SUBMITTED VERSION

Multi-Channel Multi-Objective Routing Metric for Vehicular Ad-Hoc Networks

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Abstract Nowadays, distributed mobile wireless computing is becoming a very important communications paradigm, due to its flexibility to adapt to different mobile applications. Routing operations assume a crucial importance in system optimization, especially when considering dense urban areas, where interference effects cannot be neglected. The implementation of new routing protocols becomes challenging in Vehicular Ad-Hoc NETworks (VANETs) so, at this aim, we propose a vehicular routing scheme in which the available channels are managed for optimizing a considered composite metric for multi-channel transmissions, which takes into account different parameters (multi-objective). Network Simulator 2 (NS2) has been employed to validate the Multi-Channel Multi-Objective Distance Vector (MCMO-DV), showing how it outperforms classical approaches in terms of throughput, packet delivery ratio, and overhead.

1. Introduction

In the last years, many efforts have been made in the mobile computing research field; in particular, the IEEE 802.11 standard completely dominates the market. In wireless networks, nodes are free to move randomly and organize themselves arbitrarily; thus, network topology may change rapidly and unpredictably. VANETs provide wireless communication among vehicles and vehicle-to-Road-Side-Units (RSU) equipments. RSU construct the infrastructure of the VANETs using wired and wireless communications among each other. Communication performance strongly depends on how the routing takes place in the network: the existing routing protocols for VANETs are not so efficient to meet the needing of every traffic scenario, since the high degree of mobility and propagation phenomena have a high impact on system performance. In this paper, the multichannel characteristic of VANET devices is considered, in order to improve system performance in terms of routing optimization. In fact, in a distributed multi-hop architecture, a mobile node may potentially find multiple routes for a given destination and, when it evaluates the network topology through its routing table, the availability of different channels may enhance the quality of communication if properly exploited. The main aim of this work is to introduce this feature when considering classical routing metrics. In detail, a new routing protocol for interference reduction and link-duration enhancement is proposed for VANET environments, taking the advantage of a dynamic allocation of the Dedicated Short Range Communications (DSRC) spectrum, in order to reduce interference level among mobile nodes and to increase the overall link stability in the considered network. The proposed scheme can be integrated with different already-implemented routing protocols and its metric take into account the best values of Inter-Channel Interference (*ICI*), Link Duration Probability (LD_{PROB}) and Hop Count (H_{CNT}). So, MCMO-DV aims at choosing different channels along the path from a source to a destination, obtaining a global metric minimization for the considered connection. This paper is organized as follows: Section 2 presents an in-depth overview on state-of-the-art routing in VANET; Section 3 offers a deep description of the proposed idea, then Section 4 shows the obtained results. Finally, Section 5 concludes the paper.

2. Related work

In literature for VANETs many authors have proposed some routing schemes, but most of them lack the employment of the multichannel availability of mobile devices. In [1], DIR protocol constructs a series of diagonal intersections between the source and destination vehicle. The DIR protocol is based upon the geographic routing protocol in which source vehicle geographically forwards the data packets towards the first diagonal intersection, second diagonal intersection and so on until the last diagonal intersection and finally geographically reaches to designation vehicle. In [2] the authors proposed the ROMSGP algorithm. It is an integration of the receive on most stable path (ROMSP), with the grouping of nodes according to their velocity vectors, as previously demonstrated, with certain modifications to suit it to the VANET scenario. For example, the non-disjoint nature of ROMSP is not considered due to the strict mobility pattern of VANET networks The effects of mobility are also considered in [3], in which a new metric is introduced in order to proactively adapt to a constantly changing topology. The scheme proposed by Sofra et al. considers the life-time of a link and the forwarding operation is carried-out on the basis of how much a link can be considered stable during routing operations. Link duration is evaluated by a precise mobility model, able to capture the trend of link degradation fluctuations. The authors have shown how introducing some fragmentation approaches, network performance can be improved, also in terms of delivery ratio. In our previous works [4], [5], [6], [7],[8] an enhancement of On-demand Distance Vector protocol has been proposed, in terms of metric optimization. In particular it has been modified in order to take consideration of the availability of different transmission channels with an integrated metric, which takes into account the interference level over the different channels. In particular, it allows the management of the multi-channel capability of the WAVE standard at the routing layer through a higher-level channel selection, which is based on a interference-aware algorithm.

