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Heterogeneous Architecture for DSRC/LTE Vehicular Communication Networks Based on the ITS Reference Architecture with Fuzzy Logic for Decision-Making

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***Abstract*—Methods to integrate different access technologies such as heterogeneous communication architecture remains a challenge. Among a variety of V2X-supporting access technologies, Dedicated Short Range Communication (DSRC) and cellular communications, e.g., Long Term Evolution (LTE) is promising reliable and efficient vehicular communications. DSRC has been designed to allow for direct low-latency communications among different vehicles (i.e., V2V) and between vehicles and roadside units (RSU). On the other hand, DSRC suffers from link quality degradation with the presence of buildings and vehicles, especially in urban areas, where channel collisions become serious when vehicle density is high. LTE networks can provide wide area coverage and are favorable to bandwidth-greedy applications, which require high data rates and reliability. Considering the relatively high end-to-end delay for message transmission due to the long transmission time interval (TTI) current LTE networks have drawbacks regarding latency to support high-frequency safety-related information exchange among vehicles in local areas. Combining LTE and DSRC approaches as a heterogeneous solution is essential to fast introduce V2X services for future automated driving. By this intelligent Vertical Handover (VHO) algorithms are needed to ensure seamless connectivity of vehicles to the best network at a particular point in time. For this paper, we propose a 3-input fuzzy-logic-based VHO scheme for Heterogeneous DSRC/LTE Vehicular Communication Networks. The simulation results in this paper show that the proposed 3-input fuzzy-logic model can be able to make decisions and select the best network to connect to base on the network with the highest HF value. The 3-input fuzzy-logic model was also tested in a vehicular highway scenario simulation. The proposed model shows optimized communication results in terms of the mean end-to-end delay against that of the literature.**

***Keywords*—vertical handover, heterogeneous vehicular communication, DSRC, cellular networks**

I. INTRODUCTION

Every year, millions of people die in road traffic accidents around the world. About 1.25 million people die each year as a result of road traffic accidents (3400 deaths per day) [1] according to the World Health Organization (WHO) review on road traffic injuries (May 9, 2016). Furthermore, forecasts predict worse conditions by 2020 and estimate that road traffic accidents will increase to become the seventh leading cause of death [2]. Preventing these accidents by clearly articulating this prediction has been a challenge. Urgent action and focused efforts are required to prevent and reduce vehicle accidents and improve road safety.

Intelligent Transportation Systems (ITS) have recently attracted academia and industry to save lives, money, time, and the environment. Japan and Sweden have publicly announced the goal of a zero-traffic fatality society by 2020 and beyond, hoping for such technologies (ITS) [3]. The Intelligent Transportation Association (ITSA)'s “Vision Zero” manifesto summarizes its mission to minimize fatal accidents and delays [4]. With the recent development of automobile and wireless communication technology, the development of ITS solves many vehicle traffic problems, such as information dissemination and traffic congestion. One component of ITS for mobile vehicle connectivity and wireless communications is the Vehicle Ad-hoc Network (VANET). VANET which has evolved into the Internet of Vehicles (IoV), is one of the new technologies with high demand in connectivity [5].

VANET refers to an ad-hoc network made up of different nodes where a node can be a vehicle or a roadside unit. Since vehicles are mobile devices that are always in transit, there is a need to switch from one network to another network [6]. This process of switching from one network to another network is known as handover and has become a very interesting topic of research for the VANET research community.

In modern days, wireless networks have played an important role, as many communication nodes continue to grow daily [7]. Increasing network limits to fulfill the developing needs of consumers has prompted the advancement of cell correspondence networks from 1G to 5G and beyond [8]. Terminals in heterogeneous wireless networks perform horizontal handovers in a homogeneous network and vertical handovers between different types of networks [9]. Heterogeneous networks are designed to route some of the data traffic of mobile networks through

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other co-located wireless access networks. This technique increases the capacity of the mobile network. In such networks, a vertical handover process plays an important role in providing seamless and uninterrupted connectivity as well as the required level of quality of service along with wide coverage for all mobile nodes [10]. Traditional vertical handover algorithms that are based on a single criterion (e.g., received signal strength) are not performing well in terms of excess handover rates, ping-pong effects, handover delays, handover cost, etc. [10-15].

The research seeks to propose a modified C-ITS protocol stack for the heterogeneous DSRC/LTE vehicular network. The research also seeks to provide a study on the performance of the handover decision in highway scenarios and the impact on the network in terms of end-to-end delay.

The rest of this paper is structured as follows. Combining DSRC and LTE as a Heterogeneous solution for vehicular communication is discussed in Section II. Vertical Handover in Heterogeneous Networks is discussed in Section III. Applying Fuzzy Logic in Heterogeneous Networks is briefly described in Section IV. Section V discusses Handover Using Velocity. Section VI discusses the Formulation of the proposed fuzzy handover model. Section VII discusses the Simulation and Results.

II. Combining DSRC and LTE as a Heterogeneous Solution for Vehicular Communication

With the advancement of information and communication technology (ICT), connected vehicles have become one of the key enablers of cooperative intelligent transportation systems (C-ITS). Communications between vehicle and vehicle (V2V), vehicle and pedestrian (V2P), and vehicle and infrastructure (V2I), which is termed as a vehicle to everything (V2X), greatly improve road safety and efficiency. For accelerating the implementation, the first set of C-ITS standards have been published in 2014 by the European Telecommunication Standards Institute (ETSI), where a common communication architecture, i.e., ITS station [16] was introduced. The ITS station reference architecture consists of horizontal and vertical layers, which are interconnected via logical interfaces between two adjacent layers. The horizontal layers include the access layer, the networking, and transport layer, the facilities layer, and the application layer, which follow the layered architecture of the open system interconnection (OSI) architecture with modifications. The newly introduced facilities layer provides services such as messages generation, positioning, and timing to support C-ITS applications. The vertical layers include the management layer and the security layer, which take care of cross-layer management and security, respectively. Though the current standard focuses on dedicated short-range communication (DSRC)/802.11p, the C-ITS is designed to support other radio access technologies (RAT) such as WiFi, and wide-range communications such as long-term evolution (LTE). However, methods to integrate different access technologies such as heterogeneous communication architecture remain a challenge. Among a variety of V2X-supporting access technologies, DSRC and cellular communications, e.g., LTE is promising reliable and efficient vehicular communications. DSRC has been designed to allow for direct low-latency communications among different vehicles (i.e., V2V) and between vehicles and roadside units (RSU) (i.e., V2I) [17]. On the other hand, DSRC suffers from link quality degradation with the presence of buildings and vehicles, especially in urban areas, where channel collisions become serious when vehicle density is high [18]. While DSRC is yet to be implemented, cellular V2X (C-V2X) is catching up thanks to the advancement of radio access technologies as well as the well-maintained infrastructure. Standard targeting

V2X has been published by the 3rd generation partnership project (3GPP) in Release 15 [19], and evolution to LTE advanced and future 5G networks is under standardization. LTE networks, as the de-facto cellular networks, can provide wide area coverage and is favorable to bandwidth-greedy applications, which require high data rate and reliability. Considering the relatively high end-to-end delay for message transmission due to the long transmission time interval (TTI) current LTE networks have drawbacks regarding latency to support high-frequency safety-related information exchange among vehicles in local areas.

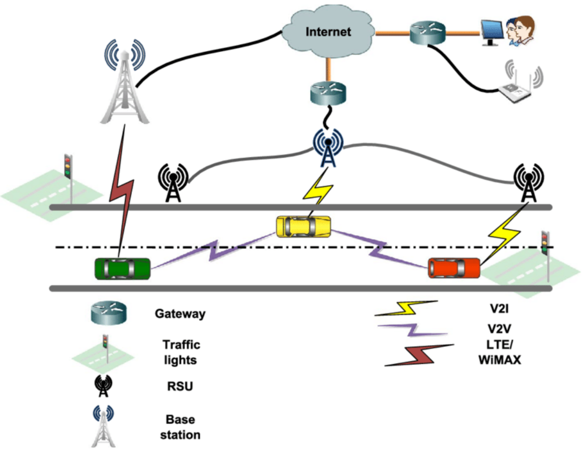

Figure 1. Communication in heterogeneous VANET.

As seen in Fig. 1 combining LTE and DSRC/WAVE approaches as a heterogeneous solution is essential to fast introduce V2X services for future automated driving. A realistic simulation scenario based on a city for hybrid LTE/802.11p vehicular communications was proposed in [20], allowing the investigation of system performance in different use cases. Several studies, e.g., [21, 22], introduced hybrid architectures, where either DSRC interface or cellular networks is used for vehicular communications with an Always Best Connected approach. Authors in [23] proposed a hybrid approach to support video streaming applications by offloading data transmission based on RAT selection. However, the experiments were conducted using a testbed embedded in only two vehicles with basically no competition on bandwidth. Thus, more realistic scenarios with vehicles' competition for transmission under complicated road and traffic conditions should be investigated. The abovementioned approaches [22, 23] usually take an either-or approach by switching between LTE and DSRC interfaces mainly based on the performance of DSRC assuming that LTE has unlimited resources, which is not realistic. Future V2X services have various service requirements. Safety-related messages need to be transmitted frequently with very low latency and high reliability, while emerging advanced services such as see-through systems [19] require high bandwidth and reliable video streaming but could be only active for certain situations. Since neither LTE nor DSRC can support V2X integrating both as a heterogeneous solution is promising. RAT selection and vertical Handover Algorithms are needed to ensure seamless communication.

