Optimized Handover Mechanism in Heterogeneous Vehicular Communication Systems

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ABSTRACT

In current years, vehicular communication systems are evolving for Intelligent Transportation System (ITS) by providing its wireless network services with increasing demand for high data rate. Vehicular communications supports for various applications that include safety, traffic efficiency and infotainment. However, the high mobility of vehicles and frequent topology changes in such communication systems pose challenges for the mobility management, including frequent, unnecessary and ping-pong handovers, with additional problems related to increased delay and packets loss rate, and failure of the handover process. In this article, we propose a solution to optimize the handover in vehicular networks. Our solution resides in creating a novel multi-criteria network selection mechanism. The objectives of the proposed solution are: to decrease handover failure, handover delay, and packet loss rates, also to distribute traffic load uniformly among available networks to improve the average system resource utilization. The proposed mechanism is based on Fuzzy Logic scheme to support the decision making process. Simulation results demonstrate that, compared to existing works, the proposed approach significantly reduces the handover failure, handover delay and packet loss rates. In addition, the proposed solution achieved an improvement in network resources utilization.

Keywords— *V2X communications, 5G, LTE-Advanced Pro,* Fuzzy Logic, *Handover*

1. INTRODUCTION

The world of mobile communication systems is ever expanding and evolving. This can be seen by the appearance of successive generations. Long-Term Evolution Advanced (LTE-A) [1] is the fourth-generation (4G) of mobile communication technology, developed by the Third Generation Partnership Project (3GPP) organism in 2014 with release 10. LTE-A provides: a very high data rate that can reach 3 Gbps in downlink and 1.5 Gbps in uplink [2]. LTE-A extensions are provided with release 11 and release 12, by the introduction of further enhancements in the functionalities that came in release 10. At the recent, LTE-A evolved to LTE-Advanced Pro (LTE-A Pro) with 3GPP release 13 [2] and release 14 [3]. LTE-A Pro brings higher speeds, greater capacity, lower latency, and support for new use cases and services, such as, Internet of Things (IoT), and ultra-low latency services. Another interesting and prominent use case of LTE-A Pro is Vehicle-to-Everything communications or cellular V2X (C-V2X) communications. In fact, LTE-A Pro gives vehicles the ability to communicate with each other and everything around them. LTE-A Pro V2X technology defines two complementary transmission modes, namely, direct communications and network communications. Direct communications via the LTE PC5 interface, which operates in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network [4]. Network communications using the LTE Uu interface between the vehicle and the eNodeB (eNB).

While there are many open challenges in vehicular communication systems, our focus here is on identifying a solution to the problem of handover management during mobility. Understandably, the high mobility of vehicles and frequent topology changes in vehicular communication systems increase the handover count. This situation may result in a large accumulation of unnecessary and frequent handovers, and also increase the risk of handover failure. In this article, we propose a solution to optimize the handover in heterogeneous vehicular communication systems. Our solution resides in creating novel multi-criteria network selection mechanism. The objectives of the proposed mechanism are: to decrease handover failure and delay, to reduce packet loss rate, and to distribute traffic load uniformly among available network to improve the average system resource utilization. The main contributions of this work are as follows: (i) Development of a novel clustering strategy. (ii) Proposal an efficient network selection mechanism based on multi factors. (iii) Evaluation of the proposed solution following several simulations.

The remainder of this article is organized as follows. In section 2, we describe the most relevant related solutions. In section 3, we present our proposed solution. In section 4 we discuss the simulation results. In section 5, we conclude our research work and give our future direction.

2. RELATED WORK

This section presents some related works of literature including cluster development, as well as handover management mechanisms in vehicular communication systems. Vodopivec et al. [9] defined the concept of clustering as: "A process of grouping nodes (mobile devices, sensors, vehicles etc.) in geographical vicinity together according to some rules." Duan et al. [10], have proposed a vehicle clustering based on dynamic information provided by software-defined networking SDN's global network view. The simulation results

demonstrated that user's bit error rate (BER) and trunk link throughput rates are enhanced. However, the proposed approach presents several problems such as the complexity of the proposed schemes. Singh and Bali [11] developed a hybrid backbone based clustering algorithm. The authors used the number of links between vehicles and vehicular mobility for cluster formation. In this algorithm, the vehicles with relative higher degrees of connectivity form a backbone and the vehicle with a minimum relative mobility is selected as a CH. Ren et al. [12], proposed a clustering algorithm. These authors used the vehicle's moving direction, relative position and link lifetime estimation for cluster formation and selected the central node as a CH. Chiti et al [13], proposed a context-aware clustering mechanism by introducing the coalitional game theory to optimize cooperation among vehicles.

