An On Demand Interference Aware Routing Protocol for VANETS

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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 adequate for highly-variable network topologies. On the other hand, communication protocols become very complex and, sometimes, signaling overhead may waste bandwidth availability. Vehicular Ad-hoc NETworks (VANETs) are able to provide a wireless networking capability in situations where no fixed infrastructure exists: 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. Attention is focused on the routing level of VANET and we propose an interference aware routing scheme for multi-radio vehicular networks, wherein each node is equipped with a multi-channel radio interface. In order to relieve the effects of the co-channel interference perceived by mobile nodes, transmission channels are switched on the basis of a periodical Signal-to-Interference Ratio (SIR) evaluation. A new metric is also proposed, based on the maximization of the average SIR level of the connection between source and destination. Our solution has been integrated with the Ad-Hoc On-Demand Distance Vector (AODV) routing protocol to design an enhanced Signal-to-Interference-Ratio-AODV (SIR-AODV). NS-2 has been used for implementing and testing the proposed idea, and significant performance enhancements were obtained, in terms of throughput, packet delivery and, obviously, interference.**

***Index Terms*—Multi-channel routing, VANET, Interference Aware Routing, 802.11p, WAVE, DSRC, SIR.**

I. INTRODUCTION

Recently, wireless communication technology has made enormous progress. It allows very high mobility and, 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. Nodes are free to move randomly and organize themselves arbitrarily; thus, network topology may change rapidly and unpredictably. Such a network may operate in a standalone fashion, or may be connected to the larger Internet. In general, routes between nodes in an ad hoc network may include multiple hops and, hence, it is appropriate to call such networks “multi-hop wireless ad hoc networks”. 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. Furthermore, VANETs consist of wireless-equipped outdoor units that provide motorists with information about their immediate surroundings and are able to provide communication with other facilities such as the Internet. Units on the road can be any equipment-certified packet forwarding, such as GSM, WLAN, and WiMAX towers. These outdoor units are most useful when an individual is isolated from other VANETs units because the driver will still be able to receive vital information, provided within range of the drive way. 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. Examples include lane union warning, blind spot warning and curve speed warning. The current rules that are now in use during the development of VANETs are IEEE 802.11 WLAN, Dedicated Short Range Communications (DSRC), or GSM / UMTS. DSRC networks are refined in a very efficient version that will soon evolve into a communication standard IEEE 802.11p [1]. Due to the higher signaling burden than the one of infrastructure systems, communication protocols become very complex and, sometimes, signaling overhead may waste bandwidth availability. VANETs are able to provide wireless networking capability in situations where the communication among nodes can be either direct or made via relaying nodes, as in classical ad-hoc networks. The overall perceived QoS strongly depends on how the routing 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. QoS routing in multi-hop wireless networks is very challenging due to interference among different transmissions, but VANETs offer the chance to reduce them since multiple simultaneous transmissions are possible. In this paper, on the basis of the work proposed in [2,3], a new interference-aware routing protocol for VANET environments is proposed, taking the advantage of a dynamic allocation of the DSRC spectrum, in order to reduce the interference level among mobile nodes. 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. So, in this scenario, each node should select the best route in terms of QoS, not only considering a typical cost metric (bandwidth, delay, traffic load or a combination of them), as in the classical multi-hop architecture, but taking into account the benefits that can be obtained if different interference levels, i.e. different channels, are considered. The proposed idea is mainly based on the AODV [4] protocol, which has been properly modified to take into account the chance of dynamically changing the channel used for data transmission. In particular, a new metric has been defined, based on the Signal-to-Interference (SIR) evaluation on the different available channels; on the basis of our proposal on interference aware routing protocol on UWB technology [5], in this manuscript an interference aware metric in the VANET context has been proposed, as well as a routing protocol able to choose different channels, one for each hop on the path, in order to obtain a global SIR maximization for the connections between sources and destinations. The main contributions of this paper consist mainly in the proposal of a new version of the AODV protocol, properly modified in order to take the neighbors' interference level into account. The evaluation of the new metric is based on:

- Management of the multi-channel capability of the WAVE standard at the routing level through a higher-level channel selection, which is based on a interference-aware algorithm;
- Implementation of a 2-ray propagation model in order to take path-loss between Transmitter and Receiver nodes into account;
- Periodical Signal-to-Interference Ratio (SIR) estimation on the available transmission channels;
- Definition of a SIR threshold value in order to choose if a new transmission channel must be selected;
- Transmission of synchronization packets in order to advise the receiving node of a new channel selection.

This paper is organized as follows: Section II introduces an in-depth overview on the related work regarding routing in VANETs; Section III introduces the considered scenario and the proposed protocol. Then Section IV offers an extensive description of the obtained results. Finally Section V concludes the discussion.

II. State of the Art and Related Works

There are many recent works in the literature on VANETs, mostly focusing on investigating new approaches to enhance routing operations. Topology based routing protocols use links information that exist in the network to perform packet forwarding: they are divided into proactive and reactive.

