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Survey on Collision Avoidance System in VANET

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Abstract:
The biggest problem regarding the increased use of private & public transport is the increasing number of accidents on the roads. To overcome this new technology emerged VANET. Vehicular adhoc networks(VANETs)are classified as an application of mobile adhoc network(MANET) that has the potential in improving road safety and in providing travelers comfort. Recently VANET shave emerged to turn the attention of researchers in the field of wireless and mobile communications; they differ from MANET by their architecture, challenges, characteristics and applications. In this paper we present aspects related to this field starting from VANET architecture and ending up with the most appropriate simulation tools to simulate VANET protocols and applications. [1]

***Key words**: VANET, MANET, architecture, Applications, Protocols*

1. Introduction

In today's world we have increase in number of vehicles, creating huge traffic and more chances of any type of accidents. To avoid the chances of accidents VANET is special tool that needed to be used. VANET provides a wireless communication between moving vehicles, using a dedicated short range communication (DSRC). DSRC is essentially IEEE 802.11a amended for low overhead operation to 802.11p; the IEEE then standardizes the whole communication stack by the 1609 family of standards referring to wireless access in vehicular environments (WAVE). Vehicle can communicate with other vehicles directly forming vehicle to vehicle communication (V2V) or communicate with fixed equipment next to the road, referred to as road side unit (RSU) forming vehicle to infrastructure communication (V2I).

These types of communications allow vehicles to share different kinds of information, for example, safety information for the purpose of accident prevention, post-accident investigation or traffic jams. Other type of information can be disseminated such as traveler related information which is considered as non-safety information. The intention behind distributing and sharing this information is to provide a safety message to warn drivers about expected hazards in order to decrease the number of accidents and save people's lives, or to provide passengers with pleasant journeys. [1]

2. VANET Architecture

The communication between vehicles or between a vehicle and an RSU is achieved through a wireless medium called WAVE. The main system components are the application unit (AU), OBU and RSU. Typically the RSU hosts an application that provides services and the OBU is a peer device that uses the services provided. The application may reside in the RSU or in the OBU; the device that hosts the application is called the provider and the device using the application is described as the user. Each vehicle is equipped with an OBU and a set of sensors to collect and process the information then send it on as a message to other vehicles or RSUs through the wireless medium; it also carries a single or multiple AU that use the applications provided by the provider using OBU connection capabilities. The RSU can also connect to the Internet or to another server which allows AU's from multiple vehicles to connect to the Internet.

2.1. On Board Unit (OBU)

An OBU is a wave device usually mounted on-board a vehicle used for exchanging information with RSUs or with other OBUs. It consists of a resource command processor (RCP), and resources include a read/write memory used to store and retrieve information, a user interface, a specialized interface to connect to other OBUs and a network device for short range wireless communication based on IEEE 802.11p radio technology. . The OBU connects to the RSU or to other OBUs through a wireless link based on the IEEE 802.11p radio frequency channel, and is responsible for the communications with other OBUs or with RSUs; it also provides a communication services to the AU and forwards data on behalf of other OBUs on the network. The main functions of the OBU are wireless radio access, ad hoc and geographical routing, network congestion control, reliable message transfer, data security and IP mobility.

2.2. Application Unit (AU)

The AU is the device equipped within the vehicle that uses the applications provided by the provider using the communication capabilities of the OBU. The AU can be a dedicated device for safety applications or a normal device such as a personal digital assistant (PDA) to run the Internet, the AU can be connected to the OBU through a wired or wireless connection and may reside with the OBU in a single physical unit; the distinction between the AU and the OBU is logical. The AU communicates with the network solely via the OBU which takes responsibility for all mobility and networking functions.

2.3. Roadside Unit (RSU)

The RSU is a wave device usually fixed along the road side or in dedicated locations such as at junctions or near parking spaces. The RSU is equipped with one network device for a dedicated short range communication based on IEEE 802.11p radio technology, and can also be equipped with other network devices so as to be used for the purpose of communication within the infrastructural network. According to C.C. Communication Consortium, the main functions and procedures associated with the RSU are extending the communication range of the ad hoc network by re-distributing the information to other OBUs and by sending the information to other RSUs in order to forward it to other OBUs.

