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A Bus-Oriented Mobile FCNs Infrastructure and Intra-Cluster BSM Transmission Mechanism

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ABSTRACT With the concept of edge computing being put forward, the edge node should play an important role in resource allocation and local computation. However, there are two basic problems to confront in this arena: the performance of basic safety message (BSM) exchange and the frequency of service migration, both of which are related to the vehicle's mobility feature. To decrease the frequency of service migration and enhance the efficiency of the BSM exchange, in this paper, a bus-oriented mobile fog computing nodes infrastructure is proposed, while a mobile similarity-based clustering method is given. In the proposed method, the bus node, which is considered as a fog-computing node (FCN), is used as a sink node, which fulfills communication resource allocation and convergence computing tasks. MATLAB is used to simulate the path loss feature, while a network simulator (NS-3) is employed to investigate the performance of the proposed scheme. The simulation results show that the proposed scheme significantly decreases the frequency of service migration and perform high communication efficiency for intra-cluster BSMs exchange.

INDEX TERMS Mobile FCNs, bus oriented clustering method, mobile similarity, BSM transmission.

I. INTRODUCTION

V2X (Vehicle to Everything) communication, which helps road drivers avoid potential threats by exchanging safety warning information, such as environment feature [1], bad driving state [2] and mechanical failure, is considered as an important approach to pave the way for a drastically improved road safety and driving experience via reliable and low latency wireless services [3], [4]. V2X system incorporates different information exchange paths, such as V2I (Vehicle-to-Infrastructure), V2V (Vehicle-to-Vehicle), V2N (Vehicle-to-Network), and V2P (Vehicle-to-Pedestrian) communication. The V2X features specified in 3GPP(Third Generation Partnership Project) TS 23.285 [5] offer two independent data exchange modes of operation for inter-vehicle UE (User Equipment). The one is PC5 mode, a direct communication mode, which is used to establish V2V and V2I connection, while the other is LTE-Uu (Long Term Evolution-Uu) mode, which is used to connect UE to eNB (Evolved Node B).

With the development of the automatic driving vehicle, the developing automobile is expected to completely change the transportation and support a safer, faster and more entertaining intelligent object, not just a mobile unit. It is well recognized that the travel-related data is an important and valuable source for research and industry [6]. V2X technologies should be enhanced to enable these service attributes. To meet these demands, V2X network not only serves as a bit pipe that is used to exchange messages, but also execute data processing task. With the development of edge computing, computing nodes, such as MECNs (Multi-access Edge Computing Nodes) and FCNs are introduced to establish an open cloud environment in a close proximity to the RAN (Radio Access Network) accessible by third parties in an effort to overcome the shortcomings of centralized cloud computing in terms of latency and throughput.

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By offering data intensive tasks, critical communication services, e.g., road safety, and content via the MEC (Multi-access Edge Computing) platform in close proximity to the vehicles and end users, mobile operators can meet stringent performance demands and reduce congestion probability [7]. Moreover, MEC could provide new services and business model [8]. However, the high mobility of vehicles, which connect with eNB MEC, should lead to topology change and service migration.

On the other hand, FCNs is defined as physical devices with processing and sensing capabilities. No hard rule dictates that FCNs should be bound to eNB, which illustrate more optional possibilities.

As a key component of VANETs (vehicular ad-hoc networks), RSU (Roadside Unit) is a computing device located on the roadside and provides connectivity support for passing vehicles. The main function of RSU is transmitting data between vehicles and transport infrastructure. LTE-V2X RSUs are equipped with both PC5 and Uu interfaces, and provide the ability of preliminarily analyzing and data processing. With the concept of vehicle fog computing being put forward [9], RSUs are considered as an optional equipment for fog computing node, and could upload output data to cloud platform via Uu interface. Hence, the user plane may be sink to RSUs, which not only facilitate communication, but also fulfill computing task and allocate communication resources [10], [11]. Then network coverage ratio could be improved and communication delay among vehicles could be reduced.

Due to the mobility of users, the lower the user plane, the greater the probability of switching. Then the mobility of vehicles chould greatly influence the performance of RSU based applications. RSUs, which are installed along road, not only act as generation and relay nodes of BSM, but also provide data processing service. However, RSUs are fixed nodes, and their relative speed to road vehicle are relatively high. As a result, corresponding Doppler shift [3] shall influence communication performance. Moreover, the higher the vehicle speed is, the higher the service migration rate. Hence, we believe that employing a mobile sink node chould benefit to improve the performance of FCNs base applications.

As the traditional transit mode, public bus route covers most areas throughout cities [12]. In China, the distribution density of bus is very high. Generally, there are two or three buses in a road section. That is said, if bus is employed as sink node, road vehicles may find two or three mobile sink nodes at the same time. Meanwhile, due to its high stability, strong processing ability, and uniform distribution feature, bus sink node is appropriate to act as a coordinator, which is in charge of communication resource allocation. Furthermore, a mobile fog-computing node is ideal to decrease computing migration frequency.

Therefore, in this paper, a bus oriented V2X infrastructure, is proposed. Specifically, our research contributions are as follows:

- According to the bus network, a mobile FCNs infrastructure is defined;
- A bus oriented clustering method is proposed for regional vehicle grouping;
- An intra-cluster resource allocation mechanism is presented to enhance vehicle message dissemination performance.

The rest of this paper is organized as follows. Section II presents the related work, while proposed mobile sink node infrastructure is given in Section III. In section IV, a mobility similarity based CH (Cluster Header) selection method is proposed, and the corresponding clustering algorithm is explained in detail. The intra-cluster message dissemination mechanism is presented in Section V. Then the simulation results are analyzed in Section VI, while conclusion is given in Section VII.

II. RELATED WORK

In [13], the main V2X use case categories are discussed, while the architecture of 5G V2X radio access network is presented. The analysis results show that the performance of autonomous driving relies heavily on the communication system performance. To meet the requirements of corresponding use cases, such as low latency, high reliability, and scalability, existing V2X technologies should be extended. Reference [14] focuses on ADAS (Advanced Driver Assistance System) system design. The authors believe that communication control efficiency and local processing capacity should deadly influence marketing progress of autonomous vehicles. In the past few years, researchers have devoted themselves to both above two areas to promote evolution of autonomous technologies.

In terms of local processing capacity, the presence of ‘‘Edge devices’’ provides an approach to reduce the latency in dealing with the requests, and allows for real-time processing request set. The edge layer can be divided into three categories, MEC, FC (Fog Computing) and CC (Cloudlet Computing) [15]. The researchers believe that transfer cloud computation load to edge devices should benefit in response speed improvement. Then several standard organizations, such as 3GPP, ETSI (European Telecommunications Standards Institute) ITS (Intelligent Transportation System), US SAE (Society of Automotive Engineers), and IEEE (Institute of Electrical and Electronics Engineers), devote to specification definition on V2X services. For public safety purposes, 3GPP has designated direct communication between UE, which can also realize vehicle-to-vehicle communication [7].

