Vehicular Networks and Road Safety: an Application for Emergency/Danger Situations Management Using the WAVE/802.11p Standard

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Abstract. *Car-to-car communication makes possible offering many services for vehicular environment, mainly to improve the safety. The decentralized kind of these networks requires new protocols to distribute information. The advantages that it offers depend on the penetration rate, that will be enough only after years since the introduction, due to the longevity of the current cars. The V2X communication requires On-Board Units (OBUs) in the vehicles, and Road-Side Units (RSUs) on the roads. The proposed application uses the peculiarities of the VANETs to advise danger or emergency situations with V2V and V2I message exchange. IEEE 802.11p is standard on which the communication is based, that provides the physical and the MAC layers. The WAVE protocol uses this standard, implementing other protocols defined by the family of standards IEEE P1609 in the upper layers. They define security services, resource management, multichannel operations and the message exchange protocol in WAVE. The performance of the application will be evaluated through many simulations executed in different scenarios, to provide general data independent from them.*

Keywords

802.11p, car-to-car, communications, road safety, routing, VANET, vehicular, WAVE.

1. Introduction

More than 200 000 road accident happened in Italy in the 2010, causing more than 300 000 injuries, and 4 000 deaths [1]. If the cars involved in accidents can advise the event instantly to the emergency services, a timely intervention of rescue means would be possible. If also the near cars can receive this information, they would avoid danger situations, and reduce inconveniences. Car-to-car communication allows the development of many new applications in a vehicular environment, especially to the road safety. Current on sale applications that permits to manage some features tied to the reception of traffic information are based on GPS, users advise and institutional sources. The prevention and advising of accidents uses optical validation or connection with the car control unit. The advantages are just for the vehicles near the accident position. The research and development activity in the Intelligent Transport System (ITS) environment is due to the increasing diffusion of transport vehicles and, proportionally, to the number of accident that happens. The majority of them is caused by the violation of the traffic rules, so a solution that allows cooperation between vehicles, and with the infrastructures, will prevent danger situations. WAVE (Wireless Access in Vehicular Environment) technology was published in its final version in July 2010. The frequency that uses is situated around 5,9 GHz. It supports both communication typologies. The PHY and MAC layers are implemented by IEEE 802.11p standard, the upper layers by IEEE P1609.

2. State of the Art

Many applications developed to improve road safety use the GPS and users advisories. To prevent accidents, optical validation is used. To minimize the time necessary to the intervention of emergency vehicles, the detection of the accident is done by the connection with the car control unit, and the notification is done automatically by calling the emergency number or sending data to a dedicated server. Systems that allow the reception of information on traffic are usually integrated to navigation systems. They have a GPS receiver and a memory to store the maps. Through these systems, the Traffic Message Channel (TMC) transmits information of FM frequencies, using the protocol of the same name. It needs a dedicated hardware to receive messages. HD Traffic is another solution developed by TomTom, which allows receiving up-to-date information related to the path the vehicle is following, collecting data from other devices that use this service. A free navigation software that make use of advisories coming from other users about accidents, traffic jams, blocked roads and other dangers are Waze. To prevent accidents when driving, the current systems make use of vehicle detection through active (e.g. laser) or passive (e.g. camera) sensors. The laser allows calculating the distance from other cars that come across during the drive. Passive sensors permit to acquire data in a non-intrusive manner [2]. Accident detection allows reducing the time required to the notification, and makes possible a timely intervention by the emergency vehicles. Current systems use the OBD-II connection, available on all cars produced since 2003. European Union developed eCall to provide the warning of accidents, with the target of improving the road safety using intelligent safety systems based on advanced electronic technologies available on cars. The advisory happens by transmitting data to 112 service, available and free in all Europe.

