Inside VANET: hybrid network dimensionning and routing protocol comparison

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Abstract— **In this paper, we are interested in the properties of vehicular ad hoc networks (VANET). We study the mean connection lifetimes to evaluate the feasability to support non-safety applications. Because connection lifetimes are in the order of a few minutes, an infrastructure network is highly recommended to maintain connectivity between car clusters. Using an hybrid network, we perform comparisons of routing protocols used in the VANET. We show that reactive and geographic routing protocols are very close in terms of performance. However the reactive protocol are more accurate since it does not require neither geolocalization systems nor location services. We propose the use of hybrid networks and we give dimensionning rules to ensure connectivity of the network.**

I. Introduction

Vehicular ad hoc networks (VANET) using 802.11 based wireless technology have recently received considerable attention. Vehicles are equipped with 802.11 WiFi card configured in ad hoc mode. The VANET can be used for driver-vehicle safety applications and non-safety applications. The feasibility and quality of the non-safety applications will be dependent on the topological and dynamical properties of the ad hoc network. Moreover, the routing protocol has to be efficient in this high mobility context where topological changes are very frequent. A number of studies on the network properties and on routing comparisons have been done. This study adds some new quantities and new parameters to the network properties. We particularly investigate the 'connection lifetime', defined as the time for which there exists a path between two vehicles. This quantity limits the use of a pure ad hoc VANET network. Indeed, we shall show that the connection lifetime is short even in optimistic situations. It may be penalizing for non-safety applications which can require connections of the order of several minutes. We think the use of hybrid networks is the best solution to support non-safety applications. In such a network, access points (AP) are deployed along the highway but does not cover the full highway. Between the APs the VANET is used. It allows supporting new applications: access to the Internet, intervehicle voice communications, broadcast of traffic conditions, advertisements on available restaurants, hotels, etc. Another benefit is that the access points can be deployed progressively or partially leading to a lower cost.

We propose in the second part of this paper, dimensioning rules for the APs deployment. Specifically, we evaluate the distance between the APs which guarantees that a mobile node will have access to an AP via the VANET with a high probability. The third contribution of this paper is the comparison of two ad hoc routing protocols. The first one uses reactive control (DSR: Dynamic Source Routing Protocol) and the second uses geographic information (GPSR: Greedy Perimeter Stateless Routing). These both approaches are the most suitable in ad hoc networks with fast topological changes. In a previous study [7], the authors found that the geographic protocol was more efficient than the reactive one. We think that it was the consequence of particular parameterization or assumptions that they made. In the contrary, our simulations show that both these protocols achieve the same performance. All the simulations we performed, are based on a traffic simulator that we have developped. It uses techniques of micro simulations to obtain realistic trajectories of vehicles on a highway. The results are thus very specific to highway traffic and would lead to very different results with different mobility patterns.

This paper is organized as follows. In Section , statistical quantities on the connection lifetime are presented. They are obtained with the traffic simulator. In Section III, dimensioning rules for the infrastructure part of a hybrid network are given. The results of a comparative study of DSR and GPSR and a discussion on the implications are given in Section IV. Section V concludes the paper.

II. Connection lifetimes

Due to the dynamics of the vehicles traffic on the highway the VANET is often split up. The vehicles are gathered into clusters. A cluster is composed of all the vehicles which are in the same radio range. As a consequence, there is a path between all pairs of vehicles of the same cluster but not between two vehicles of two different clusters. In Figure II, an example of such clustering (with three clusters) is shown. The radio links between vehicles are represented by the black lines. In this section we are interested in the connection lifetime. It is defined as the time during which the two cars belong to the same cluster.

In order to obtain vehicle movements close to the reality we use a traffic simulator. In it, each vehicle has to emulate the driver behavior. On a highway, the driver behavior is confined to accelerate, brake and change lanes. We assume that there is no on-ramp on our section of the highway. A desired speed is associated to each vehicle. It corresponds to the speed that the driver would have reached if he had been alone in his lane.