3GPP has specified a MEC based architecture to support local MBMS (Multimedia Broadcast Multicast Service) for mission critical communications. ETSI MEC introduces an open cloud environment in a close proximity to the RAN accessible by third parties in an effort to overcome the shortcomings of centralized cloud computing in terms of latency and throughput [7].

However, the use of MEC platform for vehicular communications may bring some challenges in terms of service continuity due to frequent service migration, and alternations in radio and traffic load. For assuring service continuity, orchestrating MEC services across a set of platforms is a significant aspect for assuring efficient network resource utilization and performance guarantees [16]. Unfortunately, both ETSI and 3GPP do not present authoritative MEC architecture. ETSI MEC focuses on internal structure of MEC and does not consider network coordination, while 3GPP concerns about the flexibility of user level selection and task division; both of them are related to the application demands.

On the other hand, Fog Computing presents a computing layer leveraging devices like M2M (Machine-to-Machine) gateways and wireless routers [17]. The FCNs are used to compute and store data from end devices locally before forwarding to the Cloud [15].

Fog nodes are distributed fog computing entities enabling the deployment of fog services, and formed by at least one or more physical devices with processing and sensing capabilities (e.g., computer, mobile phone, smart edge device, car, temperature sensors, etc.) All physical devices of a fog node are connected by different network technologies (wired and wireless) and aggregated and abstracted to be viewed as one single logical entity, that is the fog node, able to seamlessly execute distributed services, as it were on a single device [18].

Compared with MECNs, FCNs perform a better flexibility character. To get rid of eNB, all physical devices, such as RSU, OBU (On-Board-Unit), can be employed to implement computing and aggregating task. Moreover, FCNs also could be considered as sink node and access gateway; then should fulfill communication resource allocation, and improve V2X communication performance of local area.

From the aspect of communication control, researchers focus on control mechanism optimization. Cluster header, which serves as a point coordinator, is considered as the key point to ensure reliability and efficiency of intra-vehicle message exchange [19]. In fact, an appropriate cluster header is useful to maintain cluster's stability. In [20], a physical and mobility-based cluster header selection mechanism is introduced to improve the stability of clusters. Reference [21] proposes a dynamic CH selection algorithm, which is adaptable to drivers' behavior and presents a learning mechanism to predict the future speed and position of all CMs (cluster members). Combining geographic locations and movement trajectories, [22] presents an adaptive clustering method for mobile wireless networks, the clusters are independently controlled, and are dynamically reconfigured as the nodes move. Reference [6] apply the popular DBSCAN algorithm to get clusters since the algorithm can identify clusters with different density and shape. In our previous work [23], a large-vehicle-first clustering method, in which cluster header is selected according to the load of road vehicles, is proposed to ensure the transmission performance of BSM generated by high risky level vehicle. Public bus is the most common large vehicle in urban area. According to the idea of [20] and [23], we believe that a bus first header selection method is useful to improve road safety level, while the mobility factor should be considered in header competition procedure.

From the view of resource allocation, [24] presents a RSU centric resource allocation protocol to minimize allocation time management overhead. An RSU allocates the limited bandwidth of this region to prefixed overlapping spatial clusters, and the channel allocated to each cluster is divided into time slots. A time slot is allotted to a vehicle in accordance to the priority of the request and availability of the channel. In [25], beacon message is used to realize adaptive TDMA (Time Division Multiple Access) slot allocation and vehicles with similar velocity could acquire near slots. Then speed similarity should be considered in timeslot allocation. Moreover, [26] presents a hybrid TDMA/CSMA (Carrier Sense Multiple Access) multichannel MAC (Media Access Control) protocol for VANETs that allows efficient broadcasting of messages and increases throughput on the control channel. Based on all above three methods, in this paper, a TDMA/CSMA MAC protocol, in which public bus serves as coordinator and is in charge of timeslot allocation, is proposed. Mobile similarity is used to select cluster header and prioritize transmission orders of cluster members.

Then the question is, who should serve as FCNs, which implement both computing and communication control tasks. RSU, which is used as a sink node for passing vehicles, may be a possible candidate. However, as fixed position equipment, RSU FCNs also faces the difficulty of frequent service migration. Moreover, in [3], path loss feature of V2I communication is discussed. Simulation results show that compared with V2V, V2I manner should endure relatively high path loss.

In 2013, Dr. Song presented a bus-based cluster routing mechanism, and believed that city public bus should be selected as cluster header to coordinate regional V2V timeslot allocation [27]. For its mobility feature, bus node could alleviate all mobile related problems, such as service migration and path loss. Hence, we believe that bus oriented FCNs are useful to improve system performance of V2X system.

III. SYSTEM MODEL

In this section, proposed mobile FCNs infrastructure is described in detail. As mentioned earlier, proposed infrastructure is constructed based on public bus, which are considered as the sink node and should perform computation task. Hence, firstly, bus coverage feature of China is analysis to prove the rationality of proposed bus-based network. Then, the detail of proposed infrastructure is given. At last, corresponding message dissemination procedure is presented.

A. BUS COVERAGE FEATURE IN CHINA

In China, distribution density of bus is relatively higher than that of United States. Based on the city bus database, which provided by Hengtong Company, Chongqing, we get the city bus distribution state of three bus lines of different time interval. Corresponding bus distribution is given in Fig.1.