III. VERTICAL HANDOVER IN HETEROGENEOUS NETWORKS

Most of the traditional approaches use RSS to make handover decisions. These approaches compare the RSS of the current network with the RSS of the other available networks to make handover decisions. These approaches yield a severe ping-pong effect when the device moves around the overlay region of various heterogeneous networks [24, 25]. This ping-pong effect leads to unessential handover and brings low throughput, high handover delay, and a high dropping rate. In VHO, many network parameters affect deciding the handover. These include security, cost, QoS performance (throughput, data rate, delay, jitter, latency, etc.), power consumption, and available bandwidth [25]. The QoS criteria of various wireless technologies, which can be considered for handover, are listed in Table I.

A cost function-based VHO algorithm is proposed in [26]. The cost function considers different parameters such as cost, power consumption, and available bandwidth. A vertical handover decision function (VHDF) is proposed in [27]. This function is evaluated for all the available networks. The network with the highest VHDF is selected as the most desirable network for handover. To obtain the highest possible QoS, the network with the maximum available bandwidth is chosen as the target network. Authors in [28] proposed a service-aware radio access technology (RAT) selection algorithm that enables a heterogeneous LTE/DSRC solution, where LTE and DSRC are selected according to services. Each vehicle is assumed to be equipped with both LTE and DSRC interfaces. Only one parameter (packet received ratio) was considered in the handover algorithm. For handover decision-making in VHO algorithms, the consideration of more than one handover parameter is necessary for optimization.

In this paper, we propose a fuzzy logic-based handover algorithm for the heterogeneous LTE/DSRC solution. This can be implemented in the ITS station reference architecture [29]. The fuzzy logic algorithm is introduced at the facilities layer to take care of network performance monitoring and network selection as can be seen from Fig. 2. This uses three (3) handover trigger parameters to make handover decisions. That is the Received Signal Strength (RSS), Signal to Noise –to- Interference Ratio (SINR), and Vehicular velocity. By this, we develop a 3-input fuzzy system that takes the varying inputs together with a rule decision table and an output as to when handover should occur. The output is a Handover Factor (HF) which is a calculation based on the varying input parameters together with a rule decision table. The rule decision is depicted in Table II. Based on the handover factor a decision can be made. This is further explained in Section VI.

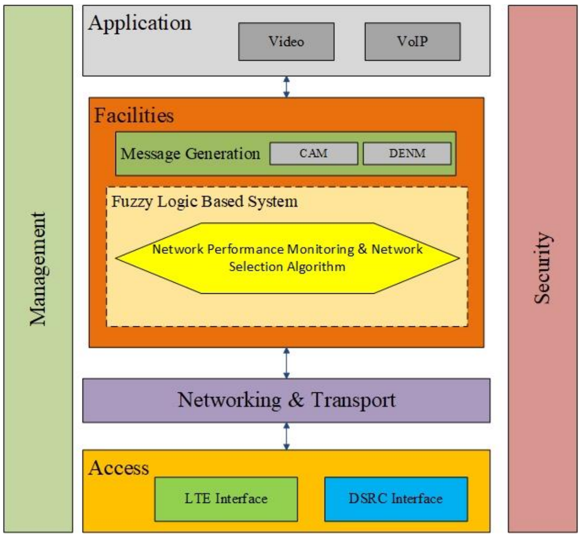

Figure 2. The proposed heterogeneous LTE/DSRC solution architecture.

IV. APPLYING FUZZY LOGIC IN HETEROGENEOUS NETWORKS

Most of the VHO decision-making depends on RSS, which fluctuates based on the velocity, distance, shadowing factor, etc. This makes the handover decision unreliable. The imprecise input parameters may cause inaccurate VHO decisions, which may cause under- or over-utilization of network resources. Fuzzy logic can effectively handle imprecise data related to radio, QoS parameters, and user preferences [25].

Fuzzy logic can also be used in VHO decisions. Fuzzy-based algorithms are intelligent, fast, and reliable, which always keeps decision delay lower even when the number of RATs and input parameters are increased. This minimizes unessential handovers and decision delays and maximizes the percentage of user satisfaction. Fuzzy-logic-based algorithms are highly accurate and offer higher network efficiency, but they are also highly complex [30-33]. The increase in the number of input parameters and the membership functions increases the complexity. Hence, to address the trade-off between reliability and complexity, the fuzzy input parameters, rules and the number of fuzzy controllers should be appropriately chosen as per the objectives.

In recent years, various fuzzy-logic-based handover decision algorithms are proposed. A fuzzy logic in conjunction with one of the MADM called TOPSIS is proposed in [34] to minimize the handover latency, blocking probability, and unessential handovers between WiMAX and 4G standards. The proposed approach uses four fuzzy controllers like RSS, QoS, velocity, and battery life to make decisions. The output from each fuzzy controller is fed into TOPSIS to determine the most appropriate target network for handover. To reduce handover latency and unessential handovers in the LTE network, a fuzzy-logic-based handover triggering approach is proposed in [35], which triggers handover on time. A QoS-aware fuzzy-logic-based network selection scheme is proposed in [36] to guarantee the network QoS. This scheme suffers from unacceptable execution time, which increases with the number of decision parameters. The increased execution time increases the handover latency. In [37], the trade-off between complexity and consistency in target network selection is addressed with the help of fuzzy logic. Here, the authors discuss three different approaches fuzzy-only approach, fuzzy integrated with AHP and principal component analysis (PCA), and fuzzy integrated with fuzzy analytic hierarchy process (FAHP) and PCA. Based on the parameters such as velocity, network traffic load, and cost, fuzzy logic controllers estimate the user satisfaction degree (USD) and the necessity of handover.

A. *RSS and SINR for Handover Decision-Making*

The RSS from the target network influences signal-to-noise ratio (SNR), signal-to-interference plus noise ratio (SINR), bit error rate (BER), and capacity [38]. The reduction in signal strength from a serving network leads to service interruption and service drop. Thus, RSS is an important metric in considering the target network for handover.

Some other works have studied the effect of considering the SINR on the handover procedure in HetNets to improve the performance of the network [39-42]. For example, in [39], the authors analyze the multi-slot performance of a moving user considering the spatial correlation and the SINR in a HetNet. Expressions of multi-slot coverage probability and the handover rate are figured out. The authors conclude that the coverage probability and the handover rate perform better when the handover procedure considers the SINR level instead of the nearest distance strategy. In [40], the position and timing parameters of the handover are predicted according to the present SINR value. With this prediction, a long-term window scheduling algorithm is utilized and compared to a window scheduling of 5 ms. With this strategy, a higher average data rate per user is achieved. However, the authors do not report an analysis of handover failures and ping-pong handovers. In [41], a performance evaluation of vertical handover in HetNets based on SINR is presented and compared to a vertical handover based on the received signal strength (RSS). The results indicate that the SINR-based vertical handover produces a higher system throughput and lower end-to-end delay in comparison to when an RSS-based vertical handover is considered. Also, in [42], an algorithm to adjust the time-to-trigger and hysteresis margin parameters (based on the energy reduction gain, SINR, and ping-pong handover ratio) of the handover procedure is proposed. The results show an improvement in the system energy efficiency and ping-pong handover ratio. The authors analyzed the uplink SINR in the downlink/uplink decoupling environment and evaluated the performance of the system, which resulted in an increased uplink SINR and decreased power consumption.

SINR is an important parameter to improve on the issues with handover decision-making. Therefore, it is considered the second input parameter for this work.

V. HANDOVER USING VELOCITY

In wireless communication networks, the estimation of the mobile users' velocity is an essential part of upgrading network execution. Subsequently, in recent years portable velocity estimation has been broadly considered in the literature [43-46]. The handover count-based strategy [44] is firmly related to the velocity estimation approach, where the UE's mobility is evaluated utilizing the handover quantity achieved by the UE in a predefined time window. Existing Long-Term Evolution (LTE) and LTE-Advanced innovations utilize the handover-count strategy to classify the mobility condition of UE into three large classes: low, medium, and high mobility. Hypothetically, the sojourn time-based velocity estimation in [46] resulted in more exact than handover count-based velocity estimation. The author appraised the UE velocity in light of sojourn time samples and small cell base station (SBS) density. However, this work used an unrealistic mobility system. Furthermore, indeterminate estimation in the limit of small cells was experienced. In [43], the radial velocity was gained through the most extreme Doppler spread estimation of the received signal in mobile communications, although it required an extensive perception interim and signal noise ratio (SNR) higher than 30 dB.

