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A TDMA-BASED SMART CLUSTERING TECHNIQUE FOR VANETS

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ABSTRACT

A vehicle's on-road time since the last pit stop has to be taken into account while forming clusters using Vehicular Ad-hoc Networks (VANET). This is important so as to keep the vehicles at optimum driving conditions and to provide rest to the driver at regular intervals. To the best of our knowledge, no clustering scheme has considered this important practical issue while designing a routing protocol for VANET. In this paper, we present a dynamic and stable cluster-based MAC protocol with a more realistic selection metric that includes the vehicle's on-road time and position messages like relative speed, direction and connectivity among neighboring vehicles while giving priority to vehicles joining a cluster. Our proposed Travel Time Based Clustering Approach (TTCA) is based on a TDMA-based MAC scheme and has been simulated using OMNET++ and SUMO. The results express a significant improvement in terms of cluster stability and throughput against existing approaches.

Keywords: *Vehicular Ad hoc networks, Cluster, TDMA, OMNET++, SUMO*

1. INTRODUCTION

Among the various application areas of Mobile Ad hoc Networks (MANET), Vehicular Ad hoc Networks (VANET) looks as the most promising area to be actively implemented in the near future. VANET has caught the attention of the academic community, government and the auto industry and is well positioned to play a major role in the realization of Intelligent Transport Systems (ITS) [1]. ITS have two main functionalities, namely to increase road safety and increase commercial purposes. Road safety can be increased by letting vehicular users to communicate among themselves about road conditions. This communication is further classified into critical messages like accidents or landslides and non critical information like parking lot information and road congestion notification. Since a car user may spend up to two hours a day while travelling, ITS can be made to provide infotainment services like email, newscasts and access to social networking media. Towards these ends, VANET enables the possibility of Vehicle-to-Vehicle (V2V) as well as Vehicle-to-Infrastructure (V2I) communications through a Dedicated Short Range Communication (DSRC) spectrum.

VANET is characterized by high mobility, lack of online centralized management and coordination entity and highly partitioned networks [2]. A number of VANET research projects have been initiated and tested in recent years. Some of them are In-Vehicle Signage using Road Side Equipments (RSEs), Probe Data Collection, Electronic payment for Tolling and Parking applications and Traveler Information/Off-Board navigation [3]. Yang et al.[4] have identified that by sending warning messages at least half a second prior to an imminent collision will reduce accidents up to about 60%.

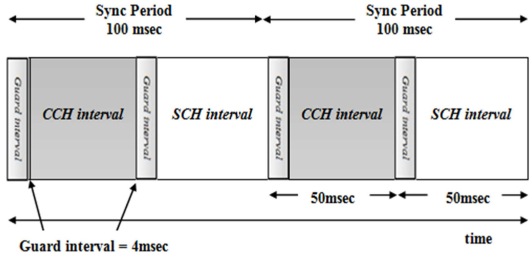

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Figure 1: Division of time into CCH intervals and SCH intervals, IEEE 1609.4 standard

All these applications that are used for safety purposes in a vehicular environment must be designed with stringent reliability and delay considerations. Safety messages are based on broadcast transmission and the existing IEEE 1609.4 trial standard for WAVE [5] allows a single DSRC radio [6] for both safety and non-safety applications. Figure 1 shows the division of time into control channels(CCH) and service channels(SCH) along with a guard interval of 4 msec. In the US, the Federal Communications Centre (FCC) allocated 75 MHz of spectrum for dedicated short-range vehicular communications. In the UK and across the EU, 30 MHz of spectrum has been set aside for vehicular networks. However, it has been found in [7] that at high traffic densities, DSRC based up onCarrier Sense Multiple Access with Collision Avoidance(CSMA/CA) mechanism cannot provide high reliability. An alternative mechanism in such scenarios would be to opt for a more reliable TDMA scheme.