A. Proactive vs Reactive Routing Protocol

Proactive routing means that the routing information such as next forwarding hop is maintained in the background irrespective of communication requests. The packets are constantly broadcasted and flooded among nodes to maintain the path, then a table is constructed within a node which indicates the next hop node towards a destination. An example of well-known proactive routing protocol is Optimised Link State Routing (OLSR). It makes us of special nodes called Multipoint Relay (MPR) to forward topology control message (TC) and it send periodically TC packets to evaluate link breakage and to build paths from sources to destinations. The one and two hop neighbor lists of OLSR are affected by timeouts, which results in inefficient flooding of topology control messages as a consequence of errors in the multipoint relay set calculation. AODV, on the other hand, is representative of reactive routing protocols. It presents a route discovery phase where the Route Request (RREQ) packets are sent in broadcast. The path is built on the reverse path forwarding through the Route Reply (RREP) packets. We omit for space limitations other well known reactive routing protocols applied in the general context of MANET. In [6] the authors evaluated the performance of OLSR and AODV in an urban environment, adopting the Vehicle Mobility Model to generate realistic mobility patterns, while in [7] the authors made an interesting comparison among OLSR and DSR from an energetic point of view. In [8,9], the authors enhanced a traditional MANET routing protocol (AODV) aiming at improving route stability and obtaining less network overhead, thus making AODV suitable for VANETs. Their study showed that more appropriate routes can be found with and without mobility prediction.

B. *Geographic Routing*

Position based routing protocols share the property of using geographic positioning information in order to select the next forwarding hops. A packet is sent without any map knowledge to the one neighbor hop which is closest to the destination. The behavior of the routing protocols is mainly triggered by events such as timeouts and the reception of routing messages, and the impact that these events have on them is different. Also, position-based routing protocols have been proposed in VANET-related literature. B. Karp et al. [10] proposed the GPSR position-based protocol, that forwards data packets by considering geographic information of the nodes which are close to destination. It has been shown that GPSR does not perform optimally when large city environments are considered, mostly because it uses direct communication among nodes that can be interrupted by obstacles. Within the Distance Routing Effect Algorithm for Mobility (DREAM) framework [11], each node maintains a position database that stores position information (entries) about each other node that is part of the network. Of course, the accuracy of such an entry depends on its age. Each node regularly floods packets to update the position information maintained by the other nodes.

C. *Interference-aware Routing Protocols*

In the last few years, many new techniques have been proposed to reduce the effects of interference, defining interference-aware metrics and routing protocols. The reciprocal interference between system nodes considerably affects the path-delay and, so, the data-rate. The older interference-aware metrics tried to optimize these parameters: the DIAR [12,13] is one of the interference-aware routing protocols for IEEE 802.11 networks and it is based on the Network Allocator Vector Count (NAVC). The simulation results that the NAVC is not dependent on the total number of nodes in the system. The path with the lowest NAVC is a path with a lower delay and a lower interference [14]. With a similar approach, in [15], where the employed metric chooses the path with the lowest path delay, defined as the interval between the Route REQuest (RREQ) dispatch and the related Route REPly (RREP) reception. In [16], the chosen interference-aware metric is different: the authors make the assumption that if there is a higher number of neighbors, a higher probability of interference for a node will be observed; for this reason, through the adopted metric, the routing protocol selects a certain number of paths, verifying that the sum of the coverage values of the nodes belonging to the single path is the lowest. In [5] the authors have designed a new routing protocol, called interference aware-based ad-hoc on demand distance vector (IA-AODV), based on the concept of interference: the optimum route is chosen on the basis of the minimum perceived interference.

D. *Routing Protocols for VANET*

Traditional ad-hoc routing protocols have also been investigated [17] 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. The AQOR protocol [18] also maintains neighbor information to incorporate interference, and broadcasts route requests. By using the neighborhood bandwidth information for the new flow, feasible paths are detected; the final choice is made at the destination. Zhu and Corson [19] proposed other algorithms to determine the exact schedule of slots for a flow through the network, guaranteeing the bandwidth by taking interference into account. Johansson et al. [20] used NS-2 to simulate the increase of link breaks and the decrease of reliability with higher node speeds. It is clear that the collected simulation results strongly depend on the implementation of the protocols and their configurations. In [21], the authors have proposed a routing protocol suitable for the urban VANET environment, in order to improve the connectivity of the network by exploiting 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 each vehicle knows its location through GPS, and has a digital street map including bus line information; it is also assumed that there is the availability of a location service, so the source node can obtain destination information. In [22] the 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 (Tg) and a time-to-live (TTL) value. The message is considered to be successfully delivered if it arrives at the nearest AP from the source vehicle before time (Tg + TTL) without any transmission error. For the prediction of a sequence of vertices or junctions, a source vehicle identifies the number of involved junctions between the source vehicle and nearest AP from it. For data forwarding, the conventional predictive directional greedy routing is used, where both position and direction of mobile vehicles are taken into consideration. VPGR is an interesting routing protocol which performs two key operations: predicting a sequence of vertices and forwarding data through the sequence of vertices by using well-known predictive directional greedy routing mechanism. In [23,25] the authors considered VANET routing for Manhattan and the Freeway mobile scenario, in order to offer network scalability, by taking into account the deterministic vehicles movement, that permits to get advantage of building specific local trajectory to reach destination node. The main contributions of this paper consist mainly in the proposal of a new version of the AODV protocol, properly modified in order to take the neighbors' interference level into account. On the basis of the work proposed in [7] where interference has been considered in the route selection, here, the protocols try to define an interference metric associated to VANET context and try to exploit the advantage of a multichannel MAC to increase the data throughput.