3. WAVE/802.11p Protocol

WAVE (Wireless Access in Vehicular Environment) [3] consists in a set of a standard, that enable vehicles to V2X communication. Main components of architecture can be identified in Resource Manager, WAVE Short Message Protocol (defined by IEEE 1609.3 at the network layer), Multichannel Operation and IEEE 802.11p at underlying layers. WAVE is enabled to support IP and non-IP applications, the last ones using WSMP protocol, which let the applications control the physical properties of the transmission channel, like the transmission power and on which channel transmit. WAVE systems need two different device typologies: Road-Side Units (RSUs) and On-Board Units (OBUs). RSUs are placed statically on the roadside, whilst OBUs are situated on vehicles and can communicate with other OBUs and RSUs. Units can also organize themselves in small networks known as WAVE Basic Service Set (WBSS), in a way similar to BSS in IEEE 802.11 standard. A WBSS can be formed of just OBUs, or OBUs and RSUs. All its members communicate through a service channel. Furthermore, the whole set can connect to a WAN if the RSU is enabled to.

WAVE architecture is composed of two stacks, with common layers, as we can see in Fig. 1. One is for IP communication, whereas the other is for WSMP. The first one is used for TCP/UDP traffic, the last

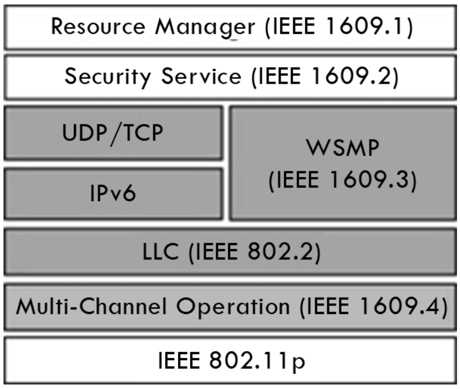

Fig. 1: WAVE stack.

one must support low latency and low error communications, like for example communications needed to road safety, when an accident needs to be advised. The basis of WAVE architecture is the IEEE 802.11 standard, modified by 802.11p to support the different properties of vehicular networks, offering many channels to use for communication, making possible also using schemes to reduce interferences in transmissions [4], with routing protocols that could maximize the signal-to-interference level [5]. It must be underlined that many routing protocols have been proposed for VANET environments, mainly aimed at multi-objective metric utilization [6] or user satisfaction [7].

4. Proposal

The application development is based on the use of WAVE protocol, which allows V2X communication. The target is to provide an application that permits reducing awkwardness and risk originated by an accident. Vehicles not involved in the accident will have benefits from the information they will receive, avoiding the road where the accident happened, so they will not come across in traffic jams or danger situations. Using this application, time of intervention of emergency vehicles will be reduced thanks to the immediate advisory; furthermore, the traffic near the accident will be lesser, because many vehicles will change their path to avoid the road subject to the event. The injured people will get assistance in a timely manner. Emergency vehicles will dynamically compute the fastest path to the destination, avoiding roads with traffic jams.

4.1. Message Typologies

Message exchange between vehicles using the application maintains traffic information always up-to-date. When an accident happens, the information is immediately transmitted to near vehicles, so they can take adequate countermeasures to avoid dangers and traffic jams. The proposed application uses two different message typologies: Cooperative Awareness Message (CAM) and Decentralized Environmental Notification Message (DENM). Each vehicle enabled to V2X communication sends CAM messages periodically. They contain information regarding the vehicle (actual speed, position, etc.). Using this information, vehicles can update traffic data in the surrounding area, so they can choose the best path to their destination. CAM messages are sent in a time interval within 0.1 and 1 seconds. Messages are broadcasted, but the application could use also more complex protocols, based on trajectory, map information or group motion [8], [9], [10]. To advise accidents and other danger situations, DENM are used. They are generated and sent immediately when a danger situation is detected. The dispatch is in broadcast, and it is repeated until the danger ceases, so the vehicles arriving later in the area will receive the information. The car subject to the accident sends the message, advising the seriousness of the happening, the position and the driving direction.

4.2. Communication Sequent to the Accident

The application advises the accident happened to vehicles in a specific range from its position. An accident, depending from its seriousness, can require emergency means to give aid to injured people, and other means to clear out the road if it is blocked by the vehicles involved in the event. Vehicles nearby the area receive the communication in real-time.

