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The Vehicular Social Network (VSN)-Based Sharing of Downloaded Geo Data Using the Credit-Based Clustering Scheme

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ABSTRACT This paper proposed a clustering scheme named as the credit-based clustering (CBC) scheme for point of interests' (POIs') geo data sharing in vehicular social network (VSN). In the proposed CBC scheme, a number of vehicles that belong to the same VSN can form a cluster to download POIs' geo data when they are approaching to a new set of POIs. One vehicle is selected as the cluster head to download POIs' geo data using its cellular network and shares the downloaded POIs' geo data to its cluster members using IEEE 802.11p network. This paper 1) uses GPS to get vehicles' locations to calculate the timing of triggering the clustering process, 2) proposes a clustering method to organize a group of vehicles that belong to the same VSN and are proximate with each other for a while during their touring to become a cluster, and 3) deploys a credit scheme to evaluate the credit that the cluster head can get and each cluster member needs to pay to encourage all vehicles to share POIs' geo data. The simulation results show that the proposed scheme can achieve the goal of fairness, the higher successful ratio of the complete sharing of downloaded POIs' geo data and the better receiving efficiency.

INDEX TERMS Clustering, credit, proximity service (ProSe), vehicular social network (VSN).

I. INTRODUCTION

Proximity Service (ProSe) [1] tries to utilize direct communication, i.e., Device-to-Device (D2D)/Terminal-to-Terminal (T2T) communication techniques, to enable some new applications and services in the next generation wireless mobile network. Although current ProSe discussions are mainly D2D/T2T based, which are handheld-device-centric [2]–[5], the concept of ProSe can be applied to vehicles, i.e., the Vehicular Ad hoc Network (VANET), for which the corresponding proximity services are achieved through the vehicle-to-vehicle (V2V) communication technique. Thus, this work utilizes Vehicular Social Network (VSN) [6] to have ProSe in VANET, for which the illustrated application is to share geo data of Point of Interests (POIs) among vehicles that are proximate with each other.

VSN is a special kind of Mobile Social Networks (MSN) [7] that can connect nearby vehicles with the common interest to perform some social interactions, e.g., downloading and sharing some geo data of POIs. Two communication modes used in the considered VSN are (1) Vehicle-to-Vehicle (V2V) and (2) Vehicle-to-Infrastructure (V2I) communications, for which (1) V2V is based on the Dedicated Short Range Communication (DSRC) technique that adopts IEEE 802.11p and (2) V2I is based on cellular network. That is, each vehicle is equipped with an On-Board Unit (OBU) that has an IEEE 802.11p network's interface and a cellular network's interface. Additionally, each vehicle is equipped with the GPS to get its current location. Thereafter, vehicles in a VSN can cooperate with each other to share with geo data for having Location-Based Service (LBS) [8]–[11].

An example of VSN's usage is as follows. Vehicles can download geo data of Point-Of-Interest (POI) such as restaurants, historical site, national parks, etc., according to vehicles' current locations and destinations during their journey. Referring to Figure 1 (a), if proximate vehicles would like to download the same data and all of them download the same data individually around the same time, it would result in the bursty traffic in cellular network and each vehicle needs to

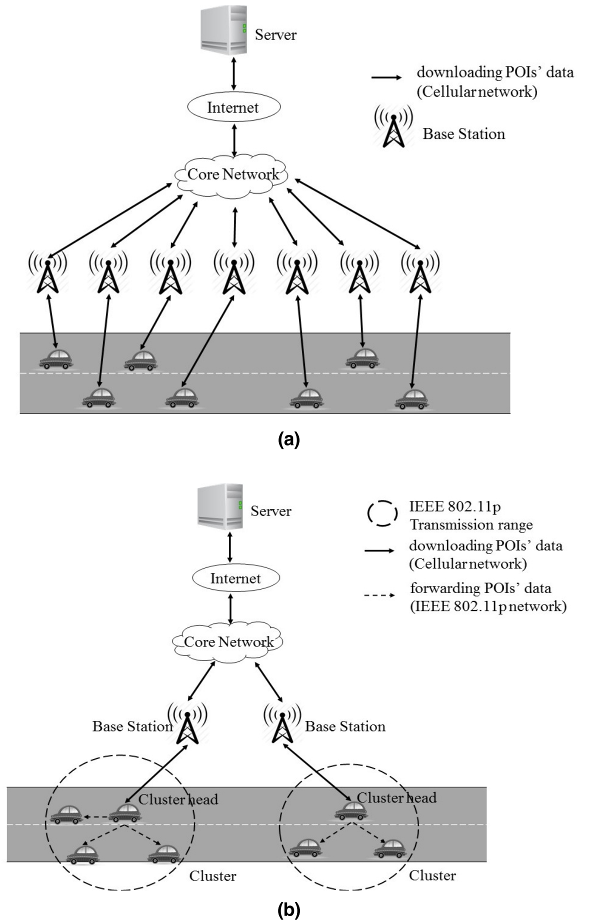

FIGURE 1. (a) The scenario of individual downloading. (b) The scenario of sharing the downloaded data.

pay the expense of using cellular network. Nearby vehicles can share the same interested geo data with each other using VSN. Referring to Figure 1 (b), let neighboring vehicles that belong to the same VSN organize a cluster. Then the cluster head can be in charge of downloading POIs' geo data using cellular network and then forwarding the downloaded POIs' data to other vehicles using IEEE 802.11p DSRC network. The aforementioned scenario in fact is just like data offloading through opportunistic mobile networks [12]. As a result, the network traffic and the expense of using cellular network is reduced to 1/n if the cluster contains n vehicles.

Most of the current research of VSN applications concentrates on cluster maintenance, i.e., it tries to prolong the lifetime of a cluster to keep a stable topology [13]–[15]. However, these works seldomly considered the fairness/incentive issue. In the aforementioned scenario, the cluster head consumes his subscribed cellular network resource and spends his own money, while cluster members do not consume their subscribed cellular network resource and expense because they get data from the cluster head through IEEE 802.11p DSRC network. To tackle the fairness issue for data sharing, this work proposed a Credit-Based Clustering (CBC) scheme for data sharing in VSN, e.g., POIs' geo data sharing in VSN. In the proposed CBC scheme, proximate vehicles that belong to the same VSN can form a cluster to share downloaded POIs' geo data. Cluster members pay the credit to the cluster head as return of receiving POIs' geo data from the cluster head. Thus, ''credit'' is also used as one of the parameters to select which vehicle to be the cluster head in the proposed CBC scheme.

Three main issues that need to be tackled in the proposed CBC scheme are as follows:

(1) When to trigger POIs' geo data downloading? POIs' geo data downloading can be triggered when it is necessary. For example, a vehicle is approaching a set of new POIs and it needs to pre-download or refresh its cached POIs' geo data before it moves into the coverage of these POIs. The timing of triggering the corresponding geo data downloading is dependent on vehicle's position, speed and the cellular network available bandwidth.

(2) When and how to form a cluster to share downloaded POIs' geo data? Depending on the cluster creating&join principle, the clustering process can be commenced.

(3) How to calculate credit? Since the cluster head spends its cellular network resource and expense to download POIs' geo data, cluster members need to pay some credits to the cluster head for the fairness/incentive concern.

This work proposes the CBC scheme to resolve the aforementioned three issues such that the proximate sharing of downloaded POIs' geo data using VSN can be effectively achieved.

The rest of this paper is organized as follows: Section II presents related works. Section III introduces the architecture and the configuration of the proposed method. Section IV presents the proposed CBC scheme in detail. Section V shows the performance analysis. Finally, the conclusion remarks and future work are given in Section VI.

II. RELATED WORK

This Section presents related works about (1) VSN, (2) Proximity Service, (3) Clustering and (4) the credit scheme for proximate sharing of downloaded POIs' geo data in the touring service.

A. VEHICULAR SOCIAL NETWORK (VSN)

Vehicular Social Network (VSN) is an opportunistic network formed by vehicles on the road. Three main components of a VSN are (1) participants, (2) mobile devices and (3) network infrastructure that are widely used in VSNs. In [6], Rahim *et al.* summarized the difference between MSN and VSN from the aspect of (1) participants, the participants in (i) MSN are mainly mobile devices held by people and (ii) VSN are mainly vehicles that are equipped with OBUs; (2) MSNs need to consider the energy problem, while vehicles can provide the power resource in VSN. The authors also discussed the architecture of VSN, which can be classified into the following three categories. (i) Centralized VSN: The vehicles in a centralized VSN need to connect to a centralized server, which manages vehicles' interactions in the VSN all the time, even when the two vehicles are physically close with each other. The communication among vehicles is Vehicular-to-Infrastructure (V2I)-based. (ii) Decentralized VSN: In the decentralized VSN, no centralized server exists and the communication between vehicles is opportunistic. That is, data are delivered only when the two peered vehicles encounter with each other opportunistically. The communications among vehicles are Vehicular-to-Vehicular (V2V)-based. (iii) Hybrid VSN: In the hybrid VSN, the communications among vehicles are based on both V2I and V2V communications.

In [9], Vegni and Loscrí studied VSN from the aspect of social, security and the applications in VSN. VSN combines the communication technology and the social information of vehicles, which can improve the packet forwarding mechanism's efficiency, to realize the collaborative content dissemination in the vehicles belonging to the same VSN. Roads are the most place for vehicles with common interests in VSN to have some social interactions. From the aspect of security, since plenty of messages are disseminated using V2V or V2I communication, how to have the data's authentication to avoid the malicious messages that may lead to the serious traffic accident should be tackled. From the aspect of applications, VSN applications are deeply associated with the social interactions. For example, vehicles can share the real-time trip information with other vehicles, which belong to the same community and have similar interests, through the help of VSN applications.

In [10], Ning *et al.* discussed some research challenges of VSN, such as (1) how messages are forwarded in VSN, (2) how to collect data or handle the context in VSN, (3) how to encourage vehicles involved in VSN to have sharing and (4) how to distinguish vehicles with different metrics in order to provide the corresponding data, e.g., traffic warning messages to the vehicles that are approaching to the road having accident or traffic jam.