III. VEHICULAR INTERNETWOKING OVERVIEW AND PROPOSED PROTOCOL

A. *Vehicular Communications through VANET*

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) [1], is defined to enable communication among high-speed vehicles or between a vehicle and a stationary roadside infrastructure network (as illustrated in Fig. 2). In addition, the IEEE 1609 standard suite is defined for 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. WAVE aims at providing standard specifications to ensure the interoperability between wireless mobile nodes of a network with rapidly changing topology (that is to say, a set of vehicles in an urban or sub-urban environment). The DSRC spectrum is divided into 7 channels, each one with a 10 MHz bandwidth; it is allocated in the upper 5 GHz range. In Fig. 1, 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 one of the service channels each channel interval.

The default value for the control/service channel interval is set to 50 ms in the standard. In Fig. 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 a station can stay on one of the four SCH's. The CCH is for delivering WAVE-mode management frames (e.g., WAVE service advertisement) and the SCHs are for delivering data frames.

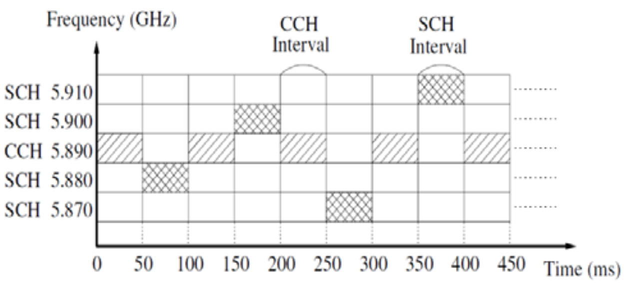

Figure 1. Direct Short Range Communication spectrum allocation.

It is possible to observe from Fig. 1 that during a CCH interval, no station can stay on any SCH. As such, if two stations would like to exchange a large volume of data with no interest in any of the services advertised on the CCH, they will have to waste one half of the bandwidth of a SCH because they need to switch back and forth between the CCH and a SCH. VANET provides wireless communication among vehicles and vehicle-to-road-side equipments. The PHY layer employs a 64-subcarrier OFDM. 52 out of the 64 subcarriers are used for actual transmission consisting of 48 data subcarriers and 4 pilot subcarriers.

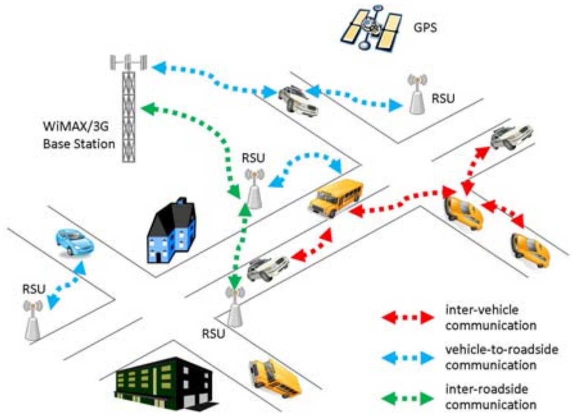

Figure 2. A typical urban VANET scenario.

Possible modulation schemes are BPSK, QPSK, 16-QAM and 64-QAM, with coding rates equal to 1/2, 1/3, 3/4 1/2, 1/3, ¾ and an OFDM symbol duration of 8μs. In Fig. 3, the WAVE PHY simulation model [25] is shown. In the transmitter part, the short and long training symbols are generated and transmitted at first. Then arbitrary data bits are randomly generated and encoded by a convolutional encoder with 1/2 code rate. Then the encoded bits are punctured to support various data rates. The interleaver is exploited to change burst errors into random errors, and the interleaved bits are modulated by BPSK, QPSK, 16QAM, or 64QAM. The 48 modulated symbols, the 4 pilot symbols, and the 12 null symbols are inserted into 64-point Inverse Fast Fourier Transform (IFFT). After that, 16 Cyclic Prefix (CP) samples are added to the 64-point output samples of the IFFT operation to make an OFDM symbol.

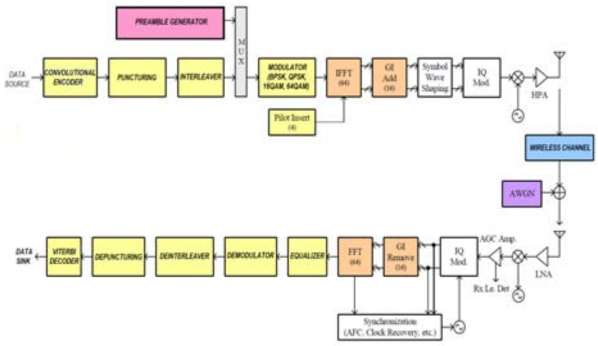

Figure 3. WAVE PHY simulation model.

The CP samples are Guard Interval (GI) samples to prevent Inter-Symbol Interference (ISI) and Inter-Carrier Interference (ICI). In order to suppress the out-of-band spectrum, the OFDM symbol is multiplied by a raised-cosine window. The WAVE standard relies on a multi-channel concept which can be used for both safety-related and entertainment messages. 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 in a timely and reliable manner, even when operating in a dense urban scenario.

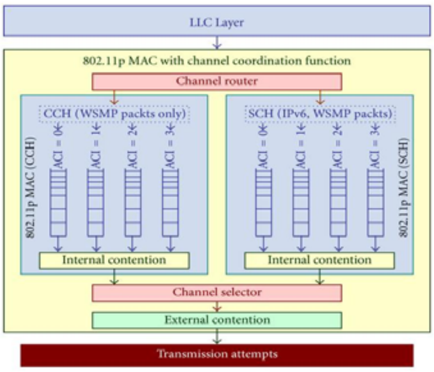

Figure 4. Multi-channel EDCA extension for WAVE specifications.