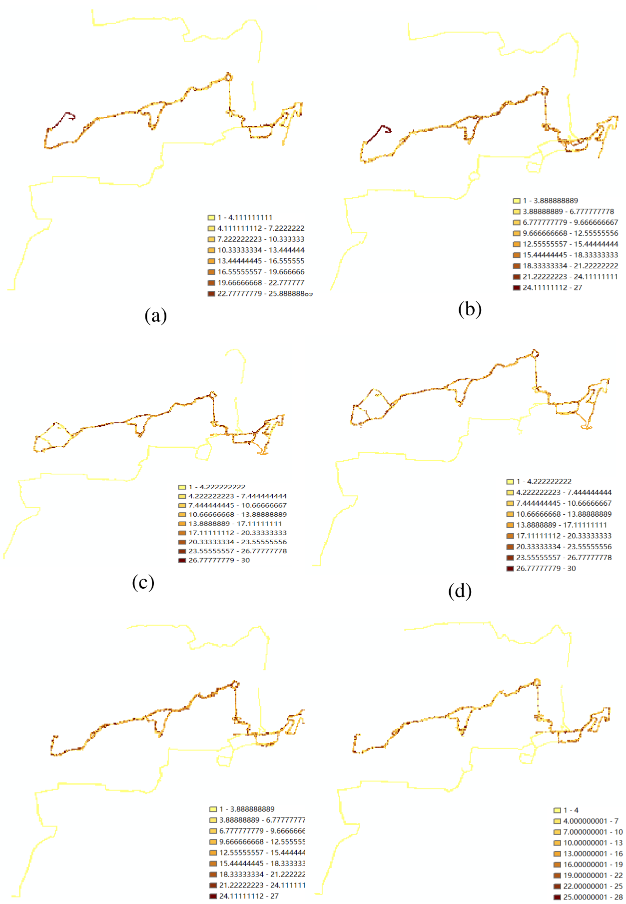


FIGURE 1. **The bus distribution states of Chongqing City. (a) 7:00-8:00. (b) 8:00-9:00. (c) 12:00-13:00. (d) 13:00-14:00. (e) 17:00-18:00. (f) 18:00-19:00.**

As shown in Fig.1, the bus density of all three bus lines is about 3-30 per kilometer length. Moreover, the density of peak time is relatively higher than the density of off-peak time. It is approximately uniform distributed. That is said, most of road vehicles could connect with a bus sink node. Hence, we can infer that a bus-based network could cover most city area.

B. MOBILE FCNs INFRASTRUCTURE

In DSRC (Dedicated Short Range Communications) manner, OBUs (On-Board-Units) are not equipped with mobile network interface. Therefore, RSUs not only act as relay nodes of inter-vehicle communication, but also serve as an interface between public mobile network and special vehicles. On the other hand, LTE-V2X OBUs are equipped with both PC5 and Uu interfaces, and have the ability of preliminarily analyzing and data processing. With the concept of vehicular fog computing being put forward [9], OBUs are considered as optional equipment of fog computing node, and could upload output data to cloud platform via Uu interface.

As we mentioned before, a bus-based network could cover most of city area. Moreover, as important public facilities, city bus is managed by official government, and could be equipped with special OBUs, which provide more powerful computation capacity and communication management capability [28]. Therefore it is feasible to use public bus as mobile FCNs to construct a V2X network. Public bus is selected as cluster header and acts as mobile FCNs to implement both local computing and communication resource allocating tasks.

Proposed mobile FCNs infrastructure is given in Fig.2.

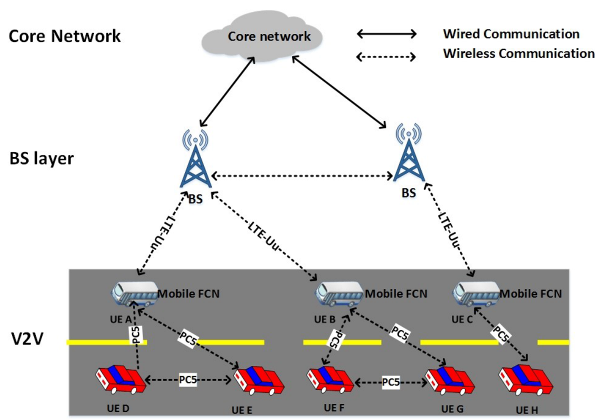


FIGURE 2. **System mode for mobile FCNs infrastructure.**

As shown in Fig.2, proposed architecture consists of multiple mobile FCNs (bus nodes). They connect to vehicle UE on the one side and to the core network on the other side. The FCNs are equipped with both PC5 and Uu interface and provide both V2V capabilities and routing functionalities.

The bus based FCNs provide functionalities of local cloud supporting smart routing and offloading. It enables communications between vehicles by coordinating communication resource. Such deployment architecture allows faster deployment, flexible adjustment and network coverage extension [8]. In FCNs, a fog node would not be a specific device, or a set of specific devices, but rather a logical concept, with heterogeneous type of devices as its physical infrastructure. And the compute and storage capacity in edge devices should be presented in terms of virtual (abstracted) computing units [29].

Here the vehicles are considered as end devices. In general, the request and service obtain procedure are divided into two parts, the one is PC5 based service, while the other is Uu based service. The Uu based service is provided by MEC based platform. Hence here we only consider PC5 based one. The detail of process is given as follows:

Step 1: Vehicle client send a join request message to one of FCNs via PC5 interface.

Step 2: FCNs receive the request message and allocate resource to vehicle clients.

Step 3: Vehicle clients send BSM to FCNs via PC5 interface.

Step 4: FCNs analysis BSMs of surrounding vehicles and feedback risky message to vehicle clients to provide

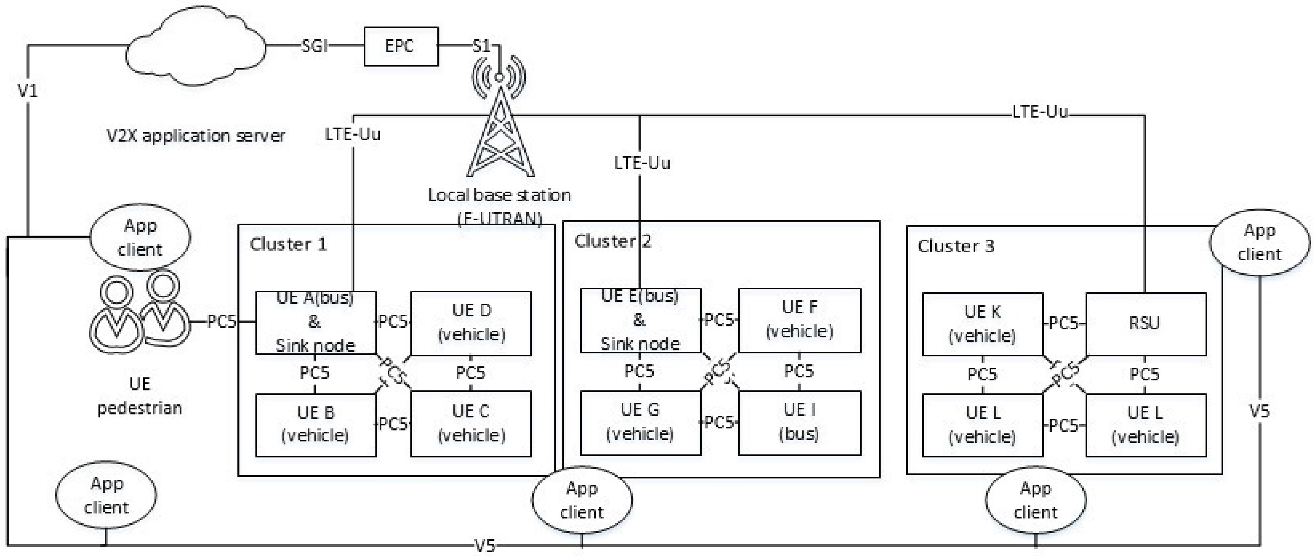


FIGURE 3. **Bus oriented mobile FCNs infrastructure.**

information for autonomous control. Meanwhile, FCNs upload the regional risky information to cloud server to support navigation service.

