Multi-originator data dissemination in VANETs

Silvia Iadicicco, Simone Infante, Pierpaolo Salvo, Andrea Baiocchi, Francesca Cuomo

DIET, University of Rome "Sapienza", Via Eudossiana 18, 00184, Rome, Italy
pierpaolo.salvo@uniroma1.it, francesca.cuomo@uniroma1.it

***Abstract*—In the framework of the Vehicular Ad-Hoc Networks we propose HBEB (Hybrid Based Election Backbone), a distributed algorithm designed to form multiple backbones of vehicles in charge of propagating data in the VANETs in a fast and efficient way. Differently from other clustering approaches we leverage the ETSI Geonetworking recent standard to form and disseminate data in the backbones. We show that the formation of these backbones is quite easy to be implemented while their use enhances the dissemination performance in an urban scenario.**

***Index Terms*—Vanets, Backbone networks, Optimization**

I. INTRODUCTION

Clustering in Vehicular Ad-Hoc Networks (VANETs) has been discussed and analyzed in many works [1]. It can be used to support different applications based on the idea to form small groups of vehicles equipped with On Board Units (OBUs), having similar characteristics. Beside clustering, several VANETs applications require the dissemination of data flows, in some cases with high data rates [2][3]. In the literature it has been demonstrated that high data rates can be efficiently supported in VANETs when backbone structures are used to forward data. This however has the cost of the overhead to form the backbone as well as the high dependency on the dynamic network topology due to the mobility of its nodes.

There are two kinds of communication in a VANET: Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I). In the case of Vehicle-to-Infrastructure vehicles can also communicate with fixed access points located along the network, the so-called Road Side Units (RSUs). However RSUs can not always be easily installed and can be expensive, and as a consequence the possibility to have communication among vehicles, Vehicle-to-Vehicle, combined with multi-hop communications pave the way to more flexible structures to be used for VANET applications.

On the basis of these considerations we combine the two paradigms: clustering and forming backbones; in this way we have a structure that can be used to have different access points (RSU or OBU) to disseminate data in the VANETs. In our approach clustering is referred to the fact that vehicles with similar characteristics (i.e., in terms of speed) and in the same urban area (in the order of tens of m^2 up to some km^2) are grouped under the control of a single node named *originator*. Forming backbones is instead related to the use of a backbone structure into the cluster to disseminate the data from the originator. So the idea is to form different small backbones having one originator each (named in the following $Orig$) and disseminate data via the originators. As an example, in Figure 1 on the left side we show a single backbone being formed by a single originator, while in the right part we have three, smaller, backbones with three originators, respectively. Note that in the first case the data dissemination may start only by the $Orig_A$ which represents the only access point toward other networks (e.g., a cellular one like LTE) or toward an infrastructure, while in the other case the access points are three ($Orig_A$, $Orig_B$ and $Orig_C$).

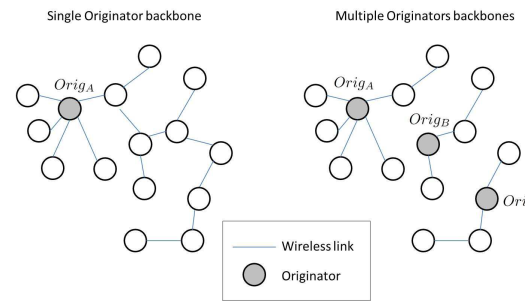

Fig. 1. Examples of single and multiple originators backbones

The idea to form multi-hop clusters in VANETs and to use them to have different access points to other networks (like cellular networks) is not new. The paper [4] proposes VMaSC-LTE, a hybrid architecture combining IEEE 802.11p based multi-hop clustering and Long Term Evolution (LTE), with the goal of achieving high data packet delivery ratio and low delay while keeping the usage of the cellular architecture at minimum level. In VMaSC-LTE vehicles are clustered selecting the cluster-head on the basis of the relative mobility metric calculated as the average relative speed with respect to the neighboring vehicles. Differently from [4] we propose to select possible cluster-heads (originators) in accordance to different criteria (that can be related to different parameters and features) and then create the cluster and the related backbone structure on the basis of the speed of the selected backbone nodes. This assures that the backbone is tailored on the specific cluster head. Possible features for selecting the cluster heads are: i) the speed of the node; ii) the channel quality that the potential originator has with the LTE or with the infrastructure in general; iii) the storage and processing capacity; iv) its position in the city map and many others. Moreover, we base our proposal on the ETSI GeoNetworking protocol and on a beaconless approach. This result in a set of three protocols that are fully compatible with the standard and quite light to be implemented.

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The rest of the paper is organized as follows. Section II and Section III deal with the related work and the motivations of this work, respectively. Three different version of the proposed approach are defined and described in Section IV.

