Vehicular Networking Enhancement And Multi-Channel Routing Optimization, Based on Multi-Objective Metric and Minimum Spanning Tree

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Abstract. *Vehicular Ad hoc NETworks (VANETs) represent a particular mobile technology that permits the communication among vehicles, offering security and comfort. Nowadays, distributed mobile wireless computing is becoming a very important communications paradigm, due to its flexibility to adapt to different mobile applications. VANETs are a practical example of data exchanging among real mobile nodes. To enable communications within an ad-hoc network, characterized by continuous node movements, routing protocols are needed to react to frequent changes in network topology. In this paper, the attention is focused mainly on the network layer of VANETs, proposing a novel approach to reduce the interference level during mobile transmission, based on the multi-channel nature of IEEE 802.11p (1609.4) standard. In this work a new routing protocol based on Distance Vector algorithm is presented to reduce the delay end to end and to increase packet delivery ratio (PDR) and throughput in VANETs. A new metric is also proposed, based on the maximization of the average Signal-to-Interference Ratio (SIR) level and the link duration probability between two VANET nodes. 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 SIR evaluation. A Network Simulator has been used for implementing and testing the proposed idea.*

Keywords

End-2-end delay, interference, link duration, multi-channel, routing, spanning tree, VANET, vehicular.

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. 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. Using vehicles to construct mobile networks can improve the quality of wireless communications and offer some kinds of entertainment during the trip. In fact, these networks aim 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. VANETs provide wireless communication among vehicles and vehicle-to-road-side equipments. The roadside units can construct the infrastructure of the vehicular networks using wired and wireless communications among each other, as illustrated in Fig. 1. 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 VANET 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 so called Quality of Service (QoS), for example in VoIP-based traffic applications as in [1], [2] and routing in multi-hop wireless networks are very challenging due to the high grade of mobility that causes interferences among different transmissions, but VANETs offer the chance to reduce them, since multiple simultaneous transmissions (on different channels) are possible. 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 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. In this paper a new interference-aware routing protocol for VANET environments is proposed, the new metric take into account the best values of Signal-to-Interference Ratio (SIR), end-2-end (e2e) Delay and Link Duration Probability (LDP).

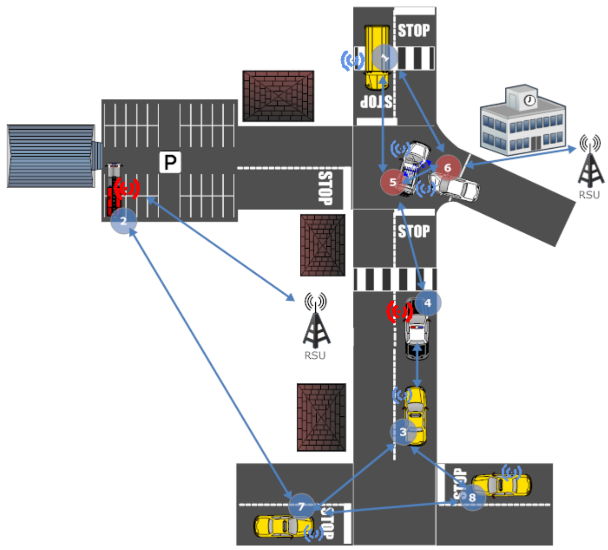

Fig. 1: Possible application scenario for VANET.

2. Related Work

There are many studies in literature about routing over VANETs , investigating classical approaches, like AODV, DSR, GPSR, etc., and several routing protocols have been defined by many researchers. In [3] Distribution-Adaptive Distance with Channel Quality (DADCQ) protocol has been proposed and that utilizes the distance method to select forwarding nodes. In this work, authors created a decision threshold function that is simultaneously adaptive to the number of neighbors, the node clustering factor and the Rician fading parameter. In [4] a two-level trajectory based routing called TTBR has been proposed in order to face the issue of protocol scalability and the reduction of routing overhead. Two joint geographic routing schemes for long range and short range forwarding have been adopted to improve the routing scheme under Manhattan and Freeway environment. Routing issues has been also considered in [5], [6], where DTN scenario has been studied, at the aim of minimizing energy consumption for the optimization of network layer operations. In [7] a novel multichannel TDMA MAC protocol (VeMAC) has been proposed for a Vanet Scenario. The VeMAC supports efficient one-hop and multi-hop broadcast services on the control channel by using implicit acknowledgments and eliminating the hidden terminal problem. The protocol reduces transmission collisions due to node mobility on the control channel by assigning disjoint sets of time slots to vehicles moving in opposite directions and to road side units. In [8] a contextual cooperative congestion control policy that exploits the traffic context information of each vehicle has been proposed to reduce the channel load and load on the communications channel, this is done satisfying the strict application's reliability requirements. In [9], [10], we propose a novel preliminary interference-aware algorithm for VANET environments able to optimize the paths from sources to destinations in terms of interference, by introducing a new routing protocol; however, time variations of SIR are not taken into account. This work represents an extension of [11] and [12] with the addition of parameters in the new metric of the proposed protocol.

