A Cluster Based Beaconing Process for VANET

Yair Allouche
Communication Systems Engineering Department
Ben-Gurion University of the Negev
Beer-Sheva, Israel

Michael Segal
Communication Systems Engineering Department
Ben-Gurion University of the Negev
Beer-Sheva, Israel

ABSTRACT

In this paper we introduce the Cluster-Based Beacon Dissemination Process (CB-BDP) based on inter vehicle communication in highway scenarios. This process aims to provide vehicles with a local vehicle proximity map of their vicinity. Based on this map, safety applications can be used for accident prevention by informing drivers about evolving hazardous situations. The CB-BDP is designed under the two following objectives. First, since it is used for safety applications, we want the map to be detailed and as accurate as possible. Second, we want the map to be coordinated with nearby vehicles, thereby allowing synchronized and coordinated reactions of nearby vehicles to evolving hazardous situations. In [1] the authors have introduced a clustering scheme design to provide an optimized topology for an efficient and reliable beacon dissemination process. The topology is adaptive and robust in order to meet the challenging VANET conditions. In this paper, we propose a cluster based aggregation-dissemination beaconing process that uses this optimized topology to distribute the vehicle proximity map. An accurate and detailed map results in a heavy load of beacon messages. Our proposed scheme deals with this load by integrating a contention-free medium access control (MAC) strategy for reliable communication.

Categories and Subject Descriptors

C.2.1 [**Computer Communication Networks**]: Network Architecture and Design – *Distributed networks*, *Network communications, Network topology*, *Wireless communication.*

Keywords

Beacon dissemination, distributed algorithm, medium access control, self-organizing topology.

1. INTRODUCTION

Key components of safety applications are the periodic beacon messages, providing vehicles with an updated and accurate *vehicle proximity map* of their surroundings. Based on this map, safety applications – usually referred to as Cooperative Awareness applications – can be used for accident prevention by informing drivers about *evolving* hazardous situations.

In this paper we introduce the Cluster-Based Beacon Dissemination Process (CB-BDP). This process aims to provide vehicles with such vehicle proximity map of their vicinity. The CB-BDP is designed with two objectives in mind. First, since it is used for safety applications, we want the map to be broad and as accurate as possible. Second, we want the map to be coordinated with vehicles located nearby. This coordination is required for the synchronized and cooperative reaction of nearby vehicles to evolving hazardous situations. However, such an accurate estimation in a dynamic environment requires a high transmission frequency of beacon messages from numerous nearby vehicles, which in turn, results in a high data load on the channel. Moreover, coordinating a map in a lossy channel is challenging because proximity information may be received by some vehicles and not received by others.

To address these challenges, we suggest replacing the traditional multipoint to multipoint transmissions of beacon messages with a cluster-based aggregation-dissemination process. In this way, nearby vehicles share a coordinated map of their vicinity. To deal with the high load of beacon messages, we introduce a contention-free Medium Access Control (MAC) scheme intended to grant the CB-BDP with efficient and reliable spatial bandwidth reuse.

The first step to achieve this goal is to integrate cluster-based MAC [2,3] into our scheme. In cluster-based MAC, the channel access of cluster members is synchronized in order to provide contention-free channel access within the cluster. Furthermore, cluster-based MAC can provide bandwidth efficiency by bandwidth reuse among clusters. However, for reliable bandwidth reuse the resulting inter-cluster interference needs to be reduced. In [1], the authors introduced the Distributed Construct Underlying Topology (D-CUT) algorithm designed especially to enable efficient and reliable inter-cluster bandwidth reuse.

The D-CUT algorithm produces a geographically optimized topology by grouping dense and consecutive vehicles into clusters that are separated by the maximal possible gaps. This type of clustering allows strong connections between clusterheads and their cluster members and reduces the inter-cluster interference, thereby providing the CB-BDP with reliable inter-cluster bandwidth reuse. In return, the CB-BDP provides the D-CUT with a real-time and coordinated vehicle proximity map. The D-CUT exploits this map in order to produce a geographically optimized topology under the challenging VANET conditions. In [1] the authors present theoretically provable bounds for algorithm performance and a simulation study to demonstrate the ability of the D-CUT algorithm to self-start and self-maintain the geographically optimized topology under the dynamic nature of VANET environments.

