A New Routing Protocol for Interference and Path-Length Minimization in Vehicular Networks

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Abstract—**Vehicular communication systems represent one of the most desirable technologies when the safety, efficiency and comfort of everyday road travel need to be improved. The main advantage is the absence of an infrastructure, typical of centralized networks, that makes them very scalable and adequate for highly-variable network topologies. Vehicular Ad-hoc NETworks (VANETs) are able to provide wireless networking capability in situations where no fixed infrastructure exists and the communication among nodes can be either direct or made via relaying nodes, as in the classical ad-hoc networks. We propose an interference aware routing scheme for multi-radio vehicular networks and a new metric is also proposed, based both on the maximization of the average Signal to Interference level and on the minimization of the path length of the connection between source and destination. Our solution has been integrated with the AODV routing protocol to design a new MIMO Distance Vector Protocol. NS-2 has been used for implementing and testing the proposed idea, and significant performance improvements have been obtained.**

Keywords-VANET; multi-channel routing, Interference Aware Routing, 802.11p, WAVE, DSRC.

I. INTRODUCTION

Recently, wireless communication technology has made enormous progress. It allows very high mobility, economic and efficient work is almost extreme. Currently, the IEEE 802.11 standard completely dominates the market and the hardware implementation is well designed. In general, Mobile Ad-hoc NETworks (MANETs) are formed dynamically by an autonomous system of mobile nodes that are connected via wireless links without using the existing network infrastructure or centralized administration. VANET is a fully mobile network whose nodes consist of vehicles equipped with a wireless router and a man/machine interface that acts as a heads-up display and monitoring for trade/infotainment services. The main objective of these networks is to further improve road safety by providing real-time alerts to drivers about the risks of their planned journey and their immediate surroundings. This is possible through the interchange with other vehicles and units of transmission of road safety. Communication performance and Quality of Service (QoS) strongly depend on how the routing takes place in the network, on how protocol overhead affects the available bandwidth and on how different channels are selected in order to minimize interference levels. In this work, the availability of different communication channels is considered in order to improve system performance. In a distributed multi-hop architecture, a mobile node may potentially find multiple routes for all the destinations. When evaluating network topology through its routing table and, in the considered case, the availability of different available channels, a protocol may enhance the quality of communication. QoS routing in multi-hop wireless networks is very challenging due to interferences among different transmissions, but VANETs offer the chance to reduce them since multiple simultaneous transmissions are possible. In this paper a new interference-aware routing protocol for VANET environments is proposed, taking the advantage of a dynamic allocation of the Dedicated Short Range Communications (DSRC) spectrum, in order to reduce interference level among mobile nodes. The proposed idea is mainly based on the AODV [1] protocol, which has been properly modified to take also into account the chance of dynamically changing the channel used for data transmission. In particular, a new metric has been defined, based on the Interference Level (I_L) evaluation on the different available channels and on the length of the path; the proposed routing protocol aims to choose different channels, one for each hop on the path, in order to obtain a global I_L minimization for the connections between sources and destinations. At the same time, the hop count on the considered path have to be optimized. This paper is organized as follows: Section II presents an in-depth overview on state-of-the-art routing in VANET; Section III introduces the considered scenario and the proposed protocol. Then Section IV offers a deep description of the obtained results. Finally, Section V concludes the paper.