Several studies in the literature address the handover management in vehicular networks. Abboud et al. [14], reviewed potential cellular interworking and IEEE 802.11p solutions for efficient V2X communications and the main interworking challenges such as vertical handover and network selection issues. Seo et al. [5], presented an overview of the requirements of the LTE based V2X services. The authors discussed also, the scenarios suitable for operating LTE-based V2X services. Brahim et al. [6], proposed a hybrid communication approach based on LTE and IEEE 802.11p technologies to support a V2X video streaming application. The proposed approach includes a network selection algorithm based on Packet Loss Rate (PLR) to provide a Quality of Service (QoS) for the video streaming application. However this solution is inefficient. In fact, the proposed algorithm consider only PLR as decision parameter. It's not sufficient for heterogeneous networks. In addition, this algorithm does not provide traffic balancing, as the IEEE 802.11p interface is selected even if it is loaded. Moreover, this algorithm increases the number of handover executions. Ndashimye et al. in [15] proposed a network selection scheme in V2I communication over heterogeneous network consisting of LTE and Wi-Fi cells. Their goal was to reduce the overall handover delay and to avoid unsuccessful handovers. In the proposal, concerned vehicles can self-select the target network, which lies in its direction of movement. Skondras et al. [16] proposed a handover management scheme for vehicular cloud computing systems, which takes into account the vehicle's velocity as well as its current connection type. However, this scheme, does not take into account the traffic load of networks.

Correia et al. [17] applied SDN concept in vehicular networks. They proposed a hierarchical SDN architecture to improve the connectivity with the SDN controller by using clustering technique. The vehicular network consists of multiple clusters. Each cluster is coordinated by the CH, which communicates with the primary SDN controller (SDNC) and serves the rest of vehicles which are referred to as members. Simulation results demonstrated that the proposed approach outperforms traditional routing protocols. It increases the packet delivery rates and improves network throughput. However, in this architecture the signaling overhead is very high, which may lead to increased handover delay and packet loss. Tartarini et al. [18] proposed an enhanced SDNC to assist handover in heterogeneous cloud radio access networks. The proposed mechanism uses context information of mobile node's (MN's) handover gathered by SDNC to perform a handover decision and to choose the best Point of Attachment (PoA) to MNs. In [19], Gharsallah et al. proposed a 5G network architecture based on SDN/NFV (Network Function Virtualization) technologies. The proposed architecture involves a handover management module in the SDNC application, which is in control of handovers in 5G networks. In addition, the authors proposed an optimized handover procedure which consists of four steps: handover information gathering, data processing, virtual-cell creation and handover execution. Virtual-cell have been proposed to avoid frequent, unnecessary and "Ping Pong" handovers, and to assure seamless handover in 5G mobile networks. Simulation results revealed that this solution ensures a low handover failure ratio and delay compared to LTE X2-handover standard. However, in these works, the proposed handover decision strategy does not consider the traffic load of networks which is relevant and important decision factors.

Quan et al [20] proposed an adaptive transmission control protocol for software defined vehicular networks (SDVN). The authors focused on how a controller schedules different transmission control policies and then negotiates with the control units at the BSs to adapt to varying vehicular environments. In addition, the authors formulated the transmission control problem, and developed a practical heuristic algorithm. Experimental results showed that the proposed SDVN protocol outperforms other state of the art solutions in term of transmission throughput. The same authors have presented in reference [21] a new network paradigm named smart identifier networking (SINET), and have proposed a novel customized SINET solution for the vehicular network (SINET-V). In SINET-V, virtualized function slices are able to be flexibly selected through crowd sensing. Moreover, crowd collaborations are served to dynamically adapt to various vehicular scenarios, including intra-slice collaborations and inter-slice ones. Simulations results demonstrated that SINET-V is able to improve the QoS in a realistic urban vehicular scenario.

He et al. [22] proposed an SDN-based architecture to enable rapid network innovation for vehicular communications. In this architecture, network elements such as BSs, RSUs and vehicles are abstracted as SDN switches with a unified interface to mitigate the heterogeneity of the vehicular network. Moreover, the proposed architecture utilizes vehicle trajectory predictions to lower the frequency of status update to reduce the SDN management overhead caused by the highly dynamic mobility of vehicles. In this work, the authors also, presented some case studies to highlight the advantages of the architecture. Finally, the authors validated the feasibility and effectiveness of the proposed architecture via simulation.