For further improvement of the cluster-based MAC, we propose an inter-cluster colouring scheme in order to synchronize channel access between adjacent clusters. The cluster colouring groups sets of connected clusters into *super-clusters* when each super-cluster is coloured independently by at most three colours. (The full description of the clouring scheme is out of the scope of this paper.) The cluster colouring is used in two ways: it enables highly reliable transmission by silencing not only its members but also members of the two adjacent clusters. It is also used to further reduce the inter-cluster interference by synchronizing concurrent transmissions taking place in adjacent clusters according to a fair Signal to Interference plus Noise Ratio (*SINR*) optimization criterion.

VANET'13, June 25, 2013, Taipei, Taiwan.
ACM 978-1-4503-2073-3/13/06.

2. Cluster-Based Beacon Dissemination Process

The Cluster-Based Beacon Dissemination Process (CB-BDP) is designed to provide vehicles with a broad, accurate, and coordinated vehicle proximity map of their vicinity. To this end, the CB-BDP applies the following three-phase process. In the first phase, beacons in the same cluster are aggregated by clusterheads using the intra-cluster aggregation protocol. The protocol provides each cluster member with access to a time bounded, contention-free channel on which to send its message. In the second phase, adjacent clusterheads exchange their cluster status using the multi-hop inter-cluster communication protocol. In the final phase, using the intra-cluster dissemination protocol, clusterheads broadcast the aggregated information to all their cluster members, providing each cluster member with a local vehicle proximity map. As the map is broadcasted from a single source, each cluster member successfully receiving this broadcast transmission obtains the same vehicle proximity map of its surroundings. In the following we describe the three communication protocols in grater details.

The Intra-cluster Aggregation Protocol: By the intra-cluster aggregation protocol, clusterheads aggregate the beacon messages from their cluster members. The D-CUT algorithm ensures that this aggregation will be done by one hop communication. The protocol is based on an interference aware TDMA scheme that is designed to provide reliable, efficient, and time-bounded intra-cluster aggregation. The protocol defines a one-to-one map between the relative location of cluster members and bandwidth divisions of time slots. As cluster size is bounded, each cluster member receives a different time slot.

As mentioned, this protocol provides the CB-BDP its efficiency by applying extensive inter-cluster bandwidth reuse. The resulting inter-cluster interference is mitigated by the D-CUT topology, which is designed specifically to this end. To further reduce the inter-cluster interference, our aggregation protocol synchronizes concurrent transmissions taking place in adjacent clusters according to a fair *SINR* optimization criterion. Broadly speaking, the protocol coordinates the channel access between adjacent clusters by taking advantage of the strong links between the vehicles located next to clusterheads to deal with the weak links of the vehicles located far from the clusterheads. In addition, a power assignment scheme is applied to fairly equalize the joint interference of the concurrent transmissions.

The Intra-cluster Dissemination Protocol: By the Intra-cluster dissemination protocol, a clusterhead disseminates the aggregated information to its all cluster members. Again, the D-CUT algorithm ensures that this can be done in one broadcast transmission. To avoid inter-cluster interference in this central transmission, we use the cluster colouring to guarantee that the two immediate adjacent cluster members will remain silent during this transmission. For this purpose, the protocol allocates three time slots for the dissemination phase in which every clusterhead accesses the channel according to its cluster colour.

The Inter-cluster Communication Protocol: By the inter-cluster communication protocol, adjacent clusterheads exchange their cluster status. The protocol uses the strong intra-cluster links incorporated with Competition Based Forwarding (CBF) to achieve reliable information exchanged in this multi-hop communication.

We perform the cluster status exchange between the two adjacent clusters C_i and C_{i+1} with the corresponding clusterheads ch_i and ch_{i+1}. During the dissemination phase, the two clusterheads ch_i and ch_{i+1} broadcast their cluster statuses to the corresponding cluster members. To increase the protocol reliability, we suggest two gateways to be selected (gw^r_i for C_i and gw^l_{i+1} for C_{i+1}) by a competition-based approach. In particular, in order to choose gw^r_i, we select the vehicle from C_i that is closest to ch_{i+1} and has successfully received the broadcast from ch_i. Similarly, we select the vehicle from C_{i+1} that is closest to ch_i and has successfully received the broadcast from ch_{i+1} as the gateway gw^l_{i+1}. Then, gw^r_i and gw^l_{i+1} forward the message they have just received to C_{i+1} and C_i, respectively. The process is completed when each clusterhead collects the adjacent cluster status from its gateways. Again, to avoid inter-cluster interference we use the cluster colouring to guarantee that the two immediately adjacent cluster members will remain silent during this forwarding process.