II. STATE OF THE ART

Some recent studies on routing over VANETs focused more on investigating classical approaches, like AODV, TORA [1],[2], etc. and several routing protocols have been defined by many researchers. In [3], authors have proposed a routing protocol suitable for the urban VANET environment, in order to improve the connectivity of the network by exploiting the urban bus lines and consequently the buses themselves, which can carry the devices with a wider transmission range. MIBR protocol estimates the density of nodes for each road segment path from a particular bus and also gives priority to buses rather than the ordinary nodes for packet forwarding. It is assumed that there is the availability of a location service, so the source node can get the destination information. In [4] authors proposed a greedy routing scheme: when a vehicle senses an event, it produces a message containing the event description and all the event-specific information such as message generation time and a time-to-live value. In [5] authors proposed an algorithm that is designed for sending messages from any node to any other node (unicast) or from one node to all other nodes (broadcast) in a mobile ad hoc network. The general design goals of the EBGR algorithm are to optimize the packet behavior for ad hoc networks with high mobility and to deliver messages with high reliability. Some scalable routing protocols have been based on hybrid routing in order to offer scalable solutions and to reduce signaling overhead, as in [6]. In [7] the authors evaluated the performance of OLSR and AODV in urban environment, adopting the Vehicle Mobility Model to generate realistic mobility patterns. Traditional ad-hoc routing protocols have also been investigated [8] through a deep performance analysis in highway scenarios; simulation results showed that the considered protocols increase the routing load on the network and decrease the packet delivery ratio and the end-to-end delay. In [9], [10] the authors propose a comparison among different proactive and reactive routing protocols. The contributions of this paper consist mainly in the proposal of a revised version of the AODV protocol, introducing a new metric which takes into account neighbors' interference level and hop count. It is based on: a) Analysis of I_L dynamics and choice of an appropriate transmission channel in order to minimize the interference; b) Periodical refresh, in order to evaluate the updated I_L value available on each channel; c) Definition of a I_L threshold value, in order to choose if a new transmission channel must be selected; d) Transmission of synchronization packets in order to advise the receiving node of a new channel selection.

III. VANETS STANDARD OVERVIEW

The IEEE 802.11p standard specifies the technology suitable for vehicular communication networks. It is an amendment to the IEEE 802.11-2007 standard. Within this amendment, a new operational mode, called Wireless Access in Vehicular Environments (WAVE) [11], is defined to enable communication among high-speed vehicles or between a vehicle and a stationary roadside infrastructure network. In addition, the IEEE 1609 standard suite is defined for the resource management, security services, networking service and multi-channel operation in the WAVE mode. The multi-channel operation in the WAVE mode is based on a combined FDMA/TDMA channel access scheme. It operates in the licensed ITS band of 5.9 GHz. Figure 1 shows a typical utilization of Service and Control channels in WAVE: one control channel (CCH) and four service channels (SCH) are shown and each of them occupies 10 MHz bandwidth.

A mobile/stationary station switches its channel between the control channel and a service channel every channel interval. The default value for the control/service channel interval is set to 50 ms in the standard. In figure 1, the rectangles filled with oblique lines represent the time intervals within which all stations must stay on the CCH, and the rectangles filled with crossed lines represent the time intervals within which Interval SCH Interval CCH a station can stay on one of the four SCH's.

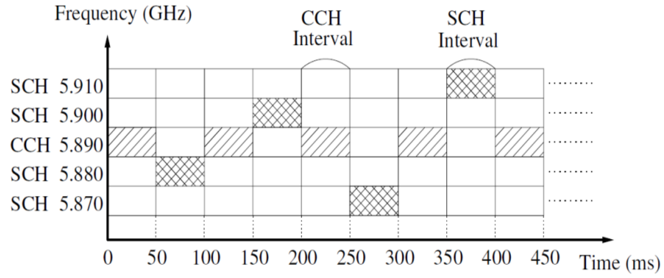

Figure 1. The WAVE-mode channel access scheme.

The CCH is for delivering WAVE-mode management frames (e.g., WAVE service advertisement) and the SCH's are for delivering data frames. The PHY layer employs 64-subcarrier OFDM. Possible modulation schemes are BPSK, QPSK, 16-QAM, 64-QAM, with coding rates equals to 1/2, 1/3, 3/4 1/2, 1/3 and ¾ and an OFDM symbol duration of 8µs. The standard accounts for the priority of the packets using different Access Classes (ACs), having different channel access settings. This shall ensure that highly relevant safety packets can be exchanged timely and reliably even when operating in a dense urban scenario. So, application messages are categorized into different ACs, where AC0 has the lowest and AC3 the highest priority. Within the MAC layer a packet queue exists for each AC.

IV. PROBLEM STATEMENT AND PROPOSED PROTOCOL

A. Scenario

In this paper the attention is focused on the routing protocol employed for forwarding operations in VANET: each node participates to routing, as in classical ad-hoc networks. Taking AODV [1] as reference protocol, path discovery procedure is still started when the source node (node A, for example, as illustrated in figure 2) needs to transmit some information to the destination (node H, for example). Our proposed protocol aims to find the best path in terms of interference and hop-count (in figure 2, it is A-C-E-G-H), basing the choice of next-hops on a new defined metric.

