Operation and Performance of Vehicular Ad-hoc Routing Protocols in Realistic Environments

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Abstract—Vehicle-to-vehicle and vehicle-to-infrastructure wireless communications are currently under development to improve traffic efficiency and safety. Routing protocols enabling multi-hop communications represent a major technology for information dissemination within vehicular ad-hoc networks. The high node's mobility and propagation conditions experienced by vehicle-to-vehicle communications require a careful routing protocol design to ensure its successful operation and performance under realistic environments. To this aim, this paper analyses the impact and importance of adequately considering physical layer effects to correctly quantify a routing protocol's performance, and understand its networking operation.

Keywords: wireless vehicular communication systems, vehicular ad-hoc routing rotocols.

I. Introduction

Wireless vehicular communication systems have been identified as a promising Intelligent Transportation System (ITS) technology to improve traffic safety and efficiency while providing Internet access on the move. However, its future deployment would require to solve an important number of research challenges, in particular those needed to ensure efficient, robust and scalable wireless ad-hoc vehicular communications.

Vehicular ad-hoc networks (VANETs) are characterised by very fast topology changes, and vehicular applications normally impose very low latency requirements. As a result, an adequate wireless vehicular communications dimensioning requires a very careful protocol's design under realistic operating conditions. For example, it has been shown that realistic vehicular mobility patterns considerably impact the performance of ad-hoc routing protocols and their consequent vehicular network topology [1]. Radio propagation modeling has also been shown to have a significant impact on the performance of radio resource management techniques in traditional mobile and wireless communication systems [2] and ad-hoc networking systems [3]. In [3] the authors conduct an interesting investigation on the importance of propagation modeling to adequately study routing protocols in low mobility MANETs (Mobile Ad-hoc Networks). In [4], the authors expand this investigation to the vehicular environment, in particular to highway scenarios. In this context, this work further advances these initial investigations by studying the impact of the radio channel modeling on the performance and networking operation of several wireless ad-hoc routing protocols in urban environments considering realistic mobility patterns. To this aim, position based routing protocols particularly suited for vehicular scenarios have been considered. The conducted research provides valuable information about the actual performance of such routing protocols, but also about their operation which will help design novel approaches that will overcome some of their inefficiencies highlighted in this work.

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II. Radio Channel Modeling

Accurate radio propagation models for system level investigations must properly reflect the effects of pathloss, shadowing and multipath fading. While pathloss represents the local average received signal power relative to the transmit power as a function of the distance between transmitter and receiver, the shadowing models the effect of surrounding obstacles on the mean signal attenuation at a given distance. The multipath fading effect results from the reception of multiple replicas of the transmitted signal at the receiver. Despite the importance of multipath fading in traditional mobile communications, its consideration in vehicular networking research is not always the case, where more simple models are often used [5]. To analyse the impact of the different radio propagation modeling on the understanding and evaluation of wireless vehicular ad-hoc routing protocols performance and operation, this work implements two different deterministic radio propagation models and a realistic channel model accounting for the variability present in the radio channel. One of the implemented deterministic models is the Two Ray Ground propagation model that approximates the pathloss as:

$$PL(d[m]) = \begin{cases} 10\log_{10}\left(\dfrac{d^2(4\pi)^2}{\lambda^2}\right) & if \quad d < d_c \\ 10\log_{10}\left(\dfrac{d^4}{h_A^2 h_B^2}\right) & if \quad d \geq d_c \end{cases} \tag{1}$$

where

$$d_c = \frac{4\pi h_A h_B}{\lambda} \tag{2}$$

d is the distance between transmitter and receiver, h_A and h_B are their respective antenna heights and λ is the carrier wavelength.

In terms of pathloss modeling, the Two Ray Ground propagation model is not capable to differentiate between LOS (Line of Sight) and NLOS (Non Line of Sight) propagation conditions, which on the other hand significantly influences the received signal and thereby the connectivity probability. To this aim, a second deterministic radio propagation model named LOS/NLOS that differentiates visibility conditions between transmitter and receiver for the pathloss calculation has also been implemented. The LOS/NLOS pathloss modeling can be expressed for LOS as [6]:

$$PL_{LOS}(d[m]) = \begin{cases} 22.7\log_{10}(d) + 41 + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d < R_{bp} \\ 40\log_{10}(d) + 41 - 17.3\log_{10}(R_{bp}) + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d \geq R_{bp} \end{cases} \tag{3}$$

where

$$R_{bp} = 4\frac{(h_A - 1)(h_B - 1)}{\lambda} \tag{4}$$

For NLOS conditions, the pathloss can be expressed as:

$$PL_{NLOS}(d_A[m], d_B[m]) = PL_{LOS}(d_A) + 20 - 12.5n_j + 10n_j\log_{10}(d_B) \tag{5}$$

where

$$n_j = \max(2.8 - 0.0024d_A, 1.84) \tag{6}$$

and d_A and d_B are the transmitter and receiver distances to the closest intersection.

