Novel Clustering Algorithm Based on Minimal Path Loss Ratio for Medium Access Control in Vehicle-to-Vehicle Communication System

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Abstract: Emerging vehicular applications such as data transfer, maps, music data updates, and video downloads, pose a host of completely new set of requirements such as maintaining end-to-end connectivity, packet routing, and reliable communication for internet access while on the move. One of the biggest challenges is to provide good quality of service (QoS) such as low packet delay while coping with the fast topological changes. In this paper, we propose a novel clustering algorithm based on minimal path loss ratio which combined with a MAC protocol will reduce data congestion. The resulting system demonstrated higher stability than the existing algorithms by measuring the rate of cluster head changes. In addition, it exhibited higher reliability and efficiency with DBTMA than with CSMA/CA in terms of throughput (with 10% increase), average access delay and packet loss ratio (half the packet loss ratio of CSMA/CA).

1. Introduction

Intelligent transport systems (ITS) have evolved substantially in the recent years with the increase of the range of applications and with the rapid growth of the technology. With cost reduction of wireless technologies, ITS is finding favour in comfort applications such as entertainment, news, remote travel assistance and concierge services [1]. There are organisations such as Car 2 Car Consortium aiming to standardise the optimal communication between vehicles and projects such as CVIS – “Co operative Vehicle Infrastructure Systems”, SAFESPOT – “Smart Vehicles on Smart Roads”, NOW – “Network on Wheels” shows the current research activity undertaken in vehicle to vehicle (V2V) communication. The objectives of these projects are network safety combined with comfort, transport efficiency and environment concerns.

However, the vehicular network applications require a medium access control (MAC) protocol which is fair and efficient. Protocols such as IEEE 802.11 standard use RTS/CTS to avoid collisions from hidden terminals. But the packet delay and data congestion increase rapidly with the number of vehicles contending for the channel in the network. Therefore an alternative concept of clustering of vehicles is considered to optimise the communication and improve network stability between nodes by avoiding flooding of data in the network. Indeed, the medium access control combined with a good clustering technique can overcome the drawbacks of having a broadcast transmission, reduce data congestion and thus increase the probability of success of delivery of safety and comfort message types. A hierarchical clustering system is used for grouping the vehicles and a head is selected for the group based on various constraints. The cluster head is intended to act as a relay point of the communication between vehicles in a cluster and also between vehicles and the roadside base station. The vehicle clustering is periodically updated to reflect the topological changes and vehicle movements. The clustering should operate fast to minimise the time lost and feature low cluster head changes for the stability of the network. Hence, a good clustering algorithm would reduce the fast reconfigurable condition of the dynamic network ensuring a better performance of the MAC protocols.

In this paper, we propose a new clustering algorithm based on minimal path loss ratio. Its performance with a MAC protocol for an intra-vehicle communication system was evaluated in terms of robustness, throughput average access delay and packet loss ratio. The medium used was 802.11p [2-3] standard for high speed data transfer between vehicles. The protocols selected for study are carrier sense multiple access with collision avoidance (CSMA/CA) and dual busy tone multiple access (DBTMA) because they don’t require synchronisation and features low sensitivity to the mobility and topology changes.

This paper is organised into the following sections. Section 2 gives an overview of the proposed system model, Section 3 describes the clustering algorithm and compares it with the different clustering techniques. Section 4 details the system setup, section 5 looks into the analysis of the results and section 6 gives the conclusions.

2. System model

The overview of the proposed system is shown in Fig.1. The system comprises of three main components - a) the mobility model, b) the implementation of cluster dynamics and finally c) the analysis of the performance of the protocol behaviour on the cluster.

The mobility model aims to generate a realistic vehicular traffic flow and facilitate the application of the clustering algorithm. The vehicle arrival time, speed and lane were obtained from Traffic Wales data. The Traffic Wales data set was obtained from the inductive loops in the Swansea-London M4 motorway. There are about 585 inductive loops in this stretch and each spaced 500m apart. The data consisted of the measure of vehicle speed in a particular lane crossing the inductive loop at a particular time and this was measured for a series of inductive loops in M4. A statistical model was derived from the Traffic Wales data and used in the generation of the arrivals of vehicles [4, 5].

The cluster dynamics is obtained from the clustering algorithm described in the following section. However, in general, vehicles moving in a group share similar traffic features such as average speed, average acceleration and direction of motion. This group of vehicles can be brought together to form a cluster. A good clustering algorithm creates stable clusters and reliable data transfer. It links the mobility model with the MAC protocol.

The final component is the implementation of the MAC protocol on rapidly evolving topology and measures the performance in terms of throughput, delay and packet loss ratio.