Tracking velocity can fundamentally enhance handover algorithm execution by simultaneously decreasing both the handover quantity and the handover delay, as demonstrated in [47, 48]. The authors of [47] perceived the effect of the handover execution on communication quality, and they thus proposed a basic, effective, aware handover management scheme endeavoring to maintain longer service continuation with serving base stations (BSs) and decrease the handover rate and its related signaling. Using mathematical expressions, they demonstrated that the proposed handover method accomplished an impressive gain in terms of throughput. However, they supposed during the handover execution that no information was transmitted. Taking into account that their numerical results for delay achieved high esteem, allowing communication and measuring packet loss through handover is attractive and will help produce the QoS achieved by their system. The authors of [48] demonstrated how low quality in handover execution could result in severe interruption and call drops in communication, which remains a pressing issue yet to be solved. The authors thus examined a handover system given distance data for LTE high-velocity rail networks. The strategy for choosing a handover reference point depended on the situation given specific channel conditions. The outcomes demonstrated that a small region appropriate to triggering in the overlap area can be obtained, and handover execution can be expanded by diminishing the HOF probability and wiping out ping-pong (PP) handover.

The above studies in the literature have shown velocity as a parameter for improving the issues with handover decision-making to be effective. Therefore, it is also considered the third input parameter for this work.

B. Considering RSS and SINR

The index HN will be used to designate a given Communication Technology (Comm. Tech.)

Let T_0^{HN} denote the considered network-serving node of Comm. Tech. HN in the reference cell.

Let then $\{T_x^{HN}, x = 1 \dots \dots . M^{HN}\}$ be the set of the M^{HN} interfering network serving nodes deployed for Comm. Tech. HN. For HN, let P^{HN} be the power emitted by T_0^{HN}. The power received (RSS) can be expressed in Eq. (1):

$$Pl^{HN}(w) = P^{HN} * \Upsilon^{HN} * X_w \tag{1}$$

where the random variables X_w are independent and identically distributed and follow an exponential distribution of parameter λ as fading is considered in [1]. Pathloss for vehicle w, $\Upsilon^{HN}(w)$ depends on the distance $l(w)$ from T_0^{HN} and can be given as seen in Eq. (2).

$$\Upsilon^{HN}(\mathrm{w}) = E^{HN}/l(w)^{\beta} \tag{2}$$

where β is the path loss exponent and E^{HN} a constant characterizing the radio propagation in T_0^{HN}.

From equation (1) the RSS of a vehicle w associated with communication technology HN can be written as seen in Eq. (3).

$$\mathrm{RSS} = P^{HN} * \Upsilon^{HN} * X_w \tag{3}$$

RSS among network serving nodes in communication technology HN can be determined using Eq. (4).

$$\delta_i^{HN} = |RSS^{HN}(w)_0 - RSS^{HN}(w)_x| < \delta_{i+1}^{HN} \tag{4}$$

where $RSS^{HN}(w)_0$ is a received RSS from the serving network node and $RSS^{HN}(w)_x$ is a received RSS from the neighboring network serving nodes, and δ_{i+1}^{HN} is the threshold determined by the AI model (Fuzzy Logic System). Neighbor cells that satisfy (4) will be designated by the AI model as candidate cells with good RSS.

SINR of a vehicle w associated with communication technology HN can be written as seen in Eq. (5).

$$SINR^{HN}(w) = \frac{P^{HN} * \Upsilon^{HN} * X_w}{\sigma^2 + \sum_{x=1}^{M^{HN}} P^{HN} * \Upsilon_x^{HN}(w) * X_x} \tag{5}$$

where σ^2 is the background noise. Also, $\Upsilon_x^{HN}(w)$ is the path loss between T_x^{HN} and vehicle w . The best SINR among network serving nodes in communication technology HN can be determined using Eq. (6).

$$\delta_i^{HN} = |SINR^{HN}(w)_0 - SINR^{HN}(w)_x| < \delta_{i+1}^{HN} \tag{6}$$

where $SINR^{HN}(w)_0$ is a received SINR from the serving network node and $SINR^{HN}(w)_x$ is a received SINR from the neighboring network serving nodes, and δ_{i+1}^{HN} is the threshold determined by the AI model.

Neighbor cells that satisfy (6) will be designated by the AI model as candidate cells with good SINR.

C. Deriving Expression for Vehicular Velocity considering RSS and SINR

$SINR^{HN}(w)$ can also be written as seen in Eq. (7);

$$SINR^{HN}(w) = \frac{Gw * Pw}{\sigma^2 w + Iw} \tag{7}$$

where Gw is the channel gain between vehicle w and its associated T_0^{HN} , Pw is the power emitted by T_0^{HN}, σ^2 is the background noise power received by the vehicle, and Iw is the interference from other neighboring network serving nodes T_x^{HN}.

The path loss model that is used here is a macro-cell propagation model for urban and suburban areas. For the antenna height of 15 meters, the path loss is [2]

$$G(dB) = 58.8 + 21\log_{10}(f) + 37.6\log_{10}(D) + \log F \tag{8}$$

where f is the carrier frequency (5.9GHz for DSRC and LTE (C-V2X)), D is the distance in meters between the vehicle and the T_0^{HN} , and $\log F$ is the log-normal distributed shadowing with standard deviation $\sigma = 10dB$.

Based on (6), the threshold for estimating a good SINR by the AI Model can be written as:

$$\delta = SINR^{HN}(w)_n - SINR^{HN}(w)_c \tag{9}$$

Substituting (7) to (9), then we have Eq. (10)

$$\delta = \frac{Gw_n * Pw_n}{\sigma^2 w_n + Iw_n} - \frac{Gw_c * Pw_c}{\sigma^2 w_c + Iw_c} \tag{10}$$

where notation c is indicating the current serving cell, notation n is indicating the neighbor cell, and w is representing w^{th} vehicle.

Substituting (8) in the ratio (antilog) form, we have Eq. (11).

$$\delta = \frac{10^{((37.6\log_{10}(Dn_w) + G_n)/10)} * Pw_n}{\sigma^2 w_n + Iw_n} - \frac{10^{((37.6\log_{10}(Dc_w) + G_c)/10)} * Pw_c}{\sigma^2 w_c + Iw_c} \tag{11}$$

where $G_n = 58.8 + 21\log_{10}(f_n) + \log F$ and $G_c = 58.8 + 21\log_{10}(f_c) + \log F$

The AI model uses, δ as a parameter to force a vehicle to stay longer in the appropriate cell concerning its velocity, we calculate the velocity in Dn_w and Dc_w, in Eq. (11). The system model in Fig. 3 is used to define the relation between δ and vehicular velocity.

where

$$Dn_w = \sqrt{(x_2 - (x_c + (v.t_\delta)\cos\alpha))^2 + (y_2 - (y_c + (v.t_\delta)\sin\alpha))^2} \quad (12)$$

$$Dc_w = \sqrt{(x_1 - (x_c + (v.t_\delta)\cos\alpha))^2 + (y_1 - (y_c + (v.t_\delta)\sin\alpha))^2} \quad (13)$$

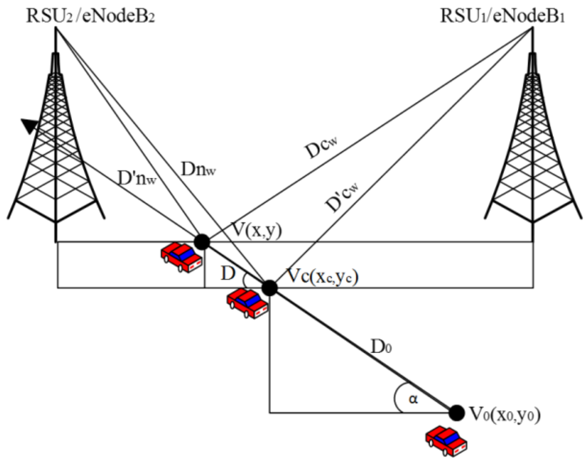

Figure 3. Vehicle traveling from point V_0 to V_c.

v is vehicular velocity and t_δ is the time needed to travel from V_c point to V point. The relation between δ and vehicular velocity can be directly understood when Eq.(12) and Eq. (13) are substituted in Eq. (11). Eq. (11) implies that for every value of velocity v, the same value of t_δ will result in a different value of δ.