To account for the signal variability present in a radio channel and realistically emulate vehicle-to-vehicle (V2V) communications a detailed urban micro-cell propagation model developed in the WINNER project [6] has been implemented. Despite not being developed for V2V communications[1], the operating conditions of the WINNER urban micro-cell model are to the authors' knowledge those that currently best fit the V2V communications scenario for a system level propagation modeling. Moreover, despite considerable progress in V2V channel modeling, to the authors' knowledge there is currently no complete system level channel model for wireless vehicular communications systems. The implemented model considers pathloss, correlated log-normal shadowing (shadowing correlation is introduced through the Gudmundson's model [7]) and multipath fading, differentiating between LOS and NLOS propagation conditions between the transmitter and the receiver. For pathloss, the WINNER model is based on the LOS/NLOS implementation, while multipath is modeled as a Ricean distribution for LOS and as a Rayleigh one for NLOS conditions.

III. VEHICULAR AD-HOC ROUTING PROTOCOLS

For vehicular networks, several authors have demonstrated the potential benefits of position-based routing protocols over traditional topology-based ad-hoc routing protocols given the highly dynamic vehicular network topologies [8]. As a result, three different position-based wireless ad-hoc routing protocols have been employed and implemented in this work to analyse the impact of radio channel modeling on their performance and operation. One of the most commonly considered position-based routing protocols is GPSR (Greedy Perimeter Stateless Routing) [9]. In GPSR, packets generated at the source node are to be routed to the final destination node using positioning information. Then, each intermediate node selects the following forwarding node based on the position of the destination node and the position of its neighbour forward-candidate nodes (the neighbours' positions can be obtained with a periodic beaconing algorithm such as the one employed for traffic safety purposes). By default, all nodes employ the greedy forwarding strategy and forward the data packet to the neighbour geographically closest to the destination. If a node cannot find any neighbour closer to the destination than itself, it follows the perimeter forwarding strategy [9].

Given that GPSR does not consider the road topology when selecting a forwarding node and such topology can influence the mobility of the selected relaying node towards the destination, the authors proposed in [10] the SAR (Spatially Aware Routing) protocol. In SAR, the source node forces data packets to be routed through specific intermediate intersections in the path towards the destination. Intermediate intersections are normally chosen following the shortest path between the source node and the destination node.

Both GPSR and SAR are position-based unicast routing protocols that base their forwarding decisions on the positions of all the neighbours in the transmission range of the forwarding node. However, due to the high vehicle's mobility and the consequent varying topology dynamics, this information can be frequently outdated, decreasing the packet delivery rate. To solve this problem, the CBF (Contention Based Forwarding) protocol was proposed [11]. In CBF, a forwarding node transmits the data packet as a single-hop broadcast message. All vehicles that have correctly received the broadcast packet start a timer which duration is proportional to their distance to the destination. As a result, the timer of the closest neighbour to the destination will expire in first place and this node will broadcast/forward the message to be transmitted. When the other nodes receive such broadcast message, they cancel their timers and do not forward the packet.

IV. EVALUATION ENVIRONMENT

Wireless vehicular communications will be based on the IEEE 802.11p standard or WAVE (Wireless Access in Vehicular Environments) [12], for the PHY and MAC (Medium Access Control) layers. WAVE, based on seven ten-megahertz channels consisting of one control channel and six service channels in the 5.9GHz band, adapts the IEEE 802.11a standard to the vehicular environment. The service channels are used for public safety and private services, while the control channel is used as the reference channel to initially detect surrounding vehicles and establish all communication links. WAVE is based on the DCF (Distributed Coordination Function) of IEEE 802.11a and consequently makes use of the CSMA/CA medium access mechanism to grant the vehicles

[1] The model is based on the 5GHz band but considers a minimum transmitter antenna height of 5m.

access to the channel. The radio transmission effects are modeled in this work through the inclusion of the PER (Packet Error Rate) performance for the WAVE control channel transmission mode [13].

