Propagation of Public Safety Warning Messages

A Delay Tolerant Network Approach

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Abstract—**This work presents an auxiliary mechanism to aid in the distribution of warning messages for Emergency Alert Systems (EAS). The main objectives of the proposed mechanism are to speed up and broaden the warning messages distribution process to provide to the public faster access to crucial information. EAS are public safety message systems designed to enable authorities to address the population in case of an emergency. This kind of system has been in use for a long time, however traditionally they are composed of radio/TV broadcast messages or sirens spread thought endangered regions. This system on the other hand addresses the next generation of EAS systems that will be based on wireless computer networks and satellite technologies. The method proposed here is a complementary way to spread warning messages that not only successfully broadens the EAS reachability but also significantly speeds up the messages distribution process.**

Keywords-Public safety; warning message, multi-hop; vehicle-to-vehicle communication

I. INTRODUCTION

This work addresses the problem of speeding up the process of message distribution in public safety situations. We want to be able to increase the coverage of the existent network to reach more people in a faster way. Traditional Emergency Alert Systems (EAS) normally rely on either broadcast transmissions mediums, e.g. radio and TV, or some kind of sound notification device, e.g. sirens, to warn people about catastrophes and potential threatening situations. However theses systems have some limitations, first sirens are expensive and only cover a small area. Second, people on the road, possibly in imminent danger, may not be aware of the transmissions on public broadcast mediums. People in cars do not have access to TV and may not be listening to the radio. However, in the near future cars will be equipped with driving aid equipments dedicated to increase road safety that will work continuously to provide drivers information about the road conditions.

Initiatives such as i2010 Intelligent Car Initiative [10] dedicated to decrease the accidents and CO_2 emissions in Europe advise the use of sensors and vehicle-to-vehicle (V2V) communication to increase road safety. On the view of this kind of project, cars should be equipped with devices to enable roadside units, and close by vehicles, to transmit traffic and road safety information to the nearby cars. The ETSI 102 638 technical report [9] forecasts that by 2017 20% of the running vehicles will have communication capabilities. The same report estimates that by 2027 almost 100% of the vehicles will be equipped with communication devices. These devices could also be used to spread crucial information, such as EAS warning messages.

This work relies on the existence of infrastructure-to-vehicle (I2V) and V2V communication to spread public safety messages among users over a defined region. The method proposed here intends to take advantage of the communication capabilities of the next generation of vehicles to extend the coverage of emergency alert systems. Emergency warning messages are not frequent, but when they are issued they must be spread as fast as possible to all the people in the affected region. In this situation all the available means should be used to increase the awareness of the population regarding the imminent threat. We proposed here that the available roadside units (RSUs) and other cars, acting as virtual road side units (vRSUs), help on the spreading of the EAS warning messages in case of an emergency.

The remainder of this paper is organized as follows. In Section II, we discuss some related work. In Section III, we introduce the proposed architecture and discuss some of its characteristics. In Section IV, we present the evaluated disaster scenarios. In Section V we introduce the experiments and analyze their results. Section VI draws conclusions and points the next steps for this work.

II. RELATED WORK

Most traditional network algorithms, for fixed and mobile environments, consider nodes to be connected and paths to be available all the time between the source and the destination [5]. This work focuses on another kind of scenario, it relies on the concept of occasionally-connected networks. This means that a path may not necessarily exist between the origin and destination during the whole communication time. We target here sparse network environments, or areas that have their infrastructure damaged by some kind of disaster or sabotage action. The networks build to work on this kind of environment are normally referred as delay or disruption-tolerant networks (DTNs). Huge efforts have been made in the last few years on

DTNs as means to provide connection in rural areas, spread vehicular emergency warnings and vehicle to vehicle communication. However, the start point for DTNs was the need to handle the problems of delay and packet corruption for deep-space communications and networking in sparsely populated areas [6].

