Enhancement of information propagation on the highway in VANET based on Multiple Vehicle Class

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***Abstract*—The Intelligent Transportation System (ITS) has become a part of smart cities and road safety. Based on communication systems technologies, ITS can solve several road issues, such as accidents. A vehicular ad-hoc network can be part of ITS. We analyze the connectivity characteristics, the effectiveness of message propagation distance on the network connectivity, and the delivery of alert message delay. Several factors can affect the delivery of alert messages within a suitable time(i.e., low connectivity between vehicles). The free-flow state allows drivers to drive their vehicles as they want; the flow and speed of vehicles are independent. The different lanes on the highway have associated speed limits; multi-speed on the road can increase the connectivity among the vehicles and lead to minimizing the message delivery time. The fast vehicle acts as a bridge node, and it can bridge the gap between different clusters and allow information to be shared with other clusters.**

***Index Terms*—VANET, Bridge node, ITS, Multiple Vehicle class, safety message propagation**

I. Introduction

The vehicular ad-hoc network (VANET), it is part of Mobile Ad-hoc Network [1], supports the Intelligent Transportation System (ITS) through three communication modes. The vehicle communicates only with other vehicles, known as vehicle-to-vehicle, while the second type, the vehicle, communicates with infrastructure. The third type of hybrid of the two mentioned types of VANET(V2V and V2I). The different use cases in VANET can improve the ITS by reducing communication resources(i.e., roadside units). The V2V can identify some of them as improving connectivity, increasing the efficiency of vehicle traffic on the road, accident avoidance, services supporting the drivers on the way, etc. [2]. The number of accidents increased exponentially on the road, leading the researchers to design a proper communication system to improve the delivery of messages in a short time and a reliable mode. Our paper increases the mean message propagation distance through the bridge node in the multi-class minor. Most of the published papers consider a single class with constant speed [3]. The different speeds of vehicles with additional lanes lead to difficulty in analyzing the desired message propagation model [4], [5].

When an accident occurs somewhere on the highway, the decision taken by drivers should be at the appropriate time to avoid another crash. The types of applications in VANET can be employed in the management of ITS, such as safety messages. On the other hand, the safety efficiency service [6] play an important role in road safety and accident avoidance model.

The proposed model, in our paper, considers the parameters affecting the safety message delivery and its delay probability, such as antenna type, direction and different speeds of vehicles (i.e., Multi-class), type of communication mode (i.e., V2V, V2I, and etc.) [7].

The messages that are exchanged between the vehicles are alert message and beacon messages. However, the alert message can be affected by the radio range and the distance between the vehicles. The two types of exchange information, beacon message (i.e., information update position, direction, and etc.) and safety message (that is related to the dangerous message) [8] can be improved in VANET through the type of communication and by using some type of cluster to apply two-dimensional message propagation compute distance of propagation instead of one-dimensional [9]. Some types of communication can cause some problems, such as hidden node [10], when two vehicles use a control channel to exchange critical information. The direction of vehicles on the highway can be another afficating parameter. It can duplicate the message. In this paper, we consider the highway environment with multi-classes (i.e., different vehicle speeds) and alert message propagation by accident position. We simulate and compute information propagation distance with multi-speed, and extended the model to different clusters associated with their speed, to complete the investigation we add bridge node ($\mathcal{BN}$) that connect two different cluster, where the bridge node always from the faster class.

II. Related Work

VANET has many applications in different fields. Many researchers have published a number of scientific research papers related to it. They developed protocols , radio channels, ceiving the message after propagation by vehicle depends on the distance between the vehicles, collaboration between the vehicles, and etc [11]. Due to the high cost and complexity, the deployment of RSUs is difficult [12]. Other type of VANET such as V2V technology we can increase the efficiency by bridge node ($\mathcal{BN}$) to connect between different cluster to increase the distance of message propagation by low cost. However, in this paper, we use V2V instead of V2I, where the alert messages can be transfer only between vehicles.

The effect of a hidden terminal (i.e., radio channel) on the message transmission delay as investigated by several papers, the most affected parameters and most propagation models described by published survey [13]. Furthermore, the properties of the physical layer are considered by [14] and it will be another aspect of message delivery approach.

