A Geographical Self-Organizing Approach for Vehicular Networks

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***Abstract*—Cooperative vehicular networks have always been considered as the perfect way to bring more comfort to the passengers and more safety to the human life. Thus, research community and governmental organizations are interested to study and deploy these networks. The vehicular networks principle is connecting vehicles to each other and to existing infrastructure. However, their industrialization faces some challenges: (i) high mobility, (ii) frequently partitioned network, (iii) geographically constrained topology, and (iv) scalability. Therefore, in contrast to traditional networks, vehicular network protocols focus on both achieving adequate QoS level and reducing overhead. Achieving these two opposite requirements was the key driver of this work. The most promising way to do it is to self-organize the network. In a previous work, we introduced a proactive self-organizing architecture for vehicular networks called "CSP" (*Cluster-based Self-organizing Protocol*). In this paper, besides detailing CSP function, we define a mathematical model to estimate CSP overhead and to show the effects of the different parameters on it. We also set up a developed simulation study to validate the mathematical model and to compare CSP to other self-organizing solutions. This study shows interesting results of CSP in terms of generated overhead, end-to-end delay and delivery ratio.**

***Index Terms*— vehicular networks, self-organization, clustering, virtual backbone, performance evaluation, analytical study.**

I. INTRODUCTION

Today, the vehicle is the third living place and a major position for communication and content consumption. In fact, according to the ACEA's (European Automobile Manufacturers' Association) statistics [1], the European fleet is increasing by almost 15 million vehicles every year, and the road traffic annual growth is about 1.9%. In 2008, the daily driving time of the 200 million European fleet's vehicles is almost 14 billion minutes. This important fleet is related to many challenging issues as traffic congestion and road safety. In 2008, the traffic congestion management cost represented 2% of the global European GDP (*Gross Domestic Product*) and road safety expenses in Europe amount to a total of 160 billion Euros. All these statistics make governmental organizations allocating more and more interest to improve the driving conditions and decrease the road safety costs. To do that, one of the possible solutions is the deployment of ITS (*Intelligent Transportation Systems*). In 1999, the Federal Communications Commission allocated in the USA 75 MHz of spectrum in the 5.9 GHz band for ITS. Besides, in 2008, the ETSI (*European Telecommunications Standards Institute*) allocated 30 MHz of spectrum in the same band. In Japan, since 2001, the ARIB STD-T75 has permitted the use of the 5.8 GHz frequency band for ITS applications. Car manufacturers, automotive OEMs, networks operators, and service providers found a great interest in the domain since they attract people by providing many comfort and safety applications. As a result, several projects and consortium have been launched. The most known are the Car2Car consortium [20], SafeSpot Project [21], CALM Project [22], CVIS Project [23], and GeoNet Project [24], etc. All these projects have roughly three targets: (i) harmonization of vehicle communication standards worldwide, (ii) development of realistic deployment strategies and business models, and (iii) development of more efficient applications.

One of the emerging ways of ITS deployment is vehicular networks. Vehicular networks are an instantiation of MANETs (*Mobile Ad-hoc NETworks*) that include the deployment of infrastructures. However, vehicular networks behave in different ways than conventional MANETs. In fact, regarding the own characteristics of vehicular networks have some own challenging characteristics that have injurious implications for designing solutions. We can mention: (i) high mobility, (ii) frequently partitioned network, (iii) geographically constrained topology, and (iv) scalability.

These networks are promising in providing a set of on-board potential services for drivers and passengers as well as providing different communication facilities between moving vehicles. They also enable new infotainment services apart from the safety applications, such as info-mobility and traffic efficiency by introducing less delay and less cost. As examples of sighted services we can cite services for the passengers (Infotainment) to enhance their trip, and services for companies/authorities (municipalities, city managers, highway managers, mangers of a fleet of vehicles such as public transport or taxis, emergency services, etc.) to enhance the fleet management task and for a better life-quality in our cities.

We can expect that many services and then many protocols destined for different services have to be deployed simultaneously. Unfortunately, this can engender an excessive bandwidth use and then deteriorate the quality of the offered services in such highly dynamic networks. An effective way to permit the deployment of many services without congesting the network is to organize automatically the vehicular network: self-organization. In fact, self-organization architecture has to facilitate the network management task and permits to deploy simultaneously wide panoply of services and protocols (e.g. data dissemination [2], data collection [3], etc.). This architecture should take advantage of node properties to issue a global virtual structure enabling the network self-organization [4]. 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 [4], self-organization allows favoring the collaboration between the different local properties, not interesting in themselves, to establish useful global information or services by permitting optimized data collection, optimized data dissemination and optimized packets routing between nodes, etc.

According to the situation, an operator/service provider can be led either to deploy a permanent self-organizing architecture on the whole network, or only to temporary self-organize a road portion [5]. 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 reactive organizing architecture is established temporary on demand to provide a service locally (e.g. CGP data gathering architecture [5]) whereas, a proactive architecture has to be established at the beginning and then to be maintained continuously without generating a great overhead. In a previous paper, we introduced a new proactive self-organizing architecture called CSP (*Cluster-based Self-organizing Protocol*) [6]. This architecture minimizes the effects of the vehicles' mobility 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, data gathering and routing, etc. In other words, it must ensure the user's connectivity in specific environment and allow service continuity. To validate this work [6] we presented some simulation results that were incomplete. Thus, the aim in this paper is (i) to study some performances of our new proactive self-organization architecture analytically, and (ii) to prove its efficiency with more realistic and complete simulation studies.

This paper is structured as follows. Section II exhibits briefly the most relevant proactive self-organization related works. In Section III, we present the adopted network model and we describe our proposed protocol CSP. After the presentation and comparison of the analytical study and simulation results in Section IV, we discuss the solution in Section V. Section VI concludes the paper.

II. Proactive Self-organization in litterature

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

A. *Proactive self-organizing architectures*

In this paragraph we introduce the proactive self-organizing item and present briefly the existing proactive self-organizing architectures.

The definition of a self-organizing architecture is a cross layer problem. It affects both Layer 2 and Layer 3. On the one hand, several recent works also discuss the impact of spatial frame contention at the MAC (*Medium Access Control*) layer on the global performance of multi-hop routing [7], [8]. The authors of [7] 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. On the other hand, the routing protocol must be able to uncover multi-hop routes by using other intermediate nodes to relay the messages [9], [10], [11].

Most researches interested in Layer-3 self-organizing issue suggest clustering [12] [13] as most efficient architecture to self-organize the MANET and to achieve scalability and effectiveness in broadcasting.

Clustering-based self-organization consists in partitioning 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 architecture usually permits the establishment/update of a virtual backbone. The idea of defining a virtual backbone is brought from the wired networks. The principle of this solution is to constitute a dorsal of best interconnected nodes (usually, the cluster heads are the backbone members). 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.

In [14], authors define two main methodologies to organize the vehicular network based-on clustering: traffic-centered cluster-based organization and peer-centered cluster-based organization. The traffic-centered cluster-based organization considers the associative nature of the traffic for forming groups of peers with similar characteristics. These clusters are usually dynamic and are used when vehicles circulate in group even with a great mobility. The advantage of the traffic-centered clustering approach is the maintaining of the organization architecture in case of long road sections where the vehicles circulate in group (even with a great mobility).

The other methodology for organizing the vehicular network is the peer-centered cluster-based organization. Within this method, each peer defines, constructs and maintains its VPS (*Virtual Peer Space*). 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. The VPS can be determined based on geographical criteria (location criterion, destination criterion, etc.) or vehicle criteria (public means of conveyance and private vehicle). The advantage of the peer-centered clustering approach is the limitation of the generated overhead to form clusters in case of dense traffic.