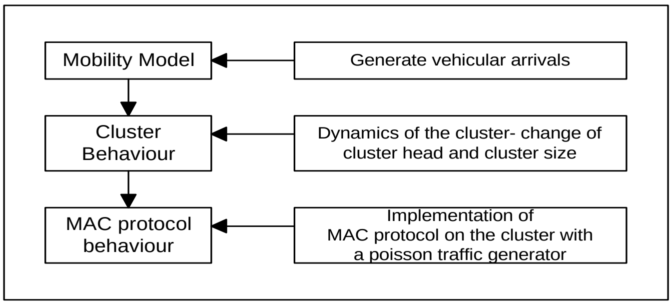

Fig.1. Overview of the system model

3. Clustering algorithm

In most hierarchical clustering architectures [6, 7], a cluster head (CH) is selected to act as the co-ordinator for data exchanges within the cluster and the base station. Although the cluster head acts as the controller of the cluster, it is different from base station, in that it does not require special hardware. The cluster head is dynamically selected from the group of adjacent vehicles. There are two most popular techniques for cluster head selection. One is based on the lowest identifier (Lowest-ID) clustering algorithm [8]. This algorithm assumes that each node has a global unique identifier and the node with the lowest ID in a cluster is elected as the cluster head. Its direct neighbours (single hop) become the members of the cluster. The second algorithm is based on the node maximum connectivity degree (Highest Degree) [9]. The cluster head in this method is selected on the basis of maximum number of direct links to its neighbours. These two algorithms can result in both severe re-clustering and cluster instability.

Here the cluster head is selected based on the physical constraint, path loss which is characterised by the distance between the vehicle and base station. Indeed, a good cluster head should have strong signal to the base station and minimal path loss. Clusters with a single vehicular node are formed when there are no vehicles within its transmission range or the nearest cluster is fully loaded that it will not be able to service anymore requests and long delays are expected.

We measure the performance of the clustering algorithm to ensure network stability and robustness with respect to V2V communication with the rate of change of cluster head i.e. the number of cluster head changes per time unit. A lower number of changes of the cluster head imply a better stability of the network. A mathematical model was used to define the rate of change of cluster head. Its results were validated against the simulation results and compared with the Lowest-ID and Highest Degree algorithms as shown in Fig. 2. The rate of change of cluster head was measured against the various transmission ranges. The proposed clustering algorithm based on minimal path loss exhibits the fewest cluster head changes. Thereby it offers greater robustness than the existing algorithms.

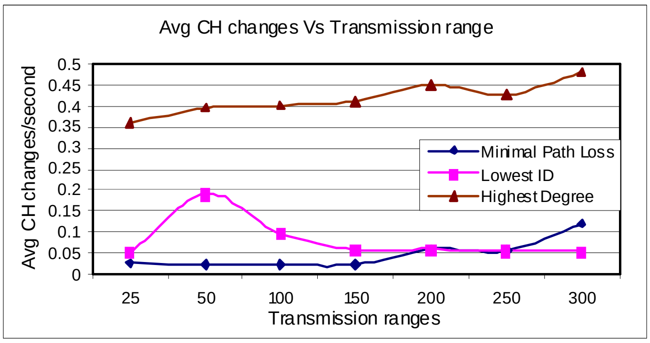

Fig .2. Rate of change of cluster heads vs. transmission range

4. Proposed system simulator

Our proposed scenario is based on a motorway with 3 unidirectional lanes. The lanes typically have three different speeds 60mph, 70mph and 80mph with vehicle density varying from high to low respectively. It was assumed that the vehicle motion was directed. The base stations are typically installed every 5 km in a motorway stretch of 100km. The motorway network was simulated based on time-discrete microscopic model. Within microscopic models, time discrete model was selected as it is simple and helps in reducing the computational time, yet models realistic behaviour. The simulator models the road network with base stations and traffic [10]. The vehicular arrival model and speed model obtained from Traffic Wales data were integrated into the simulator. A Poisson traffic generator was used to generate the data traffic for each vehicle. The simulator was designed as an event driven simulator and implemented using Java.

With the help of clustering mechanism, the clusters were created by network grouping vehicles within the transmission range of each other and a cluster head was nominated head based on the distance parameter between the vehicle and the base station. Hence, the vehicles in the cluster communicate with each other and any communication to the base station is routed via the cluster head. The cluster head changes are dependent on the speed of the vehicles in the motorway. The communication medium assumed in this model is 802.11p (WAVE technology), operating in the 5.8 GHz with an achievable payload data rate of 3-27 Mbps, with a coverage range from 500m to 1000m.