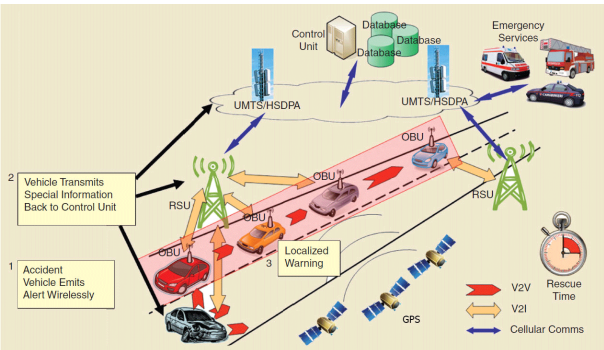

Fig. 2: Accident advisory.

A RSU sends the request to a server, which receives the DENM related to the accident and in its turn sends the request of assistance to another server enabled to manage this kind of data. The advisory is sent in real-time to authorities and/or to rescuer, so they can intervene in a timely manner to limit the effect of the accident, assisting injured people and/or restoring the viability (as in Fig. 2).

4.3. Dynamic Choice of Path

Cars can change their path according to messages they receive. This operation can be done also when there is no accident, using the data contained in CAM messages about other vehicles. Storing and managing this information, the conditions of the road network around the vehicle are inferable. So, congested areas that require more time to be driven can be avoided.

4.4. Optimal Path Planning

To plan the optimal path, Dijkstra algorithm is used. There are two nodes sets, S visited nodes and T nodes to visit. At each step, the node x_m successor of a node in S and contained in T, reachable at minimum cost, is chosen. It is moved in S, and for each of its successors x, the cost will be updated using the following formula:

$$c_x = minc_x, c_v + w_e, \tag{1}$$

with c_x cost to reach node x, c_v cost to reach its predecessor, w_e weight of the connection edge. The algorithm ends when the destination is reached. Road network is represented as oriented graph, defined as:

$$G = \langle V, E \rangle \,, \tag{2}$$

with V nodes set, E edges set. To each edge E is connected a weight with real values, as following:

$$w : E \longrightarrow R. \tag{3}$$

Each node coincides with a crossroad. A road corresponds to an oriented edge for each driving direction. So, a one-way road will be represented as one edge, a two-way one as two edges oriented each one in a different direction. An example of conversion from the road network to graph is shown in Fig. 3.

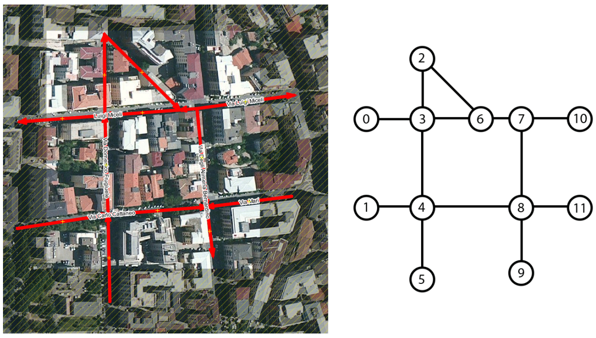

Fig. 3: Conversion from the road network to graph.

Each edge weight is given by the average travel time for its driving direction. This parameter is calculated using the following formula:

$$w(e) = l(e)/s(e), \tag{4}$$

with e specifying the edge associated to the road, $l(e)$ its length, $s(e)$ the average speed on the road. If a vehicle did not receive any information about a road, the speed limit will be considered as its average speed.

4.5. Algorithm Operations

Using the information about the position in CAM messages, the road that the message sender is going through can be established. Since the message contains also the speed, the average speed of the vehicles situated on the road can be calculated. From this, the average travel time can be determined. When an advisory of an accident is received by a DENM, the road on which the event happened is excluded from the new path computation, setting its average travel time to $+\infty$. Emergency means store the information received during their path to reach their destination, so they can calculate the fastest way. This is important especially when means arrive near the event position, since they have to change their path if they sense, from data collected, that there is a traffic jam on a road. Moreover, they can choose the way that leads as near as possible to the destination area.

