Conditional transmissions: a communication strategy for highly dynamic vehicular ad hoc networks

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Conditional transmissions: performances study of a new communication strategy in VANET

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Abstract—**Many solutions have been developed for routing messages in ad hoc networks. However, few of them are efficient when the network is highly dynamic. Indeed, building a routing table, discovering and maintaining a route or localizing a node is a great challenge when the dynamic is high. This topic is currently attracting attention with vehicular ad hoc networks (VANET), a special case of highly dynamic networks. VANET may allow to enhance road safety, and to develop new driver or passengers oriented services.**

In this paper we present a novel approach for routing in highly dynamic networks, relying on conditions-based communication. Instead of transporting addresses (or positions), a message is sent with some conditions used for retransmission or reception. Thanks to the dynamic evaluation of the conditions, we show that this solution can efficiently support the high dynamic of vehicular networks.

I. Introduction

An ad hoc network is composed of nodes connected by wireless links. Usually, the topology of such a network cannot be planed, especially when the nodes are mobile. In order to route messages, each node is invited to participate in the message's retransmission.

Many works have been done to design ad hoc routing algorithms to deal with the node's mobility: updating routing tables (pro-active algorithms), discovering routes (reactive algorithms), using geographical information (geocast algorithms), detecting stable structures (clusters), using the node's movements for messages transportation, using the broadcast approach for messages forwarding, etc.

Besides the node's mobility, the algorithms have to take into account the node's dynamic: a node may appear or disappear in a neighborhood due to power failures, obstacles, etc. An ad hoc network is *highly dynamic* if its topology is continuously and very frequently changing (due to node's mobility and node's dynamic) in such a way that nodes localization is never stable, either locally or globally. Routing messages in such a network is a great challenge.

This subject attracts much interest for developing inter-vehicle networks. Among the applications, we may quote automatic driving, enhancing safety by propagating emergency alerts, and novel driver and passengers services. Road accidents statistics have showed that an appreciable part of them is due to accident prone situations initiated by localized events [6], like deficient drivers behaviour or bad weather conditions. The inter-vehicles communications would help signalling those events at the very first moments, thus improving the road visibility [1]. Beside the safety applications, and when the bandwidth is abundant, entertainment applications may be deployed [7].

A Vehicular Ad hoc NETwork (VANET) is characterized by a strong mobility of the nodes, a high dynamic of the topology, a significant loss rate and a very short duration of communication. Our experiments on the road with IEEE 802.11 showed that two vehicles that cross each other at 110 km/h can communicate during 8 seconds and transfer around 800 KB (unicast UDP). Moreover, simulation studies showed that the performances of communications in VANET depend mainly on the inter-vehicles distance, and the inter-packets delay [8]. Based on these works, we believe that specific solutions are required for multi-hop communications in VANET networks, and more generally in highly dynamic networks.

Indeed, in topological routing algorithms, the messages are routed with the help of the network topology, considered as a (moving) graph. However, when the dynamic increases, more control messages are required. The geographical routing protocols mainly rely on the information given by some GPS receivers. When the dynamic increases, the positions are not stable, and the geographic area defining the destination should be larger, leading to bandwidth waste. With the hierarchical routing protocols, the network is composed of several clusters. The overhead needed to build such clusters increases with the network dynamic, while the clusters are less and less stable. In the movement-based routing protocols, the messages progress towards the destination by means of node's movements. However, a routing solution should not rely entirely on the movement of the nodes because it is not sufficient nor practicable in all the situations. Finally, in the broadcasting-based routing protocols, upon receiving a message, each node makes a decision whether it will forward the packet or not. The evaluation of such parameters requires more control messages and then consumes more bandwidth when the dynamic increases. A more complete analysis of the related work (as well as bibliographic references) can be found in [9], [4].

In this paper, we introduce the conditional transmissions and we focus on their performance evaluation. Instead of transporting addresses or positions, a message is sent with some conditions used for retransmission or reception. Thanks to the dynamic evaluation of the conditions, the conditional transmissions can efficiently support the high dynamic of the VANET. A stand-alone implementation has been developed to perform tests on the road with several

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vehicles [3]. Moreover an implementation in network simulator [11] allowed scaling up the study of performances to a large number of vehicles and different traffic scenarios. The results – presented in this paper – show the interest of such a strategy of communication in dynamic networks.

In Section II, we sketch a new approach for communicating in highly dynamic networks. In Section III, the conditional transmissions technique is explained, and examples of specific road conditions are presented. The performance study is presented in Section IV. Comparisons with well known routing protocols have been done with network simulator using several road scenarios. Concluding remarks end the paper.

II. A NEW APPROACH FOR VANET

A. Avoiding the addresses

Our team is involved in the development of an embedded platform allowing to carry out vehicle to vehicle communication tests on the road [2]. Beside the software communication core [3], we developed distributed applications such as alert diffusion, road foreseen (visibility, obstacles...), distributed entertainments (talks, games...). This bottom-up approach shows that very few VANET applications need to establish a unicast communication.

Indeed, the receiver is often indicated by some kind of conditions, such as “those who are behind the sender” (they will for instance encounter the congestion spot), “those who are in front of the sender” (they could for instance send information related to the road), “those who are a bridge towards another network” (they could relay the message to infrastructure access points), “those who are in a given geographical area” (around a dangerous position such as a smoggy area for instance), “those who can offer a specific service” and marginally, but still a condition, “those who have the identity x” (a single receiver denoted by its identity).

