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Software Defined Network-Based Multi-Access Edge Framework for Vehicular Networks

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ABSTRACT Vehicular networks aim to support cooperative warning applications that involve the dissemination of warning messages to reach vehicles in a target area. Due to the high mobility of vehicles, imperative technologies such as software-defined network (SDN) and edge computing (EC) have been proposed for the next-generation vehicular networks. The SDN separates the control plane from data plane entities and executes the control plane software on general purpose hardware. On the other hand, EC aims to reduce the network latency and packet loss rate by pushing the computations to the edge of the network. Nevertheless, the current solutions that integrate SDN and EC could not satisfy the latency requirements for data dissemination of vehicle-to-everything (V2X) services. To bridge the gap between the two technologies, the conventional EC is enhanced to multi-access edge computing (MEC) by collocating the edge computing servers with the radio access networks. In order to improve the latency for V2X services, we propose in this paper, an SDN-based multi-access edge computing framework for the vehicular networks (SDMEV). In the proposed solution, two main algorithms are implemented. First, a fuzzy logic-based algorithm is used to select the head vehicle for each evolved node B (eNB) collocated with road-side unit (RSU) for the purpose of grouping vehicles based on their communication interfaces. Afterward, an OpenFlow algorithm is deployed to update flow tables of forwarding devices at forwarding layers. In addition, a case study is presented and evaluated using the object-oriented modular discrete event network (OMNeT++) simulation framework which includes the INET framework-based SDN. Simulation results depict that the data dissemination based-SDN supported by multi-access edge computing over SDMEV can improve the latency requirements for V2X services.

INDEX TERMS Data dissemination, software-defined vehicular network, eNB-type RSU, multi-access edge computing, vehicular ad hoc network, fuzzy clustering.

I. INTRODUCTION

Vehicular ad-hoc networks (VANETs) support vehicular communication technologies to allow the deployment of vehicle-to-everything (V2X) services [1]. Thus, vehicle-to-vehicle (V2V) communication uses the dedicated short range communication (DSRC) which is based on IEEE 802.11p [2], [3] technology to exchange in-vehicle information (IVI) messages between the vehicles. However, IEEE 802.11p MAC-based enhanced distributed channel access (EDCA) [4] is unreliable due to packet collision [5]. To address the issue of packet collision in order to enhance V2X services, next-generation V2X technology, for instance, IEEE 802.11bd and new radio (NR) V2X are under standardization by IEEE task group 802.11bd (TGbd) and third generation group project (3GPP) and their recommendations are found in Release 15 respectively [6], [7]. In addition, cellular vehicle-to-everything (C-V2X) communication increases reliability in disseminating road safety messages. Although C-V2X reduces resource allocation, the performance of DSRC and C-V2X drop drastically when the road traffic increases [8], [9].

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The C-V2X communication technology includes the use of long term evolution device-to-device (LTE-D2D) and LTE-Uu for V2X services. V2V and vehicle-to-pedestrian (V2P) communicate with the evolved node B (eNB)-type road side unit (RSU) through direct communication technology over the PC5 interface. PC5 refers to user equipment (UE), which directly communicates with another UE over the direct channel. Furthermore, vehicle-to-network (V2N), pedestrian-to-network (P2N) and infrastructure-to-network (I2N) [10] enable the vehicles to access the internet infrastructure using the eNB-type RSUs over the Uu interface (Uu refers to the logical interface between the UE and the eNB) [11]. In C-V2X, eNB-type RSUs would work as relay nodes for vehicle-to-network (V2N) [12]. Although the direct communication over PC5 interface and LTE-Uu increase the reliability in the dissemination range by leveraging the cellular core network, new emerging technologies such as software-defined network (SDN) and mobile edge computing (MEC) are proposed by 5G automotive association (5GAA) to enable evolved V2X (eV2X) services for Fully autonomous driving (FAD) [3]. In fact, SDN and MEC are considered by 5GAA as an imperative solution to the next-generation of VANETs.

The SDN and MEC are networking and computing concepts for next-generation vehicular networks [13]. SDN separates the control plane and data plane entities. SDN executes the control plane software on general purpose hardware. The SDN controller keeps the global view of the network and conveys the logic of routing paths and policies implemented at the application layer. Moreover, Multi-access Edge Computing is a concept that allows MEC servers to collocate with different network elements to support network edge such as cellular base stations (BSs) including macro-eNBs, small-eNBs, wi-fi access points, radio network controller sites, routers, switches and optical unit [14]. The distributed topology of the SDN controller at each multi-access edge computing alleviates the computation of the global view of the network [13]. Certainly, SDN based VANETs architectures manage the network latency [15], enhances routing protocols, efficient utilisation of network resources [16] and selection of best routes [17].

The research on SDN and MEC over vehicular networks has attracted much attention from automotive makers, mobile operators and academia. In [18], a new vehicular ad-hoc network architecture based SDN and edge Computing (SDFC-VeNET) is presented. The new vehicular architecture was designed to control the handover and proper allocation of radio resources to mitigate the challenge of mobility management and transmission delay. To the issue of the high mobility which affects the network topology of the vehicles, the authors adopt a hybrid handover scheme with quality of service (QoS) constraint for vehicles. In [19], an SDN-enabled heterogeneous vehicular network supported by MEC was proposed. This architecture provided simultaneously the desirable data rate and reliability in V2X communications. The use cases in their work demonstrate that their architecture is developed to be a scalable and rapid response system. In [4], social-enhanced 5G-V2X framework is proposed. The proposed framework has been designed to facilitate the management, establishment, storage, maintenance and distribution of social relationship messages among V2X entities. Furthermore, the study on disseminating in-vehicle data efficiently over 5G V2X communications was conducted in [20]. The authors discussed a new 5G-V2X architecture using Side Link over PC5 as a substitute to DSRC for V2V communication. In [21], the authors propose a collaborative code dissemination (CCD) approach based on three cooperative communication methods such as roadside smart devices (RSDs) to vehicle (R2V), V2V and R2V combined V2V (R2V-V2V) communications. Nevertheless, fewer works in the literature discuss the latency requirements for deploying V2X services. It is worth noting that the prospective solutions that integrate SDN and MEC should satisfy a latency requirement of less than 100 ms for data dissemination of V2X services supporting V2V directly or via RSU [22]. Therefore, new and innovative schemes to manage data dissemination and reduce communication latency for the next generation vehicular network deserve further investigations.

To satisfy the requirements of low latency transmission and high reliability of data dissemination for vehicular networks, a novel vehicular network architecture that features SDN and multi-access edge computing including eNBs collocate with RSU is proposed in this article. The main contributions of this paper are as follows:

1) We propose a novel software-defined and multi-access edge computing vehicular network (SDMEV) architecture that features a distributed multi-access computing that includes evolved Node B(eNB) collocated with RSU inside mobile network operators. The architecture consists of four logical layers: the forwarding layer, the control layer, the multi-access edge layer along with the access layer. The four logical layers improve routing paths in SDN and reduce computation latency with multi-access edge computing for the vehicular networks.
2) Based on the presented SDMEV architecture, a data dissemination scheme in SDMEV framework using two algorithms is deployed. Firstly, an algorithm to select neighboring vehicles receiving in-vehicle information (IVI) messages over V2V or V2I communication. Secondly, an OpenFlow matching flow entries algorithm to update flow tables of forwarding devices at forwarding layers.
3) We provide an implementation for the eNB collocated with RSU and multi-access edge computing in OMNeT++ simulator. Moreover, the existing fuzzy logic-based algorithm in the INETmanet-2.0 framework is customized to select the head of vehicles in MEC cluster.
4) We conduct a simulation for SDMEV architecture to disseminate IVI messages to support in-vehicle speed limit service and discuss the relevant improvements of