3. Problem statement and proposed protocol scheme

This paper focuses its attention on the enhancement of routing operations in VANETs, taking into consideration both neighbors' interference level and link duration, in addition to classical hop-count term. The proposed idea, called Multi-Channel Multi-Objective Distance Vector (MCMO-DV), is general and does not depend on the considered routing protocol. It can be integrated with the majority part of existing routing protocols and it is based on analysis of interference dynamics for choosing an appropriate transmission channel in order to minimize the interference; periodical refresh, in order to evaluate the updated interference value available on each channel; definition of Link Duration Probability (LDP), in order to choose more stable paths; transmission of synchronization packets in order to advise the receiving node of a new channel selection.

We consider a vehicular scenario in which each node participates to routing operations as in classical ad-hoc networks. Let us consider the VANET topology illustrated in Fig. 1. Let $V=\{v_1,\ldots,v_n\}$ be the set of vehicles (vehicular nodes or vertex) in the network, with $||V||=n$ and $E=\{e_1,\ldots e_m\}$ be the set of direct peer-to-peer links, with $||E||=m$ and $e_k=(v_h,v_k)$, $v_h,v_k\in V$. Let $CHAN=\{c_1,\ldots c_p\}$ be the set of available channels in DSRC spectrum, with $||CHAN||=p$. A path discovery phase is initiated each time a source node $v_i\in V$ needs to transmit to a destination node $v_j\in V$.

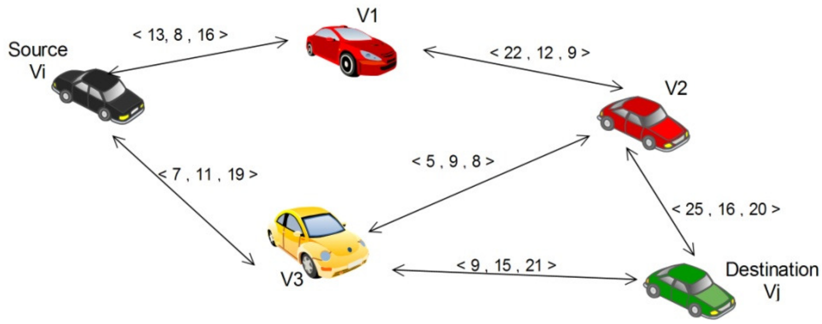

Fig. 1. An example of a typical VANET scenario.

Our proposed protocol scheme aims at finding the best path in terms of interference, hop-count and link-duration (for example v_i-v_2-v_4-v_6-v_j), basing the choice of next-hops on a new defined metric. We hypothesize that:

– When a new node enters into the network it discovers its neighbors by broadcasting HELLO messages;

- The source node initiates the path-discovery phase by broadcasting a Route REQuest (RREQ) packet to its neighbors; if a neighbor has a route to the desired destination, then it sends a Route REPly (RREP) back to the source; otherwise the RREQ is forwarded again;
- All the nodes transmit at the same power level P_t, independently on the chosen channel and each node knows the power level of the received signal on each available channel.

When dealing with wireless communications (especially in vehicular environments), classical metrics become inadequate, since they do not consider all the negative effects that are present when paths from sources to destinations are built. If only the hop-count is considered, the obtained paths may suffer huge interference levels and/or short duration and, on the contrary, minimizing the interference may bring the considered protocol to obtain longer paths with scarce duration. In [3] and [4] the importance of link-duration and link-interference has been remarked, so we propose a new multi-objective metric that takes into consideration interference, link-duration and hop count parameters.