II. Related works

The ETSI GeoNetworking protocol [5][6] enables the multi hop dissemination of messages in the VANET, merging the dissemination functionality into the vehicular networking layer and preserving the underlying MAC and PHY radio protocol layers as they are defined in the IEEE 802.11p. The Contention Based Forwarding (CBF) component of the GeoNetworking protocol (section E.3 of [5]) defines a timer-based dissemination logic to broadcast messages. A node A receiving a message from node B, checks if this has been already received and managed. In case it is new, A sets a timer according to the value

$$T = \begin{cases} T_{max} + (T_{min} - T_{max}) d_{AB}/R & d_{AB} \leq R \\ T_{min} & d_{AB} > R \end{cases} \quad (1)$$

where T_{max} and T_{min} are the maximum and minimum values set for the GeoNetworking broadcast message timer; R is the theoretical maximum communication range of the wireless access technology; d_{AB} is the distance between A and B. As proposed in recent works, clustering can be used to form small groups of vehicles in the network with similar characteristics. Recent studies have shown an incompatibility for standard clustering approaches in VANET scenarios, due to the high mobility involved [7], which has led to new proposals. The solution described in this work takes inspiration from these proposals, and employs a hybridization between clustering and beaconless (greedy) backbone creation.

Arkiam et al. [8] propose the supporting of local RSU to orchestrate various local clusters by communicating with cluster leaders, chosen for their relative distance between each other; once leaders are chosen, they will be exclusively in charge of disseminating data coming from the RSU to their personal local cluster. The remaining vehicles will listen for messages coming from leaders, or just send a cluster join request message, M_{cjr}, to join the nearest cluster and wait for incoming data.

As for the beaconless dissemination we consider the seminal approach of the distance-based-forwarding (CBF) [9]. In CBF, whenever any node broadcasted a message, the neighboring nodes would start a self-election process; instead of using beacons to find the more convenient nodes to disseminate incoming data, each node calculates a "suitability" based on its properties compared to the sender of the message; after that, this suitability is translated into a parameter, a timer, which represents the amount of time the node will stay idle before propagating the message; this self-imposed timer is known as self-delay and used to propagate or inhibit the propagation of messages. The result is that "suitable" nodes transmit the message since their timers expire before the other nodes and they are the only allowed to disseminate the data.

This per-packet greedy process greatly lowers the amount of overhead in the network, since only a few chosen nodes will be in charge of disseminating. Other similar works are DBD [2] and SEIYA [10]. DBD deals to the set up a backbone, taking into account the cardinality of the resulting backbone in order to allow for high-throughput multimedia content, possibly for safety video streaming, SEIYA instead tries to relax the goal of achieving the lowest cardinality and tyres to increase the stability of the backbone. Both algorithms have one main purpose: discern backbone nodes from inhibited nodes, and allow backbone nodes to disseminate any incoming source data throughout the whole network, while inhibited nodes are just supposed to gather data without propagating it. Suitable nodes are chosen using self-delays in a similar way to CBF, but their election is permanent, and not packet-related. Both DBD and SEIYA were employed in high-speed highway scenarios, which can be described as mono-dimensional environments, where rapid shifts in direction are not taken into account. On the contrary HBEB has been developed to be employed in urban scenarios, with possibly sudden changes in direction and speed, due to traffic and topological characteristics in cities.

III. Motivations

A. Backbones

Differently from beaconless per-packet algorithms for disseminating data in VANETs (like CBF and all related approaches), backbones seek to lower the total time a single packet is propagated through the network, keeping the number of accesses in the medium at a minimum when the backbone is fully formed. In general, the backbone formation is not even event-related, and it can fully form itself before there is an actual need for the infrastructure to be set up, already being operative the moment it is needed.

Suitability criteria to select backbone nodes are challenging, since they may be less reliable than the ones used in CBF because of the network dynamics. Indeed in CBF the criteria are applied per-packet, since CBF constantly checks the suitability of nodes and rewards them accordingly, for every trigger of an incoming packet. On the contrary backbone-related approaches, permanently consider the elected nodes as the most suitable in the network to disseminate incoming messages. Obviously, this cannot be the case, given the highly dynamic environment the VANETs represent. In fact, criteria used as for suitability become increasingly less truthful for elected nodes as time goes by.

For this reason, self-healing mechanisms are employed, which practically downgrade nodes belonging to the backbone to normal nodes, and make them undergo suitability evaluations once again.

B. Urban environments

The formation and maintenance of a backbone in urban scenarios is not an easy task: buildings may shield signal and prevent nodes within transmission range of each other to be able to communicate; nodes in crossroads may report untruthful statistics on their soon-to-be direction and speed;

backbone nodes might drastically change their intended route and severely damage the integrity of the whole backbone.