Vehicular networks is another field that has received a lot of attention in the last few years. Other researchers have already proposed the use of vehicle-to-vehicle communication (V2V) for safety purposes. For example, Xu et. al. [7] evaluate the feasibility of using dedicated short range communication to warn vehicles about road accidents. Yang et. al. [8] propose the use of V2V to warn vehicles about road conditions. However, the existent works focus mainly on road safety problems. They try to minimize latency and characterize the requirements for warning neighbor vehicles about road conditions or avoiding road accidents. Our main goal here is distinct, we want to issue an warning message to all the vehicles of a region regarding a broader public safety issue. Not only the range of the communication is larger, but the target audience for the messages is also considerably broader. Other particular characteristic is that our architecture uses not only V2V communication but also infrastructure-to-vehicle (I2V) communication as well.

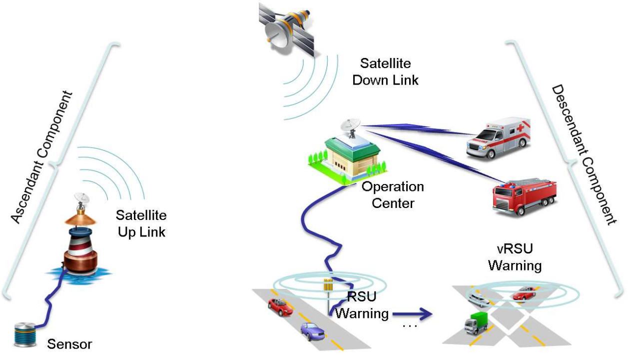

Figure 1 - Ratcom project main architecture plus our proposal for road side units and virtual roadside units warning message redistribution

This work is also close related to the one of Chen et al. [14]. On this work Chen et al. study the network delay as a function of the number of cars and their velocity, they noticed that node mobility on highways can improve end-to-end transmission delay when messages are relayed. Furthermore, that low density networks may experience higher delays. We can use these results to gauge the RSUs locations in a way that the information is not too widely spread and messages can reach their destinations in a shorter time.

Emergency alert systems play an important role on many countries and have also evolved and received considerable investment through time. For example, only in 2009 the budget requested to develop the new American EAS, the Integrated Public Alert and Warning System (IPAWS), was 37 million dollars [3]. IPAWS [4] development is under the responsibility of the Federal Emergency Management Agency. When complete it will permit the broadcast of emergency messages not only through radio and TV but also by e-mail, cell phones and other different mediums. During a test pilot conducted in 2007 in Alabama, Louisiana, and Mississippi the system was able to send alerts to 60,000 residential phones in ten minutes and also with Spanish and Vietnamese translations [4].

The Japanese nationwide warning system, J-Alert, was launched in February 2007. It uses satellite wireless communication to issue a simultaneous warning to all municipal governments and interested agencies [2]. J-Alert works with warn sirens and an emergency broadcast system. The system is automatically activated and, from the time an emergency is confirmed, it is able warn the population in less than 7 seconds.

III. PROPOSED ARCHITECTURE

We consider a system like the one proposed by the Ratcom project [1], depicted at Figure 1. On the next generation of EAS, sensors will capture data and, if a real anomaly is detected, warning messages will be distributed automatically over the endangered region. The Ratcom alert system is composed of two main components: one ascendant and one descendant. The ascendant component is responsible for sensing the related data, filter false positives and retransmitting the relevant collected information to the coordination center. The descendant component is responsible for spreading the information of the imminent dangerous situation among the authorities and population in general. This work focuses on this last phase: we try to increase the awareness of the general population of the imminent danger using the wireless medium and V2V communication.

In case of a natural or industrial catastrophe road side units (RSU) may also help spreading a beacon warning message to the nearby vehicles informing about the specific threatening situation. We can either use the RSUs already deployed for road safety purposes or deploy some purpose specific equipment over the region to warn people in case of an emergency. These equipments will help to increase the awareness about the threatening situation using the onboard road safety equipment present on the vehicles. One problem that may arise in consequence of economic reasons or even as a result of the disaster itself, is that part of the target area may be uncovered by RSU's, or any other warning system. To solve this we propose that the vehicles that have eventually received the warning message from a RSU, should also be responsible for re-broadcasting it over the uncovered areas helping to spread the warning message. In this way the mobile nodes would act as virtual roadside units (vRSU) for the regions that do not have a RSU.

