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ANALYSIS OF VEHICULAR STABLE CLUSTER-BASED DATA AGGREGATION

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Abstract

In-network data aggregation contributes the usage of bandwidth and co-existence of different applications in vehicular ad-hoc networks (VANET). In data aggregation, VANET are grouped into two categories. These are structure free and structure based data aggregation. In structure-free data aggregation, vehicles apply pre-defined delay value before forwarding a data packet to the next hop. The performance of data aggregation based on structure based data aggregation uses a hierarchical structure that it based on either road information or vehicles. To provide efficient and scalable VANET communication, data aggregation is essential for reducing per vehicle bandwidth requirements. In this paper, we propose a multi-hop structure based data aggregation method namely VeSCA. In this method, mobile nodes are grouped based on relative mobility with minimum overhead cluster construction and cluster members apply data aggregation before forwarding data packet to the parent node. We demonstrate superior performance VeSCA compared both previous cluster based data aggregation and alternative aggregation mechanism via extensive simulations in ns-3 with the vehicle mobility input from the Simulation of Urban Mobility (SUMO) by using various key metrics of data aggregation ratio, delay and aggregated data delivery ratio.

Keywords: ADPDR, SUMO, VANET, VeSCA, VIB and WSN.

I. Introduction

VANET is a emerging technology that it improves the safety of transportation systems via efficient data dissemination. VANET applications of intersection collision warning, lane merge assistance and emergency vehicle warning [1] requires delivery of event messages to the vehicles in a geographical area. Once an event is detected, a data packet is generated and transmitted in a multi-hop manner to reach the vehicles which are possibly several kms away. During the dissemination process, each vehicle behaves individually, senses the environment and generates periodic data packets with date repetition rate 1Hz. This repetitive packet generation causes redundant data packet transmissions which degrades the available bandwidth. IEEE 802.11p suffers from heavy traffic scenarios where dissemination of data packets in multi-hop manner causes scalability problems and broadcast storm [5], high packet collision & low data packet delivery ratio. In-network data aggregation consists of merging data packets from various data sources and generating refined data packet for transmission. Redundant data transmission can be successfully reduced by using this approach. The two categories of structure free data aggregation where nodes apply pre-determined delay value before forwarding a data packet to the next node with the goal of making data packets meet

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on the same node for aggregation and structure based data aggregation where a structural organization is constructed via splitting the road or grouping mobile nodes and data packets from the same road segments or data packets at forks are aggregated. In WSN, data aggregation aims to gather the critical data from sensors and sends it to the sink node to achieve; energy efficiency and minimum data latency [9]. However, the main purpose of WSN is to maximize the network life-time via energy-efficient data aggregation. Several structure-based WSN aggregation techniques have been proposed [10] using tree hierarchy and merge applied at the forks. WSN aggregation schemes assume that one base station of sink node initiates queries to collect aggregated data sensed by nodes and they all perform data aggregation individually.

Ref.	Aggregation Tech.	Aggregation Params.	Aggregated Data	Mobility Traces	Performance Criteria
[6]	Structure-Free	Speed	Traffic Information	-	Delay, Data Delivery Ratio,Throughput
[7]	Structure-Based	Weight of Information	Traffic Information	-	# Clusters, # Data Packets
[8]	Structure-Free	-	No Information	Gauss-Markov Model	Data Accuracy, Delay
[9]	Structure-Free	Fuzzy Reasoning	Traffic Information	-	Accuracy, Speed
[10]	Structure-Free	Age and Distance	Free Parking Space	VISSIM [11]	Delay, Transmission Range
[12]	Structure Free	Age and Distance	Traffic Information	VISSIM [11]	Accuracy
[13]	Structure-Based	Age and Sector	Traffic Information	-	-
[14]	Structure-Free	Age and Sector	Traffic Information	-	# Data Packets
[15]	Structure-Free	Fuzzy Reasoning	Traffic Information	GrooveNet[16]	# Data Packets, Delay
[17]	Structure-Based	-	Location Information	-	# Data Packets
[18]	Structure-Free	Distance	Location and Speed	Not Mentioned	# Data Packets