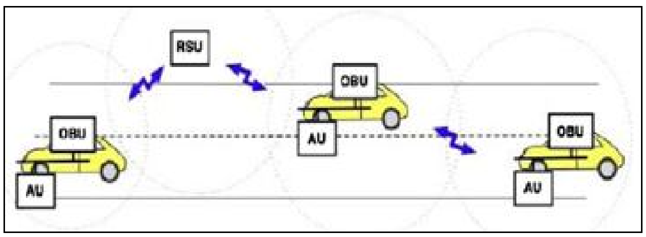


Figure 1: RSU extend the range of the ad hoc network by forward the data of OBUs (C.C. Communication Consortium,)

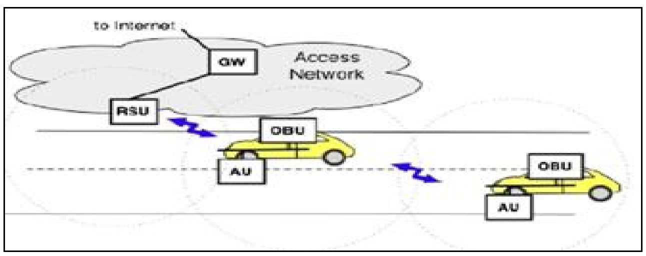


Figure 2: RSU work as information source (C.C. Communication Consortium)

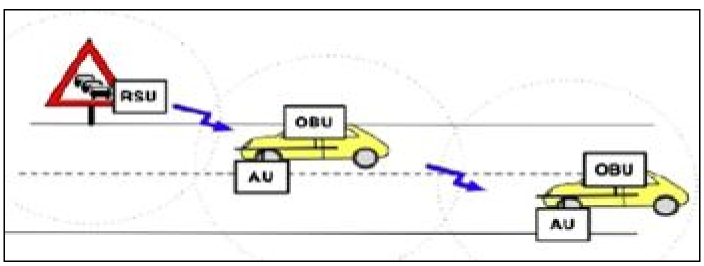


Figure 3: RSU provides internet connectivity to the OBUs (C.C. Communication Consortium,)

3. VANET Applications

V2V and V2I communications allow the development of a large number of applications and can provide a wide range of information to drivers and travelers. Integrating on-board devices with the network interface, different types of sensors and GPS receivers grant vehicles the ability to collect process and disseminate information about itself and its environment to other vehicles in close proximity to it. That has led to enhancement of road safety and the provision of passenger comfort

As shown in Fig 4, VANET applications are classified according to their primary purpose into:

3.1. Comfort/Entertainment Applications

Which is also referred as non safety application provide passenger a comfort level by showing him the current weather, nearby traffic, hotel, restaurants ,petrol station, and other places. It also enhances traffic efficiency by showing different routes to a place where there is no traffic. Passengers can play online games, access the internet and send or receive instant messages while the vehicle is connected to the infrastructure network.

