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Multicriteria and Quality of Service- Aware Vertical Handover Solution for Vehicle-to-Infrastructure Communication in Multitier Heterogeneous Networks

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Abstract— The growing integration of vehicle-to-infrastructure (V2I) communication within multitier heterogeneous networks (HetNets) introduces challenges in maintaining seamless connectivity and Quality of Service (QoS) for vehicular users. This paper introduces a modified Multicriteria and QoS-aware Vertical Handover Decision Algorithm (mV2I-MHA) tailored to address these challenges. By considering multiple criteria - such as packet loss ratio, cost, available bandwidth and packet latency - the proposed solution intelligently manages vertical handovers between different network tiers. Numerous Multi-Criteria Decision-Making (MCDM) techniques have been proposed to address the right target network selection aiming to reduce unnecessary handovers, incorrect network selections and the associated processing time. However, many of these solutions overlook the significance of varying criteria weights in vertical handover decisions made by their selection algorithms. Through comprehensive simulations and comparisons with existing techniques, the effectiveness of the proposed – in this paper - solution is demonstrated in enhancing handover success rate, reducing handover failure rate, minimizing latency, and overall elevating the QoS for V2I communication in multitier HetNets. MATLAB R2020a was utilized to simulate the work. Using packet latency and handover failure as the metrics for performance, the results were contrasted with those of an existing works in terms of handover failure rate and packet delay. The developed mV2I-MHA showed considerable percentage reductions of 10.5% and 23.9% in packet latency and handover failure rate, respectively.

Keywords— Vertical handover; Multi-criteria decision-making; Vehicle-to-infrastructure communication; Packet latency; Handover failure rate; Multitier heterogeneous network.

1. INTRODUCTION

Vehicular communication has emerged as a transformative technology, enabling seamless connectivity and data exchange among diverse entities such as vehicles, infrastructure components, and various devices [1]. In this rapidly evolving landscape, the concept of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and the emerging vehicle-to-everything (V2X) communication models have gained considerable attention. These paradigms reflect the integration of technology and transportation, heralding an era of smart mobility and communication. V2V communication is characterized by direct wireless interactions between vehicles through their onboard units (OBUs), eliminating the need for roadside infrastructure support. On the other hand, V2I communication extends this

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connectivity by facilitating direct wireless exchanges between OBUs and fixed Roadside Units (RSUs). The evolution toward V2X communication broadens the scope by encompassing interactions between vehicles and a multitude of communication entities [2].

As a result, vehicular communication is poised to revolutionize road safety, mobility, entertainment, and environmental applications. The increasing desire and need for wireless applications and services underscores the necessity for higher data rates and network capacity [3]. Nevertheless, the rise of latency-sensitive applications, such as those related to road safety and infotainment, accentuates the need for low-latency, high-throughput communication in vehicular networks. This requirement has led to an intricate challenge: to establish seamless, high-quality connections for vehicles traversing dynamic terrains with varying node densities and speeds. Addressing this challenge requires innovative solutions. One approach involves the deployment of RSUs to ensure continuous connectivity, a pivotal first step toward enabling uninterrupted communication for moving vehicle [2]. However, the practicality of deploying an extensive number of RSUs is constrained by cost considerations and the potential for interference issues. To alleviate these constraints, a two-step process emerges, involving not only RSUs but also the integration of vehicles into heterogeneous networks [2].

While V2I applications hold substantial promise, the delivery of continuous connectivity for vehicles in motion remains a formidable hurdle. The current state of the vehicular network infrastructures' inadequate coverage prevents in-vehicle users from connecting to the internet while driving. The Wireless Access for Vehicle Environment (WAVE) protocol, which incorporates IEEE802.11p at the MAC and physical levels, is the result of standardization work in vehicular communications. There are many advantages to the aforementioned inclusion, some of which include the reservation of a dedicated frequency band (5.9GHz), which mitigates interference from other wireless networks. Additional benefits include low latency communication, broadcast and multicast communications, and futureproofing.

However, this promising protocol faces challenges such as scalability concerns, communication delays, and limited coverage areas [4]. To address these challenges and usher in the capabilities of 5G networks, a multitier heterogeneous network architecture has emerged, utilizing varying cell sizes to expand coverage and capacity [3]. Notably, vehicle OBUs are incorporating heterogeneous Radio Access Technologies (RATs) such as Wi-Fi, WiMAX, LTE, and UMTS, thereby mitigating scalability issues and enhancing communication systems within vehicles [2]. This will help to address the main issue related to scalability and strengthen the communication systems of vehicles. Nevertheless, among the main difficulties in this situation will be an increase in often yet unwanted handovers, as this is one of the main performance-limiting elements in attaining QoS in V2I communications over a heterogeneous network [5].

