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A Decision Making Module for Cooperative Collision Warning Systems Using Vehicular Ad-Hoc Networks

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***Abstract*— Using a Vehicular Ad-Hoc Network (VANET) communication for cooperative collision warning system can increase safety, convenience and efficiency in driving. Intelligent vehicles can collect information about the driving environment, the driver situation and more importantly other vehicles' information using wireless communication. However, deciding what data to considered, what data to ignore and if and what action should be taken in different situations is a significant issue. In this work, we explore the use of a decision making module for accident situations which processes information from VANET communication and advises the driver based on the situation. Our decision making algorithm is a simple and effective algorithm that can be implement in each vehicle to assist the driver in certain situations. Rerouting to avoid traffic congestion caused by the accident is the major part of our decision making algorithm. This module has been implemented and evaluated using the Veins simulation.**

I. INTRODUCTION

Having information about the environment surrounding a vehicle can assist a driver in driving safer and making driving more convenient. Using wireless communication is one of the ways to obtain information about the vehicle's environment, and, in particular, the status of other vehicles, such as their location, speed and other data. Based on this information, the driver can make more reliable decisions and has a better chance of reacting properly in emergency situations.

While giving this information to the driver can be useful, there is also the possibility of overloading the driver with too much information. Existing vehicles already have some mechanisms to take certain actions if the driver fails to act, for example, adjustable cruise control or braking in the proximity of obstacles. Future vehicles may have more complex decision making modules which receive the raw data about other vehicles, the surrounding environment and even the driver; and process this data and inform the driver about the existing or impending situations and suggest, or even take, actions.

Other than exchanging information about the overall state of the vehicles, vehicles can send wireless messages to each other in emergency situations, such as an accident, to warn other vehicles about the accident and decrease the possibility of danger for them. In addition to the obvious advantage of increasing safety, warning the driver in the accident situation can be helpful in decreasing the traffic in the accident area.

We have implemented a Vehicular Ad-Hoc Network (VANET)-based decision making module for vehicles which receives the accident information from other vehicles, informs the driver about it and suggests an alternative route in order to avoid the traffic caused by the accident. This decision making module has been implemented and tested using the Vehicles in Network Simulation (Veins) which uses OMNet++ [1], (wireless network simulation tool) linked to SUMO [2] (a road network simulation tool). Our decision making module has been tested in a city network based on Erlangen [3].

A cooperative collision warning (CCW) system is one which makes use of data, including communication between vehicles, to enhance vehicle safety and warn drivers of potentially dangerous conditions. Our decision making approach contributes to research in the following ways:

- CCW systems have mostly been used to provide warning information for the driver and do not suggest possible actions. These systems inform the following vehicle about the potential collision, but do not provide rerouting choices for the driver which can help avoid traffic congestion. Our decision making algorithm provides an alternative route for vehicles approaching the accident location in order to decrease waiting and travel time and avoid traffic.
- It is the first event based decision making approach for a rerouting system based on wireless communication. Our decision making system triggers when an accident happens and the car which has been in the accident sends accident message(s). In other proposed rerouting algorithms, vehicles send request messages to other vehicles in order to find out about traffic congestion based on the responses. In our system there is no need to continue sending redundant messages and this reduces channel bandwidth by not sending unnecessary messages.
- Our system use a specific "resending" accident messages alongside the propagating messages for one hop by receivers in order to make sure that all needed vehicles are aware of the accident and can take action to reroute to avoid the traffic jam caused by the accident.

This paper is structured as follows. We present related work on which this paper is based in Section II. In Section III, the decision making module is described. In Section IV the simulation environment is explained and in Section V, the

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results of the simulation of our decision making module are examined. Finally, Section VI provides some concluding remarks and future directions for this research.

II. RELATED WORK

In this section, some of the previous work in the field of cooperative collision warning systems and decision making for collision avoidance systems are discussed. We also review simulation environments for vehicles on roads.

Using wireless communication among vehicles is a potentially useful way to make driving more intelligent. There have been several studies which have shown the beneficial use of wireless communication among vehicles in cooperative collision warning (CCW) systems and in driving assistance systems. Some of this previous work is described in the following.