The main difference between the two approaches is that peer-centered cluster-based 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 traffic-centered cluster-based organization is more appropriate for highways.

B. Proactive self-organization related works

In this paragraph, we discuss some related works which make use of these architectures to self-organize the vehicular network.

In [15] the authors propose, within the context of VANET, DBA-MAC (*Dynamic Backbone-Assisted Medium Access Control*) protocol which is a proactive traffic-centered cluster-based self-organizing protocol. DBA-MAC introduces a new algorithm to form and maintain 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 BM (*Backbone Member*) then it broadcasts a beacon message to spread the backbone creation process impulsion. After that, all the receivers enter in a distributed medium 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 imminent movement relatively to the BM. Vehicles having a residual time upper than a fixed threshold can join a contention phase whose winner will be the next BM. BMs have the highest priority in accessing the channel and then they can relay the broadcast messages. This is supported by the MAC scheme called FMF (*Fast Multi-Hop Forwarding*). 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 BM 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 DBA-MAC the self-organizing solution introduced above is very interesting, it still has two major drawbacks. First, it generates a great overhead to form and maintain clusters. Then, the communication between two vehicles is not possible unless their respective cluster heads are members of the same virtual backbone. So, to have a reliable self-organizing architecture, vehicle-to-vehicle communication is not sufficient and some infrastructure should be deployed to avoid eventual disconnections due to low traffic density.

The adding of the infrastructure is especially interesting in case of operated network. However, the location of this infrastructure must be chosen carefully.

In [16] 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 SSAs (*Sub Services Areas*) as shown in Fig. 1.

One fixed station is set up in each SSA. The SSA area is set larger than a service coverage area of the fixed station. Then, a self-organizing process is executed in each SSA to ensure the communication between the fixed station and mobile stations that are outside its coverage area. In this method, some mobile stations may be selected as relaying stations, 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 fixed station of its SSA. If this is not possible, it tries to establish a link with the fixed station using relaying mobile stations. The third alternative is to establish a link with the fixed station of a neighboring SSA using relaying mobile stations. Finally, if the mobile station is isolated from other mobile stations of its SSA and the neighboring SSAs it increases progressively its transmission power until it succeeds to communicate with another mobile station, so it uses it to relay its packets to the fixed station associated with the new neighbor. This self-organizing method is interesting since the mobile stations 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.

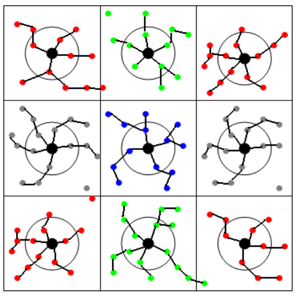

Figure 1. SSA-based architecture.

In the next section we propose a new self-organizing architecture which adopts the SSA model, and defines a peer-centered cluster-based organization scheme in each SSA based on location criterion. The purpose of this proposition is to optimize the self-organization generated overhead and improve the delay and delivery ratio. In the following section, we bring a detailed description of this architecture and present its added value compared to other existing ones.

III. CSP: A Self-Organizing Architecture for Operated Vehicular Networks

CSP (*Cluster-based Self-organizing Protocol*), is conceived to proactively self-organize an operated vehicular network in order to smooth up the effect of nodes' high mobility without generating a great overhead. It permits the management of such network for large panoply of applications and protocols. In other words CSP ensures the user connectivity in a dynamic environment, allows service continuity, and permits to extend the wired operated network. In this section, we introduce briefly the network model, give the detailed description of our architecture, and present its added values compared to other existing vehicular networks' self-organizing architectures.

A. CSP Assumptions

In this 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 device that enables positioning and time synchronization. Vehicles communicate using DSRC (*Dedicated Short Range Communications*) as wireless technology. We suppose that all vehicles have the same radio range *R*.

We consider a hybrid vehicular network where the VANET is connected to the operated wired network through fixed RSUs (*Road Side Units*) along the road. Each RSU is able to communicate with vehicles which are outside its physical transmission range. As seen in Fig. (2), the area where vehicles can be reached by the RSU via multi-hop communication is called ECA (*Extended Communication Area*).

B. CSP Architecture

In this paragraph we introduce the vehicular network self-organizing 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, associated with an RSU, is divided into *L*-length segments as shown in Fig. (3) (This choice is explained later). Vehicles located in the same geographical segment form one cluster. This geographical clustering has become realistic in view of the high accuracy of the new GPS devices. In the rest of this paper, the term 'cluster' refers to a geographical segment.

When a vehicle A has to communicate with a vehicle B in the same ECA, it just sends packets to its head. Then, the packets are relayed by neighboring heads until been delivered to destination. When A has to communicate with a vehicle C situated in another ECA, it sends packets to its head. The packets are relayed by the neighboring heads until reaching the RSU of the ECA. Then the packets are sent via the wired network to the RSU of the destination's ECA to be delivered via multi-hop V2V communication to the destination.

The associate idea of CSP 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.

Each cluster is composed of one *HEAD*, one *SUPER_MEMBER* and several *MEMBER*s. As shown in Fig. (3), the segment is partitioned into one central zone and two lateral zones.

This partition allows each vehicle 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. The effects of the choice of the *X*-value on the global overhead are studied later in this paper. Another parameter to take into account is *R* that represents the communication range of the wireless technology.

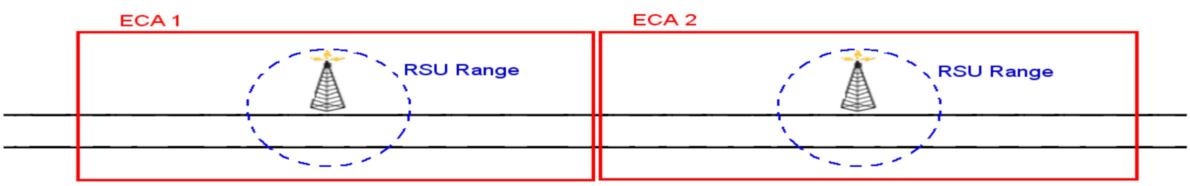

Figure 2. Arrangement of ECAs

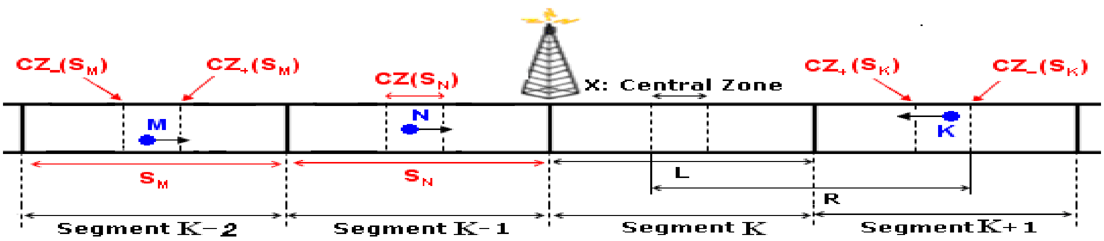

Figure 3. Segment-based architecture

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, Eq. (1), is taken into account:

$$R = L + X \tag{1}$$

The choice of central zone width is the subject of two constraints. First the width of the central zone must be inferior to the total length of a segment. In consideration of the condition expressed in Eq. (1), this constraint engenders Ineq. (2).

$$X < \frac{R}{2} \tag{2}$$

In addition, as the *SUPER_MEMBER* will be, if necessary, a relay between two adjacent segments' heads, a second constraint represented by Ineq. (3) is introduced.

$$X > \frac{\sigma}{\mu + \sigma} * R \tag{3}$$

$\mu = (V^{max} + V^{min})/2$ and $\sigma \approx (V^{max} - V^{min})/2$ are respectively the mean velocity and the standard deviation.