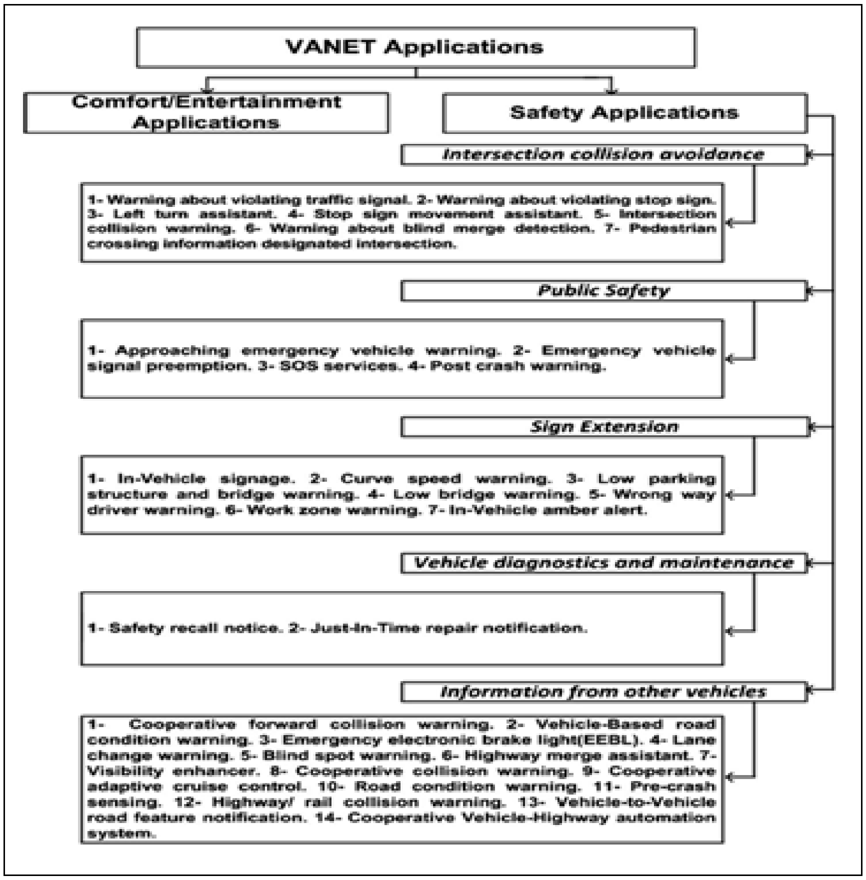


Figure 4: VANET applications

3.2. Safety Applications

These applications use the wireless communication between vehicles or between vehicles and infrastructure, in order to improve road safety and avoid accidents; the intention being to save people's lives and provide a clean environment.

Applying wireless communication technology in vehicles in order to communicate with other vehicles, or with the infrastructure, enables a wide range of applications and leads to an increase in the road safety level. It can be seen from Fig. 4, safety applications using V2V communication or V2I communication, or both can be categorized as follows,

<u>3.2.1. Intersection Collision Avoidance</u>

Improving intersection collision avoidance systems will lead to the avoidance of many road accidents; this system is based on I2V or V2I communication. The sensors at infrastructure gather, process and analyze the information from the vehicles moving close to the intersection depending on the analysis of data; if there is a probability of an accident or a hazardous situation, a warning message is sent to the vehicles in the intersection area to warn them about the possibility of the accident so that they can take appropriate action to avoid it. There are many applications that fall under intersection collision avoidance systems umbrella, all of them use a minimum frequency of 10 Hz, relying on I2V communication and using periodic safety messages with a communication range of 200–300 m, these applications are as follows:

- Warning about violating traffic signal: This application is designed to send a warning messages to vehicles to warn the drivers about a dangerous situation (accident) that would occur happen if the vehicle does not stop; when the traffic signal is running and indicating a stop, the message that is sent depends on several factors; such as traffic status, timing, the vehicle's speed, the vehicle's position and the road surface.
- ii. Warning about violating stop sign: This application is designed to send a warning messages to a vehicles to warn the driver about the current distance between the vehicle and the stop sign and the speed required to prevent the necessity of hard

breaking, so as to prevent the vehicle from violating of a stop sign, which will then lead to the prevention of a hazardous situation.

- Left turn assistant: The aim of this application is to help the driver to make a left turn at an intersection in a safe way, as shown in Fig. 5 by sending the information collected about the traffic status on the opposite side of the road to the vehicle wanting to make the left turn. This information is collected by road sensors or by in-vehicle sensors and is then sent to vehicles, either directly from roadside infra-structure, or by the vehicles requesting the information via in-vehicle systems to allow the driver to decide whether turn left or not.