To cope with this, connection and disconnection policies must happen at faster paces, to keep up with the chaotic environment of cities. It may be possible to normalize every self-delay involved in the process, but shorter self-delays may lead to an anomaly which occurs during the election process. It is the job of a newly elected node to inform all other candidates: hence, a message is soon broadcasted informing all neighbors of the promotion. The anomaly occurs when two linked nodes end their respective self-delay nearly at the same time and propagate the elective message to the other; due to latency and delays in the communication medium, the nodes might not receive the elective message of their respective neighbor in time, which leads to both of them being considered successfully elected. This anomaly is referred to as Spurious Forwarding problem [11]. The problem lies in the fact that, by shortening the self-delay interval of all vehicles, this anomaly is more likely to occur. Countermeasures to solve the problem are offered, but they require further communication between the two (or more) contestants, which in very dire circumstances may lead to the broadcast storm problem.

By disconnecting nodes at faster paces too, severe consequences may happen: nodes losing their status as backbone nodes too hastily lead to the same repercussions as nodes distancing themselves to the point of physically disconnecting from the backbone: in both cases, a new election takes place in the proximity of the node disconnecting, halting the dissemination process to wait for the reconnection of the backbone to happen. In the worst case, the dissemination would come to a complete interruption, as the backbone is rejoined and broken multiple times in short periods.

C. Stability

For all related works showing beaconless, greedy dissemination algorithms so far, one of the most important cornerstones for a successful creation of stable virtual infrastructures (as backbones or clusters) is the “suitability” definition. Whenever a node must be inhibited, or join a backbone, or be a leader of a cluster, whenever nodes must be selected among other peers for their qualities, the rules to discern among the nodes are solely responsible for the quality of the resulting infrastructure. If unsuitable nodes are chosen, the results will perform poorly as well. For this reason, selecting the right criteria to enhance specific qualities of the resulting structure is of the essence. In all related works shown, stability is the main issue, as expected of works with similar objectives: a lasting dissemination of the whole network.

It is also not by chance that all algorithms seeking to increase the stability have suitability criteria taking relative speed of links into account [8] [10]; this is also the case of this work, which includes the relative speed into the calculations.

On the other hand, all algorithms seeking to cope with the broadcast storm problem and trying to increase the resulting throughput, by lowering the number of simultaneous accesses to the communication medium [9] [2], take the relative distance of links among the suitability criteria. Again, this work includes relative distance into the calculations.

Taking this work both the above mentioned criteria into account, it seeks to enhance both stability of the resulting backbone and allow for high-throughput dissemination over the network.

IV. Protocol description

In this work we study the possible advantages of using different vehicular backbone sub-networks created by multiple originators. The protocol is designed as an independent layer placed on top of the MAC, and used by any application framework that requires data dissemination, such as a download file or streaming video. Having multiple originators the data transmission can be parallelized, because there are more nodes distributed in different places of the network that may start the data dissemination at the same time. With reference to Figure 1 right side we can imagine that all originators ($Orig_A$, $Orig_B$ and $Orig_C$) are used by the same network operator (e.g., an LTE cellular operator) to disseminate information in the city.

In addition, each originator has a backbone that meets certain characteristics based on the approach used (described later), which can spread the data more efficiently compared to a simple flooding algorithm.

Nodes candidates for each backbone are chosen using self-delays mechanism in a similar way to the CBF component of the GeoNetworking protocol, but their election is permanent, and not packet-related. The self-delays mechanism works quite simply: every node keeps track of its own timeout; if no messages have been received before the timeout expires, the node changes its policy to *Backbone Node-BN* and forwards an elective packet; otherwise it becomes an *Inhibited Node-IN*. This self-healing mechanism works for both backbone and inhibited nodes, since inhibited nodes are not allowed to forward, and a *BN* should theoretically receive incoming packets from a single source: its previous hop.

In the following algorithms we use always one or more originators who create their own backbone, and then spread the data on it; then there are other nodes that try to join the backbone. Every node is in one of the following 4 state:

1) *Initial State*: state of a node when it enters into the network;
2) *Election State*: state of a node when receives an elective packet and starts the timer, denoted as T_r;
3) *Inhibited Node*: a node enters in this state when it receives an elective packet coming from the same originator for which it has already started a timer;
4) *Backbone Node*: a node enters in this state when the timer expires; from now on, the node will forward all incoming data packets.

On the basis of this mechanism we present three different proposals named $DBEB$ (Distance Based Election Backbone), $LDEB$ (Link Duration Election Backbone) or $HBEB$ (Hybrid Based Election Backbone) and explained in the following Section. We show in details the steps for the construction of one or more backbone in a self-delay process and we present the three equations that allow to compute the timer T_r^x (with x equal to $DBEB$, $LDEB$ or $HBEB$) used by nodes to decide whether or not to join the backbone.