Ineq. (3) is justified more in details later in this paper (ref. section III.C.2).

C. *CSP Overview*

As mentioned above, CSP is a peer-centered cluster-based proactive self organizing protocol. So, initially, all the vehicles know the location of the RSUs and the different segments. This is a realistic assumption that requires only the preloading of this information in the car devices (Nowadays, similar information such as radars location, gas stations location, etc. could be preloaded in the GPS devices). In this paragraph, we describe the process of CSP execution.

CSP consists of three modules only: (i) dynamic selection of heads, (ii) head-to-head communication, and (ii) management of vehicles transition between the segments. We will detail them in the following. Some abbreviations, summarized in Table 1, are used and some of them are shown in Fig. (3).

1) *Head election process*

Since no *HEAD* is elected before, the initial head election process should be totally distributed. Then, it differs slightly from following ones which are managed by the acting head. In this subsection we describe both the first head election process and the following head election method in the segments.

a) *Initial head election process*

The initial head election process is illustrated in Fig. (4).

Initially, one head is elected for each segment in a distributed way. Each node *N* situated in $CZ(S_N)$ computes an Initial Electing Factor: *IE_Factor* according to Eq. (4). The *IE_Factor* reflects the expected time to be spent in $CZ(S_N)$.

TABLE I. CSP PARAMETERS ABBREVIATIONS

Abbreviation	**Description**
X_N	Position of node N
V_N	Algebraic value of the velocity of node N
S_N	Current segment of node N
$CZ(S_N)$	Central zone of the current segment of node N
$CZ_+(S_N)$ & $CZ_-(S_N)$	Respectively the farthest and the closest border of $CZ(S_N)$ as illustrated in Figure 3 so: $(CZ_+(S_N) - CZ_-(S_N)) \,.\, V_N > 0$
$H(S_N)$ & $M(S_N)$ & $SM(S_N)$	Head, Member and Super Member of S_N
$TABLE(S_N)$	Table in which the head stocks required information about its members

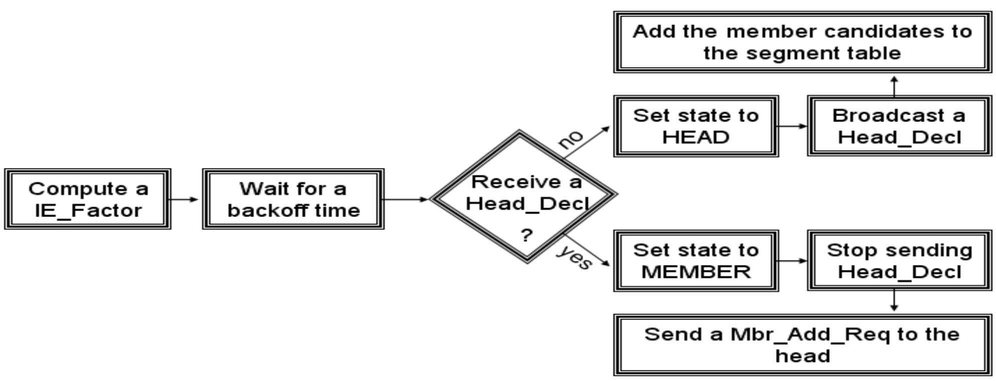

Figure 4. Initial head election process

$$IE\_Factor = \frac{CZ_{+}(S_N) - X_N}{V_N} \qquad (4)$$

Each node *N* waits for a backoff duration which is inversely proportional to its *IE_Factor*. Then it sets its state to *HEAD* and broadcasts a *Head_Decl* in S_N. When receiving the *Head_Decl*, the other nodes of the segment stop sending their *Head_Decl*, set their own states to *MEMBER*, register the information of *N* as new *HEAD*, and send an *Mbr_Add_Req* to *N*. Therefore, *N* registers each of them in *TABLE*(S_N). The elected head checks periodically (period: P_{H_Check}) its position and estimates its next one according to Eq. (5).

$$Next\_Pos(N) = X_N(N) + V_N * P_{H\_Check} \qquad (5)$$

If a *HEAD* has already been elected for a segment, the head election process becomes managed by the acting head as described in the next paragraph.

b) Head election process

In this paragraph we suppose that a vehicle *N* has been already acting as *HEAD*. If it considers leaving *CZ*(S_N) after Δ_t ($\Delta_t < P_{H\_Check}$), it sets off a new head election process as shown in Fig. (5).

- The resigning head broadcasts a *Head_Resign* in S_N,
- Each other member *M* of S_N that receives the *Head_Resign* and fulfills the conditions in Eq. (6) or Eq. (7) is a candidate to be the new head of S_N. Then, it computes an Electing Factor *E_Factor* which reflects the estimated time before reaching $CZ_{+}(S_N)$ using the formula introduced in Eq. (4),
- Each candidate waits for a backoff duration which is inversely proportional to its *E_Factor*, then it sends a *Head_Req* to *N*,

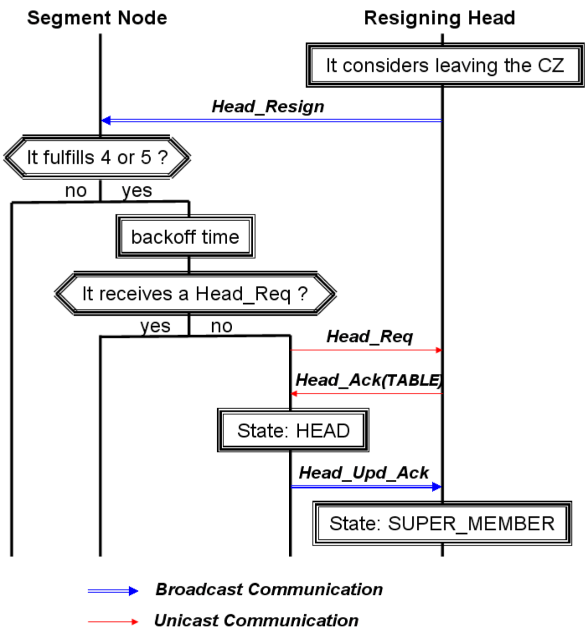

Figure 5. Head election process

- When *N* receives the *Head_Req* sent by a *HEAD* candidate *M*, it sends a *Head_Ack* to *M* in which it includes *TABLE*(S_N),
- When *M* receives the *Head_Ack* it saves the segment information in a new table (*TABLE*(S_M)), changes its state to *HEAD* and broadcast a *Head_Upd_Ack* in S_M,
- *N* removes its table and changes its state to *SUPER_MEMBER*. The other segment members receiving the *Head_Upd_Ack* change their *HEAD* and stop sending *Head_Req* if they are *HEAD* candidates.

$$\begin{cases} V_M * V_N > 0 \\ AND \\ M \text{ does not yet reached } CZ_{+}(N) \end{cases} \qquad (6)$$

$$\begin{cases} V_M * V_N < 0 \\ AND \\ M \text{ is situated in } CZ(N) \end{cases} \qquad (7)$$

The conditions introduced in Eq. (6) and Eq. (7) correspond respectively to vehicles in the green (horizontal) and red (vertical) hashed zones in Fig. (6). This choice is argued by the optimization of the head-to-head communication as explained in the next section.

2) Head-to-Head communication

In this subsection we describe the process of sending packets from head to head in order to reach the destination or the ECA's RSU.

After changing its state to *SUPER_MEMBER*, the previous *HEAD*, *H*(S_N), runs as a gateway as shown in Fig. (7).

