CSP: Cluster-based Self-organizing Protocol for Vehicular Networks

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Abstract— **Vehicle Communication (VC) represents an interesting item for both research and industry communities, since it supplies an efficient way to improve the transport quality. However, VC is confronted with a number of new challenges, in particular due to the extremely dynamic network topology and the large variable number of mobile nodes. To overcome these problems, an effective solution is to define a convenient and robust self-organizing architecture that facilitates the network management task and permits to deploy wide panoply of services In this paper, we propose CSP (Cluster-based Self-organizing Protocol), a proactive self-organizing protocol that structures intelligently the vehicular network by portioning roads into adjacent segments and where vehicles located in the same segment form one cluster. We compare our protocol to existing solutions and we analyze its performance using simulation and realistic mobility models.**

Keywords-component; Vehicular networks, Self-organization, Clustering, Routing, Broadcast

I. Introduction

Vehicular Ad hoc Networks (VANETs) can be identified as Mobile Ad hoc Networks (MANETs) where mobile nodes are wireless technology equipped vehicles [1]. The aim of Vehicular Networks is to provide communications among neighboring vehicles and between vehicles and nearby fixed equipments. The use of VANETs, based on free frequencies, has an important financial impact since it permits to reduce the use of costly cellular links. Vehicular networks have some own characteristics that have implications for designing solutions. We can cite high mobility, partitioned network, geographically constrained topology and large scale deployment.

To overcome some of these challenges, we develop in this paper a self-organizing vehicular communication architecture that facilitates the network management task and permits to deploy many services. We focus on all safety and comfort services based on data dissemination and data gathering.

This architecture should take advantage of node properties to issue a global virtual structure enabling the network self-organization. It should be sufficiently autonomous and dynamic to deal with any local change. Typically, in case of vehicular networks, the global structure has to ensure the network self-organization in order to optimize the vehicle-to-vehicle and vehicle-to-infrastructure communication with regard to nodes high mobility. In [9] self-organization allows favoring the collaboration between the different local properties, not interesting in themselves, to establish useful global information or services and to permit an optimized packets routing between nodes.

As we will see in the next section, we found in the literature some propositions of self-organizing architectures of vehicular networks using virtual backbone and clustering notions.

We introduce in this paper CSP (Cluster-based Self-organizing Protocol) a vehicular network self-organizing architecture that is based on geographical clustering to ensure an intelligent organization and management of the network. In fact, CSP adapts itself to vehicular network characteristics and permits to improve the connectivity between vehicles or vehicle-to-infrastructure without generating a great overhead.

This paper is structured as follows. Section II exhibits briefly the most relevant related works. In Section III, we present the adopted network model and we describe our proposed protocol CSP. After the presentation of the simulation results in Section IV, we conclude the paper and give some perspectives to our work in Section V.

II. Background

In this section, we give an overview of the existing self-organizing structures in the literature and we evoke some related works.

A. Self-organizing structures

The definition of a self-organizing structure is a cross layer problem. On one hand, the routing protocol must be able to uncover multi-hop routes by using other intermediate nodes to relay the messages [3], [4]. On the other hand, several recent works also discuss the impact of spatial frame contention at the Medium Access Control (MAC) layer on the global performance of multi-hop routing [5], [6].

Most researches suggest virtual backbone [7] and clustering [8] as most efficient structures to self-organize the MANET and to achieve scalability and effectiveness in broadcasting.

The idea of defining a virtual backbone structure is brought from the wired networks. The principle of this solution is to constitute a dorsal of best interconnected nodes. The other nodes will be associated with the dorsal nodes. The only constraint is the judicious choice of backbone members to avoid the rapid loss of interconnection between them.

The second self-organizing structure is clustering. It is the partition of the network in homogeneous groups named clusters. Each cluster has at least one cluster head and many members. Cluster-based solutions represent a viable approach in propagating messages among vehicles. Thus, the clustering structure is usually used as a support of backbone structure.

In the next subsection, we will discuss some related works which make use of these structures to self-organize the vehicular network.

B. Related works

Many works [11], [2] within the context of VANET introduce the concept of virtual backbone and clustering scheme in the aim of self-organizing the network.

