Distributed and Real Time Communications Road Connectivity Discovery through Vehicular Ad-hoc Networks

M. Rondinone, *Student Member, IEEE* and J. Gozalvez, *Senior Member, IEEE*

Abstract— **Recent studies have demonstrated that the performance of routing protocols in vehicular networks can be improved by using dynamic road traffic information to select the most appropriate forwarding paths or nodes. However, most of the techniques to estimate such traffic conditions imply an important communications overhead that compromises their future viability. In this context, this paper introduces and evaluates DiRCoD, a novel technique to estimate the multi-hop connectivity of road segments, and hence their capability to reliably forward data packets through multi-hop communications. As the paper will demonstrate, this technique is capable to provide such connectivity information with a high periodicity, and low overhead and implementation cost.**

I. Introduction

Cooperative vehicular communications are currently been investigated to introduce novel ITS (Intelligent Transportation Systems) services and applications aimed at improving road traffic safety and efficiency. For this purpose, cooperative systems enable the direct communication between vehicles (Vehicle-to-Vehicle or V2V communications), and between vehicles and infrastructure (Vehicle-to-Infrastructure or V2I communications). Through a dynamic and cooperative exchange of information between vehicles, drivers achieve an improved perception in time and space about the status of the road and, more generally, of the traffic. Cooperative vehicular systems also allow the establishment of Vehicular Ad-hoc Networks (VANETs) to exchange data among vehicles that are not within their communications range. This is done by means of multi-hop communications, and the use of relaying nodes (vehicles or roadside units) acting as forwarders. An example of the use of VANETs would be the notification of a traffic jam to vehicles approaching the congested area, so that they can divert their routes. The efficiency of multi-hop VANET communications is heavily dependant on the design of routing protocols that would correctly forward the information from source to destination by an adequate selection of the relaying nodes. The design of these protocols is a challenging task due to the high mobility of vehicular nodes, and the difficult radio propagation conditions. These conditions are further complicated in the case of V2V communications due to the low transmitting and receiving antennas height, and in urban environments, where the presence of obstacles obstruct the radio signal.

Different types of routing protocols have been presented in the literature, with most of them generally exploiting geographical information. Within the proposed protocols, it is important to emphasize those that select forwarding paths or nodes based on the current road traffic conditions, and hence the potential presence of relaying nodes. Although some proposals to estimate road traffic conditions have been recently reported in the literature, they usually imply a high communications overhead. In this context, this paper introduces DiRCoD, a novel Distributed and Real Time Communications Road Connectivity Discovery mechanism designed to improve the operation of routing protocols by dynamically estimating the multi-hop forwarding capabilities of road segments. As it will be shown, DiRCoD is capable to estimate such capability with low communications overhead and implementation cost thanks to the exploitation of the broadcast beacon messages that have been introduced by cooperative vehicular communications standards.

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M. Rondinone and J. Gozalvez are with Uwicore, the Ubiquitous Wireless Communications Research laboratory of the University Miguel Hernandez of Elche, Spain (+34 96 665 8955; e-mail: mrondinone@umh.es; j.gozalvez@umh.es).

II. State of the Art

To account for the instability of multi-hop wireless communications in vehicular environments, routing protocols that exploit the node's geographical position to instantaneously select the next forwarder are proposed. For example, the Greedy Perimeter Stateless Routing (GPSR) [1] and Contention-Based Forwarding (CBF) [2] protocols adopt the "greedy forwarding" scheme, which selects as forwarders the nodes that are closer to the destination node or area. Greedy forwarding techniques may present the problem of the so-called "local maximum". The local maximum indicates a situation where a packet that is currently being forwarded in a greedy manner reaches a node that has no neighbor closer to the destination than itself. In this case, since the current forwarder (or local maximum) is the closest node to the destination, it cannot further forward the packet. If this occurs, either the packet is dropped or alternative recovery methods to forward the packet are needed. It has been shown that the presence of buildings in urban scenarios can significantly impact the operation of these routing protocols by hiding the best possible local forwarder or inefficiently creating various routes from source to destination [3]. Map-assisted protocols like Spatially Aware

