A New Interference Aware On Demand Routing Protocol for 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. 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 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. In order to relieve the effects of the co-channel interference perceived by mobile nodes, transmission channels are switched on a basis of a periodical Signal-to-Interference Ratio (SIR) evaluation. The 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. 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 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.**

Keywords-Multi-channel routing, VANET, Interference Aware Routing, 802.11p, WAVE, DSRC, SIR.

I. INTRODUCTION

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 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, or GSM / UMTS. The Dedicated Short Range nets are refined in a very efficient version that will soon evolve into a communication standard IEEE 802.11p. 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 Quality of Service (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 the system performance. 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. 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 [5] 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; the proposed routing protocol aims 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. This paper is organized as follows: Section II introduces an in-depth overview on the related work about routing in VANETs; 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 discussion.

II. State of the Art and Related Works

There are many recent works in the literature on VANETs, focusing mostly 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. Proactive routing means that the routing information like 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 next hop node towards a destination. 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 destination. The behavior of the routing protocols is mainly triggered by events like timeouts and the reception of routing messages, and the impact that these events have on them is different. For instance, in AODV, which is a representative reactive routing protocol, timeouts have a great influence on the route establishment and maintenance process. 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. In [1] the authors evaluated the performance of OLSR and AODV in an urban environment, adopting the Vehicle Mobility Model to generate realistic mobility patterns. In [7,8], 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. Also, position-based routing protocols have been proposed in VANET-related literature. B. Karp et al. [12] 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. Traditional ad-hoc routing protocols have also been investigated [2] 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 [11] 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. More recently, Zhu and Corson [4] 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. [13] 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. The Distance Routing Effect Algorithm for Mobility (DREAM) framework [14] requires that each node has a database in which information about the location of all nodes in the network is inserted, consisting of information about distance and direction of the node and the instant at which the information was generated. Each node periodically floods the network with its position allowing other nodes to update their database. With the Quorum-Based Location Service [15] updates on nodes positions are sent only to a subset (quorum) of nodes in the network; similarly, requests for information are directed only to a quorum of nodes. As long as the intersection between the subsets is not empty, the service will be able to operate properly. The choice of the number of nodes in a quorum poses a trade-off issue because of the larger the number, the higher the cost of updates and requests, but the greater the quorums overlap. 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.

III. Vehicular Internetwoking Overview and Proposed Protocol

A. *Vehicular communications through VANET*

The IEEE 802.11p, also called Wireless Access in Vehicular Environments (WAVE) [9], is an extension of the IEEE 802.11 standards family for vehicular communications. It aims at providing the 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).

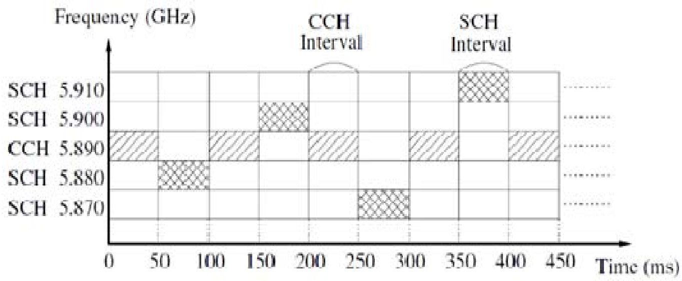

Figure 1. Direct Short Range Communication spectrum allocation.

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 a service channel every 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 Interval SCH Interval CCH 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 SCH's are for delivering data frames. One sees 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 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 64-subcarrier OFDM. 52 out of the 64 subcarriers are used for actual transmission consisting of 48 data subcarriers and 4 pilot subcarriers. 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. 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 timely and reliably even when operating in a dense urban scenario. 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.

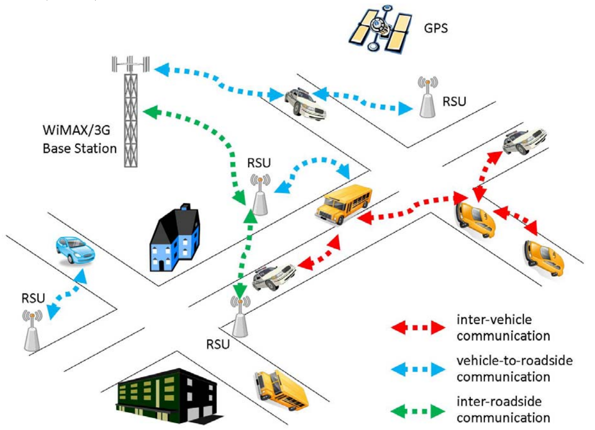

Figure 2. A typical urban VANET scenario.

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. Fig. 2 shows a typical VANET scenario. 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. 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.

