A New Framework of self-organization of Vehicular Networks

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***Abstract*— Vehicular networks are drawing a great attention from the research community and the automotive industry, where they are beneficial in providing ITS (Intelligent Transportation System) services as well as assisting the drivers on the road. In this context, vehicular networks are based on V2I (Vehicle to Infrastructure) and V2V (Vehicle to Vehicle) communications. The special characteristics of these networks such as high mobility, potentially large scale, and network partitioning introduce several challenges, which greatly impact the deployment of these networks. An efficient solution to these problems is to define a robust self-organizing architecture. Thus, the function of these dynamic networks can be quite improved. In this paper, we introduce a new proactive self-organizing protocol called CSP (Cluster-based Self-organizing Protocol) that uses the geographic clustering and the virtual backbone to structure intelligently the vehicular network. We compare CSP to other self-organizing solution by analyzing its performances using Qualnet simulator. Simulation results show good performance of CSP in terms of architecture stability, overhead and delivery ratio.**

Keywords-component; Vehicular networks, Self-organization, Clustering, Virtual backbone, Broadcast

I. INTRODUCTION

During the last decade Vehicular Ad hoc Networks (VANETs) have been the subject of many works [1], [2]. The function of Vehicular Networks lean on (i) Vehicle to Vehicle communication and (ii) Vehicle to Infrastructure communication. 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 important implications for designing solutions. We can cite (i) high mobility: vehicular networks are associated with a very dynamic environment (ii) partitioned network: VANETs are frequently partitioned, the dynamic traffic nature may lead to inter-vehicle gaps or isolated clusters of nodes (iii) geographically constrained topology: in VANETs, nodes move along roads with fixed topology, and (iv) large scale: in spite of frequent partitioning, VANETs may extend over large areas.

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 wide panoply of 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.

We found in the literature some propositions to self-organize the vehicular network using virtual backbone and clustering notions. Indeed, one way to support efficient communication between nodes is to develop wireless backbone architecture; this means that some nodes have to be selected to form the backbone. Over time, the backbone must change to match with the changes in the network topology as nodes move around. The algorithm that selects the members of the backbone should evidently be fast, but also should require as little communication between nodes as possible to avoid an important overhead. One way to solve this problem is to group the nodes into clusters, where one node in each cluster functions as cluster head.

According to the situation, an operator/service provider can be led either to deploy a permanent self-organizing structure on the whole network, or only to temporary organize a road portion. In other terms, there are two ways to self-organize the vehicular network by using a proactive organizing architecture or a reactive organizing architecture.

A *proactive* architecture has to be established at the beginning and then to be maintained continuously without generating a great overhead. This architecture is generally used to support services like Internet access or file sharing. The *reactive* architecture is created on-demand in a road portion where a service has to be deployed. This architecture is mainly used to permit traffic gathering in critical zones.

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].

The authors of [5] conclude that it is not meaningful to consider MAC and routing protocols in isolation, and suggest that a cross-layer design of MAC and routing solutions may enhance the multi-hop communication in a MANET.

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. This nodes' subset must be defined to form a stable and persistent backbone. This implies to take into account many conditions in terms of mobility, power level and security during the backbone formation process. Every other node, not chosen as dominant, must be a neighbor of at least one dominant.

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. Generally, the members of one cluster have some common characteristics as contiguous velocities or coordinates, etc. 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 since both of them are devoted to arrange the information dissemination in a VANET. The Clustering structure permits to re-elect easily the backbone members.

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], [13] 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 advantage of fixed clusters is that the vehicles have immediate information about each other and the topology of the area without generating a great overhead. The major drawback is the necessity of a road infrastructure to apply this approach.

The other methodology for organizing the vehicular network is the peer-centered organization. Within this method, each peer defines, constructs and maintains its virtual peer space (VPS). Thus, a peer analyzes the information received from other traffic participants and decides which of them should belong to its own VPS. Each peer updates periodically its VPS and maintains information about all the peers belonging to it. In this approach, different VPS overlap.