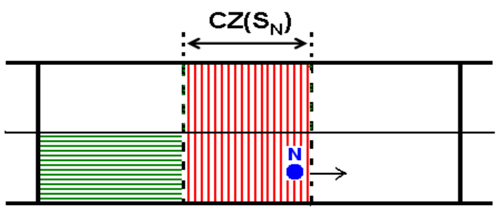

Figure 6. Location of head candidates

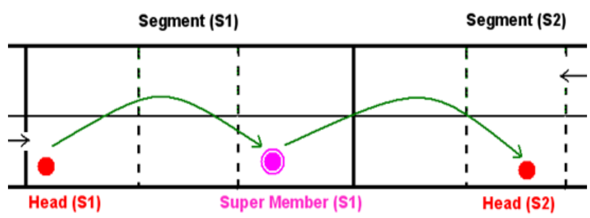

Figure 7. Super member function

This implies that it routes the packets sent by the new *HEAD* to the *HEAD* of one of the neighboring segments. 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. (6).

The use of the super member as a relay engenders a constraint related to the central zone width (expressed by the Ineq. (3)). In fact, the maximal time that could be spent by a new *HEAD* before reaching the central zone (it has to pass by the *SUPER_MEMBER* to communicate with the neighboring *HEAD*) has to be inferior to the minimal time that could be taken by the *SUPER_MEMBER* before being disconnected to the *HEAD*. Then:

$$\frac{L-X}{2*V_{\min}} < \frac{R}{2*V_{\max}} \quad (8)$$

The development of this inequation leads to the Ineq. (3).

3) *Inter-segment transitions*

This paragraph describes the process of transition of a vehicle from one segment to another one. This process is illustrated in Fig. (8).

- When entering in a new segment, a node *N* verifies periodically its position and estimates the next one using the formula of Eq. (4) 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 it a *Mbr_Add_Notif*,
- When *N* receives the *Mbr_Add_Notif*, it sends a *Mbr_Remove_Req* to its current *HEAD*,

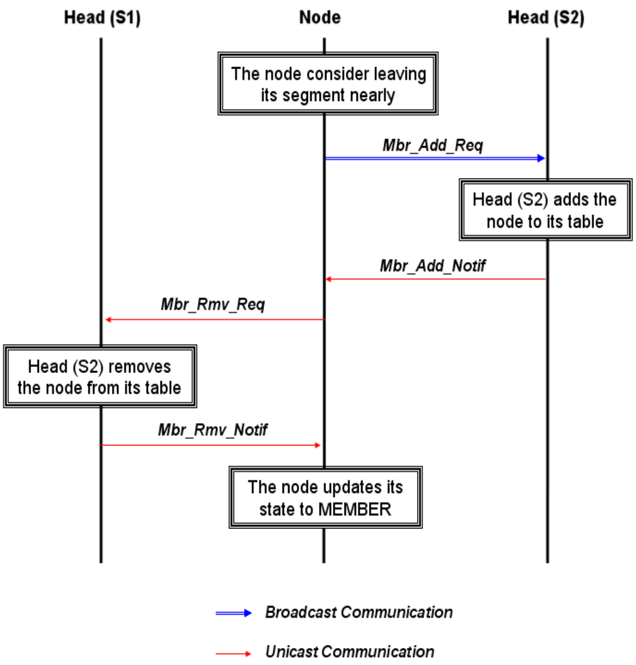

Figure 8. Inter-segment transition process

- 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*.

B. *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 as shown in Fig. (9). The other nodes are excluded even if they circulate in the same way than the current *HEAD*. In this variant, only two states are possible, *HEAD* and *MEMBER*. As heads are in the *CZ* of their segments and making allowance of Eq. (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 compared to CSP.

IV. Performance Evaluation

In this section we evaluate CSP performances via both analytical and simulation studies. First, we estimate the global overhead generated by the deployment of CSP self-organizing architecture. Then, the obtained results are compared to the simulations' results. Other performances such as delivery ratios and end-to-end delays are evaluated via simulations.

A. *Analytical study*

In this section, we first define a mathematical model to estimate the protocol overhead. Then, based on this model we show the effects of traffic density, velocity range and central zone width on the generated overhead in urban/semi urban environment.

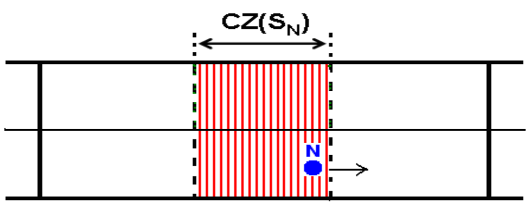

Figure 9. Location of head candidates in F-CSP variants

In this paragraph we introduce the proactive self-organizing item and present briefly the existing proactive self-organizing architectures.

1) Estimation of CSP Overhead

In case of CSP (resp. F-CSP), the generated overhead is due either to the head election process or the inter-segment transition of vehicles as shown in Eq. (9). :

$$Overhead = HE\_Ovd + IST\_Ovd \qquad (9)$$

Where *HE_Ovd* (bytes) represents overhead due to head election process and *IST_Ovd* (bytes) represents overhead due to inter-segment transition of nodes.

Let Ψ the size (in bytes) of the signaling messages exchanged by the nodes in case of CSP (except the *Head_Ack* message which contains extra data – the IP address of segment's nodes). In the rest of this subsection we are going to define a mathematical model of the overhead during a period *T*.

a) Head election overhead

As CSP is conceived for urban/semi-urban environment we assume in this paragraph that a new head circulating in the same way than the resigning one can be found.

Let λ the traffic density. On the one hand, the number of eligible vehicles circulating in the same way as the resigning head (*EV_SW*) is:

$$EV\_SW = \frac{\lambda * R}{4} \qquad (10)$$

$\lambda.R$ represents the vehicles situated in the chopped area in Fig. (10), and *EV_SW* represents vehicles in the double-chopped area in the same figure.

One the other hand, according to [17], the inter-vehicle distance could be modeled with exponential distribution. Thus, the inter-vehicle distance distribution could be expressed as follows:

$$P(x) = \lambda * e^{(-\lambda * x)}. \qquad (11)$$

Then the expected value of IVD (*Inter-Vehicle Distance*) is:

$$E[IVD] = \int_{]0,+\infty[} x * P(x)\, dx = \frac{1}{\lambda} \qquad (12)$$

Using Eq. (8) and Eq. (10), the expected value of HD, the distance that will be traversed by the new head, can be expressed as follows:

$$E[HD] = \frac{R}{4} - \frac{1}{\lambda} \qquad (13)$$

In the case studied here, the distance traversed by the head and its velocity are two uncorrelated parameters since there are no particular constraints relating them (see Eq. (13)). So, the expected value of HT, time spent by a vehicle as head, is:

$$E[HT] = E[\frac{HD}{V}] = E[HD] * E[\frac{1}{V}] \qquad (14)$$

According to [18], the velocity distribution in the case of vehicular network is a Gaussian distribution with mean μ and standard deviation σ (μ and σ are introduced above in the paper).

Then, the expected value of the time spent by a vehicle as a head can be expressed as follows:

$$E[HT] = (\frac{R}{4} - \frac{1}{\lambda}) * \int_{V_{\min}}^{V_{\max}} \frac{1}{\sigma v \sqrt{2\pi}} * e^{-\frac{(v-\mu)^2}{2\sigma^2}}\, dv \qquad (15)$$

As the head election process engenders 4 signaling messages and 4-byte extra data by segment's vehicle (to exchange the segment table between the resigning head and the new head), the estimated head election overhead *HE_Ovd* during a period *T* in a ΔL-length road portion is:

$$E_T[HE\_Ovd] = \frac{4 * T * \Delta L * [\Psi + \lambda * (R - X)]}{(R - X) * E[HT]} \qquad (16)$$

b) Inter-segment transition overhead

Let E[V] the expected velocity of vehicles. The expected value of TF (Traffic Flow) is expressed as follows:

$$\begin{aligned} E[TF] &= \lambda * E[V] \\ &= \int_{V_{\min}}^{V_{\max}} \frac{\lambda * v}{\sigma * \sqrt{2\pi}} * e^{-\frac{(v-\mu)^2}{2\sigma^2}}\, dv \qquad (17) \\ &= \lambda * \mu * erf(\frac{\sqrt{2}}{2}) \end{aligned}$$

Where erf( ) is the Error Function.