In this complex landscape, an indispensable factor for effective V2I communication in urban multitier diverse network environments is the execution of swift and efficient handovers among different cell networks. This necessity becomes more pronounced in scenarios involving both macro and small cell networks, ensuring uninterrupted mobility and communication. While numerous handover studies exist within heterogeneous networks, many have primarily concentrated on low-speed mobile users, overlooking the intricate demands of dynamic vehicular environment [6]. This paper aimed at addressing the challenges of V2I communication in a multitier heterogeneous network context. This research introduces a modified QoS-aware multi-criteria handover network selection algorithm (mV2I-

MHA). The algorithm's core objective is to ease uninterrupted handover processes for V2I communications over complex multi-tier diverse networks. By choosing the most appropriate candidate access point for handover, based on a range of performance criteria, this algorithm reduced the handover delay and handover failure rate, hence, increasing the overall network throughput and holds promise in enhancing the connectivity and user experience of vehicular communication systems.

The remaining part of this paper is organized as follows: Section 2 provides literature reviews on Multicriteria Handover Decision Methods in heterogeneous networks, along with mathematical models related to the proposed scheme. Section 3 delves into the methodology employed in achieving the research objectives. Section 4 discusses the simulation and results obtained. Finally, Section 5 offers the concluding remarks for the entire research work.

2. RELATED WORK

The of work [4], presented a fuzzy logic-based vertical handover decision algorithm for vehicular ad-hoc networks. It integrates fuzzy logic with Media Independent Handover (MIH) protocol to improve handover performance. Input parameters like RSS, available bandwidth, service types are fed to fuzzy inference system. Fuzzy rules are defined to estimate link status and trigger handover events via MIH. Simulations compare fuzzy logic scheme with RSS-based handover in WiFi, WiMAX, LTE networks. Results show fuzzy logic reduces handover latency by 20%, delay by 21%, packet loss by 13% on average. Nonetheless, the suggested approach experiences an elevated ping-pong phenomenon and greater resource usage when vehicles' speeds are heightened. Ref. [6], developed a network selection scheme for handover in vehicle-to-infrastructure (V2I) communication over multi-tier heterogeneous networks. It derives parameters like load index, proximity index, relative direction index and residence time index to select the best target network. These are used to shortlist potential target networks first, then select the most promising one based on Received Signal Strength and load. A dual mode LTE-A and WiFi vehicle On-Board Unit (OBU) is implemented in OPNET simulator. Performance is compared to conventional RSS-based and ANDSF-assisted handover methods. Results show the scheme reduces handovers by 50%, handover failure rate by 50%, latency by 40% and improves throughput. But their suggested approach has a key shortcoming of suboptimal system performance attributed to inappropriate or inaccurate network selection due to flawed network selection technique. Ref. [7], presented an optimized handover mechanisms in heterogeneous vehicular networks. The work aims to reduce handover failure, delay, and packet loss in vehicular networks with multiple access technologies like LTE and IEEE 802.11p. It proposes a clustering technique where vehicles are grouped based on context like trajectory and dwell time. Cluster heads communicate with base station. A fuzzy logic-based network selection mechanism is proposed using criteria like RSS, load, speed to choose best network for handover. Simulations show proposed scheme reduces handover delay and failure compared to existing RSS or QoS based schemes. The study however, did not consider effects of vehicular density on clustering efficiency and the impact of the proposed clustering on throughput and overhead to analyse the overall network QoS performance. Ndashimye et al. introduced a multi-criteria handover algorithm (V2I-MHA) for V2I - communication in mixed networks, using SAW and AHP methods for network selection. The scheme supports upward and downward handovers. The developed algorithm provided improvements over existing approaches in simulations. However, AHP's subjective criteria weighting can lead to inaccuracies in network selection in [8]. Evangeline and Kumaravelu proposed a two-stage fuzzy logic-based approach for vertical handover target network selection in vehicular networks. It uses fuzzy logic to estimate a handover factor (FHO) and fuzzy VIKOR for network ranking based on various criteria. The FVIKOR approach reduces handovers and decision delays compared to other methods but assumes known network parameters, which may not always be practical due to measurement overhead in [9]. Ref. [10], adopted a multi-criteria handover decision algorithm (MCHoD) for heterogeneous networks with carrier aggregation in LTE-Advanced systems. The key motivation is that carrier aggregation increases handover probability and scenarios, leading to challenges like high outage, throughput degradation etc. The proposed MCHoD algorithm utilizes multiple criteria - SINR, bandwidth, UE distance, load, resource availability etc. to make handover decisions adaptively based on scenario. System model simulates a 2-CC LTE-A HetNet with macro and femto cells using MATLAB. Performance is evaluated for metrics like handover failure, radio link failure, ping-pong ratio. Results show MCHoD reduces handover failure by 93%, 72% and 58% over RSS, RWTL and MIF schemes respectively. It also reduces radio link failure and ping-pong handovers effectively. Nonetheless, with increasing user equipment speed, the frequency of handovers also escalates, leading to a subsequent rise in handover failures, ultimately leading to degraded system performance. The research work of [11], adopted a fuzzy logic based vertical handover (VHO) process for vehicular networks with DSRC and LTE technologies. The VHO algorithm uses Signal to Noise Ratio (SINR), Received RSS and vehicle velocity as input parameters. Twenty-seven (27) fuzzy rules are defined based on different combinations of RSS, SINR and velocity categories like high, medium, low. The output is a handover factor (HF) which ranks candidate networks for handover selection. Simulations results obtained showed that the approach worked better when compared with SAW, TOPSIS, VIKOR and Fuzzy-SAW schemes. However, only a simple simulation scenario was used with fixed vehicle speeds. In [12], the authors proposed a cross-layer path management (PM) scheme for Multipath TCP (MPTCP) in heterogeneous vehicular networks. MPTCP can improve throughput and reliability by using multiple network interfaces in vehicles. But high mobility causes issues like handover delays, packet loss, head-of-line blocking. The proposed PM scheme runs in user space and uses RSSI measurements to estimate link quality of each interface. Based on thresholds, it disables/enables subflows before link gets disconnected. During handovers, the scheme proactively removes poor quality subflows and adds new ones on better links to reduce delay and packet loss. Simulation results show the scheme improves handover latency, reduces out-of-order packets, increases throughput compared to regular MPTCP. Overall, the cross-layer path management approach seems promising to improve MPTCP performance in vehicular networks. Nonetheless, the scheme is not without some limitations such as the RSSI thresholds for link quality estimation may require tuning for different networks, high overhead in terms of processing and signaling and evaluation is limited to a simple scenario with only 2 networks. More complex scenarios could be tested.