In [11], Yang and Wang described the social connection in VSN when two vehicles encounter on the road. The life cycle of relationship in the social network consists of three stages, (1) a weak connection is created from the community, e.g., if the two vehicles encounter with each other and share the same interest, these two vehicles are likely to establish the virtual connection and become "friends" and then exchange messages, (2) a weak connection is developed and becomes strong, e.g., if the two vehicles with a weak connection encounter with each other and there are more chance for them to exchange the data frequently and thus have a stronger connection, (3) a strong connection remains while the weak connection is terminated, which happens when the two vehicles share the data continuously and both of them can benefit from the exchanged data.

B. CLUSTERING

The clustering scheme is a technique that divides vehicles with similar spatial relationship, e.g., similar relative velocity, the same moving direction and in the same road, into several groups to improve the routing, save the network resource and stability in VANETs [16]–[18]. In a cluster, there are at least one cluster head and multiple cluster members. Cluster head is the vehicle that deals with the data dissemination to its cluster members. Various metrics that can identify different clustering mechanisms are as follows. (1) Weighted network metric: during the cluster head election, each node needs to calculate whether it is qualified to become a cluster head or not. (2) Precedence: the node recommends itself to become cluster head at first. (3) Timers: if a node is in an un-clustered state for a period of time, i.e., it cannot find any cluster head presence until the time is expired. Then it claims itself as the cluster head [13].

In [16], Hadded *et al.* discussed the following properties, with which a stable cluster should satisfy: (1) cluster head should be close to the center of the cluster; (2) cluster head should have the similar speed with its cluster members; (3) the number of clusters should not be too big, that is, when a vehicle has the maximum number of neighboring vehicles, it should become a cluster head; (4) cluster head should have the same mobility direction with its cluster members; (5) cluster head should be in the same road with its cluster members. According to the aforementioned properties, the authors proposed an Adaptive Weighted Cluster Protocol (AWCP) that aims to have a stable cluster structure and prolong the lifetime of the cluster. AWCP uses GPS and a built-in road map to get road IDs. Besides, it takes vehicles' moving directions into account during the clustering process. After filtering out those vehicles with different traveling directions and different road IDs, a weight function is applied to select the cluster head. Three parts that the weight function contains are (1) the average-distance that is used to find which vehicle is close to the center of the cluster, (2) the average-speed that is used to find which vehicle has the most similar speed as the average speed among these proximate vehicles, and (3) the number of neighbors that represents the number of proximate vehicles.

In [17], Ren *et al.* proposed a mobility and stability-based cluster scheme to form a stable cluster with low overhead. The mobility evaluation considers vehicle's position, moving direction and velocity. The authors also defined the link lifetime estimation (LLT) to evaluate the connection time in to promise the cluster stability. Vehicles with the similar mobility pattern gains more chance to stay in the same cluster.

In [18], Chai *et al.* proposed a clustering algorithm based on the utility function, which consists of the history information and current states of vehicles for selecting a cluster head. The credit history function considers the average available bandwidth, queue length and the accumulated time that the vehicle acted as the cluster head in the past. The current state function takes node degree, velocity and distance into account. When it comes to the cluster formation process, the vehicle that has the largest utility function is selected as the cluster head.

C. THE INCENTIVE SCHEMES

An incentive scheme is used to motivate vehicles to share their resources and have cooperation for efficient data delivery. Nevertheless, there may be some selfish nodes that tend to be a free-rider in order to save their resources. The incentive scheme can motivate vehicles to share resource and avoid the existence of selfish nodes. Incentive schemes can be classified into credit-based ones and reputation-based ones. The credit-based scheme is the most straightforward method to encourage selfish nodes to cooperate in the network, e.g., the node can earn credit as the reward by successfully forwarding data; for those nodes that do not want to consume their network resources can get the data from other nodes by paying the credit as return. Credit here is like virtual currency. In the reputation-based method, a node's reputation is affected by its neighbors. For example, a node's reputation increases as the node behaves well; on the contrary, the selfish node gets punishment, i.e., its reputation decreases, and leads to being isolated by other neighbor nodes [19]–[21].

In [19], Wu *et al.* adopted a game theory model of the cluster-based incentive scheme. To promise the fairness among vehicles, a set of vehicles form a cluster and each vehicle takes turn to become the cluster head. The server encodes the shared content and updates the decoded key periodically. For those vehicles that have contribution in forwarding data, they get the decoded key until the server updates the key; for those vehicles that did not contribute, they will not get the decoded key until they become the cluster head for several periods.

In [20], Ning *et al.* proposed an incentive scheme that takes the social relationship of selfish mobile nodes into account. Each mobile node is divided into several communities according to their social relationships. That is, those nodes with the similar interest will belong to the same community. Different communities denote different interests. Then, the authors defined two kinds of credits, which are called social credit and non-social credit, that can be used to reward the mobile nodes transmitting data for others. When the mobile node sends data to the other nodes that belong to the same community, the sender node gets the social credit and the receiver node consumes its social credit. Non-social credit is used when the sender node is not in the same community of the receiver node. The proposed method used the available resource of each node as the metric to manage the credit distribution instead of applying a trusted service to handle the credit management.

In [21], Ning *et al.* defined two data dissemination models called (i) data pulling model and (ii) data pushing model. In the data pulling model, the receiver node needs to pay the delivery cost to the data provider node. In the data pushing model, the data provider node wants to disseminate their own customized data to other nodes who may want the data. Thus, the intermediate nodes who help forwarding data in the data pushing model can get the reasonable credit reward from the data provider node. It also proposed a "virtual check" in order to estimate how many credits the data provider node should pay and which intermediate nodes should be paid.

III. ARCHITECTURE AND THE FUNCTIONAL CONFIGURATION

Figure 2 depicts the architecture and the functional configuration of the proposed method. Each vehicle is equipped an OBU, which consists of an IEEE 802.11p network interface and a 3G/4G cellular network interface, and the GPS system, which can get vehicle's current location. Additionally, each vehicle periodically (1) transmits a HELLO message, which includes the current time and its vehicle ID, to its proximate vehicles and (2) reports its context, which includes (i) the current time, (ii) the current location, i.e., latitude and longitude, (iii) the current speed, (iv) the current direction and (v) IDs of proximate vehicles, i.e., those neighboring vehicles whose transmitted HELLO messages can be received, to the VSN server. The VSN server collects vehicles' reported contexts and manages the cluster creation/join/leave procedures for sharing the downloaded POIs' geo data, which are stored in the POIs' geo data server.

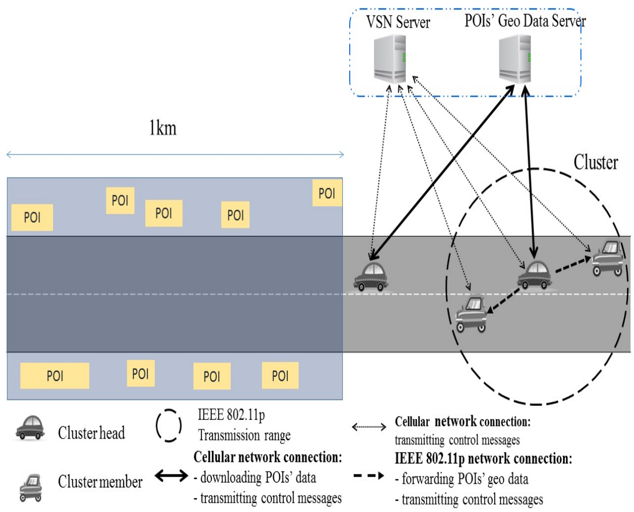

FIGURE 2. The abstract architecture and the functional configuration of the proposed method.

Referencing to Figure 2, the abstract functional scenario is as follows. Vehicles are moving from the right to the left of the road. To have extra time for viewing POIs' geo data, each vehicle can pre-download or refresh its' cached POIs' geo data before it drives into a set of the ahead POIs. Hence it needs to reserve enough time for downloading POIs' geo data through the cellular network before the vehicle enters into the ahead POI's coverage, i.e., it needs to calculate when and where the vehicle needs to start to download POIs' geo data based on vehicle's speed, location and 3G/4G's networking situation.

For convenient processing, the functional configuration is defined as follows.

(1) Since the geo coverage of each POI, e.g., natural view, heritage site, and a number of historical buildings, has its geo range, i.e., it is usually within a small area, it is assumed that POI's geo coverage is a rectangle along the road.

(2) Let POI's data contain some text and at most 5 pictures, for which the maximum size of each picture is 2MB.[1] So, the maximum data volume without considering the text content of one POI is 2MB*5pictures*8bits = 80Mbits.

(3) According to the report "Mobile Internet Speed Measurement", which is from Telecom Technology Center (TTC), Taiwan, the bandwidth of 3G while moving is 5.45∼6.88(Mbps) and the bandwidth of 4G while moving is 24.04∼31.89(Mbps). According to the Traffic Regulation of Taiwan, the speed of a vehicle should be less than 40km/hour, which is 11.11meters/second, in the urban area. Thus, it is assumed that the speed is less than 40km/hour for the sightseeing vehicles, including buses, sedans, tram, etc. Since the proposed CBC scheme aims to have a vehicle to download POIs' geo data before it enters into POIs' coverage, it considers the two worse cases for the vehicle to download a POI. (i) The cellular network only has the 3G signal and the bandwidth is 5.45 Mbps. Then corresponding vehicle will move at least (80Mb/5.45Mbps)*11.1meters/second = 162.94 meters when the POIs' geo data downloading is finished. (ii) The cellular network only has the 4G signal and the bandwidth is 24.04 Mbps. Then corresponding vehicle will move at least (80Mb/24.04Mbps)*11.1meters/second = 36.94 meters when the downloading is finished. Let the probability of vehicle's connecting to 3G and 4G be 50% and 50% respectively. A POIs' range should be at least (162.94 + 36.94)/2 = 99.79 meters. For calculation convenience, let each POI's range be 100 meters wide along the road.

(4) Since vehicles are moving along the road and the composed topology of vehicles is changed frequently considering different speeds of different vehicles, it is unnecessary caching too many POIs' geo data for one time. Hence, each vehicle is assumed to download POIs' geo data in the area that is in the next 1km, for which one POI's range is ≥100 meters according to the derivation of (3) and thus it has at most 1km/100m=10 POIs.