Table 1. Data Aggregation in VANET

II. Related Work

Data packets are transmitted and aggregation is performed on received data packets. Used performance criteria are number of data packets; where aggregation is expected to decrease the transmitted data packets, delay; overall average delay of data packets, data delivery ratio; ratio of successfully delivered data packets. [6], [8], [9], [10], [12], [14], [15] & [18] focus on structure free data aggregation techniques; [6] splits the road into segments and performs segment based data aggregation on periodic beacon messages, [8] models the data aggregation problem as a multi-objective optimization problem and exploits particle swarm optimization meta-heuristic algorithms, [9] uses fuzzy rule based technique to decide performing data aggregation, [10] splits the city area into non-overlapping hierarchical organization and performs section based data aggregation for free parking space discovery, [12] performs probabilistic data aggregation via using Flajolet-Martin sketch technique on grouped map data, [14] compares and analyzes the received data and stores it in specialized data structure which transforms the network message traffic into multilevel filtering system, [15] uses Q-Learning algorithm [12] to compute the packet delay and dynamically applies computed delay to make the data packets meet at the same node for data aggregation, [12] uses specialized data structure for aggregation process and tries to detect the attacker in the network.

In particular, while performing structure-free data aggregation two main problems become prominent.

1) Aggregated packets need to be routed on-the-fly which eventually causes low data packet delivery ratio.

2) Mobile nodes do not have their superior nodes therefore cannot decide how long to wait before forwarding data.

Alternatively [7], [13] perform structure based data aggregation; [7] performs clustering on vehicles and conveys the aggregation process to elected cluster heads, [13] uses road side unit (RSU) to collect data from vehicles and performs hierarchical data aggregation on RSU. However, performing data aggregation on highly dynamic topologies requires structured methods with minimum communication overhead. In this paper, we propose a minimum overhead stable multihop cluster based data aggregation method with the goal of minimizing the number of data packet broadcasting and maximizing the aggregated data packet delivery ratio. The inventive contributions of the paper are three folds.

a) Structuring part aggregation performed on vehicles and provides min. overhead & max. cluster stability.

b) Perform extensive analysis of the performance of data aggregation over wide range of performance metrics of data aggregation ratio, aggregated data packet delivery ratio & average delay.

c) Vehicular stable cluster based data aggregation is simulate data aggregation in multi-hop clustered network in vehicle mobilities by SUMO.

III. System Model

In the vehicular stable cluster based data aggregation system model, vehicles are clustered based on MO-VMaSC which is minimum overhead (MO) version of our earlier work VMaSC [12]. The vehicles form a multihop clustered topology in each direction of the road. Cluster members (CM) only communicate with their corresponding parent vehicle PARENT (either CH – Cluster Head or CM). The vehicles have a GPS receiver and vehicle information base (VIB) of a vehicle consists of a repository storing the information of the vehicle. VIB is used in determining the members and heads of each cluster.

IV. DESCRIPTION

We describe the algorithm & the cluster formation and notations specified in Table 2.

1. Cluster Formation: Each node includes the information of the vehicle itself & neighboring vehicles. On a packet receipt, VIB is updated.

Notation	Description
LOC_{DATA}	Location information of data packet
AGE_{DATA}	Difference between current & transmission time of data packet
ID_{DATA}	Data packet generator id
SEQ_{DATA}	Data packet sequence number
$DIFF_{LOC}$	Location differences
HELLO_PKT	Periodic hello packet
DATA_PKT	Data packet
AGG_PKT	Aggregated data packet
$STATE_{TIMER}$	Current state timer
IN_TIMER	Initial state timer
SE_TIMER	State election state timer
CH_TIMER	Cluster head state timer
CM_TIMER	Cluster member state timer
TransRange	Transmission range
MAX_HOP	Max. number of hops between CH and CM
CH_ADV	Cluster head advertisement message
MAXMEMBER_CH	Max. members CH can serve
MAXMEMBER_CM	Max. members CM can serve
$PARENT_i$	Vehicle through which vehicle i is connected to the cluster
$CHILDREN_i$	Vehicles that use vehicle i to connect to the CH