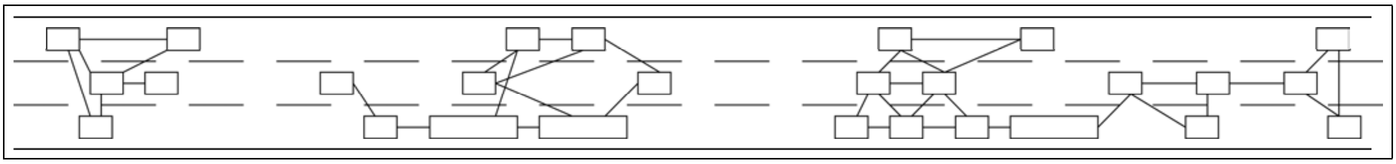


Fig. 1. An example of non-connexe cluster of vehicles

If the driver is alone, he adapts his acceleration to reach his desired speed (free flow regime). It he is not alone, he adapts his acceleration to the vehicles around (car following regime). He can also change lanes if the conditions of another lane seems better. All these decisions are functions of environment of the vehicles (speed and distance) and random variables are used to introduce a different behavior for each car. This kind of simulation is called micro simulation and the model we use is presented in detail in [1].

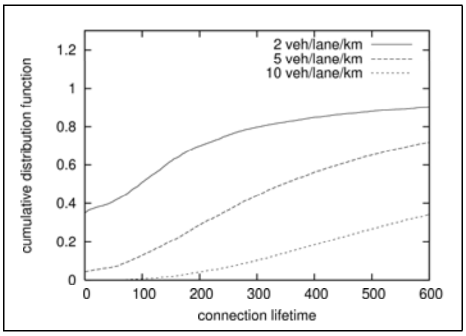
We use this simulator to study the connection lifetime. We assume that the radio range of all the vehicles is 250 meters. We consider a highway with three lanes and only one direction (one way?). Following distribution and averages are obtained from 5000 samples.

The two vehicles for which we study the connection lifetime are chosen randomly. We randomly pick up a first car and we choose as peer the car just in front of it on the same lane. For that reason we find longer connection lifetimes than in the other works [15], [17], [6]. But, even with this optimistic case, connection lifetimes are small. In Figure 2(a) for 2 (respectively 5) vehicles per lane and per kilometre, 80% (resp. 40%) of the connections lasts less than 300 seconds. We note that this corresponds to a very optimistic case since we choose two cars one behind the other. Moreover, we do not take into account interferences or obstacle which may limit the radio scope of the vehicles.

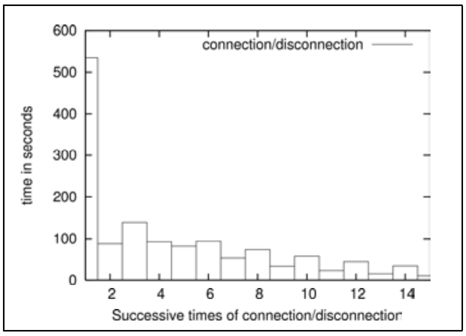
For most of the pair of vehicles, the connection lifetime is short. However, in the case where the consecutive disconnection is very short, it cannot significantly disrupt the communication between the two vehicles. In Figure 2(a), we plot the successive mean lifetimes of connections and disconnections between two vehicles for 5 veh/lane/km. The odd boxes are the successive connection lifetimes and the even boxes correspond to the disconnection. It appears that the first disconnection (box number 2) is about 100 seconds and thus very long. The other lifetimes decrease in average and are of the order of 50 seconds. For other intensities that we do not present here due to lack of space, the numerical values are quite different but there is always a long lifetime for the first connection followed by a non negligible disconnection lifetime (at least a few seconds) and decreasing sequences of connection and disconnection lifetimes. In all the cases, the first disconnection is too long to consider buffering packets during the disconnections.

One of the proposed solutions to this problem is to use the dynamicity of the network to route the packet to the destination even if the source and the destination does not belong to the same cluster. Due to this dynamicity some vehicles pass from a cluster to another. These cars can buffer the packet until they reach the destination cluster or a cluster closer to the destination. Some papers have proposed algorithms to apply this kind of mechanism and to choose the gateway which will buffer the packet until they reach a new cluster [16], [8]. We study the feasibility of this approach in the context of a VANET. A similar work has been done in [4] but the source and the destination were 10 km far. With these kind of distances, inter-vehicular communications are likely impossible because the probability of having a path between the two vehicles is too small. We take, as earlier, an optimistic case: we choose two cars one behind the other on the same lane. We consider simulation where the two cars are initially connected (belong to the same cluster) and we wait for the first disconnection. At the disconnection time, the source sends the packets which are instantaneously transmitted to all the vehicles of its cluster. All the cars which have the packets act as gateways. When a vehicle having the packets reaches a new cluster or new vehicles which do not have the packets, the packets are instantaneously transmitted to these vehicles. This scenario gives us a lower bound on the time needed to reach the destination when using vehicle gateway. In Figure 3(a), we plotted the time to deliver the packets to the destination with the use of these gateways. We associate to each point a confidence interval of 95%. There is an undeniable benefit in using gateways. For instance, there was a first disconnection lifetime of 100 seconds for 5 veh/km/lane (Shown in Figure 2(b)) but with the use of a gateway the packet delivering takes only about 18 seconds. But, if the traffic is heavy, packets cannot be buffered for several seconds and congestion could appear in the network.