4.6. Requirements

To immediately advise the accident, a RSU is needed in the communication range of involved vehicle, because the request of assistance to emergency services is made through it. Missing this requirement, an alternative advisory system is needed (e.g. eCall). An adequate number of vehicles have to use the application: it is possible to collect data from a certain sample of vehicles.

5. Results Analysis

The evaluation of the application performance is done using many simulations, changing various parameters to establish which ones influence its performance. Simulation is running using real maps, and it regarded many aspects implied by the application and the WAVE technology. The simulation framework used to simulate the V2X communication scenario is VSimRTI [11]. It permits to a couple different simulators, allowing to simulate various aspects of ITS. Simulators used combined to VSimRTI are SUMO [12], that simulate the traffic on the road network, and JiST/SWANS [13] for communication between nodes. The application was developed in two different versions: one used by generic cars supplied by WAVE technology, another one used by emergency vehicle, because operations they carry out are different.

5.1. Simulation

Various simulations were ran, to evaluate application performance and to denote differences when some conditions changes. Different sets of parameters were used to each simulation, keeping some fixed.

Parameters used in the simulation are the following:

- simulation duration: 30 minutes,
- transmission range: 250 meters,
- generated vehicles: 100, 200, 400,
- penetration rate of WAVE technology: 100 %, 75 %, 50 %, 25 %, 0 %.

One vehicle each 4, 8 and 16 seconds is generated during the simulation, respectively to a total number of 400, 200 and 100 vehicles. Each vehicle had random starting and ending point, with the only constraint that, between them, a distance of 500 meters in los must exist. Dijkstra algorithm is used to calculate the starting path offline, with no vehicles on the road network. During the simulation, path changes dynamically based on traffic conditions. The reaction time to the accident by emergency services was supposed as 2 minutes when WAVE technology is used, 10 minutes otherwise. Maps were chosen to offer a road network dense enough. During the simulations, every road was contemplated as two-way one. Two different types of map were considered, for a sum of 6 different maps. 3 of them regard urban areas, other 3 are suburban zones. The main difference between these categories is the number of roads available. Urban scenarios have more roads, so vehicles have more choices when computing a path. Furthermore, these scenarios allow more vehicles to pass through the road network at the same time, with respect to suburban scenarios. Using different kind of maps (from OpenStreetMap) is useful to evaluate the application on different scenario typologies. As urban areas, section of the cities of Cosenza, Paris and Valencia were chosen. Part of Barcelona, Munich and Rome were used to simulate suburbs. Each map area is about 1 km^2, without buildings and closed roads.

5.2. Results

Main results generated by simulations, on which an evaluation will be made, are about emergency vehicle, and they are the final distance from the accident area, the time needed to reach it and the average speed during the trip. Average speed is calculated as following:

$$v_{avg} = travel_{length}/travel_{time}. \quad (5)$$

1) Distance from the Accident

The application allows the emergency vehicle to drive through the fastest path, avoiding traffic jams. Regarding these last ones, they have a smaller probability to happen, because cars using the application change their path when they notice the event. From Fig. 4 it is possible to verify that highest distances from the accident are reached when 400 vehicles are generated, whereas the lower curve is about the least number of vehicles generated, that is 100. The curve representing simulation values with 200 vehicles is situated in the middle of them. The curves trend is decreasing when the penetration rate increases until 50 %, thereafter it stays almost stable, recording a light increment only with 400 vehicles. From data represented in this graph, it seems there is no difference in application performance when penetration rate is greater than or equal to 50 % of total vehicles.