The coordinate of V_c point is needed to start applying t_δ and it can be found when the vehicle receives the same SINR from the serving and the neighbor cell when

$$\delta = 0 \quad (14)$$

$$0 = SINR^{HN}(w)_n - SINR^{HN}(w)_c \quad (15)$$

$$SINR^{HN}(w)_n = SINR^{HN}(w)_c \quad (16)$$

$$\frac{Gw_n * Pw_n}{\sigma^2 w_n + Iw_n} = \frac{Gw_c * Pw_c}{\sigma^2 w_c + Iw_c} \quad (17)$$

Substituting (8), we have Eq. (18)

$$\frac{10^{((37.6\log_{10}(Dn_w)+G_n)/10)} * Pw_n}{\sigma^2 w_n + Iw_n} = \frac{10^{((37.6\log_{10}(Dc_w)+G_c)/10)} * Pw_c}{\sigma^2 w_c + Iw_c} \quad (18)$$

where

$$\bar{D}n_w = \sqrt{(x_2 - (x_0 + (v.t)\cos\alpha))^2 + (y_2 - (y_0 + (v.t)\sin\alpha))^2} \quad (19)$$

and

$$\bar{D}c_w = \sqrt{(x_1 - (x_0 + (v.t)\cos\alpha))^2 + (y_1 - (y_0 + (v.t)\sin\alpha))^2} \quad (20)$$

$$(37.6\log_{10}(\sqrt{(x_1 - (x_0 + (v.t)\cos\alpha))^2 + (y_1 - (y_0 + (v.t)\sin\alpha))^2}) + G_c) - \left(37.6\log_{10}\left(\sqrt{\left(x_2 - (x_0 + (v.t)\cos\alpha)\right)^2 + \left(y_2 - (y_0 + (v.t)\sin\alpha)\right)^2}\right) + G_n\right) = 10\log\left(\left(\frac{Pw_n}{\sigma^2 w_n + Iw_n}\right)/\left(\frac{Pw_c}{\sigma^2 w_c + Iw_c}\right)\right) \quad (21)$$

where t is the time for the vehicle to travel from point V_0 to point V_c. Eq. (19) and (20) to (18) and rearranging them, finally, it can be seen that V_c point is the point when Eq. (21) is satisfied.

From the above expression the vehicular velocity can be calculated by the time (t) it takes a vehicle to move from point V_0 to point V_c.

The velocity of a vehicle w associated with communication technology HN can be written as seen in Eq. (22)

$$V^{HN}(w) = \frac{\Delta v}{\Delta t} \quad (22)$$

where Δv is the change in position of the vehicle and Δt is the change in time of a vehicle to move from point V_0 to point V_c.

We can say let:

$$\delta_i^{HN} = |V^{HN}(w)_0 - V^{HN}(w)_x| < \delta_{i+1}^{HN} \quad (23)$$

where $V^{HN}(w)_0$ is the vehicular velocity from the serving network node and $V^{HN}(w)_x$ is the vehicular velocity approaching the target node, and δ_{i+1}^{HN} is the threshold determined by the AI model.

The AI model will decide on handover depending on the RSS and SINR of the serving/target network node against the vehicular velocity. If the RSS and the SINR values from the target network are good and the vehicle is moving with a low velocity, it means the AI model can initiate handover to ensure a longer connection with the target network for a better network services experience.

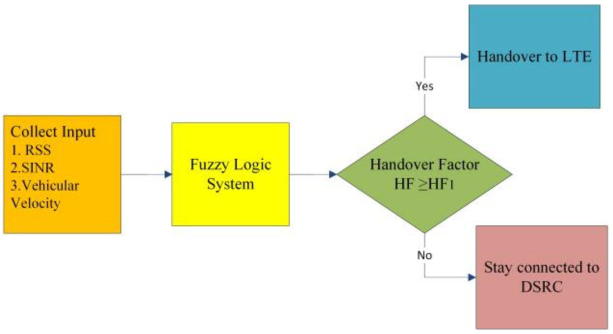

Figure 4. Fuzzy logic system with 3-inputs and 1-output.

VI. FORMULATION OF THE PROPOSED FUZZY HANDOVER MODEL

The efficient selection of appropriate inputs, membership functions, and rules make fuzzy logic a suitable candidate for target network selection. For an effective handover with minimal delay, the RSS, SINR, and Velocity (Vehicular Velocity) used in literature are considered in this work as combined handover triggers. These three (3) parameters are considered input parameters to the fuzzy logic system for decision making as shown in Fig. 4. Mamdani-based fuzzy system is used in this work [49]. Because of simple formulas and lower computational complexity, both trapezoidal and triangular membership functions are widely used in real-time applications. The subjective degree of convenience to achieve fuzzy linguistic scale coverage is more for trapezoidal than for triangular membership functions. The fuzzy input range is divided equally for three linguistic variables, and the membership functions are developed accordingly. Depending on this, 27 rules are developed. If we use five linguistic variables for every input, there will be 125 fuzzy rules, which will increase the overall computational complexity. The defuzzifier works based on the center-of-gravity method [50]. The crisp output from the defuzzifier is the handoff factor (HF), which is used to rank the networks during the target network selection stage. Five membership functions for HF are formed. The three-input fuzzy system used for VHO decision-making is illustrated in Fig. 4. After the handover, the service received from the target network should have good quality.

The fuzzy sets for RSS of the ith network are represented by the linguistic variables weak, medium, and strong. These are described by the membership functions $R_1^i(\iota)$, $R_2^i(\iota)$ and $R_3^i(\iota)$ in equations (24), (25), and (26) respectively. The range for RSS is considered to be -119 to -50 dBm as shown in Table I. The related degree of membership plot is displayed in Fig. 5.

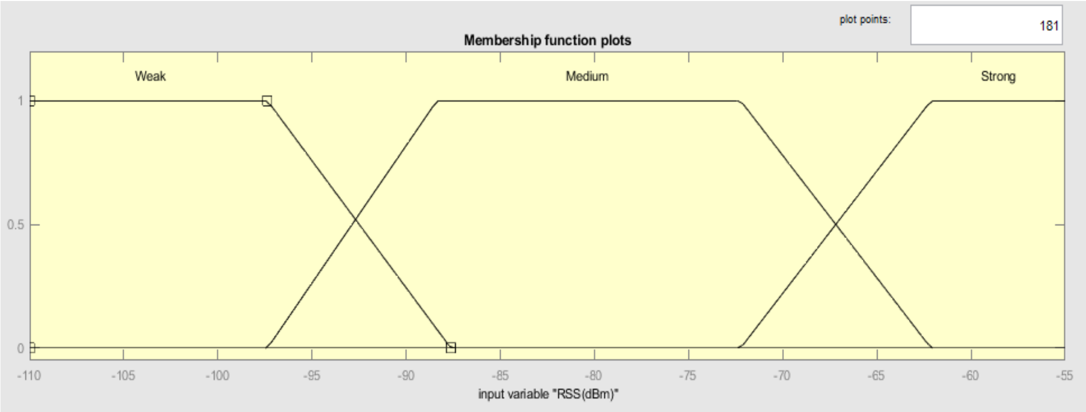

Figure 5. Membership function plot for RSS

$$R_1^i(\iota) = \begin{cases} 1, & if - 119 \leq \iota \leq -102 \\ \frac{-88.9-\iota}{13.1}, & if - 102 \leq \iota \leq -88.9 \\ 0, & if\ \iota \geq -88.9 \end{cases} \tag{24}$$

$$R_2^i(\iota) = \begin{cases} 0, & if \alpha < -102 \\ \frac{\iota+102}{13.1}, & if - 102 \leq \iota \leq -88.9 \\ 1, & if - 88.9 \leq \iota \leq -68.2 \\ \frac{-54.6-\iota}{13.6}, & if - 68.2 \leq \iota \leq -54.6 \\ 0, & if\ \iota \geq -54.6 \end{cases} \tag{25}$$

$$R_3^i(\iota) = \begin{cases} 0, & if\ \iota \leq -68.2 \\ \frac{\iota+68.2}{13.6}, & if - 68.2 \leq \iota \leq -54.6 \\ 1, & if - 54.6 \leq \iota \leq -40 \end{cases} \tag{26}$$

SNIR is a measure of Signal Quantity, Interference, and Noise Quantity. It is a very important measurement in terms of RF and sometimes it is also called SNR in absence of interference. It indicates how much the desired signal is stronger compared to Noise and interference. Maintaining a satisfactory user-experiencing SINR for a higher data rate is a major challenging task during a handover process.