In consequence, we believe that an infrastructure based network is required to support both long term and long distance connections. This infrastructure network does not need to cover the full highway. Access Points may be deployed at fixed interval in order to guarantee the connectivity of the different clusters. With this approach, long term and long distance inter-vehicle communications become possible. Another benefit of a hybrid network is that the infrastructure may be deployed partially and thus at a cheaper cost or it may be deployed progressively. But the question of dimensioning of such networks arises. In the next Section we investigate the dimensioning of the infrastructure part of the hybrid network.



(a) Cumulative distribution function for the connection lifetime



(b) Mean times of connection and disconnection

Fig. 2.

III. Dimensionning the hybrid network

In this Section we are interested in the characteristics of the topology of the ad hoc network formed by the vehicles on a highway. We study the analytical properties of the clusters in terms of size: distribution of the number of vehicles in a cluster and distribution of the cluster length. The motivation of the second quantity is to find the probability that a vehicle may have access to an access point (AP) using the ad hoc network. In order to study these quantities, we assume that the radio range of all nodes is a ball of radius R. In other words, there is a link between two nodes if and only if the distance between these nodes is less than R. Since highways are narrow (generally 3 meters for a lane), the width of the highway can be neglected with regard to the radio range of the vehicles. We can thus consider a point process on the line to model the nodes on the highway. The point process used to model the location of the vehicles on the highway depends on the traffic intensity [9], [2]. When the inter-vehicular distance (or equivalently the inter-vehicular time) are high (4 seconds for the inter-vehicular time), the behavior of the drivers are quite independent of each other and the vehicle locations are closed to a Poisson point process. When the traffic is heavy, acceleration and speed of vehicles are dependent on each other and more complicated point process must be considered. For vehicles in a city, Poisson point process cannot be considered due to the correlation between the cars introduced by traffic lights and stops, even if the traffic is very light.

The main motivation of this analysis is to dimension a hybrid network as a function of the probability that there exists a path between a vehicle and an access point. This dimensioning must be done for low traffic since it corresponds to the worst case. So, in this case, the Poisson point process is appropriate.

a) Number of vehicles in a cluster: We first give the distribution of the number of vehicles which belong to the same cluster. Let there be a Poisson point process of intensity λ ($\lambda > 0$) distributed on the line. λ corresponds to the mean number of vehicles per kilometre. Let it be the first cluster beginning after the origin, the probability of having k ($k > 0$) vehicles in a cluster is given by:

$$(1 - \exp\{-\lambda R\})^{k-1} \exp\{-\lambda R\}$$

The mean number of vehicles per cluster is then:

$$\exp\{\lambda R\}$$

b) Probability that an access point cover the cluster: From the theory of coverage processes, we know the distribution of the length of a cluster. The length is defined as the sum of the area covered by the radio of all the vehicles of the same cluster. It is given by (see [11] page 88) :

$$f(x) = \exp\{-\lambda R\}\delta_{2R}(x) + \frac{\lambda(1-\exp\{-\lambda R\})}{\exp\{R\lambda\}-1}\Big[1 + \sum_{j=1}^{[\frac{x}{R}-2]} \frac{(-1)^j}{j!} \left(\lambda\left(x-(j+2)R\right)\right)^{j-1} \times \exp\{-jR\lambda\}\left(\lambda\left(x-(j+2)R\right)+j\right)\Big]\mathbb{1}_{x>2R}$$