3. Vehicular Networks and Routing Decisions

There has been a lot of research to obtain the IEEE 802.11p standard, which specifies the technology suitable for vehicular communication networks.

3.1. Standard Overview

The IEEE 802.11p standard specifies the technology suitable for vehicular communication networks. It is an amendment to the IEEE 802.11-2007 standard. Within this amendment, a new operational mode, called Wireless Access in Vehicular Environments (WAVE) [13], is defined to enable communication among high-speed vehicles or between a vehicle and a stationary roadside infrastructure network. 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: one Control Channel (CCH) and six Service Channels (SCH), each of them occupying 10 MHz of bandwidth. A mobile/stationary station switches its channel between the control channel and one of the service channels each channel interval. VANET provides wireless communication among vehicles and vehicle-to-road-side equipments. 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, as shown in Fig. 2. Each station continuously alternates between the Control Channel (CCH) and one of the Service Channels (SCHs). The MAC layer in WAVE is equivalent to the IEEE 802.11e Enhanced Distributed Channel Access (EDCA) Quality of Service (QoS) extension. 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.

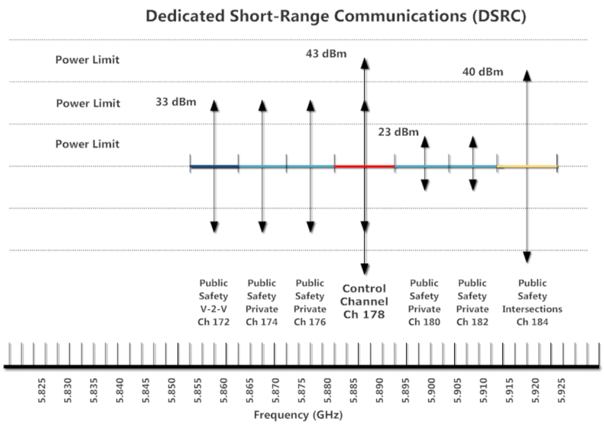

Fig. 2: Multi-channel EDCA extension for WAVE specifications.

3.2. Routing Issues

The proposed solution works in a distributed manner and exploits protocol messages to perform routing decisions and to update the routing table entries. This approach needs more time than a centralized approach to reach a stable routing path, but it is possible initiate session faster. In fact, some paths could be change during sessions for several reasons. In the transitory period some paths can change because in the routing tables are not presenting the right or complete network configuration.

3.3. Protocol Overview

VANET Adaptive Routing Optimization (VARO) is a distributed protocol and it works like the AODV protocol. In particular, a node of the network sends a neighbour discovery message to know its neighbours. The neighbour answers to this message sending its id and its routing table information. In this way, the node that sends neighbour discovery receives several messages from its neighbours, having the chance to build its own routing table. Once nodes change its routing table, it propagates changes to its neighbours. In order to maintain the presence of the node as neighbour, a node has to receive an alive message from its neighbours. If a node does not receive an alive message until 3-times the "alive period" then it erases the entry related to the neighbour from its routing table and propagates this information to its neighbour. When a new path is coming from a neighbour, the node checks if it has the entry related to the destination. If it is not present, then new path is inserted into the routing table, otherwise the node performs a routing decision algorithm, taking into account three different metrics, which will be faced in further sections of this work, to perform the update of the routing table. In order to maintain updated information about network topology, nodes exchange also messages about links information, such as end-to-end delay, LDP and SIR. This knowledge is used to perform the routing decision algorithm when multiple paths are available to reach a destination. Figure 3 resumes the main steps of the discovery process. The routing algorithm can be viewed as a linear optimization problem and its formulation is presented into the next section.

