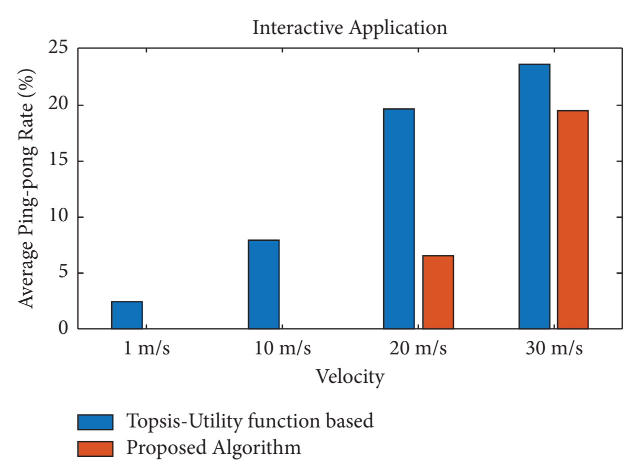


Figure 19: Interactive application average handover ping-pong rate.

the proposed algorithm achieves a low handover ping-pong rate compared to the TOPSIS utility function-based algorithm. The outstanding performance gives enhanced

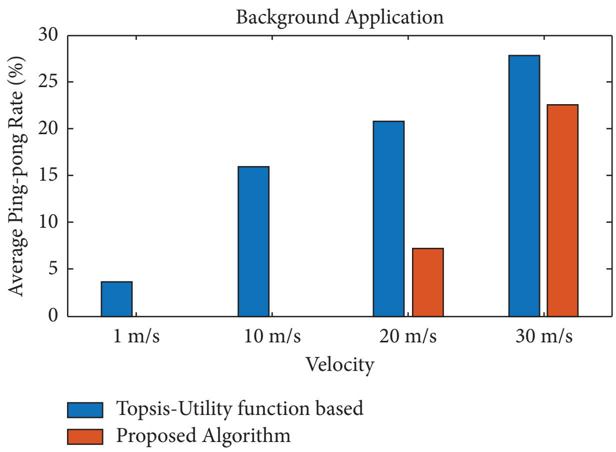


Figure 20: Background application average handover ping-pong rate.

network performance and reliable network services. Furthermore, network resources are saved by decreasing the handover ping-pong rate.

The results in Figures 12–20 show that in the proposed algorithm, as the number of unnecessary handovers increases, the handover failure rates increase, and the ping-pong rates increase. This shows that minimizing unnecessary handovers reduces handover failure and ping-pong handover rates. The proposed system improves compared to the TOPSIS utility function-based algorithm regarding the handover comparison metrics. The developed algorithm presents a more reliable vertical handover management system even in a highly dynamic heterogeneous environment. The algorithm ensures that the user preferences' requirements are always satisfied. Also, it minimizes service interruptions and wastage of power caused by unnecessary handovers, handover failures, and ping-pong handovers.

## 5. Conclusion

A user preference-based handover management algorithm has been developed in this paper. The algorithm first collects the current point of connection parameters and the mobile device velocity and evaluates the handover necessity. This evaluation is done according to the application running on the mobile device. Due to its capability to deal with imprecise data, the fuzzy logic system efficiently determines whether the vertical handover should be initiated. The handover factor and threshold development ensured only the necessary handovers were initiated, depending on the application running on the mobile device. A vertical handover is initiated if the current connection does not meet the mobile user's requirements. After the handover is initiated, the network that meets the mobile user requirements must be selected. The algorithm evaluates this as a multi-attribute decision-making problem since user preferences and the available network attributes must be considered in network selection decision-making. AHP, FAHP, and SMART as MADM methods effectively determine the user requirement in each application. These applications' needs are expressed in the form of normalized weights. MADM ranking methods, including SAW and TOPSIS, were utilized to evaluate the available access network parameters' performance. These methods rank the best available network depending on each application. The methods use the normalized weights and the instantaneous parameters to rank the access networks. Both handover initiation and network selection algorithms are used together in addressing vertical handover management to maintain the quality of service the user requires.

The proposed algorithm considers the user preference while evaluating the available access network parameters and ensures the user requirements are met every instant. The algorithm's reliability is proved in achieving minimum unnecessary vertical handovers, minimum handover failures, and a reduced number of ping-pong handovers compared to the TOPSIS utility function-based vertical handover algorithm. For the considered user applications, at 10 m/s (and below), the algorithm had an average of 0% unnecessary handovers, a 2.39% handover failure rate, and 0% a ping-pong rate. At 30 m/s, it had an average of 15.68% unnecessary handovers, a 12.24% handover failure rate, and a 23.38% ping-pong rate. In contrast, the TOPSIS utility function-based algorithm had higher rates at these velocities.

This ensures stability as the mobile device user traverses a heterogeneous network environment. This also minimizes service interruptions caused by ping-pong effects and minimizes wastage of power. In addition, the algorithm ensures that the quality of services is always maintained as the user moves across a heterogeneous network environment. In future studies, user experience should be considered in developing vertical handover necessities and network selection mechanisms. This will ensure a better quality of experience received by the mobile user.

## Data Availability

The data used in this study are made available from the corresponding author upon reasonable request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest towards the publication of this work.

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