Time Division Multiple Access (TDMA) is a channel access mechanism where the available bandwidth is slotted into time divisions and each division is used only by a single sender, thereby avoiding packet collisions. However, TDMA need modifications to be used in ad-hoc networks due to the lack of centralized control and high slot allocation complexity. Conflict-free scheduling mechanisms need to be introduced to ensure slot synchronization and to reduce overhead messages [8]. Clustering is a natural phenomenon that has been found to occur in highways as vehicle exhibit platoon behavior and tend to travel in groups. Researchers have tried to address the challenges faced by TDMA using various clustering algorithms. We have adopted the dynamic TDMA slot reservation technique followed in TC-MAC[9] where the transmission time is partitioned into consecutive non-overlapping TDMA frames as shown in Figure 2. The SCH and CCH are divided into k equal sized time slots for transferring control and status messages. Each vehicle is assigned a local-id and are said to be aligned. The basic idea is that in each logical frame a vehicle listens to its assigned time slot for status and control messages and sets the corresponding byte in. The number of vehicles (N) may change dynamically and the ClusterHead(CH) is responsible for updating the value of N and is responsible for informing all the vehicles in the cluster about the new value. Cluster stability is an important criterion by which the performance of a clustering algorithm can be measured. Stability has been found to dramatically improve the performance of communication layers by allowing for spatial reuse of resources, simplifying routing and prolonging the link life-time between nodes. In this paper, cluster stability is improved by focusing on carefully selecting the nodes based on a weightage scheme at the time of cluster formation.

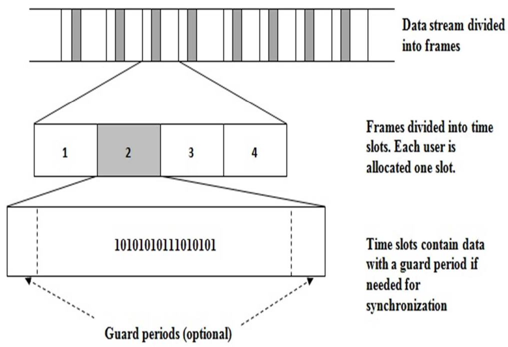

Figure 1: TDMA Time Slot Format

The objective of this paper is to improve cluster stability by proposing a novel TDMA based clustering mechanism based on a vehicle's on-road time and other positional parameters such as network connectivity, inter-vehicular distance and average relative speed of the candidate node and its cluster members. We have compared the new scheme with the existing Stability Based Clustering Algorithm SBCA [21] clustering algorithm designed for stable clusters. The rest of this paper is organized as follows; In Section II, we present the related works. Section III describes in detail about our proposed approach. Section IV provides the simulation setup, Section V presents the results and its analysis, and in section VI, we present the conclusion and future work that can be done.

2. RELATED WORK

The idea of TDMA mechanism providing collision-free transmission using time slots have attracted the research community to develop new innovative protocols with the aim of improving fairness and reducing interference between vehicles. Almost all of the existing VANET clustering schemes have their origin from MANET clustering schemes [11-13], and papers [14], [15] deal with the benefits of clustering such as communication overhead reduction and improved delivery ratio. The main challenge in clustering is

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to reduce the overhead introduced during the election of a CH and maintaining node membership in a highly dynamic and fast changing topology such as in VANET. Almalag et al. [16], have selected a cluster-head among the cluster members based on the lane where most of the traffic flows. Each vehicle is capable of computing its ClusterHeadLevel(CHL) based on its network connectivity level, average velocity level and average distance level. Lane weight is determined based in the total number of lanes on the roadway and the number of lanes for each traffic flow.

In [17], the authors proposed a node precedence algorithm and adaptively identify the 1-hop neighbors and selects optimal CHs based on relative node mobility metrics such as speed, location and direction of travel. It also introduces the zone of interest concept that reflects the frequent changes on the network and provides prior knowledge about the neighbors as they travel into new neighborhood locations.

In [18], the authors have proposed a distributed and mobility aware Cluster based MAC protocol that integrates OFDMA with the contention-based DCF algorithm in IEEE 802.11p. It can also predict the future speed and position of all cluster members. This feature helps a ClusterHead (CH) to decide on changing the used communication range based on the traffic conditions. Cluster members are elected based on the weighted stabilization factor, which is a function of change in its relative speed and direction.CH has two levels of power. The first power level P_t is used to communicate with cluster members and the second power level is used to reach a distance of 2R to communicate with its neighboring CH. Also by using the OFDMA technique, the hidden terminal problem has been addressed.

The authors in [19] present a Hierarchical Clustering Algorithm (HCA) that creates a fast randomized hierarchical cluster with a diameter of at most four hops, without the use of GPS. The above algorithm, during the maintenance phase creates hierarchical clusters in which the maximal distance between a CH vehicle and any other vehicle in the cluster is two hops. The algorithm is considered highly robust, because it does not rely on localization systems like GPS, but by inferring connectivity from sent messages.