Routing (SAR) [4] and Geographic Source Routing (GSR) [5] try to cope with the above mentioned problems by forwarding packets in a greedy manner, but over fixed geographical paths connecting the packet's source to the destination through a pre-determined number of intersections. The selection of these geographical paths is based on static information concerning the road network (e.g. the shortest path connecting source to destination), or on traffic statistics that are not continuously updated. Consequently, the selected path might not be offering an adequate multi-hop communications connectivity to ensure the delivery of packets from source to destination. In addition, these protocols do not account for the possibility to dynamically modify the selected path if such lack of connectivity is detected. To overcome some of these limitations, protocols such as Vehicle-Assisted Data Delivery (VADD) [6] and Trajectory-Based Data Forwarding (TBD) [7] have been recently proposed. These protocols dynamically select the next forwarding route at intersections in urban environments, although the selection is based on long time road traffic statistics such as the average number of vehicles that pass a certain road segment. Although these approaches might result in long-term on average stable multi-hop routes, they are not capable to instantaneously select forwarding paths ensuring multi-hop connectivity at that moment.

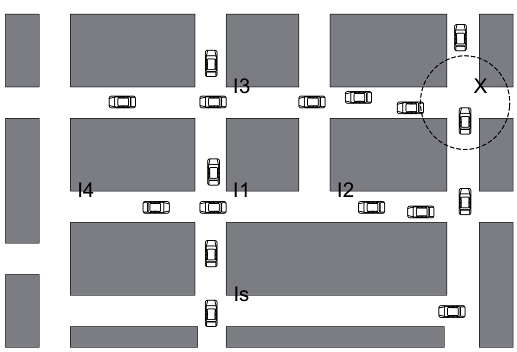


Figure 1: Scenario for VANET multi-hop routing

Newer proposals like Landmark Overlays for Urban Vehicular Routing Environments (LOUVRE) [8] or Road-Based using Vehicular Traffic routing (RBVT) [9] aim at selecting forwarding routes that improve the communications connectivity through the use of real time vehicular traffic estimations, for example road density, or number of vehicles in a road segment. Both these approaches can be considered as proactive georouting protocols where nodes periodically exchange messages to achieve a connectivity map of the road network, and create a common awareness of such map. The information is then used by vehicles to compute the most convenient road path to ensure end-to-end connectivity and deliver the source packets to a given destination. These types of protocols have been shown to obtain good packet delivery ratios. However, in order to have a fully up-to-date real time knowledge of the road network connectivity, these protocols require a considerable amount of additional communications overhead due to the periodic exchange of messages between vehicles.

Improved Greedy Traffic Aware Routing protocol (GyTAR) [10] is another interesting routing approach combining dynamic path computation at intersections and real time road traffic density assessment. Whenever a packet reaches an intersection, GyTAR forwards it to the adjacent outgoing road segment that provides the highest progress to the destination and the highest estimated traffic density. To compute the road density and deliver this information at intersections, an algorithm called Infrastructure-Free Traffic Information System (IFTIS) [11] is used. IFTIS is a fully distributed technique that aims to estimate multi-hop communications connectivity by dynamically computing road traffic density. However, as it will be shown in section IV, IFTIS introduces a relatively high signaling overhead that is traded-off with the rate at which road traffic density information is provided. Although this trade-off capacity is very interesting to control the overhead, it could somehow compromise IFTIS' capacity to provide updated road traffic density information to VANET routing protocols.