3.1 The main terms of MCMO-DV

This work focuses the attention on the proposal of a new multi-objective metric which combines inter-channel interference, link-duration probability and hop-count parameters. We are not interested now on how protocol signaling packets should be changed in order to take into account the new concepts; the main attention, instead, is focused on the definition of the key elements of a new metric. Each node $v_i \in V$ has to evaluate the metric related to each possible next-hop, so the terms are now defined.

3.1.1 The Hop CouNT (H_{CNT}) term

This is the classical term, used in the majority part of routing protocols. It simply counts the number of hops that belong to a particular path. If $Path_V(v_i,v_j)=\{v_i, v_2, v_3, \ldots, v_{p-2}, v_{p-1}, v_j\}$ with $||Path_V(v_i,v_j)||=p_{i,j}$ is a path (expressed in terms of vertex) from v_i to v_j, then each node $v_k \in Path_V(v_i,v_j)$ knows the hop-count toward v_j on $Path_V(v_i,v_j)$; in particular, node v_i will know the H_{CNT} on $Path_V(v_i,v_j)$, which can be expressed as:

$$H_{CNT}[Path_V(v_i,v_j)] = ||Path_V(v_i,v_j)|| = p_{i,j} \tag{1}$$

3.1.2 The Link Duration Probability (LDP) term

This is the term that takes into account the reliability of a link in terms of duration. If $Path_E(v_i,v_j)=\{(v_i,v_2),(v_2,v_3), \ldots, (v_{q-2},v_{q-1}),(v_{q-1},v_j)\}=\{e_1,\ldots,e_q\}$ with

$||Path_E(v_i,v_j)||=q_{i,j}$ is a path (expressed in terms of edges) from v_i to v_j, with $e_k \in E$ then, for each edge e_k, involving the couple of nodes on the link (v_h, v_k), it can be written as in [9].

At this point, the sensitivity of the receiver can be defined though a threshold of the attenuation level β_{th}, that is to say a link among a couple of VANET nodes on the edge e_k is still valid if $\beta^{e_k} \leq \beta_{th}$ and the probability of this event can be written as [9]:

$$P(\beta^{e_k} \leq \beta_{th}) = \frac{1}{2} + \frac{1}{2} erf\left(\frac{\beta_{th} - \alpha 10 \log\left(\frac{avg_s \cdot \tau}{L} \right)}{\sqrt{2}\sigma} \right) = LD_{PROB}(e_k) = LD_{PROB}[(v_h, v_k)] \quad (5)$$

Given $Path_E(v_i,v_j)$, then the link-duration probability on a path, $LD_{PROB}[Path_E(v_i,v_j)]$, can be evaluated as:

$$LD_{PROB}[Path_E(v_i,v_j)] = \prod_{k=1}^{q_{i,j}} LD_{PROB}(e_k), \quad \forall e_k \in Path_E(v_i,v_j) \quad (6)$$

3.1.3 The Inter-Channel Interference (ICI) term

The interference contribution is derived from the expression of the received power, for all the available channels. It strictly depends on the transmission power and radio propagation phenomena. Using the theory of [10], [11] for DSRC channels, it can be written that:

$$P_{loss}(v_i,v_j) = 40 \cdot \log(d_{ij}) - [10 \cdot \log(G_t) + 10 \cdot \log(G_r) + 20 \cdot \log(h_t) + 20 \cdot \log(h_r)] \quad (7)$$

which indicates the loss in signal strength (in dB) among the couple of nodes $v_i,v_j \in V$. The terms G_t and G_r are the *TX* and *RX* antenna gains respectively, while h_t and h_r are the *TX* and *RX* antenna heights. From eq. 7, the expression of the received signal strength (in dB) by node v_i, for the signal transmitted by node v_j, on channel $c_l \in CHAN$ can be easily written as follows:

