CLWPR - A Novel Cross-Layer Optimized Position Based Routing Protocol for VANETs

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***Abstract*—In this paper, we propose a novel position-based routing protocol designed to anticipate the characteristics of an urban VANET environment. The proposed algorithm utilizes the prediction of the node's position and navigation information to improve the efficiency of routing protocol in a vehicular network. In addition, we use the information about link layer quality in terms of SNIR and MAC frame error rate to further improve the efficiency of the proposed routing protocol. This in particular helps to decrease end-to-end delay. Finally, *carry-n-forward* mechanism is employed as a repair strategy in sparse networks. It is shown that use of this technique increases packet delivery ratio, but increases end-to-end delay as well and is not recommended for QoS constraint services. Our results suggest that compared with GPSR, our proposal demonstrates better performance in the urban environment.**

***Index Terms*—vehicular ad-hoc networks, position based routing, cross-layer.**

I. INTRODUCTION

In recent years, research on Vehicular Ad-Hoc Networks (VANETs) has gathered momentum due to the increased interest by auto industry and governments in an attempt to improve the quality and safety of future transport systems. It is envisaged that the future vehicles will be able to form ad hoc networks in order to exchange important traffic and safety related information in roads and urban environments. To this end, all aspects of proper communication systems including routing protocols have been considered to be optimized for efficient operation in such environments. Motivated by this demand, this paper investigates and proposes an efficient position based routing algorithm for VANETs.

Although there are existing routing protocols for Mobile Ad-Hoc Networks (MANETs), importing them directly into VANETs exhibits unsatisfactory performance [1]. Some of the differences that distinguish VANETs from MANETs are the lack of strict energy constraints, the high mobility of the nodes (vehicles) constrained by the road topology, relatively short lived communication links and the characteristics of the communication channel (path loss and fading due to buildings and other vehicles).

Routing protocols can be categorised according to their design as: topology-based, hierarchical (clustering), flooding (broadcasting), and geographical (position-based). In the first category, some representative examples are the proactive OLSR [2], and the reactive AODV [3] and DSR [4]. Proactive protocols introduce network overhead which increases as the size of the network topology is increased in order to keep their routing tables updated. On the other hand, reactive protocols add a delay in the beginning of the communication in order to discover a route whilst flooding the network with this query. Furthermore, the dynamic topology of a vehicular network will soon make the former route obsolete and thus a new query will be needed. Hierarchical protocols, such as HRS [5], divide the network into clusters, which share some common characteristics for a period of time. Even though vehicles' movement can be described with clusters especially in urban environment, the overhead needed to maintain a cluster is a disadvantage. The simplest way of disseminating a packet is to flood it in the network. That way, the complexity of the routing protocol is minimized but the overhead is exponentially increased with the size of the network and traffic load. As it can be clearly seen, these legacy protocols from MANETs are unsuitable for VANETs even when they are amended to fit the vehicular environment. The last category of routing protocols, geographical, is the one which best fits vehicular ad-hoc networks. Two fundamental assumptions are made in these protocols. First, that a node is able to know its own position. Such an assumption is valid since the use of GPS technology is widespread and every vehicle can be equipped with such a device. Apart from GPS, other means of positioning have been developed that can be used, like triangulation. The second assumption, and most significant, is that every node knows or is able to know the position of the destination when needed. This is achieved with the use of location services such as HLS [6]. The characteristics that favour position-based routing protocols in VANETs over the rest are the fact that they scale better in large networks since they only use localised information (only neighbouring information) to select the next forwarding node instead of the complete network graph that topology protocols use. In addition, the routing overhead is less than flooding protocols since they only broadcast 1-hop beacon messages as a mean of neighbour discovery. Finally, compared with the hierarchical protocols, geographical routing protocols do not have the clustering overhead. Thus, the use of position-based routing is vital in VANETs due to the highly dynamic topologies and the potential large number of nodes.