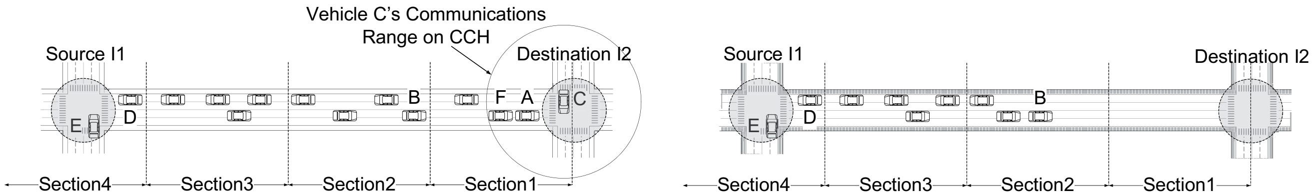
To reduce the signaling overhead while providing up-to-date multi-hop connectivity information to routing protocols, this paper presents the DiRCoD technique.

III. DiRCoD

DiRCoD has been designed to assist routing protocols in selecting the next forwarding road segment by directly detecting its multi-hop connectivity. In this context, a road segment is considered to be connected if a set of vehicles offers the capacity to transmit packets from one end to the other through multi-hop communications. As it will be shown in the following, a direct estimation of multi-hop connectivity in road segments can be achieved with lower signaling overhead compared to methods using road traffic density assessments. In addition, it helps reducing the probability that routing protocols continuously forward data packets over the densest road segments, which in turn could contribute to further congest the communications channel over them. The design of routing protocols based on direct multi-hop connectivity estimations would help to spatially distribute and balance the communications load over road segments capable to provide end-to-end connectivity without necessarily being those experiencing the highest road traffic density.

A. Concept

To illustrate the DiRCoD mechanism, this paper considers road segments delimited by two intersections as depicted in Figure 1. Let us suppose that a vehicle at intersection Is needs to transmit a certain message to the geographical area X. Contrary to routing protocols defining a routing path from source to destination without considering dynamic traffic or connectivity conditions, this work focuses on protocols that, like GyTAR, try to select the road segments ensuring the higher probability of end-to-end delivery (estimated in terms of multi-hop connectivity). Considering the example illustrated in Figure 1, when a source packet reaches the



a) b)

Figure 2: Road segment with full multi-hop connectivity (a), and partial multi-hop connectivity (b)

intersection I1, the receiving node would have to instantaneously decide whether such packet has to be routed towards I2, I3 or I4. To assist routing decisions, DiRCoD provides a measure of the multi-hop connectivity or the availability of vehicles capable to forward the packet through multi-hop communications from I1 to Ix for each one of the three possible paths (I1-I2, I1-I3, and I1-I4). A key novelty of the DiRCoD mechanism is that it exploits the broadcast beacon message also referred as Cooperative Awareness Message (CAM) to estimate the multi-hop connectivity of each road segment. It is important to clarify that DiRCoD has been designed considering the European conventions harmonizing the ITS communication architecture [12]. These conventions establish that CAM messages are broadcasted on the Control Channel (CCH) and multi-hop communications take place on Service Channel 1 (SCH1)[1]. To estimate the multi-hop connectivity of a road segment, DIRCoD assumes the use of GPS systems to retrieve vehicles' positions and of digital maps to map them on a given road network. It also divides the segment into different sections of length equal to the vehicles' communications range on SCH1[2]. The mechanism also defines the virtual distance to a certain intersection Ix as the number of road sections, or hops, that separate the closest vehicle to Ix. The example illustrated in Figure 2a) depicts a road segment with full multi-hop connectivity since there are sufficient vehicles to forward packets from one end (I1) to the other (I2). In this case, the virtual distance is equal to 0 hops. On the contrary, Figure 2b) illustrates a road segment with partial multi-hop connectivity and a virtual distance of 2 hops.

To estimate the multi-hop connectivity or virtual distance to a certain intersection, DiRCoD introduces a connectivity field that is appended to the CAM transmitted by vehicles. The connectivity field initially indicates the road section the transmitting vehicle is placed at. However, if a vehicle is aware of the presence of vehicles that are located at sections closer to the multi-hop target intersection (I2) or in the intersection itself, the connectivity field will indicate those road sections or the target intersection zone. Considering the example illustrated in Figure 2a), the vehicle F instead of appending '1' (its current section) to its CAM message, it will append a connectivity field equal to '0' since it detects the presence of a vehicle at I2. Vehicle B would initially append a connectivity field equal to '2'. However, upon receiving from F a CAM carrying a connectivity field of '0', it will append this value in the connectivity field of its own CAM. Through this sequential process, vehicles entering I1 would receive a CAM message from vehicle D with a connectivity field equal to '0', and would therefore be informed that this road segment offers full multi-hop connectivity from I1 to I2. On the other hand, vehicles entering I1 in the example illustrated in Figure 2b) would receive from vehicle D a CAM message with a connectivity field equal to 2, which would indicate that this road segment only offers partial connectivity: the higher the connectivity field value, the lower the multi-hop connectivity of a road segment.

