A Cluster-Based Cooperative Data Transmission in VANETs

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Abstract. Vehicular Ad hoc Networks (VANETs) is designed to have the capability to communicate directly with other vehicles or indirectly using the existing infrastructure. Due to the high-speed mobility of the vehicles, it is a challenging issue to route the messages to their final destination. In this paper, we discuss three relationship of velocity, mobility, relative distance, then a combined Quality of Service (QoS) metric based on them is proposed to meet the clustering requirement. Thereafter, a QoS-aware clustering protocol consisting of cluster head election and multipoints relay selection algorithms is proposed for Vehicle-to-Vehicle (V2V) communication and implemented with ns-2 simulator. Simulation results have confirmed the analysis and expected performance in terms of cluster head duration, packet delivery ratio, etc.

Keywords: Vehicular Ad hoc Networks · Quality of Service · Cluster · Mobility

1 Introduction

VANETs [1] is characterized by a very high mobility that would shorten the network lifetime and cause link failures due to the disconnections of mobile vehicles. Hence, maintaining the stability is a challenging task. Clustering is expected to be one of the most efficient solutions for this issue. In a clustering scheme, vehicle nodes may be assigned a different roles or status, such as cluster-head (CH), cluster-gateway (CG) or cluster-member (CM) [2]. The CH serves as a local coordinator for the creation and maintenance of the cluster, which is responsible for intra-cluster transmission arrangement, data forwarding etc. The CG normally can access neighboring clusters and forward the information with inter-cluster links. The CM usually is an ordinary non-CH node without any inter-cluster links. However, due to the characteristics of VANETs such as high speed, variable density of the nodes, the existing clustering schemes used for conventional MANETs may not be suitable for VANETs.

For efficient vehicle communication, many approaches are designed to form a stable cluster among the vehicles based upon position, destination, density and mobility of the node, QoS requirements, etc. For instance, [3] proposed a position-based and cross-layer-based clustering algorithm using hierarchical and geographical data collection and dissemination mechanism. However, this scheme incurs more communication

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overheads, the infrastructure information is needed. [4] proposed a utility-based clustering scheme. A status message used by utility is periodically sent by all the neighbouring vehicles to form their own CH. However it still applies many fixed parameters in utility, which fails to adapt to dynamics traffic and cluster reorganization. [5] proposed Broadcasting based Distributed Algorithm (BDA) to stabilize the existing clusters. However, all nodes attempt to re-evaluate their conditions by computing utility values at the same time which may cause traffic overhead. [6] proposed a beacon-based clustering model in which the clusters are formed based upon mobility metric and the signal power. However, it does not consider the losses in the wireless channel and the effects of multipath fading. [7] proposed a distributed clustering scheme based on force directed algorithms. According to the current state of the node, each node takes decisions to form and maintain stable clusters. [8] proposed a passive clustering aided protocol, which assesses the suitability of nodes using a multi-metric election strategy. [9] proposed a classical Optimized Link State Routing (OLSR). The basic idea is to elect a CH for each group of neighbor nodes, then the CHs select a set of specialized nodes, named Multi-Points Relay (MPRs), to reduce the overhead of flooding messages by minimizing the duplicate transmissions within the same zone.

2 The CQOLSR Protocol

In this paper, CQOLSR, a QoS-based clustering protocol for V2V communication is proposed and based on several new QoS metrics including the vehicle speed ratio, the rest distance ratio, the average relative mobility and their combined metric. The clustering scheme relies on the cluster-head election and the MPRs selection algorithm based on the stated QoS metrics. In the following, we present the details of the QoS metric and algorithms.

2.1 The QoS Metric

Before discussing the new metric, we suppose that the driving speed and the travelled distance of a vehicle can be obtained with help of the Global Positioning System (GPS) deployed in vehicles. Meanwhile we give the notations description firstly shown in Table 1, and several formulas are also defined based on these symbols.