In this paper, we propose a novel unicast routing protocol specifically designed for VANETs in an urban environment

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(sparse and dense vehicle traffic) which exploits those characteristics that deteriorate the performance of other protocols such as constrained mobility and interference. The cross-layer, weighted, position-based routing (CLWPR) protocol is more or less self-described. First of all, it is a position based protocol that uses the distance on the road as a metric instead of the actual geographic (Euclidean) distance. It also keeps track of PHY and MAC layer parameters such as SNIR and MAC frame error rate in order to estimate the link quality. In addition, queuing information is taken into consideration in terms of node utilization to provide some sort of traffic balancing for better QoS. All this information is jointly combined in a weighting function, that calculates the weight for each neighbouring node, based on which the forwarding selection is performed. We evaluated our protocol with series of simulations in a 5x5 Manhattan Grid scenario and monitor the performance based on metrics such as packet delivery ratio and end-to-end delay. The results suggest that the proposed protocol performs better than GPSR [7]. Furthermore, the use of e-Map information increases packet reception and the use of link layer information can reduce end-to-end delay.

The rest of the paper is organised as follows. In section II we present related work on position based routing. In section III the proposed protocol is described and in section IV its performance is compared against GPSR. Finally, in section V we conclude our work.

II. Related Work

A. Position-based routing for MANETs

In this section, we focus on the unicast ad-hoc protocols for MANETs and more specifically how a node selects the next forwarding node based on geographically related information. We start with what is known as Greedy Forwarding (GF) [8]. With this method the next forwarding node is selected based on the geographic (Euclidean) distance from the destination. As shown in the example scenario of Fig. 1, in GF policy, source Node S will forward its packets towards Node #4 which is the closest node to the destination Node D. This policy is employed in several protocols such as GPSR [7] and in [8]. A different approach is to take the “Most Forward within Radius” (MFR) which is proposed in [9]. This scheme suggests that the node to be selected will provide the most forwarding distance on the direct line from the source towards the destination. This can be calculated using the cosine of the angle that is formed from a node, the source and the destination. In our example, $\cos \widehat{1SD}$ provides the greatest progress towards the destination and thus Node #1 is selected. On the other hand, the “Nearest Forwarding Progress” (NFR) scheme was proposed in [10] which selected the node with the least progress (Node #3 from the example). This is proposed in order to minimize transmission power so that interference and power consumption are reduced. The third approach that uses the notion of progress was made in [11] which proposes to randomly select one of the nodes that provide a positive progress towards the destination (any of the nodes #1 - #4 from Fig. 1). The last greedy approach, known as compass routing [12], tries to minimize the angle of the selected node and the direct line between source and destination. In our example, using this method, Node #2 would be selected because the angle $\widehat{2SD}$ is the smallest. All these approaches are based on random mobility model (such as Random Waypoint) which is not suitable for VANETs with the constraints of the roads. More appropriate mobility approaches for urban environments, which better describe the movement of vehicles in cities, are the Manhattan Grid or real road networks with driver models.

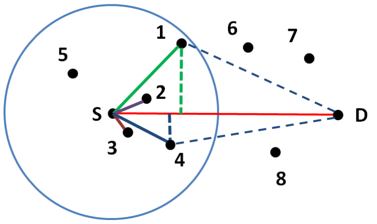

Fig. 1. Greedy Forwarding Mechanisms for MANETs

B. Position-based routing in VANETs

To solve the previous problem, protocols which employ map information are introduced. The knowledge of the underline road topology can be of great importance and improve the design of a routing protocol. Using Fig. 2 as a reference for this part of the paper we analyse the different schemes that are proposed. It has to be mentioned that in addition to the two previous basic assumptions (the use of positioning system and location service), a third assumption has to be made for this kind of schemes. Nodes should be aware of the road network which again is a valid assumption since most of the vehicles are equipped with navigation devices that can provide such functionality.