B. Implementation Aspects

To ensure DiRCoD's scalability, several implementation aspects need to be emphasized. First of all, it is important to limit and control the generation of connectivity fields by vehicles in a road segment. To explain how, let us consider the scenario illustrated in Figure 2a), where vehicle E entering I1 needs an estimation of the multi-hop connectivity between I1 and I2 to decide whether to route incoming packet through this road segment or a different one. The intersection zone is defined as a circle centered at the intersection centre and with a radius little enough for vehicles within it to be in line of sight conditions to all the road segments exiting from the intersection. Only vehicles in the inner part of the road segment excluding the intersection zones are allowed to generate DiRCoD's connectivity field. A flow diagram representing the process used by DiRCoD to generate the connectivity fields at these nodes is shown in Figure 3. Before broadcasting a normal CAM message, every vehicle checks in its neighbor table if there are neighbors in the direction towards I2. If no such neighbor exists then a connectivity field indicating the road section where the vehicle is placed is appended to the CAM (as done in figure 2b) by vehicle B). On the contrary, if at least one neighbor exists which is closer to I2 than the vehicle itself, no connectivity field will be appended. This is because the vehicle detects that the generation of DiRCoD connectivity information will take place at vehicles being closer to I2 than

[1] CAM messages are used by vehicles to periodically broadcast their presence to their closest neighbors.

[2] Different communications ranges can be expected on both control and service channels. In particular, congestion control policies are currently being designed for the CCH given its critical and potentially high channel load nature. A higher communications range is instead expected on SCH1, which is the channel that would be initially employed for multi-hop transmissions. It is important to note that, although the current DiRCoD implementation is based on current standards settings, it could be easily modified and adapted to different ones.

itself and thus just waits for receiving and forwarding it towards I1. The connectivity field will also be generated and appended to a CAM message by vehicles receiving a CAM from nodes located in the intersection I2. In this case, the connectivity field will be equal to '0' since intersection I2 can be reached through multi-hop communications. It is possible that neighboring vehicles may want to generate a connectivity field with the same information and at the same time (this situation is illustrated in Figure 2a) where vehicles F and A both receive at the same time a CAM message from vehicle C at I2). This should be avoided since it would result in redundant information that could compromise DiRCoD's scalability. To this aim, every vehicle, upon receiving a CAM message with a connectivity field (or a normal CAM from vehicles at I2) activate a timer proportional to its distance to I1 (the shorter the distance to I1, the shorter the timer). It is the node whose timer expires first that will first transmit the CAM message with the connectivity field appended. The other vehicles with an active timer will receive such CAM message twice, and will therefore cancel the generation and transmission of their connectivity field.