(5) When it is the time to refresh the cached POIs' geo data in vehicle X, X can have one of the following three choices: (i) X tries to find a cluster to get POIs' geo data. (ii) X creates a cluster and becomes the cluster head. X then sends the CLUSTER_HEAD_HELLO message to invite proximate vehicles, which also need to refresh their cached POIs' geo data, to join X's cluster. Then X downloads POIs' geo data using its cellular network and forwards the downloaded POIs' geo data to its cluster members using the IEEE 802.11p network. After forwarding, X can get credit for sharing its downloaded POIs' geo data with its cluster members and cluster members consume their credits for getting POIs' geo data. (iii) X downloads POIs' geo data to refresh its cached POIs' geo data using its own cellular network and neither shares its downloaded POIs' geo data with others nor gets POIs' geo data from other vehicles. That is, since X cannot find any proximate vehicle or none of its proximate vehicles is in the situation of refreshing their cached POIs' geo data, X does not earn or consume any credit.

[1]The authors' lab has developed a mobile digital culture heritage (M-DCH) exploring platform, which is called Demodulating and Encoding Heritage (DEH). The DEH platform (http://deh.csie.ncku.edu.tw) contains a website and several APPs in Google Play and APPLE Store. The aforementioned specification of a POI is the requirement in the DEH platform, which is for fast downloading of POIs during movement using the wireless mobile network.

IV. THE PROPOSED CBC SCHEME

This Section presents the functional scenario of the proposed CBC scheme and details of the proposed CBC scheme, including when a vehicle triggers POI's geo data downloading, when to do related actions of the clustering process and the credit scheme.

In the proposed CBC scheme, each vehicle joins the VSN and has been assigned a random credit value initially. Each vehicle X reports X's current context, including current timestamp, latitude and longitude, speed, moving direction, and the IDs of its proximate vehicles, i.e., those vehicles that X can receive their HELLO messages, to the VSN server periodically, e.g., every 10 seconds. When the VSN server receives a context report, it uses the timestamp of the report, the arrival time of the report, and the size of the report to estimate the available bandwidth between X and the server and then calculates whether it is the due time or not to trigger the clustering process, which includes (1) cluster's searching, (2) cluster's creation and (3) downloading & forwarding.

Referring to Figure 3, it shows the geo points of triggering the clustering process. Current Point (CPc) denotes the current position of a vehicle; Search Point (SPs) denotes the vehicle starts searching an existed cluster to join and tries to become a cluster member; Create Point (SPc) denotes the vehicle creates a cluster, becomes a cluster head and invites other nearby vehicles to join; Download Point (SPd) denotes the cluster head starts to download POIs' geo data and forwards POIs' geo data to its members.

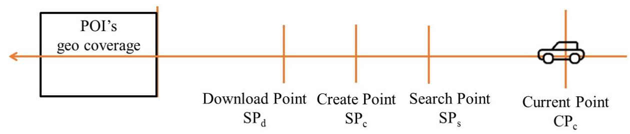

FIGURE 3. The geo points of triggering the clustering process.

After the cluster head starts to download and forward POIs' geo data, (i) the cluster head can disband the cluster when there is no cluster member, i.e., all of the cluster members have left; (ii) a cluster member can leave the cluster when it is going to be out of the transmission range of the cluster head, e.g., the cluster member and its cluster head are driving to different roads in the road intersection.

When the VSN server receives a context report from a vehicle, the VSN server calculates to see whether it is the due time or not to inform the vehicle, which does not belong to any cluster, to do the corresponding action, for which the vehicle either searches an existed nearby cluster to join or creates a cluster depending on the credit of the vehicle. If the vehicle has positive credit, which means that it has been the cluster head and shared its downloaded POIs' geo data to other members before, it has the privilege to search for a nearby cluster to join; however, when it cannot find a cluster to join, it itself still needs to create a cluster and then (i) invites other vehicles to join, (ii) download POIs' geo data using its subscribed 3G/4G cellular network and (iii) forward POIs' geo data to its cluster members. On the contrary, if the vehicle has negative credit, then it has the duty to create a cluster to be in charge of downloading POIs' geo data using its subscribed 3G/4G cellular network and then sharing the downloaded POIs' geo data with its cluster members for earning credit.

In the remaining part of this Section, details of the proposed CBC scheme are presented. Table 1 contains the terminologies that are used.

TABLE 1. The notations used for evaluating due time and downloading time.

Variable	Meaning
ST	How many GPS sampling times from vehicle's current location to the borderline of the ahead POI's geo coverage
D_c	Distance from the vehicle's current location to the borderline of the ahead POI's geo coverage
v	Vehicle's current velocity
T_s	How many seconds does a vehicle trigger GPS once to find its current location
k	Number of ahead POIs that need to be downloaded in the range of 1km
DT_{POI}	Downloading time of the ahead k POIs' geo data using 3G/4G cellular network
D_i	Downloaded geo data volume of the ahead POI$_i$, $i = 1 .. k$
B_{LTE}	LTE's available bandwidth

A. CLUSTERING

One of the goals of the proposed CBC scheme is to pre-download POI's geo data before vehicle X entering into the geo coverage of the ahead POIs. Since the speed of vehicle X and its 3G/4G cellular network's available bandwidth vary with the time, the VSN server can use the following formula to derive the due time for downloading the ahead POIs' geo data.

$$Sampling\ Times\ (ST) = \left\lceil \frac{\frac{D_c}{v}}{T_s} \right\rceil \quad (1)$$

$$Download\ Time\ of\ POIs'\ geo\ data\ DT_{POI} = \frac{\sum_{i=1}^{k} D_i}{B_{LTE}} \quad (2)$$

In formula (1), ST denotes how many GPS sampling times from vehicle's current location to the borderline of the ahead POI's coverage, where D_c denotes the distance from vehicle's current location to the borderline of the ahead POI's geo coverage, v denotes vehicle's current velocity and T_s denotes GPS's sampling period.

In formula (2), k denotes the number of ahead POIs that are in the range of 1km, DT_{POI} denotes the downloading time of the geo data of the ahead k POIs using 3G/4G cellular network, D_i denotes the downloaded geo data volume of the ahead POI$_i$, where $i = 1$ to k, B_{LTE} denotes available bandwidth of the cellular network.

After the VSN server calculating vehicle X's current ST, it knows whether the driving time length from X's current location to the borderline of the ahead POIs' coverage is enough to download the ahead POIs' geo data or not: if vehicle X's current $ST \times T_s \gg DT_{POI}$, it means that vehicle X is still far away from POIs' geo coverage; if $ST \times T_s \gg DT_{POI} \geq (ST-1) \times T_s$, then it means that if the downloading of the ahead POIs' geo data is started from the next GPS sampling time point, the time length is not enough to finish downloading before vehicle X entering into the ahead POIs' geo coverage based on vehicle X's currently attached 3G/4G cellular network's bandwidth and the vehicle's speed. Thus, the VSN server should inform vehicle X to start downloading right away.

B. THE TIME POINT FOR TRIGGERING THE CLUSTERING PROCEDURE

The next problem is (i) which vehicle should be the cluster head and which vehicles can be cluster members and (ii) when to trigger the clustering process. With the help of the ST depicted in Equation (1), it can clearly define when a vehicle should start downloading POIs' geo data. However, it needs to have some time to let other vehicles to join a cluster. Let a vehicle create a cluster one GPS sampling time period before its due time for triggering downloading POIs' geo data. When a vehicle's credit is positive, it means that it has been a cluster head before, thus, it has the privilege to be a member to get others' downloaded POIs' geo data unless it cannot find a nearby cluster head for a while. Let the waiting time for a vehicle, which has positive credit, to find a nearby cluster head be one GPS sampling time period before it is forced to be a cluster head, i.e., it cannot find any nearby cluster head during one GPS sampling time period and thus it itself creates a cluster. Let the due time for triggering the downloading of the ahead POIs' geo data be the last SP_d^{th} GPS sampling point before entering into the borderline of the ahead POIs' geo coverage, i.e., the vehicle will enter into the geo coverage of the ahead POIs after $SP_d \times T_s$ seconds if the speed remains the same. Let the due time of creating a cluster be the last SP_c^{th} GPS sampling point before entering into the borderline of the ahead POIs' geo coverage. Let the due time of searching a nearby cluster head be the last SP_s^{th} GPS sampling time point before entering into the borderline of the ahead POIs' coverage. Then, referencing to Figure 3, $SP_s = SP_d + 2$ and $SP_c = SP_d + 1$.

C. THE CLUSTERING PROCESS

Table 2 and Table 3 show the messages that are used in the clustering process, which includes (1) cluster's searching, (2) cluster's creation, (3) member join, (4) member leave, (5) downloading & forwarding and (6) cluster disband.

1) CLUSTER'S SEARCHING

To make sure that a vehicle can stay in the cluster before the cluster head finishing downloading and forwarding POIs' geo data, a vehicle M that wants to join an existed cluster C needs to evaluate the connected time between itself and the cluster head H at first. The connected time depends on

TABLE 2. Messages and parameters used in the clustering process.