Two schemes, Advanced Greedy (AG) and Restricted Greedy (RG), define “anchor” points at each intersection (e.g. I-1, I-2, I-3, and I-4 in Fig.2). A node will search the route towards the destination using a well-known algorithm, such as Dijkstra, and identify the minimum number of intersections that a packet has to pass through. Then, the node will try to forward the packet towards the first intersection using one of the previous map-less greedy approaches. Once the packet has reached a node at the intersection (e.g. node #1) it will then be forwarded towards the next intersection node using again a greedy method. Protocols that use this kind of approach are CAR [13], GPCR [14] and GyTAR [15]. One optimization on this approach is made in GPSRJ+ [16] where the forwarding node can predict the road that the packet will follow and thus skip the intersection (e.g. forward to node #4 or #2 directly instead of #1). Therefore, a decrease in the number of hops will be made. The beacons that each node broadcasts could not only include their position but also their speed, heading etc. Using this additional information, a node can make smarter decisions on the forwarding nodes (e.g. forward towards nodes on the same direction). Protocols that use this scheme include VADD [17], A-STAR [18], AGF-GPSR [19] and Optimized GPSR [20]. Similar to the latter,

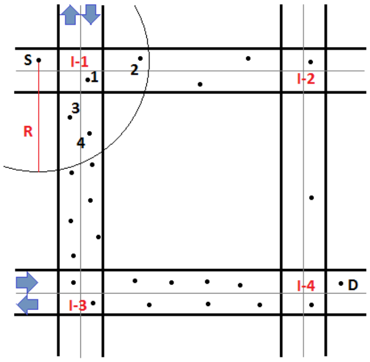

Fig. 2. Forwarding Mechanisms for VANETs

using the information about velocity, a node can predict the current position of another node from its latest known position and the time difference between present time and the time it received the beacon. This method is used in VADD [17], MP2R [21], and MAGF [22]. GPSR-L [23] introduced the concept of lifetime of a communication link in the routing. Using the information about the speed and position of a node, it can predict the time it will remain in the communication range and thus select the forwarding node accordingly. Finally, more advanced schemes use information about the vehicle traffic and the road network such as the maximum speed of a road (VADD [17]) and the traffic density (GyTAR [15]). The disadvantage of "anchor" approaches is that they are not very dynamic. If the destination changes its position, the optimal sequence of intersections should be re-calculated. Also, the overhead is increased since this sequence of intersections is included in each packet. None of these protocols take into account the characteristics of the communication channel or the node's utilization. This paper is intended to contribute to the aforementioned issues by introducing a link quality estimator using SNIR information and MAC Frame Error rate and the node's utilization to balance the traffic load.

C. *Cross-layer routing designs*

In order to provide better QoS there have been proposals for cross-layer designs that consider lower layer metrics, such as channel state information, transmissions count, for their path selection. The main objective of these approaches is to use channel quality information from PHY as means of link quality prediction based on which the routing protocol will perform the path selection. Using information about the received signal strength and arrival time of packets at the PHY, authors in [24] calculated the Link Residual Time (LRT) metric. This is an indicator of the remaining time that the specific link can be used for transmission. LRT is "exposed" to upper layers, such as routing. However, calculating LRT is not trivial. It requires removal of the noise from the data, estimation of the model parameters and finally renewing LRT. The advantage of this approach is that is generic; LRT can be used by any other upper layer. On the other hand, SBRS-OLSR [25] is restricted to OLSR. Here, SNR information from PHY is used by the OLSR routing protocol in order to select the best MultiPoint Relay (MPR) node; the one with the highest SNR. These nodes are responsible for the topology broadcasting contrary to the original OLSR where all nodes were broadcasting topology information. MOPR [26] on the other hand uses movement information available at the MAC layer to predict the future positions of the relay nodes and calculate the "link stability" based on which the forwarding selection will be performed. Since this is MAC layer information, the upper network layer could be either a topological protocol or a geographical. It may seem similar to GPSR-L [23] but in MOPR the position information is available at MAC whereas in GPSR-L it is directly available to NET thus it is not counted as cross-layer protocol. Another protocol that uses MAC information is R-AOMDV [27]. It combines transmission count available at MAC and hop count available at NET to calculate its routing metric thus providing QoS based on the complete path and not only per link. A triple constrained routing protocol to provide better QoS in VANETs is DeReHQ (Delay-Reliability-Hop) [28]. It is based on AODV but also considers the end-to-end Delay, link Reliability, and Hop count giving different priorities in these metrics. PROMPT [29] is a geographic routing protocol which has a bi-directional cross-layer design. It is developed for Vehicle-to-Infrastructure applications and provides (a) delay-aware routing through traffic statistics collected in MAC and (b) robust relay selection at MAC layer supported by mobility information from NET.