Each station continuously alternates between the Control Channel (CCH) and one of the Service Channels (SCHs) or the safety channels. The MAC layer in WAVE is equivalent to the IEEE 802.11e Enhanced Distributed Channel Access (EDCA) Quality of Service (QoS) extension (Fig. 4 shows how the EDCA is extended to meet WAVE specifications). Therefore, 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. An important issue in VANET is the choice of an appropriate transmission channel, not only considering the type of traffic (emergency, security, platooning, etc.) but, mainly, focusing on the reduction of the inter-node interference. As shown in Fig. 5, the PPDU frame format consists of OFDM Physical Layer Convergence Protocol (PLCP) preamble, PLCP header, PSDU, tail bits, and pad bits.

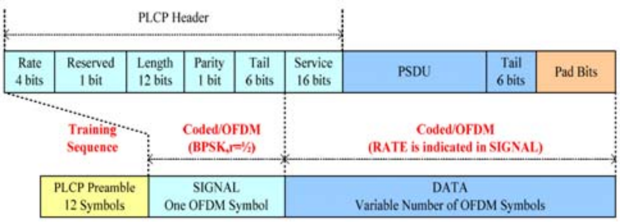

Figure 5. PPDU frame format.

The PLCP header [25] includes rate, reserved, length, parity, tail, and service fields where the fields excluding the service field are defined as SIGNAL. The SIGNAL forms one OFDM symbol with 1/2 code rate and BPSK modulation. The DATA contains service field, PSDU, tail bits, and pad bits. It is transmitted via a variable number of OFDM symbols.

The PLCP preamble with 32 μs length consists of 10 identical short training symbols and 2 identical long training symbols as shown in Fig. 6.

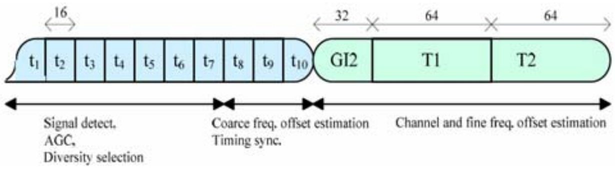

Figure 6. PLCP preamble structure.

The short training symbols are recommended to be used for signal detection, automatic gain control, diversity selection, timing synchronization, and coarse frequency offset estimation, and the long training symbols are recommended to be used for channel estimation and fine frequency offset estimation.

B. Signal-to-Interference-Ratio-based-AODV (SIR-AODV)

Our attention is focused on the network layer of a VANET, and it is assumed that the channel router of the WAVE MAC layer is able to analyze the LLC data unit in order to choose the right priority queue. As in the traditional scheme, the path discovery process is initiated whenever a source node needs to communicate with another node for which it has no routing information in its table. 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. So, the proposed protocol called Signal-to-Interference-Ratio-AODV (SIR-AODV) has the basis of the AODV, from which it inherits control packets and packet exchange procedures. HELLO messages in SIR-AODV have the same meaning of those in the traditional protocol, and so they are broadcasted in the coverage area in order to know the identity of neighbor nodes and to validate the availability of links. AODV is a reactive protocol designed for ad hoc networks. It derives from the DSDV protocol and it also associates with a routing table with each node, but it minimizes the number of broadcast messages sent over the network, creating and updating the paths present in the tables only when needed (on demand) and not regularly as for the DSDV protocols.

1) Proposed interference-aware metric and assumptions

The novelty of the proposal consists in the adopted metric for the choice of the optimal route from source to destination, and in the route maintenance procedure: it is not based on the minimum hop count, as for the traditional AODV, but on the interference concept, as explained later.

Also, it was necessary to modify some control packets. In particular, the SIR_{MAX} field is added to both RREP and RREQ packets. The SIR-AODV is based on the following assumptions:

- Data packets can be delivered on six Service CHannels (SCH - 172,174,176,180,182 and 184), while signaling ones are transmitted only on the Control CHannel (CCH - 178);
- Each node can transmit/receive on one channel, so no simultaneous transmissions are allowed;
- Each node is equipped with a single interface (with multiple channels);
- When two nodes decide to switch their communication channel, a certain amount of time is spent for synchronization, during which some signaling packets are exchanged;
- The time needed for channel switching is negligible (in terms of the 802.11p MAC implementation, the channel router only has to forward data units to a different queue).

For the SIR-AODV, it is also supposed that a node knows exactly the SIR level on the available channels for each neighbor (in our work we use a transmission model to evaluate it, but real nodes can evaluate it via hardware) and packet 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 minimize the inter-node interference, achieving better signal quality during the considered session. The proposed metric is based on the evaluation of the interference level among a couple of nodes, so an overview on the considered channel model should be given. SIR calculation basically consists in the evaluation of the received signal power and it is determined by the transmission power and the radio propagation conditions. Path-loss effects are dominant in VANETs, because channel coding makes the bit error performance of an OFDM link in a frequency-selective channel depend more on the average received power than on the weakest subcarrier power [26]. Although real mobile nodes can directly evaluate the received power via hardware, it is necessary to have an analytical model, for simulation purposes; so, for a generic receiver node, we can consider the received power P_r to be [27]:

$$P_r = \frac{P_t}{(4\pi)^2 \left(\frac{d}{\lambda}\right)^{\gamma}} \left[1 + \alpha^2 + 2\alpha \cos\left(\frac{4\pi h^2}{d\lambda}\right)\right] \tag{1}$$

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, α is the reflection coefficient of the ground surface and γ is the path-loss factor. Once a node is able to evaluate the received signal power, the calculation of SIR for each channel can be carried out. Let us suppose that mobile node k n_k needs to evaluate the SIR level on channel i due to the presence of n neighbors in its coverage area, then:

$$SIR^{k}{}_{i} = \frac{P_{t_k}}{\sum_{j=0}^{n-1} P_{r^i{}_j}}, \tag{2}$$

where P_{tk} is the transmission power of n_k and P_{rj}^i is the received power from neighbor node j on channel i.