$$P_r(v_i,v_j,c_l) = P_t - P_{loss}(v_i,v_j) \quad (8)$$

where P_t is the transmission power (the same for each node on each channel). In real environments, the value of P_r can be easily evaluated via *HW*, but for our simulation purposes, the expression of eq. 8 is very suitable. It can be used for accounting path-loss effects, that 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. From the value of eq. 8, the expression of the ICI term for node v_i on channel c_l is obtained as follows:

$$ICI(v_i, c_l) = \sum_{j}^{|adjacents(v_i)|} P_r(v_i, v_j, c_l) \tag{9}$$

where *adjacent*(v_i) is the set of nodes adjacent to v_i. At this point, each node v_i can evaluate the best value of ICI associated to a particular channel:

$$ICI_{MIN}(v_i) = \min_{c_l \in CHAN} \{ICI(v_i, c_l)\}, \quad c_{l_{MIN}}(v_i) = index\left\{\min_{c_l}\left(ICI(v_i, c_l)\right)\right\} \tag{10}$$

3.1.4 The proposed scheme for routing in VANETs

As in the previous sub-sections, let us hypothesize that node v_i has to transmit data to node v_j (v_i, $v_j \in V$) and the considered routing protocol allows the utilization of *RREQ-RREP* mechanism to discover all the available paths from v_i to v_j. When a *RREQ* packet is forwarded by an intermediary node $v_I \in V$ which participates to routing operations, the information about $ICI_{MIN}(v_I)$ evaluated in eq. 10 is inserted into the message. When a *RREP* is created by an intermediary node $v_I \in V$, which has knowledge of a path towards destination, the value of the H_{CNT} is appended into the packet (our attention is not focused now on how a packet is modified in order to give each node the knowledge of the considered parameters), giving to the previous hop, indicated with v_{I-1}, the knowledge of ICI_{MIN} and H_{CNT}. Thus, through the exchange of *RREQ* and *RREP* messages, a set of paths P from v_i to v_j is discovered and, for each of them, the source node can evaluate the hop-count $H_{CNT}=p_{i,j}$ (from eq. 1), the average ICI_{MIN}, denoted with $\underline{ICI}_{MIN}$, and the average probability of path duration, denoted with $\underline{LD}_{PROB}[Path_E(v_i,v_j)]$:

$$\underline{ICI}_{MIN}\left[P_V(v_i, v_j)\right] = \frac{\sum_{v_I \in P_V(v_i, v_j)} ICI_{MIN}(v_I)}{p_{i,j}}, \quad \underline{LD}_{PROB}\left[P_E(v_i, v_j)\right] = \min_{e_k \in P_E(v_i, v_j)} P\left(\beta^{e_k} \le \beta_{th}\right) \tag{11}$$

where $ICI_{MIN}(v_I)$ is the *ICI* value obtained through eq. 10 for the intermediate node v_I. Eq. 12 shows that $\underline{LD}_{PROB}$ is evaluated on $P_E(v_i,v_j)$ by considering the minimum probability, which represents the bottleneck of $P_E(v_i,v_j)$ in terms of link duration. After the node v_i received all the RREPs from its neighbors, it knows the set of paths P toward v_j and all the related values of H_{CNT}, *ICI* and LD_{PROB}, through the expressions of eq. 1, 11. At this point the metric for the MCMO-DV has to be defined adequately, as a multi-objective function:

$$m_{\substack{MCMO-DV \\ p \in P}} = \gamma_1 \cdot m_{H_{CNT}}(p) + \gamma_2 \cdot m_{ICI}(p) + \gamma_3 \cdot m_{LD_{PROB}}(p) \tag{12}$$

where $m_{H_{CNT}}$, m_{ICI} and m_{LDPROB} are three normalized terms related to the expression of the parameters, defined by using the following definitions:

$$ICI_{MAX} = \max_{Path_V(v_i,v_j)\in P}\{ICI[Path_V(v_i,v_j)]\}\ ,\ H_{CNT_{MAX}} = \max_{Path_V(v_i,v_j)\in P}\{H_{CNT}\lfloor Path_V(v_i,v_j)\rfloor\} \quad (13)$$

$$LD_{PROB_{MAX}} = \max_{Path_V(v_i,v_j)\in P}\{LD_{PROB}\lfloor Path_E(v_i,v_j)\rfloor\} \quad (14)$$