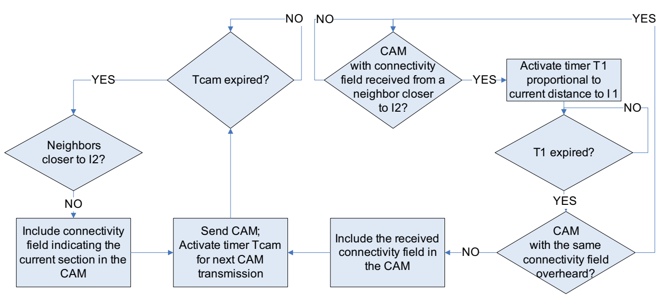


Figure 3: Flow diagram of the DiRCoD algorithm

Another situation to be carefully addressed is that in which there are two or more vehicles at I2 at the same time. In this case, a vehicle in Section 1 would receive different CAM messages from different vehicles located at I2. For what explained above, the reception of CAM messages from vehicles located at I2 results in that vehicles at Section 1 generate a connectivity field and append it to its CAM message. However, this would imply redundant connectivity data generated at short time intervals. To avoid such redundancy, DiRCoD defines a second timer of x seconds. Vehicles in Section 1 would wait for such timer to expire before generating another connectivity field and appending it to their CAM messages. If several CAM messages are received from different vehicles at I2, only one connectivity field will be generated by the vehicles located in Section 1.

To finish the description of the DiRCoD proposal, it is important to describe the format of the connectivity field appended to normal CAM messages. The size of this field has been set to just one byte. When received at an intersection (I1 in Figure 2), the first bit is used to distinguish whether the connectivity data refers to the direction from I1 to I2, or from I2 to I1. The remaining seven bits quantify the virtual distance to the target intersection (I2 in Figure 2) defined as the number of multi-hops on the SCH1 necessary to reach this intersection from the closest vehicle (if the communications range on SCH1 were 100m, 7 bits would be enough to represent the virtual distance on road segments of length equal to 12.7 km). Finally, the identification of the road segment that the connectivity information refers to does not require additional bits. In fact, this information can be inferred from the position of the vehicle transmitting the connectivity field to I1 (this position is always included in CAM messages) and the use of digital maps.

IV. Performance Evaluation

The performance and overhead of DiRCoD have been evaluated using IFTIS as benchmark for comparisons.

A. IFTIS

In IFTIS [11], road segments are divided into equally distributed cells of radius equal to the vehicles' communications range. These cells are circles placed next to each other and partially overlapping at their edges in such a way that the centers of adjacent cells are approximately separated by a distance of two communications ranges. Using the road segments of Figure 2, vehicles implementing IFTIS and arriving at intersection I2 generate and transmit a cell density packet (CDP). This packet is then transmitted towards I1 using subsequent geounicast multi-hop transmissions from cell center to cell center. More precisely, successive transmissions address the closest vehicle to the next cell center in each of the cells along the road segment from I2 to I1. The vehicles that receive the CDP packet at the cell centers count the number of their current neighbors (using the received CAM messages) and store this value in the CDP, before forwarding it to the next cell. This way, the CDP is subsequently updated with the number of vehicles present at the different cells along the road segment. When finally reaching I1, the CDP is geo-broadcasted so that vehicles entering I1 get an estimation of the density of this road and can decide whether to forward routing packets over it or through a different road segment. To address scalability issues, only vehicles that have previously updated a CDP at one of the cell centers will generate a new CDP when arriving at I2. Following section III, since it is a multi-hop message, the CDP is transmitted on the SCH1. However, current ETSI channel management guidelines [13] establish that every SCH transmission needs to be previously announced on the CCH through a Service Advertisement (SA). This implies that for every CDP transmission, a preliminary SA has to be transmitted on the CCH. Moreover, in order to guarantee that no intersection vehicle at I1 misses the final broadcast of the CDP, the IFTIS implementation considered in this work has assumed that the final CDP geobroadcast at intersection I1 is performed on the CCH. As the CDP payload carries information about each cell of the road segment, the size of the CDP is proportional to the number of cells, which in turn depends on the communications range. The part of the CDP payload dedicated to each cell consists of three subfields: the cell identifier, the cell position, and the cell density. However, a portion of fixed size (carrying information about the road segment identifier and the packet generation timestamp) is present in the CDP payload. For the fixed part of the payload, this work assumes the use of eight bytes to represent the road identifier and four bytes to indicate the packet generation timestamp. Eight additional bytes are added to indicate the geographical coordinates of the intersection I1 that is the last anchor to be addressed by the CDP packet after traversing all the cells of the road segment. For the CDP payload portion dedicated to one IFTIS cell, eight bytes have been considered for the coordinates of the cell center, six bits for the cell identifier, and ten bits to represent the cell density[3]. In order to compute the size of entire CDP packets including NET/TR and MAC headers, the current ETSI definitions of ITS geonetworking packets have been used [14]. In this case, geounicast, geobroadcast and SA of CDP messages would require 153, 149 and 95.5 bytes excluding the part of variable size of the CDP payload data.