3. HANDOVER APPROACH FOR VEHICULAR COMMUNICATION SYSTEMS

Figure 1 presents the system model, which is based on a heterogeneous vehicular network composed of diverse types of base stations serving different coverage areas. There are a multiple macro cells and small cells contain several competing communication technologies such as LTE-A Pro, IEEE802.11p, etc. LTE eNBs is connected via S1 interface to the core network, i.e. Evolved Packet Core (EPC) [23]. Access Network Discovery and Selection Function (ANDSF) is within the EPC [24]. The ANDSF is a network entity helps a multimode device to automatically discover and select the most suitable underlying radio access technology (RAT), based on certain priorities and policies predetermined by the network operators. The ANDSF is interfaced to the MN via the S14 interface for the exchange of access network discovery and selection information [25]. Moreover, in the proposed scenario, vehicles are equipped with multi-interface such as LTE PC5, LTE Uu and IEEE 802.11p. Vehicles also, are equipped with different types of sensors and a Global Positioning System (GPS) to determine its location information, velocity and direction [26]. The vehicular network also, consists of multiple groups of vehicles, referred to as clusters. Each cluster is coordinated by one of the vehicles, which downloads data from the eNB and serves the rest of vehicles through V2V connectivity. The eNB can determine how clusters are formed by taking into account the context information provided by incoming vehicles (e.g. ID, location, direction, speed, final destination and neighbors list). Vehicle information are predicted by different types of sensors and GPS. Also, the eNB is in charge of assisting a vehicle joining an already formed cluster by considering the context information delivered by the vehicle: when a vehicle is approaching an eNB it can, indeed, advertise its context information, application requirements and availability to join V2V cluster. Depend on this information, the eNB can select the active cluster that best match the vehicle context information and extend this cluster accordingly.

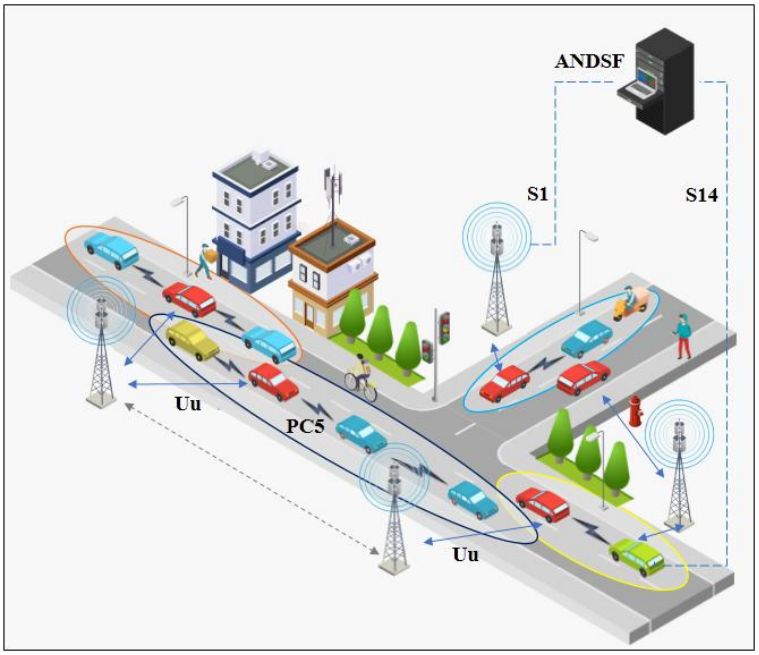

Figure 1. System Model

3.1. Proposed vehicle clustering technique

Due to the high mobility of vehicles and the massive wireless traffic between the eNB and vehicles, frequent handover should be avoided for wireless communications between the eNB and vehicles. To solve this issue, we propose a novel vehicle clustering technique. In fact, vehicle clustering is seen as a promising solution in covering vehicles, reducing frequent handovers and the overhead of cellular networks, and providing better communication quality with a low relative speed among clustered vehicles. Within each vehicle cluster, a CH is selected to aggregate traffic from other vehicles and communicate with the eNB in order to reduce signaling overhead. In addition, by decreasing the number of connections vehicle-eNB, we can reduce transmission delays and network congestion. Furthermore, vehicle clustering technique will also, minimize the consumption of radio resources and minimize the interference in the system, by integrating information, working as one station, reusing radio resources and controlling interference in different clusters.