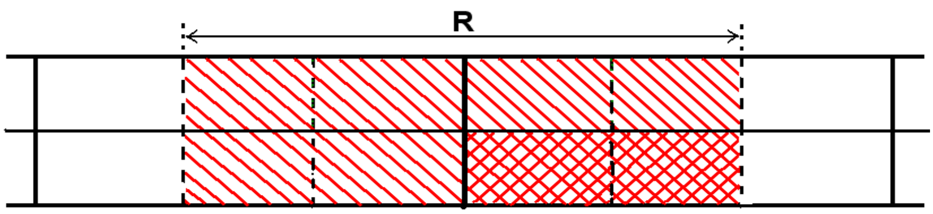

Figure 10. Eligible vehicles circulating in the same way than the current head

Assume now that two observers stand at the two entries of a segment. The expected value of the number of vehicles passing the observers during a period T is:

$$E[NV_T] = 2 * T * E[TF] = 2 * T * \lambda * \frac{\Delta L}{R - X} * \mu * erf(\frac{\sqrt{2}}{2}) \qquad (18)$$

As the inter-segment transition process engenders 4 signaling messages, the estimated Inter-segment transition overhead *IST_Ovd* during a period T is:

$$E[IST\_Ovd] = 4 * \psi * E[NV_T]. \qquad (19)$$

2) Effects of traffic density, velocity range and central zone width on the generated overhead

According to Eq. (16) and Eq. (19), the self-organizing overhead depends on three parameters: traffic density (λ), velocity interval ([V_{min}, V_{max}]), and central zone width (X). In the following we show the effects of traffic density and central zone width on the generated overhead.

a) Effects of traffic density on the generated overhead

Fig. (11) shows the variations of the *HE_Ovd* (Fig. (11.a)), *IST_Ovd* (Fig. (11.b)), and global CSP overhead (Fig. (11.c)) as a function of traffic density. The other parameters are fixed as follows: Ψ = 64 bytes, X = 150 m, T = 1 s, ΔL = 350 m, and velocity fluctuates between 30 km/h and 50 km/h.

As seen above, the generated overhead is formed from head election overhead and inter-segment transition overhead. Inter-segment transition overhead increases linearly when traffic density increases as shown in Fig. (11.b). Head election overhead depends on 2 parameters: (i) extra data (IP addresses of the vehicles located in the segment) exchanged by the successive heads which is a linear raising function of traffic density, and (ii) head election frequency which is a decreasing function of traffic density. Then, on the one hand, for densities upper than 0.05 vehicles/m, Fig. (11.a) shows the increase of head election overhead as the traffic density increases. In case of high traffic densities (> 0.1 vehicles/m), the new elected head is always located at the segment's ingress. Hence, the head election frequency does not affect the head election overhead which depends only on the amount of extra data exchanged between successive heads. Then, Fig. (11.a) shows a linear increasing of head election overhead for these densities. On the other hand, in case of low traffic densities (< 0.05 vehicles/m), a new head can not usually be found in the segment ingress, so the head election frequency increases which engenders an important overhead. In addition, the extra data exchanged between successive heads is not significant in case of low densities. So, for traffic densities < 0.05 vehicles/m, the head election overhead decreases.

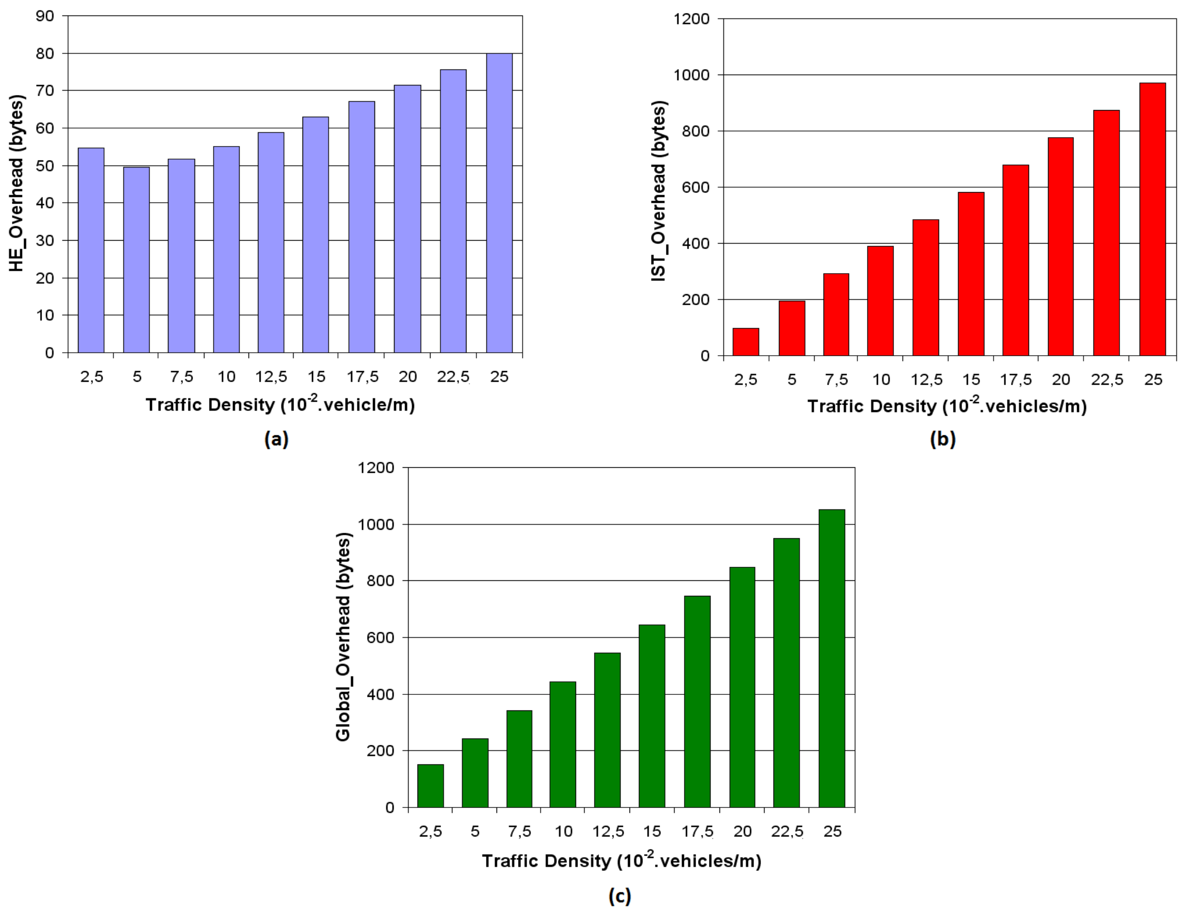

Figure 11. (a) head election overhead, (b) inter-segment transition overhead, and (c) global overhead vs. Traffic density

b) Effects of velocity range on the generated overhead

Fig. (12) shows the variations of the *HE_Ovd* (Fig. (12.a)), *IST_Ovd* (Fig. (12.b)), and global CSP overhead (Fig. (12.c)) as a function of velocity range. The other parameters are fixed as follows: Ψ = 64 bytes, X = 150 m, T = 1 s, ΔL = 350 m, and traffic density = 0.1 vehicles/m.