For all practical purposes we consider that there is no difference between the messages received from a RSU or a vRSU. The propagation mechanism is a cooperative one. Consider the scenario of Figure 2, when a vehicle *A* receives a warning message from a RSU, it carries the message and at some other point the vehicle rebroadcasts the warning to all the vehicles closer to this new region. This cooperative behavior helps to spread the warning message with a low cost through a broader region.

Even in case of a severe catastrophe, or a huge terrorist attack hardly all the RSU's would be inoperable at the same

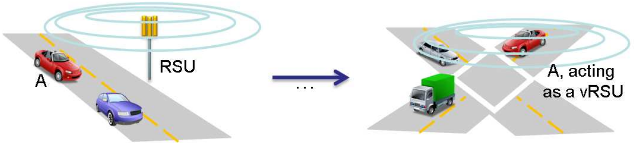

Figure 2 – Message redistribution using virtual road side units

time. We consider that some RSU will be able to rebroadcast the warning message to the population. After that, the vehicles that received the warning are also be able to spread this information to the other vehicles on their path, which in their turn may do the same. This kind of propagation scheme is normally referred in the literature as epidemic and nodes act in a *store-carry-and-replicate* paradigm [5].

To decrease the waste of resources and avoid medium access problems, vehicles act as vRSUs only when they are out of the range of a real RSU and if they have not received any communication from another vRSU over this slot of time. In the case of a disaster scenario, this kind of cooperative behavior may be the only way to disseminate useful and general information through the network.

Nodes connect with each other in an opportunistic way, they retransmit their messages when they have the opportunity to meet other nodes. However we must keep in mind that the system is a best effort one. There are no guarantees that the message will reach all the nodes on the target region. What our approach guarantees is that it tried its best to spread the information as much as possible.

The increase in the number of messages sent (*im*) is upper bounded by:

$$im = \alpha - (nvRSU * \eta) \quad (1)$$

considering that α is the number of exchanged messages and may be expressed as:

$$\alpha \leq \beta = (nvRSU * \eta) * t \quad (2)$$

Where β is the maximum number of exchanged messages, *nvRSU* is the number of virtual roadside units, η is the size of the warning message and t is the time the warning message is propagated. The minimum number of messages is given by the number of mobile stations on the region times the size of the message. I.e. each vehicle received the complete warning message just one time. This would be possible, for example, if the whole area was covered by RSUs. However, with a distributed communication algorithm this value is hardly achievable. However, it is clear that the number and locations of the RSUs will greatly affect the system's performance. The points where vehicles will act as vRSUs are direct related to the deployment of the RSUs. Well deployed RSUs can provider faster and more efficient message spreading over the target region.

IV. EVALUATED DISASTER SCENARIOS

This work intends to evaluate how robust the system is in different disaster scenarios. We evaluate here mainly two kinds of disasters, the first one is when the network is damaged by natural causes and the second kind is when the network is damaged by sabotage, possibly in result of terrorist attacks. The tested scenarios evaluate the behavior of regular nodes, before and after a catastrophe. The nodes are the same and follow realistic movement patterns. We do not advocate by no means, for example, the nodes movement patterns before and after and earthquake will be the same. However in the lack of real meaningful data, and believing the nodes will still be able to move, we chose to use realistic mobility patterns as a way to test the use of the vRSUs to improve the connectivity of the remaining nodes. The natural disasters evaluated here are earthquake and flooding, the sabotage scenario is random failures, which could be caused by a hacker attack. These disaster scenarios were abstracted in the simulation as follows:

- Earthquake: The network starts with all the APs and mobile nodes running perfectly. However, at some point, 80% of the existing APs are randomly damaged and excluded from the network. This abstraction permits us to evaluate the effect of the technique when a major part of the APs disappear randomly from the network without any warning.
- Flooding: The evaluated scenario is a flash flooding [13] one. This kind of flooding is common in mountain regions in spring, heavy rainfall during the tropical rainy season and in the case of dam failures. This situation is abstracted in the simulations by the random disabling of a slice of 20%, horizontal or vertical, of the middle of the network. All the APs in this segment of the network are disabled. This intends to simulate a river crossing the city that flooded the region in a sudden way.
- Random network failure: In this scenario random network APs fail and disappear from the network during the regular network operation. The degradation of the network coverage, in this case, is gradual, in contrast to what occurs in the other scenarios. This kind of generalized and chronic failure scenario could be triggered by hacker actions or physical sabotage of the nodes to deny access to the network.