3. TARGET CELL SELECTION FOR V2I HANDOVERS: METHODOLOGIES REVIEW

In the realm of seamless and efficient Vehicular-to-Infrastructure (V2I) handovers, the selection of target cells plays a pivotal role in ensuring uninterrupted connectivity and best user experiences. This section, delves into an extensive exploration of methodologies considered to address this critical aspect. Specifically, we will examine the application of three prominent techniques: Fuzzy Analytic Hierarchy Process (FAHP), modified FAHP (mFAHP), and Simple Additive Weighting (SAW). These methodologies not only pave the way for intelligent and data-driven target cell selection but also underscore the significance of advanced decision-making tools in the dynamic landscape of V2I handovers. By going into the intricacies of these methods, this section aims to provide valuable insights into the art and science of target cell selection for V2I handovers.

3.1. Simple Additive Weighting (SAW)

Simple Additive Weighting is a flexible MCDM method usually adopted to evaluate and rank network options based on multiple criteria. It is a straightforward and intuitive approach that allows decision-makers to give weight to different factors according to their relative priority and then compute a weighted sum for each alternative. The option with the peak weighted sum is considered the most favorable candidate network [13]. This simple MCDM method which is based on weighted average [14], can handle both quantitative and qualitative data. It is widely used in various fields, such as engineering, project management, economics, and supplier selection, to assist decision-makers in making informed and structured choices among competing options. While SAW is easy to implement and interpret, it does have limitations, such as its sensitivity to changes in criteria weights and the assumption of independence among criteria. For this reason, this work used mFAHP to generate the criteria weights. The following procedures are used to perform SAW. Given a decision matrix problem, **A**, the set of b alternatives, which are the candidate RATs at the time of handover is represented [8]:

$$b = (b_1, b_2, b_3, \dots, b_m) \tag{1}$$

The set of criteria, z, represents the application demands. The requirements which are available bandwidth, packet latency, packet loss ratio, and cost which is the amount of money a user is charged for using the service provided by different network providers.

$$z = (z_1, z_2, z_3, \dots, z_n) \tag{2}$$

To attain the best possible choices in a situation involving MCDM, an analysis of MCDM is applied. The MCDM problem is commonly depicted as illustrated by [15].

$$\mathbf{A} = (b \times z) \tag{3}$$

where **A** denotes the decision matrix, b indicates the alternative RATs, and z indicates the criterion.

Step 1: Constructing the decision matrix:

$$\mathbf{A} = \begin{array}{c} \\ b_1 \\ b_2 \\ \cdot \\ \cdot \\ \cdot \\ b_m \end{array} \begin{array}{c} \begin{array}{cccc} z_1 & z_2 & z_3 \cdots & z_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{1n} \\ x_{21} & x_{22} & x_{23} & x_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ x_{m1} & x_{m2} & x_{m3} & x_{mn} \end{bmatrix} \end{array} \tag{4}$$

Step 2: Obtaining the normalized decision matrix for both benefit criteria and the cost-related factors. As explained by [15, 16], the suitable expression for the normalization of the decision matrix element, denoted as $\overline{\boldsymbol{A}}_{ij}$ for the benefit criteria of the Min-Max method is presented as follows:

$$\overline{\boldsymbol{A}}_{ij} = \frac{x_{ij}}{x_j^{max}}, \; i = 1,2,3, \dots, m, \; j = 1,2,3, \dots, n \tag{5}$$

where x_j^{max} is a criteria parameter with high value, which is the maximum entry of the j^{th} column in $\boldsymbol{A}$.

In this case, the criterion is the available bandwidth and x_{ij} denotes the performance value of the i^{th} alternative in terms of j^{th} criterion.