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 [5], 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 it was 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 per node are allowed;
- Each node is equipped with a single interface (with multiple channels);
- Channel synchronization time is related to the signaling packets delivery delay, needed for channel switching among a couple of nodes;
- 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 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 VANET environments because channel coding and frequency interleaving make the bit error performance of an OFDM link in a frequency-selective channel depend more on the average received power than on the power of the weakest subcarrier [10]. 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 is [3]:

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

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:

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

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. 3 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.

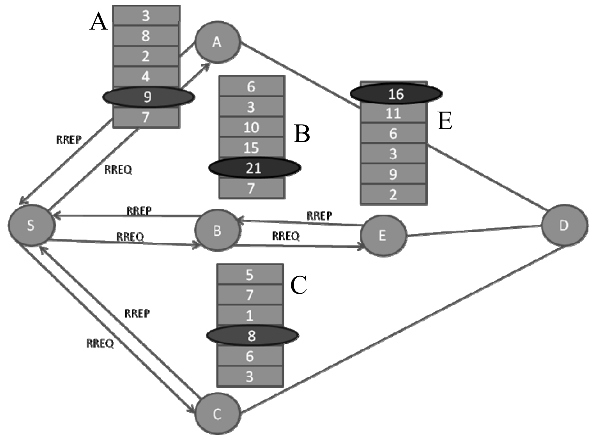

Figure 3. Path discovery procedure in SIR-AODV.

When node n_S receives these answers, it will decide to store in its routing table the next-hop n_B, since it has associated the highest SIR value. Once channels have been assigned, they need to be periodically refreshed in order to change the assignment if needed. Fig. 4 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 about the new channel; CREP contains the *ACK* field to acknowledge the switching on the new channel. A source node n_S which is unaware of the best path to destination n_D can initiate the path discovery procedure by sending a RREQ message to its neighbors.

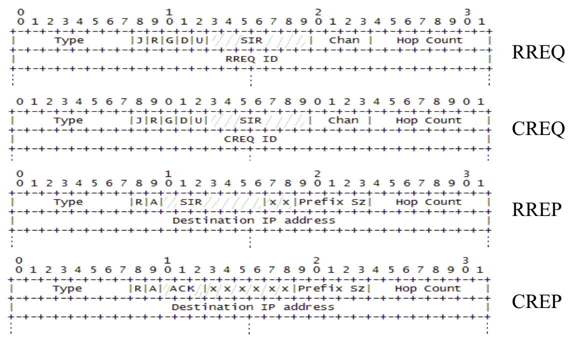

Figure 4. Signaling packets and fields in SIR-AODV.

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):

$$SIR^k{}_{MAX} = \max_i \{SIR^k{}_i\} \quad (3)$$

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 $P(n_k,n_D)= \{l_1,l_2,...,l_m\}$ is the best path, in terms of a list of links from n_K to n_D, SIR values on links l_i, $i=1...m$, are known since they have been evaluated through eq. 3. Thus, each intermediate node in the path discovery procedure knows the average SIR, denoted with SIR_{AVG_RREP}, which is evaluated as follows:

$$SIR_{AVG\_RREP} = \frac{\sum_{l=1}^{m} SIR^{k_l}{}_{MAX_l}}{m}, \quad (4)$$

where $SIR^{k_l}{}_{MAX_l}$ is the SIR evaluated on the *l-th* link (belonging to node n_{Kl}). In this way, each node has the knowledge about the average SIR towards a destination if a particular next-hop is chosen during forwarding operations.

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 has been introduced and then it has been extended in order to include all the functionalities of the multi-channel IEEE802.11p standard. Different classes (.h and .cc) have been created or modified (*mac_802_11e, aodv, aodv_packet, aodv_rtable, packet, interMod*) and a practical OTcl script has been implemented in order to have the opportunity of simulating different scenarios. The CityMob generator [6] has been used to create Manhattan patterns, with the following parameters: map dimensions 1000m x 1000m, maximum vehicle speed 15 m/s, number of damaged vehicles 3, downtown area 400m x 400m. The path-loss has been considered through eq.1, with γ=4, α=0.1 and h=1.5 m [3]. Transmission rate has been fixed at 3Mbps, and the number of mobile nodes varies 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: the chosen values of Δ and δ led to the best results for the considered parameters. 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). Fig. 5 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 number 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) has been obtained. If the number of connections is low, e.g. 4, the system is under-utilized, while for a higher number of active connections the throughput is near the maximum achievable one.