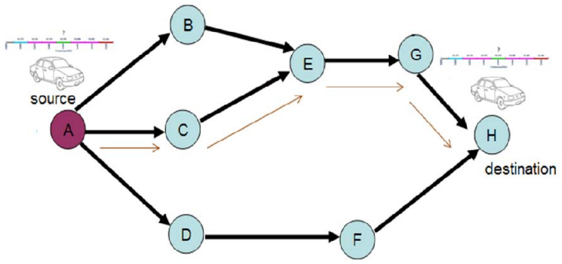

Figure 2. An example of path construction in VANETs.

When a new node enters into the network it discovers its neighbors through the broadcasting of HELLO messages. The source node initiates path discovery by broadcasting a Route REQuest (RREQ) packet to its neighbors. If a neighbor can satisfy the RREQ, it sends a Route REPly (RREP) back to the source; otherwise the RREQ is forwarded again. We propose a re-styled version of AODV called Minimum Interference MInimuM hop-cOunt aoDV (MIMO-DV), which has the basis of the traditional AODV, from which it inherits control packets and packet exchange procedures. The MIMO-DV is based on some assumptions: a) Data packets can be delivered on six Service while signaling ones are transmitted only on the Control CHannel (CCH - 178); b) Each node can transmit/receive on one channel, so no simultaneous transmissions per node are allowed and each node has only one interface with different channels; c) Channel synchronization time is related to the signaling packets delivery delay, needed for channel switching among a couple of nodes and each node can neglect the time needed for a channel switching.

B. Metric definition

It is well known that a metric is made of two or more independent terms, typically in the form of a ratio. Each mobile node in VANETs uses metrics to make routing decisions, and metric is one of the fields in a typical routing table. It is used by routing algorithms to determine the best route to a destination among multiple ones and it is typically based on such information as available bandwidth, hop count, path cost, delay, load, reliability and communication costs. When dealing with wireless communications, classical metrics become inadequate, because they do not consider all the phenomena that can affect the choice of a path: minimizing the hop-count may lead to paths characterized by huge interference levels, on the contrary minimizing the interference may lead to paths characterized by a high number of hops [6],[12],[13]. composite metrics are useful when For these reasons, we propose a new composite metric that combines both interference and hop concepts [16]. Hypothesizing, for now, that the protocol packets have been adequately modified in order to contain the appropriate fields, a generic composite metric *M* can be defined as:

$$M = \alpha_1 w_1 + \alpha_2 w_2 + \ldots + \alpha_k w_k = \sum_{i=1}^{k} \alpha_i w_i \qquad (1)$$

where each term w_i takes into account one routing factor (delay, bandwidth, hop-count, interference, etc.) and terms α_i are weight/normalization factors. In this proposal, we set $k=2$, in order to take into account the hop-count and the interference, so:

$$M_{MIMO-DV} = \alpha_1 w_{INT} + \alpha_2 w_{HOP} \qquad (2)$$

where w_{INT} and w_{HOP} are now defined and α_1 and α_2 are tuned empirically (as shown later).

1) Interference factor w_{INT}

For the MIMO-DV, it is supposed that a node knows exactly the I_L on the available channels for each neighbor and packets transmission over the final optimum path from a source node n_S to a destination node n_D will be made using a set of channels that minimizes $M_{MIMO-DV}$.

I_L calculation, basically, consists in the evaluation of the received signal power, and it is determined by the transmission power and the radio propagation conditions. Using the theory of [14], we can write that:

$$P_r = f(P_t, d, \lambda, \eta, h) \qquad (3)$$

where P_t is the transmission power, λ is the wavelength of the propagating signal, d is the distance between the transmitter and the receiver, h is the antenna height and η is the reflection coefficient of the ground surface (in our simulations $\eta=0.1$, $h=1.5\ m$ and $\lambda=0.1695e\text{-}9$ as in [10]). In this way, a propagation model is implemented. On a real device, P_r can be determined directly via hardware.