III. CLWPR

In this section we present the key facts and assumptions of our proposed protocol. First of all, this protocol is designed to be a unicast, multi-hop protocol based on opportunistic forwarding. There is no route discovery before the actual data dissemination, just selection of the next hop according to minimal weight. It is based on 1-hop "HELLO" messages (others call them beacons) that every node periodically broadcasts. These messages include positioning information (position, velocity, and heading) and other information that we will describe later on. "HELLO" messages are generated by the routing protocol and passed down to MAC layer which is responsible for their proper dissemination.

In CLWPR, the Greedy Forwarding does not calculate a geographical distance as described in section II-A, but instead calculates the distance that a vehicle would have to travel in order to reach the destination. This variation from the previous proposed algorithms is based on the fact that the nodes are vehicles and their movement is restricted within the boundaries of the roads. Any forwarding message would have to follow the path of the vehicles and thus the distance of two vehicles is better described by the distance based on the road network layout than their geographical distance. This approach is also used in the propagation model in [30]. In order to have this information available, electronic maps (e-maps) should be imported on the vehicles. Information that stems also from e-maps is the knowledge of the road that a

TABLE I
HELLO MESSAGE INFORMATION

Information Carried	Value Range
Node Position (x,y)	(double, double)
Node Velocity (x,y)	(double, double)
Node Heading	Integer ($0^o - 360^o$)
Road ID	Integer
Node Utilization	Integer
MAC Frame Error rate	double
Number of Cached Packets	Integer

vehicle is traveling on. If a message is forwarded along the road that the destination is traveling, then it is more possible to reach it. This selection is performed close to junctions where vehicles from different roads move in communication range and those traveling along destination's road are preferred. In order to get more accurate and up to date information of a node's position, "HELLO" messages should be broadcasted more frequently. However, such an approach increases the network overhead. In our protocol we use the information gathered from "HELLO" message, such as position, speed and heading, to predict the position of a node when we want to send data. In addition, when a node receives a "HELLO" message, it calculates the SNIR value to estimate the quality of the link. This value is stored in the list with the rest of neighbouring information. Another link quality metric that is used is the MAC Frame error rate. This is carried within the "HELLO" message. Finally, a node will also include the size of its queue as an indicator of utilization which will be used to balance the traffic on the network, and the number of cached packets stored from the *carry-n-forward* mechanism [31]. Table I provides a summary of all the information carried in a "HELLO" message.

Weighting Function

When a node has to send a packet (either as a source or just as a forwarding node), it calculates its routing table. For each unique destination address that a node has to send a packet, it calculates the *weight* of every node in its neighbouring list towards that destination using eq.(1). With this method, we only use localised information to select the forwarding node and don't need to know the complete network topology or a specific route to the destination (opportunistic approach). Furthermore, if a node does not have a packet to send/forward then it does not need to calculate a routing table and thus the computations are minimized. For a specific destination, it selects the next hop with the minimum *weight*.

$$\begin{aligned}\textbf{Weight} = \boldsymbol{f_1} * Distance + \boldsymbol{f_2} * NormAngle + \\ \boldsymbol{f_3} * NormRoad + \boldsymbol{f_4} * Utilization + \\ \boldsymbol{f_5} * MAC_{info} + \boldsymbol{f_6} * CnF_{info} + \\ \boldsymbol{f_7} * WeightedSNIR\end{aligned} \tag{1}$$