Message	Parameters
HELLO	(current time stamp, ID of vehicle)
CLUSTER_HEAD_HELLO	(current time stamp, Cluster_ID, Cluster Head's location, Cluster Head's speed, estimated DT_{POI}, Cluster Head's Road_ID)
CLUSTER_CREATE	(Cluster_ID)
JOIN_REQUEST	(ID of vehicle, Cluster_ID)
JOIN_OK	(ID of vehicle, Cluster_ID)
JOIN_CONFIRM	(ID of vehicle, Cluster_ID)
DOWNLOAD_REQUEST	(Cluster_ID)
FINISH_INDICATION	(Cluster_ID)
FINISH_RESPONSE	(ID of vehicle, the volume of received POIs' geo data)
FINISH_COMPLETE	(Cluster_ID)
UPDATE_INDICATION	(ID of vehicle, Cluster_ID)
UPDATE_REQUEST	(ID of vehicle, Cluster_ID)
LEAVE_INDICATION	(Cluster_ID, ID of vehicle)
LEAVE_CONFIRM	(ID of vehicle, the volume of received POIs' geo data)
DISBAND_REQUEST	(Cluster_ID)
DISBAND_CONFIRM	(Cluster_ID)
TERMINATE_INDICATION	(Cluster_ID)
TERMINATE_RESPONSE	(ID of vehicle, the volume of received POIs' geo data)

Procedure 1 Cluster Search

while vehicle M does not reach the SPc point or receive any JOIN_OK message **do**
  if a CLUSTER_HEAD_HELLO (current time stamp, Cluster_ID, H's speed, H's location, estimated $DT_{POI}(H)$, H's Road_ID) message is received from cluster head H **then**
    if M's Road_ID == H's Road_ID && CT(H,M)≧DT_{POI} (H) **then**
      M sends the JOIN_REQUEST (M,H) message to H
    end if
  end if
end while
if a JOIN_OK (ID of M, Cluster_ID) message is received from cluster head H **then**
  call Procedure Member_Join and Member_Leave // to join the cluster for which the cluster head sends the first JOIN_OK message to M
else
  call Procedure Cluster_Create//M becomes the cluster head

both relative position and relative speed of M and H. Let CT (H,M) denote the connected time between cluster head H and vehicle M. Vehicle M sends the JOIN_REQUEST message to cluster head H if its connected time with H is equal to or greater than the time for downloading POIs' geo data, which means that the corresponding vehicle will not leave the cluster before downloading the ahead POIs' geo data is finished. The procedure of cluster's searching is as follows:

The explanation of the above procedure is as follows:

TABLE 3. Messages and their denoted events.

Message	Events
HELLO	Notify the existence of a vehicle to other proximate vehicles
CLUSTER_HEAD_HELLO	Cluster head invites other vehicles to join its cluster
CLUSTER_CREATE	The VSN server notifies the corresponding vehicle to be able to create a cluster
JOIN_REQUEST	Notify the cluster head that a vehicle wants to join the cluster
JOIN_OK	Notify the vehicle to be able to join the cluster
JOIN_CONFIRM	Notify the cluster head that the corresponding vehicle has joined its cluster
DOWNLOAD_REQUEST	Notify POIs' geo data server that the cluster head needs to download POIs' geo data
FINISH_INDICATION	Notify cluster members that the forwarding of POIs' geo data is finished
FINISH_RESPONSE	Report the volume of received POIs' geo data to the VSN server
FINISH_COMPLETE	Notify that the VSN server has updated the credits of cluster head and members
UPDATE_INDICATION	Notify cluster head to update its member list
UPDATE_REQUEST	Notify the VSN server to update the member list
LEAVE_INDICATION	Notify vehicles to leave the cluster
LEAVE_CONFIRM	Report the volume of received POIs' geo data to the VSN server
DISBAND_REQUEST	Notify the VSN server that the cluster can be disbanded
DISBAND_CONFIRM	Notify the cluster head that the VSN server has disbanded the cluster and updated the credit of cluster head and members
TERMINATE_INDICATIO N	Notify that POIs' geo data downloading and forwarding are stop
TERMINATE_RESPONSE	Report the volume of received POIs' geo data to the VSN server

When vehicle M receives a notification of starting to search a neighboring cluster to join from the VSN server, vehicle M listens to all CLUSTER_HEAD_HELLO messages broadcasted from its proximate cluster heads before receiving a JOIN_OK message.

When vehicle M receives a CLUSTER_HEAD_HELLO message sent from cluster head H, M checks whether H's Road ID is the same as M's Road ID or not; if it is, then M calculates the connected time between itself and cluster head H.

If $CT\ (H,M) \geq DT_{POI}(H)$, then, M sends a JOIN_REQUEST (M, H) message to cluster head H, and continues listening to CLUSTER_HEAD_HELLO messages sent from other cluster heads; if $CT\ (H,M) < DT_{POI}(H)$ then, M keeps listening to other CLUSTER_HEAD_HELLO messages sent from other cluster heads. Since it may have the racing situation, i.e., M sends the JOIN_REQUEST (M,H_1) message to H_1 earlier than M sends the JOIN_REQUEST (M,H_2) message to H_2, but M receives H2's reply message earlier than *H1*' reply message, or some cluster heads may reject

Procedure 2 Cluster_Create

```
X becomes cluster head after receiving a Cluster_Create (Cluster_ID) message
message sent from the VSN server
expireTime←currentTime+one GPS sample time period
repeat
    X broadcasts the CLUSTER_HEAD_HELLO
    (current time stamp, Cluster_ID, X's speed, X's location, estimated DT_POI(X), X's Road_ID)
    message to its proximate vehicles periodically
    case X receives vehicle Y's message of
    JOIN_REQUEST (ID of Y, Cluster_ID):
        send the JOIN_OK message to vehicle Y
    JOIN_CONFIRM (ID of Y, Cluster_ID):
        update X's member list and send an
        UPDATE_REQUEST (ID of Y, Cluster_ID)
        message to the VSN server
    end case
until expireTime // X reaches SP_d point
call Procedure Downloading_Forwarding and Disbanding
```

requests for some reasons, M still needs to keep listen to CLUSTER_HEAD_HELLO messages sent from other cluster heads and reply the JOIN_REQUEST *(M, H_i)* message to the corresponding cluster head H_i, $i = 3$ *or* 4 *or .. m*.

M stops listening to CLUSTER_HEAD_HELLO messages until (i) *M* receives a JOIN_OK (*M, Cluster_ID*) message or (ii) M reaches the SPc point. For (i), M sends a JOIN_CONFIRM (*M, Cluster_ID*) message to the corresponding cluster head H_i, $i = 3$ *or* 4 *or .. m*, from which M receives the first JOIN_OK (*M, Cluster_ID*) message; then M becomes a cluster member and waits for the forwarded POIs' geo data from the corresponding cluster. For (ii), *M* creates a cluster by itself.

2) CLUSTER'S CREATION

Cluster's creation begins when the VSN server finds that vehicle X reaches the SPc point and vehicle X does not belong to any cluster. The procedure of cluster creation is as follows:

The explanation of the above procedure is as follows:

The VSN server assigns a unique Cluster_ID for vehicle X and sends the CLUSTER_CREATE (Cluster_ID) message to vehicle X.

After vehicle X receiving the CLUSTER_CREATE (Cluster_ID) message, vehicle X can broadcast the CLUSTER_HEAD_HELLO message, which includes current time, Cluster_ID, X's speed, X's location, estimated "DTPOI" (X), and X's Road_ID, periodically, e.g., ever one second, to invite other vehicles to join the cluster before reaching the next GPS sampling time point, i.e., the SPd time point depicted in Figure 3.

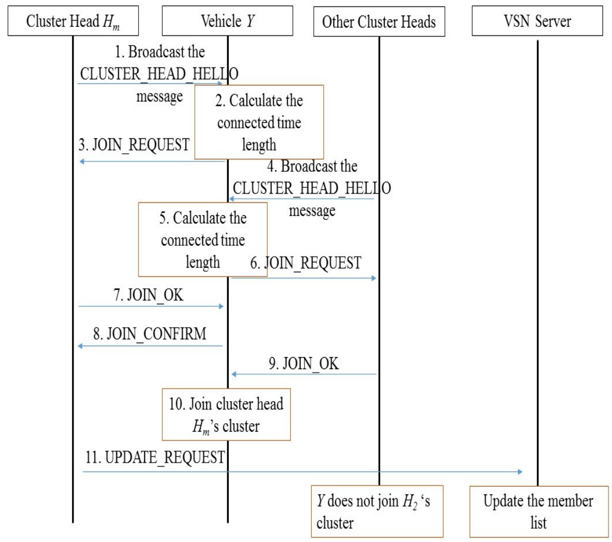

FIGURE 4. **The message flow diagram of member join.**

3) MEMBER JOIN

Since vehicle Y, which is searching for a nearby cluster to join, may send the JOIN_REQUEST message to more than one cluster head, when cluster head H does not receive the JOIN_CONFIRM message from vehicle Y after H sending the JOIN_OK message to Y for a while, it means that Y decides to join the other cluster and does not join H's cluster.

The procedure of member joining a cluster is as follows:

(1) Cluster heads H_i, *i=1..k*, broadcasts the CLUSTER_HEAD_HELLO message periodically, e.g., every one second, to their proximate vehicles during one GPS sampling time period.

(2) When cluster head H_i, *i=1..d,*receives the JOIN_REQUEST(*Y, H_i*) message from vehicle *Y*, it sends the JOIN_OK (*Y, Cluster_ID*) message to vehicle *Y*.

(3) If cluster head H_m, *m=1 or* 2 *or ... d,* receives the JOIN_CONFIRM (*Y, Cluster_ID*) message sent from vehicle *Y*, then cluster head H_m, *m=1 or* 2 *or ... m* includes vehicle *Y* as a member of its cluster and sends the UPDATE_REQUEST *(Y, Cluster_ID)* message to the VSN server.

If cluster head H_i, $i = 1 \ldots m-1$, m-2, .. d, reaches its next GPS sampling time point, i.e., the SP_d time point depicted in Figure 3, and still does not receive the JOIN_CONFIRM (*Y, Cluster_ID*) message sent from vehicle *Y*, it means that *Y* does not join H_i's cluster, $i = 1 \ldots m-1, m-2 \ldots d$. Figure 4 shows the message flow chart of member join.