C. VEHICULAR MESSAGE DISSEMINATION

From the view of autonomous driving, the decision-making system concerns about the status of vehicles nearby. Hence, researchers propose the method, which divides road vehicles into several clusters according to the position relationship of vehicles. Then the cluster oriented communication mechanism is proposed for intra-cluster information exchange.

For proposed FCNs architecture, three cases should be considered in the process of cluster header selection. The coverage range of a cluster is assumed as a 200m-length road section.

Case 1: The target 200m-length road has no bus. In this case, the bus sink node is un-available; then vehicles will be set as free nodes and employ CSMA/CA (Carrier Sense Multiple Access With Collision Avoidance) mechanism to broadcast BSM. In this case, RSUs are served as FCNs.

Case 2: The target 200m-length road has one bus. In this case, the bus should act as FCNs, which is in charge of resource allocation and computation.

Case 3: The target 200m-length road has more than one bus. In this case, one of these buses should be selected as FCNs.

All above three cases are illustrated in Fig.3.

Note: SGI (Serving Gateway Interface): The main function of the Serving Gateway is routing and forwarding user data packets. It is also responsible for inter-eNB handovers in the U-plane and provides mobility between LTE and other types of networks, such as between 2G/3G and P-GW. The DL data from the UEs in idle state is terminated at the SGW, and arrival of DL data triggers paging for the UE. The SGW keeps context information such as parameters of the IP bearer and routing information, and stores the UE contexts when paging happens. It is also responsible for replicating user traffic for lawful interception [30].

EPC (Evolved Packet Core): A framework for providing converged voice and data on a 4G Long-Term Evolution (LTE) network. 2G and 3G network architectures process and switch voice and data through two separate sub-domains: circuit-switched (CS) for voice and packet-switched (PS) for data [31].

LTE-Uu: UE connects to the main interface of E-UTRAN (Evolved Universal Terrestrial Radio Access Network) [32] including physical layer, PDCP (Packet Data Convergence Protocol) and Nas (Non-access Stratum) [33].

S1: The communication interface between LTE eNodeB (base station) and EPC (packet core network). S1 divides LTE system into wireless access network and core network.

V1: The communication interface between V2X services and V2X application servers.

V5: The communication interface between V2X servers.

As shown in Fig.3, in cluster 1, there is only one bus node, UE A in the target 200m-length road. Then UE A acts as cluster header. Cluster 2 includes two bus nodes, which are UE E and UE I. Here a cluster header competition progress is needed. There is no bus node in cluster 3, and then RSU is considered as cluster header.

Here we only concern about the performance of vehicular message dissemination and service migration. Hence, only intra-cluster communication performance and service migration frequency are considered.

IV. MOBILITY SIMILARITY BASED CH SELECTION

In the proposed bus oriented mobile FCNs V2X infrastructure, BSM is exchanged among road vehicles via VANETs in a V2V mode. It is true that State Radio Regulatory Commission of the People's Republic of China (SRRC) release the frequency band of C-V2X in Oct. 2018. However, corresponding channel scheme is not given at the same time. Then, in this paper, we still employ the channel scheme of DSRC, which defines 1 CCH channel and 6 SCH channels. Actually, C-V2X definitely uses a signaling channel, whose function is as same as CCH, to exchange management message. Hence, we believe that proposed method could also apply to C-V2X module.

It is known that the link qualities of V2V communications are influenced by many factors, such as channel fading, packet collisions, shadowing, and Doppler shifts caused by the high mobility of vehicles, etc. As a result, V2V communication is typically unreliable. The key point, which we are interested in, is how to reduce the delay and enhance reliability in BSMs propagation.

In ad-hoc networks, only one node can occupy the shared channel and transmit signals simultaneously. With the increased number of vehicle nodes, potential collision probability grows fast, which lead to high transmission delay and low delivery successful ratio.

To ensure the real-time and reliability of BSM dissemination, in this paper, a bus coordination manner is considered, and a bus oriented clustering method, which employs city bus as cluster header as far as possible is proposed. Considering the stability of cluster, a CH selection method based on mobile similarity is proposed to improve regional communication performance.

A. MOBILE SIMILARITY

Mobile similarity between two vehicles should be defined according to three factors, namely direction similarity, speed similarity and acceleration similarity. Corresponding BSM message should include vehicle ID, vehicle speed and acceleration, cruise direction, as shown in (1).

$$BSM_{vehicle} = \{ID, Loc, Dir, Time, d\} \tag{1}$$

where ID is the unique identifier of a vehicle. The vehicle location, cruising direction and BSM message generating time are expressed as Loc, Dir and Time respectively, while the transmission range of BSM is denoted as d.

According to the definition of SAE 2945, BSM message should be broadcasted every 100ms based on CSMA/CA mechanism. Here we assume that all vehicles in object area broadcast their state message firstly.

Assume there are two neighboring vehicle nodes, node i and node j, and they can communicate with each other directly. Real-time Cruise speeds are $speed_i(t)$ and $speed_j(t)$, and accelerations are $a_i(t)$ and $a_j(t)$ respectively.

Then direction similarity is denoted as

$$S_{dir}(i,j) = \begin{cases} 1 & i,j \textit{ in the same direction} \\ 0 & i,j \textit{ in different direction} \end{cases} \tag{2}$$

Speed similarity is denoted as

$$S_{speed}(i,j) = e^{-(|\Delta speed_{ij}(t)|)} \tag{3}$$

Acceleration similarity is denoted as

$$S_{acc}(i,j) = e^{-(|\Delta a_{ij}(t)|)} \tag{4}$$

Based on (2), (3),and (4), the mobile similarity factor is defined as

$$S_{mobile}(i, nei) = \frac{\sum_{j=1}^{N} s_{dir}(i,j) \times s_{speed}(i,j) \times s_{acc}(i,j)}{N} \tag{5}$$

The symbols used in the formula are explained in Table 1.

TABLE 1. Explanation of symbols.