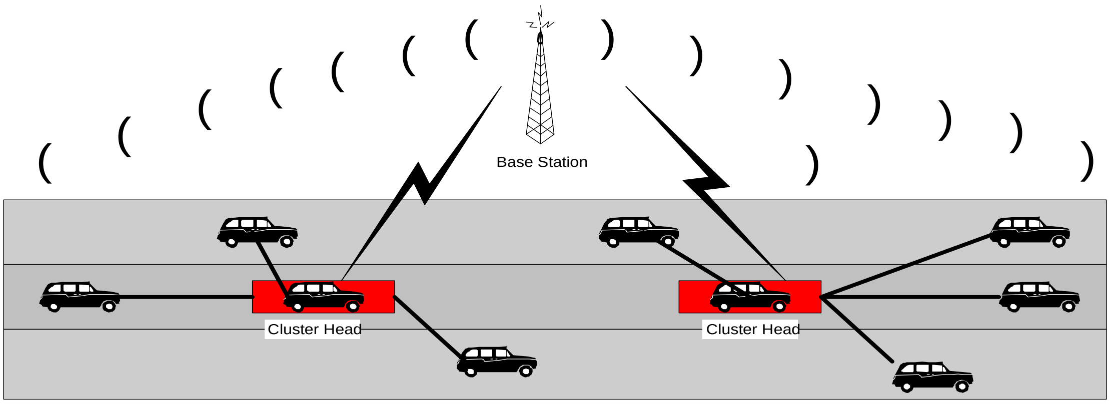

Fig. 3. Proposed system setup

Two protocols were used to characterise the system performance. They are carrier sense multiple access (CSMA/CA) and dual busy tone multiple access (DBTMA). The CSMA/CA uses binary exponential back-off algorithm to avoid collisions while in DBTMA, two busy tones are used to separate the use of forward and reverse communication. The data rate used is 6 Mbps [3] for a packet size of 1000 bytes with a coverage range of 500m.

5. Performance Evaluation

The MAC protocols CSMA/CA and DBTMA were run on each of the clusters on the motorway and performance metrics such as throughput, average access delay and packet loss ratio were evaluated through simulation. Fig. 4 shows throughput variation with normalised offered load. In both cases, the throughput increases with increasing load and reaches a saturation point. However, the DBTMA protocol exhibits better performance than the CSMA/CA. This results from the nearly-zero packet loss due to the presence of busy tones which ensures the safety of the packets. In addition, the probability of a channel being idle is higher for CSMA/CA than DBTMA.

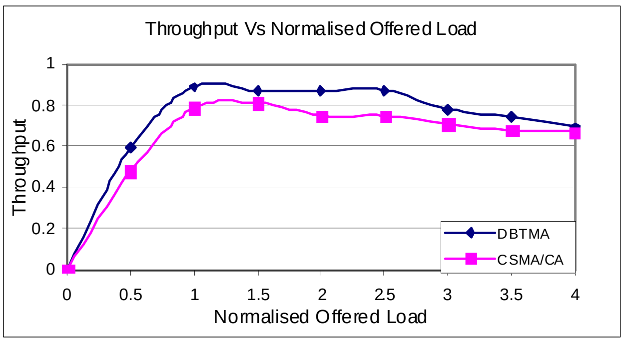

Fig.4. Throughput Vs Normalised offered load

In fig. 5, we measure the average access delay for each packet in seconds with the normalised offered load. The average access delay implies the waiting time before the packet is sent out in the channel. As expected, the access delay increases with the offered load. The resulting delay with CSMA/CA is higher than with DBTMA due to the presence of hidden and exposed terminals. Fig. 6 shows the packet loss ratio variation with normalised offered load. As mentioned earlier, due to the presence of busy tones, the packets lost with DBTMA protocol is lower than with CSMA/CA.

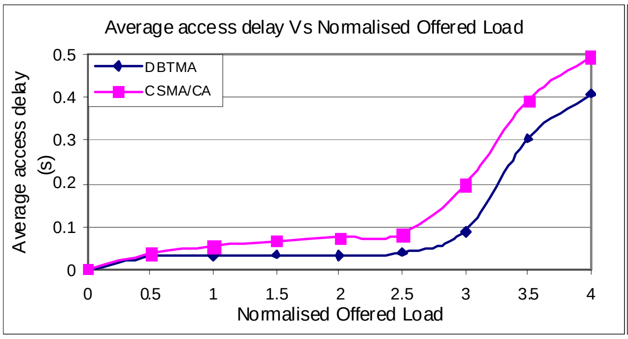

Fig.5. Average access delay Vs Normalised offered load

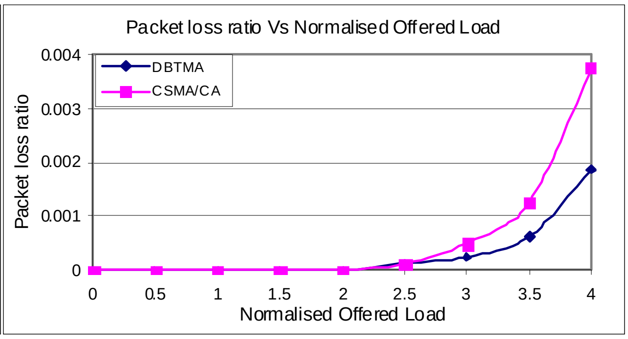

Fig.6. Packet loss ratio Vs Normalised offered load

6. Conclusions

This paper proposed a new clustering algorithm based on minimal path loss ratio for vehicular communication systems. It demonstrated better stability compared with other popular clustering techniques. Also, its performance with CSMA/CA and DBTMA MAC protocols were investigated and it resulted in higher reliability and efficiency with DBTMA in V2V networks.

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