Evaluating Warning Dissemination in VANETs

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

We based our evaluation on the 2k factorial methodology to determine the most representative factors that affect the WMD mechanism performance. We carried out simulations to evaluate the impact of varying the characterizing factors on performance. Performance metrics evaluated are: (1) time required to propagate the warning messages, (2) the number of blind nodes (i.e., nodes that do not receive these packets) and (3) 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 the most are the downtown size, the probability of being in downtown and the number of nodes. The size of the packets sent does not affect the warning dissemination protocol's behavior.

Keywords—**Vehicular ad hoc networks, performance evaluation, inter-vehicle communication.**

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 with very specific speed patterns, (c) the communication conditions, (d) the mobility patterns (e.g., signal transmissions can be blocked by buildings and frequent partition 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 [1].

In this paper, we present a performance evaluation study that analyzes the impact of a generic and basic *Warning Message Dissemination mechanism* (WMD) based on flooding and 802.11p standard. Typically, when simulating VANETs, the number of possible parameters which can affect performance is very large, increasing considerably the simulation time required to evaluate all the different scenarios. By using the 2k factorial analysis [2], we determine the most representative factors that govern the warning message dissemination performance thus reducing the simulation time required. We have selected eight parameters: 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 considered WMD.

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

II. RELATED WORK

Previous research work on warning messages for VANETs have focused on two issues: (a) message dissemination protocols and (b) collision prevention mechanisms.

Korkmaz et al. [3] proposed a new efficient IEEE 802.11 based *Urban Multi-hop Broadcast protocol* (UMB) which was designed to address the broadcast storm problem and to avoid hidden node and reliability problems of multi-hop broadcast in urban areas. Yang et al. [4] tried to achieve low-latency in delivering emergency warnings in various road situations. More recently, Zang et al. [5] studied the performance of the *Emergency Electronic Brake Light with Forwarding* (EEBL-F) application as an example of the safety application in congested scenarios, and proposed a congestion control architecture for VANETs.

To the best of our knowledge, none of the research work currently available has identified the factors that significantly impact performance of warning message dissemination in VANETs. Moreover, only [4] and [5] did focus on the new 802.11p standard for VANETs.

III. WARNING MESSAGE DISSEMINATION (WMD) IN VANETS

In this section, we describe the Warning Message Dissemination mechanism that we consider as a reference, as well as the common essential elements.

For our basic WMD, we picked the IEEE 802.11p technology 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 MAC layer is based on the IEEE 802.11e *Enhanced Distributed Channel Access* (EDCA) *Quality*

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of Service (QoS) extensions [6]. Therefore, application messages are categorized into different *Access Categories* (ACs), where AC0 has the lowest and AC3 the highest priority. The contention parameters used for the *Control Channel* (CCH) are shown in [7].

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 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 *Warning Message Dissemination 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 a warning mode vehicle; $beacon$ represents a normal message generated by an 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. Furthermore, we consider that a vehicle is a *neighbor* of another when the Euclidean distance between both vehicles is lower than the wireless transmission range, so that communication between them is possible.

