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Optimizing Vertical Handover Using Multi-Criteria Decision Making in Heterogeneous Networks

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Abstract

Vertical handover (VHO) in heterogeneous wireless networks is essential to keep users continuously connected and also to guarantee that the Quality of Service (QoS) of mobile communications is adequate. The focus of this paper is to apply various Multi-Criteria Decision Making (MCDM) tools to model a comprehensive VHO decision-making framework. This proposed methodology brings together more than one parameter of a given networking environment, such as signal intensity, QoS, and energy requirements, into one or more decision models. Using analytical methods such as the Analytical Hierarchy Process (AHP) for criteria weighting, we continuously optimize network conditions, thereby enhancing the efficiency and reliability of Vertical Handover (VHO). Several experiments were made to test the efficiency of the given MCDM-based VHO algorithm. The performance evaluation of the proposed method reveals superior handover performances in terms of success rates, less latency, and better QoS as compared to other VHO techniques. In addition, our research conclusion implies that integrating MCDM into the VHO decision-making will not only facilitate the network resource optimization but also improve the user satisfaction in the heterogeneous networking domain. This paper, in the wireless communications area, makes a significant contribution by presenting a powerful framework for DNS and VHO. The subsequent studies will be directed towards improving this algorithm for real-time applications and experimentation in the new generation networks, such as 5G Networks.

Keywords: Vertical handover, Quality of Service, wireless communications, Technology, Internet, Protocols, Standard.

Introduction

Wireless communication technologies have evolved rapidly nowadays, which subsequently results in the emergence of several types of mobile and wireless networks, or the so-called heterogeneous wireless networks. This convergence is primarily targeted at achieving efficient and optimal integration and communication in different networks. While the user is switching from one coverage area of the operator to another, it becomes imperative to ensure Vertical handover (VHO) to ensure seamless connectivity and retain the best Quality of Service (QoS). VHO is the process of transferring an active call session from one type of Network to the other with the help of multiple criteria like signal strength, network congestion, and user preferences between the parallel available networks like Wi-Fi and cellular networks. The evolution of wireless networks has led to the emergence of complex and diverse systems, which makes the effective handover with traditional methods difficult. These are the local problems of optimization of different conflicting criteria at the same time, including QoS, energy consumption, signal strength, and maintaining continuity and simplicity of connection for the user. These challenges can be met with new and higher decision-making levels that can optimize the network and respond to its current state and the users' needs. However, there is a practical issue of how VHO decisions might be improved, and one of the approaches that has shown potential is the application of Multi-Criteria Decision Making (MCDM) tools. MCDM techniques help in undertaking a uniform approach to the examination of multiple criteria to come up with balanced solutions to complex decisions. The modification of the various network parameters into an encompassing framework of MCDM techniques facilitates the improvement of VHO proficiency within a heterogeneous network environment. The newly developed MCDM-based VHO algorithm in this paper applies the AHP process to weigh target criteria and facilitate optimal handovers. The devised network architecture allows such parameters as signal strength, QoS factors, and energetics to be incorporated as dynamic components within the proposed methodology to reflect conditions of the given environment. Numerous tests were conducted to assess the efficiency of the developed algorithm, with the results indicating a dramatic increase in handover completion ratio, decreased latency, and heightened QoS as compared to conventional approaches.

In the literature survey, several investigations address the performance of VHO in heterogeneous networks, some of which present different strategies and methods used in enhancing the handover process. The use of multiple attribute decision-making algorithms has been researched for their ability to seek the overall optimal solution when compared to individual attributes of the network to improve the user experience. Other handover techniques include power optimal handover and RF fingerprinting handover, both of which consider the energy consumption aspect when seeking a new network connection. Further, in QoS and performance aspects, it is highlighted that packet loss has to be at the minimum level, and the connections need to be stable during the handover process. Current scenarios, such as location-based handovers, and techniques for vehicular networks, show challenges and a variety of uses of VHO in various dynamic and complicated terrains. Such studies emphasize the importance of having well-equipped, adaptable, and versatile VHO mechanisms to satisfy the requirements of contemporary wireless networks.