Similarly, for the cost-related criteria, the low values of these parameters are optimal. These values are obtained using Eq. (6).

For cost criteria,

$$\overline{\boldsymbol{A}}_{ij} = \frac{x_j^{min}}{x_{ij}}\ ,\ i = 1,2,3,\dots,m,\ j = 1,2,3,\dots,n \tag{6}$$

where x_j^{min} represent the minimum entry of the j^{th} column in $\mathbf{A}$.

Step 3: Calculate each SAW rank index, B_{SAW}^{i} of the i^{th} alternative using Eq. (7) [8, 15].

$$B_{SAW}^{i} = \sum_{j=1}^{n} W_j \boldsymbol{A}_{i,j} \tag{7}$$

$$\sum_{j=1}^{n} W_j = 1 \tag{8}$$

where, W_j stands for the weight of a criterion i.

Step 4: Compute the score of each alternative.

$$B_{SAW}^{i*} = \sum_{j=1}^{n} B\ {}_{SAW\,j}^{\ i},\ i = (1,2,3,\dots,n) \tag{9}$$

Step 5: Obtaining the most ranked (Y) alternative.

$$Y = max_{i=1}^{n} B_{SAW}^{i*} \tag{10}$$

3.2. Fuzzy Analytic Hierarchy Process (FAHP)

According to [16], the classic AHP approach is a tool used for evaluating uncertain choices. The goal of this conventional AHP algorithm is to imitate how people make decisions. To do so, the algorithm often takes a hierarchical approach to the analysis of the decision-making process [17]. The target layer, the criterion layer, and the layers of alternatives and solutions are often considered by this algorithm. According [18], the objective would typically access the criterion, while each alternative would access the criterion to choose among the candidate options and settle on the target option that is best for the alternatives. According to the research conducted [8], the application of the AHP process is clearly explained in the context of the V2I-communication system network selection for handover in overlayed heterogeneous network environments. The notion of people as decision-makers is not deterministic, however, as there are typically occasions where our preferences are uncertain [18]. To account for this uncertainty, fuzzy set theory is used to further model the AHP decision-making process to model scenarios that are more pragmatic to our environments [18], or as in the case of this research, the selection of the appropriate target network. The fuzzy AHP method represents a sophisticated analytical approach that has evolved from the conventional AHP methodology. It integrates fuzzy logic and linguistic variables to address decision-making challenges by effectively tackling uncertainties and enabling the characterization of imprecise data [13]. The developed Fuzzy Extent Analysis (FEA) method of the FAHP is vividly explained, the procedure and mathematical expressions are clearly and comprehensively presented in [19].

3.3. Modified Fuzzy Analytic Hierarchy Process (mFAHP)

The triangular membership function was adopted to assess the criteria considered for the FAHP method adopted in this proposed work. These criteria are ambiguously characterized by three parameters: The triangular fuzzy values (*l, m, u*), where l represent the lower value, m indicates middle value, and u denotes the upper value of the fuzzy triangle.

The process of fuzzy evaluations involves an extent analysis designed to establish synthetic priority weights. This analysis comprises a sequence of six stages, as outlined in [20]. To compare the fuzzy numbers in the fourth stage of the FEA, the degree of possibility of $M_2 \geq M_1$ is calculated as:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) \tag{11}$$

$$V(M_2 \geq M_1) = \begin{cases} 1, & if\ M_2 \geq M_1 \\ 0, & l_1 \geq u_2 \\ \frac{(l_1-u_2)}{(m_2-u_2)-(m_1-l_1)}, & otherwise \end{cases} \tag{12}$$

where d denotes the ordinate of the highest intersection point D between μ_{M_1} *and* μ_{M_2} illustrated in Fig. 1. M_1 and M_2 are convex fuzzy numbers represented as $M_1 = (l_1, m_1, u_1)$, $M_2 = (l_2, m_2, u_2)$.

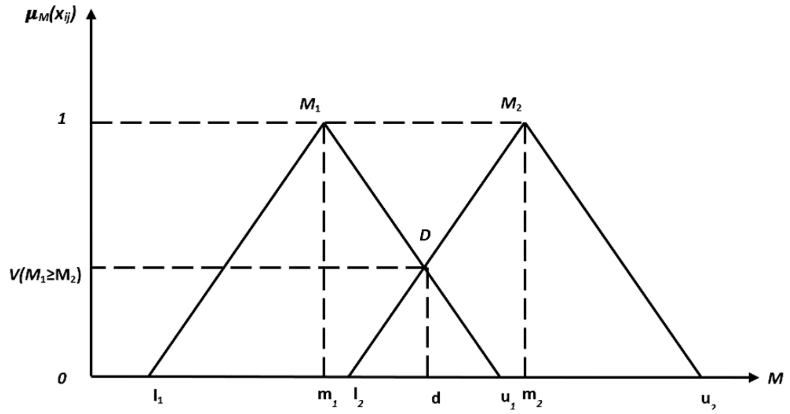

Fig. 1. Membership function of the TFN [12].