The fuzzy sets for SINR of the ith network are represented by the linguistic variables poor, good and excellent. These are described by the membership functions $S_1^i\ (\zeta)$, $S_2^i\ (\zeta)$ and $S_3^i\ (\zeta)$, in Eqs. (27)-(29) respectively. The range for data rate is considered to be 1–25 dB as shown in Table I. The related degree of membership plot is displayed in Fig. 6.

$$S_1^i(\zeta) = \begin{cases} 1, & if\ 0 \leq \zeta \leq 4.85 \\ \frac{10.25-\zeta}{5.4}, & if\ 4.85 \leq \zeta \leq 10.25 \\ 0, & if \zeta \geq 10.25 \end{cases} \tag{27}$$

$$S_2^i(\zeta) = \begin{cases} 0, & if \zeta < 7.75 \\ \frac{\zeta-7.75}{3}, & if\ 7.75 \leq \zeta \leq 10.75 \\ 1, & if\ 10.75 \leq \zeta \leq 19.25 \\ \frac{22.26-\zeta}{3.01}, & if\ 19.25 \leq \zeta \leq 22.26 \\ 0, & if\ \zeta \geq 22.26 \end{cases} \tag{28}$$

$$S_3^i(\zeta) = \begin{cases} 0, & if \zeta \leq 20 \\ \frac{\zeta-20}{5.75}, & if\ 20 \leq \zeta \leq 25.75 \\ 1, & if\ 25.75 \leq \zeta \leq 31.25 \end{cases} \tag{29}$$

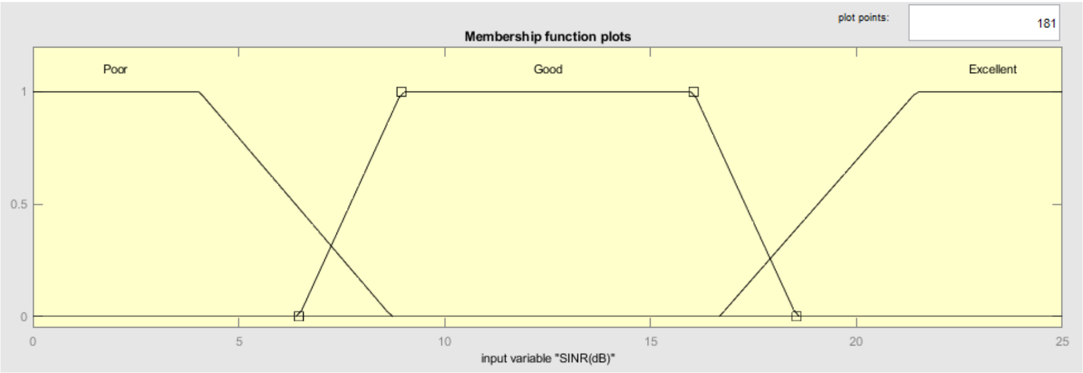

Figure 6. Membership function plot for SINR

Knowing the velocity of the vehicle determines how fast or slow a vehicle is moving into an adjacent cell or leaving the current cell. This can also be considered in handover decision-making algorithms to enable vehicles to enjoy a longer connection with available networks offering a better network connection. Thus, vehicular velocity is considered one of the inputs for FIE. The fuzzy sets for the vehicular velocity of represented by the linguistic variables slow, medium, and fast. These are described by the membership functions $V_1^i(\kappa)$, $V_2^i(\kappa)$ and $V_3^i(\kappa)$, in Eqs. (30)-(32) respectively. The range for vehicular velocity is considered to be 0–100km/h as shown in Table I. The related degree of membership plot is displayed in Fig. 7.

$$V_1^i(\kappa) = \begin{cases} 1, & if\ 0 \le \kappa \le 20 \\ \frac{40-\kappa}{20}, & if\ 20 \le \kappa \le 40 \\ 0, & if \kappa \ge 40 \end{cases} \tag{30}$$

$$V_2^i(\kappa) = \begin{cases} 0, & if \kappa < 20 \\ \frac{\kappa-20}{20}, & if\ 20 \le \kappa \le 40 \\ 1, & if\ 40 \le \kappa \le 60.9 \\ \frac{80-\kappa}{19.1}, & if 60.9 \le \kappa \le 80 \\ 0, & if\ \kappa \ge 80 \end{cases} \tag{31}$$

$$V_3^i(\kappa) = \begin{cases} 0, & if\ \kappa \le 60.9 \\ \frac{\kappa-60.9}{19.1}, & if\ 60.9 \le \kappa \le 80 \\ 1, & if\ 80 \le \kappa \le 100 \end{cases} \tag{32}$$

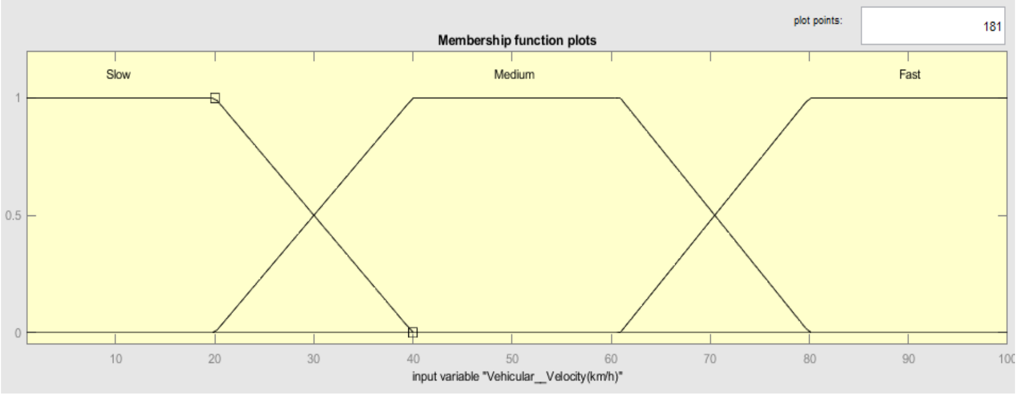

Figure 7. Membership function plot for vehicular velocity.

A fuzzy set called HF is used to decide the target network. The fuzzy sets for HF of the ith network are represented by the linguistic variables very low, low, medium, high, and very high. These are described by the membership functions $HF_1^i(\theta)$, $HF_2^i(\theta)$, $HF_3^i(\theta)$, $HF_4^i(\theta)$ and $HF_5^i(\theta)$, in Eqs. (33)-(37) respectively. The related degree of membership plot is displayed in Fig. 8.

TABLE I. FUZZY INPUT PARAMETERS

Input Parameters	Excellent	Good	Poor
RSS	>=-50dBm	-65dBm to -90dBm	< = -119dBm
SINR	>= -25dB	-20dB to -10dB	<= -10dB
Vehicular Velocity	< 35Km/h	35Km/h to 75Km/h	>75Km/h

$$HF_1^i(\theta) = \begin{cases} 1, & if\ \theta \le 0 \\ \frac{0.225-\theta}{0.225}, & if\ 0 \le \theta \le 0.225 \\ 0, & if \theta \ge 0.225 \end{cases} \tag{33}$$

$$HF_2^i(\theta) = \begin{cases} 0, & if\ \theta \le 0 \\ \frac{\theta}{0.225}, & if\ 0 \le \theta \le 0.225 \\ 1, & if\ 0.225 \le \theta \le 0.275 \\ \frac{0.475-\theta}{8.68}, & if\ 0.275 \le \theta \le 0.475 \\ 0, & if\ \theta \ge 0.475 \end{cases} \tag{34}$$

$$HF_3^i(\theta) = \begin{cases} 0, & if\ \theta \le 0.275 \\ \frac{\theta-0.275}{0.2}, & if\ 0.275 \le \theta \le 0.475 \\ 1, & if\ 0.475 \le \theta \le 0.525 \\ \frac{0.725-\theta}{0.2}, & if\ 0.525 \le \theta \le 0.725 \\ 0, & if \theta \ge 0.725 \end{cases} \tag{35}$$

$$HF_4^i(\theta) = \begin{cases} 0, & if\ \theta \le 0.525 \\ \frac{\theta - 0.525}{0.2}, & if\ 0.525 \le \theta \le 0.725 \\ 1, & if\ 0.725 \le \theta \le 0.775 \\ \frac{1-\theta}{0.225}, & if\ 0.775 \le \theta \le 1 \\ 1, & if \theta \ge 1 \end{cases} \quad (36)$$

$$HF_5^i(\theta) = \begin{cases} 0, & if\ \theta \le 0.775 \\ \frac{\theta - 0.775}{0.225}, & if\ 0.775 \le \theta \le 1 \\ 1, & if\ \theta \ge 1 \end{cases} \quad (37)$$

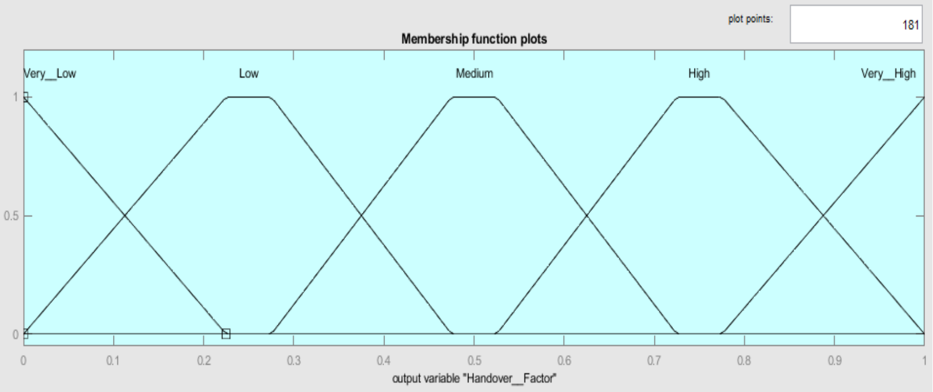

Figure 8. Membership function plot for handover factor.