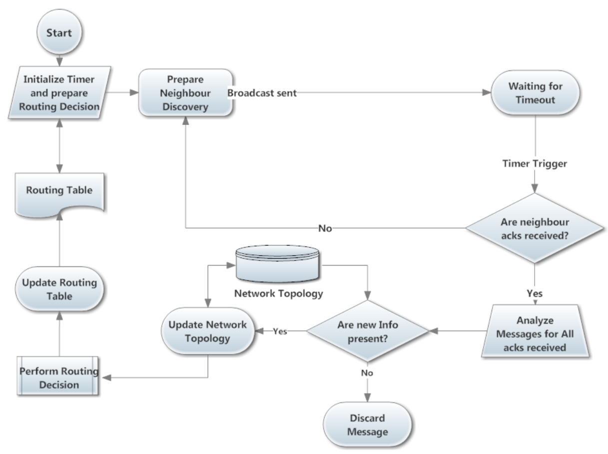

Fig. 3: Flow chart of neighbours discovery process.

3.4. Linear Optimization

In order to present the linear optimization problems, it is convenient to recall some key concepts about the Graph Theory and its analytic representation. A generic graph can be presented as $G(V, E)$, where V is the set of nodes that compose the graph and E is the set of edges. Three terms are associated to each edge:

- $\delta_{i,j}$ is the term related to the delay along the link that connect a node (i) with a neighbor (j),
- $\gamma_{i,j}$ is the term related to the SIR among the node (i) and a neighbor node (j),
- $\varsigma_{i,j}$ is the term related to the Link Duration Probability (LDP) among the node (i) and a neighbor node (j).

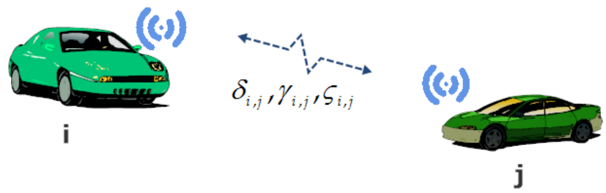

Fig. 4: An example of a generic link and its related weights between two generic node (i, j).

Once a source node $s \in V$ is chosen, it is possible to define a set s and a set D, composed of all remaining nodes, which is defined as shown in Eq. (1):

$$D = V - S = \bigcup_{i=1}^{n} V_i \mid i \neq s. \tag{1}$$

V is the full set of nodes that composes the vehicular network therefore:

- $n = |V|$; $z = |D|$.

Given a source node s the related Tree (T_s) is defined as $T_s = G(V_T, E_T) \subset G(V, E)$ in particular:

- $V_T = V = S \cup D \mid S \cap D = \emptyset$,
- $E_T \subset E$.

Given a Tree (T) it is possible to define a Path between node s and other nodes. Therefore:

- $\forall_{j=1}^{Z} d_j \in D_T \; \exists$ Path $(s, d_j)_T \subset V_T$,
- $m_j = |$ Path$(s, d_j)_T$ $|$.

Hence, m_j is the number of the nodes (HOPs) that a generic packet has to pass through to go from node s to node d_j.

1) Constraints Definition

Let us define the SIR contribute as:

$$\gamma_{i,j} = \frac{Ptx_{i,j}}{\sum_{k=1}^{Nch} Prx(i)_{j,k}}. \tag{2}$$

Where:

- *Nch* is number of the available channels to transmit the data packets between two neighbor nodes,
- $Ptx_{j,k}$ is the transmitted power between nodes (i) and node (j),
- $Prx(i)_{j,k}$ is the received measured power from neighbor node (j) to node (i) on the channel k.

The concept of End-to-End delay between two nodes can be described as in Eq. (3). Here the source node is the radix of the tree; instead, the destination node is one of the nodes that belong to the set D. However, the cumulative delay is carrying out considering each edge that belongs to the path between the source (s) and the considered destination (d).