To analyse the performance and operation of vehicular ad-hoc routing protocols a wireless vehicular simulator has been implemented using The Network Simulator ns2. The investigation has been carried out considering a Manhattan-like urban scenario consisting of a uniform grid of 6x6 blocks, depicted in Fig. 1. This scenario has been selected mainly because of its challenging propagation constraints due to the presence of obstacles like buildings and the possibility to envision multi-hop transmissions given the high traffic densities generally found in urban environments. In this scenario, all streets have two lanes except the horizontal street with traffic lights at the intersections, which presents four lanes.

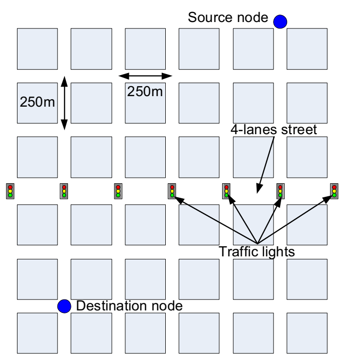

Figure 1. Urban scenario.

All simulated vehicles are WAVE-equipped and periodically transmit broadcast safety beacons on the WAVE control channel for traffic safety purposes every T_s=0.1s. All packets are transmitted at 6Mpbs following the 1/2 QPSK transmission mode defined for the WAVE control channel [12] and using a 0.5W transmission power[2]. Data packets are generated every T_d=3s at the source node, which seeks to forward them to the destination node (see Fig. 1) using the wireless ad-hoc routing protocols previously described. Given that the performance and operation of ad-hoc routing protocols can be strongly influenced by the network topology, this work also considers realistic mobility patterns within the selected urban scenario obtained with the microscopic road traffic simulator SUMO (Simulation of Urban Mobility). For example, traffic lights and intersection priorities significantly influence the vehicle's mobility. An average vehicular traffic density of 12 vehicles per kilometre road is simulated.

V. ROUTING PROTOCOLS PERFORMANCE

Fig. 2 shows the performance of the three implemented vehicular ad-hoc routing protocols for the different propagation models analysed. The figure differentiates between packets correctly routed to the destination, and packets that could not reach the destination. For the unicast protocols (i.e. GPSR and SAR), the packets that cannot reach the destination node can be dropped by an intermediate node because the intermediate node does not have any neighbour node to forward the packet (Dropped RTR) or because the maximum number of retransmissions at the MAC level is reached (Dropped MAC). For the CBF protocol, a data packet is not able to reach the destination when a broadcasted message could not find any node to further rely the packet to the destination. The figure clearly shows that the considered radio propagation model strongly influences the vehicular ad-hoc routing performance and thereby the protocol's operation. In fact, the figure highlights that the percentage of packets dropped due to the lack of neighbours at some intermediate point between the source and the destination nodes in the case of unicast protocols significantly increases under the LOS/NLOS and Detailed radio propagation models, with respect to the Two Ray Ground model. Accurately modeling buildings as obstacles to determine the visibility conditions between the transmitter and the receiver reduces the number of neighbours that each node detects, as depicted in Fig. 3 for the analysed unicast protocols. This effect is due to the fact that the LOS/NLOS and Detailed propagation models adequately differentiate between LOS and NLOS propagation conditions, which results in higher signal losses under NLOS conditions, and consequently in a reduced capability for vehicles to communicate through buildings and detect neighbouring nodes. It is important to note that while GPSR and SAR achieved similar rates of packets correctly received at the destination node under the simplistic Two Ray Ground model, SAR's performance is considerably degraded under realistic

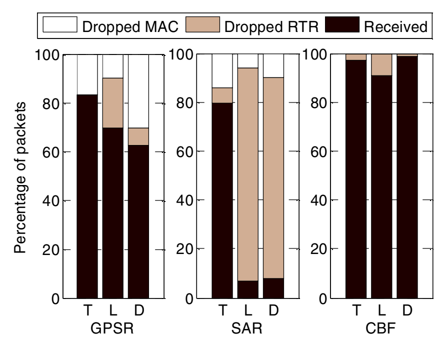

Figure 2. Routing protocols packet delivery ratio. (T=Two Ray Ground; L=LOS/NLOS; D=Detailed).

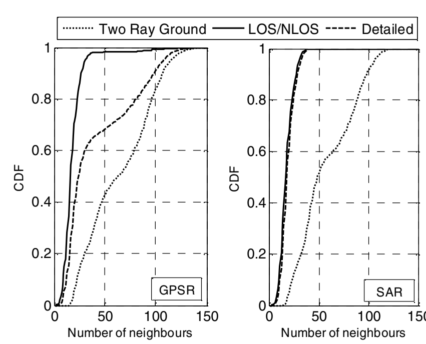

Figure 3. Cumulative Distribution Function (CDF) of the number of neighbours detected by any wireless vehicular node; i.e. nodes that fall within its radio coverage.

