Cluster Based Semantic Data Aggregation In VANETs

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***Abstract*—Recently, we are witnessing increased interest in the research of Vehicular Ad-hoc Networks (VANETs). Due to the peculiar characteristics of VANETs, such as high speed, the unstable communication link, and network partitioning, information transfer becomes inevitably challenging. The main communication challenges in vehicle to vehicle communication is scalability, predictability and reliability. With increasing number of vehicles in highway congestion scenarios, the congestion application need to disseminate large amount of information over multiple hops to the control center. This challenge can be solved by reducing the data load through clustering and data aggregation. In this paper, we propose cluster based semantic data aggregation (CBSDA) protocol that divide the road into different segments based on the cluster-ID and aggregate the data in each cluster. The aggregation scheme is a lossy aggregation with maximum precision. CBSDA scheme stores the data using a data structure that consists of super cluster, cluster and cluster member (CM) nodes. CBSDA is proposed to adaptively adjust the number of super cluster nodes. Moreover, the CBSDA scheme consists of weighted deviation scheme that decides which data to be fused for aggregation. Additionally, the aggregation level is controlled based on the density of vehicles and channel busy ratio (CBR). Simulation results show that the CBSDA using weighted deviation decision scheme is able to quickly reduce the channel congestion and improve the data precision even in congested traffic scenarios.**

I. Introduction

In recent years, even with the improvement in road safety, road accidents have increased by an enormous rate, on an average 75 people lose their lives everyday on European roads and 750 are seriously injured [1]. This motivates to the development of traffic safety and efficiency applications using VANETs to reduce road accidents and traffic congestion [2], [3]. VANETs comprises of vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communication which can support exchange of safety and non-safety messages. Each vehicle in VANETs is equipped with an On Board Unit (OBU). OBU sends Cooperative Awareness Messages (CAM) [4] at the rate up to 10 times per second as specified in the ETSI ITS-G5 standard [5]. The CAM include sensor data like temporal id, current position, longitudinal acceleration, skid resistance, heading and velocity. Moreover, the number of vehicles in traffic jams are higher as compared to normal traffic. Furthermore, there will be more number of CAMs generated in that area.

For example, consider a traffic flow in a 4 lane highway scenario with high vehicle density shown in figure 1. Moreover, considering the transmission radius of each vehicle be 250 meters and each vehicle require the information of other vehicles (position, speed, total number of vehicles) that are in the range of 7 kilometers for re-routing traffic. Additionally, there will be about 360 CAMs per second with generation rate at 1hz in its one hop neighborhood, while considering the length of the each vehicle be 4.5 meters and each vehicle separated from each other by a safety distance of 1 meter. There will be about 5040 messages that need to be forwarded by each vehicle per second along the 7 kilometer range. Furthermore, it is unlikely even in ideal channel conditions this amount of messages can be forwarded over large distance. This lead to the collisions and delay of packets. This problem can be alleviated using clustering and data aggregation techniques.

Clustering means grouping vehicles based on some common characteristics such as geographical location, speed, direction of movement etc. This technique make the VANETs more robust and scalable. Cluster-based approaches may be the only viable solutions for supporting scalable multi-hop communication for high density VANETs. Clustering protocols normally consists of CMs and CHs. CH is normally elected by the CMs of the cluster. CH collects all information from the CMs and aggregates all information and only disseminate the merged information to next CHs or cluster.

Aggregation technique is used to solve redundant data problem to improve wireless channel efficiency. Considering the traffic congestion scenario using CHs, the CHs can aggregate their own view with warnings received from other CMs and only disseminate the aggregate message. Aggregation techniques can be either syntactic or semantic. Syntactic aggregation uses a technique to compress or encode the data from multiple vehicles in order to fit the data into a single frame. This results in lower overhead than sending each message individually. In semantic aggregation, the data from individual vehicles is summarized. For instance, instead of reporting the exact position of five vehicles, only the fact that five vehicles exist is reported. The trade-off is a much smaller message in exchange for a loss of precise data. This paper is based on semantic aggregation with maximum precision using cluster