4) MEMBER LEAVE

To avoid the situation that (1) cluster members and cluster head drive to different roads, e.g., cluster head or some cluster members drive to the other road in a road intersection, or (2) the connected time between cluster head and it cluster

Procedure 3 Member_Join and Member_Leave

1: vehicle V sends the JOIN_CONFIRM (ID of V, Cluster_ID) message to the corresponding cluster head H and join the cluster
2: **while** vehicle V is a cluster member of H **do**
3:     **if** V receives the LEAVE_INDICATION (Cluster_ID, ID of V) message from the VSN server **then**
4:         send a LEAVE_CONFIRM (ID of V, volume of received POIs' geo data) message to VSN server
5:         **EXIT**
6:     **else if** V receives a FINISH_INDICATION (Cluster_ID) message from cluster head **then**
7:         V sends the FINISH_RESPONSE (ID of V, volume of received POIs' geo data) message to the VSN server and cluster head H
8:         **EXIT**
9:     **end if**
10: **end while**

member is not enough due to the sudden speed up/down of vehicles, the VSN server periodically checks whether the topology of each cluster keeps the same or not. If any of the aforementioned situations happens, the VSN server informs cluster members to leave. The procedure of member's joining and member leave is as follows:

The explanation of the member join part is given previously; the explanation of the member leave part is as follows:

(1) While cluster member M reports its current context to the VSN server periodically, the VSN server checks whether the corresponding *CT* with M's current cluster head is enough or not and checks whether the current Road ID is still the same as that of the cluster head or not.
(2) (a) When the VSN server finds that M's current Road_ID is not the same as cluster head H's Road_ID, i.e., cluster member M or cluster head detours to the other road in a road intersection, the VSN server sends a LEAVE_INDICATION (*Cluster_ID, M*) message to cluster member M to notify M to leave the cluster. (b) When the VSN server finds that the corresponding *CT* is not enough, i.e., cluster head or M changes its speed too much, it sends a LEAVE_INDICATION (*Cluster_ID, M*) message to cluster member M to notify M to leave the cluster.
(3) Once cluster member M is informed to leave the cluster by the VSN server, M sends the LEAVE_CONFIRM (*Cluster_ID, volume of received POIs' geo data*) message, which contains the volume of received POIs' geo data to the VSN server.
(4) The VSN server sends the UPDATE_INDICATION (*M, Cluster_ID*) message to cluster head H to update its member list.

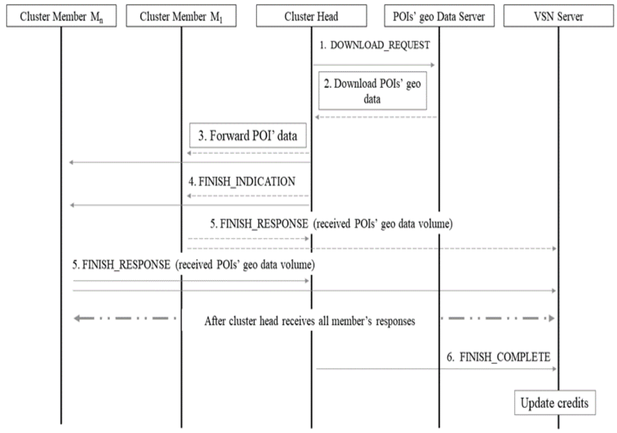

FIGURE 5. The message flow chart of downloading and forwarding POIs' geo data.

(5) Line 6 of Procedure 3 is for the processing of regular leave, i.e., cluster head H has finished downloading and forwarding and notified members to leave, which is explained in the following DOWNLOADING&FORWARDING part.

5) DOWNLOADING & FORWARDING

Cluster head H waits for a sampling period to let other vehicles join its cluster after cluster creation; then H starts to download POIs' geo data and forward POIs' geo data to its cluster members.

The procedure for POIs' geo data downloading and forwarding is as follows:

(1) Cluster head H sends the DOWNLOAD_REQUEST (*Cluster_ID*) message to the POIs' geo data server and then starts downloading the ahead POIs' geo data and forwarding the data to its cluster members at SP_d.
(2) When H finishes downloading and forwarding POIs' geo data to its cluster members, H sends the FINISH_INDICATION (*Cluster_ID*) message to cluster members.
(3) Once a cluster member receives the FINISH_INDICATION (*Cluster_ID*) message, the cluster member M_j, $j = 1 .. k$, sends back the FINISH_RESPONSE (*Cluster_ID*, M_j, *volume of received POIs' geo data*) message to cluster head H and the VSN server.
(4) After cluster head H receives the FINISH_RESPONSE (*Cluster_ID*, M_j, *volume of received POIs' geo data*) messages sent from all cluster members $M_j, j = 1 .. k$, H sends the FINISH_COMPLETE (*Cluster_ID*) message to the VSN server.
(5) After the VSN server receives the FINISH_COMPLETE (*Cluster_ID*) message, the VSN server calculates and updates the credit of cluster head and each of these cluster members.

Figure 5 depicts the message flow chart of POIs' geo data downloading and forwarding.

Procedure 4 Downloading_Forwarding and Disbanding

```
Cluster head H sends a DOWNLOAD_REQUEST (Cluster_ID) message to POIs' geo data server and start to download POIs' geo data
while H does not reach the exit borderline of the pre-downloaded area || does not finish downloading do
    if H has cluster members do
        H forwards POIs' geo data to each cluster member M_i, i = 1...n
        H sends a FINISH_INDICATION (Cluster_ID) message to M_i, i = 1...n after H finishes forwarding POIs' geo data to M_i, i = 1...n
    end if
    if H receives the FINISH_RESPONSE (ID of vehicle, the volume of received POIs' geo data) messages from all of its cluster members do
        H sends a FINISH_COMPLETE (Cluster_ID) message to the VSN server
    end if
    EXIT //finish forwarding the POIs' geo data to all members and H is not a cluster head
    else // H has no cluster members
        H sends a DISBAND_REQUEST (Cluster_ID) message to the VSN server
        H receives a DISBAND_CONFIRM (Cluster_ID) message from the VSN server
    EXIT// H is not a cluster head
  end if
end while// H reaches the exit borderline of the pre-downloaded area
```

6) CLUSTER DISBAND

When there is no cluster member left before the cluster head finishes downloading and forwarding POIs' geo data, the cluster head can disband its cluster.

The procedure of (1) POIs' geo data downloading and forwarding and (2) disbanding a cluster is as follows:

The corresponding explanation of the downloading and forwarding part is given previously; the explanation of the disbanding a cluster part is as follows:

(1) If all of the cluster members have left, i.e., there is no cluster member, cluster head H sends a DISBAND_REQUEST message to the VSN server.

(2) After the VSN server receives the DISBAND_REQUEST message, the VSN server removes the corresponding cluster's information and then the VSN server sends back the DISBAND_CONFIRM message to cluster head H.

(3) The VSN server calculates and updates the credits of cluster head H and its cluster members.

7) EXCEPTION HANDLING AND DISCUSSION

Since vehicle's speed and 3G/4G cellular network's situation may be varied, some exception may happen. Figure 6 shows the exception situation for which while the cluster head does not finish downloading and forwarding, the cluster head has reached the exit borderline of the pre-downloaded area. In this situation, the cluster head should stop downloading and forwarding POIs' geo data and disband the cluster immediately.

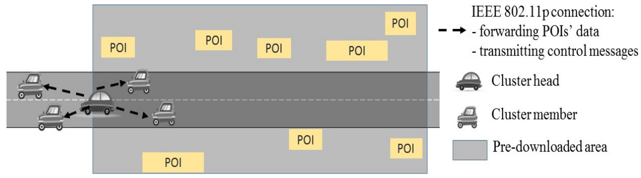

FIGURE 6. An example of the exception handling.

(1) *H* sends the TERMINATE_INDICATION message to its cluster members and the VSN server.

(2) Once a cluster member receives the TERMINATE_INDICATION message, the cluster member sends back the TERMINATE_RESPONSE message, which also contains the volume of received POIs' geo data, to the VSN server.

(3) Then the VSN server calculates and updates the credit of cluster head and its cluster members.

When the cellular network becomes congested, the situation of downloading the ahead POIs' geo data in the next 1km is discussed as follows:

Referring to Figure 7, the vehicle is moving from the right to the left of the road. Pc denotes the current position of the vehicle. The vehicle has not finished downloading/receiving POIs' geo data in cached area 1, but the vehicle has already reached the geo point (SPc/SPs) of cached area 2 and needs to trigger the clustering process of searching/creating a cluster. In this situation, two clustering processes are executed in parallel. That is, the vehicle continues downloading/receiving POIs' geo data for cached area 1 and then joins other vehicle's cluster/create a cluster to receive/download the POIs' geo data of cached area 2.

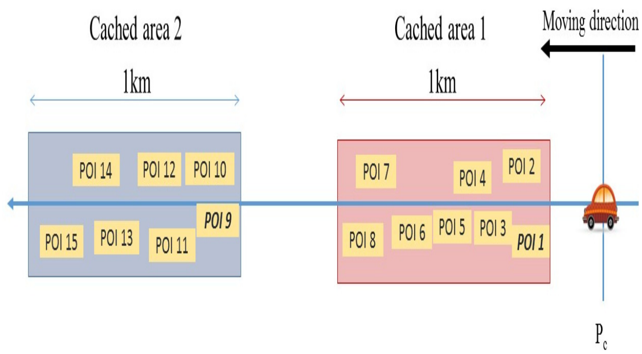

FIGURE 7. The ahead POIs' geo data that need to be downloaded in the area that is in the next 1km.

D. THE PROCEDURE OF THE CLUSTERING PROCESS EXECUTED IN THE VSN SERVER

The VSN server collects vehicles' reported context and executes the cluster creation/join/leave/disband procedures.

TABLE 4. The notations of credit calculation.

Variable	Meaning
DV_i	The volume of the downloaded POIs' geo data
k	The maximum number of POIs that need to be pre-downloaded in the next 1km, i.e., k=10
DV_{max}	The summation of the top k largest size of POIs among all POIs
n	Number of cluster members
R_i	Received data volume of member i

When the VSN server receives (i) a context report from a vehicle that does not belong to any cluster, (ii) a context report from a vehicle that is a cluster member and (iii) a message from a vehicle that is the cluster head, it needs to do related actions accordingly.

For (i), the VSN server calculates whether it is the due time for vehicle X either searching for a cluster to join or creating a cluster depending on the credit of X or not.

For (ii), when vehicle X is a cluster member, the VSN server checks whether (a) the connected time length between X and X's cluster head is enough to receive the POIs' geo data from X's cluster head or (b) X and X's cluster head are still in the same road or not. If the VSN server finds that the connected time length is not enough or cluster member X and X's cluster head are not in the same road, the VSN server informs cluster member X to leave and also informs X's cluster head to update its cluster member list.

For (iii), when vehicle X is a cluster head, the VSN server updates its recorded member list according to the received X's context. If there is no more cluster member, the cluster head informs the VSN server to disband the cluster.

