A New Approach for Modeling Vehicle Safety Based on Cooperative Awareness in Emergency Scenarios[*]

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Abstract

Supporting of Safety Applications is the main motivation behind the development of Vehicular Networks. These applicationsare supposed to specify the safety level of the current situation and then, inform the control system or the driver. The successof safety applications relies on delivering messages in a timely manner. Delivered messages are used to establish a certain levelof awareness about the surrounding area for the receiver vehicle. Successive message losses will degrade the reliability of safetyapplications and also, reduce the level of awareness. So, determining the impact of successive packet losses on safety and awarenessis important. This paper models the safety and awareness values according to successive message losses using Markov chain model.Our model provides some new guidelines for analyzing a vehicle's safety based on the current situation of the network and thevehicle's kinematical properties. This model gives us the channel situation as well as the vehicle's risk value. In the proposedmodel, the uncertainty of the driver perception about an upcoming event due to the lack of information is also taken into account.We numerically investigate the impact of distance and velocity on safety. The safety applications can use this model to makedecisions in order to prevent the upcoming accidents.

Key words: Vehicular Networks, Safety Modeling, Markov chain model, Awareness, Uncertainty

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1. Introduction

Vehicular networks in context of the Intelligent Transportation Systems (ITSs) have attracted plenty of attentions in the recent years. Supporting safety applications is the main driving force behind their development. Safety applications, like other safety control systems and decision making systems, need real time and accurate information in order to perform with high performance. In vehicular networks, messages play an important role in creating mutual awareness between the vehicles and delivering necessary information to the safety applications. The awareness helps the drivers to take appropriate actions (e.g. slow down or change lane) in timely manner as mentioned in Feng et al. (2009).

In order to create the situational awareness, Xu et al. (2004),ElBatt et al. (2006) proposed thateach vehicle broadcasts its position, direction, velocity and acceleration following a specified period(e.g. each 0.1, 0.5, 1 second). This information is given to the safety application to assess the situation and produce appropriate warnings, alerts and other form of assistance to the drivers. Thus, each message loss causes a minimum degree of error on tracking process, however, Kalman filter can be used as a help to fill these gaps between exact positions and approximated values, based on the researches in Sinopoli et al. (2004). Determining how much a host vehicle is safe based on the current situation and successive packet losses embrace every safety application as a challenge.

ElBatt et al. (2006), Bai and Krishnan (2006)use network performance metrics such as packet reception rate (PRR) to analysis the reliability of safety application. However, these metrics may have a weak performance in the situation assessment of current moment. Handling the errors and uncertainty of delivered data should be considered in situation assessment process.

In order to evaluate the current situation based on packet reception rate and dynamic properties more appropriately, we have used the Markov chain modeling aiming at proposing a framework for safety evaluation of the safety applications, i.e. Forward Collision Warning (FCW) and Emergency Brake Warning (EBW). Awareness Ranges (AR) introduced in this paper refers to the required awareness levels that prevent the accident. Meaning that, they determine whether human inception or the awareness created by communication or even both of them can handle an unsafe situation or not. First of all, we calculate the awareness regions for the host vehicle with respect to its leading vehicle. Then, we compute the safety of host vehicle based on the number of successive packet losses which are tolerable. To the best of our knowledge, this paper is the first study in field of safety modeling and assessment. Our analysis provides new quantitative guidelines and analytical inputs for the design of adaptive V2V safety protocols which should be capable of maintaining high reliability and efficiency in the face of large variations in vehicular traffic and V2V network conditions.

The rest of this paper is organized as follows. In Section 2, we explain the related works. Our proposed model is described in Section 3. Numerical study and simulation evaluation are presented in Section 4. Finally, we conclude this paper in Section 5.

2. Related Works

The driver’s perceptions are the primary source which can recognize the events in surrounding environment and react to them properly. In fact, based on the researches in Green (2000),speed of human reaction to a specified event which depends on perception quality and uncertainty of the driver will increase the reaction time. Thus, the driver must be notified before in time regarding to human reaction constraints because the received alarms can reduce the driver perception time effectively. Based on the findings inGreen (2000), Green (2009), the perception-reaction time in presence of alarm is between 0.3 and 0.7 second and otherwise is between 1.1 and 1.8 second.

Creating situational awareness helps driver or control system to percept the situation more accurately and always has been a hard task to accomplish. Many technologies are invented to realize this matter. Using sensors is one of the usual ways to create situational awareness for the drivers. Nevertheless, certain properties of wireless networks such as acceptable coverage range, customizable attributes and accuracy of delivered data make them suitable frameworks for the development of safety applications. Based on ElBatt et al. (2006),information dissemination between communicating vehicles leads to enhancing situational awareness in VANET. This information reflects real-time dynamic properties of the sender vehicle. However, successive packet losses in some situation have dramatic effects on the situational awareness in cases which use VANET as a framework.