So, the terms m_{HCNT}, m_{ICI} and m_{LDPROB} in eq. 12 can be rewritten as follows:

$$m_{\substack{MCMO-DV\\ p\in P}} = \gamma_1 \frac{ICI_{MIN}(p)}{ICI_{MAX}} + \gamma_2 \frac{H_{CNT}(p)}{H_{CNT_{MAX}}} + \gamma_3 \left(1 - \frac{LD_{PROB}(p)}{LD_{PROB_{MAX}}}\right) \quad (15)$$

where the terms in the metric have been normalized, in order to be comparable. At this point, when node v_i has to choose among different paths to destination in the set P, it chooses the one for which:

$$m_{\substack{MCMO-DV\\ p^*\in P}} = \min_{p\in P}\left(m_{\substack{MCMO-DV\\ p\in P}}\right) \quad (16)$$

The proposed protocol, now, has three degrees of freedom (γ_1 called *ICI* weight, γ_2 called *HC* weight and γ_3 called *LDP* weight), which have to be set adequately. Next section shows some considerations about them. Before observing performance evaluation, it must be said that, due to the presence of mobility and wireless phenomena, some degradations are dynamically introduced into the system so, once the optimal channels have been chosen for data transmission, they have to be checked and refreshed each Δ amount of time, verifying if some better conditions (in terms of channels and paths) exist. If a change is needed, a node, which is aware of new channels conditions, sends a Change-REQuest packet (CREQ) to its neighbor, then waits for the acknowledgement Change-REPly (CREP).

4. Performance evaluation

NS-2 has been used to integrate the proposed idea with different existing protocols. An example on how the signaling packets are changed in order to take into account the additional fields can be found in [4]. The C4R mobility generator, which represents a powerful extension of [12] with a user-friendly GUI, has been used to create mobility log-files. Differently from [13], we are not considering only a Manhattan scenario, but different urban scenarios have been taken into account, in order to deal with more effective maps: without loss of generality, we illustrate the results obtained for the centre of Rome. We considered a transmission rate of 3Mbps. The optimal values of some simulation parameters have been determined through different campaigns of simulation: the number of concurrent connections has been fixed to 15, Δ has been fixed to 60ms, while the values of γ_i have been chosen by considering the following figures. In particular a first addicted campaign of simulations has been carried out, with a number of network nodes equals to 50, in order to evaluate protocol performance (in terms of Packet Delivery Ratio PDR and Throughput) by considering different values for γ_i belonging to the set of values {0.2, 0.4, 0.6, 0.8}.It is demonstrated that, fixing the values of γ_2, there are some values of γ_1 and γ_3 that lead to maximum values on the surfaces. So, it can be concluded that if a higher weight is given to the Interference term and to the link duration probability (γ_1=0.2 γ_2=0.4 γ_3=0.8), then the system will observe a higher percentage of correctly delivered packets. Likewise the average system throughput, an optimal value can be obtained for the configuration $\gamma_1=0.2$, $\gamma_2=0.4$, $\gamma_3=0.8$, for which the maximum performance is obtained. The figures are not shown due to space limitations. At this point, the $m_{MCMO\text{-}DV}$ metric is completely defined and it can be used to evaluate the performance of the proposed protocol scheme. We compared the MCMO-DV scheme to AODV single (only one transmission channel is used as in the traditional definition), AODV multi (multiple transmission channels are chosen randomly), GPSR and OLSR (both with a single transmission channel). Simulation parameters are the same of the previous campaign, but in this case the number of mobile vehicles varies from 40 to 100. From Fig. 2 and Fig. 3, it can be noticed how the MCMO-DV outperforms the other protocols in terms of PDR and Aggregated Throughput (the sum of the throughputs of all connections): introducing a composite metric, interference level and link duration are taken into account, so more stable paths are chosen, reducing the probability of packet loss and retransmissions. So, this is evident when considering the percentage of correctly delivered packets and system throughput.