The technical feasibility of CCW systems was shown by R. Sengupta et al. [4]. In their paper, they introduced a CCW prototype that provides the driver with both warnings and situation awareness through displays provided in the vehicle. Their prototype has been tested in low speeds in an urban office campus with poor GPS coverage, and at high speed on an unused airfield. This prototype is the first prototype able to provide 360-degree awareness by using GPS and wireless communication. However the warning system used in this prototype simply informs the driver about ongoing situation and does not suggest any alternative actions to take. In other words, the analysis the information provided by the system is left to the driver. Also, this approach does not make use of a map and results in shortage of information about road geometry.

A DGPS (Differential Global Positioning System)-based vehicle-to-vehicle collision warning system is introduced by H. Tan [5] which requires a simple GPS unit and basic motion sensors to detect a possible collision situation. This system predicts the hazard situation using the information of nearby vehicles to provide safety but it covers a very small area around the vehicle so it cannot support traffic leading applications.

S. Dashtinezhad et al. have proposed the "Traffic View" system which gathers information about other vehicles and the environment through wireless ad-hoc communication among vehicles and provides traffic information that helps driving in situations such as foggy weather, or finding an optimal route in a trip several miles long [6], [7]. This system provides a map of the vehicles nearby. However, it does not have any prediction of their actions or any information about hazard situations.

X. Yung has proposed another vehicle to vehicle communication protocol for meeting delay constraints in cooperative collision warning systems [8]. In this protocol, if a vehicle faces a mechanical failure or unexpected road hazard, the warning system repeatedly transmit the emergency wireless message to other equipped vehicle in range of 300m and by defined congestion control polices for emergency warning messages, a low emergency warning message delivery has been achieved.

Biswas has presented an overview of a highway cooperative collision avoidance (CCA) system, which is an emerging vehicular safety application using the IEEE- and ASTM-adopted Dedicated Short Range Communication (DSRC) standard [9]. In this paper it is assumed that all the equipped vehicles are aware of each other and communicate via wireless to warn each other about a collision.

C. Huang has proposed a joint rate-power control algorithm for broadcast of a self-information message that enables neighbor tracking in VANETs. This algorithm decides how frequently a vehicle should broadcast its own sate information and how far the state information should be broadcast to obtain the best performance. This algorithm is evaluated through realistic network and microscopic traffic simulations [10]. However, sending the state information to other vehicles frequently can consume channel bandwidth.

T. Elbatt has studied the suitability of the standard DSRC protocol for inter-vehicle communication applications and, in particular, cooperative collision warning systems [11]. In this paper two novel latency metrics are introduced to calculate the performance of CCW system using the DSRC protocol: Packet Inter-Reception Time (IRT) at the vehicle for packets sent by a given transmitter and Cumulative Number of Packet Receptions at the vehicle from a given transmitter.

A. Lakas has proposed a traffic jam detection system which uses wireless communication for information exchange. In this system each vehicle periodically sends a request message to other vehicles and by their responses a vehicle can detect road congestions. Then a modified version of the Dijkstra algorithm can be used to find a better route for the requested vehicle [12]. The main problem with this system is that every vehicle has to frequently send a request message to other vehicles in order to detect and avoid road traffic congestion.

A. Dogan has designed an intersection collision warning system using digital GPS location data and then broadcasts this information at a certain distance from the intersection using an ad-hoc wireless network [13]. This intersection collision warning system has been evaluated by a MATHLAB-based simulator which consists of vehicle traffic simulator and wireless simulator.

Decision making methods have also been implemented and used in some sensor-based or vision-based collision avoidance systems. A method for decision making in collision avoidance applications was presented by J. Jansson et al. [14] This method uses modern tracking theory along with a decision making module to avoid or mitigate the accident. The prototype system presented in this paper significantly reduces the impact speed in frontal collisions [14]. The decision making model has to predict how the position of the tracked object evolves in time. This model is based on the coordinated turn model, where the object is supposed to follow straight line segment and circle segment.

A framework for a collision avoidance system is provided by J. Jansson using statistical decision making and stochastic numerical integration [15]. This system uses radar sensors to detect and track other vehicles. Since inaccurate sensor information can lead to uncertain state information and can influence the performance of collision avoidance system, a statistical decision making algorithm has been used to deal with estimation uncertainties by calculating the probability for each action.

The potential benefit of using sensor-based collision mitigation systems and the prediction uncertainties of these kinds of systems are two significant tradeoff issues which J. Hillenbrand has tried to deal with [16]. Hillenbrand has proposed a decision making approach to allow an intuitive tradeoff between potential benefit on one hand and readiness to take risk with respect to product liability and driver acceptability on the other hand. The performance of this system is investigated on three dangerous traffic situations: rear-end collision due to an unexpected braking; cutting-in vehicles; and crossing traffic at intersections.