where

- f_i : is the weighting factor for each parameter.
- $Distance$: is the distance from the destination measured ON the road.
- $NormAngle$: is the normalized weight for the angle parameter calculated using (2).
- $NormRoad$: is the normalized weight for the road parameter calculated using (3).
- $Utilization$: is the number of packets in the node's queue.
- MAC_{info} : is the MAC Frame Error Rate.
- CnF_{info} : is the number of packets cached from the *carry-n-forward* mechanism. This mechanism is used as our recovery strategy, mostly employed in low vehicle densities. A vehicle employs this mechanism when it is in a *local maximum*; it is the closest one towards the destination (or in our algorithm with the minimum *weight*) but without reaching it in one hop. The selection of the particular recovery mechanism is due to the fact that vehicles are expected to move relatively fast and a new neighbour can be found soon. The number of cached packets is used in the weighting function in order to 'penalize' nodes that are found in *local maximum*. There is always a tradeoff with this mechanism. Caching packets means that the end-to-end delay is potentially increased. So, depending on the priority and QoS requirements a packet could be cached (for best effort - increasing PDR) or not (for strict QoS restrictions - minimizing end to end delay).
- $WeightedSNIR$: is the weight of the received packet's SNIR value calculated using (4). The selection of such a SNIR weighting function is justified by the characteristics of message dissemination. Interference is relatively high in VANETs and nodes that are located at the border of the communication range experience the most. Thus their SNIR is lower. Our approach is to give lowest weight to nodes that are far enough from the source but not at the border. This is achieved with the selection of the appropriate SNIR threshold ($SNIR_{th}$). Nodes with lower SNIR will have higher weight because they are closer to the border and the probability that the message will be dropped is increased. Also, we increase the weight of SNIR for nodes that lay closer to the destination to force messages as far from the source as possible. The results presented in Fig.3 where obtained using the Two-Ray Ground Propagation Loss model, $a = -2.77$, $b = -0.6$, $SNIR_{th} = 21.6dB$ and $SNIR_{min} = 21dB$. This particular equation is just an example; more are to be investigated for different propagation models, but the concept of the preferred region with minimum weight is the same.

$$NormAngle = \begin{cases} -0.5 & \text{if vehicles are moving closer} \\ +0.5 & \text{if vehicle are moving away} \end{cases} \tag{2}$$

$$NormRoad = \begin{cases} 0 & \text{if vehicles on same road} \\ +0.5 & \text{if vehicle on different roads} \end{cases} \tag{3}$$

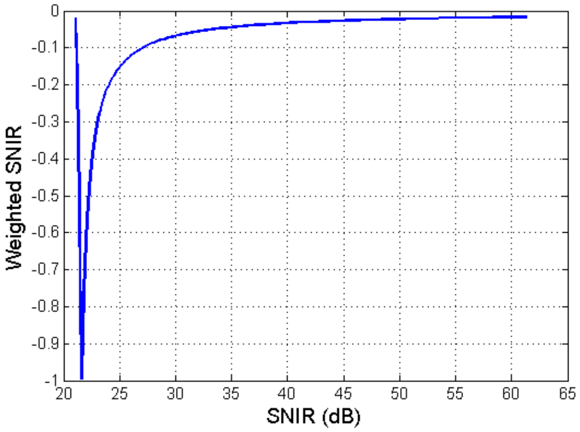

Fig. 3. Weighting Function for SNIR

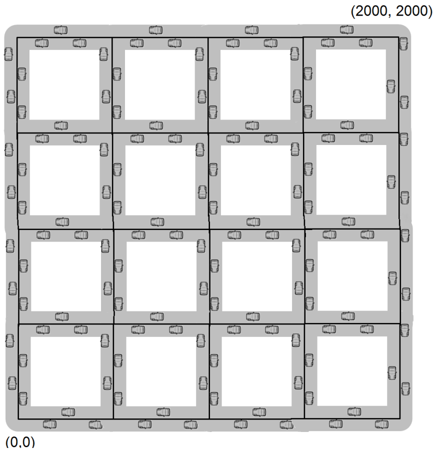

Fig. 4. 5x5 Manhattan Grid Road Network

$$WeightedSNIR = \begin{cases} ax^2 & \text{, if } SNIR \leq SNIR_{th} \\ be^{-x} & \text{, if } SNIR \geq SNIR_{th} \end{cases} \quad (4)$$

where $a/b = e^{-x}/x^2\big|_{x=(SNIR_{th}-SNIR_{min})}$ and x is the difference between the obtained SNIR value and the lowest SNIR at the border of the communication ($SNIR_{min}$).