A. Single backbone formation

The sequence of steps which leads to the full formation of a functional backbone is:

1) A certain node (labeled as ”originator”) triggers a broadcast elective message informing its neighbors of its promotion as backbone node (leader).
2) Every neighbor listening to this message enters into a *Election State*, activating a self-delayed election to determine the best one to become backbone node; this self-delay lasts T_r^x seconds, after which the node will be either elected (*Backbone Node*) or inhibited (*Inhibited Node*).
3) After a certain amount of time, as one of the electing nodes will be the first to have its self-delay expired, it will greedily promote itself as backbone node; this node will then trigger a broadcast elective message to its neighbors, claiming its successful election.
4) All nodes receiving this broadcast message will immediately stop their election process and change their forwarding policy to ”inhibited” (*Inhibited Node*); this means they will not forward any messages until the backbone disconnects; on the contrary, all nodes not in the transmission range of the broadcast message will keep waiting for their self-delay time.
5) Steps (2) to (4) are repeated in a greedy fashion by all nodes to form a backbone; once all nodes in the network are either inhibited or elected, the backbone is fully formed and operational.

The backbone expands with breadth-first characteristics.

To choose the appropriate candidate backbone nodes, we can observe that if the backbone nodes are too close, the backbone could not spread out effectively, moreover if the backbone nodes have movement patterns too different, the resulting backbone could be unstable in time.

We consider three different cases: in the first case, nodes are elected when their physical distance from the previous hop is maximized and $DBEB$ equation will be used (Section IV-C). In the second case, nodes are elected due to their particular relative speed configuration and $LDEB$ equation is to be used (Section IV-D). In the last case, an hybrid equation between $DBEB$ and $LDEB$ is used and the resulting approach is denoted as $HBEB$ (Section IV-E).

B. Multiple originators

As previously stated, the most important change of the work concerning the formation of a backbone lies in the ability to generate multiple fragments of backbone from multiple originators. This solves a number of problems from previous implementations, such as:

- multiple access points (the originators) to disseminate data to the vehicles;

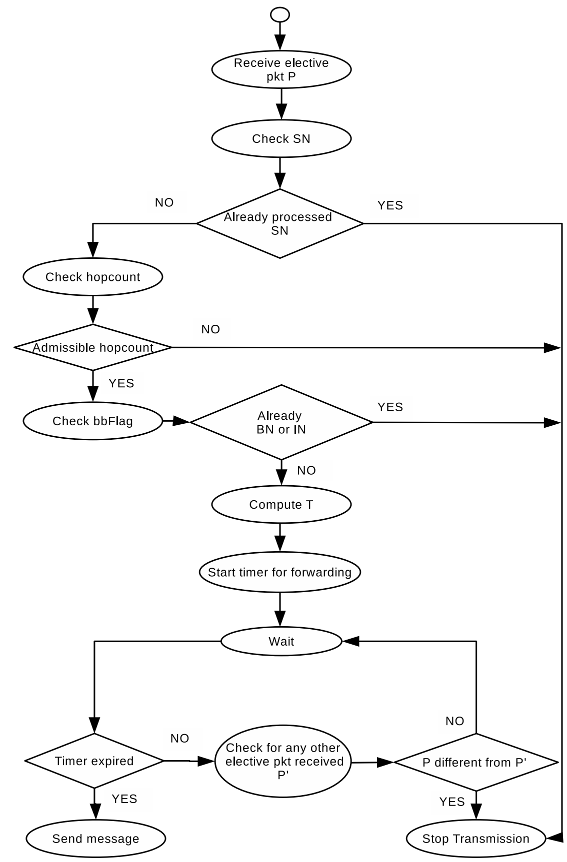


Fig. 2. A flowchart summarizing single backbone formation

- a faster backbone formation time (similar to clustering algorithms);
- more homogeneous backbones in terms of their characteristics and the stability of a entire backbone are less dependent from a single source (single originator) ;
- backbone structures with a low number of hops and consequently more efficient to disseminate data in a fast way.

In order to chose the originator nodes, each node a random chance to become an originator. Notice that for sake of simplicity here we select a random approach but in general originators may be chosen on the basis of different criteria as stated in Section I. The suitability parameter is used in a local scope: in this case, it means that every node belonging to the frontier of the backbone is responsible for the election of the next backbone nodes, in a greedy fashion. Moreover, a backbone node discards any other elective packet received from other backbones. The extension of the backbone is interrupted when each node that belongs to the edge sends an elective packet and this is only received by nodes belonging to the edge of another backbone: this means that the area is already covered.

A node that is elected as the originator will be originator until the backbone disconnects. This newly forming backbone has all characteristics of a single-generator backbone, besides the fact that it is now not the only one in the network. In addition to this, the ID of the generator appears as a field throughout all election messages coming from the backbone, propagating at every hop to all nearby nodes, which will store it until the backbone is fully formed and "belonging" to its originator.

C. Distance Based Election Backbone - DBEB

The Distance Based Election Backbone tries to reduce the number of nodes that forward a message on the basis of their distance from the previous BN. DBEB uses a self-election process and creates a backbone, using a "suitability" parameter where it is not taken into account the speed of the nodes. The underlying idea is to associate the smallest timer at the best node candidate, following the equation (2).