Emergency and beacon are two types of DSRC messages which are triggered differently from each other. Beacon messages mostly are used for tracking purposes and also enhance the overall awareness. On the other hands, emergency message are used to cover unexpected events in a way that create awareness about the events which endanger safety. However,Bai and Krishnan (2006)mentioned many factors degrade the reliability of safety applications. In ElBatt et al. (2006),Ma et al. (2011),Yousefi and Fathy (2008), new metrics for performance evaluation of the vehicular network have been introduced. Packet reception rate (PRR), Packet Delivery Rate (PDR) and Effective Range (ER) are three metrics which are mostly used for performance evaluation. However, these metrics cannot be used to evaluate the current situation and do not give us the level of awareness at the moment. In R.K. Schmidt (2010), new metrics have been introduced for analyzing the quality of cooperative awareness in presence of beacon messages. In there, message forwarding is used to improve the quality of awareness. In Rezaei et al. (2010), new adaptive beaconing method for enhancing the overall awareness has been proposed. Nevertheless, in none of them the impact of awareness on situation assessment and decision making in emergency scenarios have not been considered.

3. Modeling Vehicle’s Safety

Based on the importance of awareness,we investigate the effect of safety packets on awareness and vehicle safety. Obviously, when a vehicle crashed all sent messages have not the same value for all the involved vehicles. Vehicle’s dynamics give them a value. Fig.1 shows the impact of vehicle’s dynamics on number of successive packet losses which are tolerable. The Fig.1 also shows the number of packets which are sent during human perception-reaction time when alarm do not exist.

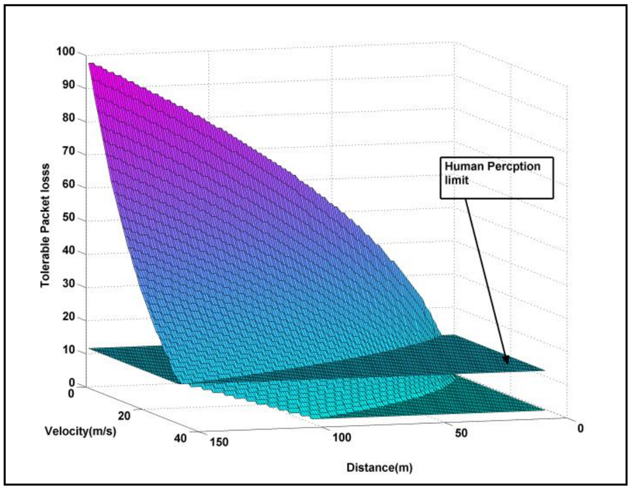

Fig. 1: The number of tolerable messages losses. Human perception limit shows

The relative safety of two vehicles in the case which the front vehicle has crashed is modeled by Markov chain. Each message delivery and loss changes the rear vehicle's current state. Our model skips all predictable and inessential situations and just focuses on emergency situations. In this regard, Awareness Ranges (ARs) are introduced which help us to better understand relative situation of host vehicle respect to the other vehicles. Our model concept is presented based on the following assumptions in order to show the applications of model more clearly. Two vehicles V_H and V_L are host vehicle and leading vehicle respectively. Both of them are equipped with GPS and DSRC for positioning and communication respectively. Vehicles only use communication for informing each other from the incident along the road. The safety applications have a precise estimator for the tracking purposes. Built in sensors within a vehicle gives us velocity, acceleration and deceleration. Besides, vehicles are totally aware of situation of each other before the first packet loss. Finally, the rear vehicle is in AR of the front vehicle during first packet loss.

1. Awareness Range

Awareness Range (AR) is defined as the distance required to response to a particular event while considering a particular source for awareness. In this paper, two types of awareness ranges are defined respect to their source of awareness: Visual Awareness Range (VAR) and Communication Awareness Range (CoAR). VAR is the distance in which a driver can handle his/her vehicle without getting any alarms provided that an event occurs. CoAR is the distances in which a driver can handle upcoming events if there is awareness created by communication network. The host vehicle is allowed to be closer if the level of awareness is high enough. Our model only works for the area between CoAR and VAR. As Fig.2 shows, the area between two vehicles is divided in a way that both zones are distinguished from each other.