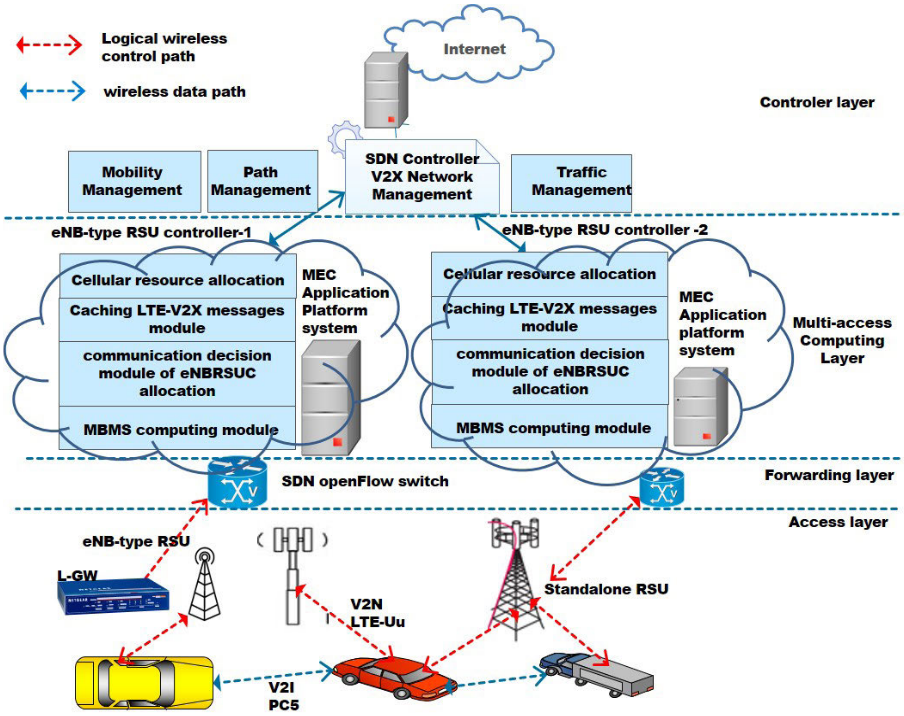


FIGURE 1. SDMEV network architecture.

using SDN and MEC to reduce the latency requirements in 5G enabled V2X applications.

We compose the remainder of the paper as follows: We discuss the functional components of the SDMEV architecture in Section II while the data dissemination scheme of IVI messages over SDMEV is described in Section III. Simulation results are presented in section IV. Finally, we draw our concluding remarks in Section V.

Note that the three words are used interchangeably throughout this paper. Firstly, eNB-type RSU and eNBRSU; secondly, multi-access edge computing and network operator enabled V2X and lastly, V2X UE end-devices and vehicles.

II. SYSTEM ARCHITECTURE OF SOFTWARE-DEFINED MULTI-ACCESS EDGE COMPUTING VEHICULAR NETWORK

Next-generation vehicular networks need to support heterogeneous radio access technology, deploy reliable data dissemination and routing protocol, allow data collection and analysis at the edge of the vehicle network. Therefore, practitioners and researchers consider focusing on communication technologies and programmable mobile cellular network elements. Furthermore, the flexibility in extending network elements, centralizing network management and collocating radio access with MEC servers are expected to be incorporated into a framework that provides reliable data dissemination, routing and control. Thus, we develop a novel vehicular network architecture as follows.

The proposed SDMEV architecture is proposed in Fig. 1. It consists of four logical parts, corresponding to four layers: access layer, forwarding layer, multi-edge computing layer, and control layer. The forwarding and multi-edge computing layers are logically distributed at the edge of the vehicular networks. For simplicity, the multi-edge computing resources refer to Mobile Network Operators (MNO) enabled V2X (MNO-V2X) computing throughout the paper. The multi-access computing layer consists of eNB-type RSU controllers. The access layer includes forwarding devices. Forwarding devices forward the packets according to actions configured into its flow entries for each incoming packets. Next, unmatched packets are sent to the control layer which includes SDN controllers to provide control functions such as network status, cellular resource management, eNB-type RSU state. Altogether, a detailed description of each layer is provided in the next subsections.

A. ACCESS LAYER (DATA PLANE)

The access layer includes forwarding devices. These forwarding devices are: The V2X UE end-devices, eNB-type RSU or EU-type RSUs. The V2X UE end-devices have a V2X UE application that runs on top of it (V2X UE end-devices). As defined in the 3GPP, the V2X UE end-devices such as a vehicle is equipped with a communication entity similar to the End User (EU in the actual design of LTE). In SDMEV, the V2X UE end-device is considered as a simple forwarding network device where the control plane responsible for determining the packets routing path is set apart. Eventually, side link (SL) over PC5 [13] (direct mode with LTE PC5 interface) establishes wireless direct communication among the V2X UE end-devices. In 3GPP Release 14 for V2X [24], SL direct communication would provide end-to-end latency of 5 ms or less between the vehicles and over 99 percent packet delivery [24].

By consideration with SDMEV, the eNB-type RSU (eNBRSU) includes two components: the eNB and eNB-type RSU application server. The eNB as a base station to manage radio resource, mobility and enable the V2X UE end-devices to access control layer infrastructure over V2N service (assisted by LTE-Uu). The eNB-type RSU application server that specifically stores the road traffic conditions or caching information from any by-passing vehicles. The communication between V2X UE end-devices and the eNBRSU is over LTE-uu. In addition, EU-type RSU is the traditional RSU where the collocation with the eNB is unpractical. The PC5 type of communication over V2I is used to allow the V2X-UE end-devices to communicate with the EU-type RSU. PC5 enables both V2V and V2P communication services. In simpler terms, SDMEV proposes RSUs to be collocated together with the eNBs communication infrastructures. These RSUs can operate as they are set up with eNBs or standalone [12]. In short, collocating RSU with eNBs at MNO introduces the concept of MNO-V2X computing.

B. FORWARDING LAYER

The forwarding layer includes high speed data forwarding in the term of SDN OpenFlow client switch, which provides routing (forwarding) policies to eNB-type RSU and V2X UE end-devices at the access layer. SDN OpenFlow client switch uses control signaling to convey an unmatched packet in the access layer's flow tables to SDN controllers. Besides the SDN OpenFlow client switch, the L-GW (local gateway) enables the local access of V2X-UE end-devices.

C. MULTI-EDGE COMPUTING LAYER

The MEC layer includes eNBRSU controllers (eNBRSUCs) and the MEC application platform system. The eNBRSUC acts as a local controller that manages the network and optimal communication mode to the vehicles in the network edge. The eNBRSUC defines reliable communication mode based on the feedback of information collected by access layer's V2X UE end-devices such as traffic status, multi-edge status, vehicle's mobility speed, V2X-UE's access technology, quality of service (QoS), and so on. Furthermore, eNBRSUCs are configured to dynamically allocate V2X communication resources and improve data dissemination efficiently to reach the vehicles at a wide radio coverage area. The topology of the SDMEV architecture envisages the eNBRSUCs to work in distributed network design. Hybrid SDN based VANET [25] with distributed SDN controller was mostly proposed to deal with high mobility of vehicles, then enhance routing protocol in SDN based VANETs.

MEC application platform system is located at the edge of SDMEV where the computing, storage, and network are designed to operate in the closest topology of the V2X UE end-devices. Furthermore, due to the hardware virtualization concept, combined applications can be hosted in the MEC application platform system server. The MEC application platform system server collects the data applicable to traffic jam management, remote in-vehicle diagnostic or data relevant to traffic surveillance. The data can be generated by in-vehicle sensors or convenience sensors or roadside infrastructures. On the other hand, data generated are transferred into the cloud for further analysis. The cloud will store a huge size of traffic data for instance image recorded in real-time inside a public transportation bus. Therefore, the eNBRSUC is configured with the following function modules:

1) cellular resource allocation of the eNBRSUCs module: deriving the control results based on the frequency division duplex (FDD) or time division duplex (TDD) [26] and the carrier aggregation of SDMEV.
2) caching in-vehicle messages module: saving the data of LTE-V2X applications at eNBRSUCs to decrease the transmission delay for V2X services.
3) communication decision module of eNBRSUCs: monitoring the link status using unicast or broadcast communication over the SDMEV to implement routing decisions.
4) multimedia broadcast multicast service (MBMS) computing module: allowing all the vehicles subscribed to eNB-type RSU simultaneously receive the same in-vehicle information messages.