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 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
```

When a $node_i$ starts the broadcast of a message, it sends m to all its neighbors. Whenever a node receives m for the first time, it rebroadcasts by relaying m to its neighbors. Depending on their characteristics, every node repeat $send(warning)$ or $send(beacon)$ operations periodically with different periods (T_w and T_b, respectively). When a new message m is received, the receptor tests if m has already been received. To achieve this, each node maintains a list of message IDs. An incoming warning message ID is inserted in the list if m is received for the first time (i.e. its ID is not present in the list). Then m is broadcasted to the surrounding nodes. If the message is a *beacon*, it is simply discarded, since we are not interested in the dissemination of beacons.

IV. Parameters Determination using 2k Factorial Analysis

In the simulation of VANETs, the number of possible parameters and their values, or levels, can be very large. In this section, we use the 2k factorial analysis [2] to determine the most relevant factors that govern the warning message dissemination performance in order to reduce the required simulation time. Based on this analysis, we measure and compare the behavior of some important metrics such as the propagation delay of warning messages, the number of blind nodes and the number of packets received per node when modifying the most relevant parameters of a VANET scenario.

We studied eight different 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 outskirts, the probability of being in downtown, as well as the priority and periodicity of the messages sent by vehicles.

The use of 2k factorial is important for two reasons: (a) it allows us to reduce the overall number of simulations, and (b) it allows us to evaluate the relationship between different factors. The basic approach of this method is based on selecting a set of k parameters and determining 2 levels (indicated with -1 and 1), for each one of them. An experiment is run for all the 2^k possible combinations of the parameters. From each simulation run, we can also extract the $\binom{k}{2}$ two-factor interactions, the $\binom{k}{3}$ three-factor interactions, and so on.

Finally, using the sign table method, we can analyze the results and detect variations which depend on the various combination of factors. The impor-

TABLE I
FACTORS CONSIDERED AND THEIR VALUES

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

tance of a factor will depend on the proportion of the metric *total variation*.

We chose eight factors ($k = 8$) as indicated in Table I with their respective two levels values. Each performance metric can be regressed on x_A, x_B, x_C, x_D, x_E, x_F, x_G and x_H using a nonlinear regression model of the form:

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

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 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, also called *Sum of Squares Total* (SST) using Equation 2.

$$\begin{aligned}SST = {} & 2^8 (q_A^2 + q_B^2 + q_C^2 + q_D^2 + q_E^2 + ... + q_H^2 \quad (2)\\ & + q_{AB}^2 + q_{AC}^2 + q_{AD}^2 + q_{AE}^2 + ... + q_{GH}^2 \\ & + q_{ABC}^2 + q_{ABD}^2 + q_{ACD}^2 + ... + q_{FGH}^2 + \\ & ... + q_{ABCDEFGH}^2)\end{aligned}$$

The obtained values are: $\mathrm{SST}_{blind} = 163055.594$, $\mathrm{SST}_{received} = 366366.308$ and $\mathrm{SST}_{propagation} = 24.615$. To calculate the impact of element i, we have to compute the ratio: $\frac{2^8 q_i^2}{SST}$. For example, the joint impact of the number of nodes (B) and the map area (C) on the average of blind nodes, is calculated as follows: $\mathrm{BC} = \frac{2^8 q_{BC_{blind}}^2}{SST_{blind}} = \frac{2^8 (14.309)^2}{163055.594} = 0.321 = 32.15\%$.

The results of the 2k factorial analysis allow us to state that:

- The average number of blind nodes is 26.113. This metric is mostly affected by the map area (39.91%), the number of nodes (12.68%), and also their combination (32.15%).