Symbol	Explanation
i	Node i
j	Node j
N	The number of neighbors of node i
$\Delta Speed_{ij}$	The difference value of speed between node i and node j
Δa_{ij}	The difference value of acceleration between node i and node j
ΔS_{mobile}	The mobile similarity between object vehicle and neighbors

Note here, $S_{mobile} \in [0, 1]$. The higher the value, the more similar the object vehicle and its neighbors should be.

B. CH SELECTION RULE

After receiving the status information of surrounding vehicles, the buses calculate their own mobile similarity and broadcasts the calculated result message in CCH channel. Corresponding message is defined as

$$BSM_{bus} = \{ID, MobileS\} \tag{6}$$

where MobileS is the calculated mobile similarity factor. Here a CH selection procedure based on mobile similarity is designed for Case 3. The detail of proposed procedure is given in Algorithm 1, while related variables and functions are presented in Table 2.

As shown in algorithmic 1, firstly the mobile similarity between bus and other vehicles should be calculated according to (5). Then the bus node shall broadcast its mobile similarity value and save it to $V_{targetList}$. Comparing the mobile similarity factor of local bus with surrounding buses, the bus with largest mobile similarity should be selected as cluster header.

As shown in Table 2, firstly the mobile similarity between bus and other vehicles should be calculated according to (5). Then the bus node shall broadcast its mobile similarity value and save it to $S_{targetList}$. Comparing mobile similarity factor of local bus with surrounding bus, the bus with largest mobile similarity should be selected as cluster header.

Algorithm 1 CH Selection

Input:
Bus set B
Output:
Cluster header set ch
Main:
for B_{target} each in B **do**
$S_{mobile}(B_{target}, N_{target})$
broadcast its $S_{mobile}(B_{target}, N_{target})$ to nearby buses
receive $S_{mobileother}$
$S_{targetList}.pushback(S_{mobileother})$
$S_{mobilemax} \longleftarrow \max(S_{targetList})$
if $(S_{mobile}(B_{target}, N_{target}) < S_{mobilemax})$ **then**
$ClusterheaderFlag(B_{target}, false)$
else
$ClusterheaderFlag(B_{target}, true)$
end if
end for
ch <– Find()
Return ch

TABLE 2. Explanation for Algorithm 1 variables and functions.

Variable / Function	Explanation
N_{target}	The neighbor list of local bus node
B_{target}	The bus node being traversed in B
$S_{mobile}(B_{target}, N_{target})$	Compute the mobile similarity between bus and other vehicles using equation (5)
$S_{targetlist}$	The mobile similarity values of surrounding buses.
$S_{mobileother}$	The mobile similarity values of other buses within the transmission range of B_{target}
$S_{mobilemax}$	The maximum value in $S_{targetList}$
$max(X)$	Find the maximum mobile similarity value in list X
$ClusterheaderFlag(X, Y)$	Assign boolean variable Y to the cluster header flag of vehicle X
$Find()$	Find the nodes whose cluster header flag is true and return their ID set from the bus set B

C. CLUSTER JOINING RULE

As soon as a bus is selected as cluster header, it will broadcast its own status messages periodically through CCH. In general, each vehicle node selects one cluster to join according to the signal strength and residual energy of each cluster header. In this paper, to improve the stability of cluster, relative speed between target vehicle and the cluster header is considered in cluster joining procedure. Here three scenarios are discussed.

Scenario 1: Vehicles sense only 1 CH, join the cluster.

Scenario 2: Vehicle sense 2 or more CHs, and these headers cruise in the same direction. In this case only the closest 2 CHs will be considered. The relative speed and distance between the target vehicle and CH can be calculated, as

$$\Delta speed_{v,i}(t) = speed(v) - speed_{header}(i), \quad i = 1, 2 \quad (7)$$

$$\Delta D_{v,i}(t) = position_x(v) - position_{xheader}(i), \quad i = 1, 2 \quad (8)$$

The positive direction of coordinate x is cruise direction.

The vehicle will choose a cluster to join according to the following rules:

If $\Delta speed_{v,1}(t) > 0$, $\Delta speed_{v,2}(t) > 0$, choose the CH with $\Delta D_{v,i}(t) < 0$;

If $\Delta speed_{v,1}(t) < 0$, $\Delta speed_{v,2}(t) < 0$, choose the CH with $\Delta D_{v,i}(t) > 0$;

If $\Delta speed_{v,1}(t) > 0$ and $\Delta D_{v,1}(t) < 0$, $\Delta speed_{v,2}(t) < 0$ and $\Delta D_{v,2}(t) > 0$, choose the cluster header whose $|\Delta speed_{v,i}(t)|$ is higher;

If $\Delta speed_{v,1}(t) < 0$ and $\Delta D_{v,1}(t) < 0$, $\Delta speed_{v,2}(t) > 0$ and $\Delta D_{v,2}(t) > 0$, choose the cluster header whose $|\Delta speed_{v,i}(t)|$ is smaller;

Scenario 3: Vehicle senses 2 or more CHs, and these headers cruise in the opposite direction; only CHs cruise in the same direction will be considered and vehicle should join the same cruising direction cluster according to the rules in Scenario 1 or 2.

D. CLUSTER GENERATION AND UPDATE PROCEDURE

1) CLUSTER GENERATION

At the beginning of the system cycle, all vehicles in the VANET switch to default channel and monitor the environmental noise at the same time. Then they broadcast own attribute data message to the nearby vehicles according to CSMA/CA. After that, all buses will get the information about neighboring vehicles' attribute and meanwhile, and the mobility similarity values are calculated. Then CH selection procedure will be employed to decide the CH according to the CH selection rule mentioned before. As soon as a bus is selected as cluster header, a cluster is formed and selected CH will broadcast its own status messages periodically through CCH. Other vehicles (including buses who are not selected as CH) will choose the appropriate cluster to join following the rule mentioned above. Then cluster generation procedure is finished.

2) CLUSTER UPDATE

Due to the mobility of CH or cluster members, cluster structure will also change. The cluster update procedure is needed to maintain the stability of the cluster structure according to the changes in the topology. The node perceives the dynamic change of the cluster structure through periodic messages. For the three different types of vehicles in the road environment, namely CH, non-CH bus, and other vehicles, different updating procedure will be employed.

a: CH
if the distance between two CHs is less than one hop, a CH bus will receive a periodic CH BM from other CH, and CH selection procedure should be employed. CH with larger mobility similarity will be selected as new CH, and the one with smaller mobility similarity will be set as cluster member.

b: NON-CH
for a non-CH bus, or bus which newly enters the road environment, it will keep listening for a fixed time for the periodic BM to decide if there is an existing cluster nearby. If there are existing clusters, one appropriate CH will be chosen and join. If there is no cluster around, CH will be selected and a cluster generation procedure will be started.

c: OTHER VEHICLES
other vehicles should keep listening for the periodic BM to keep up with one appropriate cluster. If the other vehicles cannot find any cluster head node within a fixed time, it will be set as free node as in case 1.