For the proposed vehicle clustering technique, we consider that the map is divided into a set of cells based on the map size and its coordinates. Each cell is controlled by one eNB. The vehicles in the same cluster can communicate together. In the proposed clustering technique, vehicles are classified in three elements:

- Cluster Head (CH): vehicles that relay the communication of vehicles to the eNB.

- Members vehicular (MV): vehicles that are members of the cluster.
- Non-Defined (ND): vehicles that have not joined a cluster.

The clustering mechanism can be divided into three main processes: (i) cluster creation; (ii) cluster head selection; and (iii) maintenance.

(i) Cluster creation: In the beginning of the cluster building, vehicles are considered as Non-Defined (ND), due to the fact that they do not belong to a cluster. The clustering process is initiated by the eNB when it sends Hello message to all the vehicles in its communication range. After sending this message, the eNB waits for a definite time for the response messages. The response messages indicates whether there are ND vehicles that want to create a cluster. The response message contains:

< ID, traj, Tcell, nbList >

The ID is the sender's identifier; traj is the path that the sender vehicle will take; Tcell indicates the time that the sender will stay in the cell; and nbList indicates the number of vehicles neighbors to the sender that are traveling in the same direction. The nbList is the sum of beacon messages received from neighboring vehicles moving in the same direction as the vehicle. The Tcell computes the time required to reach the boundaries of a cell based on a vehicle's path. Hence, Tcell is the sum of the time that vehicles will spend to cover the entire trajectory over a cell, as presented in equation 1.

$$T_{cell} = \sum_{i=indexCurrent}^{indexBorder-1} \frac{|Position_{[i]} - Position_{[i+1]}|}{Speed} \qquad (1)$$

(ii) Cluster head selection: Upon receiving the packets from the vehicles, the eNB analyses their context information and checks the residual time to stay in the cell and the longest list of neighbors of each vehicle. The vehicle which will spend a longer amount of time in the cell and has a higher number of vehicles in its neighborhood than other vehicles will be elected as a CH by the eNB. After the CH election, the eNB sends a CH message to other vehicles. The CH message contains:

< ID, ID_CH >

Where ID is the sender's identifier, ID_CH the CH's identifier.

(iii) Maintenance: After building the cluster, each vehicle inside a cluster periodically sends a beacon message to the eNB, which contains information such as:

< ID, ID_CH, state, coord, Tcell, nbList >

Where ID is the sender's ID, ID_CH is the cluster head's ID, state indicates whether the sender is CH or MV, coord denotes the GPS coordinates of the sender's location, Tcell indicates the time that the sender will stay in the cell; and nbList indicates the number of vehicles neighbors to the sender that are traveling in the same direction. This message will help in the maintenance phase. The maintenance process is divided into two events:

- **Joining a cluster:** If there is only one CH in the neighborhood, then a potential CH will accept the vehicle in case their hop is lower than a predefined threshold. Otherwise, the eNB creates another cluster. If there are more than one CH exists, the eNB selects the cluster that best match the context information of the vehicle. In other words, the vehicle joins a cluster where it will remain for the greatest trajectory similarity, provided the hop is lower than a predefined threshold. After selecting a cluster, the vehicle becomes an MV, and sends a Join Message to the CH. The Join Message contains:

  <ID, traj, Tcell, nbList>

- **Leaving a cluster:** This event occurs in two scenarios, the first when the vehicle loses its connection. In this case, the eNB will start to look for a nearby cluster. The second scenario, when the vehicle going through another cell, thus needing to leave the current cluster. In this case, the eNB will try to find a new cluster in another cell.