The LDP on a generic path between tree source (s) and a generic destination (d) is presented in Eq. (4) for more details see at [14]:

2) Minimum Spanning Tree (MST)

Considering QoS constraints, it is possible to define the Minimum Spanning Tree (MST), modeling our issue as an optimization problem:

- $Min_{x \in X} \; F(x)$,

subject to:

- $Max_{j=1}^{z} \left\{ \sum_{k=1}^{m_j - 1} \Delta_{k,k+1} \mid k \in \text{Path}(s, d_j) \right\} \leq \Phi$,
- $Min_{j=1}^{z} \left\{ \forall_{k=1}^{m_j - 1} \gamma_{k,k+1} \mid k \in \text{Path}(s, d_j) \right\} \leq \Psi$,
- $Max_{j=1}^{z} \left\{ \forall_{k=1}^{m_j - 1} \zeta_{k,k+1} \mid k \in \text{Path}(s, d_j) \right\} \leq \Gamma$,

where the Φ, Ψ and Γ are the delay, SIR and LDP bounds respectively, $x \in X$ represent the Paths between the source node and destinations set along the tree T_x, while X is the set of all available Trees. Moreover, $f(x)$ is the objective function to minimize.

$$f(x) = C_\delta \cdot g(x) + C_\gamma \cdot h(x) + C_\zeta \cdot t(x). \tag{5}$$

$$\Delta_{s,d_j} = \sum_{k=1}^{m_j-1} \delta_{k,k+1} \mid s \in S, d_j \in D, k \in \text{Path}(s,d_j)_T. \tag{3}$$

$$\varsigma_{s,d_j} = \frac{1}{2} \cdot \prod_{k=1}^{m_j-1} \left[1 + erf\left(\frac{\beta_{th}(k,k+1) - \alpha \log\left(\frac{\upsilon_{k,k+1} \cdot \tau_{k,k+1}}{L}\right)}{\sqrt{2} \cdot \sigma} \right) \right]. \tag{4}$$

In Eq. (5) the *g(x)* is the scalar evaluation of the delay along the path in *Tx*, *h(x)* is the scalar evaluation of the SIR along the path in T_x and at last the *t(x)* is the scalar evaluation of the LDP along the path in T_x. The C_δ, C_γ, C_ζ is the set of the scalar weight costs related to delay, SIR and LDP function respectively. These weight costs have to be greater than zero, commonly, the above weight costs are set to one.

4. Performance Evaluation

The protocol proposed in Section 3.2 has been implemented in the NS2 simulator; first of all, the QoS MAC of IEEE 802.11e has been introduced and then it has been extended in order to include all the functionalities of the multi-channel IEEE 802.11p standard. The CityMob generator [15] has been used to create mobility log-files, with the following parameters: map dimensions 1800 m × 1800 m, maximum vehicle speed 13.9 m·s^{-1}. Transmission rate has been fixed to 3 Mbps and the number of mobile nodes from 40 to 100. The number of concurrent connections has been fixed to 15.

At this point, VARO metrics are completely defined and they can be used to evaluate the performance of the proposed protocol. VARO has been compared with AODV, GPSR and DSR. In this work some set-up campaigns have been carried out in order to find the right parameters. In particular, once a scenario is defined, it is important to well design the related bounds, otherwise it will be not possible to find admissible solutions. This step is made at simulation beginning and in future works it will be studied an automatic procedure to self-configure the bounds of the networks. From Fig. 5, it can be noticed how the VARO protocol outperforms other protocols in terms of PDR, Aggregated throughput (the sum of the throughputs of all connections) and delay end-to-end. Introducing a composite metric such as interference level and links durability more stable paths can be chosen by the routing decision algorithm achieving a reduction of packet loss probability, retransmissions number are reduced too following the packet loss trend.

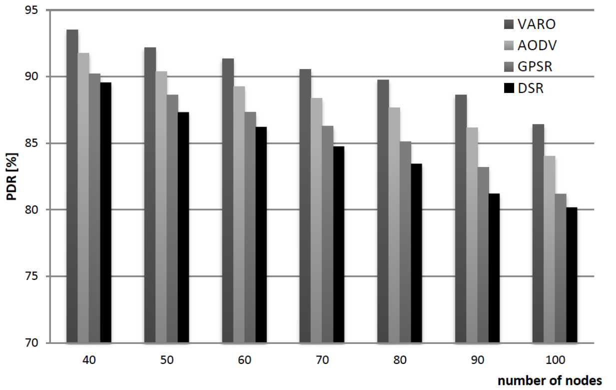

Fig. 5: Average PDR vs the number of mobile nodes.