R. Karlsson, has implemented a decision rule in a collision mitigation by braking (CMbB) system for late braking using an hypothesis test based on estimates of the relative longitudinal dynamics. The brake decision is based on estimates from tracking sensors. The required acceleration to obtain a zero velocity at a possible impact has been calculated for this statistical decision making system [17].

To develop an intelligent transportation system, a reliable simulation environment is a key element. There has been some simulation environments developed in this area:

D. Gruyer has presented a cooperative system simulation architecture developed within the interconnection of the sensors simulation platform SiVIC (“Simulateur Véhicule-Infrastructure-Capteurs”, Vehicle-Infrastructure-Sensors Simulator) and the prototyping platform RTMaps (Real Time Multisensor Advanced Prototyping Software) [18]. The SiVIC simulator is interfaced in real-time with the RTMaps software which allows prototyping and testing ADAS (advanced driver assistance systems) and behavioral analysis applications in a simulated environment.

S. Eichler has presented a simulation environment which can be used to analyze the effect of real-time vehicle-to-vehicle warning message distribution applications on road traffic [19]. Three major components of this simulation are: the traffic simulator CARISMA, developed by BMW to simulate the traffic network; the network simulator NS2 to simulate mobile Vehicle-to-vehicle network; and a comprehensive ad-hoc agent for vehicle-to-vehicle warning message propagation.

C. Sommer has developed a simulation framework that provides coupled network and road traffic simulation called Veins (vehicles in network simulation) [3]. For network simulation, OMNeT++, a simulation environment free for academic use, is implemented to model realistic communication pattern of VANET nodes and traffic simulation is performed by the microscopic road traffic package, SUMO. Veins supports the active exchange of control and statistics data and also Veins provides a framework for the real-time interaction between the network simulation and the road traffic microsimulation. Both road traffic simulation and network simulation are bi-directionally coupled and simulations are performed on-line. This way, not only the influence of road traffic on network traffic can be modeled, but also vice versa. In particular, the influences of inter-vehicle communication (IVC) on road traffic can be modeled and complex interactions between both domains examined.

III. DECISION MAKING MODULE FOR VEHICLES

In this work, we assume that all vehicles are equipped with the communication hardware for vehicle to vehicle communication and wireless protocols, a GPS, maps of the roadways and street information, namely, the length of each street, maximum legal speed of each street, and the decision making algorithm. We have also assumed that the traveling route has been determined by the driver and that the decision making algorithm has access to the basic information of the travelling route.

Travel time is the approximate time that one vehicle needs to travel through that specific street and at a point in time it is calculated by the length of the street divided by the maximum legal speed of the street; a delay constant is added for each accident, if any, in progress on that street (Equation 1). Since each car is provided with a map of the road it has access to, travel time information of each street, and when it is informed about an accident on a specific street, it can change its local travel time information for that street. In this work any situation which causes the vehicle to stop unusually for a while would consider as an accident. The Delay Constant is the mean delay (s) which an accident would cause for a vehicle.

$$TravelTime\ (S_i) = \left(\frac{length(S_i)}{Max\ Speed\ (S_i)}\right) + (DelayConstant * NumAccident(S_i)) \tag{1}$$

When an accident happens, the vehicle which had the accident broadcasts an accident message containing the identifier for the type of message (*accident* or *release*) and location of itself. Then the travel time for the street on which the accident happened will increase by a specific amount (see Equation 1).

The vehicles which receive the *accident* signal are divided into three different categories based on the location of the accident and their current locations: those not affected by the accident; those affected by the accident but can do nothing and those affected by the accident and can change route. The decision making module in a vehicle can determine the category of its vehicle by comparing the street on which the accident has occurred to the route provided by the driver for each vehicle.

The first category contains the vehicles where the street on which the accident happened is not in their trajectories. Therefore, they simply ignore the accident message and continue their journey. The second category contains the vehicles which are currently on the same street that the accident has happened. They may or may not be able to change their routes; however they can reduce their speed to avoid the accident. These vehicles are often those that become stuck in the traffic. The last category of vehicles is those that are not currently on the same street that the accident has happened but that street is on their route. These vehicles can change their route to avoid the traffic jam created by the accident. The decision module will try to find a new route to avoid the accident and where the travel time is minimal.