3.2. Proposed multi-criteria RAT selection mechanism

In vehicular heterogeneous networks, a vehicle moves in and out of the coverage areas of other vehicles, APs and BSs, and change their communication PoA. Figure 2 presents the proposed multi-criteria RAT selection mechanism for V2X communications. We suppose that a cluster head (CH) and a member vehicle (MV) are in V2V communication via LTE PC5 interface. The vehicle CH relays the communication of vehicle MV to the eNB. We assume that each vehicle evaluates periodically the quality of the link. A handover is triggered when the triggering condition, equation (2) is satisfied.

$$V2V_{RSRP} < V2V_{Th} \qquad (2)$$

$V2V_{RSRP}$ is the Reference Signal Received Power (RSRP) between vehicles. $V2V_{Th}$ is a constant variable that represents whether the vehicle CH can provide services to the vehicle MV. After the handover decision is performed, the RAT selection process is activated. The vehicle MV begins to seek another CH in its proximity to transfer its communication. It triggers a timer and sends a "V2V cluster discovery request" message to the eNB

for availability to join new cluster. This message contains context information of the vehicle such as the ID, coordinate and trajectory. Based on this information, the eNB can select the active cluster that best match the context information and extend this V2V cluster accordingly.

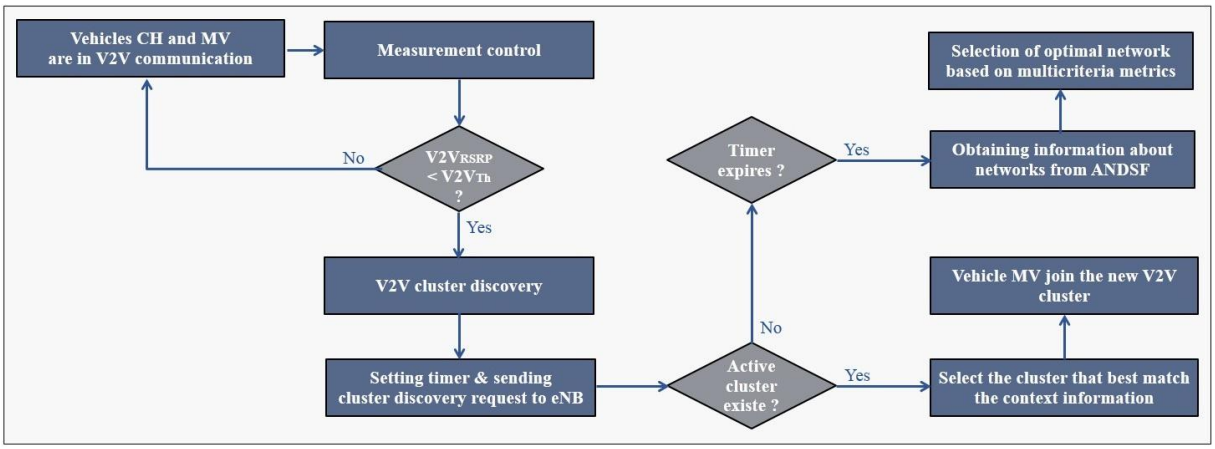

Figure 2. Proposed multi-criteria RAT selection mechanism

The vehicle needs to select only the potential candidate based on multi-criteria metrics. The considered criteria are as the follow:

- Network conditions: these refer to the characteristics of each RAT such as RSS and load. The RSS for non-3GPP networks or RSRP for 3GPP networks of the available RATs is a measurement used for evaluating the signal quality of the neighbor base stations. The traffic load of the network is the ratio between the number of resources used in the network and the total number of resources in the network for a period of time t.
- Vehicle conditions: The speed of the vehicle is a crucial decision parameter. Fast moving vehicle may cross over a Wireless Local Area Network (WLAN) coverage rapidly. Thus, handing it over from a cellular network to a WLAN could cause quick successive handovers which may result in high signaling overheads and delays.

3.3. Fuzzy logic modelling

For our solution, we have chosen to use a fuzzy logic system to support the decision making process. In fact, fuzzy logic context-based schemes are a good choice to handle the handover decision making problem for a number of reasons: They have better performance compared to simple RSS or QoS-based schemes. Their behavior is better, compared to decision function based schemes (e.g., MADM), when the handover parameters are rough estimated values [27]. Moreover, fuzzy logic system can be used as a supporting-tool for efficient RAT selection. The fuzzy logic controller is composed of four elements. These are fuzzification, rule base, inference mechanism and defuzzification. A block diagram of a fuzzy logic control system is shown in figure 3.