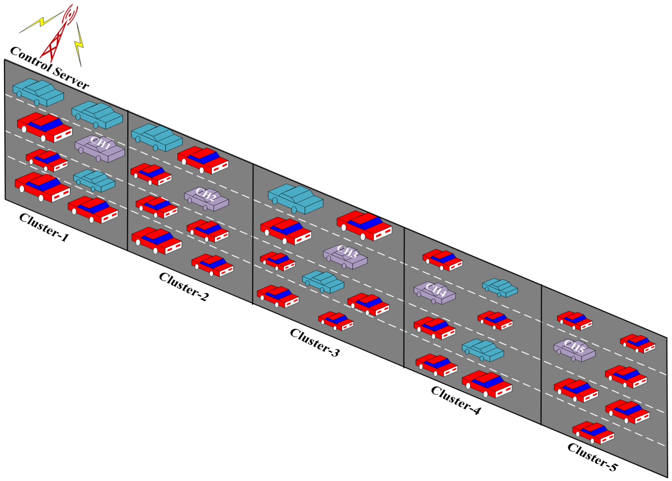


Fig. 1: Road Network

data structure for storing information of vehicles in the road.

In this paper, we present a CBSDA protocol that divides the entire road network into different segments which helps to reduce the load of conveying full information to the server node or control center. Additionally, the information is further reduced by aggregation. The aggregated data is stored using CBSDA data structure with the help of aggregation framework developed in [6]. Moreover, the aggregation framework consists of various components such as decision, fusion etc. In addition, we present weighted deviation scheme in decision component that helps to reduce the error occurred during the fusion of various data. Furthermore, the aggregation levels can be controlled by the CBR and density of vehicles in the CH.

This paper starts with an overview about related work on data aggregation in Section II. In Section III and IV we describe the CBSDA protocol and aggregation decision schemes. Section V and VI describe the aggregation level control schemes and CBSDA data structure. All the schemes are simulated and results are discussed in Section VII. A summary concludes the paper in Section VIII.

II. Related Work

Clustering can efficiently minimize traffic congestion [7], and guarantee different QoS needs [8] for both non real-time (e.g. road/weather information) and real-time (e.g. safety messages) applications. In Hierarchical Clustering Algorithm (HCA) [9], authors proposed a new formation of clusters with a range of maximum four hops. Additionally, HCA protocol schedule transmissions and channel access inside the cluster to ensure reliable communication. Furthermore, HCA does not depend on global positioning systems (GPS), which reduces the position errors. However, overhead and packet loss is increased due to inter cluster interference. HCA does not consider the direction of movement which decreases cluster stability and CH duration.

SBCA [10], creates clusters with a more stable structure by taking into account the mobility, number of neighbors, and leadership (i.e., CH) duration of the vehicle. In paper [10], the vehicles in the cluster have three different states, primary CH (PCH), secondary CH (SCH) and CMs. The vehicles in the cluster are associated with cluster-ID rather than with the CH, which increases the stability. Additionally, when a PCH lose the connectivity with CMs of the cluster, after a certain period of time SCH changes its state to PCH. Moreover, lifetime of the cluster is increased. However, the CHs does not aggregate the packets before forwarding to next CHs.

In [11], Region-based Clustering Mechanism (RCM) is introduced to improve the scalability of MAC protocol for VANETs. In RCM, the network is partitioned into a number of space division units, and each division unit is limited to a fixed number of vehicles for avoiding contentions of channels. Additionally, a non-interfering radio channel pool is allocated to a region. As a result, the contention period is reduced and throughput is increased by limiting the number of vehicles in division units.

Data aggregation is a technique of combining data messages of different vehicles [12] to reduce the redundant information. CHs might receive and aggregate vehicular data before it is forwarded to a next hop CH or control center. Many data aggregation approaches have been proposed in recent years. These algorithms can be classified into various sections based on the topology for the nodes they require. Tree-based topologies consist of one root node which often represents the data sink. Tree-based aggregation schemes [13], [14] facilitate nodes arranged in a tree-based topology. Cluster-based aggregation schemes [15] group the nodes into clusters. Other aggregation schemes [16]–[18] do not require any specific topology.

In TAG [13] two data nodes are aggregated by fusing all its contained values. Thus, two rows of the table structure are merged. CASCADE [15] is a cluster based aggregation scheme suitable for dissemination of vehicle speeds. Contrary to the previously presented systems, the CASCADE system employs only syntactic, lossless compression of data. At local scope in front of a given vehicle, single reports are disseminated and collected using geo-broadcast. This local view is then clustered using fixed size segments and differential coding is used to compress vehicle information in each cluster. The compressed information is then disseminated further. CASCADE suggests to store only relative values to a fix point compared to absolute values used in TAG. In CASCADE vehicles are clustered and the center or median of the cluster values is used as fix point. During the decision process, data records are identified for fusion.

