2009 IEEE 34th Conference on Local Computer Networks (LCN 2009)
Zürich, Switzerland; 20-23 October 2009

A Performance Evaluation of Warning Message Dissemination in 802.11p based VANETs

Francisco J. Martinez
University of Zaragoza, Spain
Email: f.martinez@unizar.es

Juan-Carlos Cano, Carlos T. Calafate, Pietro Manzoni
Technical University of Valencia, Spain
Email: {jucano, calafate, pmanzoni}@disca.upv.es

***Abstract*—In this paper, we present a performance evaluation study analyzing the behavior of a generic Warning Message Dissemination (WMD) mechanism in a 802.11p based VANET. In our WMD method, warning-mode vehicles notify nearby vehicles in order to improve traffic safety and to control traffic congestion.**

Our evaluation uses 2k factorial methodology to determine the most representative factors that affect WMD performance. We performed simulations to evaluate the impact of different characterizing factors. Performance metrics evaluated are: (a) the time required to propagate the warning messages, (b) the number of blind nodes (i.e., nodes that do not receive these packets), and (c) the number of packets received per node.

Simulation results show that the propagation delay is lower when node density increases, and that the percentage of blind nodes highly depends on this factor too. Factors that affect the number of packets received include downtown size, the probability of being in downtown, and the number of nodes. Lastly, we discovered that the size of packets sent does not significantly impact WMD performance.

I. Introduction

Vehicular ad hoc networks (VANETs) are a type of wireless network that does not require any fixed infrastructure. These networks are considered essential for cooperative driving among cars on the road. VANETs are characterized by: (a) a constrained but highly variable network topology, (b) a great number of nodes, (c) poor communication conditions (signal transmissions can be blocked by buildings), (d) vehicle specific mobility patterns (frequent partitioning due to the high mobility), and (e) no significant power constraints. The development of VANETs is backed by strong economical interests since *vehicle-to-vehicle* (V2V) communication allows the sharing of wireless channels for mobile applications, improving route planning, controlling traffic congestion, and improving traffic safety.

In this paper we rely on the 2k factorial analysis [1] to determine the most representative factors affecting the performance of a generic *Warning Message Dissemination mechanism* based on flooding when using the 802.11p standard. We have selected eight factors: the number of warning mode nodes, the total number of nodes, the map area and the size of the downtown area, the maximum speed in the outskirts, the probability of being in downtown, as well as the priority and periodicity of the messages sent by vehicles. We then performed a detailed evaluation of the target WMD scheme taking into consideration the outcome of the 2k factorial analysis.

This paper is organized as follows: Section II presents the generic operation of the WMD scheme. In section III, we determine the key factors in VANET simulation using the 2k factorial analysis. Section IV presents the simulation environment. Simulation results are then discussed in Section V. Finally, Section VI concludes this paper.

II. Warning Message Dissemination (WMD) in VANETs

In this section, we describe the WMD mechanism that we take for reference in our subsequent analysis, as well as the common essential elements.

For the underlying media access, we have chosen the IEEE 802.11p because it is expected to be widely adopted by the industry. The data rate employed by our system is of 6 Mbps, which is the maximum data rate used for broadcasting with IEEE 802.11p. The 802.11p MAC layer is based on the IEEE 802.11e *Enhanced Distributed Channel Access* (EDCA) *Quality of Service* (QoS) extensions. Therefore, application messages are categorized into different ACs, where AC0 has the lowest and AC3 the highest priority. The contention parameters used for the CCH are shown in [2].

In our considered WMD, we assume that each vehicle periodically broadcasts information about itself or about an abnormal situation (when the road is slippery because of ice, a traffic jam, etc.). We have two types of vehicular nodes: $warning$ and $normal$. Warning-mode nodes send $warning\ messages$ periodically (every T_w seconds) to inform the rest of the vehicles about their situations. These messages have the highest priority (AC3). We assume that the warning packets sent by warning-mode nodes can be received by all the vehicles in the nearby area, and so flooding offers the best reliability in terms of coverage. Normal-mode vehicles enable the diffusion of these warning packets and periodically send $beacons$ with information such as their positions, speed, etc. These periodic messages have lower priority (AC1) than warning messages and are not propagated by other vehicles. With respect to warning messages, each vehicle is only allowed to propagate them once for each sequence number; older messages are dropped.