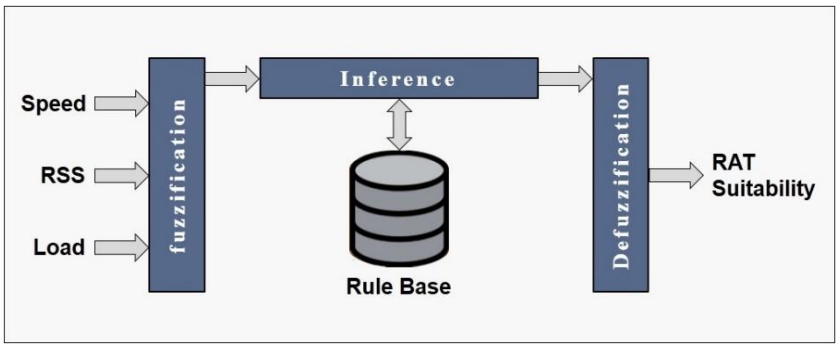

Figure 3. Block diagram of a fuzzy logic control system

The fuzzifier undertakes the transformation (fuzzification) of the input values to the degree that these values belong to a specific state (e.g., low, medium, high, etc.) as shown in Table 1. After that, the inference mechanism correlates the inputs and the outputs using simple "IF…THEN…" rules. Then, the output degrees for all the rules of the inference phase are being aggregated. The output of the decision making process, comes from the defuzzification procedure. In the proposed scheme, fuzzy logic controller is applied on the following criteria: speed, RSS and load. We assume three types of networks such as LTE macro cell, LTE pico cell and Wi-Fi. The process starts from the fuzzifier where the input parameters are fed up, there by which gets transformed to fuzzy sets of values (low, medium, and high). Next the inputs are being combined in the interference engine, by a set of rules; at this case for each of the three fuzzy reasoners (eNB, HeNB and Wi-Fi) we have defined 27 rules to cover all the potential input combinations. Examples of fuzzy inference system (FIS) rules:

(a) IF (Speed = = medium) AND (RSS_{RAT1} = = high) AND ($Load_{RAT1}$ = = medium) THEN RAT1 selection probability is high.
(b) IF (Speed = = medium) AND (RSS_{RAT1} = = low) AND ($Load_{RAT1}$ = = medium) THEN RAT1 selection probability is low.

The strategy of the rules is the following. The RAT, which is characterized by high RSS and low load, is advantageous for the vehicle choice. On the other hand, high mobility vehicles are preferably placed in larger cells and small cells are avoided to minimize the unnecessary handover. On the contrary, vehicles characterized by low or medium speed will be served by small cells, in order to offload the traffic of the macro cells. Finally, the defuzzification process aggregates all the outcomes of all the rules and ends up to a certain degree of the output value, i.e., RAT suitability. The network with the highest RAT suitability will be selected; in case of a rejection the second in the list is being selected. The suitability value ranges from 0 to 1 (0 to 100% respectively).

Table 1. Values of decision variables

Decision variables	Low	Medium	High
Vehicles speed (km/h)	From 0 to 40	From 40 to 60	From 80 to 140
RSS (dBm)	From -140 to -70	From -70 to -60	From -60 to -44
Load (%)	From 0 to 30	From 30 to 70	From 70 to 100

4. PERFORMANCES EVALUATION

In this section, we investigate the performances of our proposed algorithms for heterogeneous vehicular networks via simulation analysis. The main system parameters are summarized in Table 2 [28, 29, and 30]. To assess the performance of our approach, we compare it with two handover management solutions from the literature Qos-aware protocol in [6] and V2I-based mechanism in [15]. The following metrics are measured in the simulations.

Table 2. Simulation parameters [28, 29, 30].

Parameters	Values
Number of macrocells	24
Macrocell coverage	1000 m
Number of small cells	50-500
Small cell coverage	250
LTE BW	20 MHz
LTE data rate	100 Mbps
LTE range of RSRP	From -140 dBm to -44 dBm
Resource blocks (RBs)	100 RBs and 180 kHz per RB
IEEE 802.11p BW	10MHz
IEEE 802.11p data rate	6Mbps
IEEE 802.11p range of RSS	From -90 dBm to -30 dBm
Number of vehicles	125-1250
Vehicles speed (km/h)	20-140
Mobility model	Random walk model
Minimum association RSRP for D2D communication	-112 dBm

1) Handover delay analysis according to the handover request arrival rate

Figure 4 shows the simulation results of handover delays for the proposed and existing handover procedures. It can be seen from this figure that our proposed handover mechanism gets significantly lower delay than the existing works Qos-aware protocol in [6] and V2I-based mechanism in [15]. By analysing figure 4, we note that the proposed handover solution minimizes the handover delay by 13% and 17% compared to existing handover mechanisms in [15] and [6] respectively. This best results is due to the use of clustering and multi-hop relay methods, which facilitates the handover control and provide fast handover in heterogeneous vehicular networks.