Comparing the fussy numbers by computing the degree of possibility of the triangular fuzzy values in the conventional FEA method within FAHP introduces potential erroneous decisions and has high computational complexity. To correct these potential erroneous decisions and mitigate the computational intricacy associated with the FEA method, this work modified the FEA method of FAHP utilizing magnitude value evaluation [21-24] of triangular fuzzy numbers, as delineated in Eq. (13) to compute the degree of possibility of triangular fuzzy values. Hence, the mathematical representation of magnitude value is as follow:

$$Mag(S_i) = \frac{1}{2}\int_0^1 \left(\left(\bar{A}(\alpha) + \underline{A}(\alpha) + core\ (\bar{A}) + core\ (\underline{A})\right) f(\alpha)\ \right) d\alpha \tag{13}$$

where $f(\alpha)$ is defined as a differentiable, non-negative and non-decreasing function on [0,1] with $f(0) = 0, f(1) = 1$ and $\int_0^1 f(\alpha) d\alpha$

The α - cut of fuzzy number A is given as,

$$A(\alpha) = \{x \in | \ \mu_A(x) \geq \alpha\}, \alpha \in [0, 1] \tag{14}$$

where A(α) is defined as a convex subset that belongs to U.

The lower and upper limits of α – cut A is given as,

$$\bar{A}(\alpha) = \{x \in | \ \mu_A(x) \geq \alpha\}, \tag{15}$$

$$\underline{A}(\alpha) = \{x \in | \ \mu_A(x) \geq \alpha\}, \tag{16}$$

Hence,

$$\bar{A}(\alpha) = u \tag{17}$$

$$\underline{A}(\alpha) = l \tag{18}$$

The core of a fuzzy number A consists of the element x whose membership grade is 1. That is,

$$core\ (A) = \{x \mid \mu_A\,(x) = 1\,\} \tag{19}$$

If A is a fuzzy triangular number such that $A = (\,l, m, u)$ then,

$$core\ (\bar{A}) = Sup\{x \mid \mu_A\,(x) = M_A\,\} = m \tag{20}$$

$$core\ (\underline{A}) = inf\{x \mid \mu_A\,(x) = M_A\,\} = m \tag{21}$$

To obtain the values of the magnitude $Mag(S_i)$ of the triangular fuzzy number and the normalized weight values the following steps are used:

Step A: For each fuzzy number, Eq. (23) is applied to calculate the magnitude $Mag(S_i)$.
Step B: The normalization of $Mag(S_i)$ is determined using Eq. (24) to obtain the weights.

Simplifying Eq. (13); in this work, the fuzzy numbers are normal, therefore, $M_{S_i} = 1$.

Furthermore, $core\ (\overline{S_i}) = core\ (\underline{S_i}) = m$, because of the fuzzy triangular number.

Substituting these values into Eq. (13), the magnitude $Mag(S_i)$ can be rewritten as:

$$Mag(S_i) = \frac{1}{2}\int_0^1 ([(u - (u - m)\alpha) - (l + (m - l)\alpha) + 2m]\alpha)d\alpha \tag{22}$$

$$Mag(S_i) = \frac{l + 10m + u}{12}, i = 1, \ldots, n. \tag{23}$$

Therefore, the criteria weights can be generated as:

$$W = \frac{Mag(S_i)}{\sum_{j=1}^{n} Mag(S_i)} \tag{24}$$

where the normalized weight vectors in Eq. (24) are non-fuzzy numbers.

3.4. Methodology

This research study utilizes a multicriteria decision making method to choose the best target cell for handover for V2I system in a multitier heterogeneous networks environment. The FAHP, SAW techniques and the methods considered for the modification of FAHP are vividly explained in Sub-section 3.1, 3.2, and 3.3.

The splicing of the mFAHP and SAW as well as the flowchart in Fig. 2 for the developed algorithm, are delineated in the following sub-sections.

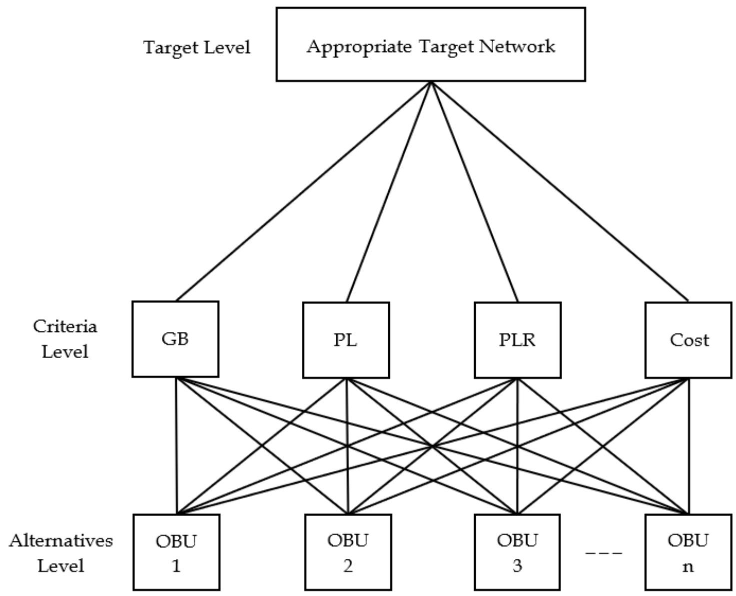

Fig. 2. Hierarchical model for the handover decision.