Let us consider a mobile host *MH* which has detected the presence of *N* neighbor nodes in its coverage area and which is transmitting with a power P_t. It needs to evaluate the interference level in terms of I_L on the available channel ch_i, due to the presence of the neighbors; the following expression can be used:

$$I_L(ch_i) = \frac{P_t}{\sum_{j=0}^{N-1} P_r^{\,j}(ch_i)} \qquad (4)$$

where $P_r^j(ch_i)$ is the received power from neighbor node *j* on channel ch_i. At this point the mobile node *MH* needs to know both the channel and the best (the minimum) associated I_L, denoted with ch_i* and I_L* respectively. Supposing that *MH* can rely on *S* available channels, then:

$$I_L* = \min_{ch_i}\{I_L(ch_i)\}, \quad ch_i* = index\left\{\min_{ch_i}(I_L(ch_i))\right\}. \qquad (5)$$

At this point, each intermediary node on a path knows exactly the best channel to use when communicating with each neighbor and the related I_L*.

2) Hop-count factor w_{HOP} and metric definition

This term, used in eq. 2, derives from the AODV's classical approach and it simply counts the number of hops that belong to a particular path. If $P(MH_x,MH_y)= \{ MH_{I1}, MH_{I2}, \ldots, MH_{In},\}$ is a path (in terms of intermediary next-hops) from MH_x to MH_y, then each $MH_{Ij} \in P(MH_x,MH_y)$ knows the hop-count toward MH_y on $P(MH_x,MH_y)$; in particular, node MH_x will know the hop-count H_C on path $P(MH_x,MH_y)$ that can be expressed as:

$$H_C\left[P(MH_x, MH_y)\right] = \| P(MH_x, MH_y) \| \qquad (6)$$

When an intermediary node MH_{Ij} receives the RREQ for destination node MH_y and no entry for MH_y is present in its routing table, it forwards the RREQ packet to its neighbors nodes, inserting the information about I_L^* evaluated through eq.5 on the *S* available channels. On the other hand, if an intermediary node MH_{Ij} has knowledge of a path towards MH_y, it answers with a RREP packet, giving to the previous hop MH_{Ij-1} the knowledge of I_L^* and $H_C[P(MH_{Ij},M_y)]$ (along the path towards MH_y). Thus, through the exchange of RREQ and RREP messages, each intermediate node MH_{Ij} can evaluate, on path $P(MH_{Ij},M_y)$, both the average I_L*, indicated with $\overline{I}_L*$, and the hop-count H_C:

$$\overline{I}_L*\left[P(MH_{Ij}, M_y)\right] = \frac{\sum_{MH_{Il} \in P(MH_{Ij}, MH_y)} I^l{}_L*}{H_C\left[P(MH_{Ij}, M_y)\right]} \qquad (7)$$

where $I^l{}_L^*$ represents the value I_L* obtained from eq. 5 for the intermediate node MH_{Il}.

At this point, node MH_x knows the set of paths ***PS*** toward MH_y and all the H_C so, recalling eq.2, we can write:

$$\underset{P\in PS}{M_{MIMO-DV}} = \alpha_1 \bar{I}_L*(P) + \alpha_2 H_C(P) \quad , \qquad (8)$$

which represents the metric evaluated for path $P\in$ ***PS***. The best path $P^*\in$ ***PS*** will be the one that satisfies:

$$\underset{P^*}{M_{MIMO-DV}} = \min_{P\in PS}\left(\underset{P\in PS}{M_{MIMO-DV}}\right). \qquad (9)$$

3) Weights/Normalization factors tuning

At this point, some considerations on α_1, α_2 have to be made. Since interference and hop-count assume very different values, they have to be normalized to make possible a comparison among them. Since each source node MH_x, knows $\bar{I}_L*(P)$ and $H_C(P)$ separately (for each P), first of all we have to normalize them in the interval [0,1], so defining:

$$I_L*_{MAX} = \max_{P\in PS}\left[I_L*(P)\right] \ \ and \ \ H_{C_{MAX}} = \max_{P\in PS}\left[H_C(P)\right] \qquad (10)$$

terms α_1 and α_2 can be written as:

$$\alpha_1 = \alpha \cdot \frac{1}{I_L*_{MAX}} \quad and \quad \alpha_2 = \beta \cdot \frac{1}{H_{C_{MAX}}} \quad . \qquad (11)$$