Algorithms 1 and 2 describe our considered WMD mechanism, where $node_i$ indicates each vehicle in the scenario; m indicates each message sent or received by each vehicle; $warning$ represents a warning message generated by

Algorithm 1: Send()

```
P_w = AC3;    // set the highest priority
P_b = AC1;    // set default priority
ID = 0;       // initialize sequence number of messages
while (1) do
    if (node_i is in warning mode) then
        create message m;
        set m.priority = P_w;
        set m.seq_num = ID++;
        send(warning) to all neighbors;
        sleep (T_w);
    else
        create message m;
        set m.priority = P_b;
        send(beacon) to all neighbors;
        sleep (T_b);
```

Algorithm 2: OnRecv()

```
for (every received message) do
    if (m is a warning message and m.seq_num received for the first
    time) then
        broadcast(m);
    else
        discard(m);
        // duplicated warnings and beacons are not rebroadcasted
```

a warning mode vehicle; $beacon$ represents a normal message generated by a normal vehicle; T_w is the interval between two consecutive warning messages; T_b is the interval between two consecutive normal messages; P_w indicates the priority that warning messages have and P_b indicates the priority that normal messages have.

III. Determining Representative Factors using 2k Factorial Analysis

In the simulation of VANETs, the number of possible factors and their values, or levels, can be very large. In this section, we use the 2k factorial analysis [1] to determine the most relevant factors that govern WMD performance, and to reduce the required amount of simulation time. We consider 8 factors which we felt are significant. They are listed in Table I. We tag each factor with A, B, C, ..., H, as stated in the table. Thereafter we specify two possible environments for each factor, which is described by two different levels, i.e. Level -1 and Level 1. Each level provides different parameters values to that factor, thus defining the experimental scope. Once all the required simulation experiments (2^8) are completed, each performance factor can be regressed using the 2k factorial method through a nonlinear regression model of the form:

$$\begin{aligned} \mathbf{y} \;=\; & q_0 + q_A x_A + q_B x_B + q_C x_C + ... + q_H x_H + \\ & q_{AB} x_A x_B + q_{AC} x_A x_C + ... + q_{GH} x_G x_H + \\ & q_{ABC} x_A x_B x_C + ... + q_{FGH} x_F x_G x_H + \\ & ... + q_{ABCDEFGH} x_A x_B x_C x_D x_E x_F x_G x_H \end{aligned} \quad (1)$$

Substituting the values for $\mathbf{y}$ in Equation 1 and solving it for q_i's, we obtain a set of expressions that are linear combinations

TABLE I
Factors considered and their values

Factor	Level -1	Level 1
number of warning nodes (A)	3	10
number of nodes (B)	25	100
map area (C)	$2000m \times 2000m$	$5000m \times 5000m$
normal message priority (D)	AC0	AC3
periodicity of messages (E)	$1\ packet/sec.$	$20\ packets/sec.$
maximum speed (F)	$14\ meters/sec.$	$23\ meters/sec.$
downtown size (G)	$500m \times 500m$	$1500m \times 1500m$
downtown probability (H)	0.3	0.7

of the responses such that the sum of the coefficients is zero. From these values, we can calculate the total variation for each of the three metrics of interest (blind vehicles, packets received, and propagation time).

Finally, using the sign table method, we can analyze the results and detect variations which depend on the various combination of factors. The importance of a factor will depend on the proportion of the metric *total variation*. Moreover, the use of 2k factorial allows to evaluate the impact of combining different factors. Results of our 2k factorial analysis show that:

- The average number of blind nodes is largely affected by factors C, B, and the BC combination.
- The average number of packets received per node is largely affected by factors G, H, B, and the GH combination.
- The average time required to complete the propagation of warning messages is largely affected by factors B and C.