The new protocol published by [15], it is possible to achieve fast message propagation speeds with the new forward scheme. the authors of [16], proposed new algorithm that increase the delivery of message with short delay. Our investigation focuses on the analysis of message propagation distance models. Some papers used same assumption that we are consider in our paper, In [3] analysis different model to determine life time of the message, Poisson arrival process, constant transmission range are assumed by the authors, that lead not explicit results, but When different vehicles are traveling at different speeds, it is approximate. In our paper, we assume that messages of all classes (moving at various speeds) have an infinite lifetime. Hence, alert message is never dropped, and the bridge node (high speed vehicle) forward it to another vehicles(low speed and high speed vehicles) within transmission rage. In order to simulate message propagation distance for both single class and multi-class systems, in addition to developing a new tool based on the C++ programming language, we characterized the joint conditional complementary cumulative distribution function (ccdf) differential equation for the pdf of the message propagation distance.

III. Description of Proposed Model

All vehicles in our model have various antennas [17] and the same transmission range R. The heterogeneous highway vehicles, such as buses, trucks, and cars, are also taken into account. The transmission range R of vehicles is deterministic value in our investigation. a variable with a probability distribution.

Our assumptions:

- Two classes of vehicles are on the road, positioned according to independent Poisson processes with intensity λ_1; λ_2,and moving with speed v_1; v_2 respectively (homogeneous within each class), where $v_1 > v_2$.
- For fast type the parameters are: λ_1; v_1 and $\vartheta_1 = \lambda_1/v_1$
- For slow type the parameters are: λ_2; v_2 and $\vartheta_2 = \lambda_2/v_2$

Parameter	Definition
R	Radio coverage , 150 m
v	Multi-speed in the highway, 40 and 25 m/s
λ_1	Arrival rate of Vehicle , in vehicles/second
λ_2	Arrival rate of Vehicle, in vehicles/second
ϑ_1	The exponentially distributed vehicle density parameter for fast vehicles is given in car/meters.
ϑ_2	The exponentially distributed vehicle density parameter for slow vehicles is given in car/meters.
$\mathcal{D}(t)$	distance of Message propagation at time t
$\mathcal{NB}$	Bridge Node (fast type with v_1)
$\mathcal{G}_F$ and $\mathcal{G}_L$	Representing the class of the first and the last vehicle of the cluster respectively

- Type of distribution is Poisson distribution.
- IEEE 802.11p assign as wireless communication protocol.

The notation used in the sequel is summarized by Table I

IV. Analysis of Message Propagation based on Multi-classes

In our paper, we assume a crash somewhere on the highway, at position X. Information about the accident travels to the left, and the vehicles within communicating range R share information. Within each class(i.e., fast or slow), these clusters $\mathcal{G}$ of the same class are connected (equivalence cluster) and within the same class, connected due to the same speed of a class. The information between clusters within the same class can only 'jump' due to help from another cluster. Both classes (fast and slow) on the road are positioned according to independent Poisson Process intensity. If there is a gap between the fast and slow informed classes, one vehicle from the fast class overtakes the slow cluster and acts as a bridge node $\mathcal{NB}$ as shown in figure 1. We can use the bridging technology instead of RSUs by reducing the high cost and complexity of the RSUs deployment on the highway.

The published result of the right-continuous stochastic process $\{\mathcal{D}(t), t > 0\}$ [9], [18], deals with single class constant speed, where $\mathcal{D}(t)$ is the information propagation distance of alert message, that is the position of the last car measured from X having the message received at time t, plus R (the radius of its radio coverage) . On the other hand, the authors in [19] provide the differential equations governing the evolution of $\mathcal{D}(t)$, but it is for a single class. Our paper provides the characterization of the joint conditional ccdf of stochastic interpretation $G_{ji}(x)$ and information propagation distance $\mathcal{D}(t)$ for multi-classes with different speeds.

As shown in Figure 1, at time t cluster of vehicles gets informed, and after $t + \Delta$; the fast vehicle overtakes the last