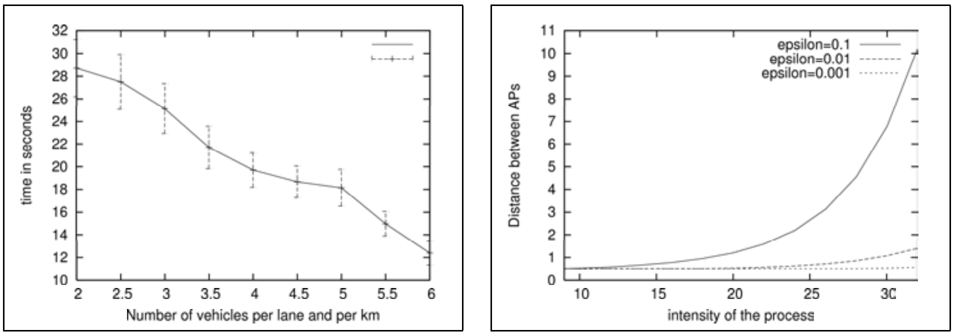
where $[\frac{x}{R}-2]$ denotes the integer part of $\frac{x}{R}-2$, $\mathbb{1}_{.}$ is the indicator function ($\mathbb{1}_{x>2R}$ equals 1 if $x > 2R$ and 0 otherwise) and $\delta_{.}(.)$ is the Dirac measure.

We assume that APs are deployed regularly along the highway i.e. the distance between APs is constant, say L. The radio range of the AP is supposed to be the same of that of the vehicles (R). In this case, all the vehicles of a cluster will have access to an AP if the size of the cluster denoted by C is at least L. A way to dimension the AP along the highway is to guarantee with a high probability that the vehicles can reach the APs via the ad hoc network. We can guarantee with a probability of $1-\epsilon$ that a vehicle can reach an AP if $\mathbb{P}(C \geq L) \geq 1-\epsilon$, with

$$\mathbb{P}(C \geq L) = 1 \text{ if } L \leq 2R$$

$$\mathbb{P}(C \geq L) = 1 - \int_{2R}^{L} f(x)dx \text{ if } L > 2R$$

In Figure 3(b), we plot the required distance between Access Points when the intensity varies and for different values of ϵ. The radio range is equal to 250 meters. We observe that there is a significant distance between the APs only for $\epsilon = 0.1$.



(a) Time to reach the destination with the use of gateway

(b) Distance between the APs

Fig. 3.

For $\epsilon > 0.1$, the distance between APs is very close to $2R$ when the intensity is small, which means that the APs cover the highway in full. In the case where the number of vehicles per kilometre (λ) are high ($\lambda = 32$ which means 100 meters between vehicles on a highway with three lanes or equivalently an inter-vehicular time close to 3 seconds between vehicles of the same lane) the distance between AP is approximately six times the radio range of the vehicles ($L = 1.4$ km). In this case, it is beneficial to use a hybrid network since there is at least a probability of 99% of reaching an AP through other vehicles, that works for relatively small intensity ($\lambda = 32$: in Paris and its suburbs this intensity is only observed late in the evening and at night) and there are three times less AP to deploy than that for an infrastructure network.

IV. Simulation

In this section, we are interested in the performance evaluation of the ad hoc part of the hybrid network. We compare two ad hoc routing protocols. We choose the routing protocols which have been shown the most efficient in a very mobile context. They are of two kinds: reactive and geographic routing protocols.

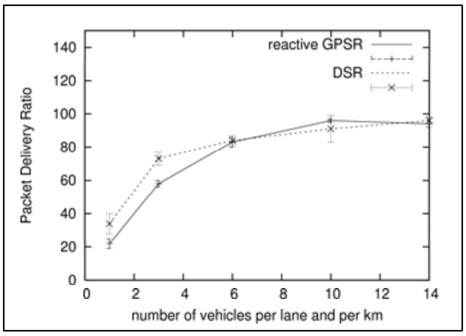
The geographic protocol that we consider is the Greedy Perimeter Stateless Routing protocol [13] (GPSR). Under GPSR, nodes are supposed to know their geographical location using a geolocalization system like GPS. Packets are marked by the source with the destinations location obtained by a location service [3]. A source or a packet forwarding node makes a greedy choice in choosing the packets next hop. More precisely, a node knows its radio neighbours positions and the choice of next hop is the neighbour geographically closest to the destination. Forwarding in this regime follows successively closer geographic hops, until the destination is reached. If this algorithm reaches a local optimal (if in the neighbourhood of the current forwarding node, there are no nodes closer to the destination) a perimeter mode is used to turn around the void region. One of the requirements of this protocol is for each node to know the location of its neighbours (node within the radio scope). In the initial version of GPSR it is done by the periodical exchanges of Hello packets.