The procedure of managing context reports and messages in the VSN server is as follows:

Procedure 5 VSN Server's Managing Context Reports and Messages

If the VSN server receives a context report sent from vehicle V **then**
  Update V's context record
  if V does not belong to any cluster **then**
    if V's credit>=0 **then**
      if it is due time for V to search a nearby cluster head **then**
        inform V to call Procedure Cluster_Search
      end if
    else
      if it is due time for V to create a cluster **then**
        inform V to call Procedure Cluster_Create
      end if
    end if
  else if V is a member of cluster head H **then**
    if V's Road_ID != cluster head H's Road_ID || CT (V, H)≤DT_{POI} (H) **then**
      send a LEAVE_INDICATION (Cluster_ID, ID of V) message to V
      if the VSN server receives a LEAVE_CONFIRM (ID of V, the volume of received POIs' geo data) message **then**
        the VSN server sends an UPDATE_INDICATION (ID of V, Cluster_ID) message to V's cluster head H
      end if
    end if
  end if
else if the VSN server receives a DISBAND_REQUEST (Cluster_ID) message sent from cluster head V **then**
    send a DISBAND_CONFIRM (Cluster_ID) message to V
    calculate credits and update the credits for V and its cluster members.
end if
else
if the VSN server receives a TERMINATE_REQUEST
(Cluster_ID) message sent from cluster head V **then**
    calculate credits and update the credits for V and its cluster members.
end if

E. THE CREDIT SCHEME

The credit scheme is used to represent the contribution of each vehicle. Each vehicle's credit is set to a random number when it just joins the VSN in the beginning. When a vehicle becomes a cluster head and shares its downloaded POIs' geo data to its cluster members successfully, it can earn credit; when a vehicle becomes a cluster member, it needs to consume its credit to get POIs' geo data from others. This work takes into account of (1) the downloaded data volume and (2) the number of cluster members for calculating credit. For (1), it needs to pay more cellular network resource when downloading a higher data volume and thus the credit is in proportion to the top k largest size of POIs. For (2), all of the cluster members and cluster head evenly share the credit that needs to give to the cluster head. Referring to Table 4 and formula (3) and formula (4), the cluster heads' earned credit and cluster members' consumed credits are as follows.

Consumed credit of cluster member i:

$$Consumed\_Credit_i = \frac{DV_i}{DV_{max}} \times \frac{1}{n+1} \times \frac{R_i}{DV_i} \tag{3}$$

Credit of cluster head i:

$$Earned\_Credit = \sum\nolimits_i^n Consumed\_Credit_i \tag{4}$$

In Formula (3), DV_i denotes the volume of the downloaded POIs' geo data; k denotes the maximum number of POIs that need to be pre-downloaded in the next 1km, i.e., k=10; DV_{max} denotes the summation of the top k largest size of POIs among all POIs; n denotes number of cluster members; R_i denotes the received data volume of member i.

If the cluster member leaves the cluster or the cluster is disbanded before POIs' geo data forwarding is finished, the consumed credit is reduced according to the member's received data volume of POIs' geo data. R_i/DV_i denotes the received data volume of cluster member i in proportion to the downloaded data volume.

Formula (4) denotes how many credits a cluster head can earn. The earned credit is equal to the summation of the credit that each of its cluster members consumed.

V. PERFORMANCE ANALYSIS

This Section presents performance analysis of the proposed CBC scheme. To evaluate the proposed scheme, the simulation was performed using network simulator NS-3 (Network Simulation 3.25) [23]. The traffic trace mobility model was generated using SUMO (Simulation of Urban MObility) [24].

Let the OBU equipped in each vehicle consist of an IEEE 802.11p network interface and a LTE network interface. Each vehicle periodically reports its context to the VSN server for every GPS sampling period. Based on the proposed CBC scheme, vehicles form clusters to share the downloaded POIs' geo data when they reach the SPc time point depicted in Figure 3. Multicast is used to forward the downloaded POIs' geo data to cluster members.

A. THE SIMULATION ENVIRONMENT

The performance analysis is based on the vehicles moving through the urban touring scenario. Table 5 shows related simulation parameters.

TABLE 5. Simulation configuration parameters.

Parameter	Value
Velocity	0.0 m/s - 11.1 m/s
Transmission range	300m
Duration of simulation	1870s
GPS sampling period	10s

Referring to Table 6, vehicles enter into the road with different periods, which denote how many seconds a vehicle is generated [25], based on different vehicle's density. Let Vn denote the total number of vehicles on the urban scenario, e.g., in the situation of high vehicle's density, a new vehicle is generated every 5 seconds and the total number of vehicles on the urban scenario is 40. Each vehicle's available network bandwidth becomes less when vehicle's density increases.

TABLE 6. Vehicle density parameter.

Vehicle Density	Period (Seconds)	V_n
Low	10	20
Middle	6.66	30
High	5	40

Our proposed CBC scheme is compared with the following three methods.

Method A is to have each vehicle to download POIs' geo data using its own cellular network individually. That is, when the vehicle reaches the SPd point, each vehicle downloads its needed POIs' geo data individually. Method A can be divided into the following two sub-methods. In sub-method A1, the downloading point is the last 1st GPS sampling point before entering into the geo coverage of the ahead POIs. In sub-method A2, the downloading point is the last SPdth GPS sampling point before entering into the geo coverage of the ahead POIs, i.e., the vehicle will enter into the geo coverage of the ahead POIs after SPd $\times$ T_s seconds if the speed remains the same. The SPd point is determined using the equations and the principles depicted in Section IV.A and Section IV.B.

Method B is to have each vehicle starts the clustering process from cluster search when it reaches SPs point. Method B can be divided into the following two sub-methods. In sub-method B1, the SPs/SPc/SPd points are the last 3rd/2nd/1st GPS sampling point before entering into the borderline of the ahead POIs' geo coverage. When the vehicle reaches the SPc point and it still cannot find a nearby cluster head, it creates a new cluster and then invites other vehicles to join until it reaches the SPd point. When the vehicle reaches the SPd point, it starts to download POIs' geo data. In sub-method B2, each vehicle starts the clustering process from cluster search when it reaches the SPs point. When the vehicle reaches the SPc point and it still cannot find a nearby cluster head, it creates a new cluster and then invites other vehicles to join until it reaches the SPd point. When the vehicle reaches the SPd point, it starts to download POIs' geo data. The SPs/SPc/SPd point is determined using the equations and the principles depicted in Section IV.A and Section IV.B. In summary, except without using the credit scheme, the principle of sub-method B2 is the same as the proposed CBC method.

Method C considers credit, which is similar to our proposed CBC scheme, but the SPs/SPc/SPd point is the last 3rd/2nd/1st GPS sampling point before entering into the geo coverage of the ahead POIs. Using sub-method C, the vehicle that has positive credit starts the clustering process from cluster search when it reaches the SPs point. When the vehicle reaches the SPc point and it still cannot find a nearby cluster head, it creates a new cluster and then invites other vehicles to join until it reaches the SPd point. When the vehicle reaches the SPd point, it starts to download POIs' geo data. The vehicle that has negative credit starts the clustering process from cluster creating when it reaches SPc point, it creates a new cluster and invites other vehicles to join until it reaches SPd point. When the vehicle reaches the SPd point, it starts to download POIs' geo data.

B. EXPERIMENT RESULTS

The metrics that are used to evaluate the performance of each method are as follows: (1) standard deviation of credits, (2) the downloaded data volume, (3) sharing portion, and (4) receiving efficiency index. To get the general trend of the above (2)~(4) metrics in each method for different situations of vehicle's density, each method is executed for 10 times based on the same touring scenario. Then the sum of these 10 times for each metrics is divided by 10 respectively.

1) STANDARD DEVIATION OF CREDITS

Figure 8 depicts the average standard deviation of the credit value for the situations of low, middle, and high vehicle's density, respectively. It needs to get the average of the credit value, which is calculated based on each vehicle's credit value at the end of the experiment. Then it is used to get disparity between the average value and each vehicle's final credit value to get the credit's standard deviation.

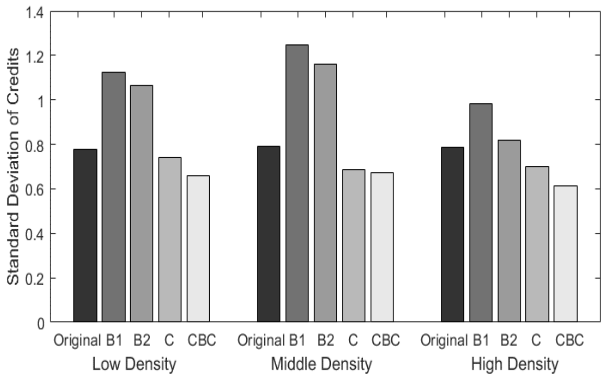

FIGURE 8. The standard deviation of credits in the situations of different vehicle's densities.

In the situation of the low vehicle's density, comparing with the original distribution, method C and the CBC scheme have lower credit's standard deviation than that of sub-methods B1 and B2, which represent that considering the current credit value for selecting the cluster head in method C and the CBC scheme can have all vehicles to play the cluster head more alternatively. Thus, the credit distribution is converged. Sub-methods B1 and B2 have higher standard deviation of credits than that of the original distribution. The reason is that some vehicles in sub-methods B1 and B2 may be selected as cluster heads more often without taking turn with other vehicles and thus these vehicles earn more credits. As a result, the credit distribution is more distributed after using sub-methods B1 and B2. Additionally, (1) sub-method B2 has the lower standard deviation of credits than sub-method B1 and (2) the CBC scheme has lower standard deviation of credit than method C. The reason is the same for both cases, i.e., vehicles in sub-method B2 and the CBC scheme have sufficient time to receive the complete POIs' geo data and thus cluster heads in sub-method B2 and the CBC scheme can earn more credits than that of sub-method B1 and method C. As a result, the credits of using sub-method B2 and the CBC scheme can be more converged.