V. INTRA-CLUSTER BSM DISSEMINATION

Instead of CSMA/CA mode, in this paper, a bus oriented point coordinate method is designed for transmission resource allocation and intra-cluster message dissemination. Here we only consider timeslot allocation, then a TDMA mode is employed.

A. INTRA-CLUSTER DISSEMINATION CYCLE

Once a cluster generated, CH should server as a point coordinator to realize timeslot allocation. The dissemination cycle is given in Fig.4.

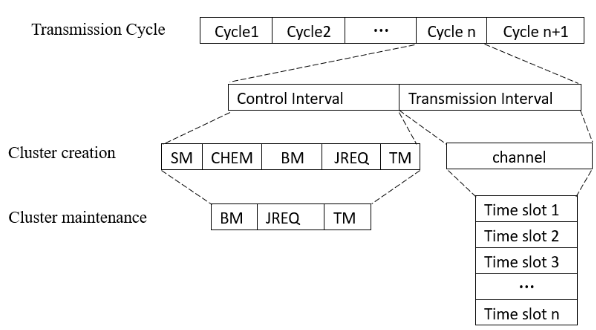


FIGURE 4. **BSM transmission cycle.**

As shown in Fig.4, CCH is used for cluster generation and maintenance, while SCH is allocated to CM to exchange BSM.

B. TIMESLOT ALLOCATION

In this paper, a mobile similarity based timeslot allocation method is proposed. The basic rules are as follows:

Algorithm 2 BSM Transmission Cycle

Input:
SlotTable
Main:
for t each in T **do**
    for m each in M **do**
        for i each in N_{List} **do**
            s <– find(i)
            if $s == m$ **then**
                i broadcast BSM
            else
                i listens to the channel and receives BSM from other cluster members.
            end if
        end for
    end for
    if no change in cluster structure **then**
        the time slot in *SlotTable* is added *one cycle time* based on original time slot.
    else
        reconstruct cluster
    end if
end for

- CH calculate the mobility similarity value of each cluster members according to (5), correspondingly, j represents other members in the cluster apart from CH.
- CH determines the sequence of channels allocations according to the mobile similarity value. The larger the value is, the higher the similarity with other members in the cluster is, the later the time slots will be allocated.

C. BSM DISSEMINATION

In the proposed mechanism, the transmission cycle in cluster is separated into 2 stages.

Stage 1 [CI (Control Interval)]: Cluster generation and update will be done in the beginning of CI. Then all member vehicles report the changes in speed and relative position to CH by RM (Request Message). CH recalculates the mobile similarity of all cluster members and allocates time slot according to mobile similarity factor. The higher the mobile similarity is, the lower the priority should be. Once CH finishes the timeslot allocation process, it should broadcast the timetable to all the cluster members by AM (ACK Message).

Stage 2 [TI (Transmission Interval)]: This is the BSM transmission stage and is based on time division. All the cluster members (including CH) transmit or receive BSM, according to the timetable broadcasted by CH in CI.

The detail of BSM dissemination process is given in Algorithm 2, and the explanation of symbols are presented in Table 3.

VI. SIMULATION AND EXPERIMENT RESULTS

In this paper, three simulation tools are employed to verify performance of proposed method. Firstly, MATLAB is

TABLE 3. Symbols explanation for Algorithm 2.

Variable / Function	Explanation
$SlotTable$	The slot allocation table broadcasted by CH in CI.
t	The current time.
T	The simulation time.
m	The current timeslot.
M	The total number of slots per second.
i	Cluster member i that belongs to N_{list}.
N_{list}	The cluster member table.
$find(X)$	Find the allocated timeslot of cluster member X from $SlotTable$.
$Bcbsm(X)$	The cluster member X in broadcast slot broadcast BSM.
$Rebsm(X)$	The cluster member X that are not in sending slot r eceives BSMs from the cluster.

used to simulate CDF (Cumulative Distribution Function) feature of SINR (Signal to Interference plus Noise Ratio) and throughput. Then an agent-based modeling simulation platform Anylogic is employed to analyze the CH selection procedure. At last, NS-3.24 simulator is employed to analyze the Sink node transfer rate and BSM dissemination procedure.

A. BASIC PERFORMANCE ANALYSIS

Here we are interested about whether proposed bus oriented architecture could bring benefit to both communication performance and service migration performance. To verify these two features, two kinds of simulations, which are communication oriented and sink node transfer rate oriented, are done in Matlab and NS-3.24 respectively.

1) COMMUNICATION ORIENTED ANALYSIS

Here we consider two parameters, namely SINR and throughput.

According to [34], path loss of V2I is denoted as

$$PL_{dB} = 100.7 + 23.5 \log_{10}(d) \quad (9)$$

while path loss of V2V is denoted as

$$PL_{dB} = 63.3 + 17.7 \log_{10}(d) \quad (10)$$

Based on (9) and (10), Matlab is employed to simulate SINR performance of both fixed RSU mode and proposed bus oriented mode. Here Gaussian function is called to calculated distance factor d. AWGN (Additive White Gaussian Noise) model is used to simulate signal environment. Moreover, LTE System Toolbox functions are called to generate a multi antenna downlink Reference Measurement Channel (RMC) R.12. The comparison of SINR and throughput between RSU mode and bus oriented mobile FCNs mode are given in Fig.5.

As shown in Fig.5, the bus oriented mobile FCNs mode performs better than RSU mode. Hence, we believe that mobile FCNs mode is useful to improve local communication performance.

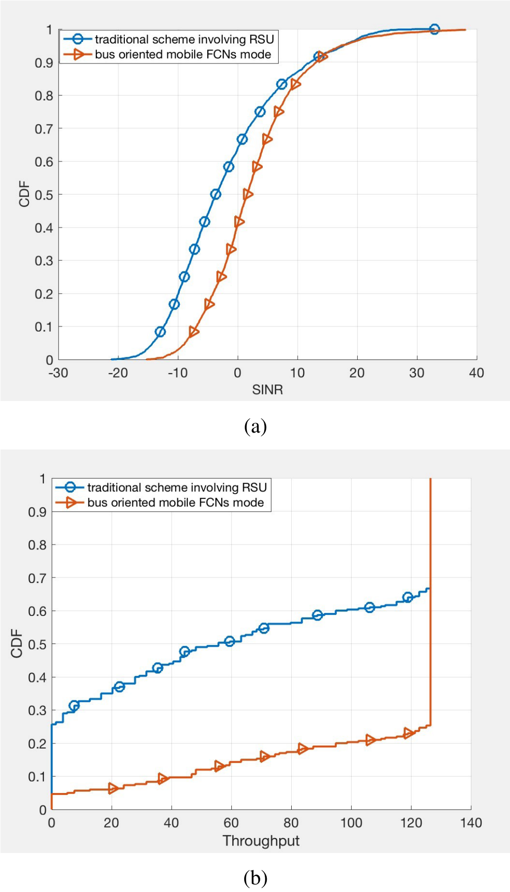


FIGURE 5. SINR and throughput between RSU mode and bus oriented mobile FCNs mode. (a) SINR. (b) Throughput.