Figure 1 shows a vehicle which is sending an *accident* message to other vehicles. The red circles indicate the vehicles which are stopped because of the accident, the green circles shows the vehicles which are not effected by the accident (first category), the blue ones shows the vehicles which are on the same street as the one where the accident happened (second category) and the yellow circles indicate the vehicles which can reroute to avoid the accident (third category).

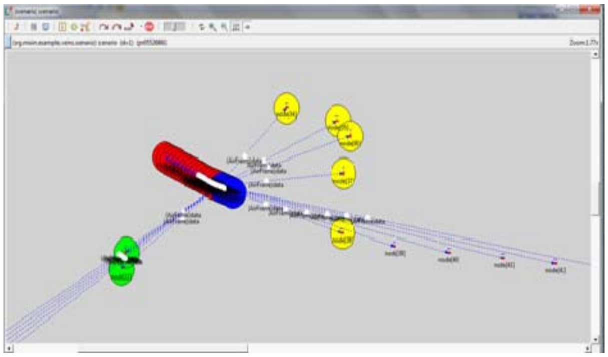

Figure 1. A vehicle sending an accident message to other vehicles

We also assume that when a vehicle is "removed" from the accident situation (by driving away or being taken away), it broadcasts a *release* message to other vehicles in the range and each vehicle which receive release message reduces the street travel time by the specific amount of delay constant.

The vehicles which receive the *release* signal are categorized as follows. Not affected; affected but can do nothing and finally, affected and can reroute. The first category contains the vehicles where the accident was not in their way and therefore they ignore the message. The second category contains the vehicles which are currently affected by the accident street and are stuck in the traffic. They ignore the release message as well. The last category contains the vehicles which are not currently on the street where the accident has happened, but this street is on their way. As they receive the release signal they calculate the best travel route based on new information and reroute if necessary. Again, these categories are based on the information about the route for each vehicle.

The vehicle which had the accident can send the *accident* message periodically rather than send it just once to inform upcoming traffic about the accident. In this case, more vehicles receive the message and take the proper action. The other method to inform more vehicles is message propagation. Each vehicle that receives the *accident* message or *release* message can propagate it to other vehicles in range.

By using the combination of these two methods more vehicles will be informed about the accident and therefore the decision making system can be more efficient and more reliable. Therefore, we can compare four versions of decision making module based on how they propagate the accident message.

In the first and very simple version the car that has had the accident sends the accident message once and each other car which is stuck in the accident broadcasts this message once. In the second scenario, the car which had the accident sends the *accident* message once and each car which receives this message propagates it once. The next scenario is the case in which the car that had the accident sends the *accident* message periodically and no other vehicle propagates this message. Finally, in the forth scenario the car which had the accident sends the *accident* message periodically and other vehicles which receive the *accident* message propagate it once.

The other question that should be addressed is how often should a message be resent and for how long should a car resend a message. The very first seconds of the accident are the most critical and making sure that all vehicles around are informed about the accident soon enough is very important. However, the more time that passes from the occurrence of the accident the less critical it would be to resend the message and after a while it is not necessary to resend the message again.

In our decision making module the car that had the accident sends a message every 2 seconds for the first minute, every 10 seconds for next minute, every 30 seconds for third minute, every 60 second for forth minute and it stops resending the message after five minutes. The simulation environment and its details are discussed in next section.

IV. SIMULATION

In order to test our decision making module, we have used a simulation environment for inter-vehicle communication. To model the communication pattern of VANET nodes, OMNeT++ using the MiXiM framework has been used. Road network simulation is done using Simulation of Urban Mobility (SUMO) package. The Vehicle in Network Simulation (Veins) simulator has been used to link OMNeT++ with SUMO[3]. Our decision making module is implemented as a custom module of OMNeT++.

A multi-Channel IEEE 1609.4 and IEEE 802.11p Enhanced Distributed Channel Access (EDCA) model is implemented in Veins. This model encompasses the 80211.p DSRC PHY and MAC layers, including Access Categories for QoS, the Wave Short Message (WSM) handling, and beaconing WAVE service announcements, as well as multi channel operation, such as the periodic switching between the Control Channel (CCH) and Service Channels (SCHs) [20], [21].

The messages are transmitted with a bitrate of 18Mbps and transmission power of 20mW on the Control Channel (CCH). We model path loss with path loss coefficient of 2.0 and shadowing with a mean signal attenuation of -89dB and standard deviation of 4dB.