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 [13] 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 RT (Residual Time) which reflects its imminent movement relatively to the backbone member (BM). 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 (Short Inter Frame Space) delay. Since a reactive scheme for repairing the backbone would need break-detection capability and overheads, DBA-MAC proactively refreshes the backbone. Each backbone member maintains a refreshing timer which depends on its chain sequence. 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 [13] 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.

To have a reliable self-organizing architecture VANET communications are insufficient and some infrastructure should be deployed, but the location of the deployed infrastructure must be chosen carefully.

In [12] which is one of the first works that handle the self-organization problem in mobile ad hoc networks, the authors take inspiration from the organization of the cellular network in adjacent cells to propose the division of the service area into a number of sub services areas (SSA) as shown in Fig. 1.

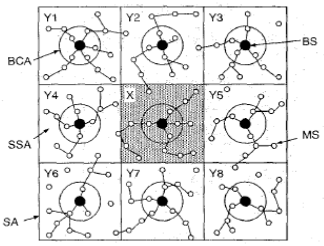

Figure 1. SSA-based architecture

One base station (BS) is settled in each SSA. The SSA area is set larger than a service coverage area of one BS. Then, a self-organizing process is executed in each SSA to ensure the communication between the BS and Mobile Stations (MS) that are outside its coverage area. In this method, MSs may be selected as relaying MS, so they support two radio communication channels, one for link establishment control and the other for data transmission. The link establishment process in this proposition is classified into three types. First, an MS tries to establish a direct link with the BS of its SSA. If this is not possible, it tries to establish a link with its BS using relaying MSs. The third alternative is to establish a link with a neighboring BS using relaying MSs. Finally, if the MS is isolating from another MS in its SSA and the neighboring SSAs it increases progressively its transmission power until it succeeds to communicate with another MS, so it uses it to relay its packets to the BS associated with the new neighbor.

This self-organizing method is interesting since MSs do not need to collect topology information of the whole network, but they only have to collect topology information of SSA that they belong to.

In the solutions we propose, we adapt the proposition introduced in [12] to vehicular networks by portioning each road stump (equivalent to a SSA) 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 it is based on geographically defined clusters.

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. It permits the management of the vehicular network for many applications such as chat, delivering advertisements and announcements about sale information and data gathering, etc. In other words, CSP ensures the user connectivity in specific environment, allows service continuity and permits to extend the wired networks.

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 that enables positioning and time synchronization. Vehicles communicate between them using DSRC (Dedicated Short Range Communications) as wireless technology.

We consider an hybrid vehicular network where the VANET is connected to the wired network through fixed road-side-units (RSU) along the road. An access point is able to communicate with vehicles which are outside its physical transmission range. The area where vehicles can be reached by the RSU via multi-hop communication is called ECA (Extended Communication Area).

B. CSP architecture

CSP forms temporarily single hop clusters to get rid of the hidden node problem as it is unlikely for a vehicle to be a hidden node for a transmission between two one-hop-distanced vehicles. For this purpose, the ECA of an access point is divided into L-length segments as shown in Fig. 2. 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 vehicle of its segment. iii) MEMBER: vehicles that are not HEAD and have never been HEAD of their current segment.

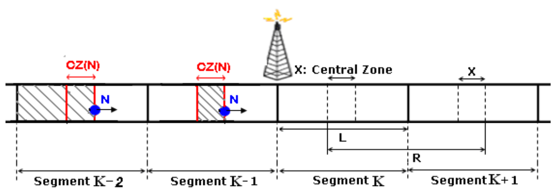

Figure 2. SSA-based architecture

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. 2). 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. The respective lengths of central and lateral zones are X and (L-X)/2. Another parameter to take into account is the fixed parameter R representing the communication range provided by the wireless technology.

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. To answer this assumption, an additional condition (1) is taken into account

$$R = L + X \qquad (1)$$

The abbreviations we will use in the rest of this paper are summarized in Tab. 1.