V. EVALUATIONS

The evaluations were carried out using Sinalgo simulator 0[11] in a 15000x9000 square meters area that encloses Sophia-Antipolis in the south of France, as depicted in Figure 3. The simulations were conducted with 1000 nodes with 200 meters communication range and speeds varying between 40km/h and 90km/h. The scenarios follow a realistic mobility pattern generated with the VanetMobiSim [12] tool. Each generated scenario has a number of RSUs placed randomly along the roads of the target region. All experiments were conducted using Linux Fedora Core release 6 on an Intel Xeon 1.86GHz machine with 16GB of RAM. All graphs are presented with a confidence interval of 99% and each point is the result of the averaging over at least 34 runs with different network configurations. The nodes arrive randomly and are placed uniformly over the observed area.

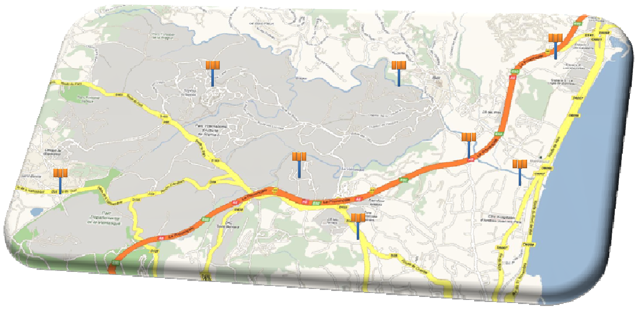

Figure 3 – Area used to perform the tests

We vary the number of RSUs, the size of the message and analyze the impact of the occurrence of different disasters over the RSUs performance. The source of the stream generates a CBR traffic of one packet per second that is distributed simultaneously by all the available RSUs. If the message is too big to send in one time interval, it is divided into smaller packets and these are broadcasted, one packet per second, continuously in a cyclical way. We consider transmission intervals of one second.

The graph of Figure 4 shows the number of nodes that received the one packet warning message for the different disaster scenarios. For all the scenarios evaluated with 10 initial RSUs, the use of vRSU enabled the distribution of warning messages to all the network nodes. The most severe disaster evaluated is the earthquake one. On this scenario 80% of the initial RSUs are damaged during the experiment. However, even in this situation the vRSUs delivered the warning to all the nodes in the region in less than 20 minutes. Even though the mechanism used to decrease the number of RSUs is different, for the earthquake and the random failure scenarios, their results are close. This occurs because with the time the number of damaged stations in the random failure scenario increases. In the end of the simulation the number of RSUs is nearly the same for both scenarios, however the smoother degradation of the random failure scenario grants it a better performance, when compared to the earthquake one. For the flooding scenario, only the nodes on the central strip of the area are removed. Although this affects the total number of nodes that received the warning message completely and slightly increases the time required to distribute the message to all the nodes in the network, the vehicles movement compensates the lack of RSUs on the central part of the area. Nodes that did not receive the message because they were in that region, on the next moment may be in a region that is covered by RSUs.

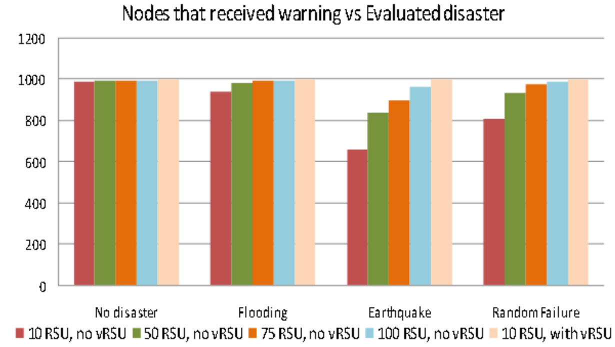

Figure 4 – Number of nodes that received the warning message taking into account the evaluated disaster scenario