In fact, in a highly dynamic network, nodes can be designated by means of *identities* or *conditions*, but to our opinion it seems hazardous to denote them by means of *network addresses*. Each identity is unique, which can be given by the MAC address (already included in 802.11 packet header). It can also be randomly and periodically chosen to preserve privacy of the drivers (so-called pseudonymity). It is used only to distinguish two cars. On the contrary, a unicast address gives two kinds of information: uniqueness identity of the node, and some information related to the node’s position in the network. However, managing the node’s positions in the network seems too costly in a highly dynamic network. Indeed, both local (related to a neighborhood) and global (related to the entire network or landmark), either logical (eg. hierarchical address) or geographical (eg. GPS coordinates) positioning are difficult to maintain when the network dynamic increases. For instance, when sending a message towards a given position, it is likely that the receiver has moved, and that the information related to its position is out-of-date.

In order to deal with the highly dynamic network, we consider *conditional addressing* instead of *network addressing*, *path maintaining* instead of traditional unicast, and *conditional transmissions* instead of broadcast. Conditional transmissions are a kind of one-to-many communication, that can also be used for unicast communications [9].

B. Path maintaining

The path maintaining problem consists in maintaining a communication that began when the receiver was in the neighborhood of the sender. A communication between two cars is usually initiated in such a situation, and not when they are far from each other. Indeed, the identity – and even the presence in the network – of a distant vehicle is not known from the potential sender, as it would be too costly to provide such information.

Sometime after a communication being initiated in the neighbourhood, further to unforeseen events on the road, several hops may be needed to achieve it. This means that the path was initially of length 1, and has to be maintained to allow the communication within a reasonable length. Note that the receiver is known by the sender because it was initially in its neighborhood. No address is needed and the communication can be maintained from neighborhood to neighborhood simply by using the unique identities. Indeed, if the path length increments regularly, then the last relay can deduce the new next hop in the path without geographical nor network address (given that a unique identifier per vehicle is available).

C. Conditional transmission

The conditional transmissions selects the relay nodes by means of conditions included in the messages. The receivers are also selected by means of conditions included in the messages: only the nodes that fulfill the conditions will pass the message to their application layers.

Such a technique encompasses the VANET broadcast algorithms: any conditions can be used, as well as combinations of them. Moreover, receiver and transmitter conditions can be different and in many cases, no control messages are required in the neighborhood as explained below. The conditional transmission also encompasses the geocast algorithms when the condition defines a geographic area (”being in a given area”). Note that in some way, it also encompasses the unicast communication when the condition defines a unique receiver (”having the identity x”) and could be used for the path maintaining.

However, its main interest relies on the dynamic evaluation of the conditions carried out upon the message reception. The conditional transmissions can be seen as an intermediate solution between static addressing in the header of messages, and mobile agents that may lead to dynamic behaviors. The former solution is not well adapted to dynamic network. The latter may not be accepted due to security issues[1]. Here, the condition evaluation allows to deal with the dynamic in an efficient way, without compromising any security requirement. For

[1]Validating the code of an agent is not easy in a VANET, as the keys management is problematic.

instance, instead of designating the receivers as the cars which are in area x, the conditional transmissions designates those behind the sender and not farthest than y meters from it. The durability of such a condition-based addressing is larger than the classical addressing approach, even when it relies on geographical position (such as area x).

Another important characteristic of the conditional transmission is that the retransmission decision is *receiver-oriented*. In a multi-hop communication, the next relay can be decided either before the transmission (so-called *sender-oriented*) or after the transmission (*receiver-oriented*). Indeed, the omnidirectional wireless communication implies that in any case all the neighbors of the current relay will receive the message. When the decision is sender-oriented, the current relay indicates in the message header which neighbor will be the next relay and the others will ignore the message. When the decision is receiver-oriented, each neighbor decides whether they retransmit the message or not. In the sender-oriented approach, the current relay needs some information on its neighbors, and control messages are required to gather the information. But when the network is highly dynamic, the neighborhood is always changing and the frequency of the control messages should increase, leading to an unstable situation as for the proactive topological routing protocols [9]. Hence, in a highly dynamic network, the retransmission decision should not necessitate information on the neighborhood (or with low accuracy). In the receiver-oriented approach, the decision can be taken without any knowledge of the neighbors, avoiding the control messages. The drawback of this approach is that several nodes may decide to retransmit the message, leading to collisions and/or bandwidth wasting. But this can be solved with simple techniques such as lazy retransmissions. We address this problem in Section III-C.

Note that the conditional transmissions could be used for optimizing other routing strategies. However we present in this paper some results for a stand-alone implementation, described in the next section.

III. Conditional transmissions technique

A. Principle

A message is sent with two conditions, namely the *upward condition* (CUP) and the *forward condition* (CFW). When a message is received by a node, it is passed by to the application layer if CUP is true and it is forwarded to neighbors when CFW is true.

The conditions are provided by the applications. Instead of asking the routing layer to send a message to a given address, the applications ask for sending a message to the nodes that satisfy a given CUP condition, which will be relayed by the nodes that fulfill a given CFW condition. Hence, the conditions are application-dependent and a distributed game would not use the same conditions as a safety alert application for instance. A short logical language with specific keywords allows to express conditions.

The conditions may require information related to the last relay. In this case, part of the control data in the messages could be modified by the relay nodes themselves. An example of such a *relay-dependent condition* would be "being 100 m behind the last relay". However we do not consider such relay dependent conditions in this paper.