There are API calls (known as commands) available in TraCIScenarioManager and TraCIMobility modules of Veins which each module can use to directly interact with running traffic simulation (SUMO). In order to design our decision making module, we have used some of these commands and also we have implemented additional commands which were not available in the original TraCIScenarioManager module or in TraCIMobility module. For this simulation we have implemented four commands which are listed as follows:

- commandReroutingByTravelTime: this command computes a new route using the vehicle internal and the global edge travel time information and replaces the current route by the found.
- commandGetCurrentTravelTime: this command returns the travel time amount for the edge which the vehicle is currently in.
- commandGetEdgeTravelTime: this command returns the travel time amount for a specific edge.
- commandChangeEdgeTravelTime: this command change the amount of travel time for a specific edge.

Using these commands, the vehicles can react based on the message they receive in the simulation and take action(s).

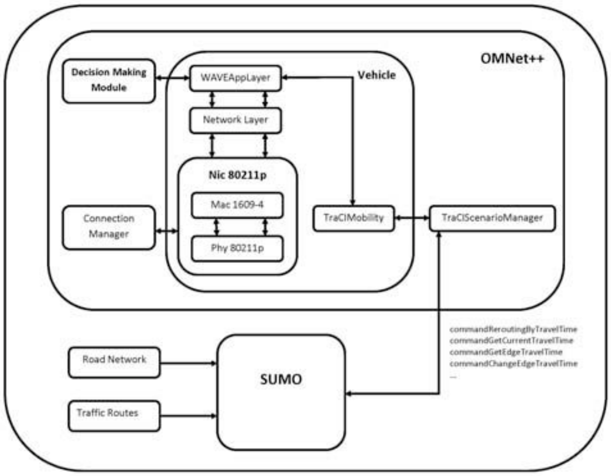

Figure 2. Simulator Components Integrationa

Figure 2 shows the simulator components and flow of information between these components as well as our decision making module in related to other modules in the simulation.

We have tested our decision making module with Erlangen city map with 100 vehicles traveling in it and there is one accident scheduled for this simulation. This simulation network has been tested with and without our decision making module with four different scenarios. The results are summarized and analyzed in the following Section.

V. EVALUATION

In order to test our decision making module we execute our simulation without using our decision making module and with this module and in four different scenarios. In the first and very simple scenario (Scenario1), the decision making module in the car which had the accident sends an *accident* message and each car which is stuck in the accident send this message again. In next scenario (Scenario2), after the car which had the accident sends the *accident* message, each vehicle which receives it will propagate it once. The third scenario (Scenario3) is the case in which the car that had the accident sends an *accident* message periodically but no other vehicle propagates it. And in last configuration (Scenario4) the car which had the accident sends the *accident* message periodically and any other vehicle which receives this message will propagate it once.

We calculated the waiting time for each vehicle, the overall travel time of each vehicle and the number of messages transferred between all vehicles in each case. Waiting time is the time the vehicles have been stopped due to an accident, a traffic light or even heavy traffic jam. One result of our approach is that the overall waiting time of the vehicles is reduced by 47% using Scenario1, it is reduced by 38% using Scenario2, 54% using Scenario3 and the best result was by using Scenario4 which reduced waiting time by 86%.

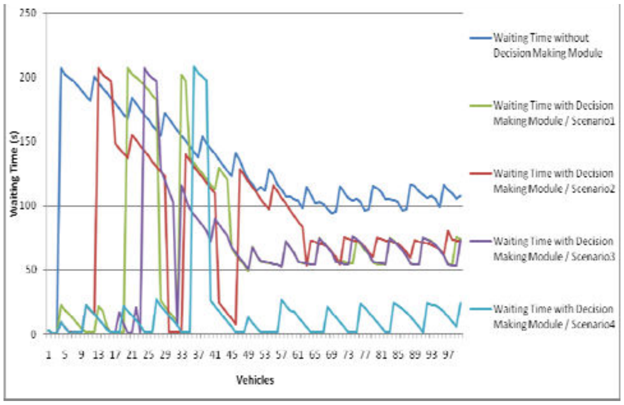

Figure 3. Waiting Time for each vehicle in the road network.

Figure 3 shows the waiting time(s) for each vehicle on the road when they use the decision making module in different scenarios and when they do not use decision making module.