where HF ∈ [0,1]. In fuzzy logic, linguistic variables are used to map the input sets to the output sets. The rules for the FIE are developed based on the input and output fuzzy sets. The fuzzy rules used by the FIE are listed in Table II. RSS is the fundamental parameter in VHO decisions. In general, RSS-based algorithms are low-complex and the least accurate. The fluctuations in RSS will also cause inaccurate decisions [51-53]. To achieve smooth handover and seamless connection SINR and Vehicular Velocity were also considered as input parameters in the VHO decision-making process. The conventional approaches do not consider the complexities arising when dealing with uncertainties and sudden input variations. Because of its strength in adapting the randomly changing inputs and dealing with uncertainties, fuzzy logic is used in the proposed VHO decision-making process. RSS and SINR of every available network with the Vehicle's Velocity are given as the input for FIE. Based on the developed fuzzy rules, the FIE output HF of every network is identified. The network with maximum HF is the most preferable network for handover so that the handed-over vehicle may get a smooth connection with minimal delay. Figs. 9-11 explain the process of HF calculation. For samples of simulation scenarios:

- RSS, SINR, and Vehicular Velocity take values of 56, 25.8, and 21.3, respectively in fig. 9. The degree of membership of RSS for the linguistic variables like weak, medium, and strong are 0, 0.05, and 0.95, respectively. The degree of membership of SINR for the linguistic variables like poor, good, and excellent are 0, 0, and 1, respectively. Similarly, the degree of membership of Vehicular Velocity for the linguistic variables like slow, medium, and fast are 0.9, 0.1, and 0, respectively. These values fall under rules 1 and 11.
- RSS, SINR, and Vehicular Velocity take values of 84.5, 8.22, and 21.3, respectively in Fig. 10. The degree of membership of RSS for the linguistic variables like weak, medium, and strong are 0, 1, and 0, respectively. The degree of membership of SINR for the linguistic variables like poor, good, and excellent are 0.65, 0.35, and 0, respectively. Similarly, the degree of membership of Vehicular Velocity for the linguistic variables like slow, medium, and fast are 0.95, 0.05, and 0, respectively. These values fall under rules 14 and 16.
- RSS, SINR, and Vehicular Velocity take values of 102.5, 8.8, and 81.6, respectively in Fig. 11. The degree of membership of RSS for the linguistic variables like weak, medium, and strong are 1, 0, and 0, respectively. The degree of membership of SINR for the linguistic variables like poor, good, and excellent are 0.67, 0.33, and 0, respectively. Similarly, the degree of membership of Vehicular Velocity for the linguistic variables like slow, medium, and fast are 0, 0, and 1, respectively. These values fall under rules 24 and 27.

HF is calculated with the help of the center-of-gravity method [54] using:

$$HF = \frac{\sum_{i=1}^{T} HF(\omega_i)\omega_i}{\sum_{i=1}^{T} HF(\omega_i)} \quad (38)$$

where T is the number of samples required to calculate HF. For the considered sample scenarios, HF obtained is 0.878 for Fig. 9, 0.407 for Fig. 11. and 0.225 for Fig. 12.

TABLE II. FUZZY RULES USED BY THE FIE

NO.	RSS	SINR	Vehicular Velocity	HF
1.	Strong	Excellent	Slow	Very High
2.	Strong	Excellent	Medium	Very High
3.	Strong	Excellent	Fast	Medium
4.	Strong	Good	Slow	Very High
5.	Strong	Good	Medium	High
6.	Strong	Good	Fast	Medium

7.	Strong	Poor	Slow	Low
8.	Strong	Poor	Medium	Low
9.	Strong	Poor	Fast	Very Low
10.	Medium	Excellent	Slow	High
11.	Medium	Excellent	Medium	High
12.	Medium	Excellent	Fast	Medium
13.	Medium	Good	Slow	High
14.	Medium	Good	Medium	Medium
15.	Medium	Good	Fast	Low
16.	Medium	Poor	Slow	Very Low
17.	Medium	Poor	Medium	Low
18.	Medium	Poor	Fast	Very Low
19.	Weak	Excellent	Slow	High
20.	Weak	Excellent	Medium	Medium
21.	Weak	Excellent	Fast	Medium
22.	Weak	Good	Slow	Medium
23.	Weak	Good	Medium	Medium
24.	Weak	Good	Fast	Low
25.	Weak	Poor	Slow	Very Low
26.	Weak	Poor	Medium	Very Low
27.	Weak	Poor	Fast	Very Low

TABLE III. SIMULATION PARAMETERS

Parameter	**Value**	
Simulation Time	300s	
Road Model	250*250m^2	
Number of lanes	2	
Highway Speed	100km/h, 90km/h and 80km/h	
Total No. of Vehicles	100	
Standard	DSRC	LTE
Carrier Frequency	5.89GHz	DL:2.1/ UL:1.7GHz
RSS (dBm)	-55dBm to-100dBm	-55dBm to -100dBm
Bandwidth	20MHz	DL:10/UL:10M Hz
SINR (dB)	7dB to -40dB	7dB to -40dB
Traffic		
CAM Message Size	Uniform(300B,400B)	
CAM Transmission Frequency	40Hz	
Voice Packet Size	100B	
Voice Data Rate	128kbps,1,4,7,8,9,10Mbps	

Available Networks	Transmit power(dBm)	Cell radius (km)	Bandwidth (MHz)
LTE-A	46	3	100
DSRC	13	0.30	20
WiMAX	47	10	40
HSPA	43	1	40

VII. SIMULATION AND RESULTS

Here we used MATLAB 2021b, to create the simulation scenario and fuzzy toolbox to build the FIE. We also used OMNET++ and SUMO to set the simulation environment for the vehicular highway scenario.

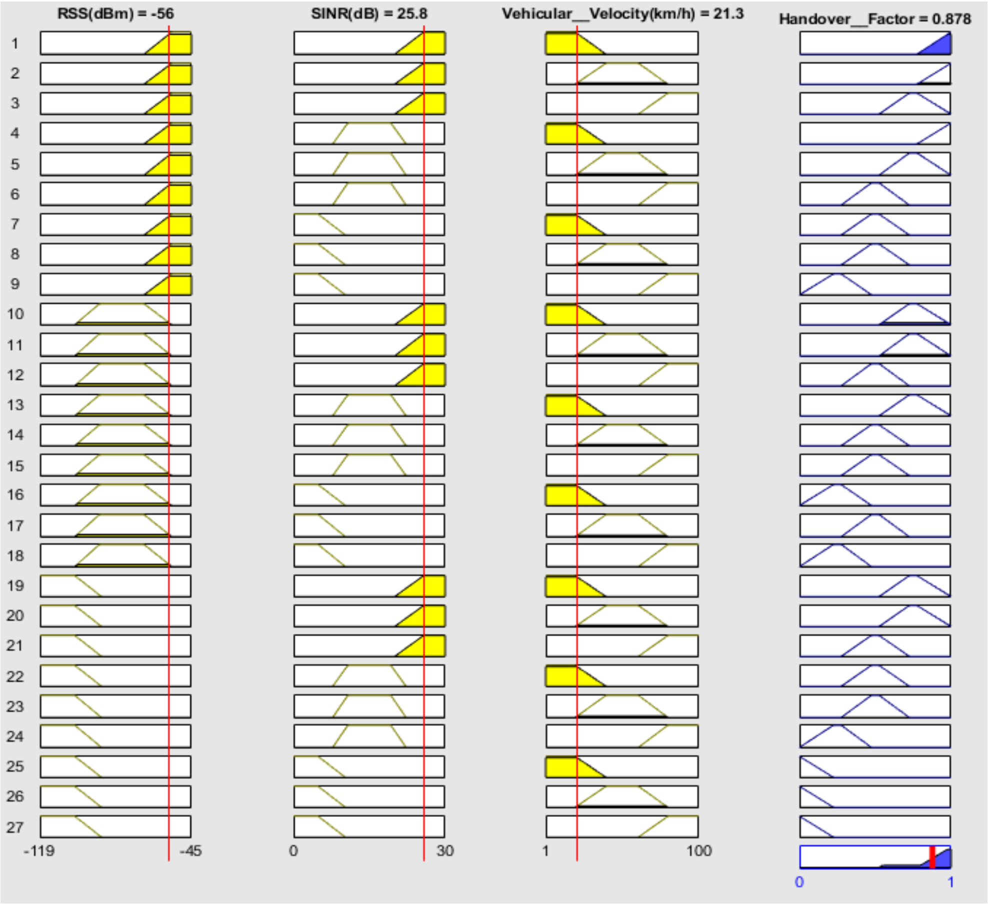

Figure 9. Rule viewer plot for very high HF calculation.