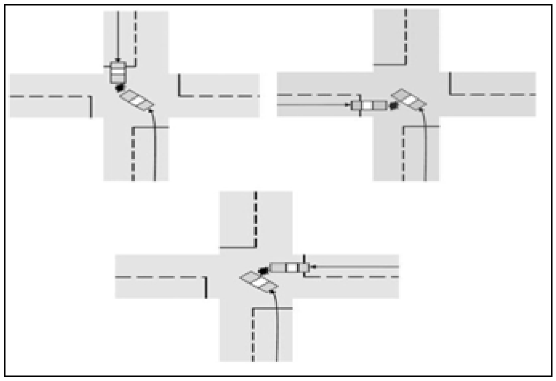


Figure 5: Left turn driver assistant to avoid accidents

- Intersection collision warning: This application collects the information about the road intersection via sensors and in-vehicles sensors and analyses this information, if there is a probability of an accident occurring the system will gen-irate and send a warning messages to all the vehicles approaching the intersection. The data gathered by the sensors includes vehicle velocity, position, acceleration and road surface information.
- Warning about blind merge detection: This application aims to prevent a collision at the merge point where the visibility is poor. The system will alert vehicles trying to merge if there is an unsafe situation, at the same time it will warn the remaining vehicles on the road. The system collects and processes the data at the intersection and if there is an unsafe situation detected it will generate a warning message to vehicles.
- Stop sign movement assistant: The aim of this application is to warn drivers about hazardous situations that may occur if their vehicles pass by an intersection. This is achieved by collecting data from road sensors and in-vehicle sensors and sending this information to the vehicles trying to pass the intersection; this means the driver will know if there are other vehicles approaching the intersection at the same time, and should lead to the prevention of accidents at intersections. This application relies on both V2V and V2I types of communications.
- Pedestrian crossing information designated intersection: The main goal of this application is to warn drivers if there is a pedestrian crossing the road, by collecting information about the walkers via sensors installed in the walk side. After collecting this information the sensors can send it to the system; meanwhile at the same time the system has the ability to collect data if somebody has pressed the walk button

Located at the crossing signal, as shown in Fig. 6, after the system has processed all the data and there is a possibility of collision found it will send warning messages to the vehicles approaching the walk side area.

3.2.2. Public Safety

Public safety applications aim to aid drivers when an accident has occurred and to support emergency teams by minimizing their travel time and provide their services, most of the emergency vehicles response time are wasted in their way to the destination. The average time for the emergency vehicle to response is 6–7 min, while in some cases this can be as much as 25 min. The frequency used by this application is 1 Hz relying on I2V communication, V2V communication or both and using event-driven safety messages with a communication range of 300–1000m.

The most familiar applications within this category are:

- Approaching emergency vehicle warning: This system is designed to satisfy the requirements to provide a clear road to allow emergency vehicles to reach their destinations without waiting in traffic, as shown in Fig. 7, the system accomplished this task by disseminating alert messages relying on one way V2V communication between vehicles travelling on the same route in an attempt to clear the road clear for the emergency vehicle, this message contains information about the emergency vehicle's velocity, direction, lane information and path.