In SOTIS [16] and CASCADE [15], and TAG [13] all data within a certain group is fused to reduce the wireless channel load. These groups can based on road segments. Another type of aggregation based on mathematical models or complicated computation are used for the decision process in Quantil Digest [14] and Probabilistic Aggregation [17]. The drawback of all the above aggregation techniques is either the requirement of computing cost and complex structure. A third decision strategy is used by TrafficView [18]. Its decision component uses a cost function to identify the two items with least fusion costs. This function takes the distance of the vehicles and the number of vehicles represented by a data record into account. This cost function could solve the problem of missing single extreme values, since the cost of fusing such a car should be too high for aggregation. However, Traffic-views cost function falls short in considering other metrics than the distance of the vehicles and the number of vehicles represented by a data node.

In any case, fusing data by one certain metric may have disadvantages in our use case. Individual extreme values might get lost by fusing over all elements of a group, a safety threat, e.g. a slow car might not be identifiable after fusion. Most data aggregation schemes only focus on averaging data in the fusion process. In this paper, we present a CBSDA protocol to improve the scalability of VANETs by formation of a stable cluster and election of a CH. The aggregation application in the CH aggregates information using semantic method due to the similarity of data from CMs. The schemes uses in-node and in-network aggregation of information. CBSDA scheme is introduced for storing different data types, combining data of multiple sources into one structure and size reduction by data fusion. CBSDA scheme introduce a new scheme for decision component based on weigh factor and standard to reduce the loss of extrema values and increase the precision. Moreover, adaptive vehicle density parameter is introduced to control the amount of aggregation required in each CH.

III. Cluster Based Semantic Data Aggregation Protocol

We propose a Cluster Based Semantic Data Aggregation (CBSDA) Protocol which create stable clusters in vehicular networks. The main idea of clustering the network is to group the vehicles with similar characteristics such as velocity, position, direction of movement etc. VANETs are highly dynamic in nature, it is essential to have a stable cluster to avoid constant cluster reconfigurations. The vehicles in the road network can be either linked to a cluster-id or a CH. In CBSDA algorithm, the vehicles are linked to cluster-id instead of CH to reduce the reconfigurations.

The CBSDA algorithm is divided into two sections setup and aggregation. In the setup, the cluster formation and CH election takes place. In aggregation, CH aggregate the information collected using the aggregation frame work. The aggregate messages are stored using cluster data structure.

A. Setup

Initially, the road network is divided into different segments based on the number of lanes and direction of movement. From figure 1, the road network has four lanes and travel in same directions. All the vehicles in the road segment traveling in same direction are grouped together and given a cluster-id. All the members will update the one hop neighbors with the current cluster-id. Initially, after waiting for a certain period of time t, one vehicle randomly elects itself as CH. The elected CH sends CH-information (CHI) message to the all neighboring CMs. The CHs who receive adjacent CHI messages updates itself with new next hop CH.

- **Cluster Member (CM):**
  A CM is a vehicle that belongs to a particular cluster and it regularly broadcast the CAM messages.

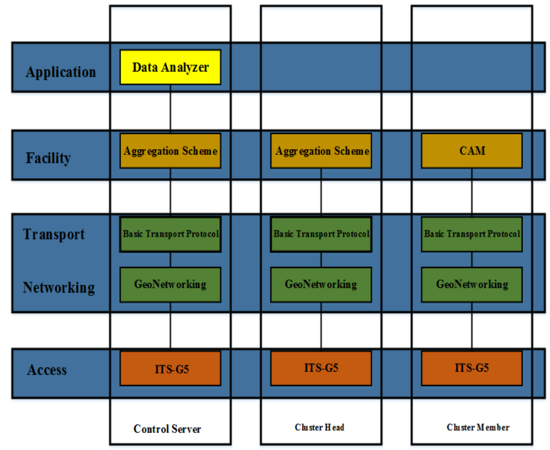


Fig. 2: Protocol Stack

- **Cluster Head (CH):**
  A vehicle in this mode gather information regarding speed, direction, lane, and location from its CMs and it aggregates the information received from all the CMs. The CHs have the aggregation scheme installed in itself as shown in figure 2.
- **Control Center:** Control center is responsible for running the aggregation scheme in the facility layer and data analyzer in the application layer. Moreover, it is responsible for adjusting rate of dissemination.