Suppose a node j receives a packet from a node i; the node j computes the timer value according to the following rule:

$$T_r^{DBEB} = \begin{cases} T_{max}(1 - \frac{d_{i,j}}{R}) & d_{i,j} \leq R \\ \infty & d_{i,j} > R \end{cases} \quad (2)$$

where T_{max} is a maximum timer level, $d_{i,j}$ is the distance between the nodes i and j, R is the theoretical maximum communication range. Following the equation (2), the timer value increases if the distance between the node i and j decreases: in fact the idea of the *DBEB* is exactly to prefer nodes furthest (but within the communication range), because nodes that are too close have similar coverage. When referring to node coverage, it is meant the amount of network covered by the node: in order to decrease the cardinality of the backbone, the relative distance of a candidate (a potential backbone node) in respect to a backbone node is used as a "suitability" parameter, since it is assumed that farther vehicles will provide transmission to more uncovered vehicles than ones closer to the backbone. In addition, if the relative distance is greater than R, the node j is not a good candidate, and it sets the timer to infinity.

D. Link Duration Election Backbone - LDEB

LDEB makes use of an equation which takes both total weight and cardinality of the backbone into account. To do so, it takes advantage of an already well-known hybrid equation to determine the relative mobility of couples of vehicles which fall within their mutual transmission range, the *LDT* (*Link Duration Time*) [12].

Two main vehicle properties are taken into account: the absolute position of the vehicles and their absolute speed. More formally, for two vehicles i and j, let : their absolute speed v_i and v_j, their absolute positions in the scenario (x_i, y_i) and (x_j, y_j), their respective movement directions degree θ_i and θ_j, and the maximum transmission range for vehicles R, the algorithm computes the LDT of link (i, j) between the vehicles at instant t, as shown below:

$$LDT_{i,j}^t = \frac{-(ab + cd) + \sqrt{(a^2 + c^2)R^2 - (ad - bc)^2}}{a^2 + c^2} \quad (3)$$

with a, b, c, d defined as follows:

- $a = v_i cos(\theta_i) - v_j cos(\theta_j)$ at instant t;
- $b = x_i - x_j$ at instant t;
- $c = v_i sin(\theta_i) - v_j sin(\theta_j)$ at instant t;
- $d = y_i - y_j$ at instant t.

The main idea behind equation (3) is to derive the relative (vectorial) speed of vehicles and their relative distance to obtain a value inversely proportional to the relative speed and directly proportional to the relative distance. The result is a value inversely proportional to the relative mobility of the two vehicles in the link. In other words, the lower the value of *LDT*, the quicker the their disconnection of i and j will occur.

For this very reason, knowing the inversely proportional relationship between relative mobility of two communicating vehicles and eq. (3), the timer in *LDEB* is selected as:

$$T_r^{LDEB} = min\left(\begin{cases} \frac{k}{LDT_{i,j}} & a^2 + c^2 \neq 0 \\ T_{min} & a^2 + c^2 = 0 \end{cases}, T_{max}\right) \quad (4)$$

with $k \in \mathbb{R} \setminus \{0\}$. The result is a value inversely proportional to the reliability of the link, normalized with a certain coefficient k and included in the range $[T_{min}, T_{max}]$.

This is the basis behind the $LDEB$. The value derived from (4) is used as "suitability" parameter to determine which link is the best one in a local scope, which will lead to the best links becoming part of the backbone. Indeed, the purpose of $LDEB$ is to obtain a backbone with vehicles that have similar speeds, so make it less likely that the backbone breakes.

E. Hybrid Based Election Backbone - HBEB

Since the speed is a very important parameter to be considered in VANETs, having nodes in the backbone at different velocity levels can lead to frequent partitioning of the network. *LDEB* addresses just this problem, but in an urban scenario where there is high density and many vehicles are standing still (for example waiting at a traffic light), the eq. (4) can lead to anomalies. Using *LDEB* in this case leads the candidate nodes to have similar timers and then expire at very close time instants. As a consequence too many candidates become backbone nodes, increasing the cardinality of the backbone.

HBEB tries to solve this problem in urban settings where speed may not be quite discriminative, with a hybrid approach between *DBEB* and *LDEB*. Let us consider candidate node j that receives an elective packet from *Backbone Node* i. The purpose of this formula is to divide the coverage area of node i in ns equal sectors (numbered from 1 to ns), and distribute timers to choose the candidate node j according to the sectors where it is located. Candidate nodes in a sectors are discriminated by the relative mobility with respect to node i, using a stability factor of the link (i, j), defined as follow:

$$sf_{i,j} = \min\left(1, \frac{LDT_{i,j}}{T_{max}}\right) \quad (5)$$

where T_{max} and $LDT_{i,j}$ are the same as defined in section IV-D. The stability factor is a value between 0 and 1, and it is proportional to the link duration obtained by $LDT_{i,j}$. This hybrid approch tries to elect a node with higher stability factor, in the sector ps with $1 \leq ps \leq ns$; if there is no node, it looks for a sectors closer to the backbone node, and so on. If there are not nodes in these areas it starts from the farthest sectors (namely ns) to return to the ps.