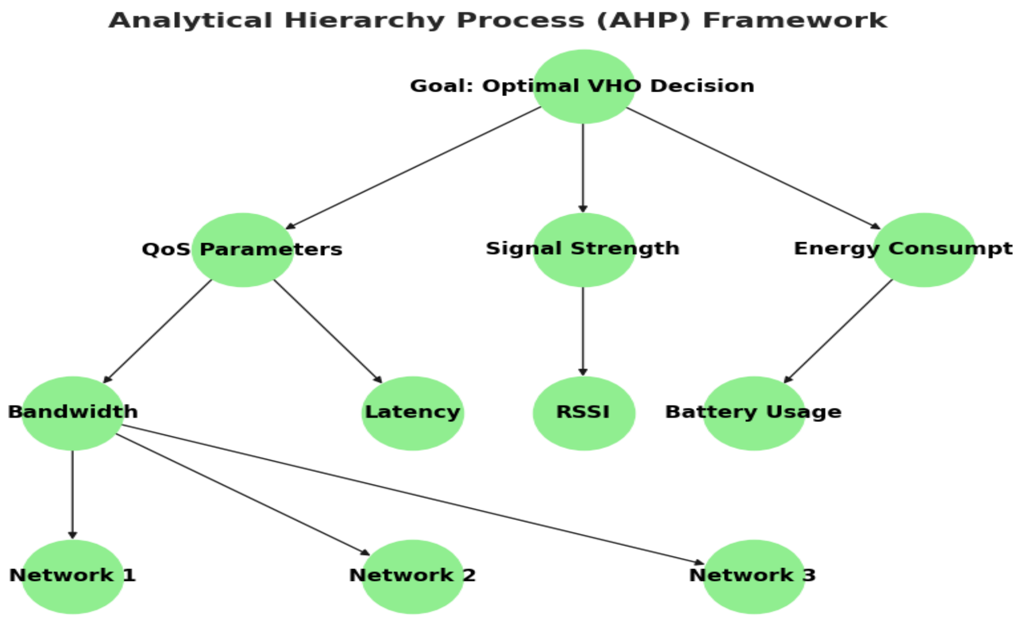

Figure 1. AHP Framework

That is why the proposed approach of using MCDM in dynamic network selection and vertical handover optimization leans on this body of research. This is made possible by ranking a number of criteria alongside the set criterion and making handover decisions based on the algorithm-acquired ranking, which adapts appropriately to the ever-changing network conditions. Besides, it is a favorable approach when it comes to the use of networks and general network performance, as well as input from users. Therefore, the incorporation of MCDM techniques in decision-making processes of VHO is a mark of progression in the technological aspect of wireless communication. Because of the features of the heterogeneous network, including the high variability and the complexity of the network connectivity, the proposed method presents the most effective solution for ensuring unobstructed and high QoS connectivity at larger network scales. Nearby research will be aimed at developing an improved real-time version of the algorithm, as well as a study of its further potential in relation to new generations of networks, such as 5G and more. Contributing to the wireless communications body of knowledge, this paper seeks to propose a framework for VHO decision optimization in heterogeneous networks that is systematic and implementable.

The remainder of this paper is organized as follows. Section 2 reports a literature review. Section 3 focuses on the methodology proposed. Section 4 describes the experimental setup. Section 5 explains the implementation and experimental results, and Section 6 concludes the paper.

Literature Review

Vertical handover (VHO) in heterogeneous wireless networks plays a crucial role in maintaining continuous connectivity and potentially providing better service when users switch between different types of wireless networks. Use of quality of service (QoS), signal quality, and energy efficiency all call for an enhanced handover mechanism and thus are needed in the case of complication and diversification of the network base. This paper focuses on several protocols and methodologies related to VHO discussed in recent literature, including the Multi-Criteria Decision Making (MCDM) scheme, energy-aware handover strategies, and the security challenges associated with VHO.

Figure 2. Categories of Literature Review

Multi-Criteria Decision Making for VHO

Starting with the sound introduction of the vertical handover decision-making problem by (Liang et al., 2017) in the context of visible light communication (VLC)-Femto system, which is a multi-attribute system. It is flexible to conditions, including signal intensity, user decisions, and networks, to optimize handover work. This method aims at attempting to achieve the best balance of the various trade-offs between the two users and the network and its various attributes.

Tamea et al. (2011) developed a soft Multi-Criteria Decision Making (MCDM) technique for vertical handover in heterogeneous networks. This approach considers various parameters such as signal strength and user mobility within the network. As a result, the soft decision-making method is particularly suitable for such network systems, as it offers the flexibility needed to adapt to the dynamic nature of the environment.

Santi et al. (2021) analyzed vertical handovers in WLANs using the Mobile Broadband Wireless Access (MBWA) technique, focusing on location-based handover mechanisms in IEEE 802.11ah networks. Their results indicate that location-based algorithms are indeed feasible, as they enable efficient information transfer without overloading the radio access interfaces.

Energy-Efficient Handover Schemes

Song et al. (2014) proposed a sleep-efficient vertical handover protocol aimed at improving the integration of wireless networks. Their scheme utilizes three sets of data to minimize the time required to connect to a new network by selecting the one with the most efficient power consumption. This approach is especially beneficial for handheld devices with limited battery capacity, such as smartphones, as it enhances both communication time and overall device usability.

Pan et al. (2019) introduced a P-persistent, energy-aware handover decision mechanism that employs RF fingerprinting in adaptively sized heterogeneous cellular networks. By leveraging RF fingerprints to predict optimal handover points, the method effectively reduces unnecessary handovers, thereby conserving energy.

QoS and Performance Analysis

In the case of vertical handover analysis, Ali et al. (2013) presented the instantaneous packet loss-based vertical handover algorithm for heterogeneous wireless networks. Their investigation shows that it is crucial to keep the level of packet loss low during handovers to ensure high QoS. The proposed algorithm controls handover decisions with real-time packet loss information, thus providing a highly stable and robust connection. Ren et al. (2017) analyzed the handover rate for K-tier heterogeneous cellular networks with general path loss exponents. Some of the findings of their study give insight into the factors that are essential to the number of handovers and the performance of handovers in different kinds of network structures. These factors include; Understanding these dynamics is very important, especially if one needs to develop proper handover strategies.

Ather et al. (2022) compared the specific throughput, handover latency, service disruption time, packet loss, and signaling overhead of the handover architecture’s comparative performance evaluations. As evident from the model findings presented above, there is evidence that the proposed architecture enables mobility from one heterogeneous network to another within a mobile network. Even without offering a solution to reduce handover latency, the overlapped receiving of packets from two or more access routers (RSUs) significantly minimizes packet drops during handover. Sarma et al. (2016) proposed handover points with enhanced context-aware load balancing in WiFi–WiMAX network integration. Their work points to the fact that context-aware approaches are crucial to guarantee a smooth flow of handover and network stability.

Security in Vertical Handover

Another work by Ramezani et al. (2016) conducted a formal security analysis of the Extensible Authentication-Re-Authentication Protocol (EAP-ERP) using Casper. While providing insight into the security issues of vertical handover, their work specifically falls under two subcategories: mutual authentication and key integrity. The results indicate that despite offering flexibility and security to VHO through EAP-ERP, there are some risks as follows. Security is presumably a pertinent issue in VANETs because of the existence of threats and issues such as Sybil attacks, DoS attacks, message manipulation, location privacy crises, and jamming attacks (Raj et al., 2023). To combat these threats, there are measures such as message authentication, secured communication, secure group communication, privacy-preserving techniques, and intrusion detection systems. Cooperative security, in which vehicles exchange security-related information, can improve the security of VANETs.