2) Dynamic channel switching and next-hop selection

Fig. 7 shows an example of the path discovery mechanism in SIR-AODV. The source node n_S sends the RREQ to its neighbors n_A, n_B and n_C for a path towards destination node n_D. Since n_A, n_B and n_C know a path to the destination, they will answer with a RREP, containing the maximum achievable SIR value and the associated channel. When node n_S receives these answers, it will decide to store the next-hop n_B in its routing table, since it has the highest associated SIR value.

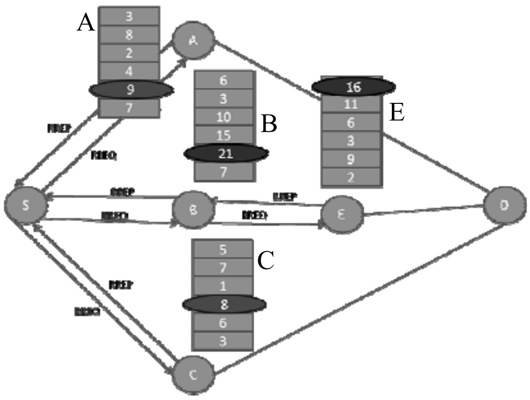

Figure 7. Path discovery procedure in SIR-AODV.

Once channels have been assigned, they need to be periodically refreshed, in order to change the assignment if needed. Fig. 8 shows the structures of CREQ and CREP messages; CREQ is the same as a RREQ, but only the *CHAN* field is used in order to make the receiver aware of the new channel; CREP contains the *ACK* field to acknowledge the switching. A source node, unaware of the best path to destination, can initiate the path discovery procedure by sending RREQ messages to its neighbors.

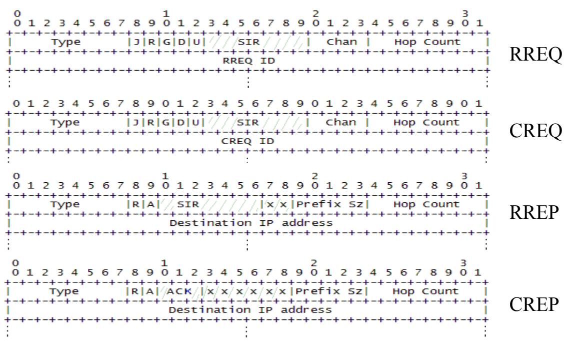

Figure 8. Signaling packets and fields in SIR-AODV.

When a node n_k receives the RREQ for destination node n_D and no entry for n_D is present in its routing table, it modifies and forwards the RREQ packet to its r neighbor nodes $\{n_{k1}, n_{k2}, \ldots, n_{kn}\}$ inserting the information about the best SIR value measured on the available channels, denoted as $SIR^K{}_{MAX}$, so from eq. (2):

$$SIR^k{}_{MAX} = \max_i \left\{ SIR^k{}_i \right\} \tag{3}$$

On the other hand, if node n_k has knowledge of a path towards n_D, it answers with a RREP packet, giving to node n_S the knowledge of the average SIR along the path towards n_D. Fig. 4 shows the structure of the RREQ and RREP packets: in addition to the traditional AODV fields, *SIR* and *CHAN* fields have been added to them; they are used by a node when forwarding the packet and when the receiver must be aware about SIR_{MAX}. If $P(n_k,n_D)=\{l_1,l_2,\ldots,l_m\}$ is the best path, in terms of a list of links from n_K to n_D, SIR values on links l_i, $i=1\ldots m$, are known since they have been evaluated through eq. 3. Thus, each intermediate node, through the reception of the RREP packets in the path discovery procedure, can evaluate the average SIR, denoted with SIR_{AVG_RREP}, as follows:

$$SIR_{AVG\_RREP} = \frac{\sum_{l=1}^{m} SIR^{k_l}{}_{MAX_l}}{m} \tag{4}$$

where $SIR^{k_l}{}_{MAX_l}$ is the SIR evaluated on the *l-th* link (belonging to node n_{Kl}). So, each node has the knowledge about the average SIR towards a destination if a particular next-hop is chosen during forwarding operations. The following pseudo-code is executed periodically by each node (every Δ seconds); T denotes the number of available channels for the WAVE interface, C denotes the number of neighbor nodes and δ an input threshold that represents the minimum SIR level that must be granted on each selected channel.

CHANNEL REFRESH/SWITCH ROUTINE

- *For all neighbors, update the received power level P_r and store it in a vector of dimension C;*
- *For each available channel, evaluate the SIR level through eq.(2) and store the values in a vector of dimension T;*
- *If c is the active channel and SIR[c]< δ:*

Send a Change REQuest (CREQ) packet to a neighbor on channel c; once the CREQ has been received, the neighbor node replies with a Change REPly (CREP) packet, as acknowledgement.