As explained in Section II-C, conditions that need control messages between the neighbors to be evaluated should be avoided in highly dynamic networks. Indeed, the neighborhood becomes more and more unstable when the dynamic increases, leading to additional control messages and bandwidth consumption.

It is important to note that the conditional transmission has no impact on the security of the routing layer. Both conditions and addresses based routing can take benefit of already proposed security solutions [12].

B. Useful conditions

Interesting conditions concern geographic information (distance from the sender, geographic position or area...) or time-related information (delay from the emission, date, message duration...). They can also concern trajectories-related information to determine whether a mobile is on the same trajectory than the sender or not. Of course, the conditions may also be related to the identity of nodes (sender, receiver, relay) or the kind of messages for instance (while this seems less useful in practice). Moreover any combination of conditions can be used.

The trajectories related conditions are often useful in VANET applications. For instance they allow to address a message only to the vehicles that will encounter a stationary car, and not to those which are on the same road but in the opposite direction. In order to have an accurate evaluation of such conditions, we developed a specific trajectory matching algorithm, well adapted to the road linear characteristics.

Actually, using just the last GPS position of a vehicle to tag the messages is not efficient as even vehicles following the same road would never have exactly the same GPS footprints. Furthermore, the relative error in the GPS position would not be necessarily identical to all vehicles in close vicinity, even if they are covered by the same satellites constellation. So our trajectory matching algorithm logs the last GPS positions of a vehicle in a circular buffer (ten positions are sufficient in practice). This GPS *positions history* is added to each exchanged message as the position tag of the emitter. When a node receives a message, it computes its geographical relevance by the following procedure: for each GPS position from the receiver GPS positions history, a perpendicular projection is issued to the corresponding position in the emitter GPS positions history (Figure 1). The lengths of these projections are respectively multiplied by weights, fetched from a predefined table, in order to attribute more weight to the recent positions if needed. Then, we obtain the sum of theses products and normalize it, yielding the *association factor*. Finally, the correlation between the received trajectory and the receivers own trajectory is evaluated by comparing the obtained *association factor* to a predefined empirical threshold (in practice, a threshold of 10 meters is sufficient, close to the GPS mean relative positioning error). This approach is quite similar to the GPS filtering solutions used in the map matching phase of a geo-localisation procedure. See also [14] for a similar approach.

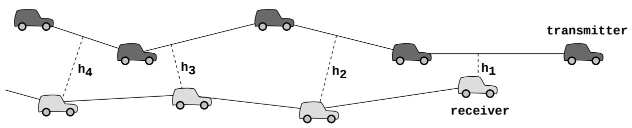


Fig. 1. Trajectory matching based on successive GPS positions.

C. Performances discussion

1) Control overhead: Besides the CUP and CFW conditions, other data are added to the messages, in order to evaluate these conditions. For instance, when one of the conditions is related to the distance from the sender, the geographical position of the sender is sent with the message. Hence, the header of a message contains two conditions and some data necessary for their evaluation. This leads to variable length headers, which are often larger than those of classical routing algorithms. For instance, the condition used in Section IV relies on distance and on trajectory matching. The header is about 200 bytes (20 char for CUP and 20 for CFW, 10 doubles for the latitudes and 10 for the longitudes). For comparison, the header of an OLSR message is about 16 bytes and the header of the geocast algorithms such as GAMER or LBM is about 80 bytes.

However HOP does not require control messages whereas OLSR needs control messages to build the tables. For instance, HELLO messages contain a neighborhood description with a minimum of 16 bytes and 4 bytes per neighbor. Moreover AODV requires control messages to build the routes. The RREQ messages are broadcasted; they contain 24 bytes.

The performance study presented in the Section IV takes into account the control overhead of each protocol, and shows very interesting results for HOP.

2) Processing time: The processing time depends on the complexity of the conditions. In [8], the impact of the *inter-packets gap* (IPG) in inter-vehicles wireless communications is studied: a too short IPG gives a poor throughput because it leads to many collisions [8]. Hence, the processing time necessary to evaluate the conditions has generally no impact on the performances in VANET.

3) Collisions: Designing the relay nodes by means of receiver-oriented conditions (see Section II-C) implies that many mobiles in the same neighborhood may fulfill the CFW conditions. In this case, they could all resend the message, leading to bandwidth waste. To solve this problem, some already known solutions can be used. For instance, the conditions can take into account local parameters and some random techniques. A condition such as "rand() $< 1/n$" where n denotes the number of known neighbors could be added to the CFW condition for instance. If some clusters are available, the conditions may forbid any retransmission in the vicinity of a cluster head. However, better performances are reached if the transmission decision does not require an accurate knowledge of the neighborhood. For instance each node may wait for a random delay before sending the message, except if a neighbor already re-sent it (lazy retransmission) [13]. This additional delay may not affect the performances because a reasonable inter-packets gap (IPG) is needed. In order not to distort the performance study presented in Section IV, we do not consider such optimization in this paper.

D. Implementation

An implementation of a conditional transmission service (called HOP) has been developed as part of our embedded distributed framework [2], [3]. We also implemented HOP under Network Simulator [11] for larger performance studies. This has been done with a network layer structure: HOP is implemented as a routing agent (similarly to DSDV, AODV, DSR...), and can send packets toward the other layers. The sending and receiving code is written in C++, while the condition checking is written in tcl scripts, allowing to share code between the embedded platform and ns-2. The ns-2 implementation allows comparisons with other routing techniques in several scenarios while scaling up the number of vehicles. This is presented in the next section.