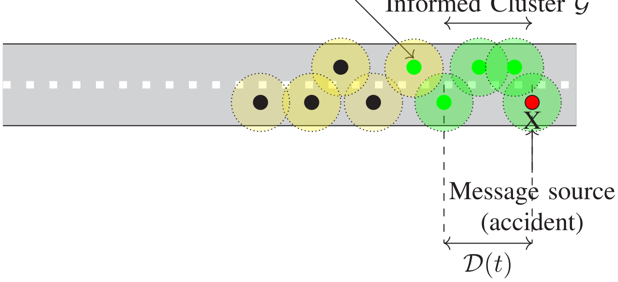

Fig. 1. The highway snapshot at time t for multiple class

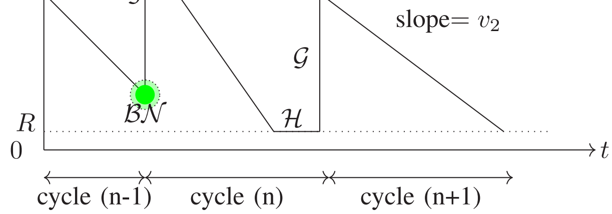

Fig. 2. The information distance′s trajectory $\mathcal{D}(t)$

informed vehicle in the cluster, acting as a bridge node ($\mathcal{BN}$) to connect the informed cluster and the uninformed cluster. At time t cluster of vehicles gets informed, after $t+\Delta$ one vehicle from fast class acts as bridge node ($\mathcal{BN}$) to connect the informed cluster and the slow class.

A. *message propagation distance* $\mathcal{D}(t)$

If the distance between the vehicles is less than the radio range, the group of vehicles is referred to as a ”cluster”, it is denoted by $\mathcal{G}$ [20]. We introducing multiple vehicle classes with different speed assigned to them. If there are N classes, the ratio of vehicles belonging to class i is denoted by α_i and the corresponding speed is denoted by v_i. With these parameters the arrival rate of class i vehicles is $\nu_i = \alpha_i \cdot \nu$ and An exponential distribution describes the distance between two class i vehicles with parameter $\lambda_i = \nu_i/v_i$. Since, Poisson process governs the arrival of the vehicles, with$\lambda = \sum_{i=1}^{N} \lambda_i$, the distance between two vehicles of any class is still exponentially distributed. Figure 2 shows the trajectory of the message propagation distance,$\mathcal{D}(t)$.

There can only be one informed cluster on the highway at a time t because we have a multi-speed class and no RSUs present. According to various speeds, the system adapts dynamically.

The information during these intervals, which is represented by the exponentially distributed random variable $\mathcal{H}$, is only known to the static message source.

The new cluster $\mathcal{G}$ is started once the new vehicle has reached the accident scene and is within radio range of the message source. After that, the message propagation distance starts to shorten at a rate of v_2. The bridge node initiates a new cluster again; otherwise, there will be no informed vehicles on the highway after time $t+\Delta$, and the fast vehicle receives information from the last informed cluster.

B. *The conditional cluster length distribution*

$\mathcal{G}$, which is crucial to the analysis of the single class case, will be equally crucial to the analysis of the multiclass case. . Instead of investigating the cluster length alone, to derive the transient description of the system we need to study a more complex quantity that also depends on the class of the first and the last vehicle in a cluster.

Hence, besides cluster $\mathcal{G}$, we introduce two more random variables $\mathcal{G}_F$ and $\mathcal{G}_L$ representing the class of the first and the last vehicle of the cluster, respectively. When no vehicles received the alert message, the only ”cluster” of the system consists of the alert source itself (at position X). To allow this degenerate case, we extend the set of vehicle classes $\{1,\ldots,N\}$ by $\emptyset$ representing the ”no vehicle” case, hence we get $\mathcal{G}_F, \mathcal{G}_L \in \{\emptyset, 1, \ldots, N\}$.

In this section we characterize the joint conditional ccdf $G_{ji}(x) = P(\mathcal{G} > x, \mathcal{G}_L = i | \mathcal{G}_F = j)$. From the stochastic interpretation it is possible to express $G_{ji}(x)$ recursively as

$$G_{ji}(x) = \begin{cases} e^{-\lambda R}\delta_{ij} + (1-e^{-\lambda R})\frac{\lambda_i}{\lambda}(1-\delta_{i\emptyset}) & x \le R, \\ \int\limits_{y=0}^{R} \lambda e^{-\lambda y} \sum\limits_{k=1}^{N} \frac{\lambda_k}{\lambda} G_{ki}(x-y)dy(1-\delta_{i\emptyset}) & x > R, \end{cases} \tag{1}$$

where δ_{ij} is the Kronecker delta function for which we have $\delta_{ij} = 1$ if $i = j$ and 0 otherwise.

The first term of the $x \le R$ case is relevant when there is no vehicle in the range of the radio coverage R. Since x falls into the coverage area, $\mathcal{G} > x$ holds with probability one, and $\mathcal{G}_L = \mathcal{G}_F$. According to the second term, when there is a vehicle in the coverage area, $\mathcal{G} > x$ still holds with probability one, and the last vehicle of the cluster is of class i with probability λ_i/λ.