We can perceive in Figure 4 that when no disaster occurred, the number of nodes warned is nearly 100%, regardless of whether vRSUs are used or not. Indeed, the final number of nodes aware of the message is similar, when we do not consider any disaster. However the graph of Figure 5 shows the time it takes for all the target nodes to receive the message. We consider transmission cycles of one message per second, i.e. at each one second the warning message, or a part of it, is broadcasted. The plot shows the time when all nodes in the network received the warning message. Whether all nodes had received the messages or not the simulation experiment stops after 3600 seconds. If any node failed to receive the message within that interval, the registered time is 3600 seconds. Without the use of vRSU's the network needs more than 200 RSU's to be able to spread the message to all the nodes in less than one hour. With the use of the vRSU, even in the worst case scenario, the earthquake with only two RSU's remaining working, it takes around 20 minutes to send the warning message to all the nodes in the region.

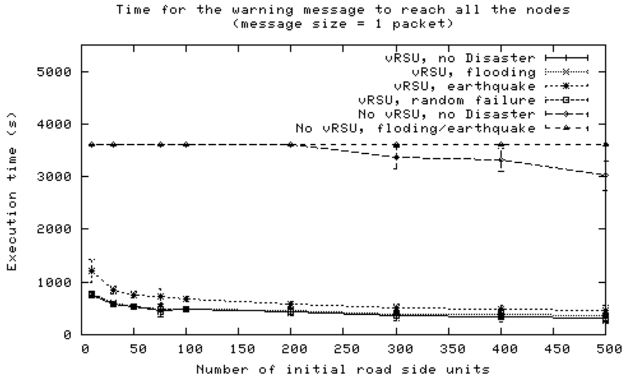

Figure 5 – Average time for the warning message to reach all the nodes on the region. The simulation stops after 3600s, this means that scenarios that had their time registered at 3600s did not deliver the message to all nodes.

The tendency is that the time required to spread the warning message decreases when the number of RSU's increases. However, the gains become proportionally smaller when number of RSUs increases beyond 50. If we consider the no disaster scenario, if we increase the number of RSUs from 10 to 50 we speed up the message distribution by 28.8%. However, when we increase the number of RSUs from 50 to 500 the gain is 29.8%. I.e. with 50 RSUs + vRSUs we are able to warn the whole population in 8 minutes, whereas if we increase the number of RSUs to 500 RSUs, the process will take around 5 minutes. This result is interesting since it shows that the increase in the number of RSUs does not linearly impact the time needed to warn the population over a given target area. This means that we could decrease the number of RSUs, and the cost of the system deployment, without compromising significantly the quality of the service offered. This effect is also clear from the graph of Figure 6. From this graph we see that when we increase the number of RSUs we do not increase proportionally the number of nodes that receive the warning message. Even without the use of vRSUs, the node coverage for all scenarios, except for the earthquake one, is almost 100% with only 50 RSUs. However, this value of active RSUs also holds for the earthquake scenario. The earthquake scenario reaches nearly 100% of warned nodes when we increase the number of initial RSUs to 200, this means that on average 40 RSUs were working during all the experiment. I.e. roughly the same number of nodes of the other scenarios.

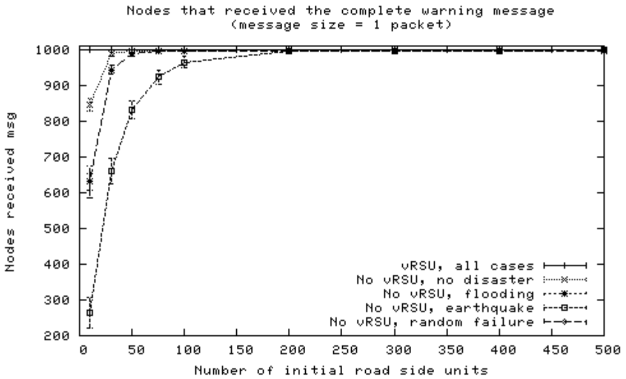

Figure 6 – Number of nodes that received the warning message versus the number of roadside units on the network

The apparent discrepancy between the graphs of Figure 5 and Figure 6 is given by only a small percentage of vehicles that did not receive the warning message during the simulation time. Because of their mobility patterns these nodes did not cross any RSUs during all the evaluated time. When we use vRSUs we increase the coverage of the EAS, which permits not only to reach these nodes, but to reach them in a fast way.