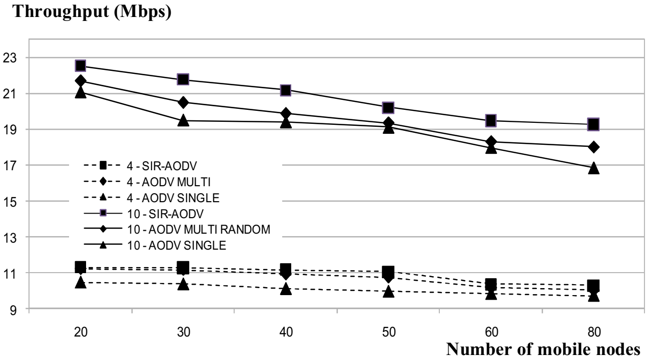

Figure 5. The average throughput (Mbps) for the simulated network.

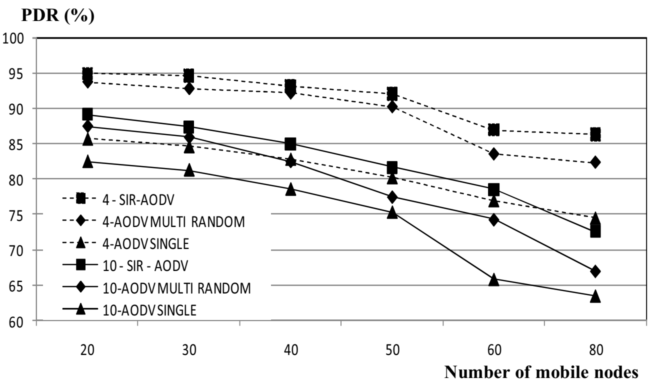

Figure 6. The average Packet Delivery Ratio (PDR) for the simulated network.

Fig. 6 shows how the protocols perform in terms of Packet Delivery Ratio (PDR): when the VANET accommodates a higher number of vehicles, as well as a higher number of concurrent connections, PDR decreases independently of the adopted routing scheme but, also in this case, the SIR-AODV has better performance and an enhancement of about 8% is reached. Fig. 5 and Fig. 6 demonstrate how an interference-based metric can increase the performance of the system: collisions and interference errors are heavily reduced.

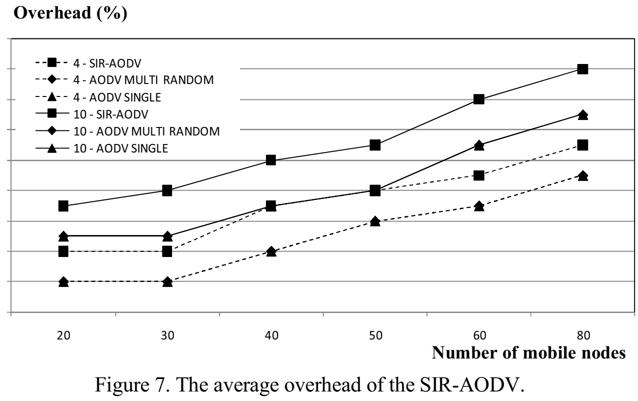

Figure 7. The average overhead of the SIR-AODV.

The introduction of the periodical channel refresh leads to the exchange of CREQ and CREP messages as introduced in section III. Fig. 7 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. It increases for higher number of connections number and mobile nodes. 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.

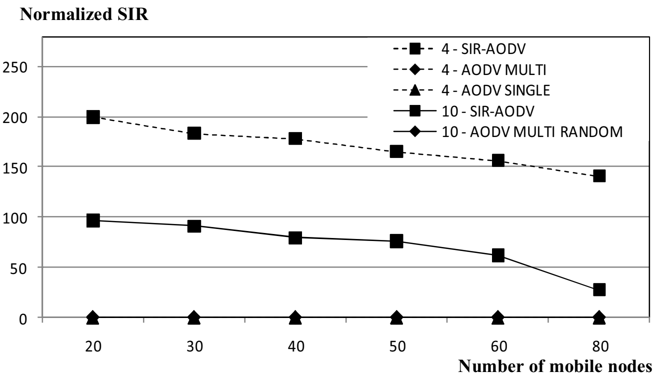

Figure 8. The average SIR perceived by mobile nodes.

Fig. 8 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 is decreasing when the number of vehicles increases. When the number of nodes is too high the number of available channels is limited (six in the considered case) so the interference cannot be heavily reduced.

V. CONCLUSIONS

A new routing protocol for VANET environments, SIR-AODV, has been proposed. It is based on the traditional signaling scheme of AODV, but 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 the next-hop in routing operations depending on the best perceived SIR value on the link. An implementation for the NS2 simulator has been developed, and vehicular mobility has also been taken into account. Despite of a negligible increase in terms of protocol overhead, simulation results have shown that there are good enhancements in terms of throughput, packet delivery ratio and normalized SIR.

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