- The average number of packets received per node is equal to 27.559. This factor is mostly affected by the downtown size (22.39%), the probability of being in downtown (18.55%), the number of nodes (17.69%) and finally by the combination of the downtown size and the probability of being in downtown (11.37%).
- The average time required to complete the propagation is 0.469 seconds. This factor is mostly affected by the number of nodes (53.25%) and the map area (20.96%).

Thus, we confirm that having more density of nodes is very important to reduce the number of blind nodes and the time required to complete the information propagation. Also, when the vehicles are concentrated in downtown, the number of packets received per node increases considerably.

In this analysis, the priority of the normal messages and their periodicity does not seem to affect the studied metrics. Next, we performed simulation to further evaluate the impact of these factors on performance.

V. SIMULATION ENVIRONMENT

In this section, we present our VANET simulation setup. Simulation results presented in this paper were obtained using the ns-2 simulator [8]. The ns-2 is a discrete event simulator developed by the VINT project research group at the University of California at Berkeley. We modified the simulator to follow the upcoming WAVE standard closely. Achieving this requires extending the ns-2 simulator to implement IEEE 802.11p. In terms of the physical layer, the data rate used for packet broadcasting was fixed at 6 Mbit/s. 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 Random Waypoint Model is considered unrealistic [9], in our simulation, nodes moved according to a mobility model that we had developed, called *Downtown Model* (DM) [10]. It is a model 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, 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.

Our model also simulates semaphores at random positions (not only at crossings), and with different delays. When a vehicle meets at a semaphore, it comes to a stop until the semaphore turns to green. Moreover, our model adds traffic density 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. The Downtown area is defined by the coordinates ($start\_x$, end_x, $start\_y$, end_y). Parameter p is used to establish the probability of a node being initially located inside the downtown area, and also the probability that nodes on the outskirts move into downtown. Finally, there are two types of nodes. Nodes that are in warning mode and send warning messages, and the rest of vehicles that propagate these messages over the whole map area.

VI. Performance Evaluation

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

The results shown in this section represent an average of different executions of the simulation with different randomly generated mobility scenarios and with warning mode vehicles placed randomly. Since the performance results are highly related to the specific scenarios used, and due to the random nature of the mobility model, we repeated the simulations to obtain reasonable confidence intervals. All the results shown have a maximum error of 10% with a degree of confidence of 90%.

We evaluated the following performance metrics: (a) average percentage of blind nodes, (b) propagation delay, and (c) average number of packets received per node. The percentage of blind nodes is the percentage of vehicles that do not receive the warning messages sent by the warning mode nodes. These nodes can remain blind because of their positions or due to collisions.

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.

Figure 1 depicts the average propagation delay of the warning messages. As shown, information does not reach all nodes, but in only 0.15 seconds about 60% of the vehicles received the warning message, and in less than 0.3 seconds the information reached about 80% of the vehicles. From now on, we will use as a reference the time it takes to reach 80% of the vehicles (or 60%, in case there are too many blind nodes). For our basic scenario, the propagation process was completed in 0.8 seconds.

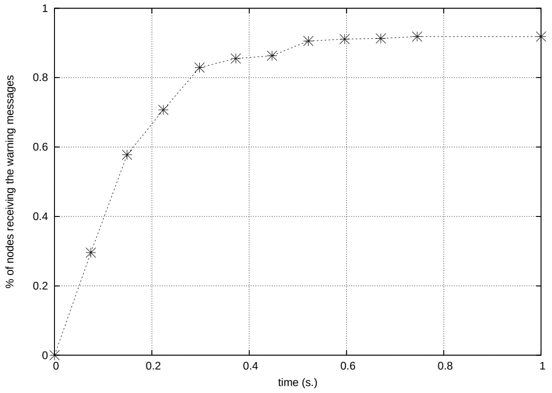

Fig. 1. Average propagation delay of warning messages in the basic scenario.