B. Evaluation Environment

The performance of DirCoD has been evaluated through a simulations analysis based on vehicular traces obtained from the traffic simulator SUMO (Simulation of Urban Mobility) [15]. The scenario considered is a single road segment of 750m length, similar to those shown in Figure 2, with one lane per direction and two intersection zones at its end points. The intersection zones have been defined with a radius of 20m, while the DiRCoD's road sections have been fixed at a value of 300m that, as explained in section III.A represents the communication range on the SCH1. On average, a vehicle density of 21 vehicles per kilometer per lane is experienced. Vehicles have a constant communications range on the CCH that will be varied to analyze its effect. It is also assumed that the CAM messages are transmitted with 1 Hz, although similar trends are obtained at different frequencies. The simulation results presented in this section have been obtained with simulations of 5000 seconds duration in order to ensure their statistical accuracy.

C. Performance Results

Figure 4 shows the probability that vehicles at intersection I1 receive at least one connectivity message (CAM with connectivity field in the case of DiRCoD, and a CDP in the case of IFTIS) before leaving the intersection zone[4]. This metric represents the ability of the techniques to provide vehicles entering an intersection with updated connectivity information to decide over which road segment to forward packets in the case of multi-hop transmission where they act as relaying nodes. As shown in Figure 4, DiRCoD always achieves a higher probability of providing such updated information, irrespectively of the vehicles' communications range and the DiRCoD implementation. In addition, the DIRCoD's performance increases with the communications range. The obtained results demonstrate that DiRCoD is capable to update the multi-hop connectivity information of road segments with a higher periodicity than IFTIS. This will in turn improve the operations of VANETS routing protocols that dynamically select the next forwarding path. The lower IFTIS performance is due to the fact that CDP packets can only be generated by vehicles that previously updated CDP packets while traversing the cells before reaching I2. As the authors pointed out, this feature was necessary for scalability reasons. Besides analyzing the capacity of each technique to provide valuable multi-hop connectivity information to routing protocols, it is very important to investigate their communications overhead. In this context, Figure 5 depicts the average communications overhead needed by each technique to forward the connectivity information from the intersection I2 to I1 following the example illustrated in Figure 2a). It is important to remember that DiRCoD's overhead is created on the CCH since it appends the connectivity field to CAM messages. On the other hand, IFTIS' overhead is distributed between the CCH (transmission of SAs and geobroadcast at I1) and SCH1 (multi-hop geounicast transmissions). Moreover, for lower communication ranges the CDP size increases since a higher number of cells is needed to cover the road segment. The results obtained clearly show that DiRCoD generates a lower communications overhead than IFTIS. However, since DiRCoD updates more frequently than IFTIS the multi-hop connectivity information (see Figure 4), it is necessary to analyze such overhead not only per I2-I1 transmissions but also within a certain time range. In this context, Figure 6 illustrates the average communications overhead for both techniques over a time range of one second. In this case, the difference between the DiRCoD and the IFTIS techniques is reduced. However, as previously explained, the communications overhead generated by DiRCoD can be decreased by reducing the periodicity at which connectivity fields are appended to CAM messages. This gain is achieved without a significant reduction of the probability at which the connectivity information is received at I1 (see Figure 4). Finally, Figure 7 represents the ratio between the average communications overhead per second introduced by each technique on the CCH, and the probability of receiving at least one connectivity message at I1. This metric is very important since it represents how valuable the overhead has been in providing updated connectivity information to VANET routing protocols. In fact, the lower this ratio is, the more useful the communications overhead has been to provide updated multi-hop connectivity data to vehicles entering I1. In this context, the obtained results have shown that DiRCoD is capable to dynamically and effectively provide multi-hop connectivity information with a low overhead and implementation cost.