Table 2. Notations

The vehicle information includes its direction, location, velocity, current clustering state, the number of hops to the cluster head if it is a cluster member, the ID of the vehicle through which the node is connected to the cluster, the ID of the vehicles that use the node to connect to the cluster head, clustering metric, and the source ID and sequence number of the data packets that are generated recently. During its lifetime, a vehicle can operate under one of the following four states at any given time:

1. INITIAL (IN) is the starting state of the vehicle.
2. STATE ELECTION (SE) is the state of the vehicle in which the vehicle makes a decision about the next state based on the information in VIB.
3. CLUSTER HEAD (CH) is the state of the vehicle in which the vehicle is declared to be cluster head.
4. CLUSTER MEMBER (CM) is the state of vehicle in which vehicle attached to an existing cluster.

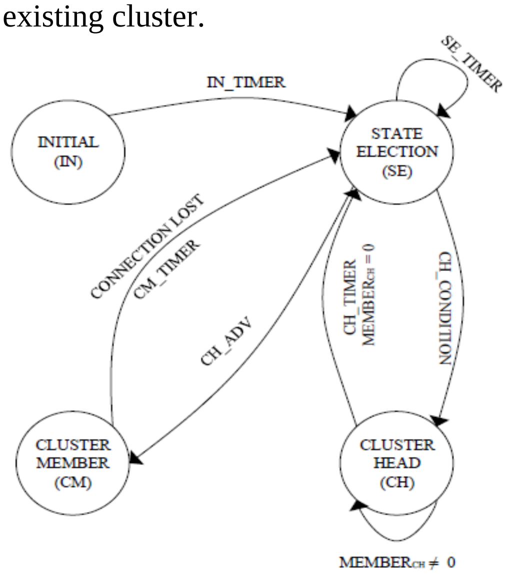

Fig. 1. State Transition of MO-VMaSC

The above figure 1 shows the possible state transitions of a vehicle. The vehicle starts in state IN, stays in this state for a duration denoted by IN_TIMER. The periodic exchange of HELLO_PKT in this state helps the node build its own V IB. The vehicle then transfers to state SE in which it makes the decision about whether to become a CH or CM. In SE, vehicles can go either CH or CM based on evaluated conditions. A vehicle transfers to CH state if the condition CH_CONDITION satisfied where it denotes the condition of having the minimum average relative speed among all vehicles in VIB. In addition, to prevent system from large size clusters, the number of vehicles that a CH can serve is limited to MAXMEMBER CH. If a vehicle in SE state receives a CH ADV from CH then the vehicle transfers to CM state. If no CH ADV is received then vehicle controls 1- hop CM via investigating VIB. If CM that is not MAX_HOP away from CH found, then vehicle tries to connect to this vehicle as multi-hop CM. Likewise, multi-hop cluster member number is controlled so that CM vehicles can serve up to MAXMEMBER CM vehicles to avoid large size clusters. If none of the transitions can be made, then the node stays in state SE for a certain time denoted by SE_TIMER, then reruns clustering algorithm. The transition from state CH to SE is controlled via CH_TIMER where the number of the members of the CH denoted by MEMBER_CH is checked when the CH TIMER is expired. If MEMBER_CH is zero then vehicle changes states to SE. Finally, the transition from CM to SE occurs if the vehicle has lost connection to the neighboring node through which it is connected to the cluster. When the CM_TIMER expires, CM vehicle checks the VIB to control if it receives packet from parent vehicle. If CM vehicle does not receive any packet from parent vehicle, CM vehicle assumes that it has lost the connection and changes state to SE. MO-VMaSC differs from our previous works VMaSC [6] in maintaining cluster structure. MOVMaSC does not require explicit message exchange between vehicle pairs. Instead, it only uses CH ADV of CHs and periodic HELLO PKT to control cluster structure.

2. Data Aggregation: The aim of VeSCA is to aggregate the data packets and disseminate the aggregated packets at a certain vehicle to all the vehicles within a geographic area with small delay and high delivery ratio. The data aggregation and forwarding at a vehicle depends on its clustering state. If its clustering state is SE, the vehicle broadcasts the DATA_PKT so that it reaches a member of any cluster in the network. If the clustering state of the vehicle generating or receiving a DATA_PKT is CM or CH, the vehicle runs Algorithm 1.