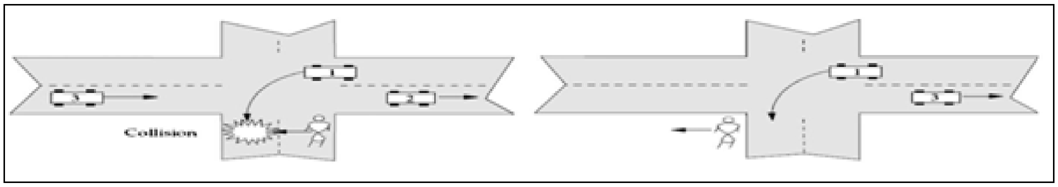


Figure 6: Pedestrian Crossing Warning

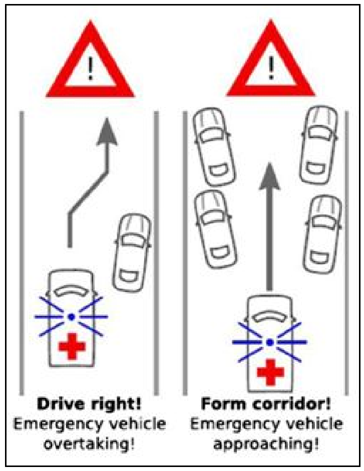


Figure 7: Approaching Emergency Vehicle Warning

- Emergency vehicle signal preemption: Available infrastructures at each intersection support emergency vehicles by sending messages to all traffic lights on the route to the destination using V2I communication. This sets all the lights to green when the emergency vehicle arrives at the traffic signals, minimizing the response time for the emergency vehicle, and reducing the possibility of an accident occurring involving it.
- SOS services: The SOS system works in conditions where a life threatening situation occurs; by sending SOS messages in the case of accidents. The SOS signal can be trigged either automatically by the system or a driver. Both types of communication (V2V and V2I) can be used to serve the system, depending on the situation for instance, the signal could be sent to the nearest infrastructure point directly, alternatively it depends upon the vehicles in range repeating the signal and delivering it to the nearest infrastructure.
- Post crash warning: This application aims to prevent potential accidents before they happen; a vehicle which is disabled because of foggy weather or due to an accident sends a warning messages to other vehicles coming travel-ling in the same direction, or the opposite direction by using both types of communications (V2I and V2V) to inform them about its location, heading, direction and status information.

3.2.3. Sign Extension

The main goal of this application is to alert inattentive drivers to signs that are placed on the side of the road while driving in order to prevent accidents. Most of the sign extension applications use a minimum frequency of 1 Hz relying on I2V communication and the use of periodic safety messages with a communication range of 100–500 m, these applications can be classified as follows:

- In-vehicle signage: This application relies on the RSU being fixed in a specific area; for example in a school zone, hospital zone or animal passing area to send alert messages to vehicles approaching the zone.
- Curve speed warning: This application relies on the RSU being fixed before the curve to disseminate messages to approaching vehicles alerting them about the location of the curve, the speed required to negotiate the curve safely and the road conditions.
- Low parking structure and bridge warning: This application is designed to alert the driver regarding the minimum height of the park they are trying to enter, by sending a warning message to the vehicle via an RSU installed close to the parking facility, and then the OBU can determine whether it is safe to enter the structure.
- Low bridge warning: This application is designed to alert the driver to the height of the bridge they are trying to pass under, by sending warning messages to the vehicle via an RSU installed close to the bridge, then the OBU can determine whether there is sufficient clearance.
- Wrong way driver warning: This system is designed to alert a vehicle if it is travelling in the wrong direction. By using V2V communication a vehicle travelling the wrong way can alert the other vehicles around it via warning messages to prevent accidents occurring.
- Work zone warning: This system relies on the RSU installed closed to the work zone in order to warn approaching vehicles about the work zone area, sending warning messages using I2V communication.

- In-vehicle Amber alert: This system depends on I2V communication and send Amber warning messages (America's missing: broadcast emergency response) to vehicles; this messages is disseminated when the police confirm that there is a vehicle involved in the crime and it is issued to all vehicles in the area, except for the suspect vehicle.

3.2.4. Vehicle Diagnostics and Maintenance

This application aims to send notification messages to vehicles in order to remind drivers about safety defects and that it is time for the vehicle to receive maintenance.

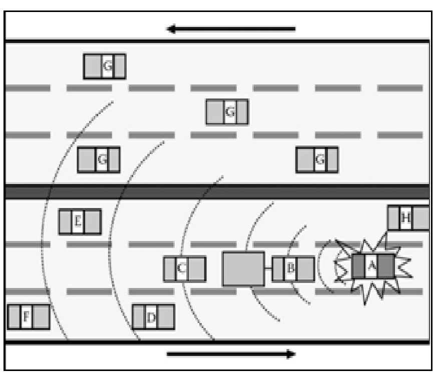
- These applications rely on I2V communication and use event-driven safety messages with a communication range of 400 m, these applications can be classified into:
- Safety recall notice: A message sent to vehicles to remind the drivers when a recall is issued.
- Just-in-time repair notification: In this system if there is a fault within the vehicles, the OBU will send a messages to the infrastructure using V2I communication, the vehicles will receive a reply message containing instructions from the support centre to tackle this problem using I2V communication.