[3] These last two values are motivated by worst case scenarios. In fact, using a low communications range of 100m, 6 bits for the cell identifier allow representing 64 different cells on road segments of 12.8 km. On the contrary, if high communications ranges of 500m are considered, 10 bits for the cell density are enough to represent very high density scenarios consisting of more than 1000 vehicles per cell.

[4] The DiRCoD performance is shown for three different configurations considering that the connectivity field is appended to every CAM message (1), or one every two (2), or every three (3) CAM messages.

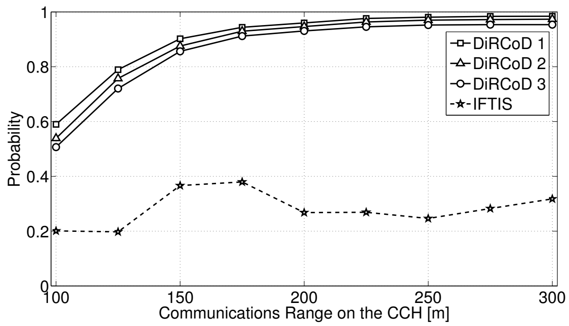


Figure 4: Probability of receiving at least one connectivity message at I1

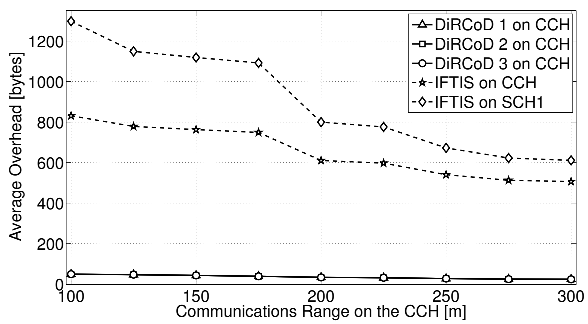


Figure 5: Average overhead

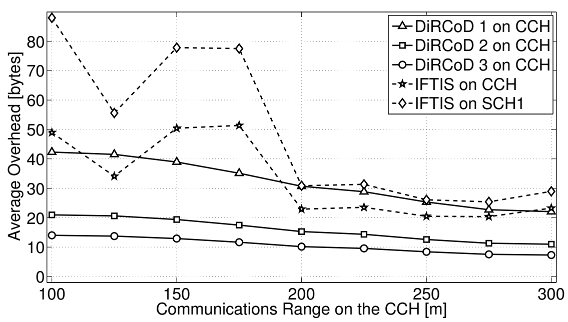


Figure 6: Average overhead over one second

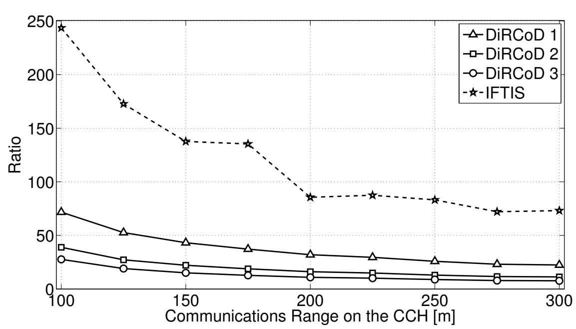


Figure 7: Multi-hop connectivity efficiency of the communications overhead

V. CONCLUSION

Multi-hop routing protocols using dynamic forwarding path selection based on traffic conditions have been shown to improve conventional forwarding schemes in VANETs. In order to drive effective and dynamic multi-hop path selections with low communications overhead, supporting methods aimed at computing and updating the multi-hop forwarding capabilities of the road segments are needed. To this aim, this paper has presented DiRCoD, an efficient and lightweight scheme using standards cooperative awareness messages that allows estimating in a fully distributed manner the forwarding capabilities of road segments in terms of multi-hop connectivity. As shown in this work, DiRCoD can dynamically assess the multi-hop connectivity capacity of road segments with a low communications overhead and implementation cost.

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