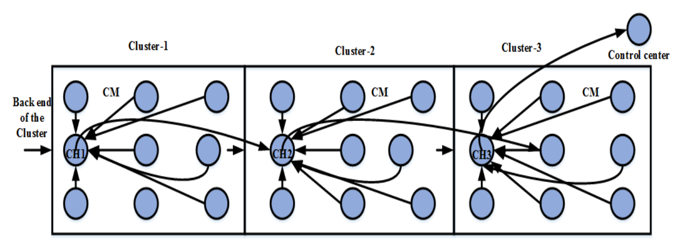


Fig. 3: CH election Scenario

The vehicles in the road is associated with different cluster-ID based on its current position. After initial formation of clusters, and election of initial CH. The CH re-election can happen when current CH leaves the cluster and joins the other cluster. The CMs elect a new cluster head when current CMs does not receive the CHI message for a period of 3T, T is the generation rate of CHI message. The CH is elected based on relative velocity of all CMs and the distance between the vehicle to back end of the cluster. Back end of the cluster is considered here to increase the CH life time in the cluster. The scenario used in this paper is shown in figure 3. Firstly, the CMs listens to all CAM broadcasts from its one hop neighbors. Then each CMs calculates its distance from itself to back end cluster using equation 5, where $D_{i,bend}$ is distance between vehicle i and back end of the cluster. Moreover, each vehicle calculate the relative speed between itself and its neighbors in same cluster using equation 6, where S_{avg} represents average

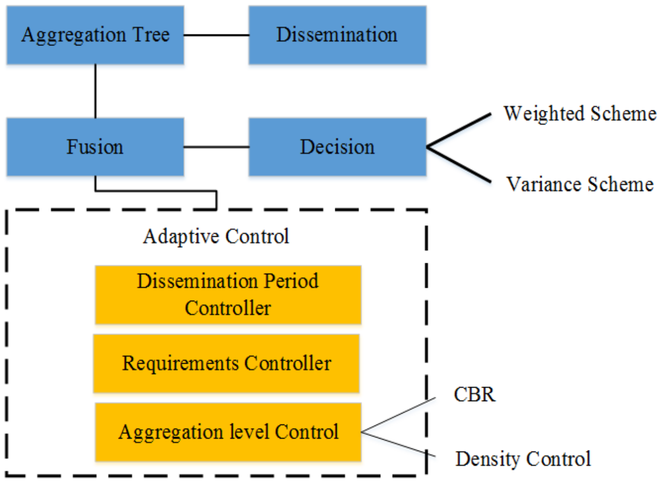


Fig. 4: Aggregation framework

speed of all its neighbors in same cluster. $S_{i,nei}$ represents difference of speed of vehicle i and average speed of vehicle i neighbors. From equation 7, each vehicle calculates its chance to become the CH. α is the weigh factor, where higher value of represents more weight to vehicles nearer to back end of cluster. The value of α can be anywhere between 0 and 1. The vehicle with minimum value of equation 7 is elected as CH.

$$\triangle D_{i,bend} = \sqrt{|D_{xbend} - D_{xi}|^2 + |D_{ybend} - D_i|^2} \quad (1)$$

$$S_{avg} = \left(\frac{S_1 + S_2 + S_3 + ...S_n}{n} \right) \quad (2)$$

$$\triangle S_{i,nei} = |S_i - S_{avg}| \quad (3)$$

$$F_i = \alpha \times \frac{D_{i,bend}}{R_{trm}} + (1 - \alpha) \times \frac{S_{i,nei}}{S_{max}}$$

(4)

B. Aggregation

In aggregation phase, aggregation framework shown in figure 4 provides a foundation to design CBSDA scheme. It is developed based on a modular architecture with five main modules. Each of them has a well defined interface that allows to interchange different implementations of a module easily. Each phase of the aggregation process is represented by a single module. When a CH receives vehicular information the data is stored in a data structure. The decision component chooses the most similar data records for fusion to achieve high data precision. It is based either weighted or variance scheme. The fusion component fuses the data which has been selected by the decision component. The data dissemination component defines when and how data is disseminated by a CH to the next CH in the direction of the control center. The adaptive control is responsible for the reliable delivery and the end-to-end delay. It monitors the CBR and density of vehicles in order to control the aggregation level of CBSDA scheme.