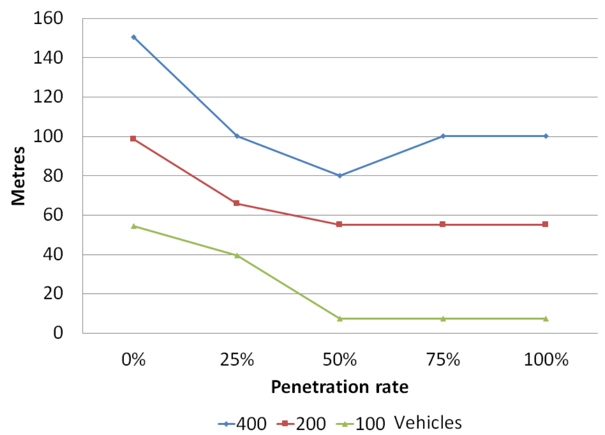

Fig. 4: Distance from the accident with different penetration rates.

A comparison between central and suburb scenarios about the distance of emergency vehicle from the position of the accident is shown in Fig. 5. Using the application, urban areas get a higher improvement than suburb ones, which coincides with distances lower than a half from what results when no application is used. This is due to denser road network in central areas, so emergency mean has more choices to reach the accident position. This opportunity does not occur sometimes in suburb zones, so the final position of emergency vehicle is farther.

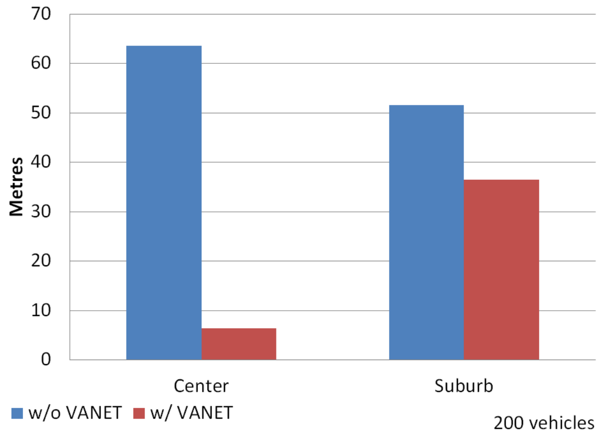

Fig. 5: Distance from the accident in the center and suburb scenarios.

2) Average Speed

Another outcome that allows evaluating the application and the benefits its use entails consists in the average speed achieved by emergency vehicle during the path to its destination. Therefore, it is possible to have an idea of the time it needs to reach the area also when the path length is different, like in this simulation, where the starting point and accident position are generated randomly. In Fig. 6, there is the graph concerning the average speed of emergency vehicle, with a comparison between the cases when vehicular network is used or not. In urban areas, average speed is higher, but improvement using the application is very little. Suburban zones allow reaching lower average speeds, but there is a notable improvement when the application is used. With reference to this parameter, the application provides a better improvement in suburb areas.

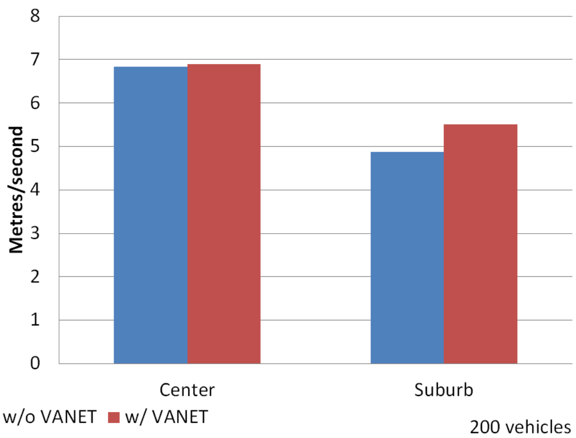

Fig. 6: Comparison between average speed in urban and suburb scenarios.

3) Travel Time

To compare travel times between central and suburban zones, average values calculated using scenarios of the same type is taken in account. Furthermore, five runs were done on a particular scenario, keeping fixed the starting point of the emergency mean, and changing randomly, but in the same manner for the two cases, the point where the accident happens. Therefore, a more accurate evaluation of the advantage caused by the application is possible. Figure 7 shows how travel times of emergency vehicle are higher in urban scenarios. On average, a greater advantage is obtained in suburban zones. Examining this time saving in percentage, collected data points out that in central road networks the time required for intervention is lower of 7,3 % using the application. The percentage increases until 16,7 % in suburban zones.