Therefore, the node j computes the timer T_r^{HBEB} as:

$$T_r^{HBEB} = \text{rand}\left[T_{min}^{HBEB}, T_{max}^{HBEB}\right] \quad (6)$$

where T_{max}^{HBEB} and T_{min}^{HBEB} are respectively the maximum and minimun values, defined as follows:

$$\begin{aligned} T_{max}^{HBEB} =& \alpha T_{max}\left(1 + \frac{1}{sf_{i,j}} + \left(ns - \left\lceil \frac{d_{i,j}}{R} ns \right\rceil + \right.\right. \\ & \left.\left. + ps\right) \text{mod}(ns) - sf_{i,j} + \frac{1}{\beta}(1 - sf_{i,j}) ns \right) \\ T_{min}^{HBEB} =& \min(0, T_{max}^{HBEB} - \alpha T_{max}) \end{aligned} \quad (7)$$

R and $d_{i,j}$ are the same as defined in the previous sections; ps is the first explored sector; ns is the number of sectors; $sf_{i,j}$ is a stability factor of the link (i, j); α and β are scale factors ($0 \leq \alpha \leq 1$, $0 \leq \beta \leq 1$), where α is used to determine the maximum values of the timers, instead β is used to control the correlation between the timers with different stability factors.

An example is shown in Fig.3 with 16 vehicles, in which the gray vehicle is the backbone node that sends the elective packet to all vehicles in its transmission range in order to choose the next backbone node. There are five sectors ($ns = 5$), and the first sector explored to find the vehicle with higher stability factor is central one ($ps = 3$). There are three vehicles for every sector, and blue vehicles have stability factor equals to 1, green vehicles equals to 0.8 and red vehicles equals to 0.6. The vehicles compute timers according to equation (6), and distributed as shown in Fig.3. Using this scheme, the green vehicle in the sector 4 compute a timer longer than timers of vehicles with greater stability factor or with equal stability factor but in the sectors explored before by the protocol (sectors 1, 2, 3, 5). In addition the timer of this vehicle is shorter than the timer of vehicles with lower stability factor (red vehicles). The candidate node with the shortest timer is the blue vehicle in the third sector, because it has the greatest stability factor and belonges to the third sector ($ps = 3$).

V. PERFORMANCE ANALYSIS

In order to test the presented algorithms, various simulations were performed and the results compared with the CBF algorithm. The chosen scenario is roughly a 12 km^2 area of New York city, in particular it includes part of the Manhattan district: an ideal scenario to simulate the impact of different algorithms over urban areas, characterized by high density and obstacles that compromise the wireless communications.

We evaluate the performance of our proposed mechanisms by using a multi-layer simulation tool that is constructed as a composition of the following simulation modules: SUMO [13], for the vehicular micro-mobility simulation, OMNET++ [14],

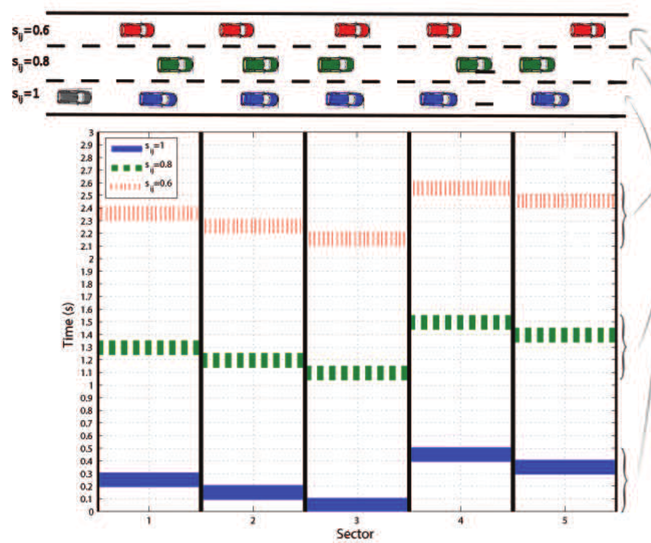


Fig. 3. Example of timers distribution, with $ns = 5$, $ps = 3$, $\alpha = 0.001$, $\beta = 0.1$, $T_{max} = 0.1$

for the communication network simulator, and Veins [15], a software module that interconnects SUMO and OMNET++, allowing data import and export between the two.

We consider actual urban map of the city centers of New York, obtained by OpenStreetMap [16]. This map is mainly characterized by a regular grid of avenues and streets that create a considerable number of junctions. Mobility of vehicles is generated by the micro-mobility simulator SUMO, according to the so called "random trips" model.