D. CONTROL LAYER

The core architecture of SDMEV includes the global SDN Controller (SDNC). The SDNC is adopted as a central network structure that focuses on network traffic forwarding and resource allocation. The SDNC holds the global management and network intelligence of SDMEV. Therefore, the control layer in the SDMEV takes in charge the control of network traffic flow as well as the alteration of the routing decisions of the networking (forwarding) devices.

SDNC draws the global network topology [18]. To this, the applications on network management are implemented as a software module without the need of dealing with proprietary wireless interfaces deployed inside V2X UE end-devices [16]. The data path routing decisions defined by the network operators are stored into the SDNC which conveys them in forms of networks command through northbound API [16]. These commands in the form of messages events are conveyed to be implemented on eNBRSUC located at the edge of the network. Certainly, the MEC application platform system server collects real-time vehicular speed, multi-edge traffic status, road infrastructure status information for allowing SDNC to manage and coordinate networks efficiently. Therefore, policies of data path routing and forwarding available on the SDNC are mainly deployed to solve the V2X UE end-devices mobility since the global topology network is known in advance by the SDNC.

III. DATA DISSEMINATION SCHEME IN SDMEV

Vehicular networks use either DSRC or C-V2X communication technology to allow vehicles to exchange in-vehicle

TABLE 1. C-ITS services grouped by category of information to road users and propagation range [23].

Services	type	Category	propagation range
Traffic jam ahead warning	V2V	Warning	100m
The slow vehicle warning	V2V	Warning	100m
Cooperative collision warning	V2V	Warning	100m
Emergency brake light	V2V	Warning	100m
Hazardous location notification	V2V	Warning	100m
In-vehicle speed limits	V2V/V2N	Information	<10km
Shockwave damping	V2I/V2N	Information	<10km
Traffic signal priority by designated Vehicles	V2I or V2N	Information	<10km
Green light optimal speed advisory	V2I/V2N	Information	<10km
Active braking	V2I/V2N	Actuation	5m

information (IVI) messages supported by cooperative-intelligent transportation systems (C-ITSs) [27]. C-V2X would also be used to download a huge amount of content requested from cloud-based vehicular applications. However, DSRC and C-V2X technology drop drastically in performance at some road segment when the vehicles are deployed in a highly dense manner. Although the integration of hybrid architecture of LTE and IEEE802.11p is proposed to ensure the quality of service [20], the cost of massive RSU deployment is a challenge for road operators. The solution is to collocate eNB with RSU as well as deploy the C-V2X interface in vehicles. However, it is not practical in the future that next generation vehicles would support both IEEE 802.11p and C-V2X interfaces [28]. In other words, automakers would select to use communication interface that has most net benefit [28]. In addition, it is unseemly to shift all traffic communication to C-V2X due to cost of cellular communication and poor performance of spectrum due to enormous number of V2X UE end-devices. Therefore, this section discusses C-ITS services grouped by category of in-vehicle information message, data dissemination schemes based on SDN and multi-edge computing for SDMEV. Next, this section provides also a use case scenario of a data dissemination of an in-vehicle information messages (vehicle's speed notification).

A. COOPERATIVE-INTELLIGENT TRANSPORTATION SYSTEMS (C-ITSs) SERVICES GROUPED BY CATEGORY AND PROPAGATION RANGE

C-ITSs provide the set of technological and functional elements specifically defined to allow functionalities of V2X communication services [23]. Therefore, C-ITSs specification group works essentially on the definition of a number of C-ITS services. Moreover, the C-ITSs services grouped in category is given in Table 1. The first five (5) of C-ITS services in category of warning provide general information to the driver about road traffic, vehicles and conditions, but do not alert the driver to an immediate danger. The second type of C-ITS services in the category information (in-vehicle speed limit, shockwave damping, traffic signal priority by designated vehicles, green light optimal speed) provide information about a potential immediate danger such as collisions or speed notification. Finally, category of information of type actuation include C-ITS services that lead towards fully automated cars. A full description of these C-ITS services can be found in [23].

TABLE 2. definition of parameters in algorithms.

parameters	definition
$cmsg$	category of V2X messages
VUE_0	Cluster Head vehicle
$nveh_{neigh}$	neighboring vehicles
VUE_j	vehicle to receive V2X messages
$wirelessinterface$	type of wireless interface
$pktmsg$	packet
$cell-RSU$	RSU deployed inside eNB
$eNBOFW$	openflow switch at eNB
$SDNOFW$	SDN openFlow
eNB	evolved Node base station

The european telecommunications standards institute (ETSI) has released packets format and dissemination guideline of two different kind of messages, namely cooperative awareness messages (CAMs) and decentralized environmental notification messages (DENMs) [29] to support above-mentioned C-ITS services in Table 1. Therefore, this paper considers worth discussing in-vehicle information (IVI) messages [27], which specifically transmit to the vehicle regularly static and dynamic data about infrastructure such as speed limit information [14].

B. DATA DISSEMINATION OF IN-VEHICLE INFORMATION MESSAGE OVER SDMEV ARCHITECTURE

The data dissemination scheme of in-vehicle information messages based on SDN-multi access edge computing is provided in Fig. 2. The details of the two algorithms used to implement the data dissemination scheme based SDN-multi access edge computing are described . The list of parameters used in the algorithm 1 and algorithm 2 is described in Table 2.

1) MODELING CLUSTER HEAD VEHICLE

There are three types of node (vehicles) in the SDMEV architecture: neighboring vehicles (free node) veh_{neigh}, cluster head vehicle VUE_0 and cluster member VUE_j. The fuzzy clustering algorithm considers the one-hop neighboring of each vehicle and the cluster size is decided by the cluster head vehicle's communication range. VUE_0 is responsible for requesting in-vehicle wireless access $wirelessinterface$