The authors in [20] have utilized fixed infrastructure like road-side units to gather information from cluster heads and to fill the communication gap that may occur when any data packet is lost. The RSU units are given the role of selecting the CH according to the environment. The above protocol aims to improve communication between Cluster heads and between neighboring clusters.

The authors in [21] propose a protocol which focuses on reducing the communication overhead by formation and maintenance of clusters. The overall cluster architecture has been based on the idea that the mobile node should be associated with the cluster and not to a cluster head. The protocol has two phases, the cluster setup phase and maintenance phase. In the setup phase, nodes with close proximity to each other are formed into a cluster and during the cluster maintenance stage; a Primary ClusterHead (PCH) and a Secondary ClusterHead(SCH) are selected. Whenever the PCH leaves the cluster, the SCH takes over. This arrangement greatly increases the cluster life time and reduces the overhead involved in selecting a new cluster.

Hassan et al in [22] have proposed a multichannel MAC scheme that focuses on transmitting high priority messages without delay. The scheme also focuses on addressing the problem related to transmission collisions caused by node mobility. It reduces the collision probability by assigning disjoint sets of time slots to vehicle moving in opposite directions and to road side units. This technique helps each node to access the control channel once per frame, thus providing them an opportunity to transmit high priority messages without delay. One drawback of the scheme is that the parameter for decreasing merging and access collision rates needs to be calculated theoretically and needs to be tested under realistic mobility models.

In [23], a distributed algorithm for cluster stability maintenance is proposed. A one-hop neighbor set is formed and based on which each node forms a cluster with its neighboring nodes. The drawback of this mechanism is its unsuitability under sparse traffic conditions. All the protocols discussed so far have their own merits and

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demerits. All the above approaches tend to focus on just the positional information of vehicles and do not take into consideration the temporal aspects of clustering. In our proposed protocol, we take this often neglected aspect in allowing a vehicle to become a cluster member as well as to function as a CH for longer periods of time. Our proposed protocol has been found to increase cluster stability compared to the existing TDMA based approaches.

3. OUR APPROACH

3.1 Key Assumptions

We clarify on the assumptions that we have made for each vehicle travelling independently or with a group of vehicles. Each vehicle has its unique identifier and is equipped with a Global Positioning System (GPS) or Differential Global Position System (DGPS) receiver to obtain its geographical position and to ensure that vehicles have synchronized clocks. A digital map is provided to recognize which lane it is in. Each vehicle is fitted with a wireless transceiver for directly communicating with nodes that are within its communication range and indirectly (i.e. through inter-mediate nodes) with nodes that are not within its communication range. As recommended by DSRC, the transmission range of safety related vehicle-to-vehicle messages is assumed to be 300 meters, and channel contention is resolved using a TDMA based slot allocation mechanism as proposed in [9]. The clustering scheme we are using in our proposed protocol is clusterhead (CH) based, where the cluster decisions is dictated by the CH. Our protocol is based on the multi-channel DSRC layout, with 1 CCH and 6 SCHs. We have considered a highway scenario in the design of our proposed approach. As per [10], 'daily time' refers to the total driving time accumulated between the end of one daily rest period and the beginning of the following daily rest period or between a daily rest period and a weekly rest period. The maximum allowable daily driving time for a vehicle is fixed to nine hours. Thus a vehicle's on-road time needs to be continuously monitored and is achieved by means of a digital tachograph attached to a vehicle's on-board sensor. In 2006, EU has made digital tachograph to be fitted into vehicles as mandatory for monitoring driving times and rest periods.

In our proposed Travel Time based Clustering Approach (TTCA), a weight-based node election system has been developed for allowing a vehicle to be part of a cluster and also to be elected as a CH. This approach is similar to that of the Utility Function [24] and TC-MAC [9], but with a different set of parameters. We have considered the effect of a vehicle's continuous travel time, network connectivity, average inter-vehicular distance, and average velocity for calculating node weight N_w based on which a stable cluster is formed. The higher the value of N_w, the better is the probability for a node to be selected as a clusterhead as well as to be part of any new cluster. The node weight is defined as

$$N_w = (NC_i + \alpha_i + A.S) * \omega_i \qquad (1)$$

Where,
N_w = Node weight
NC_i = Network Connectivity Level of vehicle i.
α_i = Average Intervehicle distance level between any two vehicles
A.S = Average Speed of vehicles
ω_i = Travel time Weightage for vehicle i.