The OMNET++ simulation tool is used to simulate the behavior of the communications process, including the operations of the Physical, MAC and network layers. The MAC and PHY parameters are set equal to those specified by the IEEE 802.11p standard. We have embedded the implementation of the dissemination logic described above in the network layer. To model the impact of buildings and other obstacles to signal propagation, we have jointly used two attenuation models: the Two Exponents Model (TEM) [17] and the Simple Obstacle Shadowing Model (SOSM) [18]. The TEM models the distance dependent component of the power loss: it assumes that the attenuation is $A(d) = \kappa d^{\alpha_1}$, for distances d up to a break point value d_{bp}. For $d > d_{bp}$, it is $A(d) = \kappa d_{bp}^{\alpha_1 - \alpha_2} d^{\alpha_2}$. Typical values of the path loss parameters are $d_{bp} = 120\ m$, $\alpha_1 = 2$, and $\alpha_2 = 4$. The SOSM reproduces in Veins the shadowing effect of a real urban environment: it describes the attenuation as a function of the depth of the buildings crossed by radio links.

Numerical values used for simulation parameters are listed in Tab. I. The proposed algorithms were tested by varying the number of originators from 1 to 5, and for each originator were made 5 simulations. It is important to note that the originators were chosen in a random way between all nodes in the considered network. In all simulations we considered both the network formation and the transmission of a data stream, with a duration equal to 20 seconds for low data rate (a packet every 2 seconds), while a duration equal to 1 second for high data rate (a packet every 0.01 seconds).

TABLE I
SIMULATION PARAMETER VALUES

Parameters	Values
Max transmission range of vehicles (R m)	830
Max self-delay (T_{max} ms)	100
Average total vehicle density (veh/Km^2)	110
Normalization coefficient (k)	1
SpeedRefreshRate (s)	1
MAC, PHY parameters	IEEE 802.11.p
Low data rate (bit/s)	4000
Hight data rate (bit/s)	800000
Packet size (bit)	8000
Number of sectors (ns)	5
First explored sector (ps)	3
α	0.001
β	0.1

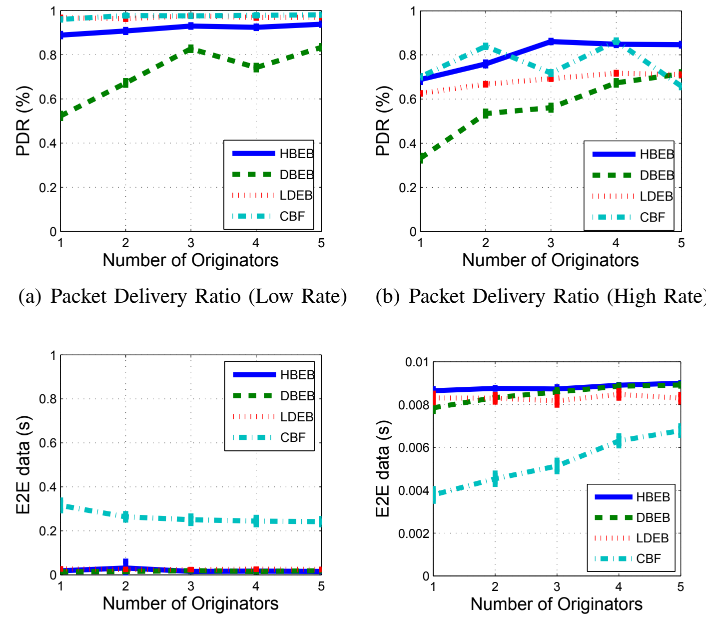
The performance evaluation metrics considered in our simulations are:

- *Packet Delivery Ratio (PDR)*: the ratio between correctly received data packets and the total sent data packets;
- *Forwarding Ratio (FWR)*: the ratio between number of nodes that forward the data packets and the total number of nodes in the scenario;
- *E2E election*: average end-to-end delay of elective packets;
- *E2E data*: average end-to-end delay of data packets;
- *Throughput*: the number of broadcast bits correctly received by all vehicles in the scenario per unit time (as measured over the observation period of the simulation);
- *Stability*: percentage of the nodes covered in a given time interval;
- *PDR order*: the ratio between number of data packets received in sequence of sending and the total sent data packets.

A. Results and discussion

Figures 4 and 5 show the results obtained by simulating the algorithms proposed in this paper and the CBF. The aim is to compare the effects of having backbones to disseminate data with respect to the simple CBF, where there is not a disseminating structure. In all graphs the x-axis corresponds to the number of originators in the network, and each value is obtained by averaging 5 simulations runs with 95% confidence interval.