For more details on the architectures of vertical mobility management in wireless networks, Fernandes et al. (2012) presented a clear and concise survey. Their work also points to the necessity of strong security measures to enforce integrity of transferred data and privacy protection for users. The results of the survey reveal different measures and strategies applied to protect VHO processes in heterogeneous networks.

Novel Approaches and Techniques

Marquez et al. (2015) highlighted the analysis of vertical handover approaches in the context of the focused Heterogeneous Vehicular Network (HeVN). For their research, they aim to remove the constraints of vehicular wireless communications by coming up with favorable VHO techniques, which address the dynamics inherent to vehicular networks. Another useful research study in the partially related field has been done by Wang et al. (2015), suggesting an efficient vertical handover scheme in the context of a VLC-RF heterogeneous system. Their plan is to enhance the VLC- and RF-based system handover mechanism in such a way that there will be a proper connection from one system to another and the overall performance will be better.

He et al. (2022) explored the bidirectional human-robot bimanual handling of large planar objects with a vertical orientation. Their work provides insight into the need to have clear and accurate handover methods in the cases of human-robot interaction that may be incorporated in VHO practice strategies in real-world environments. In a VLC/WLAN integrated system, a study on location-aware vertical handover has been performed by Zeshan et al. (2021). Their approach also uses localization to facilitate proper handover by determining the best time to transfer from VLC to WLAN in the blended model.

Lemic et al. (2019) investigated Location-Based Discovery (LBDD) and VHO in Heterogeneous Low-Power Wide-Area Networks (HLP-WAN) network environments. Work on location-based movement methods suggests that it can greatly improve the effectiveness of the handover process in low power wide area networks that are important in IoT. The work by Raj et al. (2024) enables the overall assessment of current V2V protocols for VANET deployments with recommendations on areas of interest to address in future VANET systems in emerging economies. This coincides with the general endeavors of enhancing Intelligent Transportation Systems for the developing world, aiming for the realization of harmonized and intelligent traffic flow, safe roads, and overall optimum traffic flow.

Moons et al. (2019) discussed an efficient vertical handover for different HLP-WAN networks that can be categorized as heterogeneous systems. Key aspects of their work include understanding the best way to improve handover procedures in systems, which can provide dependable connectivity in low-power platforms. The authors propose a detection system based on machine learning (ML) to identify wormhole attacks within VANET environments. An important point highlighted is that proper normalization of the dataset significantly contributes to improved detection performance. Ali et al. (2020).

In the context of heterogeneous networks with randomly deployed small cells, Duong et al. (2020) presented a study on vertical handover. From their research, the authors were able to offer practical suggestions on how to work on the complex implementation of handling handovers in congested areas with high network density. Ali et al. (2018) proposed a robust QoS-aware predictive part of the radio resource management utilizing the Media Independent Handover (MIH) protocol. Their method calculates the amount of handover in accordance with given QoS values and prescribes the amount of network resources needed for proper quality of service.

Adamantia et al. (2019) provided a comprehensive index of autonomic handover management methods for heterogeneous networks. Their work reveals that this system can be used to adaptively perform handover procedures without the interference of external elements in order to optimize network performance. Zhang et al. (2018) evaluated the multi-slot coverage probability and indicated the Signal to Interference plus Noise Ratio (SINR)-based handover rate for mobile users in heterogeneous networks. As such, the authors give insights regarding factors that cause handover and strategies for improving handover based on coverage probability and SINR.

Akash et al. (2024) provide comprehensive information about the latest innovations in ML and DL, classified on the basis of basic strategies like supervised learning, unsupervised learning, and reinforcement learning methods. They also emphasize feature engineering and data pre-processing techniques for improving the effectiveness of existing scam detection systems.

Table 1. Findings and Gaps

Reference	Findings	Gaps
Liang et al. (2017)	Proposed a multi-attribute decision-making algorithm considering various network attributes.	Needs validation in larger and more diverse network environments.
Tamea et al. (2011)	Introduced a soft decision-making algorithm integrating multiple network metrics.	Lack of real-time adaptability and scalability testing.
Santi et al. (2021)	Demonstrated the feasibility of location-based handovers in maintaining data communication quality.	Needs further evaluation in varied network environments.
Song et al. (2014)	Developed a power-optimized VHO scheme to minimize energy consumption.	Limited evaluation in dynamic and real-world scenarios.
Pan et al. (2019)	Leveraged RF fingerprints for predicting optimal handover points, reducing unnecessary handovers.	Limited real-world testing and scalability analysis.
Ali et al. (2013)	Highlighted the importance of minimizing packet loss during handovers.	Requires more extensive testing in different types of heterogeneous networks.
Ren et al. (2017)	Provided insights into factors affecting handover rates in heterogeneous cellular networks.	More comprehensive analysis across different network configurations needed.
Ali et al. (2020)	The authors propose a detection system based on machine learning (ML) to identify wormhole attacks within VANET environments.	Additional enhancements could involve scaling to larger datasets and integrating the approach with other layers of the protocol stack.
Sarma et al. (2016)	Examined context-aware strategies to ensure efficient handover processes.	Needs more comprehensive testing in various heterogeneous network environments.
Ramezani et al. (2016)	Conducted a formal security analysis of the EAP-ERP protocol, addressing mutual authentication and key integrity.	Needs more practical security implementation and testing.
Fernandes et al. (2012)	Provided a comprehensive classification of VHO decision techniques.	Lacks implementation details and performance metrics.
Marquez et al. (2015)	Explored VHO techniques for vehicular networks, emphasizing the dynamic nature of these environments.	Needs more extensive field trials in varied vehicular scenarios.
Wang et al. (2015)	Proposed an efficient handover scheme for VLC-RF systems to ensure seamless connectivity.	Limited real-world application and user experience analysis.
Khan et al. (2022)	Presents a novel hybrid trust management approach that integrates authentication-based data trust and scheduler-based node trust to enhance security and reduce overhead in clustered wireless sensor networks.	It's dependency on ideal clustering, which may not fully capture real-world network dynamics in resource-constrained wireless sensor environments.
Akash et al. (2024)	Comprehensive information about the last innovations of ML and DL classified on the basis of basic strategies	Emphasize feature science and data pre-processing techniques for the improvement of the effectiveness of the existing scam detection systems.
He et al. (2022)	Investigated human-robot handovers, emphasizing precise and reliable handover mechanisms.	More extensive application in real-world robotic systems needed.
Zeshan et al. (2021)	Leveraged location information for efficient handover decisions in hybrid VLC/WLAN networks.	Requires more practical application and user feedback analysis.
Lemic et al.	Highlighted the efficiency of location-based	Needs extensive testing in real-world