In this way, eq. 8 becomes:

$$\underset{P\in PS}{M_{MIMO-DV}} = \alpha \cdot \frac{1}{I_L*_{MAX}} \cdot \bar{I}_L*(P) + \beta \cdot \frac{1}{H_{C_{MAX}}} H_C(P) \qquad (12)$$

The proposed protocol, now, has two degrees of freedom (α,β), which have to be set adequately. In the next section, α and β will be chosen from a limited admissible area, in order to obtain best protocol results.

It must be observed that, due to mobility and wireless degradations, once the optimal channels have been chosen for packet transmission, they have to be periodically checked, in order to verify if there exists a new transmission channel distribution or alternative paths which can enhance protocol performance. So, the parameter Δ is introduced in order to define the refresh interval. When a node observes that better paths are available, it sends a Change-REQuest packet (CREQ) to its neighbor, then waits for the acknowledgement Change-REPly (CREP).

V. PERFORMANCE EVALUATION

The protocol proposed in Section IV has been implemented in the NS2 simulator; first of all, the QoS MAC of IEEE802.11e has been introduced and then it has been extended in order to include all the functionalities of the multi-channel IEEE802.11p standard. The CityMob generator [15] has been used to create mobility log-files, with the following parameters: map dimensions 1500m x 1500m, maximum vehicle speed 13.9 m/s. Transmission rate has been fixed to 3Mbps and the number of mobile nodes from 30 to 100. Many simulation have been carried out in order to determine the optimal value of some simulation parameters. The number of concurrent connections has been fixed to 15, Δ has been fixed to 60ms, while the admissible region for α and β illustrated in figure 3 has been obtained. Values of α and β out of this region lead the system to have bad performance.

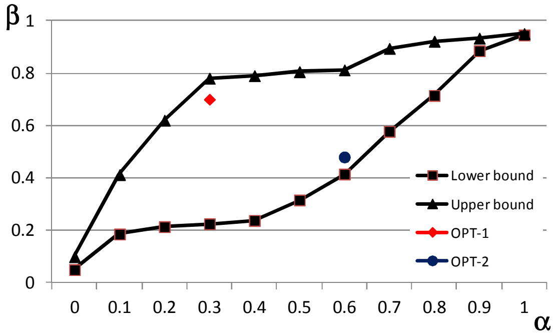

Figure 3. Admissible region for α and β.

If the number of connections was lower than 15, the system appeared to be under-utilized, while values of Δ higher than 60ms led the system to be heavily overheaded. Two points in the admissible region make the protocol to perform better: *OPT-1* (*α=0.31,β=0.72*) and OPT-2 (*α=0.592,β=0.48*). The MIMO-DV protocol (evaluated in *OPT-1* and *OPT-2*) has been compared to the traditional AODV (AODV SINGLE in the captions) and the traditional AODV with a random channel selection (AODV MULTI RANDOM in the captions). Figure 4 shows the average aggregate throughput of the network (the total amount of bits received by all nodes during simulation time): it can be seen how it decreases for higher number of mobile nodes, because of the higher overhead burden, but the MIMO-DV outperforms the classical schemes AODV SINGLE/MULTI and a considerable gain (about 7Mbps) has been obtained.

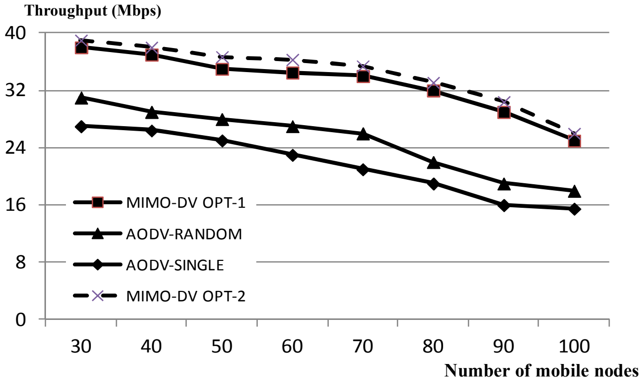

Figure 4. The average throughput (Mbps) for the simulated VANET.