In the situation of the middle vehicle's density, comparing with the original one, method C and the CBC scheme have smaller values than that of sub-methods B1 and B2. It is because method C and the CBC scheme consider the credit for selecting the cluster head and thus the credit distribution is more concentrated after using method C and the CBC scheme than using sub-methods B1 and B2. Sub-method B1 has the higher standard deviation than sub-method B2. The reason is that vehicles in sub-method B1 do not have enough time to receive the complete POIs' geo data and thus the credit that cluster heads/members in sub-method B1 earned/paid decreases. As a result, the credit distribution is more distributed after using sub-method B1. Method C has a little higher standard deviation than the CBC scheme. The reason is that, in the situation of middle vehicle's density, there are more vehicles on the road than that in the situation of low vehicle's density, and the network is not so congested as in the situation of high vehicle's density. Thus, some vehicles in method C may finish downloading in time and thus method C's standard deviation is a little higher than the CBC scheme's standard deviation.

In the situation of high vehicle's density, comparing with the original one, method C and the CBC scheme have smaller values than that of sub-method B1 and B2, which shows that the consideration of the current credit value for selecting the cluster head in method C and the CBC scheme can have the credit distribution be more converged than sub-method B1 and sub-method B2. It is because method C and the CBC scheme can have all vehicles to play the cluster head more alternatively.

The standard deviation of sub-methods B1 and B2 in the situation of middle vehicle's density $>$ the one in the situation of low vehicle's density $>$ the one in the situation of high vehicle's density. The reason is that in the situation of middle vehicle's density, vehicles have higher chance to form more clusters than in the situation of low vehicle's density. However, since it does not consider the credit value for selecting the cluster head, some vehicles may always become the cluster heads and some vehicles may always become cluster members. Thus, the credit distribution is more distributed and the standard deviation becomes bigger in the situation of middle vehicle's density. In the high vehicle's density, the vehicles have higher chance to fail the complete downloading of POIs' geo data because the network is more congested. Thus, the credit that cluster heads/members earned/paid decreases, which results in the credit distribution being not so distributed and having smaller standard deviation.

The standard deviation of method C is similar to the CBC scheme in the situation of middle density, but the CBC scheme's standard deviation is smaller than that of method C in the situation of low and high density. The reason is that in the situation of middle vehicle's density, there are more vehicles on the road than that in the situation of low vehicle's density, and the network is not so congested as in the situation of high vehicle's density. Thus, some vehicles in method C may finish downloading in time and thus method C has the similar standard deviation as that of the CBC scheme's standard deviation. But, in the situations of low and high vehicle's density, since method C may not have enough time to have the complete downloading of POIs' geo data, it results in the exchange of credits becomes smaller. Thus, method C's standard deviation is bigger than that of the CBC scheme.

2) DOWNLOADED DATA VOLUME

Figure 9 depicts the average downloaded data volume using the 3G/4G cellular network of each vehicle in the situations

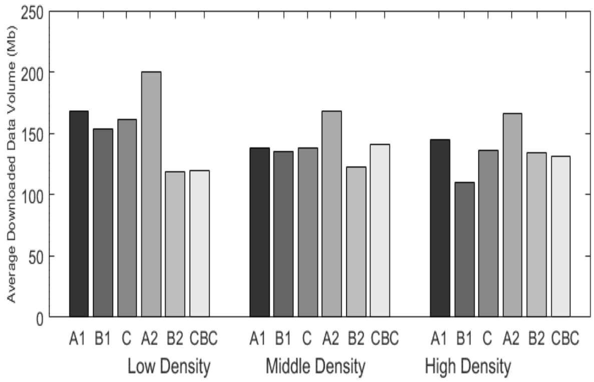

FIGURE 9. Average downloaded data volume in the situations of different vehicle's densities.

of the low, middle, high vehicle's density. The average downloaded data volume using the 3G/4G cellular network for each method is calculated as follows. The sum of the downloaded data volume using the 3G/4G cellular network is divided by the total number of vehicles.

Sub-method A1 and sub-method A2 have higher average downloaded data volume than the other four methods. It is because each vehicle in sub-method A1 and sub-method A2 needs to download the needed POIs' geo data individually.

The average downloaded data volume in sub-method B1 and method C is decreased when the vehicle's density is increased. However, the difference between sub-method B1's average downloaded data volume and method C's average downloaded data volume (i) is similar in the situations of the low and middle vehicle's density, but (ii) is more different in the situation of high vehicle's density. In the situation of low vehicle's density, there are not so many vehicles on the road. Both sub-method B1 and method C may not form so many clusters and thus the downloaded data volume is similar. In the situation of middle vehicle's density, both sub-method B1 and method C do not have enough time to download the complete POIs' geo data and thus have similar downloaded data volume. In the situation of high vehicle's density, the velocity of each vehicle is slower than that in the situations of other two vehicle's density. Thus, both sub-method B1 and method C triggered the clustering process much near the entering point of POIs. Since it does not need to consider the credit value for selecting the cluster head in sub-method B1, each cluster in sub-method B1 has more cluster members but may download smaller portion of POIs' geo data because the network is congested and thus does not have enough time to download the complete POIs' geo data. In method C, since vehicles having negative credit need to create new clusters without joining existed clusters, the number of clusters in method C is higher than that of sub-method B1 and thus method C's downloaded volume is higher than that of sub-method B1.

The average downloaded data volume in sub-method B2 and the CBC scheme is increased when the vehicle's density is increased. However, the difference between sub-method B2's average downloaded data volume and the CBC scheme's average downloaded data volume (i) is similar in the situations of the low and high vehicle's density, but (ii) is more different in the situation of middle vehicle's density. The reason is that sub-method B2 does not need to consider the credit value for selecting the cluster head and those vehicles that have negative credit values need to create clusters for themselves in the CBC scheme. Thus, each cluster in sub-method B2 has more cluster members than the CBC scheme has in the situation of middle vehicle's density. As a result, more POIs' geo data is forwarded using IEEE 802.11p rather than using the cellular network. Thus, sub-method B2 has lower average downloaded data volume than the CBC scheme. In the situation of low vehicle's density, there are not so many vehicles on the road. Both sub-method B2 and the CBC scheme may not form so many clusters and thus the downloaded data volume is similar. In the situation of high vehicle's density, network is congested and thus does not have enough time to download the complete POIs' geo data. As a result, sub-method B2's downloaded data volume and the CBC scheme's downloaded data volume are similar.

The average downloaded data volumes of sub-method B1 and method C are apparently higher than that in sub-method B2 and the CBC scheme in the situation of low vehicle's density; but the difference becomes smaller in the situations of middle and high vehicle's density. In the situation of low vehicle's density, sub-method B1 and method C may not have the chance to organize clusters to share downloaded POIs' geo data because there are not so many proximate vehicles comparing with that in other two situations of vehicle's density. Thus, sub-method B1 and method C may need to download POIs' geo data individually more often and have higher downloaded data volume. In the situation of high vehicle's density, the network becomes much congested such that vehicles in these four methods cannot download more data and thus four methods have little difference.

3) AVAILABLE DISTANCE

Available distance denotes the distance to the exit borderline of the pre-downloaded area when a vehicle finishes downloading/receiving the complete POIs' geo data. If a vehicle does not finish downloading or receiving the complete POIs' geo data when it reaches the exit borderline of the pre-downloaded area, then the distance value is 0. The higher distance means that vehicles have more sufficient time to watch downloaded POIs' geo data.

Figure 10 depicts the available distance to the exit borderline of the pre-downloaded area when a vehicle finishes downloading/receiving the complete POIs' geo data for the situations of different vehicle's densities.

In the situations of low, middle and high vehicle's density, sub-method A1 has smaller available distance than sub-method A2, sub-method B1 has smaller available distance than sub-method B2, method C has smaller available distance

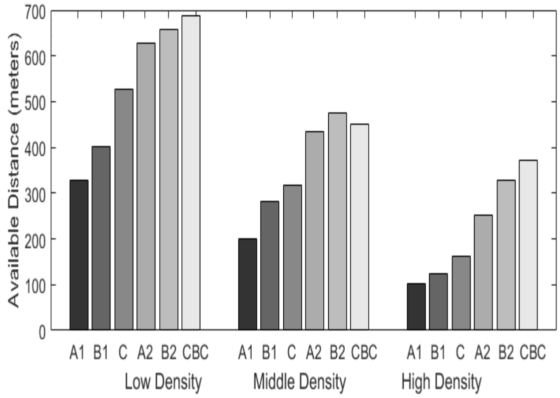

FIGURE 10. The available distance in situations of different vehicle's densities.

than the CBC scheme, sub-methods A1, B1 and method C have smaller available distance than sub-methods A2, B2 and the CBC scheme. The reason is the same, i.e., sub-methods A1, B1 and method C start to download POIs' geo data later than sub-methods A2, B2 and the CBC scheme and thus sub-methods A1, B1 and method C have smaller available distance than sub-methods A2, B2 and the CBC scheme have, respectively.

Generally speaking, the available distance of each method becomes smaller when the vehicle's density increases. The reason is that higher density makes network more congested and thus vehicles need more time to or even cannot finish downloading and forwarding POIs' geo data. Thus, it would be more near the exit borderline of the pre-downloaded area when the downloading and forwarding of POIs' geo data are finished.

Sub-method B2 has smaller available distance than that of the CBC scheme in the situations of the low and high vehicle's density, but has the bigger available distance in the situation of middle vehicle's density. In the situation of low vehicle's density, the speed of a vehicle can be faster and thus the distance between searching point and creating point may be longer. Thus, there are more vehicles in sub-method B2 that may reach the searching point around the same time because all of the vehicles in sub-method B2 started the clustering process from searching an existed cluster such that all of them created a new cluster without forming a cluster. As a result, sub-method B2 may need to download POIs' geo data individually more often and have smaller available distance than the CBC scheme has. In the situation of high vehicle's density, network is congested and thus vehicles need more time to or even cannot finish downloading and forwarding the complete POIs' geo data. As a result, each cluster in sub-method B2's cluster has more cluster members than the CBC scheme has, which leads to more vehicles in sub-method B2 receive the complete POIs' geo data later than the CBC scheme. In the situation of middle vehicle's density, sub-method B2 does not need to consider the credit value for selecting the cluster head and those vehicles that have negative credit values need to create clusters for themselves in the CBC scheme. Thus, each cluster in sub-method B2 has more cluster members than the CBC scheme has in the situation of middle vehicle's density. Sub-methods B1 and B2 did not consider the credit for selecting cluster head, all the vehicles in sub-methods B1 and B2 start the clustering process from searching an existed cluster to join. Once a vehicle is due for creating a new cluster first, the proximate vehicles that are still searching a cluster can join the cluster. As a result, since vehicles in sub-method B2 created clusters earlier than that in sub-method B1, more vehicles in sub-method B2 can receive the complete POIs' geo data earlier. It is the same for the comparison of method C and the CBC scheme.