TABLE I. ABBREVIATIONS

Abbreviation	Description
X_N	Position of N
V_N	Algereic velocity of N
S(N)	Current segment of node N
CZ(N)	Central zone of S(N)
$CZ_+(N)$ & $CZ_-(N)$	Respectively the farthest and closest border of CZ(N) so they verify: $(CZ_+(N) – CZ_-(N)) . V_N > 0$
H(N)	Head of S(N)
M(N)	Member of S(N)
SM(N)	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 (Initial Electing Factor) according to (2). The IE_Factor reflects the expected time to be spent in CZ(N).

$$IE\_Factor(N) = \frac{CZ_+(N) - X_N}{V_N} \qquad (2)$$

Each node N waits for a backoff duration which is inversely proportional to its IE_Factor. Then it broadcasts 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). The elected head checks periodically its position (Period P_{H_Check}) and estimates its next one according to (3).

$$Next\_Pos(N) = X_N(N) + V_N \,.\, P_{H\_Check} \qquad (3)$$

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 (4) or (5) 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 $CZ_+(N)$ using the same formula as (2).

$$(V_M \,.\, V_N > 0)\,\&\,(M \text{ does not yet reached } CZ_+(N)) \qquad (4)$$

$$(V_M \,.\, V_N < 0)\,\&\,(M \text{ is situated in } CZ(N)) \qquad (5)$$

The conditions (4) and (5) correspond respectively to vehicles in the hashed zones in segments K-1 and K (Fig. 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 (TABLE(M)), changes its state to HEAD and broadcast a *Head_Update_Ack* in S(M). Hence, N can remove its table and changes its state to SUPER_MEMBER. The other segment members receiving the *Head_Update_Ack* change their head and stop sending *Head_Req* if they are head candidates.

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 the one of candidates circulating in the opposite way in Fig. 2.

2) Inter-clusters transition

When entering in a new segment, a node N verifies periodically its position and estimates the next one using the same formula as (2) with a period P_{Check}. If N considers leaving its segment after Δ_t ($\Delta_t < P_{Check}$), it broadcasts a *Mbr_Add_Req*. Receiving this request, the head of the next segment adds N to its table and sends a *Mbr_Add_Notif*. When N receives the *Mbr_Add_Notif*, it sends a *Mbr_Remove_Req* to its head. Receiving this request, the current head removes N from its table and sends a *Mbr_Remove_Notif*. When N receives the *Mbr_Remove_Notif*, it updates its segment and its head and sets its state to MEMBER.

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, and making allowance of (1), neighboring heads can reach each other without requiring any super member. The problem with this solution is the limited life cycle duration of clusters comparing with CSP.

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 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 this portion a variable number of vehicles are deployed randomly.

In our simulation, results are averaged over 6 runs and all the key parameters of the simulation are summarized in Tab. 2

TABLE II. Simulation Parameters

Parameter	Value
Simulation time	30 sec
Number of segments / ECA	8
Communication range	500 m
Segment / Central zone length	350 m / 150 m
Road width	30 m
P_{H_Check} & P_{Check}	0.4 sec & 0.5 sec
Data packet size	512 bytes
Packet sending interval	0.1 sec – 0.7 sec
Number of vehicles / ECA	100 – 300
Vehicles velocity	30 km/h – 50 km/h

B. Simulation results

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

1) Clusters life cycle duration

Fig. 4 shows the mean of the life cycle duration for different traffic density (the number of vehicles ranges from 100 to 300). 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. 4, 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.

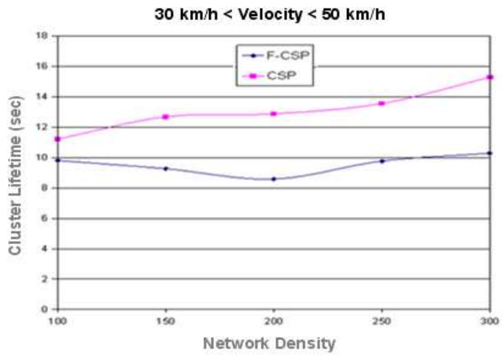

Figure 3. Clusters lifetime vs Network density

2) Overhead

In Fig. 5, we evaluate the overhead of CSP, F-CSP and the intelligent broadcast as function of vehicle density. So, we simulate the diffusion of 10 advertising messages in one ECA.