3.2 Continuous Travel Time:

The main aspect of our approach is to give a weightage level for the continuous time travelled by a vehicle, since the last pit stop. The weightage level ω_i is set at the upper limit when the vehicle begins its journey and is inversely proportional to the time travelled T_i. Thus the value of ω_i reduce as the vehicle travels over a period of time.

$$\omega_i \propto \frac{1}{T_i} \qquad (2)$$

3.3 Network Connectivity Value

The network connectivity value Nc refers to the maximum number of vehicles that are within the direct communication range of vehicle i and is defined as

$$Nc_i(t) = \sum_j A(i,j,t) \qquad (3)$$

Where j is a probable neighboring vehicle A(i,j,t) =1 if i and j are connected and is equal to 0, if there is no connection.

Average Intervehicle distance level

$$\alpha_i(t) == \frac{\sum_j \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}}{NV} \qquad (4)$$

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Where (x,y) are the coordinates of any two vehicles and NV is the total number of vehicles that are connected to vehicle i in any lane.

Average Speed:

It refers to the difference between the average speeds of all vehicles in range of clusterheadvehicle i and the potential neighboring vehicle. It is calculated as

$$\text{Average Speed A.S} = \sum_j \left| s_i - s_j \right| \quad (5)$$

where j is a potential neighboring vehicle and i is clusterheadvehicle.

4. SIMULATION SETUP

We have chosen OMNET++/INET [25] as the wireless network simulator since that it implements the IEEE 802.11p standard at both the physical and the MAC layers. We have used the SUMO traffic simulator [26], [27], which is a C++-based open-source space continuous microscopic simulator for vehicular traffic. We use TRACI interface [28] to connect the discrete-event simulator OMNET++/INET with the continuous simulator SUMO. TRACI uses a client/server architecture, where SUMO is configured as a server and OMNET++is configured as a client. The client sends request commands to SUMO to perform the simulation run or for accessing environmental details. SUMO responds with a status response to each command and a traffic trace is generated after each action. Both the requests to the SUMO and the traffic traces from SUMO are transported using TCP/IP written in INET. The TCP segment consists of a small header that gives the overall message size and a set of commands or traffic traces contained in the segment. Each vehicle in SUMO is mapped to a mobile node in OMNET++. We have extended OMNET++ with a module that allows us to define the specification of a single vehicle node which is created in SUMO. However, the calculation for node's travel time and deleting it once it reaches a threshold is performed in OMNET++. SUMO executes in discrete time steps, and the trace generated by SUMO is parsed by a manager module in OMNET++. The manager module then monitors the traffic trace to the nodes.

The length of the road is set to 10kms. We have tested our scheme in a highway scenario with only sedan type of vehicle in our simulation. The clusterhead that is selected is mainly positioned in the middle of the cluster so that the number of links it maintains with its neighbors is high. It essentially continues moving in the same direction as the majority of the traffic flow.

Each simulation ran for 9 hours, however only the last 6 hours were used for performance metric calculations. This was to ensure that sufficient numbers of vehicles are injected into the scenario and clusters are formed with minimum of 30vehicles per km and has an elected cluster head before measuring its performance. Table I shows the simulation parameters that were used to compare the two approaches.

Table 1: Simulation Parameters.

Parameter	Value	Parameter	Value
MAC protocol	IEEE 802.11p, TC-MAC	Mini Slot Size	0.26 msec
No. of vehicles	100	SCH Slot Size	1.6 msec
Vehicle length	4 m	Maximum no of slots per frame	100 slots
Vehicle insertion rate	0.5s	Channel type	Wireless Channel
Vehicle density	50 cars/m^2	Radio Range	300m
Acceleration	5 m/s^2	Radio Propagation model	Two Ray Ground
Maximum speed	60kmph	Antenna model	Omni Directional
Road length	10 kms	Data Rate	6 Mbps
No. of lanes	2	Carrier frequency	5.89Hz
TDMA Frame size	100ms	Beacon interval	5s
Max Safety Packet Size	200 bytes	Maximum Cluster Length	1.4 Km

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Max Non-Safety Packet Size	1200 bytes	Inter vehicular spacing	10m

5. RESULTS

The simulation results show the performance of the existing SBCA clustering algorithm and our proposed approach under similar operating conditions. The simulation was run for a maximum duration of 9 hours, out of which the cluster performance was noted after an initial cluster formation time of 3 hours. Figure 3 shows the stability of the cluster using TTCA as well as SBCA at various intervals of time. We measure the stability of a cluster in terms of cluster stability ratio, which is the ratio of the nodes leaving a cluster and the original number of nodes.