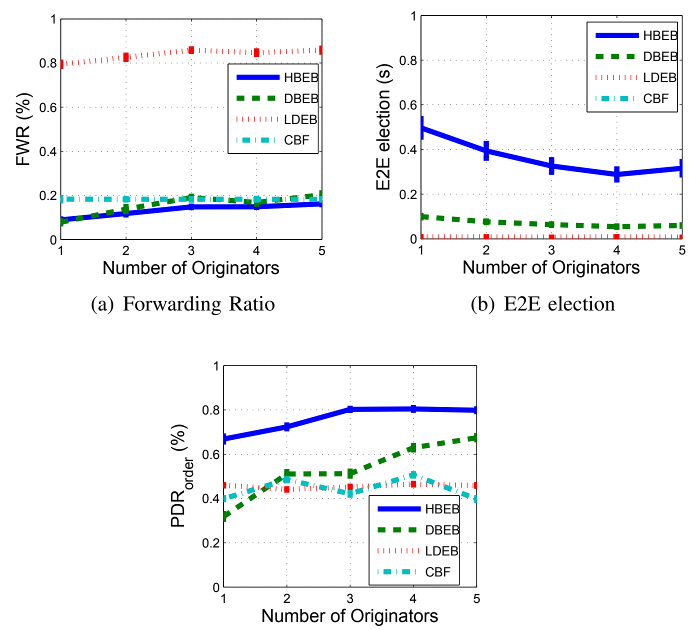
By looking at Figure 4(a) 4(b) it is possible to note that for every protocol the PDR increases with the number of originators, both high and low data rate; this is due to the fact that having more originators scattered across the network allows to reach wider areas and a greater number of nodes. $LDEB$ guarantees a high PDR , especially at low rate, but it can be noted that the number of nodes in the network that forwards packets is always greater than 80%. The scenario considered is high density, and this in an urban setting means that it is likely to find vehicles stuck in traffic. All these vehicles have a speed equal to zero, so if they receive an



(a) Packet Delivery Ratio (Low Rate) (b) Packet Delivery Ratio (High Rate)

(c) E2E data (Low Rate) (d) E2E data (High Rate)

Fig. 4. Packet Delivery Ratio and E2E data delays



(a) Forwarding Ratio (b) E2E election

(c) PDR order (High Rate)

Fig. 5. FWR, E2E election delays and PDR order

elective packet from a still backbone, they start a timer equals to T_{min} (according to equation (4)), and then all vehicles are elected as backbone nodes.

If the protocols are evaluated only in terms of PDR and FWR at low rate, it might emerge a disadvantage to create structures in the network since the CBF has low FWR and high PDR. This behavior is justified by the fact that, as mentioned above, *CBF* is packet-based, namely it behaves adaptively to the system conditions, so as for the two metrics above it may behave in an optimal way. But Figure 4(c) shows the average trend of transmission delay of the data stream and the disadvantage of the CBF is that it has larger delays between one packet and another respect protocols backbone based that do not have delays in delivery of data.

The advantage of the presented backbone based algorithms is that, independently from the equation used to compute the timer, they lower the overall delay on a data stream. In addition HBEB maintains a high PDR with low FWR respect to the compared protocols, moreover it maintains low the overall delay on a data stream. Moreover as it can be seen from Figure 5(c) HBEB outperforms the other solutions in term of ordered data flows delivery at high data rates, with good throughput values and with a great percentage of nodes covered over time as shown in Table IV, for this reason it particular is suitable to be used by applications such as video streaming.

TABLE II
THROUGHPUT VALUES ($kbit/s$)

	Hight rate				
Protocol	**1 Orig**	**2 Orig**	**3 Orig**	**4 Orig**	**5 Orig**
HBEB	696.7	696.7	696.7	696.7	696.7
DBEB	605.3	605.3	605.3	605.3	605.3
CBF	451.7	451.7	451.7	451.7	451.7
LDEB	374.4	374.4	374.4	374.4	374.4

TABLE III
THROUGHPUT VALUES ($kbit/s$)

	Low rate				
Protocol	**1 Orig**	**2 Orig**	**3 Orig**	**4 Orig**	**5 Orig**
HBEB	3.794	3.779	3.786	3.772	3.893
DBEB	3.292	3.181	3.465	3.42	3.476
CBF	3.931	3.938	3.927	3.934	3.942
LDEB	3.882	3.876	3.918	3.891	3.893

TABLE IV
STABILITY HBEB

	nodes reached (%)				
seconds	**1 Orig**	**2 Orig**	**3 Orig**	**4 Orig**	**5 Orig**
2	0.9160	0.9251	0.9289	0.9233	0.9079
4	0.8780	0.8896	0.9150	0.9244	0.9273
6	0.8740	0.9115	0.9208	0.9147	0.9364
8	0.8745	0.8843	0.9139	0.8832	0.9246
10	0.8775	0.8908	0.9291	0.9150	0.9288
12	0.8359	0.8938	0.9346	0.9128	0.9438
14	0.8829	0.8866	0.9163	0.9271	0.9086
16	0.8939	0.9075	0.8993	0.9010	0.9223
18	0.8916	0.9004	0.9206	0.8860	0.9282
20	0.8048	0.8766	0.9240	0.9384	0.9328

VI. CONCLUSIONS

This work presented three different approaches to build multi-hop clustered structures to be used in VANETs to disseminate data. All the structures leverage the Contention Based Forwarding approach defined in the Geonetworking protocol to select the backbone nodes. The flexibility is to define multiple backbones, homogeneous in their characteristics and aiming at a good coverage of the city map. We provide a simulation analysis showing the gain of having multiple originators and small backbones. Future work will be dedicated to test different criteria to select the originators in order to fit some specific applications requirements.

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