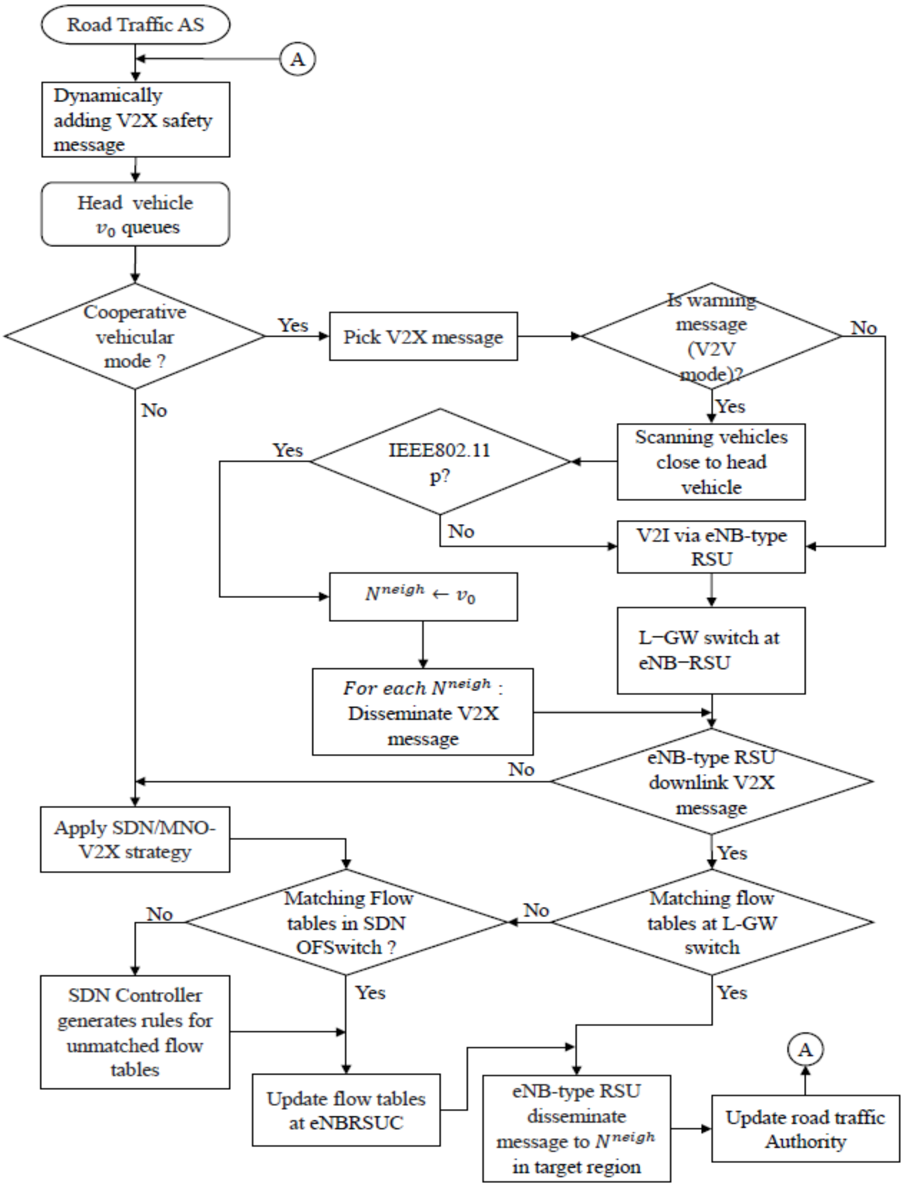


FIGURE 2. **Data dissemination scheme of in-vehicle information message over SDMEV architecture.**

collecting data and service-based IVI message from VUE_j. VUE_0 uploads to eNBRSUC current V2X communication mode (V2V or V2I) and cluster network topology from VUE_j. This paper defines three factors such as position, velocity and signal quality to select the cluster header vehicle. All vehicle download and know the road navigation map. The position of each node is obtained from its own location information using a beacon message after a predefined interval (1 second by default) [30]. The average distance, P_{vue}, between VUE_0 and VUE_j should be shorter, which is given by

$$P_{vue} = \frac{1}{n}\sum_{j=1}^{n}\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \tag{1}$$

where n is the number of neighbours of nodes veh_{neigh}, x and y are coordinate values of two veh_{neigh}.

The velocity of VUE_0, Vs_{UE0} is evaluated to be the difference between the velocity of a candidate veh_{neigh} (Vs_{UEj}) driving toward the same direction. The average velocity for the current road traffic flow is given by :

$$Vs_{UE0} = \left| Vs_{UEj} - \frac{1}{n}\sum_{j=1}^{n} Vs_{UEjl} \right| \tag{2}$$

where Vs_{UEjl} is the velocity of the j-th neighbor of the veh_{neigh} node.

In order to avoid traffic congestion, the signal quality of the veh_{neigh} node is reflected by the type neighbor's wireless

Algorithm 1 Vehicle Selection Algorithm for Selecting Vehicles According to Their Wireless Communication Interface

```
Input: $cmsg$, category v2x message like speed notification
Input: $VUE_0$, cluster head vehicle
$VUE_0 \leftarrow cmsg$
$VUE_0$ extracts information included in $cmsg$
scanning neighboring vehicles close to $VUE_0$ getting $nveh_{neigh}$
$VUE_j \leftarrow nveh_{neigh}$
for $VUE_j$ in $nveh_{neigh}$ do
    $wirelessinterface \leftarrow IEEE802.11p\ or\ C-V2X$
    if $wirelessinterface = IEEE802.11p$ do
        $V2V \leftarrow true$
    else
        $V2V \leftarrow false$
    end
end
Output: $VUE_j \leftarrow VUE_1, VUE_2, \ldots, VUE_j$ where $V2V == True$
```

access interface *wirelessinterface*. A number of veh_{neigh} node with the same access wireless interface is N_{VUEj}. The number of vehicles per unit length of the roadway is defined by k. In road traffic flow, the two considered densities are of two groups [31]: the critical density of k_c and jam density k_j. Therefore, k_j is the maximum density achieved under congestion. In general, traffic congestion density is seven times the critical density k_c. The inverse of density is spacing s [31], which is the center-to-center distance between two vehicles. The density k within a roadway of length L at a given time t is calculated to be equal to the inverse of the average spacing of the n veh_{neigh} and is given as :

$$K(L,t) = \frac{nveh_{neigh}}{L} = \frac{1}{\bar{s}(t)} \tag{3}$$

The theoretical signal quality is denoted as σ, which represents the maximum number of neighbouring nodes within same wireless access technology without creating traffic congestion, and is given as:

$$\sigma = 2R_t \times K(L,t) \times n_l/1000 \tag{4}$$

where R_t is the transmission range, n_l is the number of lanes. The actual signal quality, SQ_i, is to measure how close the N_{VUEj} is to the ideal value σ, i.e:

$$SQ_i = \left|N_{VUEj} - \sigma\right| \tag{5}$$

When a vehicle is free from any cluster, it sends a vehicle information packet to its neighbors' vehicles and allows them to calculates its competency rank. Each node calculates the level of competency rank to be the cluster header. The linguistic variable of Vs_{UE0} and P_{vue} are defined as Slow, Medium, Fast and Good, Fair, Poor respectively. For signal quality SQ_i, the linguistic variable is defined as Good, Medium, Bad. The rank of competency is based on predefined *if*/*then* rules as proposed in [30] to calculate the competency rank of the cluster head vehicle. The linguistic variables for the competency rank are defined as Perfect, Good, acceptable, Bad. For example, for a Rule expressed as follows: *IF* velocity is *Slow*, position is *High*, and signal quality is *Good THEN* competency rank is *Perfect*.

2) MODELING UNMATCHED-PACKET MESSAGE

Regarding the update of flow tables of SDN-enabled switch, we consider analyzing the update OpenFlow switch matching packets before the SDN controller provides routing rules. Our analysis considers the incoming of the unmatched packet on the SDN OpenFlow client switch. When a cluster head vehicle VUE_0 is connected to an RSU, say $cell-RSU$, it gets connected to another one openFlow switch, *eNBOFW*. This process focuses on asynchronous messages of $unmatched - packet$. This message updates the SDN controller OpenFlow *SDNOFW* of the vehicle unable to receive an IVI message through V2V. On the *SDNOFW* side, the global view of the SDMEV should be up-to-date. Moreover, the *SDNOFW* provides $Flow - mod$ messages to all eNBRSUC to update flow entries of *eNBOFW* in proximity with the cluster head vehicle.

A $unmatched - packet$ message generated by a *eNBOFW* can be either a new category of IVI message or interoperability of communication mode.

Now, let assume that the arrival rate of $unmatched-packet$ message initiated by a cluster head vehicle node VUE_0 is λ_{ih}. Then, the flow a $unmatched - packet$ events captured by any cluster head vehicle VUE_0 is modeled as

$$\gamma_{ih} = \lambda_{ih} \tag{6}$$

In addition, Γ_{ih} is the total arrival rate of undefined forwarding path of IVI message from the whole network to *eNBOFW* i and is given as follows:

$$\Gamma_{ih} = \gamma_{ih} + \sum_{j=1, j\neq i}^{n} \left(\lambda_{jh} \times v_j^i\right) \tag{7}$$

where $v_j^i \in \{0, 1\}$ is an observance applied to model the execution of the $unmatched - packet$ message after being performed by the controller. If $eNBOFW_i$'s flow table has to be configured based on j's $unmatched-packet$ message, then $v_j^i = 1$; otherwise, $v_j^i = 0$.