Based on the above outcome, we can state that having a higher density of nodes (i.e., B) is very important for reducing the number of blind nodes and the time required for complete propagation of warning messages. Also, when more vehicles are concentrated in downtown (i.e., H), the number of packets received per node increases considerably.

IV. Simulation Environment

In this section, we present our VANET simulation setup. Simulation results presented in this paper were obtained using the ns-2 simulator. We modified the simulator to follow the upcoming WAVE standard as closely as possible. Achieving this requires extending ns-2 to implement IEEE 802.11p. In terms of the physical layer, the data rate used for packet broadcasting was fixed at 6 Mbit/s, which is the maximum rate for broadcasting in 802.11p. The MAC layer was extended to include different priorities for channel access.

Each simulation lasted for 450 seconds. In order to achieve a stable state before gathering data traffic, we only started to collect data after the first 60 seconds. Since the Random Waypoint Model is considered unrealistic [3], in our simulation vehicles moved according to a mobility model that we had developed, called *Downtown Model* (DM) [4]. DM is a model included in the CityMob mobility generator that we had proposed and validated for use in VANETs. In this model, streets are arranged in a Manhattan style grid, with a uniform block size across the simulation area. All streets are two-way,

TABLE II
PARAMETER VALUES FOR THE BASIC SCENARIO

Parameter	Value
number of nodes	100
maximum speed	$23\ m/sec. \approx\ 83\ km/h$
map area size	$2000m \times 2000m$
distance between streets	$50m$
number of warning mode nodes	3
downtown size	$500m \times 500m$
downtown speed (min.-max.)	$3-14\ m/sec. \approx\ 11-50\ km/h$
downtown probability	0.7
warning packet size	$256B$
normal packet size	$512B$
packets sent by all nodes	$1\ per\ second$
warning message priority	$AC3$
normal message priority	$AC1$
MAC/PHY	802.11p
transmission range	$250m$

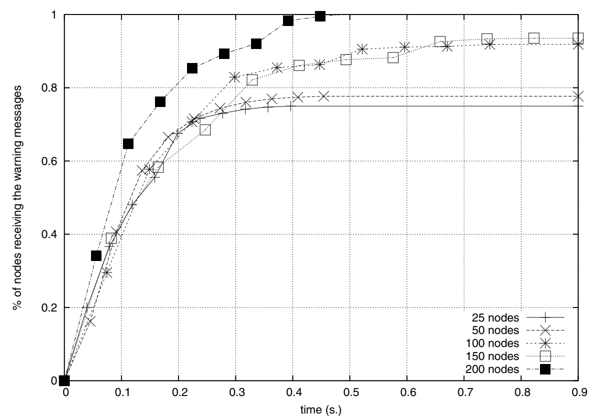

Fig. 1. Average propagation delay when varying the number of nodes.

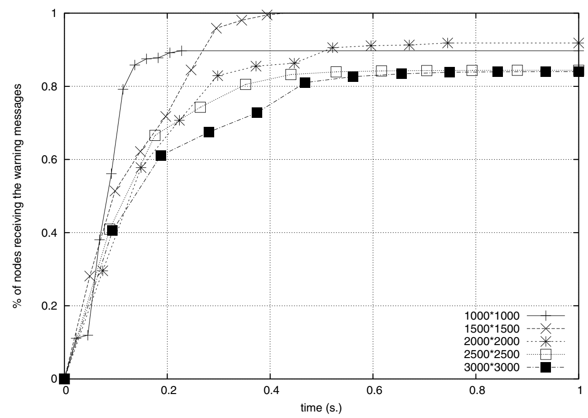

Fig. 2. Average propagation delay when varying the size of the area.

with lanes in both directions. Car movements are constrained by these lanes. Nodes will move with a random speed, lower than the maximum one defined by the user. Warning mode vehicles will not move during the entire simulation time.