Algorithm 1. Data Aggregation Algorithm

on DATA PKT generating or receipt;
Extract ID_{DATA} and SEQ_{DATA};
if (ID_{DATA}; SEQ_{DATA}) V IB then
if DATA_PKT is from $PARENT_{curr}$ then
    Multicast DATA_PKT to $CHILDREN_{curr}$;
    else
for all the DATA_PKT 2 V IB do
    Extract LOC_{DATA} and AGE_{DATA};
    if AGE_{DATA} < $STATE_{TIMER}$ then
    $DIFF_{LOC}$=LocDiff(DATA_PKTs);
    if $DIFF_{LOC}$ < TransRange then
        Combine DATA_PKTs;
        Construct AGG_PKT;
for all the AGG_PKT 2 V IB do
if CM then
    Unicast AGG_PKT to $PARENT_{curr}$;
else if CH then
    Broadcast AGG_ PKT;

In this algorithm, data aggregation process starts when a data packet is received at a vehicle. Vehicle checks whether the packet has been already received via checking the VIB. If vehicle receives the data packet for the first time, it checks the source of the packet. If it is coming from its parent vehicle in cluster tree, denoted by $PARENT_{curr}$, then it multicasts the packet to all its children. If packet is coming from its children or other vehicles, then vehicle investigates the VIB to find similar data packets for aggregation. For all data packet in VIB, location and transmit time information are extracted. If data packet is received in current state time duration then location differences of data packets are compared. If location differences of data packets are smaller than transmission range of vehicle and if they are not aggregated before, packets are combined and aggregated data packet is constructed. After aggregation process, instead of sending data packet individually, aggregated data packets are forwarded by controlling the vehicle current state.

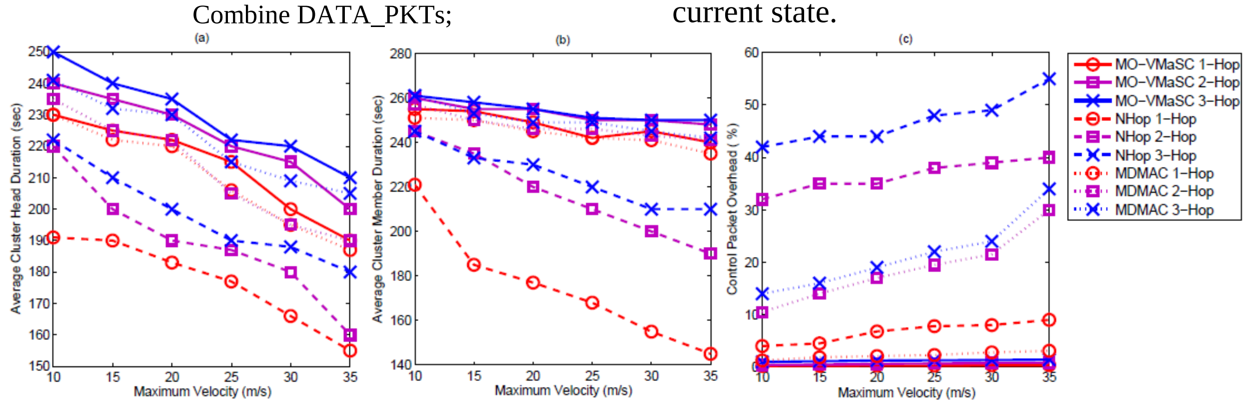

Fig. 2. Clustering Results of different algorithms at different maximum velocities for

(a) Average Cluster Head Duration (b) Average Cluster Member Duration (c) Control Packet Overhead

V. Performance Evaluation

The proposed vehicular stable cluster based data aggregation technique implemented by Network Simulator – NS3 [11] and used the topology of network generated by Simulation of Urban Mobility (SUMO) [12]. It is an open-source, space-continuous, discrete-time traffic simulator capable of modeling the behavior of individual drivers. The acceleration and overtaking decision of the vehicles are determined by using the distance to the leading vehicle, traveling speed, dimension of vehicles and profile of acceleration deceleration. Our scenarios consist of a two-lane and two-way road of length 5 km. The total simulation time is 600 s. The clustering process starts at 300 s when all the vehicles have entered the road. All the performance metrics are evaluated for the remaining 300 s. Table III lists the general simulation parameters of the VANET, and the default values.