The graph of Figure 7 presents a percentage comparison between the number of messages first received through vRSUs and real RSUs. The percentages on the graph are for the one packet size warning message and no disaster scenario. As expected when the number of RSUs increases the percentage of packets delivered through vRSUs decreases. Vehicles when acting as vRSUs are really well behaved, if they perceive the presence of a RSU or another vRSU they defer retransmitting the warning messages. When we have 10 RSUs the percentage of roads covered by the RSUs is around 3%; on the other hand, when we have 500 RSUs spread randomly throughout the target area the percentage of roads covered by these RSUs is nearly 70%. This is roughly the same percentage of nodes that received the message through RSUs in the graph of Figure 7. It is clear that in the extreme case, if we had 100% of coverage, the vRSUs would not increase the number of distributed messages. However, not only is it extremely expensive to have 100% of coverage, but also in the case of a disaster, the deployed infrastructure could be severely damaged. The main advantage of vRSUs, is their dynamicity and capacity to reach non covered areas.

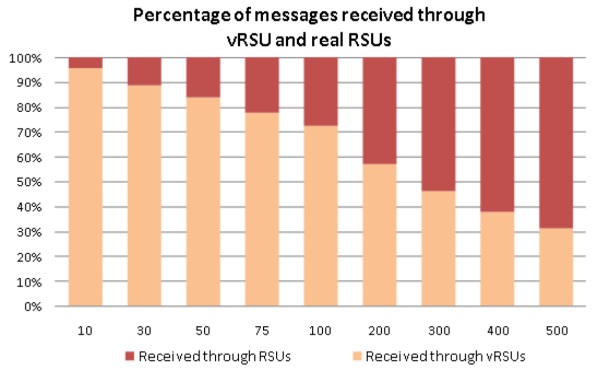

Figure 7 – Comparison of the percentage of received messages through virtual roadside units and real road side units for one packet warning message varying the number of road side units

The graph of Figure 8 shows the number of nodes that have received the whole message for increasing warning message sizes. As anticipated, increasing the size of the message decreases the number of nodes that receive it completely. However, the use of vRSU provides an increase in the number of nodes that received the message completely; this increase with respect to the case without vRSUs varies from 14.4% to 60.8%, thus leading to a relatively stable number of warned nodes, even with the increase in the size of the message.

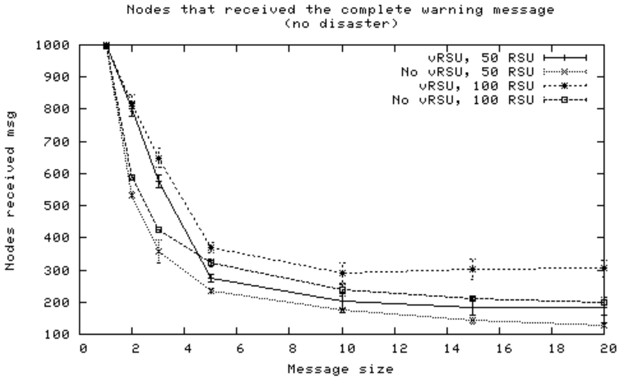

Figure 8 – Number of nodes that received the complete warning message, varying the size of the message

The experiments show that the proposed method increases the coverage and decreases the time required for all the nodes in the network to receive the message, however this has a cost. One of the ways to measure this cost is counting the number of repeated messages received by the nodes. The graph of Figure 9 shows the average number of repeated messages received by the nodes. The number of duplicated messages is considerably bigger when we use vRSUs. The augmentation in the number of messages is also expected since the algorithm is an epidemic one. However, it is important to call attention to the fact that this traffic occurs in areas that had no communication before, i.e. that these messages do not interfere with other communications.