2) Handover failure analysis according to handover request arrival rate

Figure 5 depicts the simulation results of handover failure ratios. It can be seen that the existing handover mechanisms [6] and [15], get significantly higher handover failure ratios due to the important number of executed unnecessary and “Ping-Pong” handovers. However in order to reduce the frequent and unnecessary handovers, the proposed approach uses clustering and multi-hop relay. Analyzing figure 5, we observe that the proposed approach registers a decrease of around 14% and 20% compared to the handover mechanisms Qos-aware protocol in [6] and V2I-based mechanism in [15] respectively. This improvement can be explained by the fact that our proposed approach deploy clustering and multi-hop relay, which enable vehicle to stay in the V2V transmission mode for

a long time, so that is maintains better service continuity and avoid frequent network joining and leaving. Also, the proposed mechanism considers divers categories of information, which are closely related to handover, to select the best networks in a more correct and rapid manner. This contributes to the success of the handover.

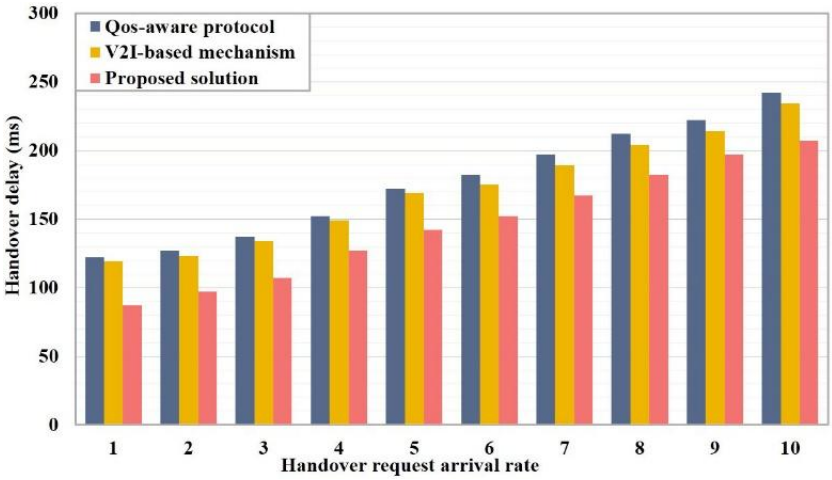

Figure 4. Handover delay analysis according to the handover request arrival rate

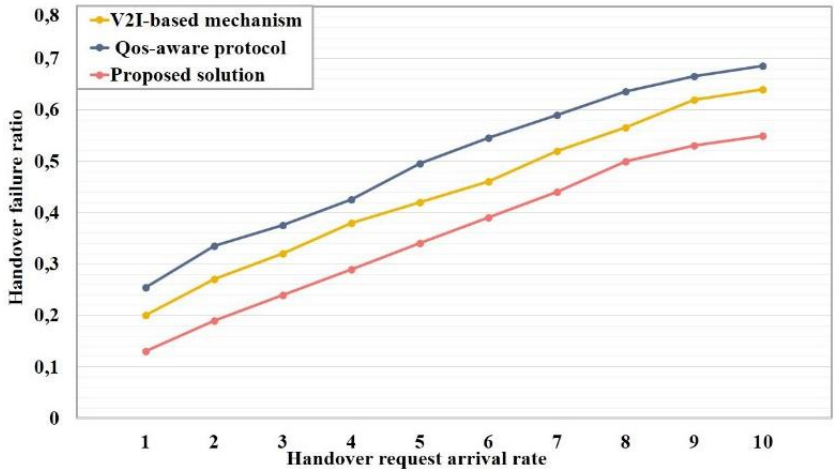

Figure 5. Handover failure analysis according to handover request arrival rate

3) Packet loss analysis according to handover request arrival rate

Figure 6 depicts the impact of the increase of handover request arrival rate values and the packet loss rate occurred following the proposed and existing handover approaches in [6] and [15]. We note that, when we use the existing handover mechanisms, as the handover request arrival rate value increases, the packet loss rate gets higher and higher. This is due to the high handover failure rates. On the other hand, by analyzing figure 6, we notice that, the solution in [15] gets lower packet loss rate than the proposed approach by about 7%. In addition, we note that the proposed approach provides a decrease of about 18% compared to the handover mechanisms in [6]. This improvement in term of packet loss rate justify the effectiveness of the proposed handover mechanism.