According to Fig. (12), the head election overhead and the inter-segment transition overhead have the same behavior towards vehicles velocity. In fact, the inter-segment transition overhead is a linear increasing function of mean velocity. The head election overhead is also a raising function of mean velocity and depends slightly on standard deviation of the velocity range.

c) Effects of central zone width on the generated overhead

Fig. (13) shows the variations of the *HE_Ovd* (Fig. (13.a)), *IST_Ovd* (Fig. (13.b)), and global CSP overhead (Fig. (13.c)) as a function of central zone width. The other parameters are fixed as follows: Ψ = 64 bytes, ΔL = 350 m, T = 1 s, traffic density = 0.1 vehicles/m, and velocity fluctuates between 30 km/h and 50 km/h.

According to Ineq. (2) and Ineq. (3), in our case (R=500 m and velocity fluctuates between 30 km/h and 50 km/h) the central zone width must be upper than 100 m and lower than 250 m. Fig. (13) shows that within this interval both head election overhead and inter-segment transition overhead are pseudo-linear functions of central zone width. In fact, Eq. (16) and Eq. (19) show that the head election overhead and the inter-segment transition overhead are inverse functions of the central zone width. In addition, in the case studied here, X is inferior to R/3, the approximation of 1/(1-x) where x=X/R around the point x=0 is: 1/(1-x)=1+x+o(x).

Then the head election overhead and the inter-segment transition overhead seem to vary linearly as a function of central zone width.

B. *Simulation study*

In this section, we evaluate the performances of CSP via simulation. The simulations have been performed using Qualnet [19]. The CSP performances are then compared to those of: (i) F-CSP, and (ii) DBA-MAC [15] the protocol presented in the related work section. In the following, we present the simulation environment and the main simulation parameters and we analyze the main simulation results.

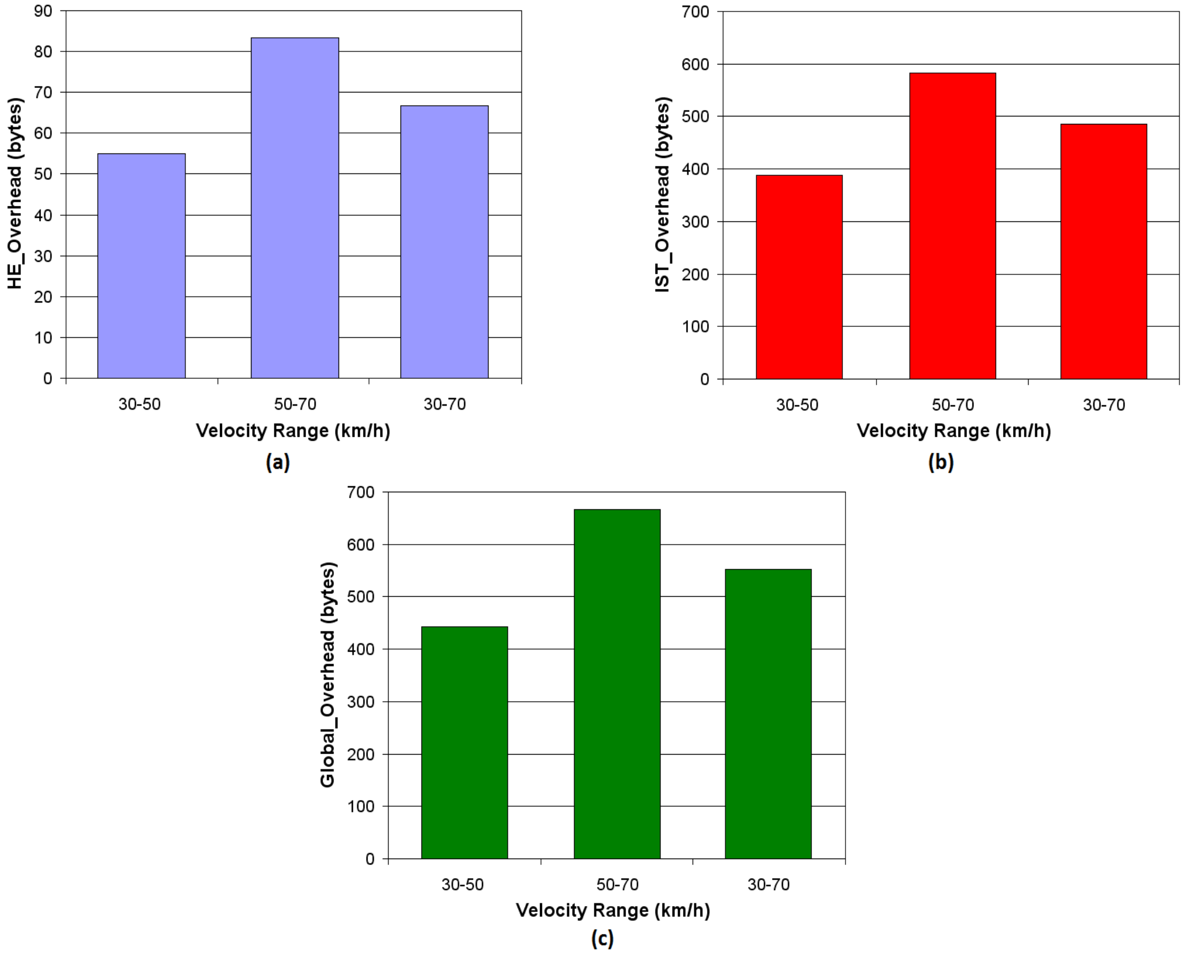

Figure 12. (a) head election overhead, (b) inter-segment transition overhead, and (c) global overhead vs. Velocity range