3.5. Hybridization of mFAHP and SAW Techniques

The hybridization of the mFAHP – SAW involves the mFAHP decomposing the problem to generate the appropriate weight factors for the criteria as illustrated in Fig. 3 and the SAW ranked and selected the best target network for handover.

The mFAHP generated the weight factors for the decision criteria is clearly explained in Sub-section 3.2 and 3.3 to obtain the normalized weight factors represented in Eq. (24).

The normalized weight factors alongside the normalized benefit and cost-related criteria in Eqs. (5) and (6) were used in Eq. (7).

The best target network selection was achieved with Eq. (9). The SAW ranked and selected the target network based on the constructed decision matrix in Eq. (4).

As delineated earlier, the formulae adopted in this paper are used to simulate how the mV2I-MHA selects the best target network for handover.

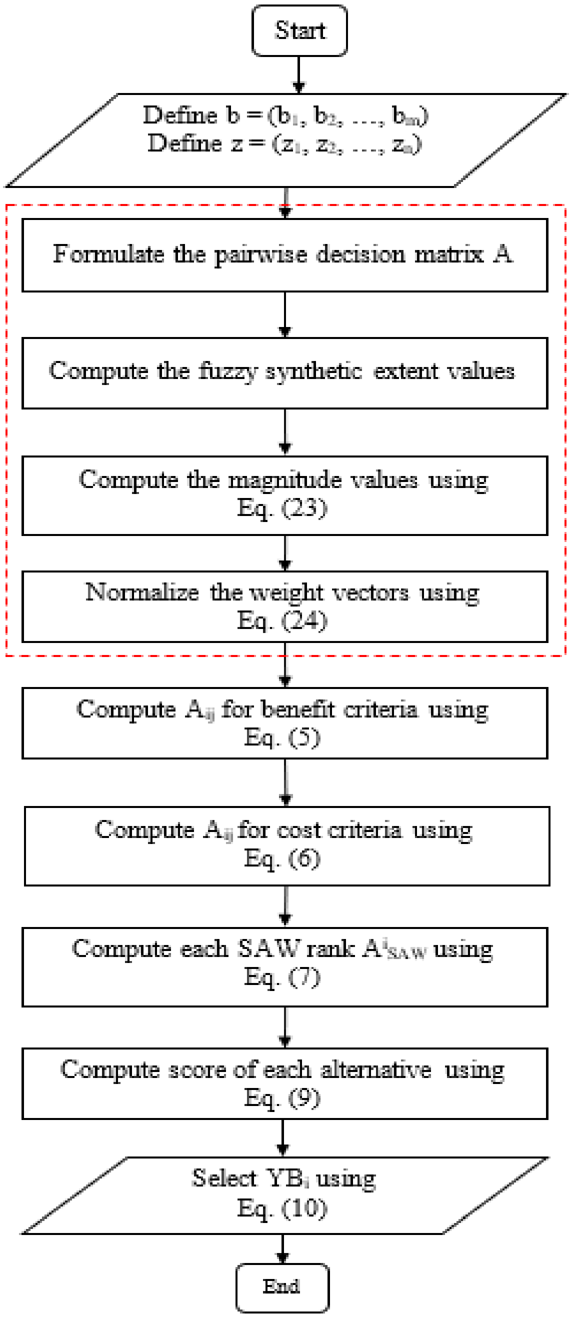

Fig. 3. Flowchart of the mV2I-MHA.

4. SIMULATION AND RESULTS

In this section, we present the simulation parameters that support the framework of this research paper, the result discussion, and the vehicle mobility model. With the consideration of presenting parameters that can mirror real-world settings, Table 1 shows the parameters adopted for the simulation outcomes.

Table 1. Simulation parameters [8].

Parameter	Value
Network area [m^2]	1000 * 1000
Transmit power of LTE-A macro/SAP	0.5W/0.1W
LTE-A macro/SAP gain	14dBi/5dBi
WiFi SAP (IEEE 802.11p) transmit power	0.05W
Vehicle speed [Km/h]	20 – 140
Path loss	$L = (40(1 - 4 * 10^{-3} \Delta hb) \log10 R - 18\log10 \Delta hb + 21 \log10 f + 80)$ dB
Radio propagation	Large-scale propagation
log-normal shadow fading	10 dB
LTE-A Channel bandwidth	1.4 MHz
Mobility	Random based trajectory
Simulation time	625s

4.1. Mobility Model and System Parameters

The velocity of the vehicle is modeled using a continuous time and continuous-state random walk model which is a mathematical representation used in motion modeling. The random process-based mobility model provides numerous benefits. To begin with, it furnishes both the direction of motion and the speed, enhancing system performance. In this model, a vehicle's velocity is treated as a continuous and random process that changes over time. It assumes that the vehicle's velocity can change at any moment and can take on a wide range of values. This model is often used to simulate real-world scenarios where a vehicle's speed is subject to random fluctuations or uncertainties, making it a useful tool for analyzing and predicting vehicle motion in situations where precise control and prediction are required, such as autonomous driving. In the context of this scenario, the vehicle's velocity is depicted as a random process, characterized by a system of differential equations as outlined in the given Eq. (25).

$$dv(t) = a(t)dt + \sigma(t)dW(t) \quad (25)$$

where $dv(t)$is the change in the vehicle speed at time t, $a(t)$ is the acceleration of the vehicle, $\sigma(t)$ is the standard deviation of the noise in the speed, and $dW(t)$ is the Wiener process.