In [11], authors define two main methodologies to organize the vehicular network in peer spaces: Cluster-based organization and Peer-Centered organization. The cluster-based organization considers the associative nature of the traffic for forming groups of peers with similar characteristics. These clusters can be dynamic or fixed. Fixed clusters are used in specific places where the possibility of accident is high such as intersections. Dynamic clusters are rather used when vehicles circulate in group even with a great mobility. The other methodology for organizing the vehicular network is the peer-centered organization. Within this method, each peer defines, constructs and maintains its own virtual peer space (VPS).

The main difference between the two approaches is that peer-centered organization considers the peer as the core of a group and organizes the vehicular network according to the peer singular interest. So, it is more appropriate for zones in which a node has a strong awareness of its neighborhood such as urban environment, whereas the cluster organization is more appropriate for highways.

In [2] the authors propose, within the context of VANET, DBA-MAC, a proactive distributed scheme to form a virtual backbone in a dynamic way in order to send a broadcast alert message to a group of potential receivers in a risk zone. To create the backbone, a node elects itself as a backbone member then it broadcasts a beacon message to spread the backbone creation process impulsion. After that, all the receivers enter in a distributed MAC access phase based on contention mechanism to elect the next backbone member. The vehicles receiving the beacon message compute a Residual Time which reflects its movement relatively to the backbone member. Vehicles having an RT upper than a fixed threshold can join a contention phase whose winner will be the next backbone member. Backbone members have the highest priority in accessing the channel and then they can relay the broadcast messages. This is supported by the MAC scheme called Fast Multi-Hop Forwarding (FMF). When BM_{N+1} receives a message from BM_N, it immediately acknowledges it and propagates it to BM_{N+2} after a SIFS delay. Even if this mechanism reduces overhead, it is totally deficient in case of great mobility of nodes. Indeed, a great variation of vehicles velocities can totally distort the predicted refreshing timer.

Even if the VANET self-organizing solutions introduced in [11] and [2] are very interesting, they still have two major drawbacks. Besides generating a great overhead for the clusters and backbone maintaining, these solutions are introduced for VANETs, that's why the communication between two vehicles is not possible until their respective cluster heads will be members of the same virtual backbone. So, it may take very long time to organize the whole network. In addition, if the link between two backbone members BM_n and BM_{n+1} is broken, vehicles situated in both sides of them cannot communicate before the backbone reparation.

In the solutions we propose, we portion each road stump in segments seen as fixed clusters and electing a cluster head for each segment to act as backbone member. This self-healing architecture is robust and permits the deployment of many services without important overhead since the clusters are geographically-defined.

In the following two sections we will describe more in details our proactive self-organizing solutions: CSP.

III. Cluster-based Self-organizing Protocol

Cluster-based Self-organizing Protocol (CSP), the protocol proposed in this paper, is conceived to self-organize the VANET in order to smooth up the effects of the high mobility of nodes without generating a great overhead.

In this section, we introduce briefly the network model, give detailed description of our approach, and present its added value compared to other existing VANET auto-organizing protocols.

A. CSP assumptions

In our work, we consider an urban environment where the vehicles velocity is limited to 50 km/h and in which each vehicle is equipped with a GPS (Global Positioning System) device and communicates with other vehicles using DSRC (Dedicated Short Range Communications). We consider an hybrid vehicular network where the VANET is connected to the wired network through fixed road-side-units (RSU) along the road. Although the wireless interface of these RSUs has a limited wireless coverage, their range can be increased using multi-hop communication. Then the road portion covered by an RSU is called ECA (Extended Communication Area).

B. CSP architecture

The ECA of an access point is divided into L-length segments as shown in Fig. 1. Vehicles located in the same segment form one cluster. The associate idea is to assign a state to each vehicle. Three states are possible: i) HEAD: the vehicle in charge of routing the segment packets. ii) SUPER_MEMBER: a vehicle that had been a HEAD and yielded the job to another h. iii) MEMBER: vehicles that are neither HEAD nor SUPER_MEMBER.

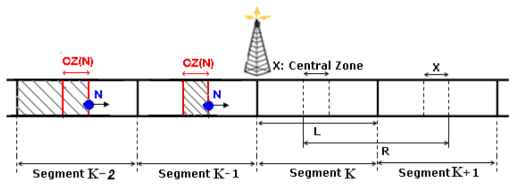

Figure 1. SSA-based architecture

Each cluster/segment is composed of one head, one super member and several members, it is split in one central zone and two lateral zones (see Fig. 1). This partition provides each node with an efficient mean to estimate its aptitude to exchange its state independently of other nodes, which limits notably the generated overhead. In fact, each vehicle in the central zone of one segment must be able to communicate with every other vehicle in the central zone of the adjacent segments.