We introduce three different parameters namely the *speedRatio* (velocity difference ratio), *restDRatio* (rest distance ratio) and *avgRM* (average relative mobility). The *speedRatio* is the velocity ratio of vehicle, which ensures the convergent velocity for cluster forming and MRP elections. Hence, its performance will contribute in prolonging the lifetime of the clusters and reducing the link failures. The *restDRatio* is the ratio of rest distance towards the destination, which is ensured to group the vehicles and to elect considerable CHs/MPRs with convergent residual distance. Hence, its performance will contribute in maintaining the stability of the clusters. The *avgRM* is a parameter for a vehicle to choose stable target vehicles within one/two-hop neighbors to form a cluster or to be a CH/MPR. This parameter is based on the relative mobility mentioned in [10], which can be calculated based on the hello packet delay on each vehicle. The specific calculation formulas of these parameters are given below where the variable *i* & *j* belongs to the set of V_n, *currXY(i)* is the current coordinates of the vehicle *i*, the others are shown in Table 1.

$$speedRatio_i = \left(\left|V_{avg}(i) - V_{ran}(i)\right|\right) \Big/ (maxVelocity - minVelocity) \tag{1}$$

$$restDRatio_i = \sqrt{(curXY(i) - D^j_{xy})^2} \Big/ D_{ij} \tag{2}$$

$$avgRM_i = \sum\nolimits_{i,i \neq j}^{j} 10log_{10} \frac{PktDelay^{now}_{i,j}}{PktDelay^{old}_{i,j}} \Big/ NB^j_i \tag{3}$$

Table 1. Notations for formulas and algorithms

Symbol	Significance
V_n	A set of vehicles
$D_{tra}(i)$	The travelled distance of the *i* vehicle in V_n by now
$V_{ran}(i)$	The random velocity between *minVelocity* and *maxVelocity*
$V_{avg}(i)$	The average velocity of the *i* vehicle in V_n by now
minVelocity	The minimum velocity limit
maxVelocity	The maximum velocity limit
D_{ij}	The distance between vehicle *i* and vehicle *j*, $i \neq j$
D^j_{xy}	The coordinates (*x*,*y*) value of the destination vehicle *j*
V^j_i	The destination vehicle *j* of the *i* vehicle in V_n
NB^j_i	The neighbor number of vehicle *i* within one or two hops
LB^j_i	The neighbor list of vehicle *i* with QoS values
$PktDelay_{i,j}$	The transport delays of two continuous messages, $i \neq j$
$avgRM_i$	The average relative mobility between vehicle *i*

Based on the above parameters, we introduce a combined QoS metric $\boldsymbol{QoS_i}$, listed below to estimate the ability of a vehicle *i* to be a CHs or CGs(MPRs). In (4), the parameter $\boldsymbol{QC_i}$ is the residual capacity of queue of the vehicle ***i***.

$$QoS_i = QC_i \times NB^j_i \times \frac{restDRatio_i}{speedRatio_i} \times avgRM_i \tag{4}$$

2.2 The CH and MPR Election Algorithm

In this section, we present a QoS-based CH election algorithm with two intervals namely *HelloDuration* and *CHDuration*. In the *HelloDuration*, the nodes broadcast *qHelloPkt* packet with their QoS values within one or two-hops away to build their own neighbor list and update the QoS values in the list. In the *CHDuration,* by locally broadcasting a special Clustering-HELLO packet (*cHelloPkt*), each node votes for its neighbor to elect the optimal CH which has the local maximal QoS metric value. Once the election procedure is done, the elected node acknowledges to act as a CH by broadcasting an ACK and Topology Control (TC) packet within 2-hops away. The pseudo-code is like this.

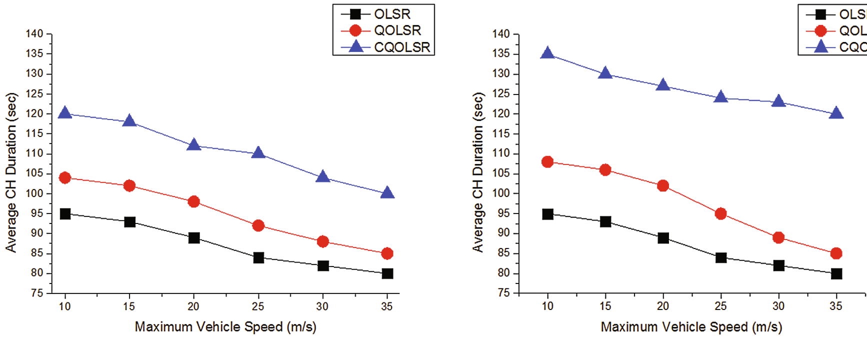
```
function CQOLSR_CH_Election{
  if(isHelloDuration()){
    foreach vehicle i,j ∊ V_n{
      if(isNull(LB_i^j)) send(qHelloPkt)
      else  collectAndUpdate(qHelloPkt,QoS_i) }
  if(isCHDuartion()){
    foreach vehicle i,j ∊ V_n {
      Broadcast(qHelloPkt);
      Seek(φ); //φ ∊ NB_i^j ∪ {i} && QoS(φ)= max{QoS(NB_i^j), QoS_i}
    }
    voteForφ (cHelloPkt); updateMPRs(i, φ)}
  else {
    elect vehicle i to be the cluster head φ }

  foreach φ ∊ V_n {
      broadcast(ACK,TC) within NB_i^j }
  }
```