[2] Given the unrealistic high transmission range with 0.5W transmission power and the Two Ray Ground model, this model employs the transmission power required to obtain a 400m transmission range following the indications in [1].

propagation conditions differentiating between LOS and NLOS conditions. Such degradation is due to a significant degradation in the number of potential relaying neighbours resulting from an adequate modeling of NLOS conditions and the predetermined SAR route selection.

Fig. 2 also highlights that packet dropping for unicast protocols is due to different factors depending on the signal variability and propagation modeling. For example, in GPSR the percentage of packets dropped at the RTR level is lower considering the Detailed propagation model than considering the LOS/NLOS model. The difference is due to the fact that the increased signal variability of the Detailed propagation model due to the multipath fading modeling increases the transmission variability and thereby the number of neighbouring nodes available to route the packet to the destination (Fig. 3). However, the signal variability reduces the link's reliability, and therefore increases the number of packets dropped at the MAC level. A similar MAC observation can be made for SAR, although in this case the signal variability simulated in the Detailed radio propagation model does not result in an increased number of neighbours due to the restrictive SAR path selection route. As a result, SAR performance degradation for LOS/NLOS and Detailed propagation models is mainly due to the RTR packet dropping.

As it can be observed in Fig. 2, while unicast protocols' performance can considerably vary depending on the propagation model used in the analysis, the CBF protocol presents a much more limited variation due to its relaying node selection process based on actual correct reception of broadcast messages by relaying candidates. In fact, unicast protocols can only reach similar performance levels under simplistic propagation models that ignore important radio propagation effects. On the other hand, Fig. 2 shows that such effects can in fact benefit the performance of broadcast protocols that achieve their higher performance under the Detailed propagation model. The results shown in this section highlight that underestimating the propagation effects can yield inadequate routing protocols performance estimations, while also providing incorrect indications about the actual inefficiencies of unicast vehicular routing protocols.

VI. ROUTING PROTOCOLS OPERATION

After analysing the impact of radio propagation modeling on the performance estimation of broadcast and unicast vehicular routing protocols, this section analyses their operation to better understand the radio propagation effects. Such understanding will help in subsequent research to design robust and efficient unicast vehicular routing protocols that overcome the current proposals limitations highlighted in this paper. Fig. 4 clearly shows that differentiating between LOS and NLOS propagation conditions considerably affects the path that the data packets use to reach the destination. Considering the Two Ray Ground model, the data packets tend to follow a straight line between the source and the destination node, which includes V2V communications across buildings. On the other hand, a realistic propagation modeling prevents such communications and thereby confines V2V communications to routes following the underlying streets. This also results into an interesting observation of the CBF operation and performance

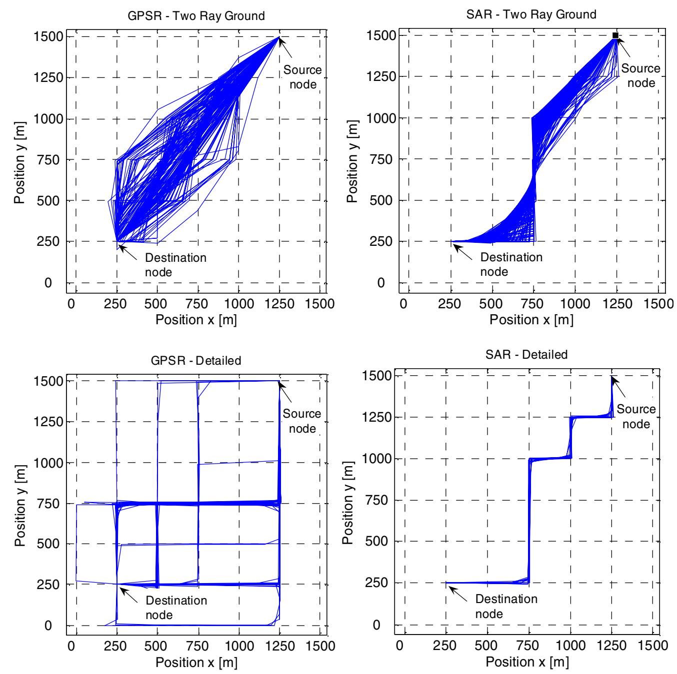

Figure 4. Routing path from the source node to the destination node in the emulated urban scenario.