3. SIMULATION

3.1 Simulation modelling and setup

The goal of this simulation study is to analyze the CB-BDP performance. To this end, we assume that all vehicles are equipped with a wireless communication device. The evaluation of the proposed CB-BDP scheme was done with a Matlab-based simulator that combines a microscopic road traffic simulation with a communication simulation.

The highway traffic model that is used in this simulation is based on the microscopic model developed by Stefan Krauß [4] designed for multi-lane traffic flow dynamics. In our highway traffic model, we assume that the vehicles run along a three-lane circular loop with a perimeter of 2000 m and we consider traffic densities of 18, 27, 36, 45, and 54 vehicles per km.

We assume that the contention free CB-BDP uses the DSRC's 10 MHz control channel for delivering its messages. The packet error decision in our implementation was made probabilistically according to the Packet Error Rate methodology described in [5]. The DSRC channel modelling in our simulator involves two aspects: large scale path loss and small scale fading. We use the two-ray ground model for modelling the large scale path loss. For a more realistic propagation model, we use the probabilistic Nakagami distribution [6] to model the small scale fading phenomena existence in mobile communication channels since it has been shown to well fit empirical data. We evaluate the performance of our proposed scheme under three different fading intensity levels: (i) *severe fading* level in which m is configured to 1, (ii) *medium fading* level in which m is configured to 3, and (iii) *low fading* level in which m is configured to 5.

We choose the following configuration settings that have been used in this simulation study. Frequency = 5.9GHz, Data rate = 3,6 Mbps, CB-BDP rate = 5 per sec, 802.11p data rate = 3 Mbps, Background noise (n_0) = -98 dBm, Preamble length = 32µ*s*, PLCP header length = 8µs, Antenna gain = 2.512db, Antenna height = 1.5m, Carrier wave length = 50.85mm, System loss = 1, Nakagami m = 1,3,5, Max. cluster size = 25, Max. transmission range = 250m, D-CUT rate = 1 per sec.

3.2 Performance evaluation

Figures 1(a) and 1(b) presents the probability of successful message reception of the intra-cluster communication protocols versus vehicle density under different fading conditions. Figure 1(a) presents the success probability for the intra-cluster aggregation protocol and Figure 1(b) presents the success probability for the intra-cluster dissemination protocol. From Figures 1(a) and 1(b) we can observe that in the intra-cluster communication, the probability of successful message reception decreases slightly when vehicle density increases. This is because when density increases, the D-CUT algorithm produces clusters that are separated by smaller inter-cluster gaps, and as a result, the amount of inter-cluster interference increases. With respect to the influence of different fading conditions, we can observe that in low and medium fading conditions, even for high vehicle density, the probability of successful message reception for both protocols is above 0.95. Severe fading condition causes slight performance degradation when density is low. The impact increases when the vehicle density increases.

Figure 1(c) presents the probability of successful inter-cluster communication protocol execution under different fading conditions, where successful protocol execution is when two adjacent clusterheads succeed in exchanging their cluster status. From this figure we can observe that the Competition Based Forwarding (CBF) strategy applied by the protocol provides highly reliable information exchange even under severe fading conditions. Notice that unlike the intra-cluster communication protocols, in which success probability decreases with vehicle density, the probability of successful inter-cluster communication protocol execution fluctuates with the increase in vehicle density. This is because when vehicle density increases, the inter-cluster gaps of the D-CUT topology become smaller. Smaller inter-cluster gaps have two opposite effects on protocol execution. On the one hand, smaller inter-cluster gaps lead to higher inter-cluster interference. On the other hand, smaller inter-cluster gaps lead to information exchange between closer gateways, which increases protocol reliability.

4. References

[1] Allouche Y. and Segal M. 2012. VANET in Eyes of Hierarchical Topology. *In: Proc. ACM Foundations on Mobile Computing*.