3) VEHICLE SELECTION ALGORITHM

The algorithm 1 selects the neighboring vehicles equipped with IEEE802.11p/LTE-D2D wireless module to exchange in-vehicle information messages. The vehicles in each MEC group are connected to eNBRSU servers via a cellular network (LTE-Uu). The cluster (vehicles in each multi-edge computing partition) is formed based on periodic Hello messages containing the sender information (road identifier, position, direction, radio access, etc.) [32]. The head of each multi-access edge is selected based on the fuzzy logic-based cluster head algorithm [33]. Based on the works in [33] and [30], we customize the fuzzy logic-based cluster to run in OMNeT++ network simulator including INETmanet-2.0 framework available at [34]. Based on the algorithm 1, the cluster (MEC partition) head picks the message and checks in which category of IVI-message (see Table 1) it belongs to. If it belongs to the warning messages category, the head vehicle (the vehicle with IEEE802.11p/LTE-D2D wireless module) sends a request message on the wireless communication interface equipped within the neighboring vehicles. The neighboring vehicles whose wireless interface comply with IEEE802.11 p receive the in-vehicle information messages via V2V assisted by IEEE802.11p. To the vehicles which do not comply with IEEE802.11p, the V2I communication mode is selected over LTE-Uu communication to disseminate the IVI message. A list of adjacent vehicles to receive the IVI message is provided from the output of the algorithm 1, which indicates that direct communication is possible (V2V is true). The vehicles for which the V2V is unpractical, V2I is selected and the dissemination of IVI message based on SDN and multi-access edge computing over SDMEV architecture is applied.

Algorithm 2 OpenFlow Switch Matching Packets Algorithm for Disseminating In-Vehicle Information Messages

```
Input: $pktmsg$, packet of v2x message
Input: $cell - RSU$, eNB type RSU
Input: $eNBOFW$, L-GW OFW
Input: $SDNOFW$, SDN OpenFlow Switch
while $cell_R SU$ do
  if routing $pktmsg == flow\ entries\ at\ eNBOFW$ do
    route $pktmsg$
  else :
    if routing $pktmsg == flow\ entries\ at\ SDNOFW$ do
      $eNBOFW \leftarrow flow\ entries\ for\ pktmsg$
      route $eNBOFW$
    else do :
      $SDNOFW \leftarrow new\ rules\ from\ SDNcontroller$
      $eNBOFW \leftarrow flow\ entries\ for\ pktmsg$
      route $pktmsg$
    end
  end
end
Output: update SDN Openflow Client Switch $SDNOFW$ and Local-Gateway OpenFlow Switch $eNBOFW$
```

4) OPENFLOW SWITCH MATCHING PACKETS ALGORITHM

The algorithm 2 is responsible for updating flow tables on the SDN Openflow client switch at the forwarding layer of the proposed SDMEV architecture. All the packets that correspond to the predefined C-ITS services, the category of IVI messages implementing these C-ITS services can be handled by SDN Openflow client switch which forwards the vehicular data at the L-GW directly with low latency. In case there is no rule matching the incoming packets in the flow table of the SDN Openflow client switch, then those packets are forwarded to the SDN Controller according to the unmatched packet action configured in the flow entries of SDN Openflow client switch. The MEC application platform system server at the multi-access computing layer provides necessary information such as target area, road status, traffic status to the SDN Controller to precisely determine optimal routing paths to reach the vehicles in their destination area. Thus, SDN Controller notifies the eNBRSU controller which in turn updates flow entries inside SDN Openflow client switch of new routing instructions to handle new packets which their forwarding actions are undefined in SDN Openflow client switch's flow table.

C. CASE STUDY ON DISSEMINATING IN-VEHICLE SPEED LIMIT BASED SDN-MULTI ACCESS COMPUTING CONCEPT OVER SDMEV

C-ITS services in VANETs involve in-vehicle information messages to reach the vehicle in the target area. For instance, an in-vehicle speed limit service initiated upon an accident ahead informs drivers about speed limit unceasingly to prevent vehicles driving towards the accident area. In fact, the shortest multi-hop broadcast [35] is used to disseminate the emergency messages to both neighboring driving ahead to unexpected events. In addition, routing protocols can also be used to transmit in-vehicle information messages to an area far away from the imminent danger such as police stations.

Disseminate in-vehicle information messages supported by in-vehicle speed limit to neighboring vehicles require direct communication technology (LTE-D2D or IEEE802.11p) among surrounding vehicles. Referring to Fig. 4, the cluster head V1 equipped with the LTE-V2X module receives the in-vehicle speed limit information to be transmitted to surrounding vehicles. The V1 broadcasts the in-vehicle limit speed using V2V service over IEEE802.11p technology. To those vehicles fail to receive the in-vehicle speed information due to spectrum use that leads to roadblock concern [36], [37]. The roadblock is the battle over the connectivity standard between the C-V2X (5G-V2X) communication and the ITS-G5 technology based on Wi-Fi connectivity (IEEE802.11p). Thus, supporting high levels of QoS and guarantee bandwidth coexistence in the same 5.9 GHz band at such the coexistence, interoperability and backward compatibility must be realized. Therefore, both systems can be deployed in the same vehicle [37]. Certainly, the SDN concept alleviates the issue of forwarding network devices (routers, switches) that run complex, distributed control software that is typically closed and proprietary. The advantage of SDN is to lower the barrier to innovation by implementing programmable functions in the network [38].

V2N (up/Download) operating in convention mobile broadband licensed spectrum [12] to reach SDN controllers is addressed in this paper to flow routing entries so that the vehicles would act as simple forwarding vehicular devices without considering software proprietary of the V2X communication module. The concept of using SDN and

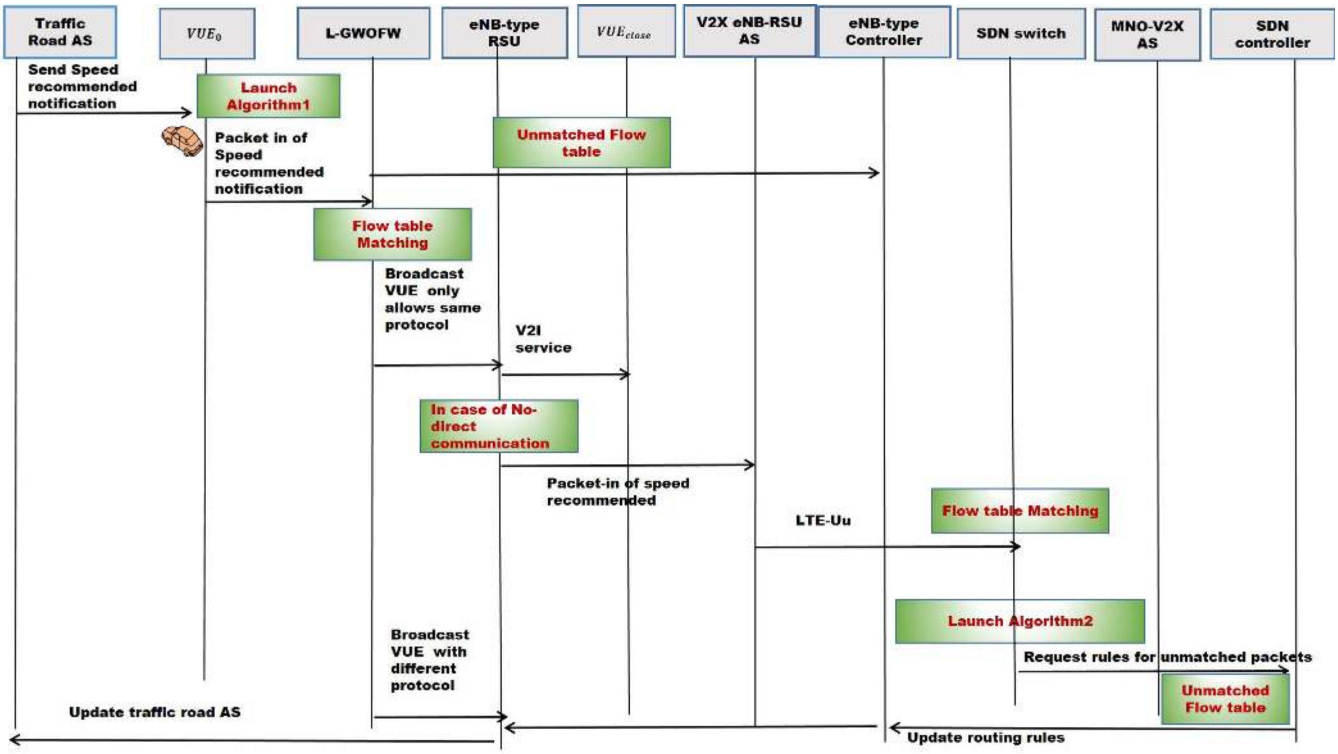


FIGURE 3. Signaling implementation to update unmatched packet over SDMEV architecture. With SDN, vehicles are simple data plane devices forwarding packets to other vehicles according to routing rules generated at the eNBRSU controller. The updates of unmatched packets are handled by the SDN controller. Openflow switch communicates with the SDN controller using OpenFlow protocol.

multi-access mobile edge computing to support QoS and ensured the 5.9 GHz spectrum efficiently use for disseminating in-vehicle speed limit. As shown in Fig. 5, in case there is 5.9 GHz spectrum interference between neighboring vehicles, the SDN controller defines the routing rules and conveys them on the SDN OpenFlow client switch located closely to the eNBRSU to update flow tables and then forwarding packets to vehicles.