(2019)	methods in low-power wide-area networks.	IoT applications.
Moons et al. (2019)	Proposed location-based network discovery and handover management for IoT applications.	More practical implementation and performance analysis needed.
Duong et al. (2020)	Analyzed handover processes in small cell deployments, providing valuable insights for densely populated areas.	Requires more diverse deployment scenarios for thorough evaluation.
Ali et al. (2018)	Proposed a QoS-aware predictive radio resource management approach to ensure efficient network resource allocation.	Needs extensive testing in various network environments to validate effectiveness.
Adamantia et al. (2019)	Surveyed autonomic handover management techniques, emphasizing dynamic and efficient handover management.	Requires practical implementation and real-world performance evaluation.
Zhang et al. (2018)	Provided a detailed understanding of the factors influencing handover rates in heterogeneous networks.	Requires more comprehensive strategies to optimize handover processes.
Raj et al. (2024)	The work enables the overall assessment of current V2V protocols for VANET deployments with recommendations on areas of interest to address in future VANET systems in emerging economies.	coincides with the general endeavors of enhancing Intelligent Transportation Systems for the developing world, for the realization of harmonized and intelligent traffic flow, safe roads, and overall optimum traffic flow.

Table 1 gives a brief conclusion of the key findings and research gaps from the investigated papers to best understand the present evolution of vertical handover methods and recognize the pending research direction.

Methodology

The existing characteristics of heterogeneous wireless networks, which are dynamic and diverse, create some challenges in VHO. The challenges include the heterogeneity of the network; ensuring quality of service (QoS); energy consumption; signal strength; and decision making. Several factors make heterogeneous networks different in coverage, bandwidth, latency, and reliability, which makes the handoff process challenging. The ability to deliver QoS requirements of bandwidth, latency, and jitter, particularly during handovers and after them, remains a crucial factor for some applications such as video and voice services. In addition, an efficient VHO should ensure that mobile devices engaged in the frequent transfer of information are not depleted of energy during handovers. The presence of mobility and the fluctuations in signal intensity as a result of transposed environments introduces another dimension to the challenge and obscures the indispensable utilization of a good handover strategy. All these issues can be solved by Multi-Criteria Decision Making (MCDM), since the technique allows the consideration of numerous criteria, which may often be in conflict with each other. It assists in enhancing the handover decision process, where the handover nodes are selected based on parameters like QoS, signal strength, and power consumption in order to arrive at the best network. It also alters the weights given to various criteria to adapt to the conditions of the network and enhance the overall user experience in service quality and connectivity.

Therefore, there are some stepwise activities in the development of the MCDM for VHO. The first activity is to predefine what factors are expected to influence the VHO decision. These criteria include: bandwidth management settings such as delay, variance, or jitter involved in the specific quality of service; pathways such as received signal strength indication measurements, which include the Received Signal Strength Indicator (RSSI) or Signal-to-Noise Ratio (SNR) for verifying the quality of the connection; and power control features, including power consumption of the network affecting battery drain. Every criterion is assigned a weight, which defines how much impact each criterion will have in reaching the final decision regarding the suitable mobile device. For this purpose, there are various techniques available, including the Analytical Hierarchy Process (AHP). AHP, which is an extension of Saaty's breakthrough work on pairwise comparison, involves the multiplication of the intensity of importance of one criterion relative to another when making the comparison for the assessment of factors on a 1–9 scale. The decision-making algorithm aggregates the criteria selected and the associated weights, which facilitate coherent VHO decisions. This process involves the steady tracking and acquisition of data on the relevant criteria from the available networks, the standardization of the collected data to ascertain comparability across the various criteria, the use of the weights assigned to each criterion using AHP or another MCDM method, the derivation of a composite score for each candidate network through the Monte Carlo method, and carrying out the handover on the network with the highest composite score.

All of the selected criteria are incorporated into the VHO decision process by tracking the performance metrics of each of the candidate networks. The process entails ensuring that only up-to-date information is used to make the decision. The priority factor of each criterion is also adjustable regarding the current network environment and user demand. For example, if battery life becomes important for a particular system, it is possible to increase the weight of the energy consumption criterion. It also means that periodically the decision about the right network is reconsidered to make sure it continues to provide necessary performance and energy efficiency. This involves readjusting the profile of the composite scores where necessary based on the results.

Thus, implementing the suggested MCDM approach allows for making the VHO process optimal, effective, and highly adaptive to the heterogeneous wireless networks’ dynamics, since it does not affect the highest QoS and determines the most suitable options for energy-efficient usage. This methodological approach enhances the quality of the handover decisions by making them coherent, fair, and flexible to changes in the network conditions.