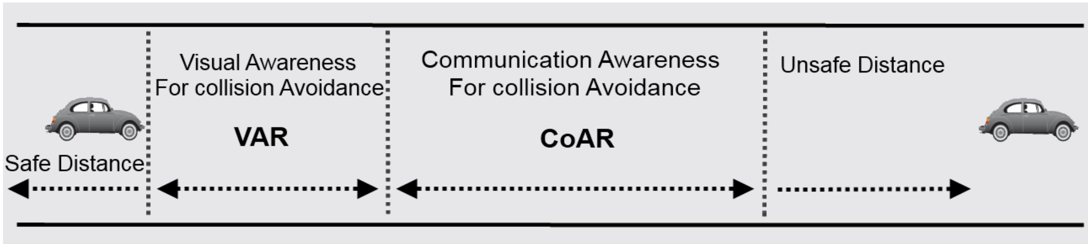

Fig. 2: Awareness types, safe and unsafe reigns

These ranges are application-related and for different applications there would be different ranges based on their corresponding events (e.g. lane changing and lane change assistant). In this paper, according to on simplicity and similarity of applications, FCW and EBW have been taken into account. VAR for the both applications are the same. ARs calculation requires kinematical information of involved vehicles. This information is captured by in-vehicle sensors. For two vehicles V_L and V_H with initial velocity v_L and v_H respectively, awareness ranges are calculated by Eqs. 1,2:

$$\mathrm{VAR} = \frac{\left(v_H + t_{r_{Visual}}\right)^2}{2d_H} \quad (1)$$

$$\mathrm{CoAR} = \frac{\left(v_H + t_{r_{Warning}}\right)^2}{2d_H} \quad (2)$$

Where $t_{r_{visual}}$ and $t_{r_{warning}}$ are reaction time for visual and warning cases.

2. Markov Chain Model

The safety of rear vehicle in respect to front vehicle is shown as a Markov chain model. In this model, each state refers to a specific number of successive messages losses. The model has two fixed states: safe and unsafe state. These two states determine initial and final states of the proposed model. The start state refers to the safe situation with full awareness and no message losses, and the end state refers to accident situation. Each middle state is displayed by S_i where index i refers to the number of successive messages losses. The transition between two consecutive states S_i and $S_i + 1$ happen when a message is lost. Number of middle states isdetermined using the tolerable network latency and packet interval. The tolerable network latency depends on vehicles dynamics and calculated by solving collision equation. Transition between S_i and S_{i-1}happens only when the state S_i is the safe state.

The transition probability P used in the model is the PRR. We also include the uncertainty of human perceptions or control system about the accident in the proposed model. Uncertainty for control system is due to the lack of information or data caused by sensors or trackers. However, the driver perceptions are related to human and environmental factors. In order to handle this uncertainty, the probability of accident,P_{acc} is added to the model which is a function of human and environmental factors. The Markov model for a simple scenario with accident probability P_{acc} has been depicted in Fig.3. Emergency braking is covered by setting $P_{brake} = 1 - P_{acc}$. In Fig.3, The red and yellow states show the border of CoARB and CoAR respectively. When a vehicle enters the area between CoAR and CoARB, by delivery of each messages vehicle will be informed about upcoming incident so if the leading vehicle has been crashed the host vehicle goes to the unsafe state otherwise it will be safe. This process for area between VAR and CoAR is different and if either accident or brake happens by delivery of each message, vehicle state transits to the safe state. During an accident, if the host vehicle is in the CoAR, the approximated risk matches with actual risk and consequently the host vehicle is in unsafe state. In other cases, if no accident happens or leading vehicle brakes, then host vehicle is in safe state provided that it is not in CoARB. When host vehicle enters unsafe state, there is no way to exit. Obviously, by increase of the number of middle states, which depends on packet interval, borders between VAR, CoAR and CoARB will be clearer.

We show the transition matrix of model by five states in Eq.3 wherein states 3 and 4 are the borders of CoAR and CoARB in the uncertain section of the model. Afterwards, P_{acc} appears in their transition probabilities. This sample has been showed for sake of showing the transition matrix not a real-world scenario.

$$TM_{4,4} = \begin{pmatrix} P & 1-P & 0 & 0 & 0 \\ P & 0 & 1-P & 0 & 0 \\ P.(1-P_{acc}) & 0 & 0 & 1-P & P.(P_{acc}) \\ P.(1-P_{acc}) & 0 & 0 & 0 & P.(P_{acc})+1-P \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} (3)$$

For the general cases the transition matrix is produced by Eq.4:

$$TM_{n,m} = \begin{cases} P & \text{for } n=0 \text{ and } R_V \geq m \leq R_{CA} \\ 1-P & \text{for } n+1, m \text{ and } m \neq m_{max} \\ P.(P_{acc}) & \text{for } n=0 \text{ and } R_{CA} \leq m < R_{CVB} \\ P.(1-P_{acc}) & \text{for } R_{CV} \leq m < R_{CVB}, m \\ 1 & \text{for } n_{max} = m_{max} \\ 0 & \text{otherwise} \end{cases} (4)$$

Where R_V, R_{CA} and R_{CAB} are VAR, CoAR and CoARB respectively.