IV. Performance study

The performances of conditional transmissions have been studied by means of simulations with ns-2. Some comparisons have been done with five routing algorithms in four road traffic scenarios. We first describe the methodology before detailing the results.

A. Simulation methodology

1) Road traffic scenarios: For this performance study, four road traffic scenarios have been considered. We focused on typical scenarios to ease the understanding. We then designed convoy scenarios with or without crossing and with or without stopped cars. Convoys appear frequently when road traffic is not sparse. They can be detected by piggybacking some information in the messages (see Section V-B). Note that when the road traffic is sparse, many routing optimizations are not efficient: a greedy broadcast algorithm possibly with messages storing may be sufficient (for either unicast or broadcast communication) without important drawback on the bandwidth.

The four scenarios are described in Figure 2. The first one corresponds to a simple convoy with 20 vehicles. In the second scenario, stopped vehicles are added each 300 meters on both sides of the road. They represent vehicles stopped at red lights or at stop signs in crossing roads. The third scenario consists of two convoys with opposite directions that cross each other on the road. The relative speed of the second convoy varies. The communications are performed in the first convoy, but are affected by the vehicles of the second convoy. Finally, the last scenario consists of two convoys on two perpendicular roads, that cross each other (through a bridge for instance). The speed of the first convoy varies while the speed of the second is equal to 50 km/h; this low speed allows to maximize the perturbations duration on the first convoy. To simplify, only rectilinear roads are considered, however the conditions used by HOP integrate our trajectory matching algorithm that supports curved roads.

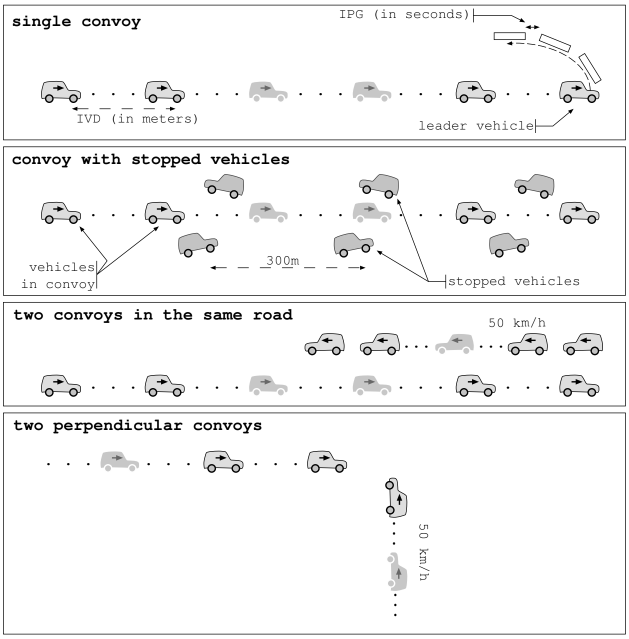


Fig. 2. Different simulation scenarios.

We consider 20 vehicles per convoy. The inter-vehicle distance takes the successive values of 27, 50, 61 and 72 meters, corresponding to the expected security distance (equivalent to 2 seconds) related to the legal limitation speeds 50, 90, 110 and 130 km/h respectively.

2) Simulator configuration and network traffic: The simulations have been done with ns version 2.28 [11]. The propagation model is the two-ray ground. This model simulates a direct communication until a given inter-vehicle distance, and a communication with a single reflection on the road if the distance is larger. Even though it can be improved [5], the ns-2 two-ray ground propagation model gives results close enough to our tests on the road for this comparison study. The communication range is uniform for each vehicle, and equal to 250 m while the interference range is of 500 m.

The first vehicle of the convoy sends regularly some packets to the others, with a constant inter-packet gap (IPG). The IPG is a convenient way to specify the sending rate in a convoy [8]. It takes the successive values of 5.5, 11, 14, 20, 30 and 50 ms, corresponding to the sending rate of 2048, 1116, 804, 562, 375 and 225 kbit/s respectively. The size of all the packets is equal to 1440 bytes (maximal size of the LLC layer).

All the wireless communications, either broadcast or unicast, are performed with an emission rate of 2 Mbit/s. This prevents the *grey zone* phenomena [10]. Indeed, the IEEE 802.11 broadcast packets are always transmitted at a basic bit rate while the data packets can be sent at higher rates. Hence the broadcasted packets (such as the RREQ messages in AODV) can reach more remote nodes than data packets. As a consequence, a node may create a routing table with some nodes that will be reached by data packets only if they are sent at the basic bit rate. This yields simulation results as close as possible to real world communications.

The transport protocol is UDP, while the routing protocol is varying. We selected representative well known routing protocols. One of the requirements for a protocol to be included in our comparison study was to be available under ns-2. The conditional transmissions technique (HOP) is compared with two proactive protocols (OLSR, Fast OLSR[2]), one reactive protocol (AODV) and two geocasts (LBM, GAMER). Note that with our scenarios, GPSR[3] would generally select the same next hop as OLSR. For all the simulations, the forward condition CFW used by HOP is a simple combination of the trajectory matching (see Section III-A) and the distance: a vehicle retransmits a message only if it is behind the leader vehicle of the convoy, and separated by at least 200m of it. This is not a relay dependant condition.