[2] Gunter Y., Wiegel B. and Großmann H. P. 2007. Cluster-based medium access scheme for vanets. *IEEE Intelligent Transportation Systems Conference.* pp. 343-348.

[3] Su H. and Zhang X. 2007. Clustering-based multichannel MAC protocols for QoS provisionings over vehicular ad hoc networks. *IEEE Transactions on Vehicular Technology*, vol. 56, no. 6, pp. 3309-3323.

[4] Stefan Krauß, Peter Wagner, and Christian Gawron (1997) Metastable states in a microscopic model of traffic flow. In: Physical Review E, vol. 55, pp. 55-97

[5] Pursley M. B and Taipale D. J. 1987. Error probabilities for spread-spectrum packet radio with convolutional codes and Viterbi decoding. *IEEE Trans Communications*, vol. 35, no. 1, pp. 1-12.

[6] Nakagami M. 1960. The m-distribution: A general formula of intensity distribution of the rapid fading . *Statistical Methods in Radio Wave Propagation*, W. C. Hoffman, Ed. Oxford, U.K.: Pergamon.

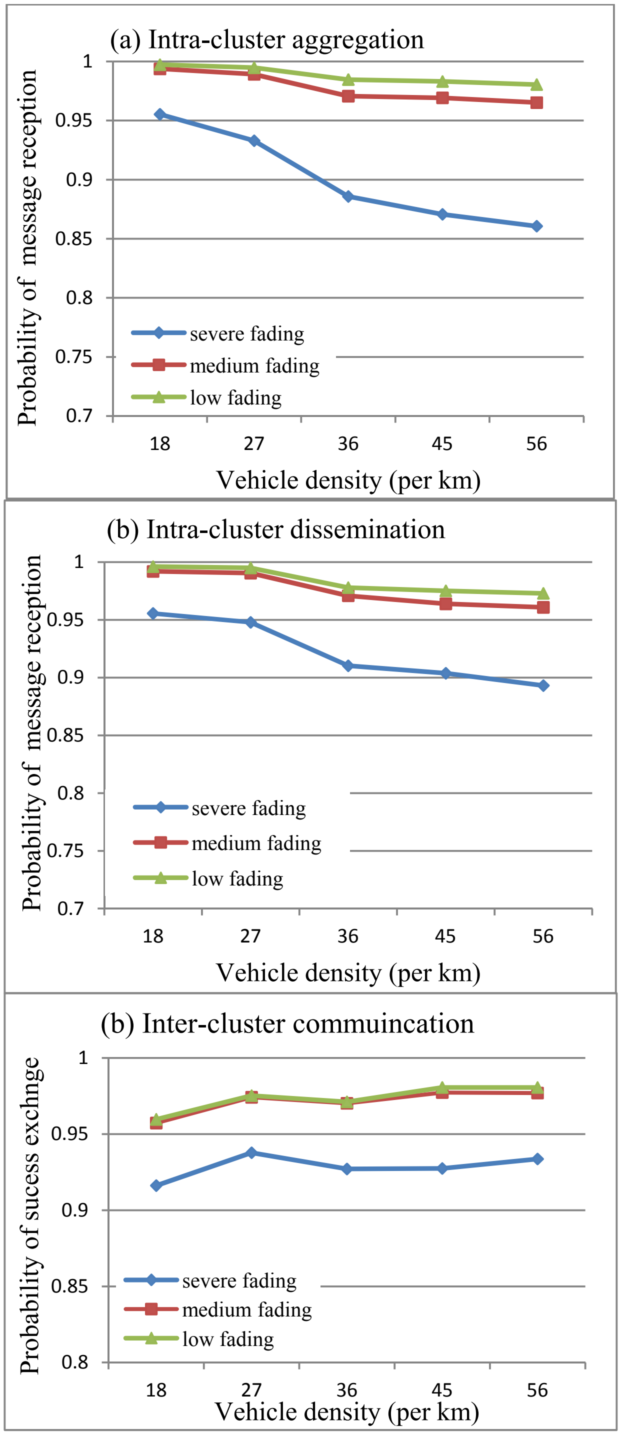

Figure 1. The probability of successful message reception of Intra-cluster and inter-cluster communication protocols under different fading conditions.