Moreover, our model adds traffic density behavior similar to a real town, where traffic is not uniformly distributed. Hence, there will be zones with a higher vehicle density. These zones are usually in downtown, and vehicles must move more slowly than those in the outskirts.

V. PERFORMANCE EVALUATION

Based on the previous 2k factorial analysis, in this section we first obtain reference results using the basic scenario. Afterward, and using a wide variety of scenarios, we vary one of the selected factors and perform a detailed analysis to evaluate their impact on the overall system performance in more detail (Sections V-A, V-B, V-C and V-D).

Table II shows the parameter values used in the basic scenario to obtain reference results. The results obtained for the measured metrics when simulating the basic scenario were: 9.07 blind nodes and 72.18 packets received per node, on average. Blind nodes are typically those nodes remaining isolated with respect to other nodes in terms of transmission range.

A. Evaluating the impact of the number of nodes

Figure 1 shows the simulation results when varying the number of nodes and maintaining the rest of parameters unaltered. We selected 25, 50, 100 (basic scenario), 150 and 200 nodes. As expected, the propagation delay is lower when node density increases. Information reaches about 60% of the vehicles in less than 0.2 seconds, and propagation is completed in less than 0.9 seconds. When simulating with 200 nodes, propagation was completed in only 0.5 seconds. The behavior in terms of percentage of blind nodes highly depends on this factor. In fact, when node density is high, there are no blind nodes. This characteristic is explained because the flooding propagation of the messages works better with higher node densities. However, the flooding of broadcast messages is prone to result in many redundant rebroadcasts, heavy contention, and long-lasting collision events, i.e., the well-known broadcast storm problem. Thus, due to collisions, the number of packets received per node slightly decreases when the number of nodes increases.

B. Evaluating the impact of scenario size

In this section, we show the simulation results when varying the size of the area, maintaining unaltered the density of nodes and the rest of parameters. We selected scenario areas of 1000m×1000m, 1500m×1500m, 2000m×2000m (basic scenario), 2500m×2500m and 3000m×3000m. Node density is set to 25 vehicles per square kilometer. Figure 2 depicts the average propagation delay of the warning messages. As shown, when the area increases, the system needs more time to inform 80% of the vehicles (approximately 0.12, 0.25, 0.30, 0.35 and 0.45 seconds respectively). The percentage of blind nodes highly depends on this factor. So, when the area is very small, the percentage of blind nodes is also very small. Similarly, when the size of the area increases, the number of blind nodes also increases. We also found that the total number of packets received per node decreases with increasing scenario sizes.

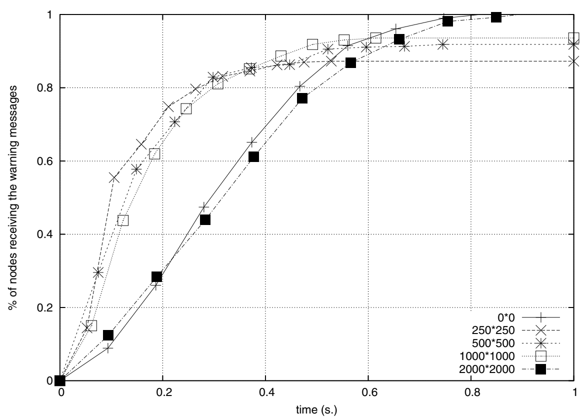

Fig. 3. Average propagation delay when varying the downtown size.

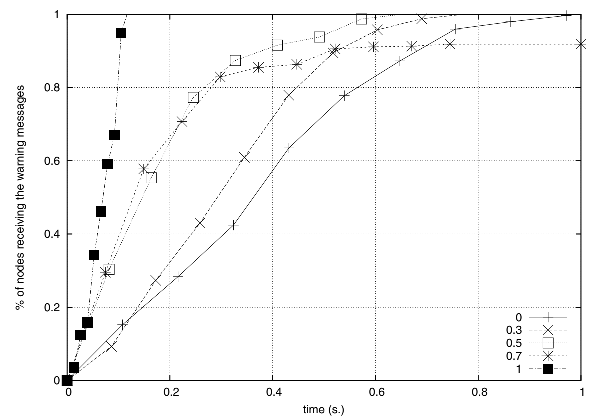

Fig. 4. Average propagation delay when varying the probability of being in downtown.