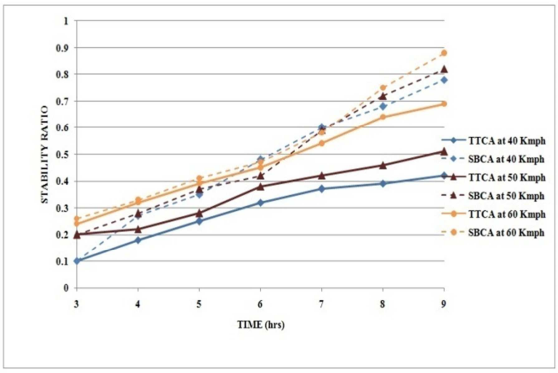

Figure 3: Stability Ratio

The cluster stability is noticed at various time intervals by keeping the initial cluster strength to be constant at 30 nodes and at different average cluster speeds of 40kmph, 50kmph and 60kmph. We have identified a moving cluster to be either in stable region (stability ratio 0.0 to 0.5) or in an unstable region (stability ratio 0.6 to 1.0). Our proposed approach allows a cluster to remain in the stable region for a longer duration than SBCA even at varying travelling speeds. This is because, the nodes of our cluster are selected based on the minimum on-road travel time. This factor allows the nodes following TTCA to remain in a cluster for a longer duration than SBCA. From the simulation result as shown in Figure 4, our TDMA based TTCA scheme consumes fewer time slots than 802.11p based SBCA algorithm. This is because TTCA efficiently utilizes pre-scheduled time slots to transmit data, while the backoff algorithm in 802.11p increases the waiting time, when the number of node increases. In Figure 5, we compare the two techniques based on packet delivery ratio. Results show that compared to SBCA, TTCA has better packet delivery ratio due to less number of packet losses. This is achieved due to better cluster stability.

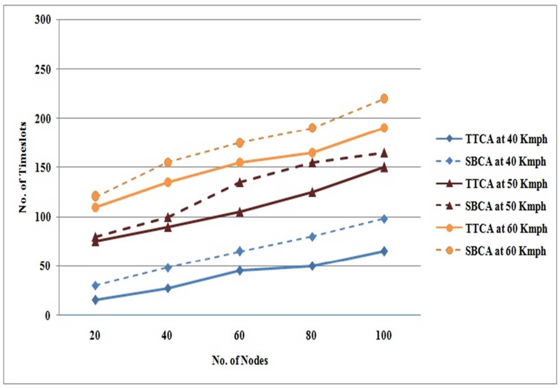

Figure 4: Comparison of Time Slot Usage

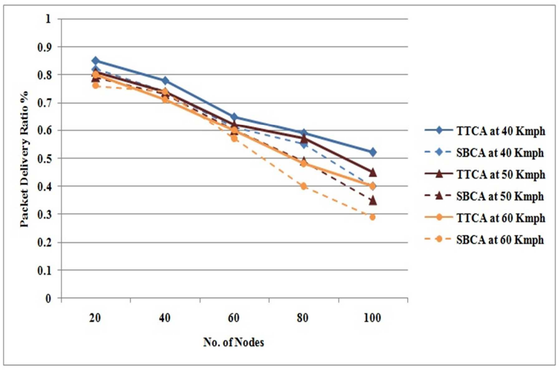

Figure 5: Packet Delivery Ratio

6. CONCLUSION

We have presented Travel Time based Clustering Approach (TTCA), a TDMA based cluster scheduling scheme for VANET based on a vehicle's driving time. As per the existing European Union regulations, a vehicle cannot drive continuously for more than 9 hours. We have given consideration to this overlooked parameter along with traditional cluster formation parameters to form a more stable cluster. The simulation results show that TTCA is able to deliver longer average clusterhead lifetime. In the future, we will further reduce the message overhead of the status message and also extend the functioning of our protocol for

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inter-cluster communications. A mathematical model can be formulated to support our simulation results and an algorithm can be developed for a node to join and leave a cluster.

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