Note that, in the first scenario, the vehicles are not mobile and it is easily checked that the mobility has no influence on the results of AODV, OLSR, Fast OLSR and HOP. Moreover, a fixed convoy allows performing comparisons with the geocast protocols GAMER and LBM. These protocols define the receivers as those belonging to a fixed geographical area. In order to make comparisons with the other protocols, the last vehicle of the convoy should receive the messages. Due to the convoy mobility, a large area should then be defined (in order that the last vehicle remains inside the area of reception). However, with such a large area, the messages will not reach the end of the convoy because many vehicles will enter in the area and will not retransmit them. Hence, the comparisons with the geocast protocols require a fixed convoy. Such comparisons will only be done in the first scenario because the mobility factor is too high for the other scenarios.

3) Measures: In our scenarios, packets sent by the first vehicle of the convoy are relayed by others until the last one. This may be seen as a kind of one-to-many communication (not a broadcast towards all the vehicles). However, we focus on the communication from the first vehicle to the twentieth. We then compare the results with unicast protocols.

Two kinds of performance criteria have been considered in order to represent different applications requirements. First, end-to-end delay of the first packet (sent by the first vehicle of the convoy and received by the last vehicle). This criterion is important for applications such as alert propagation. The second one is the ratio of the amount of data received by the last vehicle to the amount of data sent by the first one, expressed in percentage and noted *percentage of received data*. This criteria gives information about the end-to-end loss rate which is important for inter-vehicle applications. Moreover, since the amount of data sent by the first vehicle is the same for all protocols, this

[2]This is our own implementation of this specific protocol.

[3]We did not succeed to run GPSR under ns-2.

gives an indication on the end-to-end throughput as well.

As explained in Section III-C1, all the protocols do not have the same control overhead. While some protocols need many control messages (eg. OLSR), others need few (eg. AODV) or none (eg. HOP). On the other hand, some protocols have a large packet header (eg. HOP) while others have a small one (eg. OLSR). A large header reduces the payload part of the messages, but a large number of control messages impacts the bandwidth. Hence, to obtain a fair comparison of the control overhead of the different protocols, our approach was to compare both the delay of the first message and the amount of data received during a fixed period of time. Only the payload part of the messages have been taken into account when measuring the amount of sent data (and then the throughput).

Each simulation corresponds to a transmission of 60 seconds, a sufficient period to stabilize the results. Twenty simulations have been done for each case and the displayed results represent the averages. We did not observe any significant dispersion of the results (except for Fast OLSR in few cases). With 20 simulations per case, the evaluation of the four/six routing protocols on the four scenarios with different inter-packet gaps, relative speed and inter-vehicle distances leads to 2880 overall simulation runs.

B. Single convoy

The objective of this first scenario is to compare HOP with five routing protocols (OLSR, Fast OLSR, AODV, LBM, GAMER) on a single convoy of vehicles.

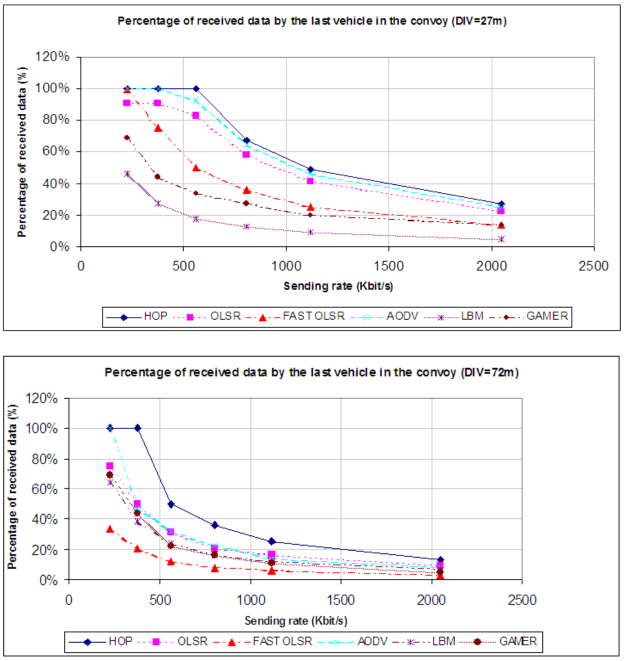


Fig. 3. Percentage of received data in the convoy with an inter-vehicles distance (IVD) equals to 27 m and 72 m.

The percentage of received data is shown in Figure 3 for small and large inter-vehicles distance (IVD). We observe very good performances of the conditional transmissions. The performances decreases for all the vehicles when the sending rate increases as the inter-packet gap decreases and more collisions appear on the convoy [8].

The percentage of received data for AODV is influenced by the inter-vehicles distance: performances are better with IVD=27 m than with IVD=72 m (Figure 3), as a large inter-vehicle distance implies more hops to reach the end of the convoy.

It seems that OLSR and Fast OLSR are penalized when the vehicles density increases, *ie.* when the inter-vehicle distance decreases (short IVD). Actually a high density increases the number of message collisions, and hence the delay for accessing the channel is larger.

The proactive protocols need to regularly send control messages, and seem more affected by the density than others. The performance of OLSR and Fast OLSR increases with the convoy speed because inter-vehicles distances also increase with the speed.

This is also the case of geocast protocols such as LBM. Since all nodes in the rectangle between the sender and the receiver retransmit the message, there is more collisions when the vehicle density is high. Hence, the performances decrease with the inter-vehicles distance IVD.