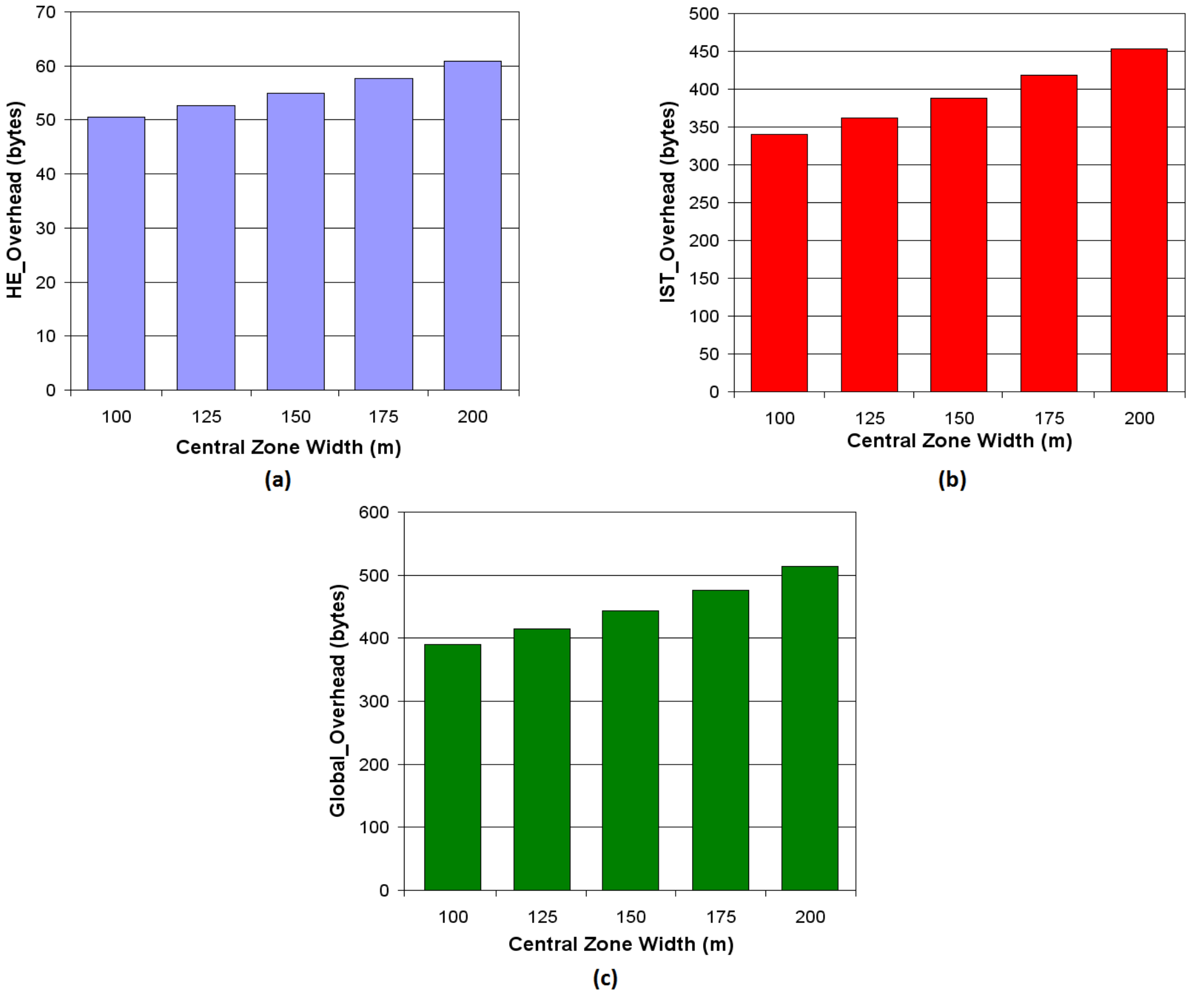

Figure 13. (a) head election overhead, (b) inter-segment transition overhead, and (c) global overhead vs. Central zone width

1) Simulation setup

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. As CSP is conceived especially for urban environment, the velocity in all simulations varies from 30 km/h to 70 km/h and the number of vehicles varies from 100 to 300. The data is broadcast using 512-byte packets with a sending rate that varies from 1.4 to 10 packets/s. All the key simulation parameters are summarized in Table 2.

2) 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 when deploying CSP, DBA-MAC and without any self-organizing architecture, by analyzing the overhead, the packets delivery ratio and the end-to-end delay.

TABLE II. SIMULATION PARAMETERS

SIMULATION / MOBILTY SCENARIO			
Simulation time	300 s	Central zone length	150 m
Packet sending rate	1.4 - 10 packets/s	Velocity range	30 – 70 km/h
Mobility model	VanetMobiSim	Number of vehicles	70 – 420
Data packets size	512 bytes	Segment length	350 m
Road width	30 m	Communication range	~500 m

a) *Cluster life duration*

Fig. (14.a) shows the mean of the cluster life duration for different traffic densities. The traffic density varies from 0.025 vehicles/m (1 vehicle per 40m) to 0.15 vehicles/m (1 vehicle per ~ 7 m). First, we notice that the cluster life duration in case of DBA-MAC is 5 times greater than cluster life duration in case of CSP. On the one hand, the clusters heads in case of DBA-MAC are always vehicles circulating at the same direction. As the simulation area is a long road portion (no intersections) and vehicles' velocities are close to each others, the backbone is maintained for a long time. On the other hand, the clusters in case of CSP are geographically defined. Then, cluster heads have to be re-elected after traversing a certain distance. We notice also that CSP procures clusters more stable than those brought by F-CSP. This is due to the fact that in CSP, nodes have the possibility to be elected as heads since they go into a new segment. In addition, Fig. (14.a) shows that in CSP, the clusters are more stable as traffic density 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.

Fig. (14.b) shows the mean of the cluster life duration for different velocity ranges. On the one hand, we remark that the life duration of clusters in case of CSP and F-CSP depends on the mean velocity of vehicles. This behavior can be argued by the fact that CSP is a peer-centered cluster-based self organizing protocol. Then the stability of clusters in case of CSP depends first on the mean velocity of each head. On the other hand, the life duration of clusters in case of DBA-MAC depends on the standard deviation of velocity (difference between V_{min} and V_{max}). This behavior can be argued by the fact that DBA-MAC is a traffic-based cluster-based self organizing protocol. Then, the stability of clusters with DBA-MAC depends on the relative velocities of backbone members which is a raising function of velocity range.

b) *Self-organizing overhead*

Fig. (15.a) shows the generated self-organizing overhead (during 1 s in a 350-meter-length road portion) as a function of traffic density. Even if clusters are more stable in case of DBA-MAC, the overhead generated in case of this protocol is greater than the one generated in case of CSP and F-CSP. In fact, as seen above, the overhead is composed in minority proportion of head election overhead and in majority proportion of inter-cluster transition overhead. Even if head election overhead is very limited in case of DBA-MAC (the clusters are more stable), this protocol generates a great inter-cluster transition overhead because heads are always close to each other and circulating in the same direction. The vehicles circulating in the opposite direction spend just a few seconds in each cluster. In case of CSP and F-CSP, clusters cover a wide area and heads are elected in each cluster independently. So, these protocols induce more head election traffic and less inter-cluster transition traffic (comparing with DBA-MAC).

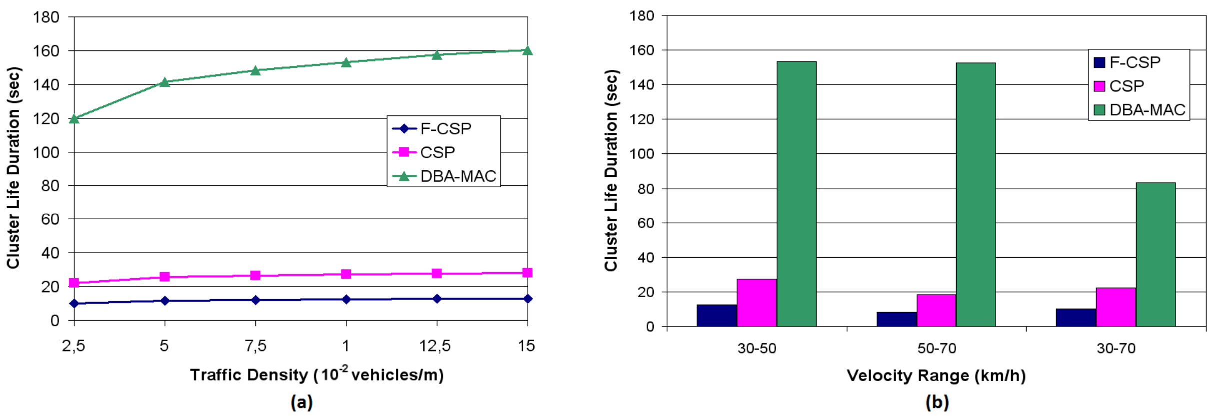

Figure 14. Cluster life duration vs. (a) traffic density, and (b) Velocity range

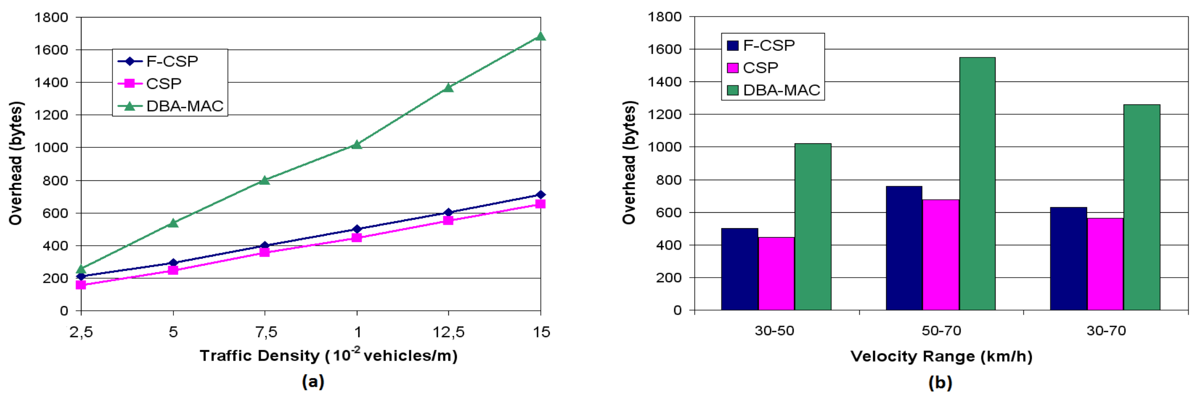

Figure 15. Generated overhead vs. (a) traffic density, and (b) Velocity range

The second interesting remark which can be deducted from Fig. (15) concerns the little difference between the overhead generated in case of CSP and the one generated in case of F-CSP. In fact, this difference is due to the difference in terms of head election frequency between the two variants.