3) *Protocol Parameters tuning*

a) *Channel refresh timer tuning (Δ)*

In order to correctly set the value of Δ, some simulation campaigns have been carried out (100 runs with 2000s of simulated time each one), evaluating the Packet Delivery Ratio (PDR), Overhead, Throughput, Delay end-to-end and SIR values on the used transmission channels, fixing the confidence interval to 95%. Different number of mobile nodes have been considered (40, 60 and 80), with an average speed of 20 m/s, 10 concurrent connections and a single bitrate of 3Mbps.

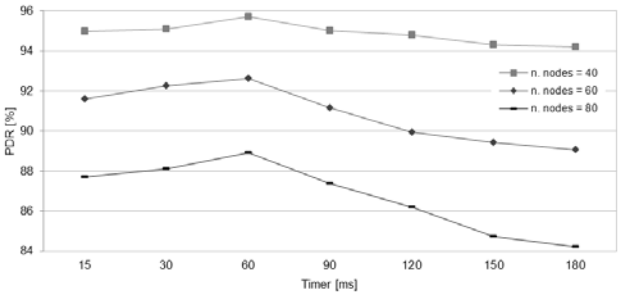

Figure 9. PDR for different values of Δ.

Fig. 9 shows how the PDR decreases for higher number of mobile nodes and for Δ=60ms it reaches the maximum value. From Fig. 10 it is possible to notice how the number of control messages decreases as Δ increases (they are sent less frequently). In addition, if $\Delta \geq$ 60ms the variation is negligible, so the overhead starts to be minimized from Δ=60. In Fig. 11, the aggregated throughput (given as the sum of the throughputs of single connections) decreases for higher number of mobile nodes and, for all the considered cases, the value of Δ=60ms leads the system to the best performance.

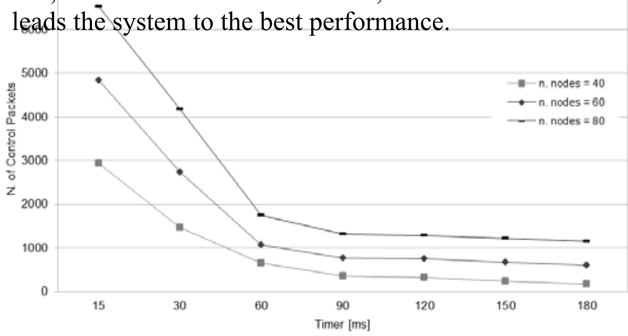

Figure 10. Protocol Control Messages for different values of Δ.

From Fig. 12 it can be noticed that the End-2-end delay is proportional to the number of mobile nodes and it is minimized for Δ=60ms. Fig. 13 shows how the SIR takes its maximum value for Δ=60 and how it decreases for a higher number of mobile nodes. From the figures above, the value of Δ has been set to 60ms, in order to obtain the best results.

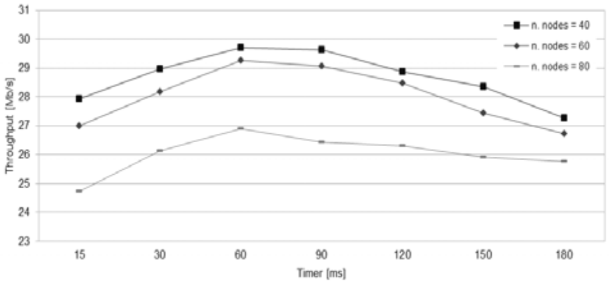

Figure 11. Aggregated throughput for different values of Δ.

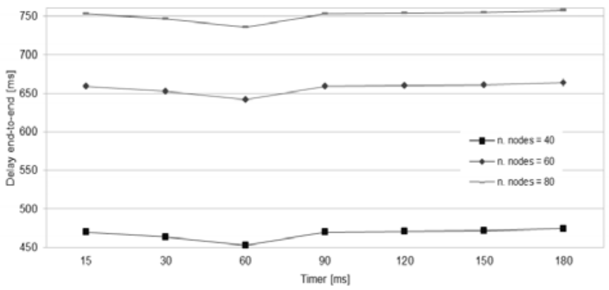

Figure 12. End-to-end delay for different values of Δ.

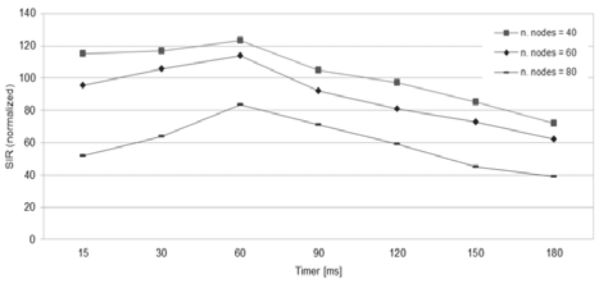

Figure 13. Average SIR on transmission channels for some values of Δ.

b) SIR threshold (δ) tuning

We considered some parameters such as Packet Delivery Ratio (PDR), Overhead, Throughput, Delay end-to-end and SIR values, in order to choose an appropriate value for δ. We fixed the number of nodes and active connections to 50 and 10, the bitrate to 3Mbps, while varying the average speed in the range [5, 25] m/s.