The reactive protocol we consider is the Dynamic Source Routing protocol (DSR). In DSR, when a node has data to send to another node, it broadcasts a request packet in the whole network. When it reaches the destination, path recorded in the request packet is sent back to the source with a response packet. Upon reception of this path, the source is able to send packet to the destination using source routing. The detailed description of DSR can be found in [12].

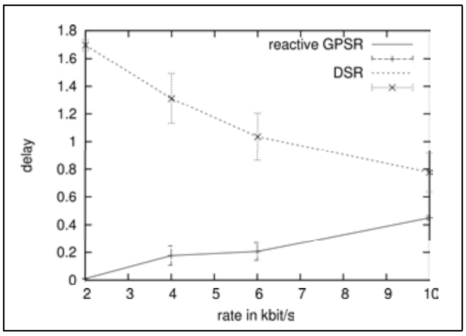
These two protocols have been already compared in [7] but we think there was a problem with the parameters the author used. Indeed, they find a packet delivery ratio of 100% for GPSR and thus concluded that geographic routing protocol was better than reactive routing protocol in high mobility context. But it has been found that the current implementation of GPSR in NS2 had a bug. The secondary result concerns a variant of GPSR in [7] and is that GPSR presents high loss ratio in high mobility context due to the out of date list of neighbors [10], [5]. To the best of our knowledge, there is no other works comparing both reactive and geographical approaches. The main goal of our simulations is to show that geographic and reactive routing protocols are in fact very similar in terms of performance and particularly in term of packet delivery ratio (PDR). The PDR is defined as the number of packets received by the destination divided by the total number of packets sent by the source.

We use a modified version of GPSR named reactive GPSR [14] to avoid the use of out of date neighbours list. In this version of GPSR, when a node wants to send a packet, it broadcasts first a query in its neighbourhood. The neighbours answer with their geographical location.

For the comparison of the two protocols we use the traffic simulator described in Section II. This allows us to obtain realistic vehicle movements. For the network part of simulation, we use the well known network simulator version 2 (NS2). We consider a highway with only one way and three lanes. The radio range of all cars is equal to 250 meters. We randomly select the sources and the destinations of 10 connections in the first two kilometres. Figures are obtained as the average of 300 samples and a confident interval at 95% is associated to each point. A constant bit rate is applied to each connection with data rate equal to 2 kbps as shown in the Figure 4(a).



(a) Packet delivery ratio for GPSR and DSR as a function of the mean number of veh/lane/km



(b) Mean delay of packet delivery as a fucntion of the rate

Fig. 4.

The most important result in the comparison is the PDR. In Figure 4(a), the two PDRs are equivalent for the two protocols. An advanced study of the trace files show that the losses in GPSR and DSR are exclusively caused by the non existence of a path to the destination. It proves that DSR and this optimized version of GPSR support high mobility and those losses appear only when the path does not exist. Comparison of the delay parameter leads to the same conclusion. In Figure 4(b), we can see that the delay is longer with DSR since it has to wait for the answer of its path request. But GPSR needs a location system to learn the location of the destination[1] This is at least the same, if not more complex, than the DSR path request. The last metric we could consider is the protocol overheads. In reactive version of GPSR, control packets are generated before the emission of a packet to discover the location of the neighbours. In DSR, control packets are used to discover and maintain the routes. In first case, the number of control packets is a function of the data packets emitted in the network, while in the other case it depends only on the number of connections (since in DSR, route maintenance does not depends on the number of data packets). Therefore, it is difficult to evaluate which protocol generates the most control packets since it depends on the traffic conditions.

V. Conclusion

We investigated the properties of the connection lifetime in a VANET. It appears that long connection lifetimes are rare even with elaborated mechanisms like the use of gateways. Therefore, we think that for non safety applications, an infrastructure is required. It will ensure the connectivity of the VANET and increase network bandwidth. We proposed for this infrastructure, dimensioning rules for a partial cover of the highway in such a way that a mobile node will have access to the APs with high probability. We also compared two routing protocols DSR and GPSR used in the ad hoc part of the network. We have shown that these two protocols present very similar results. But, the geographical routing protocol GPSR involves a geolocalization system and a location service which introduces a higher complexity with regard to DSR.

[1]It is not taken into account here. In our simulation, the source knows the destination's location by a magical way.

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