When φ is elected, it need to select a set of optimal MPR nodes to interconnect the clusters and to form a connected network. The MPR selection algorithm uses *cgHelloPkt* packet to collect the path information through the network. The algorithm works as follows. In the forwarding phase, the source cluster head of message originator broadcast *cgHelloPkt* within 2-hops neighbors. Each intermediate node receiving this packet updates the *cgHelloPkt* with updated QoS values and forwards it to the destination cluster head. Meanwhile, the *cgHelloPkt* packet records each list of the visited node for tracing back the route later. In the backward phase, the intermediate nodes extract the QoS value from *cgHelloPkt*, compute the end-to-end delay and the combined QoS value, then calculate the reliability of each path between source and destination CH. Thereafter, we can get the ratio of reliability of all available paths and choose the optimal path with a maximum reliability ratio to be the data route. Afterwards, it selects the nodes belonging to the path having the maximum reliability ratio and located within the scope of its cluster as MPRs. Next, it sends back the *cgHelloPkt* packet until reaching the source cluster head.

3 Performance

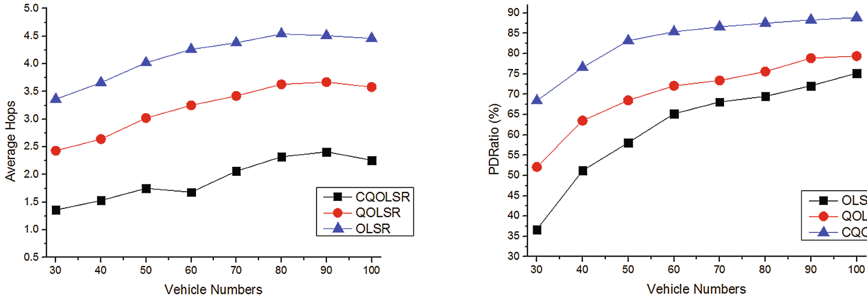
The proposed protocol CQOLSR is implemented in NS-2. A simulation scene of 1000×1000 m is used to simulate a set of nodes varying from 30 to 100. Transmission range is [100, 200] m, the velocity is [10, 35] m/s. We present a comparison between CQOLSR, QOLSR and OLSR. The latter approaches ignore some important metrics like mobility while the former uses a combined QoS metric to build the QoS function to form stable clusters and mobile communication.

As shown in Fig. 1, the CH duration decreases with increasing vehicle speed, because the CHs cannot maintain a relatively stable QoS conditions to its neighbor vehicles for a specific period. CH duration is moderately reduced in CQOLSR than in others because of the consideration of the relative mobility with their neighbors to enhance the robustness of velocity. Meanwhile, the factor of vehicle transmission range also influences the stability and duration. This has a great effect on connection between cluster members and efficiently reduces the changing number of cluster nodes' state. Therefore, it is beneficial to cluster stability that increasing transmission range.



(a) Transmission range 100m (b) Transmission range 200m

Fig. 1. Average CH duration vs. transmission range vs. maximum vehicle speed.



(a) Vehicle Numbers vs. Average Hops (b) Vehicle Numbers vs. PDR

Fig. 2. Vehicle numbers vs. Average hops & PDR

As shown in Fig. 2, the average hops and Packet Deliver Ratio (PDR) are separately compared with node density. In CQOLSR, the optimal path to dada transmission is chosen according to the highest QoS value and the highest reliability ratio. This improvement is earned by considering the route time while calculating the reliability ratio value used to select the MPRs. The results prove that the CQOLSR gives higher PDR and less number of hops compared to other approaches.

4 Conclusion

In this paper, we proposed CQOLSR protocol for V2V data transmission. The protocol is composed of two components: the QoS-based CH election and the multi-hop MPR selection algorithms. To ensure the stability of clusters, we add the velocity, mobility and relative distance that represent the mobility metrics to the combined QoS metric. Simulation results prove that our protocol is able to extend the network lifetime, increase the packet delivery ratio and decrease the path length. However, we will have a lot of work to do. We don't optimize the MPR recovery algorithm able to select alternatives and keep the network connected in case of link failures, and don't consider the misbehaving node after clusters are formed. We will take them into consideration in the future work.

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