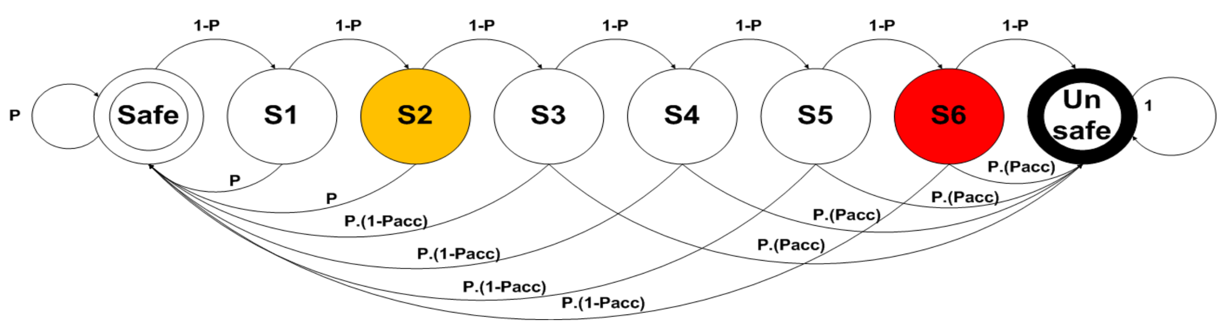

Fig.3: The Proposed Safety Markov Model in Presence of Uncertainty

3. Safety Assessment

Quantifying the safety of the host vehicle in current situation relative to a particular event is major achievement of our model. For safety assessment of current situation, steady state probabilities should be calculated. Steady state probabilities for the model are calculated using balance equations. Intermediate states probability is $P_k = (1-P)^k$ where k represents number of successive messages losses. The probabilities of the safe state P_{safe} and unsafe state P_{unsafe} which are calculated using balance equations are shown in Eqs. 5, 6 respectively:

$$P_{safe} = \frac{(\sum_{i=1}^{m} P_i)P}{1-P} + \frac{P.(1-P_{acc})(\sum_{i=m+1}^{n} P_i)}{1-P} (5)$$

$$P_{unsafe} = P_n.(P.(P_{acc}) + 1 - P) + P.(P_{acc})(\sum_{i=m+1}^{n} P_i)(6)$$

Where the first part of Eq.5 refers to sum of state probability of the states before VAR and the second part refers to the area between CoAR and CoARB in which P_{acc} has effect on safety of host vehicle. In fact safety of the host vehicle when it is out of VAR is equal to sum of state probabilities of all states between VAR and CoARso their probabilities must be added to P_{safe} because if the vehicle is informed in one of those states, it is safe. In Eq.6, unsafe state probability only depends on the states between CoAR and CoARB.

4. Numerical Results and Simulation

In this section, we numerically investigate the probability of safety of the host vehicle which is application of our interest. Our numerical results are obtained for three scenarios in which vehicles move straight in the same direction on a highway. Besides, the transmission range of each vehicle is 300 meters and each of themhas the same deceleration i.e. for the dry road case is $8\frac{m}{s^2}$. The driver perception reaction time in presence of the communication awareness is set to 0.5 second and for the visual awareness is 1.1 second. In scenario 1, $V_L$continues its path and no accident occurs, so $P_{acc} = 0$. In scenario 2,$V_L$crashes at time $t = 0$ with probability $P_{acc} = 50\%$ and brakes with probability $1 - P_{acc}$. In scenario 3, V_L crashes at $t = 0$ and V_H takes brake after t_r which depends on the type of awareness. We use formula presented in Ma et al. (2011) to compute PRR in our numerical studies. We first set up a simulation with simulator Veins which is introduced in Dressler et al. (2011) to validate PRR equations inMa et al. (2011). We use those equations in our numerical results as the probability of successful delivery P. With these three scenarios, we investigate the impact of PRR, packet interval and vehicle's dynamic on the safety.

The safety of the host vehicle based on PRR is depicted in Fig.4. As depicted in Fig.4 with increasing the PRR, the safety increases. In scenario 3 this growth totally depends on PRR.