In the second case ($x > R$) the integral represents the deconditioning with regards to the distance between the first two vehicles. The next car is of type k, the distance is y, hence $G_{ki}(x-y)$ is the probability that the cluster length is x and the last car of the cluster is of type i.

Theorem IV.1. *The length of the mean joint conditional cluster* $E_{ji}(\mathcal{G}) = \int_{x=0}^{\infty} G_{ji}(x)\,dx$ *can be expressed by*

$$E_{ji}(\mathcal{G}) = \begin{cases} R\,e^{-\lambda R}\delta_{ij}, & i = \emptyset, \\ \dfrac{1}{\lambda}\dfrac{\lambda_i}{\lambda}(e^{\lambda R} - 1) - \dfrac{\lambda_i}{\lambda} R\,e^{-\lambda R}, & i \ne \emptyset. \end{cases} \tag{2}$$

Proof. The proof of the theorem is similar to the one of in published paper [19]. ☐

C. *Speed of message transmission in the presence of roadside units*

Roadside units (RSUs) with multiple classes may be taken into consideration. RSUs are distributed evenly along the

The radio coverage of the vehicles R and the transmission range $\hat{R}$ of RSUs are different. There are two ways that RSUs can communicate with one another: either there is no direct communication between them, as is the case in the Figure 3, or there is a direct connection [21].

According to the Poisson arrival process, the vehicles enter the highway. However, the scenario is as follows in the case of RSUs deployed on the road: The RSU that is located the farthest away (at $U_k - 1$) serves as a renewal instant.

According to Figure Figure 3, the cluster length $\mathcal{G}$ needed to cover the next RSU is $D - 2\hat{R} + R$.

At the RSU, U_k receives the alert message; this RSU behaves as a cluster head if the vehicles are close enough to each other that they can be long enough to reach the next RSU (U_{k+1}) as well [22].

If the vehicles are close enough to one another that they can be long enough to reach the next RSU ($U_k + 1$), as well as [22], this RSU acts as a cluster head and receives the alert message at U_k.

The bridge node $\mathcal{BN}$ can play an important role in this case, to bridge the slow vehicles with the next RSU.

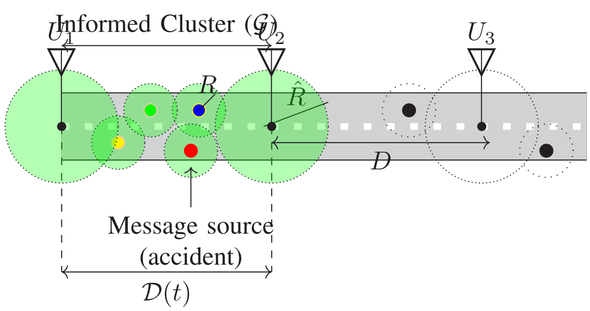

Fig. 3. The green color on the road at time t indicates the informed RSUs and Vehicles

D. Numerical examples

Here, we present the behavior of the proposed method and compare it with the procedure published in [19]. This comparison shows that the mean propagation distance based on multi-class improves the connectivity and increases the message delivery within a short time as shown in Figure 4. When the alert message is received at the proper time, the drivers on the road can decide at the appropriate time. However, that will help to reduce the number of accidents on the road.

The mean message propagation distance $E(\mathcal{D})$ is depicted as the function of the car arrival rate λ_1,λ_2 and radio transmission range R (see Figure 5). According to Figure5, the car arrival rates λ_1, λ_2, and radio transmission range R are functions of the mean message propagation distance $E(\mathcal{D})$, which is shown as a function of these parameters. Throughout the numerical examples, the vehicles' speeds are fixed at $v_1 = 40$ and $v_2 = 25$ m/s of fast and slow class respectively.