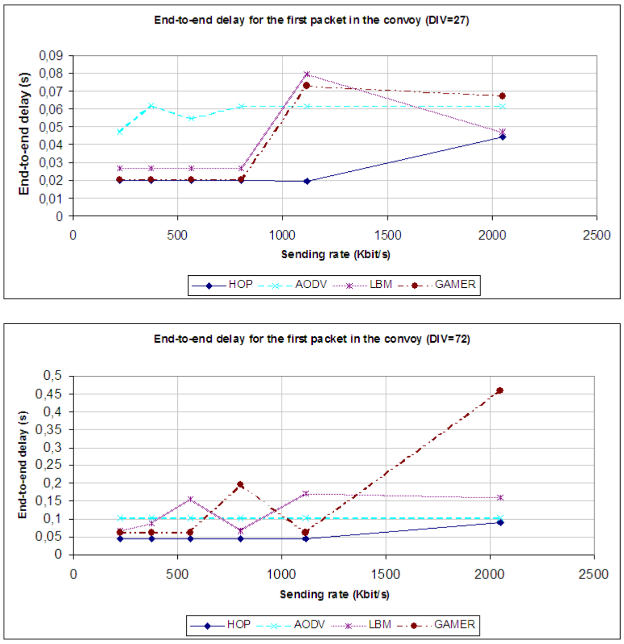


Fig. 4. End-to-end delay for the first packet with an inter-vehicles distance equals to 27 m and 72 m.

The end-to-end delay of the first packet is shown in Figure 4. We also observe very good performances for the conditional transmissions. For instance, with an inter-packets gap of 0.014 s (800 kbit/s), the delay is equal to 0.046 s with HOP and 0.103 s with AODV. The end-to-end delay is very important with OLSR (approximately 10 s with IVD=72 m). This is due to the loss of TC messages, which are sent periodically by the nodes in order to define the MPRs. However, the delay for OLSR can be improved if the measures are done after the starting phase. For instance, after 20 s, the MPRs and routing tables become stable in this scenario, and we obtained a delay of 0.267 s. But this remains large compared to AODV, and very large compared to HOP. The same phenomenon has been observed with Fast OLSR. Hence, the end-to-end delay of the first packet is not displayed in the figure for OLSR and Fast OLSR in order to keep a linear scale.

C. Convoy with stopped vehicles

This scenario allows studying the impact of stopped vehicles along the road on the communications inside a mobile convoy. As explained in Section IV-A, the geobroadcast protocols can not be compared here.

We noticed the same phenomenon related to the end-to-end delay for OLSR and Fast OLSR. The end-to-end delay for AODV and HOP is not affected by the stopped vehicles. Hence, we only present the percentage of data received by the last vehicle in the convoy (Figure 5).

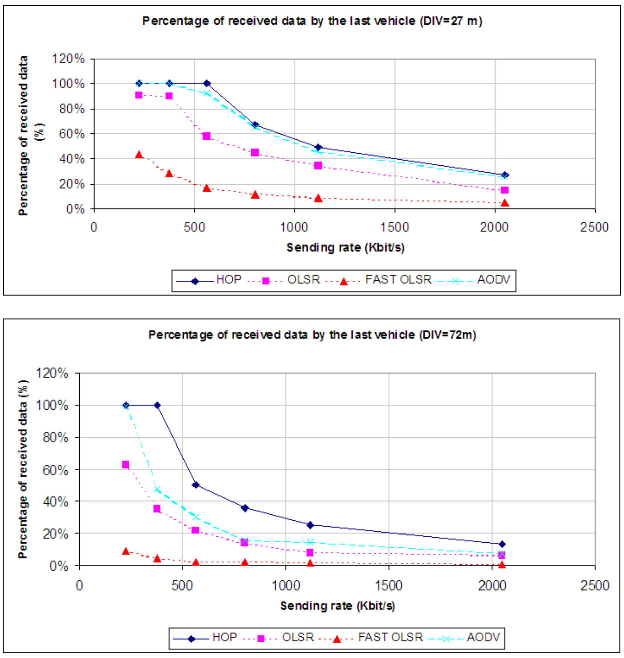


Fig. 5. Percentage of received data in the convoy with stopped vehicles (with an inter-vehicles distance equals to 27 m and 72 m).

The performances of HOP are not affected by the stopped vehicles because the forward condition (CFW) is true only for the vehicles that belong to the convoy.

On the contrary, as the inter-vehicle distance increases, AODV uses the stopped vehicles to route the messages. Indeed these vehicles become more often attractive to build a route when the inter-vehicle distance (IVD) is large. As a consequence, the percentage of routes breaking is larger when IVD increases. This impacts the percentage of received data but not the delay of the first packet.

The Figure 6 gives the percentage of received data in the first and second scenarios, for an inter-vehicle distance of 72 m, and an inter-packet gap of 0.014 s. These results confirm that the performances of AODV, OLSR and Fast OLSR are affected by the stopped vehicles along the road, unlike HOP.

D. Crossing convoys

The objective of this scenario is to compare the performances of HOP, AODV, OLSR and Fast OLSR in a mobile convoy that crosses another one on the same road.

	OLSR	Fast OLSR	AODV	HOP
Single convoy	21 %	8 %	23 %	36 %
With stopped veh.	14 %	2 %	15.7 %	36 %

Fig. 6. Percentage of received data in the single convoy and in the convoy with stopped vehicles (with an inter-vehicle distance equals to 72 m).