4) SHARING PORTION

The sharing portion is derived from dividing the total volume of received POIs' geo data using IEEE 802.11p network by the total volume of downloaded POIs' geo data, which include the ones that were downloaded by the vehicles individually and the ones that were downloaded by cluster heads, using cellular network. Figure 11 depicts the sharing portion of different vehicle's densities using different methods. The lower value of sharing portion indicates that the smaller amount of POIs' geo data was shared among vehicles through the IEEE 802.11p network.

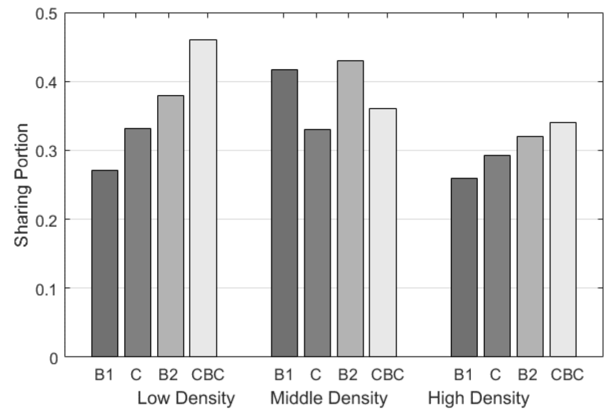

FIGURE 11. The sharing portion in situations of different vehicle's densities.

In the situations of low and high vehicle's density, the trends of sharing portion are similar: the one in sub-method B1 $<$ the one in method C $<$ the one in sub-method B2 $<$ the one in CBC scheme. It is because sub-method B1 and method C started to download POIs' geo data later than sub-method B2 and the CBC scheme did. Sub-method B1 and method C may not have enough time to finish downloading in time and thus have lower sharing portion.

In the situation of the middle vehicle's density, the sharing portion of sub-method B1 is bigger than that of method C; the sharing portion of sub-method B2 is bigger than that of the CBC scheme. It is because that sub-methods B1 and B2 did not need to consider the credit value for selecting the cluster head and those vehicles that have negative credit values need to create clusters for themselves in method C and the CBC scheme. Thus, each cluster in sub-methods B1 and B2 have more cluster members than method C and the CBC scheme have. As a result, sub-methods B1/B2 has higher sharing portion than method C/the CBC scheme has.

Sub-methods B1 and B2 have higher sharing portion in the situation of middle vehicle's density than that in the low and high vehicle's density. The reason is that in the situation of high vehicle's density, the network is too congested such that sub-methods B1 and B2 may not have enough time to finish downloading in time and the data volumes that were forwarded from IEEE 802.11p decrease and thus they have lower sharing portion; in the situation of middle vehicle's density, there are more vehicles in the approximate location than that in the situation of low vehicle's density such that each cluster in sub-methods B1 and B2 can have more cluster members in the situation of middle vehicle's density and thus have higher sharing portion.

Method C and the CBC scheme have higher sharing portion in the situation of low vehicle's density > the one in situation middle vehicle's density > the one in the situation of high vehicle's density. The reason is that when the vehicle's density increases, the network becomes more congested and method C and the CBC scheme may not have enough time to finish downloading in time and thus have the lower sharing portion. As a result, the sharing portion decreases.

5) RECEIVING EFFICIENCY INDEX

The receiving efficiency index is the evaluation of the efficiency for the cluster members received from their cluster heads through the IEEE 802.11p network. If more cluster members in a cluster, that means that more vehicles can share the same POIs' geo data and thus can have the higher receiving efficiency index. The receiving efficiency index of each method is calculated as follows. The sum of POIs' geo data volume that cluster members have received through IEEE 802.11p network is divided by the number of cluster members at first. Then, the result is divided by the volume of POIs' geo data that their cluster head has downloaded through cellular network to get the receiving efficiency index of one cluster. Afterward, the sum of the receiving efficiency index of all clusters is divided by the number of clusters. Figure 12 depicts the receiving efficiency index in different vehicle's densities.

In the situation of low, middle and high vehicle's density, the trends of receiving indexes are similar. When the vehicle's density increases, the receiving indexes become smaller. For each method in the situations of three different vehicle's density, it also shows the same trend. When the vehicle's density increases, there are more cluster members in a cluster. Since cluster heads using multicast to forward POIs' geo data only once, the more cluster members it has, the higher collision possibility it has. Thus, the volume that a cluster member received decreases. As a result, the higher vehicle's density it is, the smaller receiving index it has.

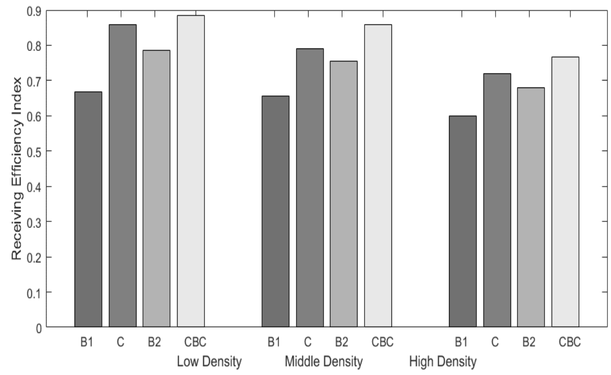

FIGURE 12. **Receiving efficiency index situations of different vehicle's densities.**

6) THE SUCCESSFUL RATIO OF COMPLETE SHARING OF DOWNLOADED POIS' GEO DATA

If all of the cluster members in a cluster have received all of the POIs' geo data successfully before reaching the exit borderline of the pre-downloaded area, then the cluster's sharing of downloaded POIs' geo data is successful; otherwise, it is failed. The successful ratio of the complete sharing of the downloaded POIs' geo data is derived from dividing the number of successful clusters by the total number of clusters. Figure 13 depicts the successful ratio in situations of different vehicle's densities.

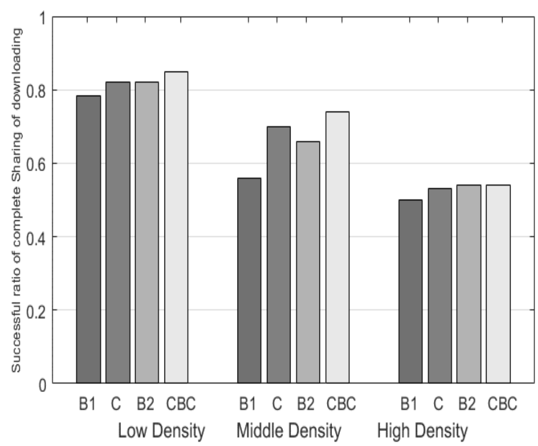

FIGURE 13. **The successful ratio of the complete sharing of the downloaded POIs' geo data in the situations of different vehicle's densities.**

Generally speaking, the successful ratio of the complete sharing of the downloaded POIs' geo data is decreased when the vehicle's density is increased for all methods. That is, the higher vehicle's density it is, the lower successful ratio of the complete sharing of the downloaded POIs' geo data it has for each method. The reason is that the network becomes more congested when more vehicles are in the road. The cluster heads may not download and forward the complete POIs' geo data in time and thus it is possible that the complete data forwarding to their cluster members is failed more often.

Sub-method B1's successful ratio is much smaller than method C's successful ratio in the situation of middle vehicle's density than that in the other two situations. Sub-method B2's successful ratio is much smaller than the CBC scheme's successful ratio in the situation of middle vehicle's density, comparing with the situations of low and high density. The reason is that sub-methods B1 and B2 did not need to consider the credit value for selecting the cluster head and those vehicles that have negative credit values need to create clusters for themselves in method C and the CBC scheme. Thus, each cluster in sub-methods B1 and B2 have more cluster members than method C and the CBC scheme have in the situation of middle vehicle's density. As a result, the more cluster members a cluster has, the lower successful ratio of the complete sharing of downloaded POIs' geo data it has. The reason is that cluster heads use multicast to forward data only once, and thus if any cluster member did not receive the complete POIs' geo data, the sharing is failed.

VI. CONCLUSION

In this paper, a clustering scheme called Credit-Based Clustering (CBC) was proposed. CBC enables a group of vehicles, which belong to the same VSN, moving on the same road with the same direction to form a cluster. Then, one vehicle is selected as the cluster head to download POIs' geo data through its cellular network and share the downloaded POIs' geo data to other vehicles in the same cluster through IEEE 802.11p network. To tackle the fairness issue for POIs' geo data sharing, a credit scheme has been proposed to evaluate the contribution of each vehicle. Those cluster heads that have downloaded POIs' geo data and forwarded POIs' geo data to their cluster members can get credit as the reward; those cluster members pay credit as exchange for receiving POIs' geo data from their cluster heads. In this way, it can encourage vehicles to share with others and the fairness can be achieved. The credit value of each vehicle is used to determine the cluster head when a group of vehicles reach the threshold and need to download POIs' geo data.

The results of performance analysis have shown that the proposed CBC scheme provides a fair scheme for vehicles in a VSN to form a cluster, have better receiving efficiency than other methods. The reason is that the proposed CBC scheme (1) does not need to download many duplicated POIs' geo data using cellular network and (2) have the vehicles to become cluster head more alternatively based on the vehicle's credit. However, in the situation of middle vehicle's density, the proposed CBC scheme has less sharing portion and the higher downloaded data volume. The reason is that the proposed CBC scheme tries to achieve the goal of fairness and thus the CBC scheme may have more clusters, which results in each cluster having fewer members. The future work can be twofold. The first one is to integrate the proposed method with the Mobile Edge Computing (MEC) mechanism to have more real time calculation to, potentially, reach the higher efficiency. The second one is to devise a trust computing mechanism that is suitable for the considered scenario such that the much safer sharing method can be derived.

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