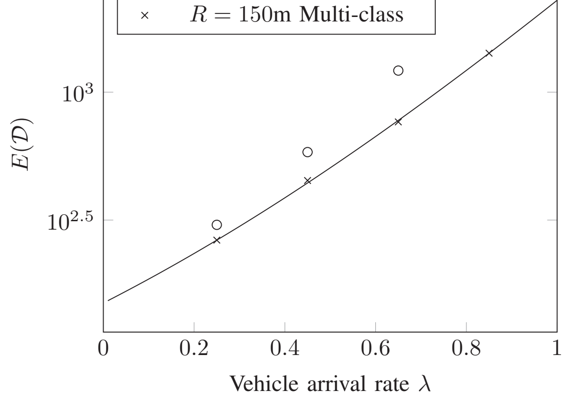

Fig. 4. Compare the mean message propagation distance between single and multi-classes

The results are as expected: The bridge node facilitates long message propagation distance for the slow class with rate arrival λ_2 leads to a long message propagation distance with the help of the bridge node.

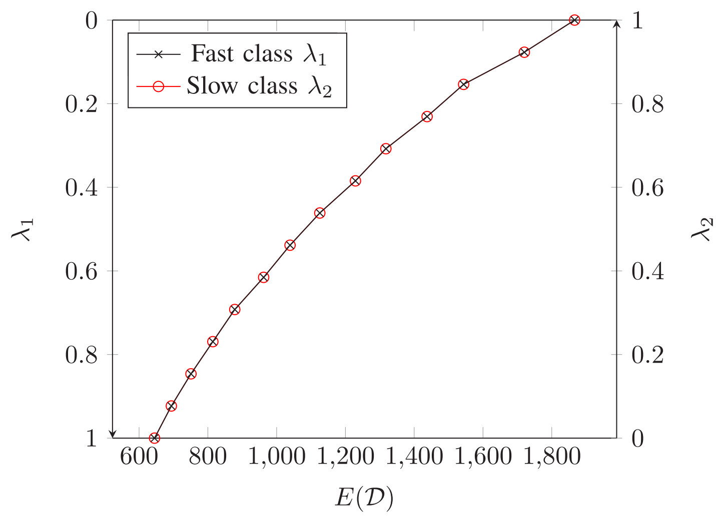

Fig. 5. The mean message propagation distance based on Multi-class

It is an interesting result that can be used for highway network planning. By using the following parameters, Figure 4 confirms that the various speeds play a significant role in the message propagation:
Where the λ_1 fast associated with $v = 40m/s$, and λ_2 slow with $v = 25m/s$, $R = 150m$, the Figure 5 presents as shown in Table II

In the conclusion, we show some studies that can be conducted at the asymptotic rate of information propagation, $\mathcal{S}$, at which the information point is moving (to the right); we point out that it is difficult to conduct an analytical investigation at this rate.

λ_2	λ_1	probability of $class_1$	probability of $class_2$
0.00	0.65	0	1.0
0.05	0.60	0.0769	0.9231
0.10	0.55	0.1538	0.8462
0.15	0.50	0.2308	0.7692
0.20	0.45	0.3077	0.6923
0.25	0.40	0.3846	0.6154
0.30	0.35	0.4615	0.5385
0.35	0.30	0.5385	0.4615
0.40	0.25	0.6154	0.3846
0.45	0.20	0.6923	0.3077
0.50	0.15	0.7692	0.2308
0.55	0.10	0.8462	0.1538
0.60	0.05	0.9231	0.0769
0.65	0.00	1	0

We want to calculate the speed of information propagation, if $\mathcal{S} < 0$, then the information point will keep on traveling further and further to the left.

E. Simulation Results

Our simulation used with three scenarios as following:

- Idealize simulation : we used the speed as constant and
- Realistic beacon : In This scenario we switch on the beacon interval to exchange the information between the vehicles.
- Multi-speed Simulation : This scenario with real parameters as shown in Table IV-E, where all used vehicles have different speed and way within two lanes.

TABLE III
PARAMETERS OF SIMULATION

Parameter	Definition
R	Radio Transmission 150m
L	Road length 10Km
Vehicle speed	25 and 40 m/s
Arrival rate	Poisson Arrival rate
Channel Frequency	5.890 GHz
Analogue Model	Simple Path loss Model
Alert message period	50 ms
Channel bandwidth	10 MHz
Channel data rate	3 Mbps
Size of message	100 Bytes
Time of Simulation	3600s

V. CONCLUSION

In our paper, we introduce a new contribution for message propagation distance based on multi-class with different vehicle speeds. Realistic simulation parameters (Veins and SUMO within OMNET++) are used to validate the results. In addition, we created a C++ simulation tool. To achieve a high message propagation speed, bridge nodes can be used in place of RSUs, according to our comparison of the results with the published study (i.e., single class constant speed).

paper will be extended. Our findings can be used to improve highway communication systems.

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