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 and only a cut-amount is due to the advertisement diffusion, therefore if we increase the number of advertising packets, the overhead produced in case of CSP and F-CSP changes slightly. On the other hand, overhead generated in case of classical broadcast without self-organizing architecture is due the fact that all vehicles broadcast the advertising messages. So, if we increase the number of advertising packets, the overhead increases linearly.

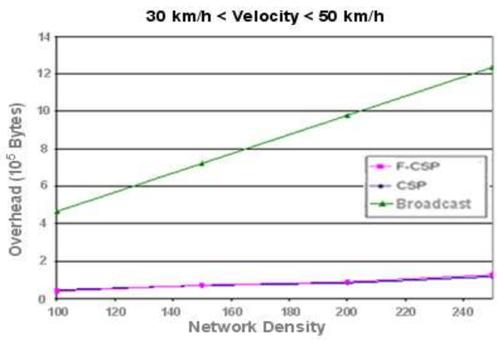

Figure 4. Overhead vs Network density

3) Delivery ratio

In Fig. 6, we present the obtained packet delivery ratio of the two variants of CSP and the classic broadcast. As stated before, the application sends periodically CBR traffic with a 512 byte packet size within intervals that range from 0.1s to 0.7s. We consider here 200 vehicles.

Even with the highest sending rate that corresponds to a packet sending interval of 0.1s, we notice that our protocol shows good delivery ratios (~ 92% for CSP and ~99% for F-CSP) while intelligent broadcast shows delivery ratio of 60%. This is due to the fact that CSP and F-CSP limit the number of nodes having to send each packet. The delivery ratio of F-CSP is lightly upper than the delivery ratio obtained with CSP because unlike CSP, in F-CSP, only the segment heads have to send packets (diffusion and relay).

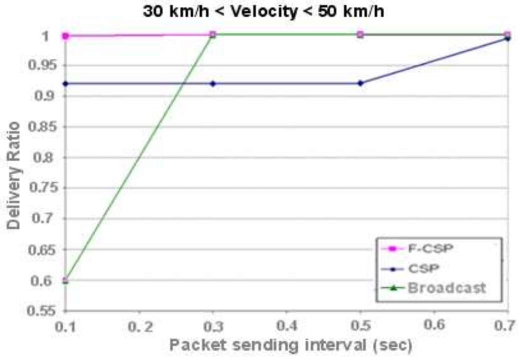

Figure 5. Delivery ration vs Packet sending interval

In Fig. 7, 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%.

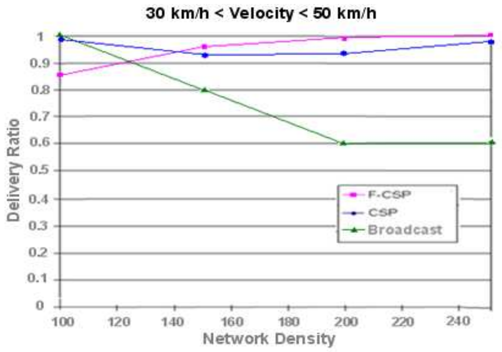

Figure 6. Delivery ration vs Network density

4) *End to End delay*

In this subsection, we compare the End to End delay when using CSP/F-CSP and the intelligent broadcast.

As we can see in Fig. 8, CSP procures delays of the same order of magnitude as those procured by the intelligent broadcast. Indeed, in our case, both of them use approximately, the same number of hops to reach destination.

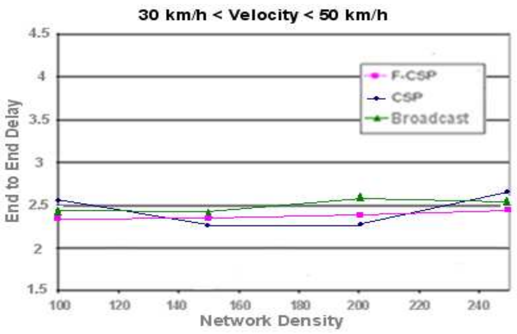

Figure 7. Delivery ration vs Network density

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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