In Fig.5, impact of message interval on safety of $V_H$has been depicted. In scenario 3 where the accident happens and VH is locates in the area between VAR and CoAR, safety is always zero because relative distance is not enough to avoid collision. Obviously, when velocity of the host vehicle increases, passed distance per second increases consequently, and just a small time remain for driver reaction. Distance affects the safety both PRR and delivering time window simultaneously. Fig.6 shows these effects with a surface plot.

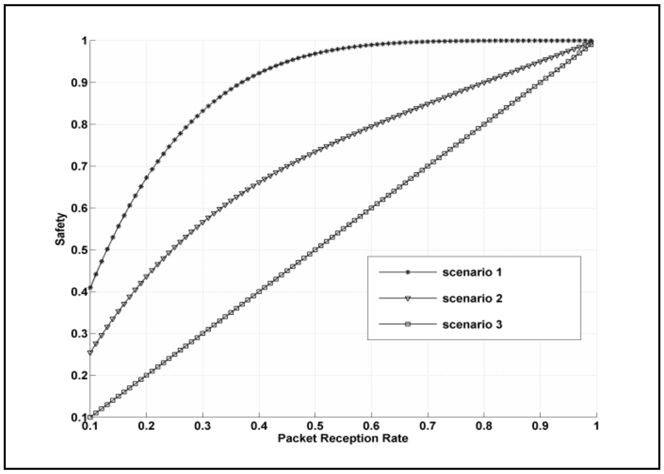

Fig. 4: Safety of V_H for different PRR

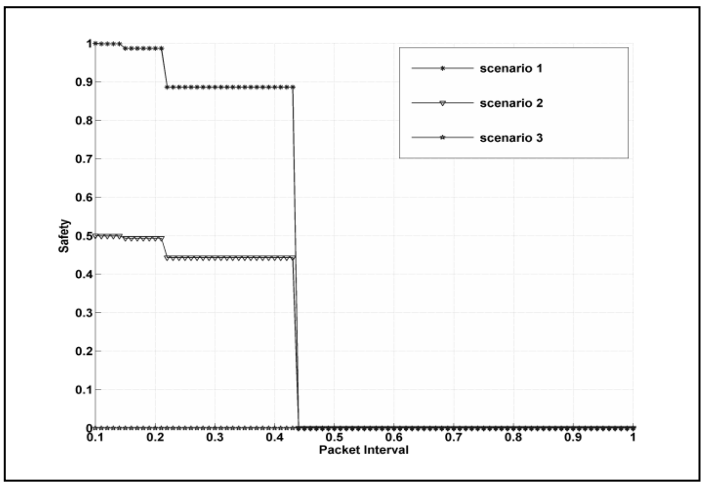

Fig. 5: Safety of V_H for different message intervals λ

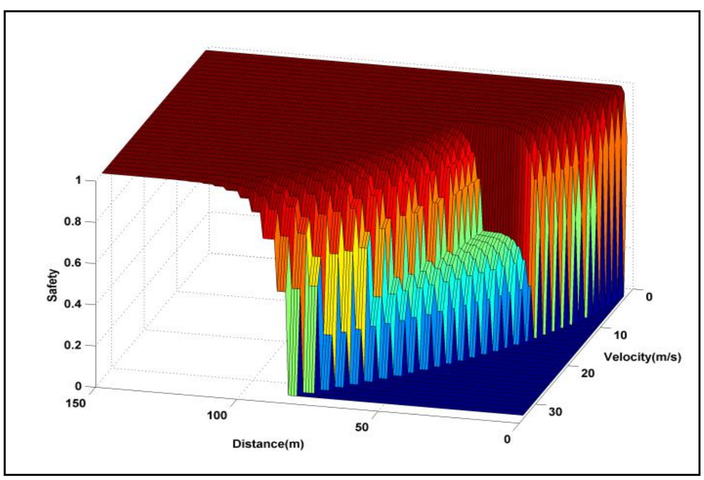

Fig. 6: Safety of VH based on its velocity and its relative distance to V_L. λ and $P_{acc} = 50\%$

5. Conclusion

In this paper, we modeled the safety of the receiver vehicle with Markov chain model approach. In this model, impact of the network and dynamic parameters were investigated. Besides, uncertainty of the driver perceptions about the upcoming events was considered in terms of P_{acc}. The awareness ranges were introduced to help us understand where exactly vehicular network has most effects on safety. We showed that, not only network performance metrics should be used as the only safety application performance metrics, but vehicles kinematic properties should be taken into accounts as well. Using the proposed model, we managed to compute the safety of the receiver vehicle more realistically. However, in order to have effective performance evaluation of safety applications, new metrics are supposed to be introduced to handle both uncertainty and risk of situations.As a future work, we work on defining new metrics aiming at improving the performance of the safety applications.

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