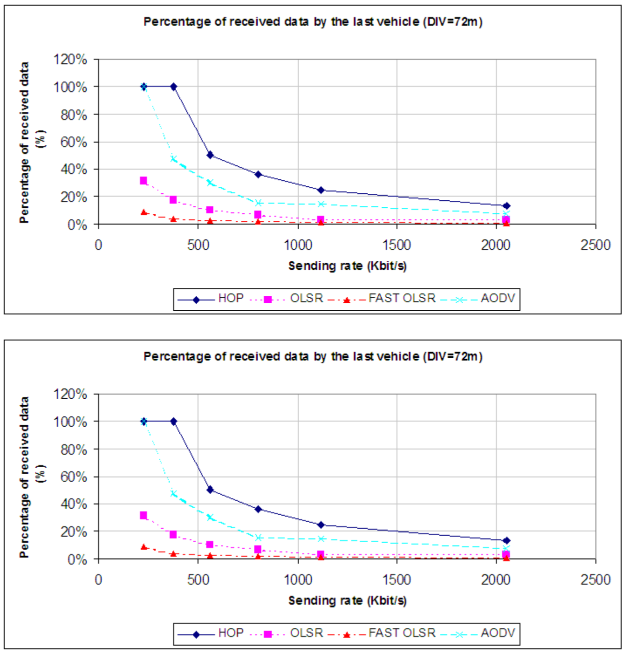


Fig. 7. Percentage of received data in the convoy with a crossing convoy and with an inter-vehicle distance equals to 27 m and 72 m.

The same comments related to the end-to-end delay still apply in this scenario. The Figure 7 illustrates the percentage of received data by the last vehicle in the convoy with 27 and 72 m of inter-vehicle distance.

The performances of OLSR are bad compared to other protocols. This can be explained by the crossing convoy, that increases the density and the control messages collisions.

The performances of AODV is affected by the second convoy. Indeed some (unstable) routes are built with the vehicles of the second convoy, increasing the number of routes breaking.

The performances of HOP are not disturbed by the crossing vehicles, because only the vehicles of the first convoy are involved, thanks to the CFW condition.

The Figure 8 gives the percentage of received data of the first and third scenarios, for an inter-vehicle distance of 72 m, and an inter-packet gap of 0.014 s. These results confirm that the performances of AODV, OLSR and Fast OLSR are affected by the vehicles in the crossing convoy. This is particularly true for OLSR (21 % compared to 7 %) and Fast OLSR (8 % compared to 2 %). These results show that only HOP is not affected by the crossing convoy.

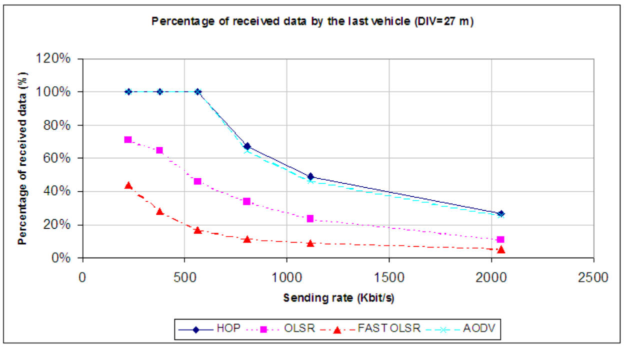
E. Perpendicular crossing convoys

The objective of this scenario is to compare the performances of HOP, AODV, OLSR and Fast OLSR in a

	OLSR	Fast OLSR	AODV	HOP
Single convoy	21 %	8 %	23 %	36 %
With crossing convoy	7 %	2 %	15.7 %	36 %

Fig. 8. Percentage of received data in the single convoy and in a convoy with a crossing convoy (with an inter-vehicle distance of 72 m).

principal convoy of vehicles with a perpendicular crossing convoy (see Section IV-A).



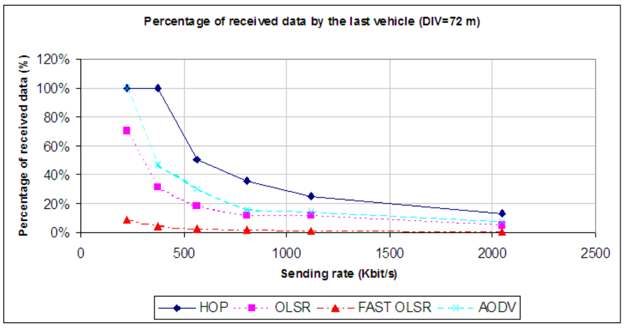


Fig. 9. Percentage of received data in the convoy with a perpendicular crossing convoy and with an inter-vehicle distance equals to 27 m and 72 m.

The same comments related to the end-to-end delay still apply in this scenario, and we only present the percentage of data received by the last vehicle in the convoy with an inter-vehicle distance of 27 and 72 m (Figure 9).

The performances of OLSR in this scenario are better than in the previous one. This may be explained by the lower vehicle density in case of perpendicular convoy compared to a parallel convoy.

HOP is not affected by the crossing convoy thanks to trajectory related condition, which is not fulfilled by the vehicles of the second convoy.

The Figure 10 gives the percentage of received data of the first and fourth scenarios, for an inter-vehicle distance of 72 m, and an inter-packet gap of 0.014 s. These results confirm that the performances of AODV, OLSR and Fast OLSR are affected by the vehicles in the perpendicular convoy.

	OLSR	Fast OLSR	AODV	HOP
Single convoy	21 %	8 %	23 %	36 %
With perp. convoy	12 %	2 %	15.7 %	36 %

Fig. 10. Percentage of received data in the single convoy and in a convoy with a perpendicular crossing convoy (with an inter-vehicle distance equals to 72 m).