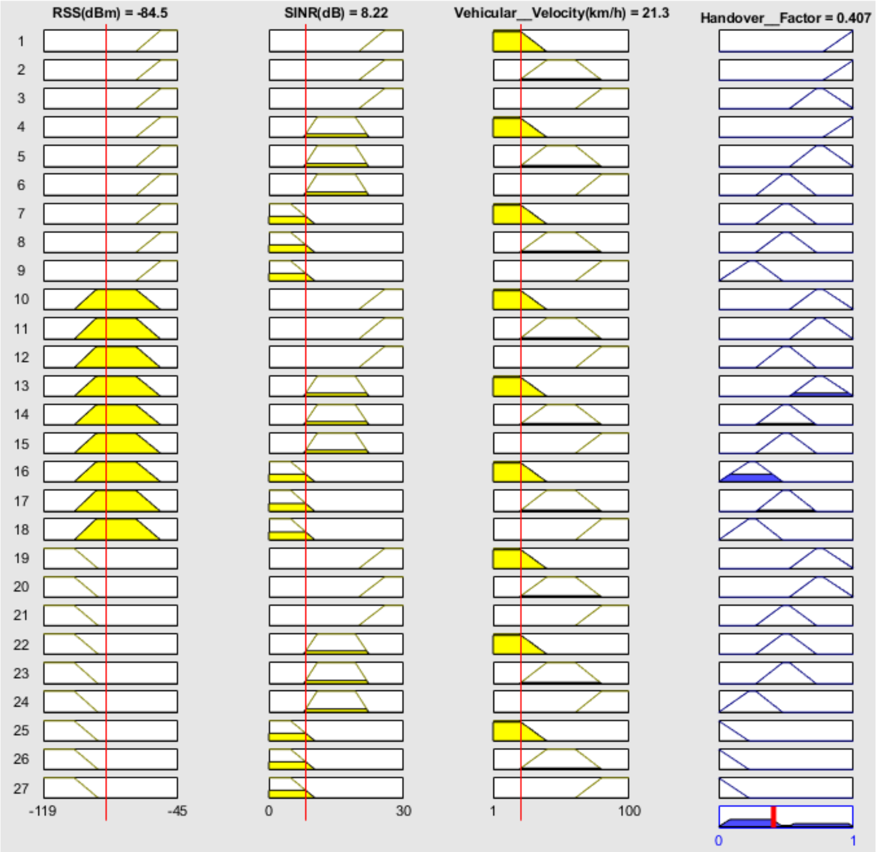

Figure 10. Rule viewer plot for medium HF calculation.

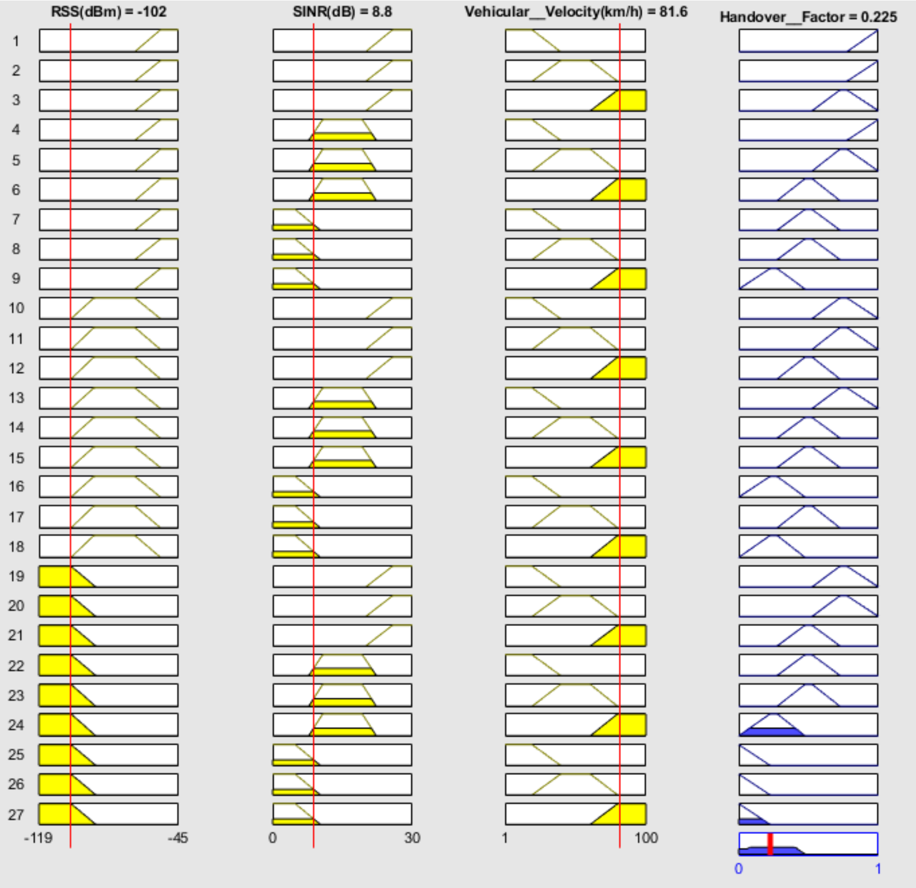

Figure 11. Rule viewer plot for low HF calculation.

A. *Available Networks Simulation*

IV.

Four (4) networks were considered for this simulation scenario. This simulation scenario is to indicate the best network to connect to base on the HF value of the available networks. The available networks for this consideration are DSRC, LTE, WiMAX, and HSPA. The HF is calculated from each network as seen in Fig. 12.

The path loss model for LTE [55] and the other networks are listed below;

$$PL(dB)^{LTE-A} = 103.8 + 20.9\log_{10} d(km)$$

$$PL(dB)^{DSRC} = 47.9 + 18\log_{10} d(km) + \sigma$$

$$PL(dB)^{WiMAX} = 47.9 + 18\log_{10} d(km) + \sigma$$

$$PL(dB)^{HSPA} = 47.9 + 18\log_{10} d(km) + \sigma$$

where PL_0=47.9dB (free space path loss at 5,9 GHz in d_0 =1m distance), d is the distance in meters, and the path loss coefficient is n = 1.8. The margin is set to $\sigma = 6 \pm\ dB$, which includes both shadow fading (±5 dB peak, according to [56]) and 1 dB transmitter calibration offsets. The margin accounts for the worst case and is thus either added or subtracted from the path loss value. Since there are no standardized path loss models for vehicular communications in current ITU standards available, these values were chosen from [57, 58], and [56] for highway scenarios excluding tunnels [59].

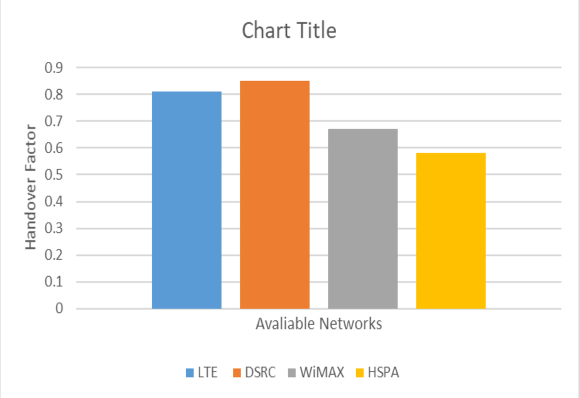

Figure 12. HF output for each available network.

Based on the transmit power and path loss, the RSS value can be measured. The RSS, SINR of a target network, and vehicular velocity are used to measure the handover factor of a target network. The propagation delay influences the SINR. As discussed in Sect. 7, RSS, SINR of each network (LTE, DSRC, WiMAX, and HSPA), and the vehicular velocity are given as the input for FIE. The corresponding fuzzy output HF of each network for the considered sample scenario is displayed in Fig. 12. The HF of the DSRC network is higher than the other three networks, so the vehicle chooses DSRC as the target network.

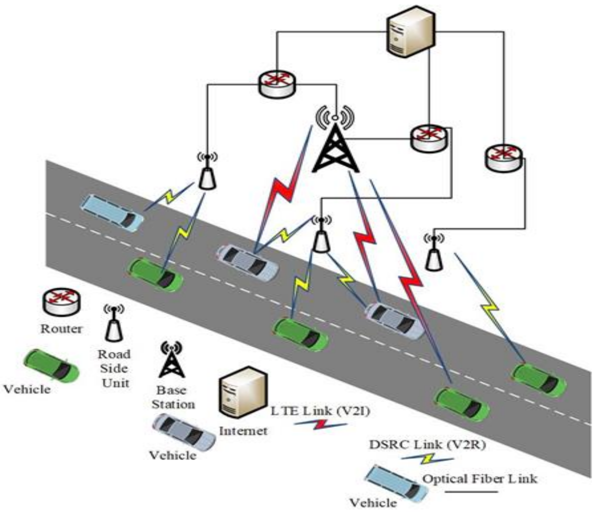

Figure 13. Vehicular highway scenario.