In this paper, we focus on the schemes used in decision and adaptive control component. Weighted deviation scheme is introduced in the decision component for selecting the vehicles that can be fused each other. In adaptive control component, a two new schemes are proposed to increase and decrease the aggregation levels based on the current CBR and density of vehicles.

IV. Aggregation Decision

The decision component takes a set of nodes as input and identifies two suitable nodes for fusion among the input set. This section introduces the Weighted deviation scheme for decision component.

A. Weighted deviation scheme

The goal of maintaining extreme data records while fusing many similar vehicles and there by maintain as much precision of the data as possible. Thus, fusing similar objects is preferable.The weighted deviation decision uses a weight function to calculate the fusion costs of two vehicles a and b, considering all contained parameters. Let consider two parameters taken into consideration here are the velocity and position of the vehicles. p denote the set of parameters and a_i be the value for the i-th parameter of node a. Furthermore, let w_i be the weight for parameter i. σ_t^i is the standard deviation of the ith metric calculated at periodic intervals of time t. Then, the cost can be calculated as indicated in equation (5).

$$cost = \sum_{i \in p} w_i * |\frac{a_i - b_i}{\sigma_t^i}| \quad (5)$$

$$w_1 + w_2 + w_3 \ldots + w_i = 1 \quad (6)$$

$$w_1 + w_2 = 1 \Rightarrow w_2 = 1 - w_1, 0 \leq w_1 \leq 1 \quad (7)$$

Using this notation, assuming a system using only two parameters $P = \{vel, pos\}$, let the weights be 0.5 for both the velocity and position. The weights allow to determine the importance of velocity and position. Furthermore, by varying weights from 0 to 1 can determine the best performance of decision component.

V. Aggregation Level Control

The aggregation level control shown in figure 2 decides when to increase or decrease the aggregation level in the framework. In this paper, we propose two methods that are CBR and Density Control. These methods will be described in detail in following sections.

A. CBR Control

CBR control method only considers two extreme values that are minimum and maximum value of CBR for each CHs. The aggregation will be done in order to keep the CBR between these two extremes. In this method, aggregation level of all CHs starts at level 0 and only increased to level 1, when the CBR of a particular CH overshoot the maximum CBR defined for a five consecutive times. Additionally, same steps are followed to reach the maximum aggregation level possible. For example, we consider for a particular CH to have level 9 and the CBR below minimum CBR for five consecutive times. Using this method, few number of aggregations is necessary to keep the CBR between the defined levels.

B. Density Control

$$DW = \frac{D_{max} - D_{min}}{n} \tag{8}$$

Aggregation Level 0	$0 < D < 20$
Aggregation Level 1	$20 <= D < 40$
Aggregation Level 2	$40 <= D < 60$
Aggregation Level 3	$60 <= D < 80$
Aggregation Level 4	$80 <= D < 100$
Aggregation Level 5	$100 <= D < 120$
Aggregation Level 6	$120 <= D < 140$
Aggregation Level 7	$140 <= D < 160$
Aggregation Level 8	$160 <= D < 180$
Aggregation Level 9	$180 <= D =< 200$

TABLE I: Aggregation levels based on channel busy ratio (CBR)

In density control, the two extreme values that are minimum and maximum number of possible vehicles in the cluster in a certain time and the number of aggregation levels are considered here. The density window size (DW) for each aggregation level can be calculated from equation (8). Where D_{max} is the maximum density of vehicles possible in a cluster, D_{min} is minimum number of vehicles in the cluster possible and n is number of aggregation levels. This method can be explained further using an example, from table 1 n is considered as 10, $D_{max} = 200$, and $D_{min} = 0$. The DW size is calculated and each window size is assigned to each aggregation level. Firstly each CH checks the number of vehicles in the cluster using the CAM message it received recently and compares with the aggregation level size. If there is a change then it updates its aggregation level. In density control the CH checks its number of CMs every $1sec$.