The use of such structure for the weighting function (1), gives us the opportunity to focus on each specific parameter and its impact on the performance. It is also highly adaptable to add more parameters if necessary. The specific factors for each parameter will be investigated through Monte Carlo simulations in order to optimize the performance of the protocol in terms of PDR, End-to-End Delay and other metrics in the next section.

IV. PERFORMANCE EVALUATION

In this section, we present the performance evaluation of the proposed protocol. There are several metrics that can be used to measure the performance of a routing protocol, but the most widely accepted ones are the packet delivery ratio (PDR), end-to-end delay for data packet delivery, and network overhead introduced by the routing protocol in terms of signalling, “HELLO” messages etc. We run several Monte Carlo simulations (set of 50 with different node distribution) with 10 random car-to-car connections for two vehicle densities using ns-3 [32]. The road network that we used is a 5x5 Manhattan Grid as shown in Fig. 4 with edge length 2000m and the node movements were generated using Bonnmotion tool [33]. We simulated two vehicle traffic densities, namely dense and sparse, with 200 and 100 nodes, respectively. The communication range is set to be 500m according to the IEEE802.11p standard [34] with RTS/CTS mechanism and the used propagation model is Two-Ray-Ground. For the dense scenario this does not cause any network partition but for the sparse we might be faced with short periods of partitioning. We compare the performance of the proposed CLWPR protocol with an open source implementation of GPSR [7]. There is no specific location service used. Each node knows the position of the destination a priori. For each connection, packets of 512bytes are constantly generated every 2 seconds using UDP. We simulated different “HELLO” intervals to capture the impact of positioning prediction on PDR. We also investigate the impact of different parameters in our proposed weighting function. For the majority of the simulation scenarios, “HELLO” message interval is set to be 1.5 seconds. The information retrieved from “HELLO” messages is kept for 2.5*(hello interval) for each neighbour. This is because some “HELLO” messages might be lost or delayed due to collisions and therefore a node would be falsely deleted from the neighbouring list although it is within the communication range and is a potential next hop for a message. The results of our performance analysis and comparisons are given in the following subsections.

A. Comparison with GPSR

Here, we compare two basic CLWPR configurations with GPSR to monitor the impact of e-map information on the routing protocol. For this scenario, we only consider f_1, f_2 and f_3 in (1), while the rest parameters are set to zero. GPSR’s design lacks the ability to predict the position of a node. Also, it does not use any map information. For these reasons, it demonstrates a poor performance in urban VANET environments, as shown in Fig. 5 and 6 for dense scenario. Our simulations suggest similar results for sparse scenario. It has to be noted that the performance gain of the proposed protocol is achieved in the cost of some overhead traffic resulting from increasing the size of “HELLO” messages. That is because “HELLO” messages include not only the position like in GPSR, but also additional information as specified in Table I. However, this overhead can be reduced by using prediction as explained in next section.

B. HELLO Interval and Prediction

In this section, we investigate the impact of node’s position prediction on the performance of the routing protocol, in terms of packet delivery ratio for both dense and sparse networks. It