2) SINK NODE TRANSFER RATE ANALYSIS

Sink node transfer rate greatly illustrate the frequency of service migration. Here mobile similarity parameter is used to denote the corresponding sink node transfer rate. The simulation is done based on NS3 simulator. The overall framework is built based on wave model, while road bus velocity is generated by Constant Velocity Mobility Model and acceleration factor of ordinary vehicles is determined by Constant Acceleration Mobility Model. Meanwhile, YansWifiChannelHelper is used to manage and create WiFi channel objects for the YANS (Yet Another Network Simulator) model (NS3 prototype).

Corresponding parameters are listed in Table 4.

- The bus speed is fixed at 30km/h, vehicle speed are greater than or equal to 30km/h, and different speeds correspond to different mobile similarity values.
- If vehicle node speed is 30km/h, which equals to the speed of bus node, the mobile similarity value equals to 1.
- The speed of RSU is considered as 0, and corresponding mobile similarity value equals to 0.

TABLE 4. Simulation setup.

Parameter	Values
Simulation time	1hour
Bus's speed	30km/h
Vehicle's speed	30-60km/h
Mobility similarity	0.0-1.0
Number of RSU/1km	5
Vehicle number	60

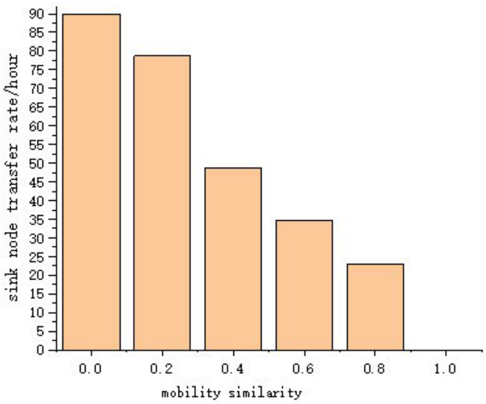


FIGURE 6. service migration.

Simulation result is shown in Fig.6.

As shown in Fig.6, the larger mobility similarity, the lower the service migration rate should be. Hence mobile FCNs could deadly decrease the sink node transfer rate, and in other words, could decrease the frequency of service migration. As the similarity value of vehicle increases, the sink node transfer rate decreases, and the service migration frequency decreases significantly. The smaller the frequency of service migration, the more stable the cluster. Hence, we believe that mobile FCNs mode is useful to maintain the stability of the cluster.

It is well known that service migration rate closely related to system computational burden. The more the migration rate is, the heavier the computational burden should be. Hence, a comparison is done to verify the validity of proposed method. The simulation is set as follows. A 100-meter-long road section is set an object area, while the vehicles number in corresponding area is change from 10 to 60. Simulation result is shown in Fig. 7.

As shown in Fig.7, the service migration rate of proposed mobile FCNs mode is lower than the fixed RSU mode, which illustrates a lower computational burden.

B. CH SELECTION SIMULATION

Here we employ Anylogic platform, an agent-based model, to simulate the CH selecting progress. The sequence flow of the model is shown in Fig. 8.

As shown in Fig.8, two agents are defined. The one is the main agent, while the other is vehicle-generating agent, which is used to generate normal vehicle and bus respectively.

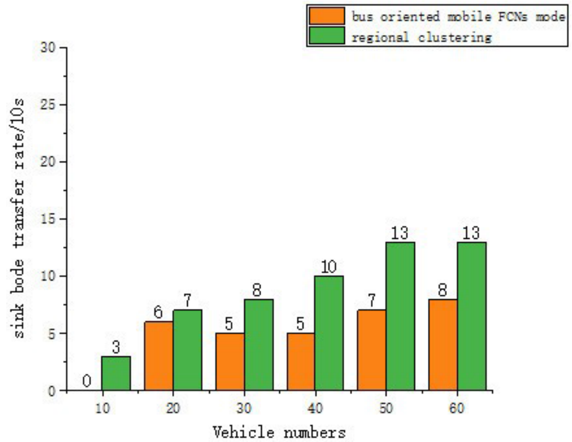


FIGURE 7. service migration.

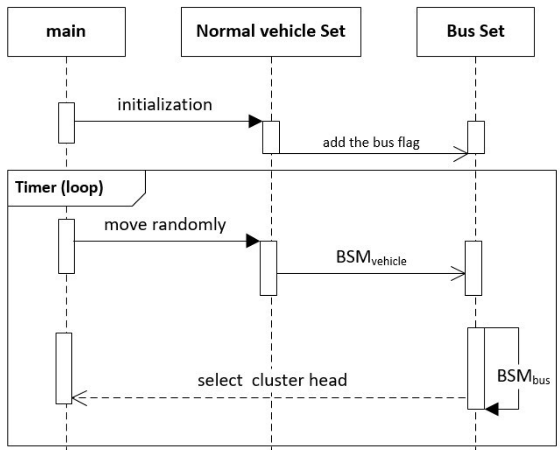


FIGURE 8. The sequence flow of the model.

Firstly, the main agent starts initialization progress, which includes two processes. The one is bus set generation, while the other is vehicle set initialization. A timer is set in the main agent who in turn triggers vehicle agent functions every 5s [35]. When the functions are called, vehicle agent functions scan all vehicles to calculate the mobility similarity of buses. Then CH is selected according to the mobility similarity values of bus.

The initial set-up of simulation is as follows:

- A 1200-m road with four one-direction lanes is used to simulate the CH selection procedure.
- Random velocity of the vehicle in the range from 30km/h to 60km/h, random acceleration of the vehicle from 1km/h^2 to 5km/h^2.
- The CH selection procedure will follow the algorithm given in the part II.
- There are 10 vehicles and 2 bus in target road section.

Here two buses, namely bus1 and bus2, are placed into target road section. Moreover, we assume that all vehicles in target road section belong to the same cluster. The mobile similarity values of both bus1 and bus2 are given in Fig.9.