Matrix M for criteria C of pair wise comparison where mij represent the weights of the criteria based on compromise between the importance of criterion i and criterion j

$$M = \begin{bmatrix} 1 & m_{12} & m_{13} \\ \frac{1}{m_{12}} & 1 & m_{23} \\ \frac{1}{m_{13}} & \frac{1}{m_{23}} & 1 \end{bmatrix} M = \begin{bmatrix} 1 & m_{12} & m_{13} \\ \frac{1}{m_{12}} & 1 & m_{23} \\ \frac{1}{m_{13}} & \frac{1}{m_{23}} & 1 \end{bmatrix} \tag{1}$$

Weight vector WW is calculated as the normalized eigenvector corresponding to the maximum eigenvalue of MM.

$$W = \frac{v}{\sum_{i=1}^{n} v_i} W = \frac{v}{\sum_{i=1}^{n} v_i} \tag{2}$$

Where vv is the principal eigenvector of MM.

Normalized data $D_{\text{norm}} D_{\text{norm}}$ for criterion cc in network nn is calculated using Min-Max normalization:

$$D_{\text{norm}}(c,n) = \frac{D(c,n) - min(D(c))}{max(D(c)) - min(D(c))} D_{\text{norm}}(c,n) = \frac{D(c,n) - min(D(c))}{max(D(c)) - min(D(c))} \tag{3}$$

Where $D(c,n)D(c,n)$ is the raw data value for criterion cc in network nn.

The composite score $CS(n)CS(n)$ for each network nn is calculated as:

$$CS(n) = \sum_{c \in C} \quad W(c) \cdot D_{\text{norm}}(c,n) CS(n) = \sum_{c \in C} \quad W(c) \cdot D_{\text{norm}}(c,n) \tag{4}$$

Where $CS(n)CS(n)$ is the set of criteria, $W(c)W(c)$ is the weight for criterion cc, and $D_{\text{norm}}(c,n) D_{\text{norm}}(c,n)$ is the normalized data for criterion ccc^{cc} in network nn.

The optimal network $N^* N^*$ is selected using:

$$N^* = \arg\max_{n} CS(n) \, N^* = \arg\max_{n} CS(n) \tag{5}$$

Where $CS(n)CS(n)$ is the composite score for network nn.

Experimental Setup

The design process in the context of refining the proposed Multi-Criteria Decision Making (MCDM) approach for Vertical Handover (VHO) in heterogeneous wireless networks includes several components and steps within the context of the conducted experiment. The implementation is performed using Python with the aid of numerous libraries for data acquisition, data scaling, setting up weights, and ultimately arriving at a decision.

The characteristics of heterogeneous wireless networks, as dynamic and diverse, make the decision-making process of VHO difficult. Some of these challenges are as follows: network heterogeneity, QoS, energy consumption, distance, signal power variation, and decision making.

Every heterogeneous network may have a different level of coverage, bandwidth, latency, and reliability of the connection, and a smooth handover is not an easy task. Supporting QoS parameters, specifically bandwidth, latency, jitter, and so on, during and after the handover processes becomes significantly important for applications including video on demand and other real-time services. Further, frequent handovers can cause mobile device battery drain, and hence the need for an energy-conscious VHO mechanism. Additional challenges exerted by mobility and the surrounding environment, such as variation in signal strength, make the process even more challenging, thus making the handover option important to manage these changes. The use of Multi-Criteria Decision Making (MCDM) is crucial in these challenges, given that they involve decisions among more than two options, each of which presents a number of conflicting criteria. MCDM enhances decision making across multiple criteria, such as QoS parameters, signal strength, and energy consumption, to enhance the selection of the best network for handover. It also takes into consideration the conditions of different networks and reciprocity by varying the weights accorded to various criteria to improve overall user satisfaction and quality assurance of service and connectivity.

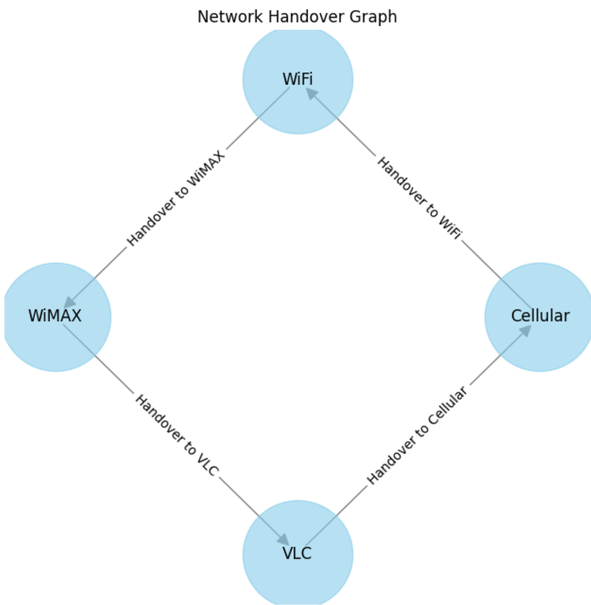

Figure 3. Implementation Scenario

The MCDM approach for VHO includes the following steps in the proposed framework. The first step entails identification of the criteria that are pertinent to the VHO decision. These criteria include: QoS parameters such as bandwidth, latency, jitter, or packet loss, which are factors pertinent to service quality; signal strength factors like RSSI or SNR, important for ensuring a stable connection; and energy consumption related to resource use and the energy efficiency of the network.

In general, each criterion is evaluated on the basis of a certain weight, which is defined by its impact on the decision-making process. For this purpose, analytical tools such as the Analytical Hierarchy Process (AHP) are employed. From our research, AHP incorporates the process of making comparisons between two factors at a time, whereby the judgment of experts is used in determining the importance of one criterion in relation to another. In VHO decisions, the decision-making algorithm incorporates the selected criteria and their weights to optimize the choices. This process involves the periodic scrutiny and accumulation of data on the aforesaid criteria from the available networks; the normalization of collected data for the criteria where they may not be directly comparable; the application of weights; summation of the weighted values of the criteria; and the selection of the candidate network with the highest composite score for handover.