In figure 5, the Packet Delivery Ratio (PDR) is illustrated: also in this case MIMO-AODV, in both optimum points, outperforms the other protocols and a gain of about 10% is obtained. Figures 4 and 5 demonstrate how an interference-based metric can increase the performance of the system: collisions and interference errors are heavily reduced. As explained in previous section, some fields of classical AODV packets have been added/modified and new protocol packes have been defined. Fig. 6 illustrates the enhancement introduced in the average perceived I_L (evaluated as in eq. 7

and normalized in the range [0,100] through a factor of 10^{10}) with the employment of MIMO-DV. When traditional routing schemes are employed, the routing protocol acts by ignoring I_L and interference problems, so the high values of normalized I_L (the maximum allowable) illustrated in the figure are obtained. The differences with the MIMO-DV are evident, although the trend is increasing when the number of vehicles increases. When the number of nodes is too high available channels are limited (six in the considered case) so the interference cannot be heavily reduced. It must be observed that, in the case of *OPT-2*, I_L is further reduced, because of the interference term in the metric has higher priority for higher values of α.

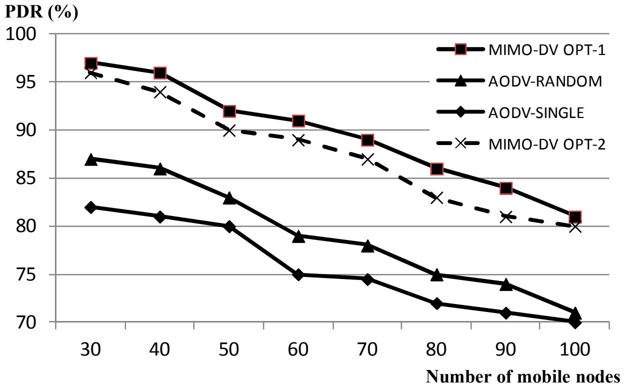

Figure 5. The average Packet Delivery Ratio (PDR) for the simulated network.

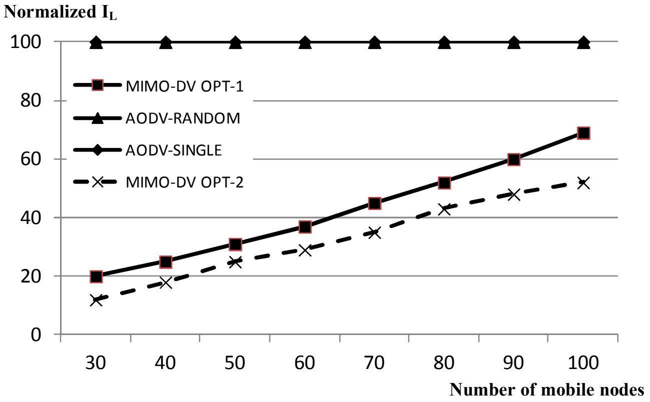

Figure 6. The average Interference Level perceived by mobile nodes.

In addition, simulation results shown an increasing in the overhead for MIMO-DV. The introduction of CREQ and CREP messages makes the overhead (evaluated as the ratio between the number of signaling packets and the number of total packets) of MIMO-DV higher than classical AODV schemes (about 2%-2.5%). Curves are not shown for space limitations.

VI. CONCLUSIONS

This work proposes a new routing protocol for VANETs, dedicated to the optimization of path-length and interference level. It is based on the traditional AODV scheme, but takes advantage of a dynamic allocation of the DSRC spectrum, in order to reduce interference levels among nearby mobile nodes. A new composite metric, based on the evaluation of interference levels and path lengths along the different links from sources towards destinations has been proposed. Through an NS2 implementation of the IEEE802.11p standard, with the simulation of vehicles mobility in a urban environment, it has been shown that the proposed idea enhances AODV performance in terms of throughput and packet delivery ratio, despite of a slight increase in protocol overhead.

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