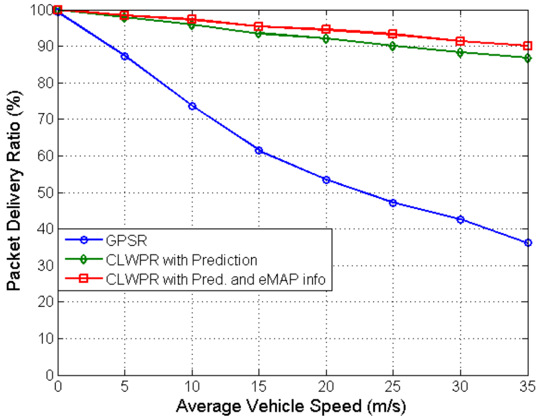

Fig. 5. PDR vs. Vehicle Speed

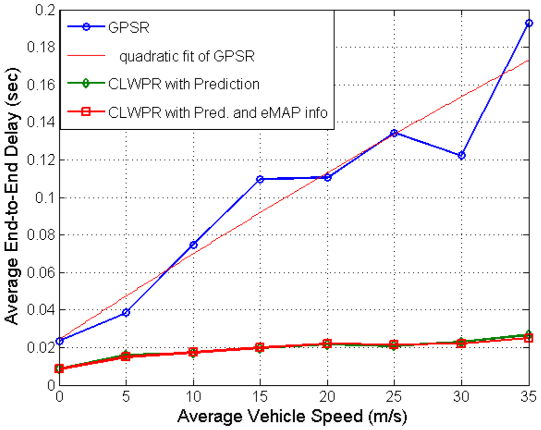

Fig. 6. End-to-End delay vs. Vehicle Speed

can be seen from Fig. 7 and 8 that more frequent "HELLO" broadcasts increase PDR. But, such increase of "HELLO" frequency means also increase in network overhead caused from "HELLO" packets. However, our results show that if we fix the PDR and speed, employing position prediction will indeed result in less overhead. For example, if PDR is 80% and speed 10m/s, without prediction the required "HELLO" interval has to be 0.5sec with "HELLO" size of 16bytes. However, with prediction 2.5sec with extended "HELLO" size of 76bytes are enough. The resulting overhead is 36bytes/sec and 30.4bytes/sec, respectively.

C. *eMAP Information*

With eMAP information, we can give more weight to nodes that are approaching the destination and are along the same road compared to those which are moving away or are on different road using (2) and (3). For this comparison we adjusted factors f_2 and f_3 in (1) for different weights of eMAP information and compared the effect they have on PDR. With this approach, the reception rate is increased as it is depicted in Fig. 9 for higher vehicles' speed.

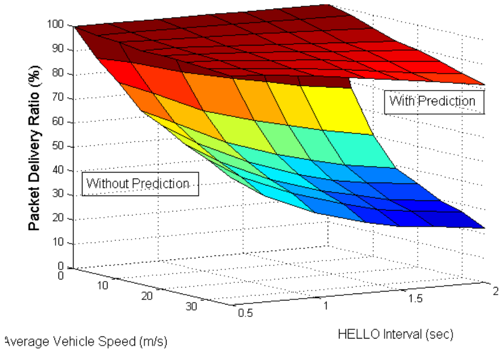

Fig. 7. PDR vs. HELLO Interval for dense traffic

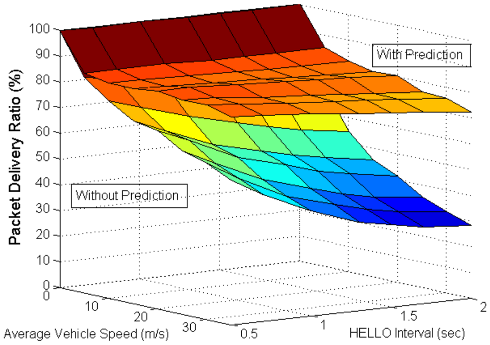

Fig. 8. PDR vs. HELLO Interval for sparse traffic

D. *Link Quality Information*

For this scenario, we measure link quality in terms of SNIR from the received "HELLO" messages and get a weight for that SNIR using (4). With this approach, nodes that are on the edge of the communication range are penalized with more weight than those at the preferred range. Also, nodes that are closer to the source have increased weight so that we encourage packets to be transmitted to the preferred communication range. Results suggest a slight decrease in end-to-end delay as