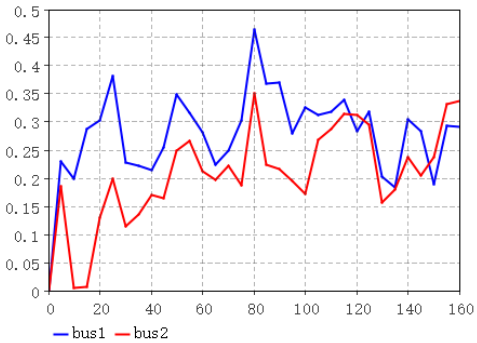
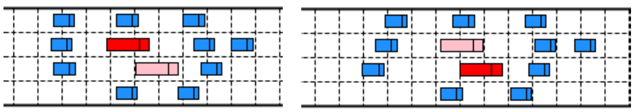


FIGURE 9. Mobile similarity values of bus1 and bus2.



(a) (b)

FIGURE 10. Vehicle distribution. (a) Snapshot of 40s. (b) Snapshot of 120s.

Here, two time spots, which are 40s and 120s, are considered. The point-in-time snapshots of road vehicles distribution are given in Fig.10.

As shown in Fig.9, at time point 40s, the mobility similarity value of bus1 is higher than that of bus2. Then, as shown in Fig.10 (a), bus1 is selected as cluster header. On the other hand, at time point 120s, the mobility similarity value of bus1 is lower than that of bus2. Then, as shown in Fig.10 (b), bus2 is selected as cluster header.

C. BSM DISSEMINATION SIMULATION

The message dissemination process is set based on IEEE 802.11p and IEEE 1609.4 protocols, while a broadcast manner without re-transmission is used. The WaveNetDevice module and ChannelScheduler module of NS3 are called to generate communication nodes. Simulation parameters are listed in Table 5.

- The vehicle velocity is between 30 km/h to 60km/h and the vehicle acceleration is set to 10% of velocity.
- Each service channel is divided into 15 time slices for BSM transmission.
- Three scenarios, which correspond low (0 bus in cluster), medium (1-2 bus in cluster), and high (3-5 buses in cluster) bus density, are selected.

TABLE 5. Simulation setup.

Parameter	Values
Simulation time	10s
Number of Bus/1km	5
Number of vehicles/1km	10-60
Vehicle's speed	30-60km/h
Transmission range	100m
Packet size	200bytes

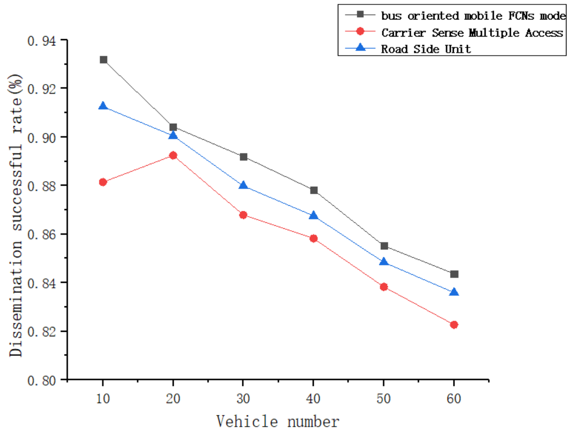


FIGURE 11. Dissemination successful rate.

To simplify the simulation procedure, here we only consider a 2 lane road, on which all vehicles cruise in the same direction. The distribution of road bus is approximately normal distribution. After the initial creation of the cluster, the CH periodically broadcasts its own information, and the cluster updates the CH according to the cluster head selection method. Then ordinary vehicles join the cluster according to the clustering rule.

All vehicles transmit BSM over a contention channel (CSMA) manner and RSU manner is employed as contrast. RSU is set every 100m along road.

The performance metrics to be observed in the simulations are as follows:

DSR (Dissemination Successful Rate): Number of packets received correctly from source vehicle V0 at the vehicle in ZOT (Zone of transmission), divided by the total number of data packets that the vehicle in ZOT should receive. DSR reflects how well an event is reported to involvers.

PDD (Packet Delivery Delay): Average time interval that a BSM is sent from the source vehicle V_0 to surrounding vehicles.

Here we only consider intra-cluster BSM dissemination. The simulation results are shown in Fig.11 and Fig.12.

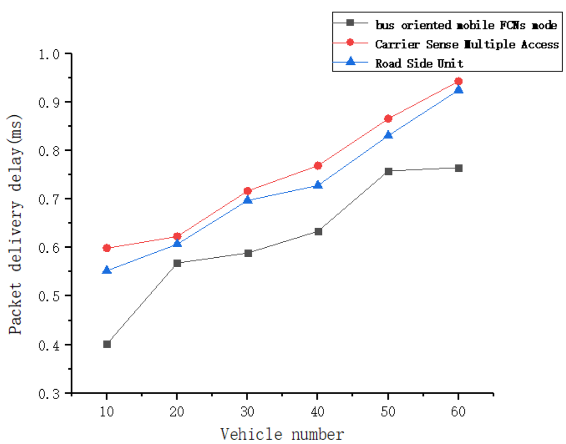


FIGURE 12. Packet delivery delay.

As shown in Fig.11 and Fig.12, with the growth of vehicle number on the one hand the dissemination successful rate in three ways all decreased and on the other hand their packet delivery delay all increased. But that is obvious no matter for dissemination successful rate or delivery delay proposed method perform better than both CSMA and RSU mode.

VII. CONCLUSION AND FUTURE WORK

The high cost of RSU installation and relatively bad V2I communication performance deadly influence the application process of V2X network. As an important public transport issue, city buses are widely distributed in city area, and could be easily turned into a mobile sink node, which could be used as a substitute of RSU. In this paper, the possibility of city bus centric network is discussed and bus oriented mobile FCNs V2X infrastructure is proposed. A bus oriented clustering method based on mobile similarity is proposed to improve regional communication performance. Then a contention free timeslot allocation mechanism is designed for intra-cluster message dissemination. The simulation results show that mobile FCNs could decrease the sink node transfer rate and service migration rate. Moreover, proposed mechanism could improve both DSR and PDD performance.

In our future work, the road vehicle density should be considered in clustering process, while the dynamic feature of cluster coverage should also be discussed. The vehicle's mobility model is critical and could affect the network and transmission. The vehicle movement trajectory data generated by the traffic simulator SUMO, or real traffic data, will be imported into the current simulation environment, making the simulation results more realistic and feasible.

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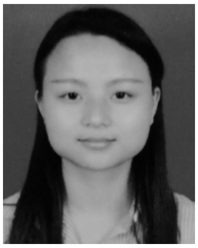

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