VI. CBSDA Data Structure

One of the key component of all aggregation schemes is their data structure. The data structure supports storing different data types, combining data of multiple sources into one structure and size reduction by data fusion. The level of aggregation is also easy to adjust using the tree as data structure. In general, the fewer nodes the tree contains, the less bandwidth it needs during transmission. The CBSDA scheme shown in figure 5 uses super cluster, cluster and CM nodes. The cluster node contains the vehicular data, cluster length and

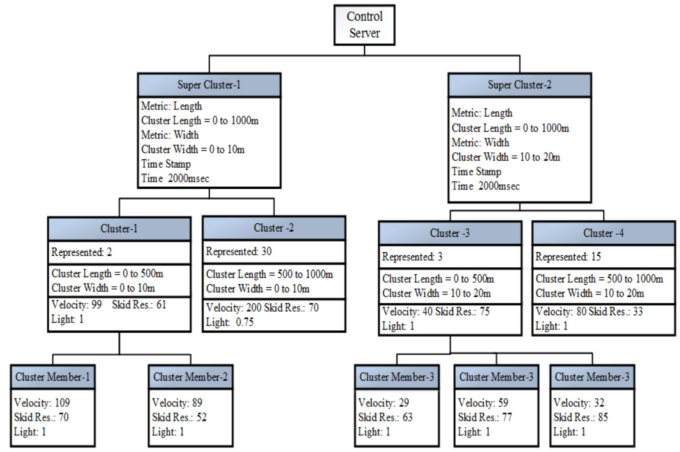


Fig. 5: CBSDA Data structure

cluster width, while CM nodes contains only vehicular data. The super cluster node consists of three metrics the length and width of the cluster and time stamp.

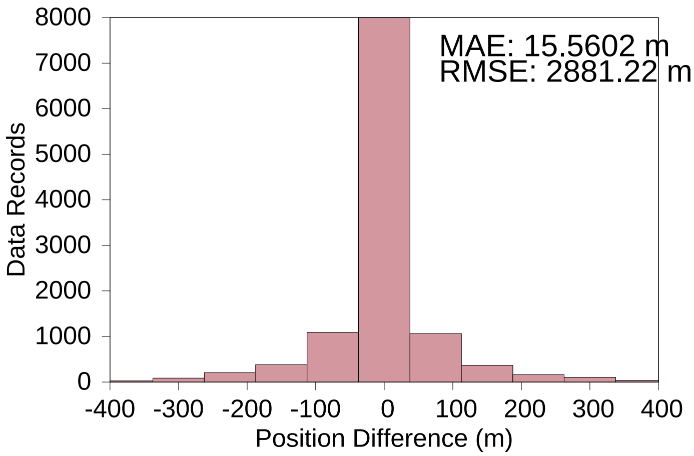
The first super cluster metric is cluster length (CL) which is user defined. The three metrics of super cluster are useful when the application requires a defined resolution of data quality. The cluster length can be anywhere between minimum of 50 meter and maximum of 1000m shown in II. Second metric defined is the cluster width, this defines how many lanes are considered in the super cluster. Third metric used here is the time-stamp metric, which records the time the data item was broadcasted by a CM to the CH. Thus, the imprecision of the length, width and time-stamp will never be higher than the specified maximal sizes. The number of super cluster nodes itself can be limited by assigning appropriate value to cluster length and width compared to the road length and width. Moreover, the number of aggregation level also depend on the cluster length and width. When keeping the children limit constant and increasing the cluster length of the super cluster, the tree shrinks and cluster, CMs are fused. In contrast, when the cluster length of the super cluster is reduced, the tree grows. The CBSDA scheme with two different adaptive aggregation level control schemes is simulated to evaluate the performance. The precision is expected best with more super cluster then there will be less fusion of cluster and CMs.