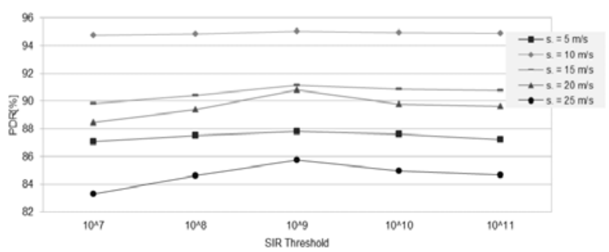

Figure 14. PDR for different values of δ.

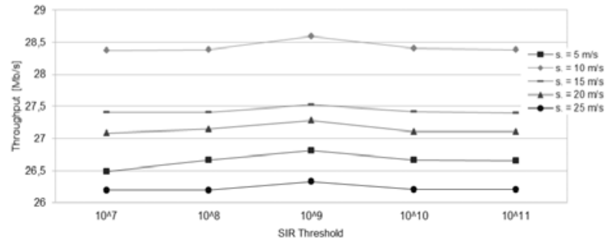

Figure 15. Aggregated throughput for different values of δ.

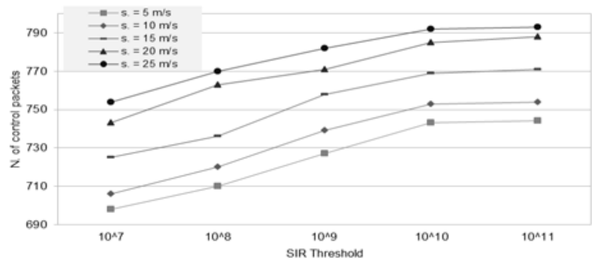

Figure 16. Protocol Control Messages for different values of δ.

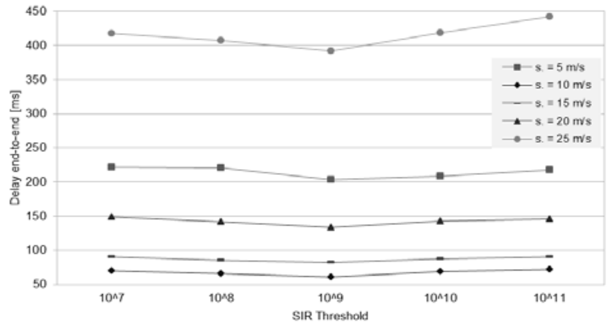

Figure 17. End-to-end delay for different values of δ.

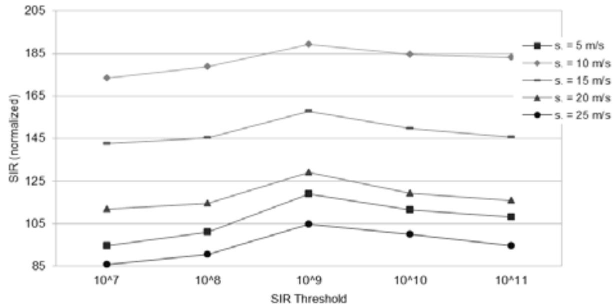

Figure 18. Average SIR on transmission channels for some values of δ.

From the figures above it can be observed that for an average nodes speed of 5, 20 and 25 m/s, worse performance is obtained because the speed is a parameter which strongly influences network topology and, consequently, the performance of the different characteristic parameters of the same network. In addition the value δ=10^9 has been chosen because better values of PDF, Throughput and SIR have been obtained, without introducing high network overhead.

IV. Performance Evaluation

The protocol proposed in Section III.B has been implemented in the NS2 simulator; first of all, the QoS MAC of IEEE802.11e was introduced and then it was extended in order to include all the functionalities of the multi-channel IEEE802.11p standard. Different classes were created or modified and a practical OTcl script was implemented in order to provide the opportunity of simulating different scenarios. The CityMob generator [15] was used to create Manhattan patterns, with the following parameters: map dimensions 1000m x 1000m, maximum vehicle speed 15 m/s, downtown area 400m x 400m. The path-loss was considered through eq.1, with γ=4, α=0.1 and h=1.5 m (these values are taken from [27]). The transmission rate was fixed at 3Mbps, and the number of mobile nodes varied from 20 to 80. Many simulation runs have been carried out in order to determine the optimal value of some simulation parameters. The number of concurrent connections varies from 2 to 10 but, due to space constraints, only results for 4 and 10 are shown (as in the captions of figures); Δ has been fixed to 60ms and δ has been fixed to 10^9: as shown before, the chosen values of Δ and δ led to the best results for the considered parameters. Also in this case, 100 runs with 2000s of simulated time each one have been carried out, fixing the confidence interval to 95%. The SIR-AODV protocol 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).

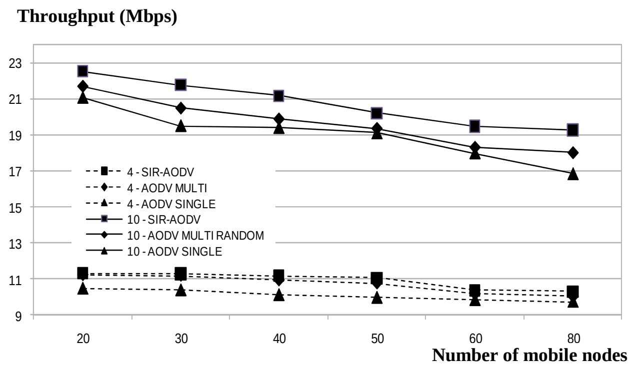

Figure 19. The average throughput (Mbps) for the simulated network.