The vehicle's acceleration can be represented as a stochastic process that considers the uncertainties and variability in the driving environment, including factors like road conditions and traffic congestion. Employing this model allows for a more authentic simulation of a vehicle's motion, factoring in real-world elements that could influence its speed. This data can then inform decisions related to vertical handovers in vehicular communication, enabling the selection of the best target network as illustrated in Fig. 4 based on the vehicle's speed and other Quality of Service (QoS) needs.

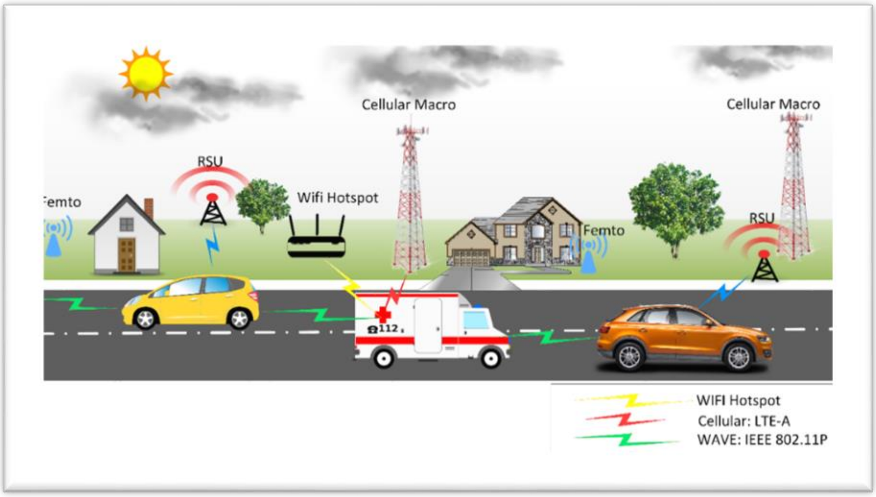

Fig. 4. Illustration of the vehicular communication.

4.2. Result Discussion

The network's operational efficiency was examined in scenarios involving varying numbers of attempted handovers and packet rates. To gauge the network's effectiveness, measurements were taken for handover failure rates, packet latency. The simulations were conducted using MATLAB R2020a, and graphical representations of the generated data were plotted. A comparative analysis between the outcomes of mV2I-MHA and the existing V2I-MHA was performed, focusing on packet latency, handover failure rates. The criteria weight factor signifies the relative significance of criteria within a decision matrix. In the context of this research study, modified Fuzzy Analytic Hierarchy Process was used to determine the appropriate weight vector for each application. In this study, the mFAHP method was applied to mV2I-MHA, which comprises just four criteria. The generated weight values for all the application profiles considered in this research are specified in Table 2. These values in Table 2, for the criteria weights assigned for the ranking of the target networks were calculated using the mFAHP explained in Sub-section 3.2 and 3.3. The mV2I-MHA selects the candidate network for handover based on network parameters like, vehicle's movement direction, vehicle speed and network node density. The algorithm filtered out the access points not in the direction of movement of the UE/vehicle or the base stations that provides very low signal strength for target network selection for handover thereby reducing the likelihood of increased HOFR and packet delay due to interference, resource contention and congestion as obtained in the simulation results.

Table 2. Weight values for the application profiles.

Parameter	Maximum Quality	VoIP	Video	General	Minimum Cost
Bandwidth	0.3215	0.3169	0.2213	0.2389	0.2327
Packet Latency	0.2959	0.2438	0.3446	0.2687	0.1874
Packet Loss Ratio	0.2052	0.2026	0.1992	0.2096	0.2389
Cost	0.1775	0.2366	0.2349	0.2829	0.3410

Fig. 5 indicates that the mV2I-MHA algorithm's mean packet delay is less than that of the V2I-MHA algorithm. The mV2I-MHA and V2I-MHA have respective mean packet latency values of 28.32 and 31.64 milliseconds. The overall delay from the time a voice packet is delivered to the time it is received is shown in Fig. 2 as the packet delay experienced by the

OBU for the voice profile. As the vehicle's speed climbed from 20 km/h to 140 km/h, there was a decrease in packet delay by 10.46% when mV2I-MHA and V2I-MHA were compared. As a result, it is demonstrated that the proposed mV2I-MHA scheme is more effective than the V2I-MHA strategy. This improvement is achieved by choosing the target network with the lowest latency for delay-sensitive applications, and the packet latency metric is given the peak priority in this selection.