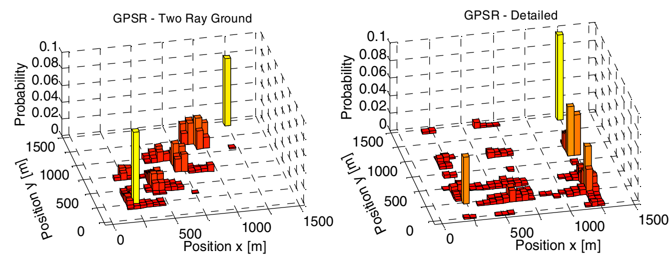

Figure 5. Geographic distribution of packet forwardings.

under various propagation models. In fact, considering simple deterministic models not differentiating between LOS and NLOS conditions, results in that 1.64 data replicas per generated data packet are received at the destination node with CBF. Such value significantly increases when differentiating LOS and NLOS conditions; 2.17 and 3.54 replicas are received at the destination for the LOS/NLOS and Detailed propagation models respectively. This is due to the fact that these two models strongly confine the radio signals to the underlying streets, thereby increasing the probability of splitting the routing path at the intersections. In this case, the same data packet can be routed through different paths, which explains the higher number of replicas received at the destination.

It is interesting to note that adequately understanding the actual operation and route path selection is important to predict the geographic packet distribution and consequent channel congestion levels. The geographic packet distribution for the GPSR routing protocol is illustrated in Fig. 5. As it can be observed, a very different geographic packet distribution is obtained with simplistic and realistic propagation models, thereby emphasizing the importance of adequately consider physical layer effects to correctly estimate the performance of vehicular ad-hoc routing protocols.

Table I provides another interesting insight into the effects of radio propagation on a vehicular routing protocol's operation considering the GPSR example (similar results were obtained for CBF). It is interesting to observe from Table I that propagation models differentiating between LOS and NLOS conditions significantly increased the travelled distance between source and destination given that the route follows the road infrastructure. Also increasing the signal variability increases the average distance between forwarding nodes and therefore reduces the number of forwarding nodes needed to route the information from source to destination.

TABLE I. ROUTING METRICS FOR GPSR

Parameter	Radio propagation model		
	Two Ray Ground	***LOS/NLOS***	***Detailed***
Average travelled distance from source to destination	1665m	2281m	2273m
Average distance between forwarding nodes	368.1m	399.0m	506.7m
Average number of forwarding nodes	4.55	5.63	4.54

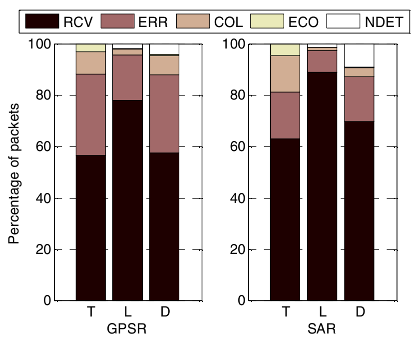

Figure 6. Packet distribution at MAC level for unicast protocols. (T=Two Ray Ground; L=LOS/NLOS; D=Detailed).

In terms of MAC operation, it is interesting to identify the causes of packet reception errors that increase the number of retransmissions and the MAC level packet dropping. Fig. 6 classifies for the unicast[3] routing protocols the packets transmitted at MAC level depending on whether they were correctly received (RCV) or not. In the later case, they could be dropped because of radio channel error (ERR), packet collision (COL), radio channel error and packet collision (ECO) or because they could not be detected due to low received signal level (NDET). Fig. 6 shows that radio channel errors represent the most important packet dropping reason at MAC level. It is also interesting to note the variance of packet collision probability across the different models. The higher collision probability observed for the simpler propagation model is due to the higher detection of neighbouring nodes (Fig. 3) observed with the model under the emulated environment, which results in a higher interference probability and packet collisions.

[3] It is important to note that MAC analysis for broadcast protocols such as CBF would be significantly different since many different nodes contribute to routing the message from source to destination. As a result, broadcast protocols can result in very high destination packet delivery ratios experiencing low average MAC system performance.

VII. CONCLUSIONS

This paper has investigated the impact of the radio propagation modeling on the performance and operation estimation of unicast and broadcast position-based wireless vehicular ad-hoc routing protocols. The obtained results have shown that not properly modeling the radio channel effects can considerably impact not only the routing protocols' performance but also their behaviour and operation thereby highlighting the need to incorporate accurate radio propagation models to properly investigate the design and optimization of reliable and efficient ad-hoc vehicular routing protocols.

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