Table 3. Simulation Parameters

S. No	Parameters	Value
1	Number of vehicles	100
2	Area range	1000 x 1000m
3	Transmission Range	200 m
4	MAX_HOP	1, 2 & 3
5	Maximum Velocity	10 - 35 m/s
6	MAXMEMBER_CH	5
7	MAXMEMBER_CM	1
8	Simulation Time	300 s
9	HELLO_PKT period	200 ms
10	HELLO_PKT size	64 bytes
11	DATA_PKT period	1 s
12	DATA_PKT size	1024 bytes
13	VIB_TIMER	1 s
14	IN_TIMER	2 s
15	SE_TIMER	2 s
16	CH_TIMER	2 s
17	CM_TIMER	2 s

Initially, we evaluate and compare the efficiency of clustering algorithm for cluster stability and overhead. Next, we conduct comparative performance analysis of vehicular stable cluster based data aggregation. The performance metrics used are average cluster head duration, average cluster member duration, control packet overhead, data aggregation ratio, delay and aggregated data packet delivery ratio. Cluster related metrics used to demonstrate the stability and reduced overhead of clustering algorithm. Alternatively, data packet related metrics used to measure aggregation performance.

1. Minimum Overhead Clustering

The proposed multi-hop clustering is compared to two previously proposed VANET multi-hop clustering algorithms denoted by MOVMaSC. Velocity of the vehicles is used to estimate the duration of the vehicles staying neighbors with each other in determining cluster heads. In the cluster stability, it is measured as average time that vehicle is connected to constructed cluster either being a CH or CM. To measure the cluster stability, CM & CH duration are computed. CH duration is defined as the time period from when a vehicle changes state to CH to when a vehicle transfers from state CH to state SE or CM. CH duration is computed by dividing the total CH duration by the total number of state changes from CH to another state.

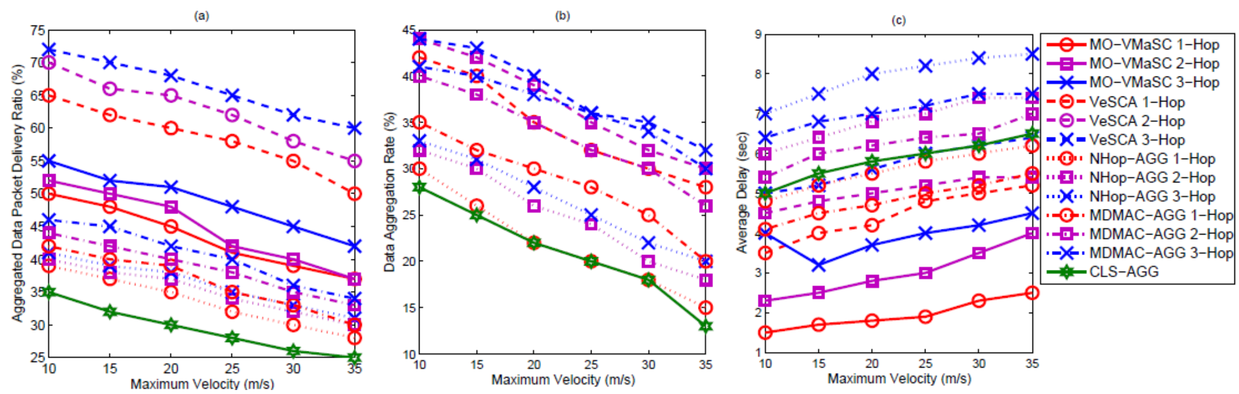

Fig. 3. Aggregation Results (a) Data Packet Delivery Ratio, (b) Data Aggregation Rate (c)Average Delay