3.2.5. Information from Other Vehicles

This type of application relies on V2V communication, I2V communication or both to per-form applications functions by a frequency of 2–50 Hz and event-driven or periodic messages requiring a communication range of 50–400 m.

Information from other vehicles applications can be classified as follows:

- Cooperative forward collision warning: This system accomplishes the goals necessary to assists a vehicle in avoiding becoming involved in an accident with the vehicle travelling ahead of it. The system uses V2V communication with a multi hop technique in order to send warning messages to a driver about the situation. These messages include information (position, direction, velocity and acceleration), each vehicle processes this information after receiving it to decide on the danger level then forward it to other vehicles.
- Vehicle-based road condition warning: This application is based on V2V communication; the vehicle collects sufficient information about the road status via the vehicle's sensors, after collecting road information the in-vehicle unit processed this data to determine the road situation in order to initiate a warning to the driver or send a warning message to other vehicles.
- Emergency electronic brake lights (EEBL): This system aims to warn other vehicles on the road if there is going to be a need for sudden hard breaking or in case of foggy weather where visibility has become very poor and brake lights are not bright enough to be recognized by other drivers; as shown in Fig. 8, by using only V2V communication vehicles can disseminate the message to other vehicles on the road and alert them to the need for hard breaking ahead.



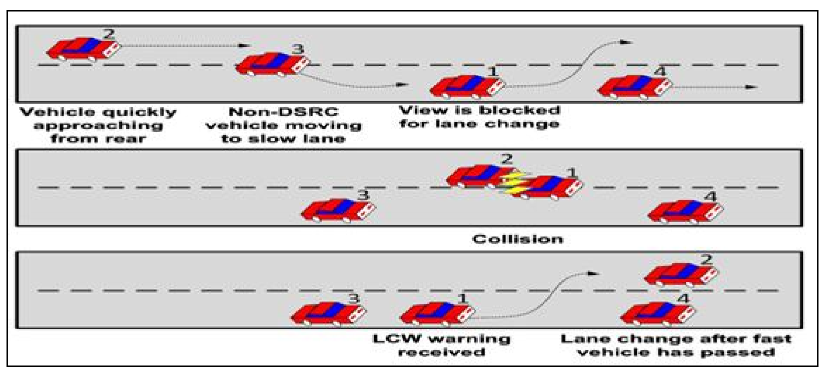


Figure 8: Emergency electronic break light system

Figure 9: Lane change warning system

- Lane change warning: As shown in Fig. 9, this application is designed to avoid crashes that might occur due to unsafe lane changing decisions being made by the driver. The system collects data about the vehicle and the surrounding vehicles; such as speed, direction and vehicle position, and when the driver decides to change his/her current lane the system processes the data collected and evaluate whether the decision will lead to an accident. The system then issues a warning to alert the driver about the potentially dangerous situation and uses V2V communication to alert other vehicles.
- Blind spot warning: This application alerts the driver if he/ she decide to change lane and there is a vehicle in the blind spot; it uses V2V communication to send a warning messages to other vehicles on the road.
- Highway merge assistant: This application prevents accidents from occurring when a vehicle is attempting to merge on the highway. If the vehicles is moving on a ramp or there are other vehicles in the vehicle's blind spot the system starts to sends a warning messages to other vehicles informing them about the speed, position and direction of the vehicle in order to take appropriate action to prevent the accident.