In case ITS 5.9 GHz spectrum interference limits V2V communication, the dissemination of in-vehicle speed limit information based on SDN and multi-access edge computing over SDMEV architecture is explained as follows. The cluster head V1 (see Fig.5) forwards vehicular data (packet) of in-vehicle speed limit information for requesting flow entries in case they are not predefined in the SDN OpenFlow client switch. Thus, eNB-type RSU collects real-time vehicular speed, traffic status, multi-access partition network status and road status information for eNBRSUC (which features the edge view of the network) to compute the routing rules. In case the eNBRSUC fails to generate routing rules due to the poor knowledge and coordination of the edge network management, eNBRSU transfers collected information (required for network coordination) to SDNC so that it can update or generate new routing rules to update the flow tables of SDN OpenFlow client switch responsible to forwarding packets to vehicles. The SDN OpenFlow client switch transmits control signaling message downlink to the EU-type RSU or eNB-type RSU in the target area via LTE-Uu. The vehicles (vehicles v5 and v4) listening to V2I/V2N communication in the target area (destination area) receive in-vehicle speed limit information to avoid road traffic congestion towards their driving directions. The simplified process of disseminating in-vehicle information based on SDN and multi-access edge computing is also presented in Fig. 3.

IV. SIMULATION AND RESULTS

A. SIMULATION SETUP

This section presents the simulation setup to evaluate the proposed SDMEV architecture with the main purpose of disseminating IVI messages (here speed data). The network simulation used in this paper is based on the OMNeT++ simulator [39]. The OMNeT++ integrates another framework that provides protocols, agents and other models to work with network simulation called INET framework [40]. The VeinsLTE [41] and SimuLTE [42] framework were also integrated to OMNeT++ to simplify the simulation of vehicular communication for both DSRC and LTE. OMNeT++ [39] is an open source discrete event simulator for wired and wireless networks. The tool has the features of being extensible, component-based, hierarchical and modular. The tool is written in C++, built on Eclipse-based IDE.

As SDMEV architecture is based on the SDN concept, the INET framework provides modules to implement this

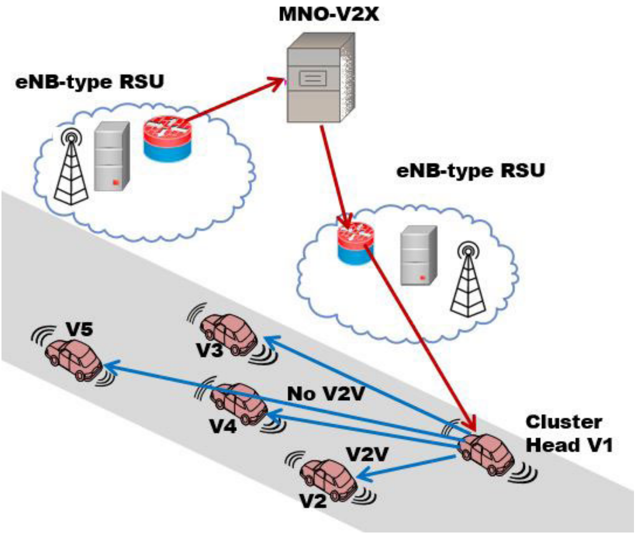


FIGURE 4. The V2V communication for disseminating in-vehicle speed limit information in conventional mode without the integration of the concept of SDN.

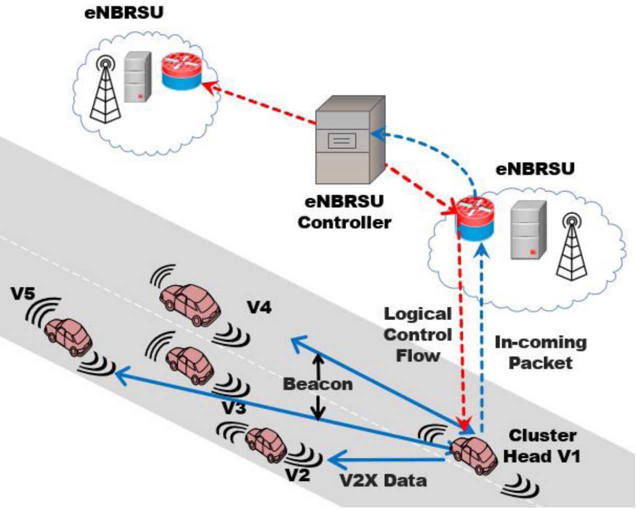


FIGURE 5. The V2V based in-vehicle speed limit service is performed in case there is 5.9 GHz spectrum interference between neighboring vehicles, SDN controller defines the routing rules and vehicles acting as forwarding devices.

concept. This paper considered an initial model presented in [43] and it consists of the two basic SDN components, the SDN centralized controller and the OpenFlow enabled switch supporting the basic OpenFlow messages for the flow establishment and communication between the components [43].

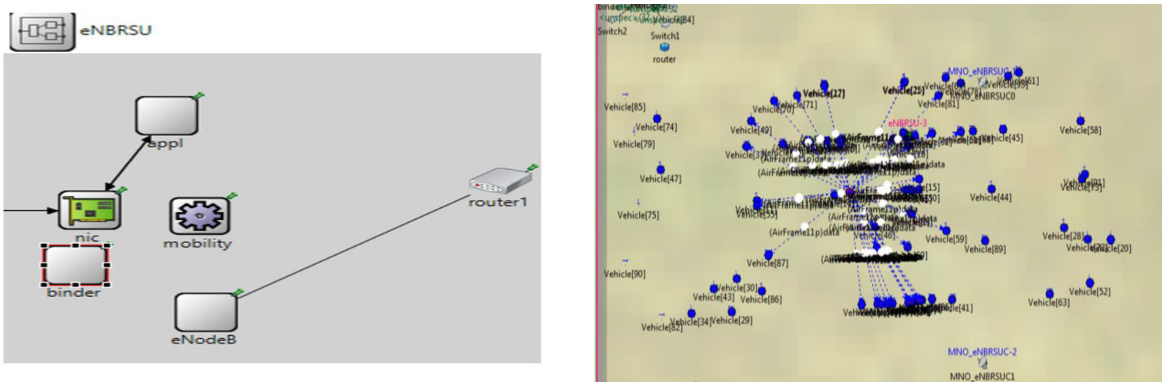
Traffic simulators are necessary to imitate real world traffic conditions. SUMO [44], a microscopic traffic simulator that includes features like vehicle movement without collisions. The real-time road traffic can be imported using Open Street Maps (OSM) [45]. In this work, we import the traffic of the city of San Francisco. Furthermore, an inter-vehicular communication framework proposed in [46] was based on OMNeT++ and SUMO, connected through the transport control protocol (TCP) layer protocol, traffic control interface (TraCI). OMNet++ supports annotation to display the connections and communication path between the nodes.

TABLE 3. Main simulation parameters and settings.