B. *Vehicular Highway Scenario*

According to [60] the maximum speed limit on rural interstate highways is 113km/h, with a 72km/h minimum in the US. On four-lane divided highways, the limit is 105km/h, and on all other highways, it’s 89km/h [60]. For this reason, the vehicular highway speeds selected for this simulation are 80km/h, 90km/h, 100km/h, and 110km/h. In Fig. 13 the vehicular highway scenario was considered. That is vehicles moving at high velocities. The communication connection between networks and serving nodes tends to drop and fail when the serving nodes in the network move at high speed from one cell to another. This causes packet drop which further affects end-to-end delay. In this scenario, we test the proposed algorithm’s performance against that of [28] by increasing the number of vehicles on a highway. Vehicles were increased in the order of 20, 40, 60, 80, and 100 in each case. A total of 100 vehicles were considered for the vehicular highway scenario with a vehicular velocity of 110km/h. Voice packet of about 100B was transmitted to the vehicles in the network with a varying data rate of 128kbps,1,4,7,8,9,10Mbps for each increase in the number of vehicles. Mean end-to-end delay was used to evaluate the performance of our proposed algorithm against that of [28]. Simulation results are shown in Fig. 14.

TABLE IV. PERFORMANCE COMPARISON FOR CAM MESSAGE DISTRIBUTION

	Reference	
	Shen, X. *et al.* [28]	Proposed Algorithm
Mean end-to-end delay (ms)	0.285	0.19
Number of Parameters	1	3
Methods	Packet Delivery Ratio Algorithm	Fuzzy logic Algorithm
Vehicular Speed	50km/h	50km/h
Number of Vehicles	50	50
Data Rate	10Mbps	10Mbps

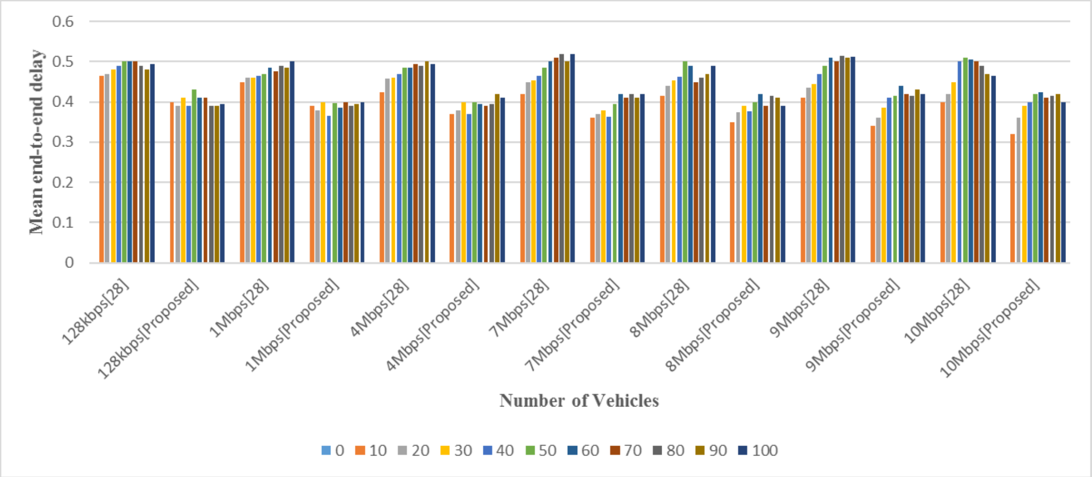

Figure 14. Graph of the Number of Vehicles against Mean end-to-end delay at 110km/h.

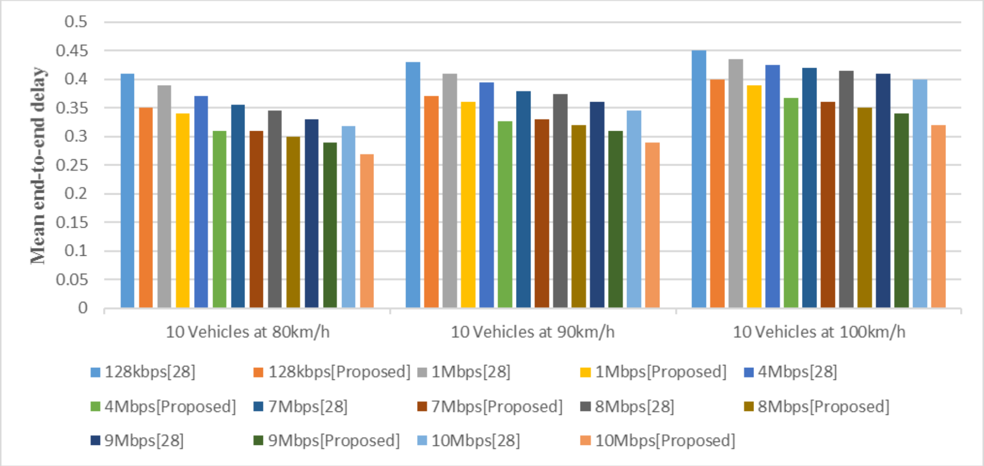

Figure 15. Graph of the 10 Vehicles against Mean end-to-end delay at 100km/h, 90km/h, and 80km/h.

Fig. 14 shows the simulation results of a varying number of vehicles at 110km/h experiencing different data rates with mean end-to-end delay. With the proposed system, the average latency of the voice messages is greatly reduced in comparison to that of [28], indicating the longer connection of vehicles to the network. This will result in a further reduction in packet loss.

From Fig. 15, 10 vehicles were varied at a vehicular speed of 80km/h, 90km/h, and 100km/h. For each of the vehicular speed scenarios data rates at 128kbps, 1Mbps, 4Mbps, 7Mbps, 8Mbps, 9Mbps, and 10Mbps were also varied. In each case, the proposal was compared to that of [28].

From Fig. 15, for 10 vehicles moving at 80km/h at data rates 128kbps, 1Mbps, 4Mbps, 7Mbps, 8Mbps, 9Mbps, and 10Mbps, the proposed scheme offers 14.6%, 12.8%, 16.2%, 12.6%, 13.3%, 12.1%, and 15.4% reduction in mean end-to-end delay over that of [28]. For 10 vehicles moving at 90km/h at data rates 128kbps, 1Mbps, 4Mbps, 7Mbps, 8Mbps, 9Mbps, and 10Mbps, the proposed scheme offers 13.9%, 11.9%, 17.2%, 13.2%, 14.7%, 13.9% and 15.9% reduction in mean end-to-end delay over that of [28]. For 10 vehicles moving at 100km/h at data rates 128kbps, 1Mbps, 4Mbps, 7Mbps, 8Mbps, 9Mbps, and 10Mbps, the proposed scheme offers 11.1%, 10.3%, 13.6%, 14.3%, 15.7%, 17.1% and 20% reduction in mean end-to-end delay over that of [28]. The results in Figs. 14 and 15 shows that as the vehicle increase in speed the mean end-to-end delay increases. In both Figs. 14-15, the proposed scheme does better with optimized delay.

VIII. CONCLUSION

In this paper, we have developed a 3-input fuzzy-logic-based VHO scheme for Heterogeneous DSRC/LTE Vehicular Communication Networks. RSS, SINR, and Vehicular velocity were set as inputs to the Fuzzy Inference System (FIS) and the output was a handover factor. This FIS makes calculations based on the varying input parameters together with the decision rule table to aggregate an output value called Handover Factor (HF). This HF value ranges between 0 to 1. The HF value determines the best network to connect to at any point. The higher the HF value of a particular network the better the network's performance.

From Table IV, a comparison of CAM message distribution for 50 vehicles at 50km/h between [28] and the proposed algorithm was made. The data rate used in each case was 10Mbps. Xiaoman *et al.* [28] uses Packet Delivery Ratio Algorithm which makes a decision based on a Packet Delivery Ratio (PDR) for network selection. The proposed algorithm uses 3 parameters (RSS, SINR, and Vehicular velocity) for network selection. Also from table 4, the mean end-to-end delay was 0.285 and 0.19 for [28] and the proposed fuzzy logic algorithm respectively. This proves it is effective to use multiple parameters for vertical handover in the heterogenous DSRC/ LTE vehicular networks.

The simulation results in this paper show that the proposed 3-input fuzzy-logic model can be able to make decisions and select the best network to connect to base on the network with the highest HF value. The proposed scheme provides optimized delay at higher vehicular speed as compared to [28]. Future works are currently being considered to test the proposed model's performance in certain vehicular communication scenarios. i.e., Vehicular density scenarios.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Michael Agyare conducted the research, analyzed the data, and wrote the paper; Jerry John Kponyo supervised the research and edited the paper; Kwasi Adu-Boahen Opare supervised the research and edited the paper; Kwame Oteng Gyasi supervised the research and edited the paper; all authors have approved the final version.

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