4) Resource utilization analysis according to handover request arrival rate

Figure 7 shows the result of the rate of resource utilization, of the proposed solution and the other solutions from the literature: Qos-aware protocol in [6] and V2I-based mechanism in [15]. We notice that the rate of resource utilization is proportional to the handover call arrival rate. The rate of resource utilization first increases with the increase of the number of vehicles in the cell. When the number of vehicles is larger than a specified threshold, the rate of resources utilization remains stationary and curves tend to stabilize. The reason is that all available resources has already been allocated for vehicles. In this case, there are not any bandwidths to be allocated for additional vehicles even if the number of vehicles is larger than a specified threshold. Analyzing the rate of resource utilization, we observe that the proposed approach is always larger than the rate of resource utilization of [6] and [15] schemes. These results can be considered satisfactory and reflect an improvement in system resources.

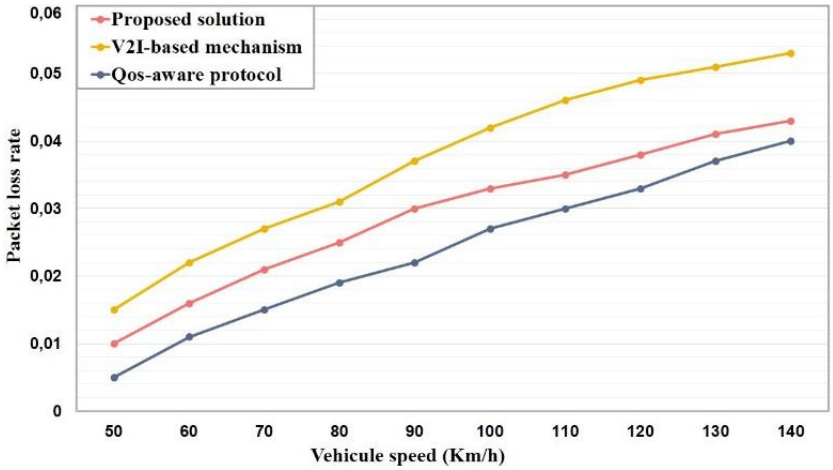

Figure 6. Packet loss analysis according to handover request arrival rate

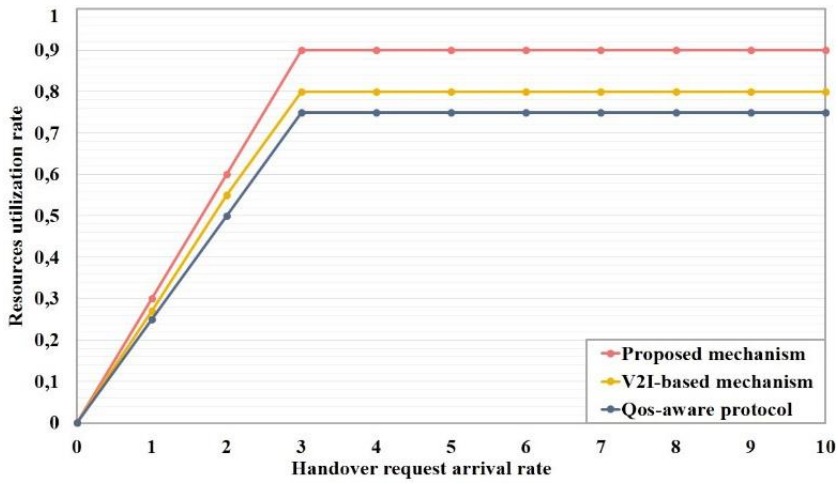

Figure 7. Resource utilization according to handover request arrival rate

5. CONCLUSION

In this work, we focus on proposing a solution to the problem of handover management in vehicular networks. We have proposed a novel multi-criteria network selection mechanism. The objectives of the proposed mechanism are: to decrease handover failure and delay, and packet loss rate, and to distribute traffic load uniformly among available network to improve the average system resource utilization. The proposed algorithm is based on fuzzy logic scheme to support the decision making process. Simulation results demonstrate that, compared to existing works, the proposed approach significantly reduces the handover delay and failure, and minimize the packet loss rates. What's more, the proposed framework achieved an improvement in network resource utilization.

As a future work, we will be interested in radio resource management in 5G vehicular communication systems.

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