MNO-eNBRSUC	
Application type	TraCIDemoRSU11p
beaconInterval of application	1s
eNBRSU	
application Type	TraCIDemoRSU11p
beacon Interval of application	1s
accident Count on mobility model	1
application on Vehicle	
application Type	TraCIDemo11p
link cloud to router	
propagation delay Type	0.1s
General parameters	
Number of eNB-RSU	3
Number of vehicles	100 -500
Number of MNO-eNBRSUC	3
Number of openFlow Controller	1
Number of openFlow switch	3
Simulation limit time	400s
playgroundSizeX	5000m
playgroundSizeY	5000m
playgroundSizeZ	50m

The main settings are reported in Table 3. We create a VANET network that has 1 cloud server, 1 router, 1 Gateway, 1 Openflow controller, 3 openflow switch, 3 eNBRSUs, 3 MNO-eNBRSUC (multi-access edge computing) and 100 to 500 vehicles (Based on SUMO model). The vehicles are placed depending on the SUMO traffic data of the city of San Francisco. All vehicles have an LTE interface to communicate with others. Next, we perform the fuzzy logic-based cluster head algorithm to select the cluster head vehicle. The head cluster vehicle runs the algorithm 1 to select adjacent vehicles to receive the in-vehicle speed limit data according to their wireless communication interface. Furthermore, communication is performed between vehicles based on V2X techniques. The simulation executes the process of packet transmission between the RSU like the eNBRSU or MNO-eNBRSUC and Openflow (SDN) controller, Openflow switch with the vehicles. To perform the simulation, we use the INETmanet-2.0 [34], SUMO-0.21.0, OpenFlow, SimuLTE and the simulation tool OMNeT-4.6. The throughput (network throughput) is the rate of successful message delivery over a communication channel. In this step, we define the channel with a data rate of about 40 *Gbps* and delay equal to 1 microsecond (1μs) to connect OpenFlow (SDN) controller and the OpenFlow switch.

eNB-type RSU model implemented in OMNeT++ is shown in Fig. 6(a). The Binder module can access every other node in the system. It is also storing data about their connections to other nodes. Binder, in particular locates the interfering eNBs in order to compute the incoming connections perceived by an RSU. The eNodeB connects to the router through peer to peer connection (10 megabit/sec Ethernet link). The openflow switch and openflow controller modules in the network models used in this work referred to the same implementation in the work [43]. For the cloud computing



(a) (b)

FIGURE 6. (a) RSU deployed at the base station (eNB), (b) Dissemination of speed data over SDMEV in omnet++ network simulator.

server, the standard host module of the INET framework can be extended to build an ethernet enabled host device respectively [47].

The simulation performs the communication of in-vehicle speed limit (vehicular data) messages between the vehicles. We simulate the process of performing packet transmission between the eNBRSU or MNO−eNBRSUC and SDN OpenFlow client switch with vehicles. Fig. 6(b) shows the dissemination of speed data like in-vehicle information message over the network topology model of the proposed SDMEV architecture. The network simulation evaluates the dissemination of in-vehicle speed limit information downloaded from eNBRSU server via cellular communication to a multi-access computing cluster's header selected using a fuzzy-based clustering algorithm.

B. RESULTS AND DISCUSSION

This section discusses the results of the simulation. The main objective is to simulate the proposed SDMEV architecture in order to meet the latency requirements settled by 3GPP for V2X services based in regard to the use of C-V2X communication. The eNB-type RSU controller requires an extra processing delay, it has to generate forwarding rules and determine which actions should be implemented on the SDN OpenFlow client switch. We set this computing delay to be 5ms, as referenced in the work [26]. OMNeT++ tool is used for analyzing the results of captured packets for the speed data along with the delivery delay.

The results show from Fig. 7 that a backhaul latency of 22 ms is the delay experimented for disseminating in-vehicle speed limit message. This happened because of the forwarding rules that are pre-installed in the flow tables within the SDN OpenFlow client switch.

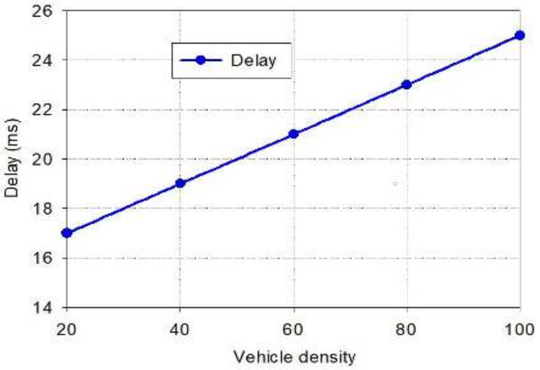


FIGURE 7. Transmission delay on disseminating in-vehicle message (speed limit data) over SDMEV.

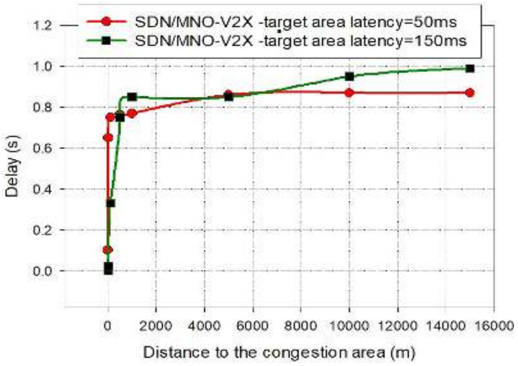


FIGURE 8. Dissemination delay of in-vehicle message (speed data) assisted by SDN concept(using OpenFlow enabled switch).

To evaluate to which extend the delay of data dissemination is performed, the assumption was to vary the distance between the cluster header vehicle and the neighboring vehicles. We consider a distance from 1m to 15km. As the mobility of the vehicle enabled V2X affects the simulation, the speed varies between 40 to 110 km/h. In addition, the average time taken by the MEC application platform system server to send the set of data (road, vehicle's speed) to OpenFlow Client Switch through the SDN controller ranges from 50 to 150 ms. The results are presented in the Fig. 8. The vehicles close to the congestion area received the in-vehicle speed limit information in less than 400ms while the vehicles far away to a distance of 10 km receive the in-vehicle information in less 1 second. The presence of the eNB-type RSU controller allows to achieve this latency which could be much higher in traffic congested areas since the eNB-type Controller instates routing path according to the location based beacon received from the vehicle. Next, the eNBRSU uploads this information to eNB-type RSU controller to keep a global view of the network in eNB-type RSU's coverage. However, increasing the flow of in-vehicle speed limit messages affects positively the results.

It is obvious that the data dissemination based SDN multi-access edge computing over the proposed SDMEV improves the latency requirements in the presence of the ITS 5.9 GHZ band for V2X services. Adding to this, the proposed SDMEV framework allows the vehicles enabled V2X to receive in-vehicles information messages from other vehicles with a backhaul latency of 22 ms in comparison to many V2X use cases with 100 ms deadline (e.g., control loss warning [24]).

C. COMPARATIVE STUDY

The behavior of the proposed scheme is evaluated in comparison with two SDN-based scheme, hierarchical software-defined VANET (HSDV) [25] and software-defined vehicular network (SDVN) using heterogeneous wireless interface [48]. These existing schemes were chosen because both the schemes use the concept of local controllers to reduce the signaling network traffic of the controller. In SDVN architecture using heterogeneous wireless interface proposes network selection and data dissemination. In fact, network selection is based on the applications requirements and network parameters. An utility function of game theory is calculated to select the ideal available network. The data dissemination is performed using route prediction deployed via the SDN controller which is responsible for network management and route prediction. However, in our proposed scheme, a cluster head vehicle is elected using fuzzy clustering algorithm to group in turn cluster member based on in-vehicle wireless interface. The cluster head reports vehicles with different wireless interface than cluster head to the SDN controller which updates flow tables of SDN openflow switch located at a given MEC region. In HSDV, the controller manages the dissemination by selecting the next hop which is closest to destination. Furthermore, GPSR [49] which does not support SDN controller is compared to evaluate the impact of the proposed scheme.