In the rest of this paper we suppose that the access point is situated in the middle of the ECA. The abbreviations we will use are summarized in Tab. 1.

TABLE I. ABBREVIATIONS

ABBREVIATION	DESCRIPTION
X_N and V_N	position and algebraic velocity
S(N)	current segment
CZ(N)	neighboring segments of S(N) respectively closer and farther away from the access point
$CZ_+(N)$ and $CZ_-(N)$	respectively the farthest and closest border of CZ(N). They verify: $[CZ_+(N) - CZ_-(N)] . V_N \geqslant 0$
H(N), M(N) and SM(N)	head, member and super member of S(N)
TABLE(N)	table in which the head stocks requisite information about its members

C. CSP protocol

In CSP consists of two modules only: (i) dynamic selection of heads, and (ii) management of vehicles transition between the segments.

1) Head selection

Initially, a head is elected for each segment in a distributed way. Each node N in the CZ of one segment computes an *IE_Factor* that reflects the expected time to be spent in CZ(N). Then, it waits for a backoff duration which is inversely proportional to its *IE_Factor* before broadcasting a *Head_Decl* in S(N). When they receive the *Head_Decl*, other nodes of the segment stop sending their *Head_Decl*, set theirs own states to MEMBER, register the information of N as new head, and send a *Member_Req* to N. Therefore, N registers each of them in TABLE(N). Meanwhile, the elected head checks periodically its position and estimates its next one.

If N considers leaving CZ(N) after Δ_t ($\Delta_t < P_{H\_Check}$), it broadcasts a *Head_Resign* in S(N). Each member M of S(N) who receives the *Head_Resign* and fulfills the conditions (1) or (2) is a candidate to be the new head of S(N). It then computes an E_Factor (Electing Factor) which reflects the estimated time before reaching $CZ_+(N)$.

$$(V_N . V_N > 0)\,\&\,(M \text{ does not yet reached } CZ_+(N)) \quad (1)$$

$$(V_N . V_N > 0)\,\&\,(M \text{ does not yet reached } CZ_+(N)) \quad (2)$$

Each candidate waits for a backoff duration which is inversely proportional to its E_Factor then it sends a *Head_Req* to N. When N receives the *Head_Req* sent by a head candidate M it sends a *Head_Ack* to M in which it includes TABLE(N). When M receives the *Head_Ack* it saves the segment information in a new table, changes its state to HEAD and broadcast a *Head_Update_Ack* in S(M). Hence, N can remove its table and change its state to SUPER_MEMBER. The other segment members receiving the *Head_Update_Ack* change their head and stop sending *Head_Req*.

After changing its state to SUPER_MEMBER the previous Head (N) runs as gateway: it routes the packets sent by the new head to the neighboring segment. This argues the fact that the area of candidates circulating in the same way that the previous Head was wider than those circulating in the opposite way.

2) Inter-clusters transition

When entering in a new segment, a node N verifies periodically its position and estimates the next one. If N considers leaving its segment after Δ_t ($\Delta_t < P_{Check}$), it broadcasts a *Mbr_Add_Req*. Then, the head of the next segment adds N to its table and sends it a *Mbr_Add_Notif*. So N can send a *Mbr_Remove_Req* to its head.

D. F-CSP variant

F-CSP (Fundamental CSP) is a variant of CSP in which potential candidates to be HEAD are the vehicles situated only in the CZ of the segment. The other nodes are excluded even if they circulate in the same way that the current head. In this variant, only two states are defined, HEAD and MEMBER. As heads are in the CZ of their segments, neighboring heads can reach each other without requiring any super member.

IV. SIMULATIONS AND RESULTS

In this section, we study the performances of our self-organizing protocol. To accomplish this purpose, we used Qualnet simulator [10] to simulate an advertisement diffusion application in a self organized ECA, and we compare its performances with those got when using an intelligent broadcast (Each node broadcasts each packet only one time).

A. Simulation settings

In primer approach we have chosen to simulate one ECA to see the behavior of our protocol. The vehicular movement pattern generation is based on a 2800-meter length road portion which is divided in 8 segments.