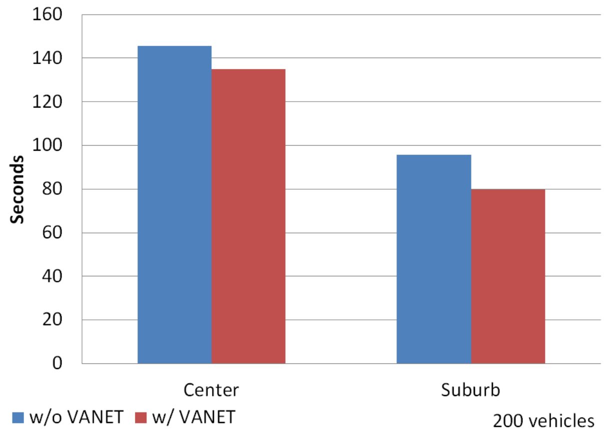

Fig. 7: Comparison between travel time in urban and suburban scenarios.

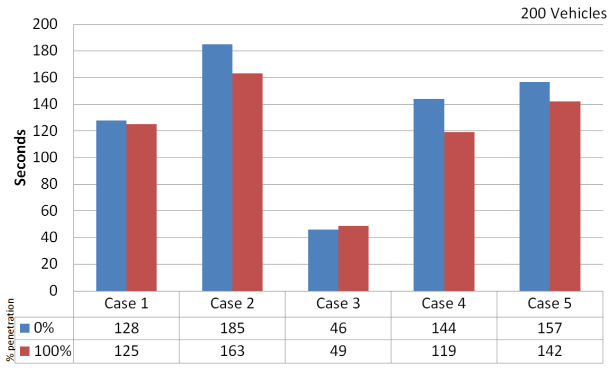

Fig. 8: Travel time with and without application.

Figure 8 shows a comparison between cases with the same starting and ending point for emergency mean. In percentage terms, the best saving is achieved in Case 4 (21 %). In other cases, there is a lower improvement. Case 3 needs more attention, because the travel time obtained using the application is higher than the one achieved without using it, with a worsening of 6 %. Therefore, without the use of the application, emergency vehicle probably did not go through the fastest path, but the shortest, and the final distance from the accident is higher compared with the result obtained when the application is used, because in this last case the vehicle found a better path, resulting nearer to the accident position. Due to the low intervention time in this case, this approach caused a time travel higher, even though just 3 seconds. Computing average between cases, the advantage achieved using the application corresponds to travel times of 9,34 % lower needed to reach the event position by the emergency mean.

6. Summary and Future Works

From the results obtained from simulations done, it is possible to establish that the proposed application to manage emergency and danger situations allows improving the reaction to those events, for general vehicles and emergency ones. The algorithm used by the application permits vehicle path updating, to avoid the generation of traffic jams near to the accident position, so they can save time and reach their destinations without incur into dangers originated by the event. Thanks to WAVE protocol, vehicles receive real-time communication about emergency generated by the accident, so they avoid the involved road, without causing other annoyance to traffic flow due to traffic jam that happens if they do not change their path. Based on collected data, intervention time of emergency means that use the application decreases. This is essential to intervene in a timely manner, to manage the danger situation in a better way. Also a little time saving can lead to benefits to injured people caused by the accident. Furthermore, in this way the normal traffic flow is restored in a lower time, minimizing inconvenience to vehicles near the event area. Distance reached by emergency means from the accident position decreases proportionally to the increasing of penetration rate. The advantage provided by the application is higher when there are more vehicles in the road network. Using an equal number of generated vehicles, the application allows achieving a greater advantage in suburbs, since their road networks are sparser than the central ones. Average speed of emergency vehicle is higher if it runs the application. As future developments of application, a better and more realistic vehicle generation model would be useful, using real data or based on a real car density in simulated area. Therefore, it is possible to get data that represent application performance in a more accurate way, compared to results using random generated data.

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