Average end-to-end (E2E) delay, packet delivery ratio (PDR) and average throughput are the performance metrics selected to compare the proposed scheme with existing scheme. E2E delay evaluates the average time taken by transmitted packets to their respective destination nodes. PDR determines the ratio between packets successfully delivered to the total number of packets transmitted. The average throughput supports the evaluation of the average rate at which packets have been successfully received by destination node over the communication channel.

1) AVERAGE END-TO-END DELAY

Fig. 9 shows the average E2E delay. The proposed scheme decreases the average E2E delay as the number of vehicles nodes increases. This is because the cluster header has much chance to choose a group of vehicle with the same wireless communication when the cluster head vehicle is established. The simulation injects some vehicles (nodes 0-20) with IEEE802.11p after 30 seconds of simulation. A large number of nodes use cellular-V2X communication. However, in our scheme eNBRSU in the MEC region provides network topology connectivity to eNBRSU controller so that the stability of the network topology is assured. Since the dissemination path is established from the eNBRSU controller, the delay is reduced gradually. The SDN controller configure s new path routing rules in case a dissemination of C-ITS messages happens, otherwise the eNBRSU controller holds ideal routes information to the requesting nodes grouped in their respective cluster region which is under control of MEC infrastructure. At the vehicle density of 100, the proposed scheme has E2E delay of 12.59 ms, which is lower than 50,64 ms in SDVN using heterogeneous wireless interface, 66,87 ms in HDSV, 72.14 ms in GPSR. In fact, SDVN using heterogeneous considers to calculate the duration of the route before it is selected and injected to the local controller which would increase processing latency. The proposed scheme proposes to use the cluster head which the competency to be selected considers the wireless interface of vehicles driving towards the same direction and the link stability. SDVN using heterogeneous performs better than HSDV and GPSR as evaluated in [48].

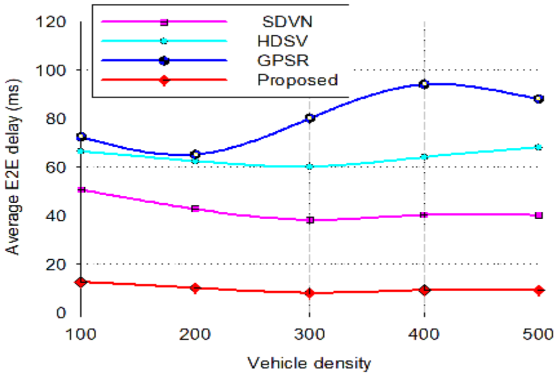


FIGURE 9. Average End-to-End delay in respect of vehicle density.

2) PACKET DELIVERY RATIO

Fig. 10 shows the packet delivery ratio versus vehicle density. In general, low density of vehicles causes the unavailability of the link. This causes the uptick of PDR. From existing schemes, the PDR starts to increase as the number of vehicle density increases, which means less number of packets dropped. However, for the proposed scheme the PDR decreases on node 200 because the selection of new cluster head happens frequently. Frequent selection of cluster head drops packets due to the transmission collision when some cluster member vehicle leaves and joins other cluster. From node 300, the simulation is configured to run nodes that have lower speed which triggers shorter distance between cluster member. This reduces transmission load to the eNBRSU. This explains why from node 300 the proposed scheme

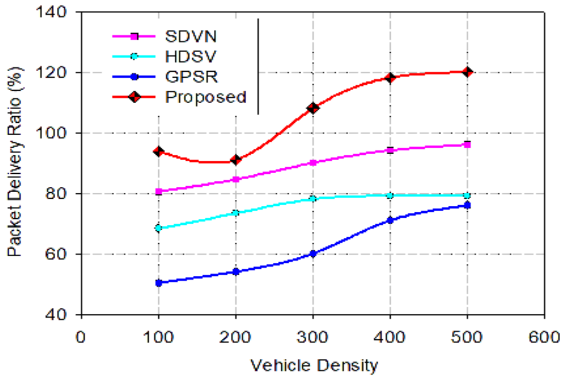


FIGURE 10. Packet delivery ratio in respect of vehicle density.

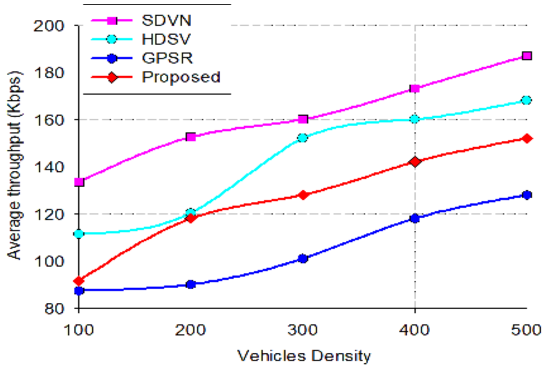


FIGURE 11. Average throughput in respect of vehicle density.

achieves higher PDR. The SDN controller approach is used both in SDVN features heterogeneous wireless interface, HSDV except in GPSR. The proposed scheme is based on SDN approach to enhance PDR because the communication management reduces lost of connectivity since the global view of the network is known in advance and up-to-date state. The routing paths are predefined in the OpenFlow switch which reduces the flow of messages exchanged between forwarding nodes, then, decreases packet collision. Clustering nodes also reduces the transmission loads between vehicles and RSU infrastructures. In case of the routing is regulated by a SDN controller as it happens for GPSR, the PDR is lower because each node has to select the next hop node to forward the packets to the destination. The proposed scheme outperforms the three compared existing schemes because a cluster member can still obtain IVI messages from the cluster head since the latter also would update flow tables with routing rules received from the eNBRSU controller. At a vehicle density of 100, PDR for the proposed scheme is 93.46 %, whereas for SDVN using heterogeneous wireless interface, HSDV and GPSR, it is 80.64 %, 68.04 % and 50.94 %, respectively.

3) AVERAGE THROUGHPUT

Fig. 11 shows the average throughput with respect the vehicle density. The proposed scheme has lower average throughput compared to the existing scheme based SDN. This is because the vehicles are grouped in cluster and are not involved to sent packets. SDVN using heterogeneous wireless interface provides more sustainable and better performance than the proposed scheme, HSDV. The selection of best routes predicted by SDN controller is the key success for a higher average throughput. At a vehicle density of 100, SDVN using heterogeneous wireless interface appears to have 131.51 *kbps*, whereas 111.45 *kbps* and 91.67 *kbps* is the average throughput of HSDV and the proposed scheme. Therefore, on increasing the number of vehicles density, the average throughput increases gradually for all discussed schemes.

V. CONCLUSION

In this article, we presented a logical SDMEV scheme for next generation vehicular networks based on SDN and multi-access edge computing concepts where the RSU are deployed inside Evolved NodeB (eNB). The multi-access computing layer and control layer are responsible to manage the control logic of the SDMEV. The forwarding layer and access layer implement the data plane. Multi-edge computing layer includes eNBRSU controllers and MEC application platform system. The eNBRSUCs act as a local controller that manages the network and optimal communication mode to the vehicles in the network edge. Furthermore, an efficient data dissemination scheme is provided to improve data dissemination of in-vehicle information message to reach vehicles at a target area. A fuzzy clustering algorithm to select the cluster head vehicle is extended using the INETmanet-2.0. A data dissemination based SDN supported by multi-access edge computing for avoiding the issue of direct communication between the vehicles is introduced. The OpenFlow algorithm is deployed to update flow tables of forwarding devices at forwarding layers. Thus, eNBRSU controller has the edge view of the network to compute the routing rules. In case the eNBRSU controller fails to generate routing rules due to the poor knowledge and coordination of the edge network management, the SDN controller updates and generates new routing rules to update the flow tables of SDN OpenFlow client switch responsible to forwarding packets to vehicles. The simulation results indicate that the proposed SDMEV scheme can satisfy the latency requirements of V2X services by means of using multi-access edge computing extended with SDN technology. In future work, we will consider the use of LTE-D2D to disseminate V2X messages based on the proposed vehicular network. Additionally, we will investigate resource allocation over SDMEV.

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