Fig. (15.b) shows the generated self-organizing overhead (during 1 s in a 350-meter-length road portion) as a function of velocity range. For the three protocols, the generated overhead depends mainly on the mean velocity of vehicles.

Fig. (15.a) and Fig. (15.b) confirm the results obtained from the analytical study. Indeed, the generated overhead in case of CSP is a pseudo-linear function of traffic density (c.f. Fig. (11.c) and Fig. (15)) and a raising function of mean velocity (c.f. Fig. (12.c) and Fig. (15)).

c) Delivery ratio

Fig. (16) shows the delivery ratio as a function of traffic density. We remark that in case of CSP and DBA-MAC, the delivery ratio still upper than 90 % even with low traffic densities. In case of F-CSP, the delivery ratio is ~ 75 % for low traffic densities (0.025 vehicles/m = 1 vehicle per 40m) which is due to the limited extent of central zone. Then, it increases in an inversely exponential way (delivery ratio ~ 100 % for traffic densities > 0.1 vehicles/m). To have an idea about the importance of a self organizing architecture, the delivery ratios obtained with the intelligent broadcast fall to 50 % in case of high traffic densities (excessive use of bandwidth).

d) End-to-end delay

Fig. (17) shows the end-to-end delay as a function of traffic density. We remark that CSP and F-CSP permit to route packets to destination faster than does DBA-MAC. In fact, the heads elected as backbone members in case of DBA-MAC are closer to each other (to ensure the best stability of clusters), so when a packet is sent, it must traverse many relay nodes. In case of CSP and F-CSP, the geographic area managed by one head has a greater extent and then less relays have to be traversed.

The little difference between CSP and F-CSP end-to-end delays is due to the fact that heads, in case of F-CSP, never use super members as relays to exchange packets.

V. Discussion

In Contrary to DBA-MAC where dynamic clusters are used to self-organize the vehicular network, CSP is a self-organizing architecture based on geographically-defined clusters. CSP permits to maximize the geographic area covered by each cluster and while keeping a permanent connection between the neighboring heads. The analytical and simulation studies results show that the extending of the cluster's geographical area permits to minimize the major part of the self-organizing overhead which is due to the vehicles transition from one cluster to another one (CSP overhead is 3 times less than DBA-MAC overhead in case of dense traffic). To ensure a permanent connection between heads without limiting the clusters life duration and then increasing the head election overhead, CSP proposes the use of a specific node (the previous head) as a relay. This operation does not introduce any extra traffic and ensures: (i) a continuous connection between the two neighboring clusters, and (ii) a minimal end-to-end delay by optimizing the number of vehicles having to relay each packet.

CSP is based on the geographical clustering. However, differently to other geographical clustering based solutions as [5], CSP deploys the self organizing architecture proactively (in advance) in a large extended area. Such self-organization of the network permits not only the data collection (case of CGP) but also other applications (dissemination, routing, etc.), and not only a local deployment (case of CGP but also a large scale deployment.

Comparing to other self-organizing solutions (e.g. DBA-MAC), CSP could be deployed in both highways and urban environments. In fact, in both of the two environments CSP permits to obtain good delivery ratios and end-to-end delays. As far overhead is concerned, CSP shows better performances than DBA-MAC in case of both high velocities (highways) and high traffic densities (urban environment).

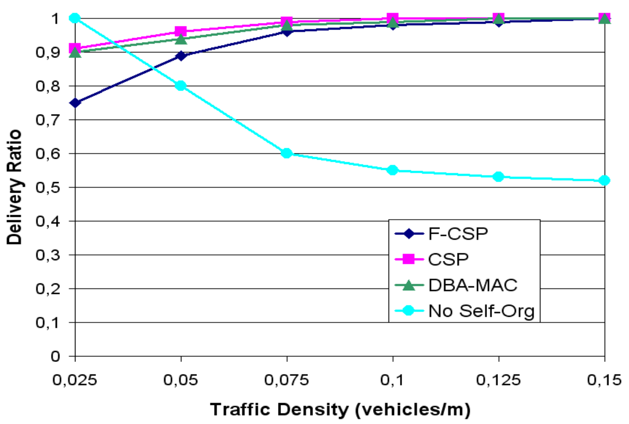

Figure 16. Delivery ratio vs. Traffic density

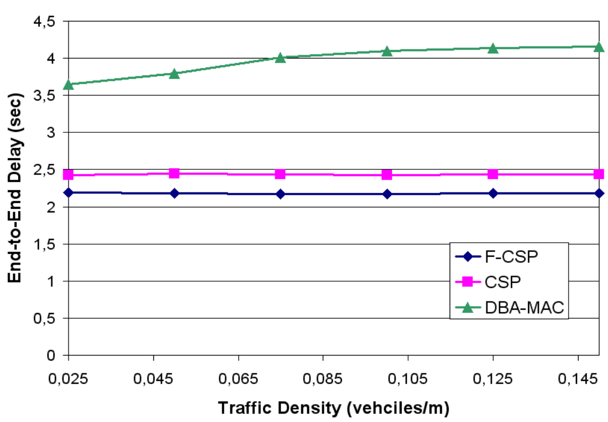

Figure 17. End-to-end delay vs. Traffic density

VI. Conclusion

Self-organization is a very important issue for vehicular networks especially in case of large scale deployment. It permits to construct and maintain a data exchange structure that acts as a basis for many networking protocols (data dissemination, data collection, routing, etc.). An efficient self-organizing architecture must permit to optimize delays and generated overhead comparing to no-organization-based solutions.

We proposed a new proactive self-organizing protocol called CSP which introduces the use of geographically pre-defined clusters to form a virtual backbone which routes packets between source and destination. CSP permits to maximize the backbone nodes inter-distance (to optimize the end-to-end delays) while preserving their inter-connectivity and minimize the frequency of vehicle transition between neighboring clusters.

The performance evaluation was done via both analytical and simulation studies. The analytical study permitted to estimate the CSP overhead as a function of many parameters: (i) traffic density, (ii) velocity range, and (iii) central zone width. This study shows that the generated overhead is raising function of the traffic density, mean velocity, and central zone width. The simulation study compared the performances of CSP, F-CSP, and DBA-MAC and proved that CSP, even if based on clusters that are less stable than those constructed in case of DBA-MAC, gave better results than the latter protocol, especially in terms of generated overhead and end-to-end delay.

As perspective for this work, it will be interesting to take into account other parameters to improve the choice of the new head. In addition to geographical location, other parameters could be integrated into the *E_Factor* formula. For example, parameters like velocity, acceleration and vehicle brand can make the comparison between different head candidates more accurate.

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