Aggregation Level	0	1	2	...	9
Cluster length (CL)	$CL \geq 50$	$\frac{CL_{max}}{2^8}$	$\frac{CL_{max}}{2^7}$	...	$\frac{CL_{max}}{2}$

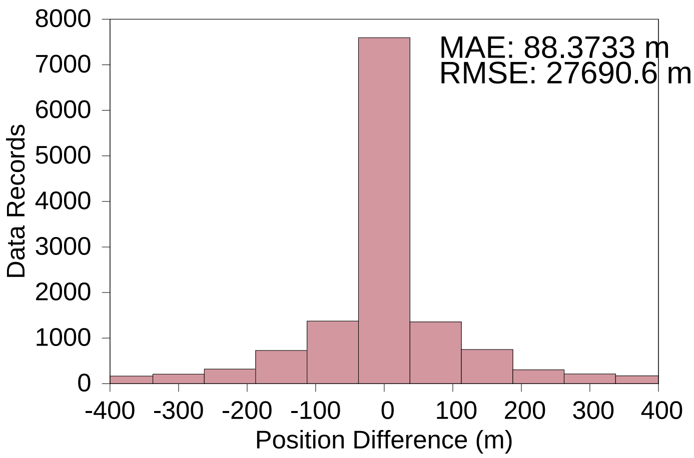
TABLE II: CBSDA scheme with varying cluster length

VII. Simulation Results

The network simulator ns-3.18 was used for evaluation. It was enhanced by ITS modules enabling simulation of ETSI ITS-G5A [1] and GeoNetworking protocols [13] as well as positioning and simple mobility modules. The simulation is setup based on the parameters shown in table III. In this section, we evaluate the performance of the CBSDA scheme with decision schemes. The evaluation parameter used for decision scheme