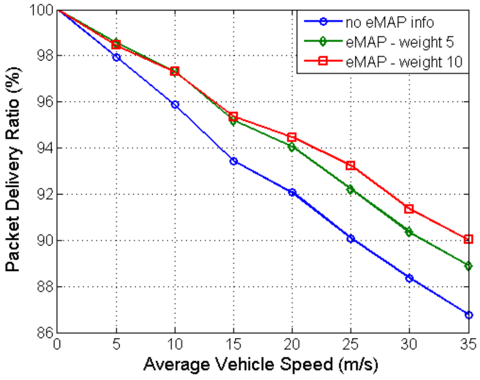

Fig. 9. PDR vs. Vehicle Speed for different eMAP weights

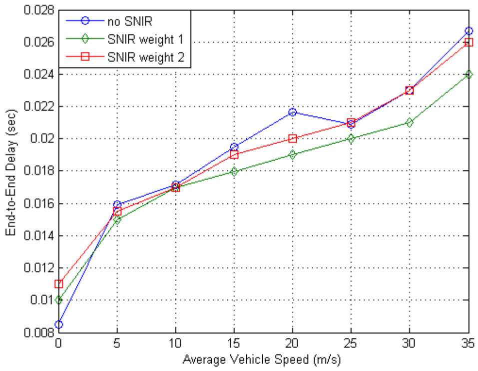

Fig. 10. End-to-End delay vs. Vehicle Speed for different SNIR weights

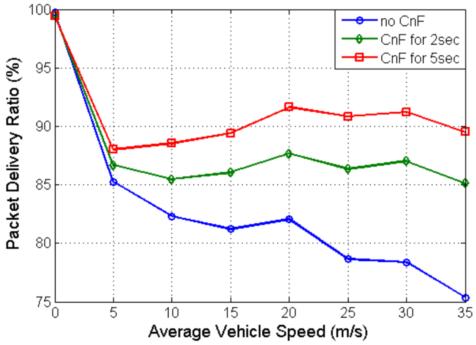

Fig. 11. PDR vs. caching time

depicted in Fig. 10. The effect of MAC_{info} is closely related to the propagation effects (interference and shadowing) that introduce errors in the dissemination of a packet. The used Two-Ray Ground model does not introduce such errors and thus there was no observed impact from MAC_{info}. It will be studied in future work where more realistic propagation model will be used.

E. Caching

The use of *carry-n-forward* is investigated in this section. For dense scenarios this does not have any major impact according to our simulations. However, for sparse scenarios it can boost PDR up to 15% but with a significant increase in end-to-end delay. Our results indicate that *carry-n-forward* weighting factor does not have major impact on the performance of the protocol. There is a slight increase in both metrics with the increase of the factor. What plays a key role is the maximum caching time. As it is shown in Fig. 11 and 12 the increase in caching time increases PDR but it increases the delay as well. Therefore, if the aim is to provide a best effort service, caching can be employed, but for QoS restricted services, caching should not be used unless the requirements are met.

V. CONCLUSIONS

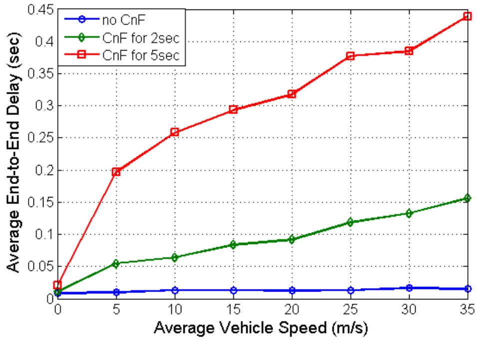

Fig. 12. End-to-End Delay vs. caching time

This paper proposed a novel routing protocol, specifically designed for urban vehicular environment. The proposed protocol relies on extended periodic “HELLO” messages to calculate weights that are associated to the neighbouring nodes, which are then used in making routing decisions. Compared with GPSR our proposal demonstrates significantly better performance in the urban environment in terms of packet delivery ratio and end-to-end delay. Our results suggest that the use of prediction can increase PDR and reduce network overhead. In addition, the use of eMap information (road, heading etc) increases PDR. The particular link quality estimator using SNIR information has shown to reduce end-to-end delay. The carry-n-forward mechanism is useful only for best effort services in sparse scenarios because it increases end-to-end delay.

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