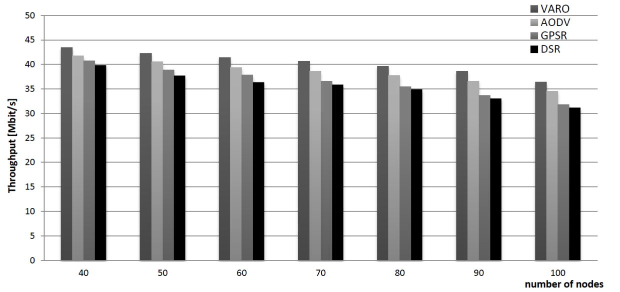

Fig. 6: Average aggregated throughput vs the number of mobile nodes.

So, this is evident when considering the percentage of correctly delivered packets and system throughput.

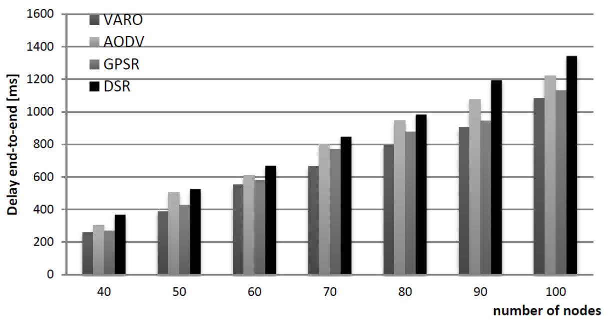

Fig. 7: Average E2E delay vs the number of vehicles.

Referring to the overhead performance, as illustrated in Fig. 8, the VARO 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.

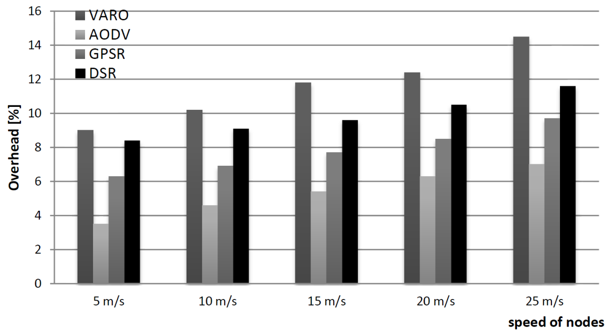

Fig. 8: System overhead for 60 mobile nodes and different average speeds.

The introduction of new protocol messages makes the overhead (evaluated as the ratio between the number of signaling packets and the number of total packets) of VARO higher than classical AODV protocol. Figure 9 shows the trend of the SIR level on selected channels to transmit data packets.

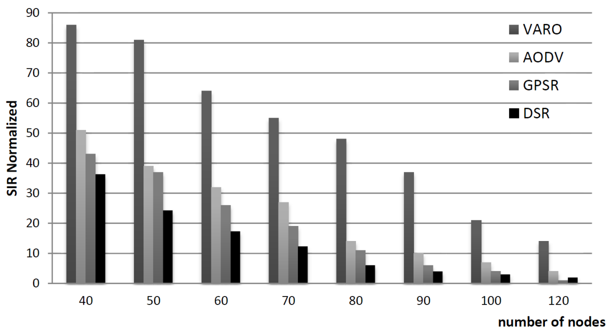

Fig. 9: SIR level normalized vs the number of vehicles.

5. Future Works and Conclusions

In the next works, we will provide some comparison campaigns in order to verify the goodness of the proposed routing algorithm and to find a better mechanism to self-adapt the parameters and the bounds of the metric in order to guarantee robustness and reliability for the found solutions. The main idea that will drive us is to search for the starting configuration considering an unloaded network and then change the optimization bounds following statistical data, which are achieved from historical sessions, and the current trend of the network load. In this work a new routing protocol for VANETs, dedicated to the optimization of path-length, interference level and link duration is proposed. It takes advantage of a dynamic allocation of the DSRC spectrum, in order to reduce interference levels among nearby mobile nodes. A new composite metric, based on the evaluation of interference levels, end-to-end delay 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 performance in terms of throughput, packet delivery ratio and e2e delay, despite of an increase in overhead.

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