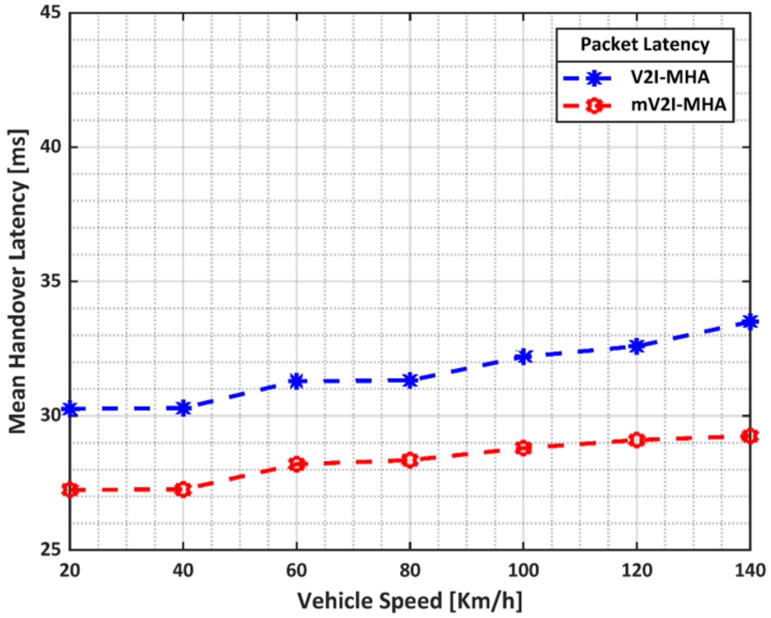

Fig. 5. Mean handover latency of mV2I-MHA and V2I-MHA.

An increase in handover failures has a detrimental impact on the quality of service. The simulation findings, as presented in Fig. 6 show how the suggested handover algorithm is more effective than the V2I-MHA technique at reducing the handover failure ratio for voice applications. When compared to V2I-MHA, the newly developed mV2I-MHA provides a reduction of 23.9%. This decline in handover failure rate demonstrates that V2I-MHA proficiently selects the optimal target network based on the QoS needs of the running profile, resulting in a reduction in disruptive handover oscillations and a decrease in instances of handover failures.

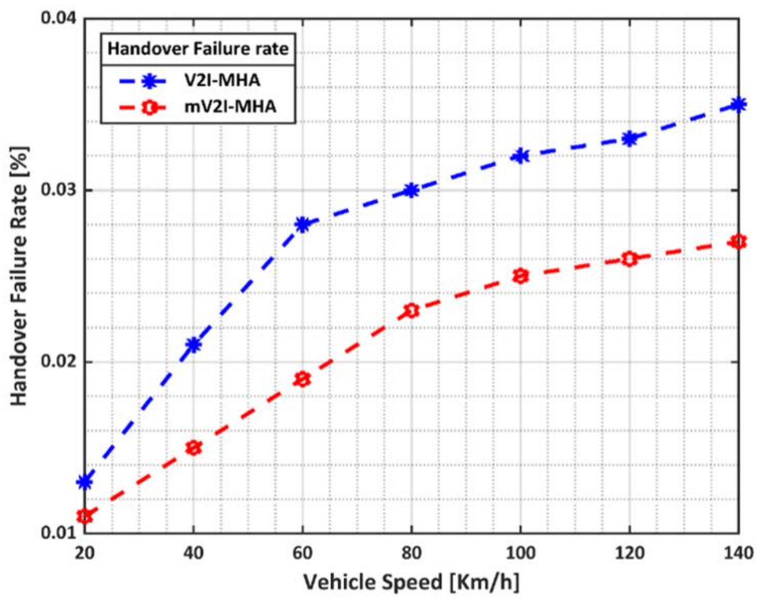

Fig. 6. Handover failure rate of mV2I-MHA and V2I-MHA.

5. CONCLUSIONS

This study modified a mV2I-MHA to select the best or optimal network for handover in integrated multitier heterogeneous networks. In a multitier heterogeneous network environment, choosing the incorrect network for handover poses a great challenge that leads to handover delay and degrade network performance. Based on packet latency, bandwidth, cost, and packet loss ratio, the mV2I-MHA chooses the best candidate network that satisfies the QoS requirements of five different application profiles for potential handover. With the development of this modified handover decision algorithm, the QoS was improved, and the number of frequent and pointless handovers, packet delay, and packet loss ratio were all decreased. The handover decision algorithm was achieved by employing the mFAHP-SAW method, which assigns weights to the network criteria and effectively selects the best target network. To validate and compare the effectiveness of this modified algorithm, its outcomes were contrasted with those of existing methods, focusing on parameters such as packet latency, and handover failure rate. The results exhibited notable improvements, surpassing the existing work with a 10.5% reduction in packet latency, and a 23.9% decrease in handover failure rate, respectively.

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