F. Conclusions on the simulations

In the four scenarios, HOP obtains better results than other protocols. The conditional transmissions allow to perform communications in a convoy without being affected by the road traffic. While the ad hoc network topology is highly dynamic, HOP always offers very acceptable performances for the applications, contrary to proactive, reactive and geocast routing algorithms. This can be explained as HOP does not need any knowledge of the neighborhood nor control messages. The small messages overhead of other protocols (compared to HOP) is counter-balanced by their need of information, collected by means of control messages. The conditions encompasses the addresses or positions based routing and lead to a more stable routing scheme. While a network address, a position, a routing table or a route are changing when the topology is dynamic, a road-adapted condition remain stable for a longer time.

By comparison, the other protocols suffer from the high dynamic. Since the topology is very unstable, the routing tables are always inaccurate, and require many messages to be updated. Our simulations show poor performances for the proactive routing protocols (OLSR and Fast OLSR). More generally, one may say that protocols requiring a knowledge of the neighborhood would suffer from the high dynamic.

On the other hand, reactive protocols (such as AODV) need to seek a route from the sender to the receiver. But the durability of the routes is short, and many control messages are needed to maintain the communication. The performances of the reactive protocols are better than the proactive ones, but suffer from disturbing vehicles (stopped vehicles, crossing convoy...).

Finally, while the geocast routing protocols (such as LBM and GAMER) are adapted to send a message in a specific geographic area, they cannot efficiently be used to send a message to a highly mobile node because the destination area would be too large (and too much vehicles would be involved). As a consequence, they should be used to reach some fixed destinations such as infrastructure relays.

V. Conclusion

A. Summary

This paper deals with communications in highly dynamic networks. Among such networks, the vehicular ad hoc networks (VANET) are currently attracting attention because they could allow to enhance road safety, and to develop new drivers or passengers oriented services. Several works have been done to design routing algorithms in the ad hoc networks: topology-based either proactive or reactive, geographical, hierarchical, movement-based, broadcasting approach... However, building a routing table, discovering and maintaining a route, localizing a node, maintaining a cluster or gathering information on the neighborhood remains a great challenge in a highly dynamic ad hoc network.

In order to deal with the dynamic, we proposed in this paper a novel approach relying on conditional transmissions. Instead of transporting addresses or positions, a message is sent with some conditions used for retransmission or reception. Thanks to the dynamic receiver-oriented evaluation of the conditions, our solution can efficiently support the high dynamic of the networks. The conditions can rely on the time or the message duration, the position or the distance, the speed or the trajectory and any combination of such conditions.

Beside a prototype dedicated to road experiments, an implementation for network simulator (called HOP) has been developed in order to investigate the performances in convoys of 20 vehicles in four different traffic scenarios and with several parameters values. This paper focused on this performance study.

The simulation results show that the conditional transmissions offer better performances than the proactive algorithms OLSR and Fast OLSR, the reactive algorithm AODV and the geocast algorithms LBM and GAMER. While the performance of HOP depends on the conditions used, we observed that the end-to-end delay of the first packet is very short with HOP and is not affected by the road traffic scenario. Moreover the end-to-end ratio of received data to sent data is also not affected by the dynamic. It logically decreases when the inter-packet gap of the source decreases as with other protocols (see [8]), but it remains very interesting.

Beside the conditional transmissions, one of the contributions of this paper is the performance analysis of well known routing algorithms in four scenarios. Our simulations show poor performances for the proactive routing protocols (OLSR and Fast OLSR) because of routing tables updates. The performances of the reactive protocols (such as AODV) are better than the proactive ones, but are affected by disturbing vehicles. The geocast routing protocols (such as LBM and GAMER) are not efficient to send a message toward a highly mobile node.

B. Future work

We compared our implementation of the conditional transmissions (HOP) with five well known protocols. Other comparisons could be done in the future with other protocols (provided that their implementation is available for network simulator). Moreover, to complete the performance evaluation, other road traffic scenarios could be tested, such as urban or sparse traffic (without convoys), by using road traffic generators under ns-2. Other parameters could also be evaluated, such as the global throughput in case of several concurrent communications.

A future work may also concern the performance study in other highly dynamic networks, not necessarily VANET. This may allow to determine some limits or network requirements for a general purpose usage in highly dynamic networks.

Besides this standalone prototype, the conditional transmissions may be used in conjunction with other routing strategies. For instance, the conditions could be related to clusters when they exist. They could complement the movement based protocols. They could optimize flooding in the routing protocols (neighborhood control messages in proactive protocols, route request messages in reactive protocols...). They could improve broadcasting approaches. This is one of the directions for future works.

Road experiments with six vehicles and different applications have already been performed and will be completed soon.

With a better knowledge of the road traffic, the conditions could be refined, and the communications optimized. For instance, when the convoy is not connected, it could be interesting to use other external vehicles to ensure the communication in sparse traffic. But such additional vehicles should not be involved if this is not necessary. This means that better performances could be obtained with context aware conditions, defined by a program that takes into account the road traffic characteristics. This of course implies to determine these characteristics on-line. We designed a distributed protocol to detect the presence of convoys and we currently develop a program for characterizing the traffic (city/highway traffic, chaotic/regular traffic, traffic jams and so one) and estimating the dynamic. They will allow to set up context-aware conditions for efficient communications on the roads. The challenge is to give accurate information without requiring frequent control messages (for instance by using piggybacking).

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