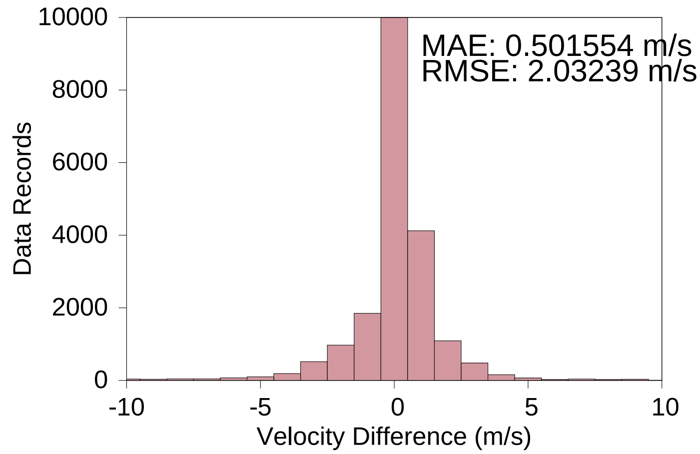


(a) Weighted Deviation Density Control

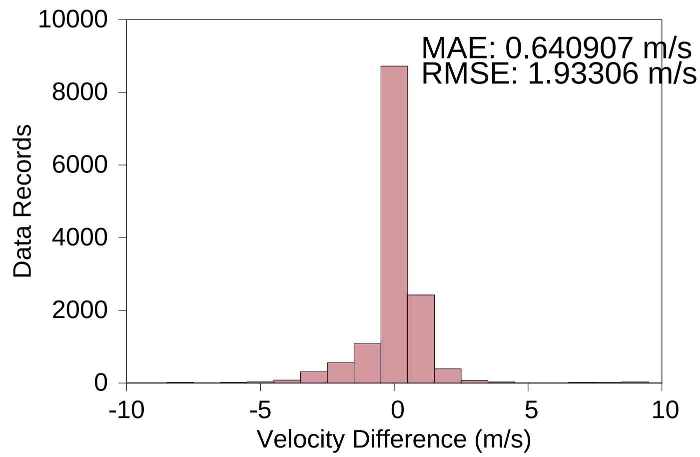


(b) Weighted Deviation CBR

Fig. 6: Position Precision



(a) Weighted Deviation Density Control



(b) Weighted Deviation CBR

Fig. 7: Velocity Precision

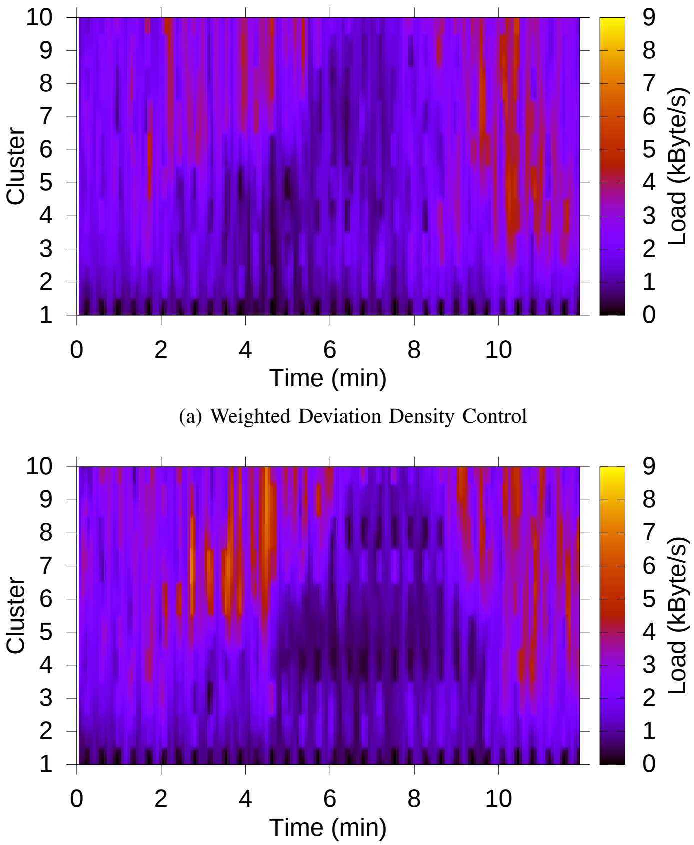
Data Rate	$6MBit/s$
Frequency	$5.9GHz$
Transmission power	$15dBm$
Highway length	$10km$
Number Of Vehicles	1500
Speed of vehicles	$20-40m/s$
Traffic Jam	$4min$
Number of clusters	10
Number of Aggregation levels	10
Cluster Length	$1000m$
Cluster Width	$20m$
Maximum CBR	0.43
Minimum CBR	0.27
Propagation model	$Nakagami$

TABLE III: Simulation setup

is by comparing their precision of velocity and position in the server. Then, we compare the Density control scheme with CBR scheme of the aggregation level control to measure how adaptively the aggregation level changes based on the number of vehicles in the cluster and CBR of CH. Finally, CBSDA scheme with CL=1000 is used to compare with both decision and aggregation level control schemes. The main objective of the CBSDA scheme using the density control is to reduce the load on the wireless channel during high density scenario. On the other hand, CBSDA with CBR control reduces the load according to the maximum value of CBR allowed in particular application. The CBR is defined as the ratio of the time a wireless device of a CH is busy to the total time.

Data precision is an important performance indicator to evaluate decision schemes. The data fusion introduces an error that each decision scheme aims at keeping low. The error introduced by each scheme is compared in two metrics: position and velocity. Each figure states the number of data records received with a certain error, the average difference from true value (Mean Absolute Error - MAE) and the Root Mean Square Error - RMSE. During free flow traffic all schemes deliver data precision with no errors because the CBR threshold was not exceeded. During traffic jam, however, the weighted deviation scheme using lossy data fusion introduce different errors.

The precision regarding the position metric is illustrated in Figure 6. The weighted deviation with density control has the lowest MAE of 15.6 meters compared to weighted deviation with CBR control has the MAE with 88.37 meters. Figure 7 shows the precision analysis of the velocity metric. The velocity metric is more precise in both the weighted deviation with Density control and weighted deviation with CBR control scheme.



(a) Weighted Deviation Density Control

(b) Weighted Deviation CBR

Fig. 8: Aggregated Data

The distribution of received aggregated data over time for all CHs is shown using the heat map in figure 8 for weighted deviation scheme with all aggregation level control schemes. The data load is high in free flow traffic (0-2 min) with CBRs below thresholds and low aggregation levels. Aggregated data increases significantly in the traffic jam situation $(4-7min)$ starting at clusters $4-5$ and extending up to cluster 9 as the dense traffic moves forward slowly.

VIII. CONCLUSION

In this paper, we presented a CBSDA protocol that forms a stable cluster and elects a stable CH. CH is elected based on the relative speed between neighbors and distance from the back end of the cluster. Moreover, CBSDA data structure is used for storing the data values of the network. The cluster length of the super cluster, and clusters can be depending upon the aggregation requirement of various applications. A new weighted deviation based decision scheme for data aggregation is introduced here. The decision scheme were evaluated using data precision graphs to understand advantages of the scheme in decision making for fusion of cluster and CM nodes. In further simulations, clusters linked to CHs will be implemented in different traffic scenarios.

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