According to our 2k factorial analysis, we selected the following parameters for evaluating their impact on performance metrics: 1) the total number of vehicles (since it affects 12.68% in blind nodes, 17.69% in packets received and 53.25% in propagation), 2) the scenario size (39.91% in blind nodes and 20.96% in propagation), 3) the downtown size (22.39% in packets received) and 4) the probability of being in downtown (18.55% in packets received).

A. Evaluating the impact of the number of nodes

Figure 2 show 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 we have expected, the propagation delay is lower when the 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. 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 3 depicts the average propagation delay of the warning messages. As shown, when the area increases, the system needs more time to inform 80%

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 nodes	1 *per second*
warning message priority	$AC3$
normal message priority	$AC1$

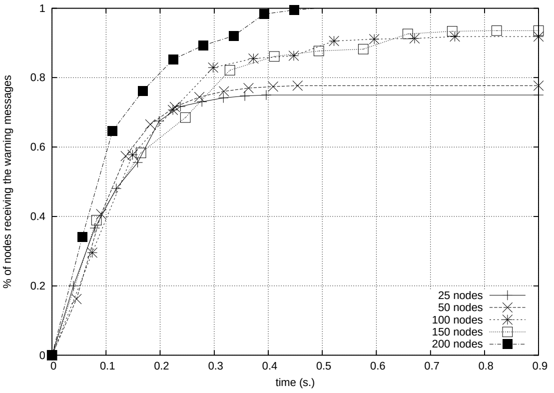

Fig. 2. Average propagation delay when varying the number of nodes.

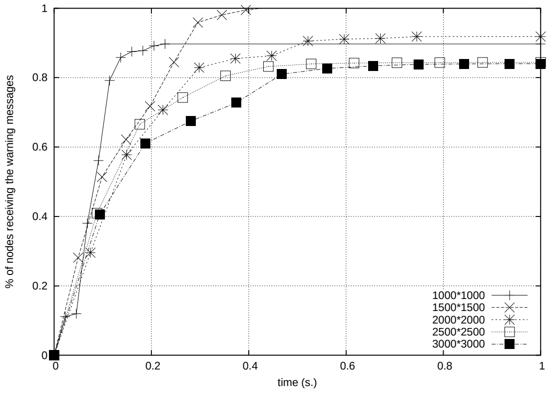

Fig. 3. Average propagation delay when varying the size of the area.

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. When the area is very small, the percentage of blind nodes is also very small. When the size of the area increases, the number of blind nodes also increases. Also, the total number of packets received per node decreases. However, it is important to note that when disseminating warning information, we are mainly interested in how to quickly send such information to a nearby region.

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 4 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) 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 outskirts that do not received the warning packets due to partition, 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 the 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 5 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 none except when the probability is equal to 0.7. The total number of packets received per node highly depends on this

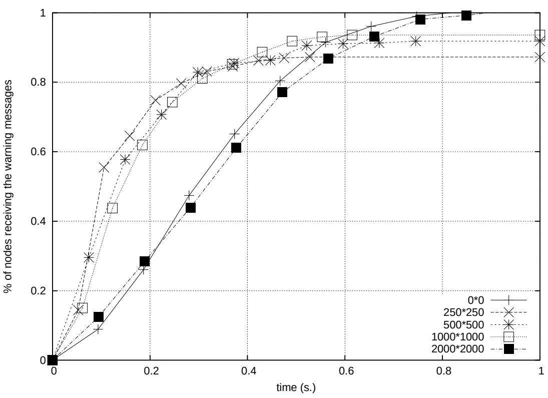

Fig. 4. Average propagation delay when varying the downtown size.

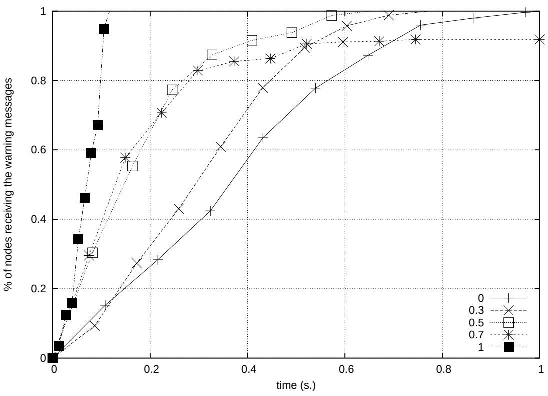

Fig. 5. Average propagation delay when varying the probability of being in downtown.

factor. When vehicles are concentrated in the downtown, the number of packets received per node increases due to the proximity of all the vehicles.

VII. Conclusion

In this paper, we presented a performance evaluation study analyzing the impact of a generic warning message dissemination mechanism in a IEEE 802.11p based VANET. We proposed a novel vehicle mobility model and we enhanced the ns-2 simulator to support the IEEE 802.11p technology.

We derived the most representative parameters for evaluating a Warning Message Dissemination mechanism (WMD) by using the 2k factorial analysis. The parameters that affect warning messages delivery the most are: (1) the downtown size, (2) the probability of being in downtown, and (3) the number of nodes.

Finally, by varying the selected factors, we exhaustively simulated more scenarios to determine their impact on performance metrics. Results obtained from our simulations allow us to draw some important conclusions. First and most importantly, node density is a crucial factor, in fact:

- The propagation delay is lower when node density increases;
- The percentage of blind nodes highly depends on node density, too. In fact, when the node density exceeds a certain threshold, there are no blind nodes;
- Due to collisions, the number of packets received slightly decreases when the number of nodes increases.

Secondly, the area size, and downtown area size has a strong impact on the performance on the WMD, in fact:

- When the area increases, the system needs more time to inform the rest of the vehicles.
- When the area is very small, the percentage of blind nodes is also very small. When the area increases, the number of blind nodes also increases. Also, the total number of packets received per node decreases.

Acknowledgments

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