Fig. 19 shows the average aggregated 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 numbers of mobile nodes. This is mostly due to the higher overhead burden, although the SIR-AODV outperforms the classical schemes AODV SINGLE/MULTI and a considerable gain (about 2Mbps) was obtained. If the number of connections is low, the system is under-utilized, while for a higher number of active connections the throughput is near the maximum achievable one. Fig. 20 shows how the protocols perform in terms of Packet Delivery Ratio (PDR): when the VANET accommodates a higher number of vehicles (so a higher number of concurrent connections), the PDR decreases independently of the adopted routing scheme but, also in this case, SIR-AODV obtains a better performance and an enhancement of about 8% is reached. Fig. 19 and Fig. 20 demonstrate how an interference-based metric can increase the performance of the system: collision/interference errors are reduced.

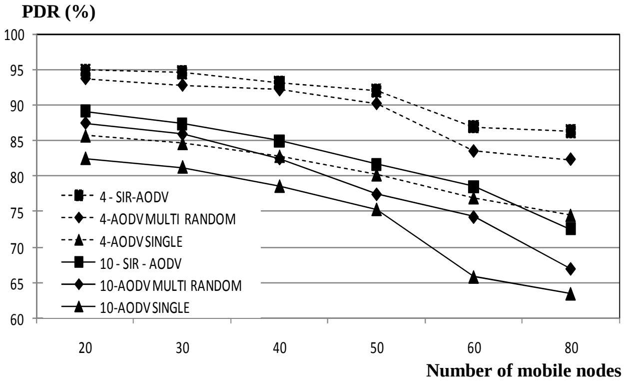

Figure 20. The average PDR for the simulated network.

The introduction of the periodical channel refresh leads to the exchange of CREQ and CREP messages as introduced in section III. Fig. 21 shows how the increasing of the SIR-AODV overhead (evaluated as the ratio between the number of signaling packets and the number of total packets) is negligible (near to 2%), when compared with traditional schemes. AODV SINGLE and MULTI have the same overhead performance because no new messages are introduced in the MULTI case, but only a random selection of a transmission channel.

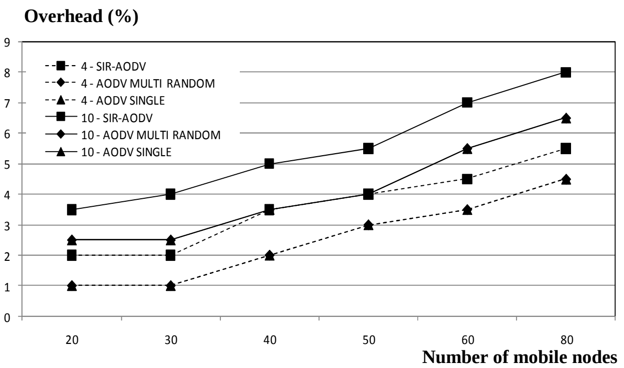

Figure 21. The average overhead of the SIR-AODV.

Fig. 22 illustrates the enhancement introduced in the average perceived SIR (evaluated as in eq. 2 and normalized to the value of 10^{10}) with the adoption of SIR-AODV. When traditional routing schemes are employed, the routing protocol acts by ignoring SIR levels and interference problems, so the values of normalized SIR (near to 0) illustrated in the figure are obtained. Clearly, SIR values increase for lower numbers of concurrent connections. The differences with the SIR-AODV are evident, although the trend decreases when the number of vehicles increases. When the number of nodes is higher, the number of available channels is limited (six in our case) so the interference cannot be heavily reduced.

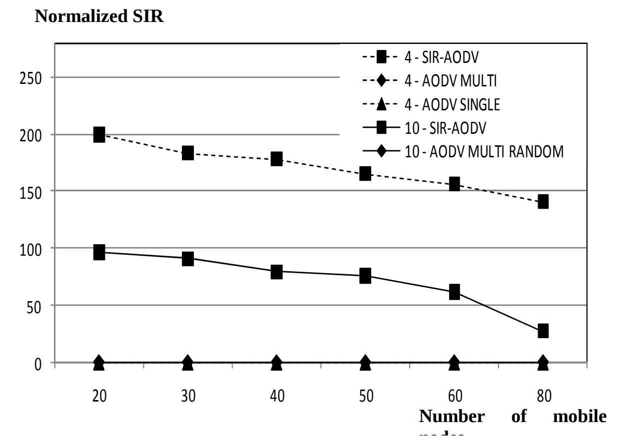

Figure 22. The average SIR perceived by mobile nodes.

V. CONCLUSIONS

A new routing protocol for VANET environments, SIR-AODV, has been proposed, based on the traditional signaling scheme of AODV. It takes advantage of a dynamic allocation of the DSRC spectrum, in order to reduce interference levels among nearby mobile nodes. A new metric based on the recurrent evaluation of the SIR level on the different links from sources towards destinations has been proposed; it gives the opportunity to choose next-hops in routing operations, depending on the best perceived SIR value on a link. An implementation for the NS2 simulator has been developed and vehicular mobility has also been taken into account. Simulation results have shown that there are good enhancements in terms of throughput, packet delivery ratio and normalized SIR. As future work, on the basis of the contributions given in [28] and [29], where a multi-objective metric is proposed for MANET in order to improve some network parameters (link stability and energy or minimum hop count and interference), an extended metric and route selection will be inserted in the proposed protocol in order to get advantage of the mobility model and to reduce the link breakage in an urban scenario.

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