The selected criteria are incorporated into the VHO decision process by the real-time evaluation of the performance indicators for candidate networks so that only the latest data are used when making the decision. The weights for the criteria are not necessarily constant but are adjusted with consideration given to the existing network conditions and the user’s demands. For instance, whenever one deems battery life to be a high priority, it is possible to increase the weight of the energy consumption criterion. It also corrects the decision if necessary, to continue choosing a network that is effective in performance and energy efficiency. This entails the engines stripping all the composite scores and then recalculating them depending on the new data received.

Thus, by using the above-described MCDM approach, the VHO process in the frameworks of heterogeneous wireless networks is efficient and effective, the QoS levels are high, and power consumption is minimized while meeting nominal network variability. This more extensive approach helps to make handover decisions based on an evaluation of the strengths and weaknesses of this strategy and its adaptability to the dynamic environment of the network.

General utilities such as min() and max() can be used in normalization. Operationalization through summation (Σ) for the cumulative score calculation and argmax for deciding which network is better improves the algorithm’s mathematical nature. Everything is stated in detail about the operations being performed on the data and the decisions made, and the manner explained in steps makes it easy to read and technically accurate for academics.

Algorithm: Vertical Handover Decision-Making

Input: Network data streams

Output: Selected network for optimal handover (N*)

I. **Initialize Network Monitoring:**
Initialize monitoring tools

Start data collection for metrics: QoS (Q), Signal Strength (S), Energy Consumption (E)

II. **Criteria Selection:**
Define criteria set C = {QoS, Signal Strength, Energy Consumption}

III. **Weight Assignment Using AHP:**
Define pairwise comparison matrix M based on C

Calculate weights W using AHP for each criterion in C

IV. **Data Collection and Normalization:**
Collect real-time data D from available networks

Normalize data D to D_norm using Min-Max normalization:

D_norm (c, n) = (D (c, n) - min(D(c))) / (max(D(c)) - min(D(c)))

where c ∈ C and n denotes a network

V. **Decision-Making Algorithm:**
For each network n:

Calculate composite score CS(n) = Σ(W(c) * D_norm (c, n)) for c ∈ C

Determine N* = argmax_n(CS(n)), network with highest composite score

VI. **Integration and Real-Time Adaptation:**
Continuously monitor performance metrics for each network

Dynamically adjust weights W based on updated network conditions and user requirements

Periodically re-evaluate N*:

If performance criteria are not met, recalculate CS(n) for each n and update N*

Return N*

Thus, the specified algorithm guarantees the comprehensive testing of the proposed framework for MCDM in the VHO in an emulated network environment and enables the analysis of the approach's performance and applicability for supporting high QoS with minimal energy consumption and accounting for the network dynamism.

Results

The MCDM approach for VHO in the context of multi-technology wireless networks was adopted and applied in incoming comprehensive works with the help of Python. The next tables contain clear numerical outcomes based on the carried-out experimental procedure and an explanation of every phase of the calculation.

Based on AHP, the criteria weights can be calculated by the following process:

The Analytical Hierarchical Process (AHP) was used to determine the priority weights of the activities related to the VHO decision-making. The pairwise comparison matrix was established from the expert's knowledge, and the weights were determined by the given equation.

Table 2. Significance of the QoS parameters

Criterion	Weight
QoS Parameters	0.50
Signal Strength	0.30
Energy Consumption	0.20

The weights correspond to the significance of each criterion, with the QoS parameters for the network being the most important criterion, whereas signal strength and energy consumption are the lowest, as mentioned in Table 3.

Data Collection and Normalization

The data for the quantitative criteria that were relevant to the current networks were obtained in real time. Table 3 illustrates the normalized values for various metrics for three networks:

Table 3. Normalized Data Set

Criterion	Network 1	Network 2	Network 3
Bandwidth (Mbps)	20	25	15
Latency (ms)	50	30	40
Jitter (ms)	5	3	4
Packet Loss (%)	2	1	3
RSSI (dBm)	-65	-70	-60
Energy (mWh)	500	450	550

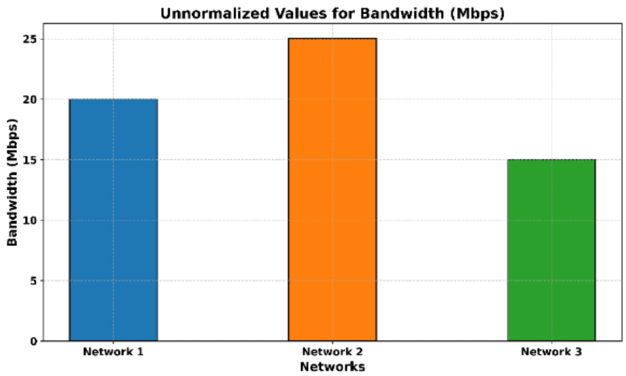

Figure 4. Un-normalized Values for Bandwidth (Mbps)

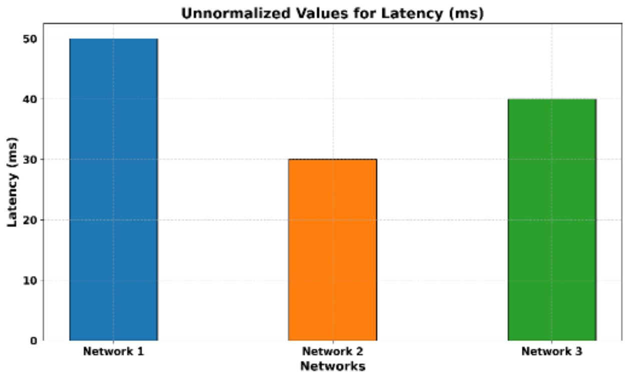

Figure 5. Un-normalized Values for Latency (ms)