Similarly, cluster member duration is computed by dividing the total cluster member duration by the total state changes from CM to another state. Fig. 2-a and Fig. 2-b show the average cluster head duration and average cluster member duration of different clustering algorithms for different maximum vehicle velocities. For all scenarios, MO-VMaSC has higher cluster head duration and cluster member duration than NHop and MDMAC. Due to higher chance to find a member to serve in multi-hop scenarios, as the hop number increases, head duration and member duration also increase. However, increase in velocity makes network topology change rapidly and causes decrease in cluster head duration and member duration. Clustering control packet overhead is defined as the ratio of the total number of clustering related packets to the total number of packets generated within the VANET. In the figure 2-c shows that the control packet overhead of different clustering algorithm for different maximum number of hops at different vehicle velocities. For all scenarios, MO-VMaSC has lower control packet overhead compared to other multi-hop clustering approach. This is because, MO-VMaSC has no explicit message exchange for cluster construction or maintenance like join request or join response.

2. Data Aggregation

Vehicular stable cluster based data aggregation is compared with previously proposed cluster based data aggregation approach in [7] namely CLS-AGG where network is grouped into clusters and elected CH performs data aggregation.

To compare the effect of clustering on data aggregation, previously proposed multi-hop clustering techniques; NHop [8] and MDMAC [9] are integrated with Algorithm 1 namely NHop-AGG and MDMAC-AGG respectively. In aggregated data packet delivery ratio (ADPDR), it is defined as the average ratio of the total number of vehicles successfully receiving AGG PKT s to the total number of the vehicles within the target geographical area. Figure 3-a shows ADPDR of different algorithms in different velocities with different maximum number of hops. For all scenarios, vehicular stable cluster based data aggregation has higher ADPDR than other cluster based aggregation techniques. The main reason behind this is the underling cluster structure where MO-VMaSC clustering maximizes the cluster life time in a way that collected data packets in parent nodes are aggregated efficiently. In addition, as the vehicle velocity increases, ADPDR value decreases. This can be explained via Fig 3-b where the velocity degrades the data aggregation rate. Highly mobile vehicles change location randomly and affect the aggregation process which eventually decreases the aggregated data delivery. In addition, as the hop number increases, ADPDR also increases. This is because of multi-level aggregation where data is aggregated in different hops up to CH for dissemination.

The data aggregation ratio is computed as the ratio of aggregated data packet counter to the number of generated data packets. Data aggregation ratio demonstrates the efficiency of underlying aggregation protocol in terms of how many packets are generated and how many of them are aggregated. Figure 3-b shows aggregation ratio of different aggregation techniques at different vehicle velocities. Compared to other cluster based aggregations, vehicular stable cluster based data aggregation has high data aggregation ratio. Moreover, we observe that increasing the maximum number of hops allowed increases the data aggregation ratio where more packets can be aggregated at forks up to parent vehicle. Furthermore, data aggregation ratio in all scenarios has tendency to decrease as the velocity increases. Data packet generated different location and mobile nodes change location randomly due to network dynamicity.

The metrics of average delay is defined as the average latency of the AGG_PKTs that travel from their source to the vehicles within the target geographical area. Figure 3-c shows the average delay of different aggregation algorithms in different velocity scenarios. Vehicular stable cluster based data aggregation has lower average delay value compared to other aggregation embedded approaches in all scenarios. The delay value of pure MOVMaSC is less than aggregated version, MO-VMaSC has lower data delivery ratio. Due to the dissemination of parent nodes, they broadcast the coming data packet without performing data aggregation. Data aggregation enables parent nodes to disseminate low number of packets but increases average delay of dissemination process.

VI. CONCLUSION

Our proposed a novel multi-hop structure based data aggregation technique vehicular stable cluster based data aggregation of vehicles are grouped based on relative mobility and CM perform data aggregation before forwarding a data packet to the next hop. Extensive simulations in NS3 with the vehicle mobility input from SUMO demonstrate the superior performance of the vehicular stable cluster based data aggregation over both earlier proposed cluster based data aggregation and alternative aggregation mechanisms. The study of aggregation is directly related with the underlying cluster structure and cluster stability plays an important role in the aggregation ratio.

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