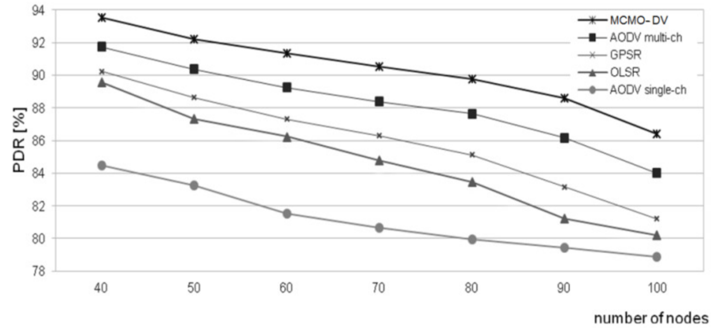

Fig. 2. Average PDR vs the number of mobile nodes.

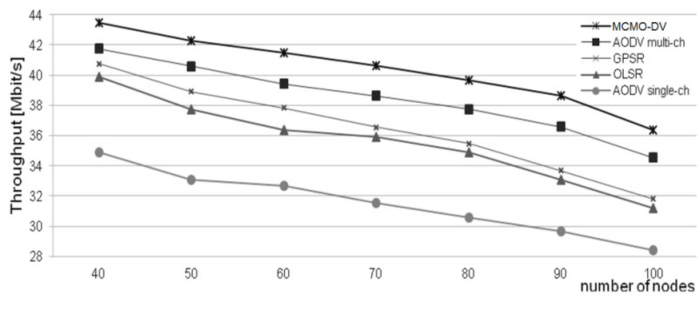

Fig. 3. Average Aggregated Throughput vs the number of mobile nodes.

Referring to the overhead performance, as illustrated in Fig.4, the MCMO-DV protocol performs slightly worse than the other ones, because of the new signaling packets that are introduced into the network traffic for the construction of alternative paths; the difference on the number of transmission channels for AODV schemes is not evident because protocol messages remain unmodified: no new messages are introduced in the AODV Multi-channel case, but only a random selection of a transmission channel.

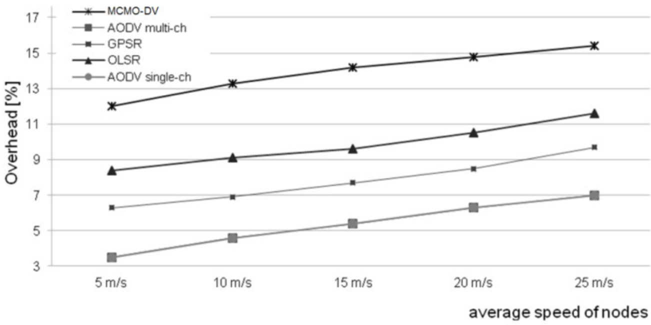

Fig. 4. Overhead vs the number of mobile nodes.

5. Conclusions

In this work a new scheme for routing in VANETs, dedicated to the optimization of path-length, interference level and link duration is proposed. It is based on a dynamic allocation mechanism of the DSRC spectrum, aimed at the reduction of the inter-channel interference and maximization of link duration, two key issues in vehicular environments. A new composite multi-objective metric, based on the evaluation of interference levels, path lengths and link duration 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 classical protocols performance in terms of throughput and packet delivery ratio, despite of a slight increase in protocol overhead and delay.

Acknowledgement

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