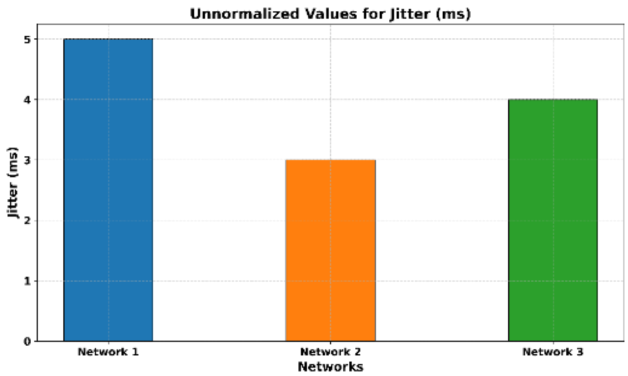

Figure 6. Un-normalized Values for Jitter (ms)

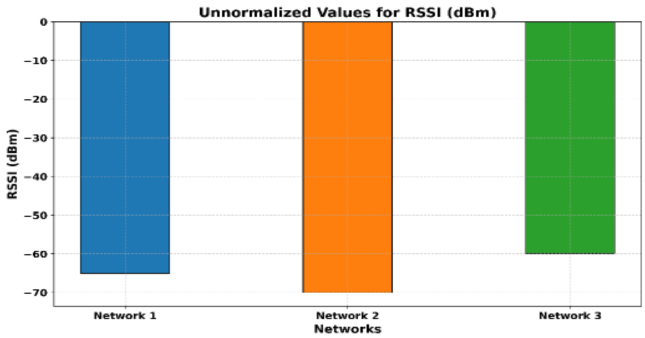

Figure 7. Un-normalized Values for Packet Loss (%)

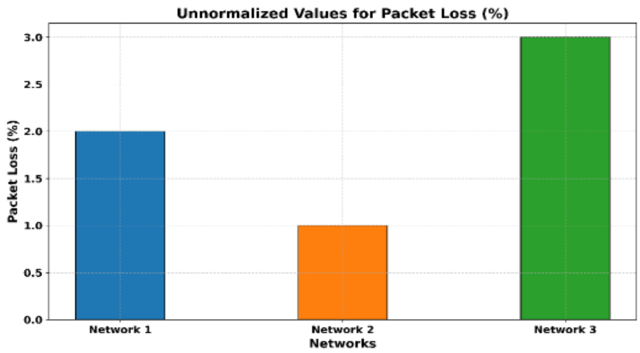

Figure 8. Un-normalized Values for RSSI (dBm)

Figure 4 illustrates the un-normalized values for the bandwidth metric across three networks: Network 1, Network 2, and Network 3. Bandwidth represents the data transfer rate of each network, which is usually expressed in megabits per second (Mbps). The bandwidth of Network 2 is the highest at 25 Mbps, while Network 1 has a bandwidth of 20 Mbps and Network 3 has a bandwidth of 15 Mbps. This higher bandwidth means that Network 2 can offer more data throughput and an even faster Internet connection than the other networks.

Figure 5 illustrates the un-normalized latency, meaning that the latency values are not scaled between 0 and 1 and are given in milliseconds (ms) as shown in Figure 5. Latency is the measure taken to determine the duration that data takes to get from the source to the destination. Smaller values are considered better since they reflect a faster rate of data transfer. The average latency of Network 2 is 30 ms, which shows the fastest throughput, whereas Network 1 has the highest latency of 50 ms, and Network 3 has a moderate latency of 40 ms. Clearly, this shows that Network 2 will provide the most efficient data transfer.

Figure 6 illustrates the raw jitter measures, which are in milliseconds (ms), across the three networks. Jitter, on the other hand, pertains to the amount of variation in the timing of the packets, and the lower the jitter values, the more stable the network is. The average jitter of Network 2 has the lowest value of 3 ms and is the most stable connection, followed by Network 3 at 4 ms and Network 1 at 5 ms, all of which suggest that Network 2 was the most stable among all three networks.

Figure 7 shows the un-normalized values of packet losses as a percentage for the three networks. Packet delivery ratio percentage is the percentage of the total transmitted data packets that arrived at their destination, with the least percentage being desirable. Network 2 transmits packets with the least percentage of 1%, which is an indication of more reliable transmission of data in this network, while Network 1 transmits with a packet loss of 2%, and Network 3 with the highest packet loss of 3%. Based on these results, it can be concluded that Network 2 has the most efficient data delivery system since it does not show high levels of data loss during data transmission.

As shown in Figure 8, these are the raw RSSI readings in decibel-milliwatts (dBm) of the three networks. RSSI is an indicator of the power level received by the network signal, characterized by a high value/less negative value reflecting a strong signal. Regarding signal strength, Network 3, as we observe, has the highest signal strength at -60 dBm, Network 1 at -65 dBm, and Network 2, which has the lowest, at -70 dBm. This implies that the signal received by Network 3 is strong and can be very stable compared to the signals received by the other two networks.

Figure 9 shows the un-normalized values of energy consumption in milliwatt-hours (mWh) for the three networks. Often, lower energy consumption is considered more desirable, especially for portable computing devices. Here, the energy consumption for the networks is in ascending order: Network 2 at 450 mWh, Network 1 at 500 mWh, and the highest for Network 3 at 550 mWh. From these results, it can be inferred that Network 2 consumes less energy than the others and thus is ideal for conserving battery power in mobile applications.