The number of duplicated messages, observed in the Figure 9, decreases when we increase the number of RSUs. This behavior is linked to the results observed in the graph of Figure

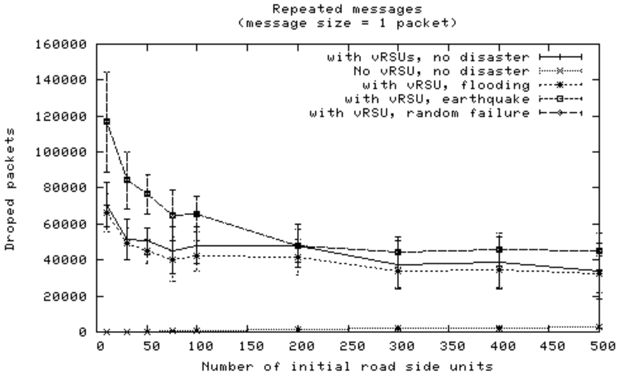

Figure 9 – Number of repeated messages received by the mobile nodes during the simulation

7. When the area covered by the RSUs increases the areas where vehicles may act as vRSUs decreases. From the graph in Figure 9 we can also observe that, apart from the earthquake scenario, the amount of traffic generated over the different scenarios does not vary significantly. As we can see in formula (2) the overhead is a function of the number of vRSUs not RSUs. The earthquake scenario is a particular case, especially for small numbers of initial RSUs, for two reasons. First because after the disaster the number of RSUs is extremely small, so the area where vehicles may act as vRSUs is bigger. The second factor is the small diversity of routes, when we have smaller number of RSUs. A vehicle only starts generating traffic after receiving the first message. When we have a small number of RSUs the number of sources of traffic is low, and the amount of routes nearby these RSUs is smaller. Nodes have then more chance of sending the message to nodes that have already received it. The nodes that really need to receive the message are the ones more distant from the RSU. The behavior of the message propagation is similar to the wave generated when we throw a stone in a lake. The wave goes in every direction, but it takes some time to spread through all the lake and reach its borders. The warning message spreads in a similar way, reaching new nodes at each step. If the number of RSUs is small the message wave takes more time to reach all the nodes in the network, as we can notice in the graph of Figure 5. The increase in the simulation time leads also to the increase in the number of messages received. However, when the number of RSUs increases the earthquake scenario starts to present a behavior similar to the one of the other disaster scenarios. None of the other scenarios presents such a severe loss in terms of RSUs. Even the random failure, which in the end loses a similar amount of RSUs as the earthquake one, does it in gradual way. In the beginning the number of RSUs is bigger, which increases the variety of places where the information is first sent, in consequence this increases the variety on the paths followed by the vehicles.

VI. CONCLUSIONS AND FUTURE WORKS

This paper proposes the use of I2V and V2V as a mean to distribute EAS warning messages to the population of a given area. Emergency alert messages are not frequent, but when they occur they should be distributed as fast as possible to everyone in the affected region. Lives may depend on how fast and how broad the warning message was distributed.

This work shows that the use of RSUs is an efficient way to distribute warning messages to vehicles in a region. We also show that even with a small amount of real roadside units, using the virtual road side units concept one can broaden and speed up significantly the warning message distribution process. The results evaluated the impact of three different disaster scenarios on the performance of the proposed method. Our experiments show that even in severe conditions warning messages can reach all the 1000 observed nodes within a reasonable amount of time. On average, sending one packet per second we can reach all nodes on the observed region, 15x9km2, in six to seven minutes.

The next steps for this work are, first, to perform an analytical analysis of the costs and overheads involving the use of vRSUs. This will provide a better understanding of the protocol behavior and will enable a better characterization of the impact of RSUs and vRSUs on the distribution process of the warning messages. We hope with these results to fine-tune the distribution of RSUs over a given region. After the analysis we want to implement the solution in a real environment and evaluate the performance of the proposed architecture in a small test bed using the WAVE protocol, IEEE 802.11p [15].

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