In our simulation, results are averaged over 6 runs. We vary the vehicles number from 100 to 250. Each vehicle has a radio propagation range of 500 meters and a speed that ranges from 30 km/h to 50 km/h. Each simulation lasts for 30 seconds. To simulate the advertisement diffusion, we rely on CBR traffic with a packet size of 512 bytes and a variable packet rate.

B. Simulation results

The performance evaluation focuses on two aspects of our solution. First, we study the protocol main characteristic (life cycle duration of clusters). Then we evaluate the performances of an advertisement application with and without CSP, by analyzing the overhead and the delivery ratio of packets.

1) Clusters life cycle duration

Fig. 2 shows the mean of the life cycle duration for different traffic densities. We notice that CSP procures clusters more stable than those brought by F-CSP. This is due to the fact that in CSP, the nodes have the possibility to be elected as heads since they go in a new segment.

In addition, in Fig. 2, it is observed that in CSP, the clusters are more stable as vehicles number increases. This is expected, since the probability to find a node at the entrance of the segment when a *Head_Resign* is broadcasted is higher.

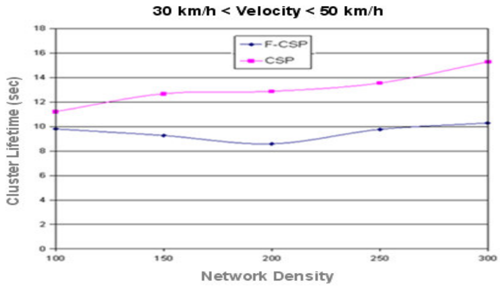

Figure 2. Clusters lifetime vs Network density

2) Overhead

In Fig. 3, we evaluate the overhead of CSP, F-CSP and the intelligent broadcast as function of vehicle density. We can observe that the increase in network density induces an increase in the routing overhead for both CSP and F-CSP, which is totally expected since the number of control messages depends on the number of nodes. On one hand, the most overhead in case of CSP and F-CSP is due to the organizing architecture packets and only a cut-amount is due to the advertisement diffusion, therefore if we increase the number of advertising packets, the overhead changes slightly. On the other hand, overhead generated in case of intelligent broadcast without self-organizing architecture is due to the fact that all vehicles broadcast the advertising messages.

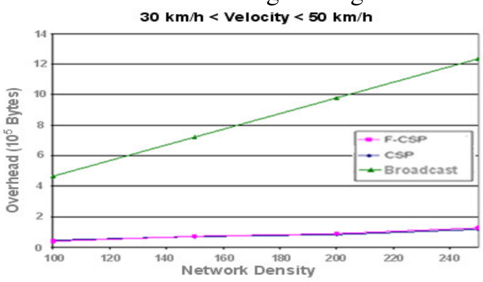

Figure 3. Overhead vs Network density

3) Delivery ratio

In Fig. 4, we set the packets sending interval to 0.1s, and we vary the number of vehicles. We remark that the obtained delivery ratio still upper than 90% apart from the density of the network. On the other hand, the values obtained with the intelligent broadcast fall to 60% which is mainly due to contentions since all vehicles have the right to broadcast data.

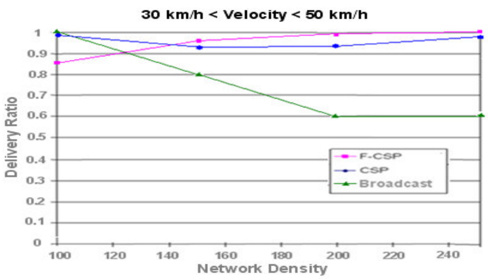

Figure 4. Delivery ration vs Network density

V. CONCLUSION AND FUTURE WORK

In this paper we introduced Cluster-based Self-organizing Protocol (CSP) for hybrid vehicular networks. It facilitates the network management task and permits to deploy wide panoply of services. For example, it allows telecommunication/service providers to better exploit/extend the existing infrastructure by overcoming its limitations using a low-cost multi-hop technology. CSP facilitates the deployment of all ITS and broadband applications based on data dissemination or data gathering.

We demonstrate via simulations that CSP is optimal when using an advertisement diffusion application on the top of it. In addition CSP does not generate a great routing overhead since it relies on fix segments to organize the network. We are currently extending this work by performing other extensive simulation in order to study the extension of CSP in order to handle the handover between the different ECAs.

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