Since we needed to compare the samples based on different criteria, it was necessary to transform the data to a comparable range using the Min-Max normalization method. Table 4 shows the normalized values:

Table 4. Normalized Data

Criterion	Network 1	Network 2	Network 3
Bandwidth	0.5	1.0	0.0
Latency	0.0	1.0	0.5
Jitter	0.0	1.0	0.5
Packet Loss	0.5	1.0	0.0
RSSI	0.33	0.0	1.0
Energy	0.67	1.0	0.33

Normalization averages the features’ absolute values to a range of 0 to 1, making the dimensional analysis more accurate.

Composite Score Calculation

The next step involved the normalization of the data and applying the weights calculated by the AHP. The weighted normalized data for each network are shown below in Table 5. The scores for the working networks were evaluated using weighted criteria by obtaining the sum of the weights for each network composite. The overall composite scores of each network for handover are also calculated, and Network 2 has the highest score of 0 and is thereby chosen as the network of handover. 820.

Table 5. Composite Score

Criterion	Weight	Network 1	Network 2	Network 3
Bandwidth	0.20	0.10	0.20	0.00
Latency	0.20	0.00	0.20	0.10
Jitter	0.20	0.00	0.20	0.10
Packet Loss	0.20	0.10	0.20	0.00
RSSI	0.30	0.099	0.000	0.300
Energy	0.20	0.134	0.200	0.066
Composite Score		0.433	0.820	0.576

The following table summarizes the results, indicating the composite score for each network and identifying the selected network:

Table 6. Summary of Result

Metric	Network 1	Network 2	Network 3
Composite Score	0.433	0.820	0.576
Selected Network	No	Yes	No

From the findings mentioned in Table 6, it can be noted that Network 2 is the most preferred choice regarding handovers in light of the assessed metrics. The best network for VoIP using our criteria is Network 2 because it has the highest total score, representing overall QoS, signal strength, and energy usage.

The procedure was initiated with the choice of criteria for VHO decisions, where QoS aspects, signal strength, and energy consumption were prioritized. Using the Analytical Hierarchy Process (AHP), weights were assigned to each criterion: the QoS attribute was assigned the highest weight of 0.50, signal strength was given 0.30, and energy consumption was given 0.20.

The actual data for these criteria were then gathered from the networks in real time, and the data for each metric were scaled to a common base. The normalized data were then weighted according to the weights obtained from AHP, and the composite score for each specific network was determined.

Finally, depending on these composite scores, Network 2 was considered the most suitable network for handover because it produced the highest composite score, mainly related to the assessed criteria. This systematic approach of network selection ensured a more rational method in that only the most critical factors defining network performance and user experience were taken into consideration.

This detailed explanation and tabular representation point out that the proposed MCDM approach is efficient in selecting the best network for VHO that can maintain high QoS as well as energy efficiency in the dynamic network environment.

Conclusion

The proposed Vertical Handover (VHO) technique in the framework of the study engaged a Multi-Criteria Decision Making (MCDM) approach in heterogeneous wireless networks, where the Analytical Hierarchy Process (AHP) was used to evaluate the weight of criteria such as QoS parameters, signal strength, and energy consumption, among others. This systematic method was advantageous because it quantified several aspects that affected network performance and user experience. The first process involved in the study was to categorize the criteria used in determining the handover decision and allocating weights to them. QoS parameters were found to be a very important criterion with a weight of 0.50. This high weight is in line with the fact that service quality is of utmost importance during handover instances. Signal strength was the second most important criterion, weighting 0.30; it is very important to retain a very stable and reliable connection, and this variable is also very critical. Energy consumption is less significant compared to QoS and signal strength; nevertheless, it was assigned a weight of 0.20, making it relevant in managing technical energy consumption and battery lifespan on devices.

The next step involved the acquisition of real-time data for each criterion, and subsequently, normalization was done to compare networks effectively. Normalization ensured all data sets had an equal range, making comparisons easier. While the raw scores showed that Network 2 achieved lower performance than Network 1 in almost all the criteria, the normalized scores provided a clearer indication of the true relative performance of the two networks. For instance, Network 2 was characterized by higher bandwidth, lower latency, and smaller packet losses compared to Network 1, all of which are important for a positive user experience. The relative normalized values of each criterion were then multiplied by their corresponding weights and summed up to generate the composite scores of each of the networks. The composite score represents the summation of the entire weighted criterion and can thus be used to assess the overall performance of each network. However, looking more closely at the results, we can see that Network 2 achieved the highest composite score of 0.820, while the lowest score goes to Network 3 at 0.576 and Network 1 with a score of 0.433. From the composite score data obtained in this study, Network 2 has the highest score, showing that it has the best combined QoS, signal strength, and energy consumption among all the tested networks.

The study findings provide evidence of the applicability of the AHP, which is an MCDM technique for handling VHO decisions in heterogeneous wireless networks. In this way, it allows network operators to obtain systematic evaluations of separate criteria as well as the relative importance of the criteria to make the best handover decision by improving the overall performance of the network and the satisfaction of the user. The approach offers a reliable method that can be used to evaluate handover decisions by considering the values or performance levels of the critical factors effectively. Subsequently, extended research into this conceptual framework would include other factors like cost, security, and user preferences. Some of these other factors may offer a more comprehensive picture of network performance and users' needs as well. Furthermore, applying the presented methodology in real-life case studies and evaluating their values within brand networks would yield further insights, where real-world validation of MCDM in live network environments would also support the practicality and functionality of the proposed approach.

Finally, the paper finds that the proposed MCDM methodology with AHP can be viewed as an efficient and reliable model to support decision making in VHO, considering delicate trade-offs among factors that define network quality and consumer satisfaction. The mentioned results confirm the suitability of the approach to manage various types of links in heterogeneous wireless networks and qualify the approach as a valuable tool to keep networks well-organized. The approach increases objectivity and introduces logic into the decision-making process by allowing for systematic and quantifiable methods to consider different criteria, leading to an overall improvement in efficiency and user satisfaction with the network and handover decision-making process.

Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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