Travel time is calculated by considering the time that the vehicle enters the network and starts its journey and the time it reaches its destination. From Figure 4, we can see that the average travel time for vehicles has been reduced significantly when they use our decision making module. The overall travel time has been reduced by 31% in Scenario1, it is reduced by 25% in Scenario2, 34% in Scenario3 and, more significantly, 52% in Scenario4 of the decision making module.

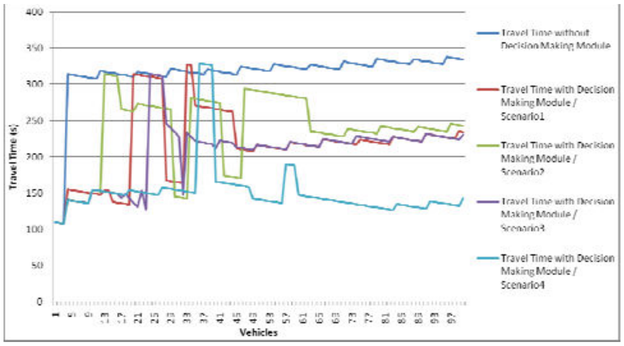

Figure 4. Travel Time for each vehicle in the road network

Table 1 shows the sums of waiting times and sums of travel times for all vehicles. It can be seen from this table that the least waiting time and travel time is obtained when Scenario4 of the decision making module has been used. In other words, when the car which had the accident sends an accident message periodically and each vehicle which receives the message propagates it, the overall waiting time and travel time of the vehicles reduced the most.

Table 1. Total waiting time and total travel time in different cases.

	Sum of Waiting Time (s)	Sum of Travel Time (s)
Without using Decision Making module	13076.5	31618.6
With using Decision Making module / Scenario1	6886.191	21666.1
With using Decision Making module / Scenario2	8102.642	23638.8
With using Decision Making module / Scenario3	5957.396	20600.5
With using Decision Making module / Scenario4	1785.692	15133.4

The other factor to be considered is the number of messages which have been passed between the vehicles. In the simple case, when the vehicles do not use the decision making module, there is no message passing between the vehicles. But when they use the decision making module, they propagate wireless messages to inform other vehicles about the accident. The total number of messages that have been sent while using Scenario1 was 40 messages and the total number of received messages by all 100 vehicles was 995 messages. By using Scenario2 of decision making module, 996 messages were sent and 17414 messages were received in total. Scenario3 involved 58 sent messages and 910 received messages and finally by using Scenario4 372 messages were sent and 3453 messages have been received. In other words, the average of 0.4 message has been send by each vehicle and each vehicle has received approximately 10 messages during its journey in Scenario1, an average of 10 messages per vehicle were sent and average of 17.4 messages were received in Scenario2, approximately 6 messages were sent and 9 messages were received by each vehicle in Scenario3 and there are about 37 messages sent and 345 messages received per vehicle in Scenario4.

Table 2. Number of transferred messages in different cases.

	Number of Sent Messages	Number of Received Messages
Without using Decision Making module	0	0
With using Decision Making module / Scenario1	40	995
With using Decision Making module / Scenario2	996	17414
With using Decision Making module / Scenario3	58	910
With using Decision Making module / Scenario4	372	3453

The total number of transferred messaged among vehicles are shown in Table 2. Overall the best result regarding to travel time and waiting time is observed in using Scenario4 of the decision making module. The number of transferred messages between vehicles is small compared to the significant reduced amount of travel time and waiting time.

VI. CONCLUSION AND FUTURE WORKS

Our decision making approach for cooperative collision system is an event based algorithm which informs other vehicles about an accident and can provide an alternative route to avoid traffic congestion. Each car that is equipped with GPS and wireless communication hardware can implement our decision making algorithm and benefit from its rerouting algorithm. Our decision making system is an event based system so it just triggers when an event (*accident* message or *release* message from the accident) happens, therefore it does not consume much channel bandwidth.

Overall, the results show that using a decision making module shows great potential for improving performance of vehicular systems by reducing travel time and wait time for vehicles. In addition, the safety of vehicles will increase since the vehicles will be informed about the accident by wireless communication.

In future work we plan to improve the decision making module by adding more information about other vehicles, the vehicle itself and even about the overall situation of the driver. More work is needed to determine, for example, when a vehicle is "released" or what are the best strategies for communicating information about the accident. We also want to consider the inclusion of other sensors, such as cameras, which can be used to determine accidents as well, say in the case where a vehicle is in an accident and communication fails. We aim to use this other information to make more appropriate decisions in various situations.

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