C. *Evaluating the impact of the downtown size*

In this section we study the effect of varying the size of the downtown area while maintaining unaltered the rest of parameters. We selected downtown areas of 0m×0m (none), 250m×250m, 500m×500m (basic scenario), 1000m×1000m and 2000m×2000m. Figure 3 depicts the average propagation delay of warning messages. It shows the importance of the downtown in terms of propagation delay, since there are two different tendencies: (i) when there is no downtown, or (ii) when it is so large the propagation the system needs more time to inform 80% of the vehicles (approximately 0.45 and 0.50 seconds respectively). In the other cases the system needs less than 0.3 seconds. The percentage of blind nodes also depends on this factor. When there is no downtown or it is so large, all the vehicles receive the warning information. When the downtown size is small, there are vehicles in the outskirts that do not receive the warning packets due to network partitioning, but all the nodes in downtown received the information correctly. In terms of packets received, the total number of packets received per node increases when the downtown is small (due to the high density of vehicles).

D. *Evaluating the impact of downtown probability*

In this section we show the simulation results when varying the probability of a vehicle being in the downtown. We selected probabilities of 0, 0.3, 0.5, 0.7 (basic scenario) and 1. Figure 4 depicts the average propagation delay of the warning messages. As shown, when the probability in downtown increases, the system needs less time to inform 80% of the vehicles (approximately 0.57, 0.45, 0.28, 0.30 and 0.10 seconds respectively). The percentage of blind nodes is null, except when the probability is equal to 0.7. The total number of packets received per node highly depends on this factor. When vehicles are concentrated in the downtown, the number of packets received per node increases due to the proximity of all the vehicles.

VI. Conclusion

In this paper we present a performance evaluation study analyzing the impact of a generic warning message dissemination (WMD) mechanism in an IEEE 802.11p based VANET. By using 2k factorial analysis, we have shown that factors affecting WMD performance the most are: (a) the number of nodes, (b) the scenario size, (c) the downtown size, and (d) the downtown probability. Through extensive simulations, we have evaluated in detail the impact of these factors on WMD performance. Simulation results show that: (a) increasing the number of nodes reduces the time needed to complete the WMD process, (b) the larger the geographic scenario size and downtown size, the longer is the time needed to complete WMD, and finally, (c) increasing the downtown probability greatly shortens WMD dissemination time. We believe that the results of our analysis can save time to researchers in this field by discarding unnecessary factors, and in the future we plan to apply a similar methodology to other related fields.

Acknowledgment

This work was partially supported by the Universidad Politécnica de Valencia, Spain, under project SECURA-3252, by the *Ministerio de Educación y Ciencia*, Spain, under Grant TIN2008-06441-C02-01, and by the *Fundación Antonio Gargallo*, under Grant 2008/B010.

References

[1] R. Jain, *The art of computer systems performance analysis: Techniques for experimental design, measurement, simulation, and modelling*. John Wiley & Sons, 1991.

[2] S. Eichler, "Performance evaluation of the IEEE 802.11p WAVE communication standard," in *Proceedings of the Vehicular Technology Conference (VTC-2007 Fall), Baltimore, MD, USA*, September 2007.

[3] J. Yoon, M. Liu, and B. Noble, "Random waypoint considered harmful," *Proceedings of IEEE INFOCOMM 2003, San Francisco, California, USA*, March 30-April 3 2003.

[4] F. J. Martinez, J.-C. Cano, C. T. Calafate, and P. Manzoni, "Citymob: a mobility model pattern generator for VANETs," in *IEEE Vehicular Networks and Applications Workshop (Vehi-Mobi, held with ICC), Beijing, China*, May 2008.