- Visibility enhancer: Bad weather conditions such as fog, rain and snow lead to poor visibility for the drivers, and this system assists the driver by sensing bad weather conditions and warn the driver about this conditions and warning the driver and other vehicles on the road about them.
- Cooperative collision warning: The main goal of this application is to warn the driver about any accidents that have been predicted, by relying on V2V communication. The system exchange messages between vehicles containing information about surrounding vehicles; describing their direction, position, acceleration, yaw-rate and velocity. The in-vehicle unit processes this information in combination with information about the vehicle itself; if there is a possibility of an accident the system warns the driver.
- Cooperative adaptive cruise control: This application adjusts the speed of the vehicle depending on the speed of the vehicles ahead and those behind; it uses V2V communication to exchange messages between the vehicles detailing their position, direction, speed, yaw-rate and acceleration. Meanwhile, the system utilizes I2V communication to acquire the speed limit of the road.
- Road condition warning: This system is concerned with alerting vehicles about poor road conditions caused by ice or other substances causing the road to be slippery, in order to prevent accidents. The road side sensors on the system collect data regarding the road to determine if there are any unsafe conditions then disseminates warning messages to vehicles to adjust, suggesting they adjust their speed to avoid accidents.
- Pre-crash sensing: The main goal of this system is to predict a situation in which an accident is about to happen, information can be collected from sensors, and additional data that can be acquired from other vehicles using V2V communication, this system increases the level of safety for peoples inside vehicles.
- Highway/rail collision warning: This application aims to prevent vehicles from becoming involved in accidents with trains, by using RSUs placed at intersections to notify approaching vehicles to prevent them colliding with trains; another method is to receive messages directly from the train to warn vehicles to take corrective action.
- Vehicle-to-vehicle road feature notification: This system is designed to collect information about the road infrastructure using V2V communication and disseminating this information to other vehicles on the road to be used by other VANET applications.
- Cooperative vehicle-highway automation system: This sys-tem controls the velocity and position of vehicles to travel on the highway as a platoon, relying on V2V communication and using V2I communication. The system collects information about the vehicle and merges the data with information regarding its position and map data in order to control the vehicle's movements and enhance the traffic flow on the highway.

There are two types of safety messages that can be disseminated by VANET safety applications they are as follows,

- Periodic messages: These types of messages contain important data used by other vehicles to take appropriate action in order to prevent unsafe situations from arising. This is done by processing the data received from the sender, which includes the vehicle's speed, current location, direction and other non-safety application data, so that vehicles can avoid any unsafe situations. Periodic messages need to be disseminated frequently containing important information for other vehicles, this may lead to waste the band-width allocated to wireless communication leading to the so-called ‘broadcast storm’ problem.
- Event-driven messages: They are a high priority messages that are sent only where hazardous conditions are detected. Event-driven messages contain the location of the sender, the type of event and the time. The difficulty with event-driven messages is that the sender has to guarantee quick delivery of the message to other vehicles if they are to obtain any benefit from their content.

4. Cooperative

4.1. Collision Avoidance System: [2]

The mechanism of CCA is explained using a three-car highway platoon example, as shown in Fig. 10. In the example, all cars are assumed to cruise initially at a steady speed of 72 mph (32 m/s), and with an intercar spacing (or headway) of 1 s (32 m). Figure 2b illustrates the platoon dynamics after the front car (car 0) initiates an emergency deceleration (at 4 m/s2) as a result of an emergency event. As shown in the figure, the driver in car 1 starts to decelerate when he sees the tail brake light of car 0, and the driver in car 2 does so when he sees the brake light of car 1. With an assumed driver’s reaction time of 1.5 s, car 0 gets hit by car 1 at a distance of 120 m, and subsequently, car 1 is hit by car 2. The conclusion from this example is that if drivers react only on visual information, all three cars in the platoon end up in a chain collision.

For the same platoon, the effects of CCA with wireless communication are illustrated in Fig. 11. In this case, upon meeting the emergency event, car 0 starts sending wireless collision warning messages (W-CWM) to all cars behind it. As shown in Fig. 10, these messages are for-warded in a multi hop manner in order to ensure a complete coverage within the platoon. Upon reception of a W-CWM, a driver reacts by decelerating, even if the brake light on the car ahead is not already lit.

As shown in Fig. 11, car 1 still collides with car 0. However, car 2 can avoid a collision if it receives the W-CWM with sufficiently small delivery latency. For instance, as shown by the solid line for car 2, with a delivery latency of 0.1 s from car 0 to car 2, car 2 manages to stop with-out a collision at a distance of 115 m from the site of the emergency event. However, for a delivery latency of 0.4 s (shown by the dotted line for car 2), car 2 cannot avoid the collision as the driver is not given enough time to start decelerating well in advance.

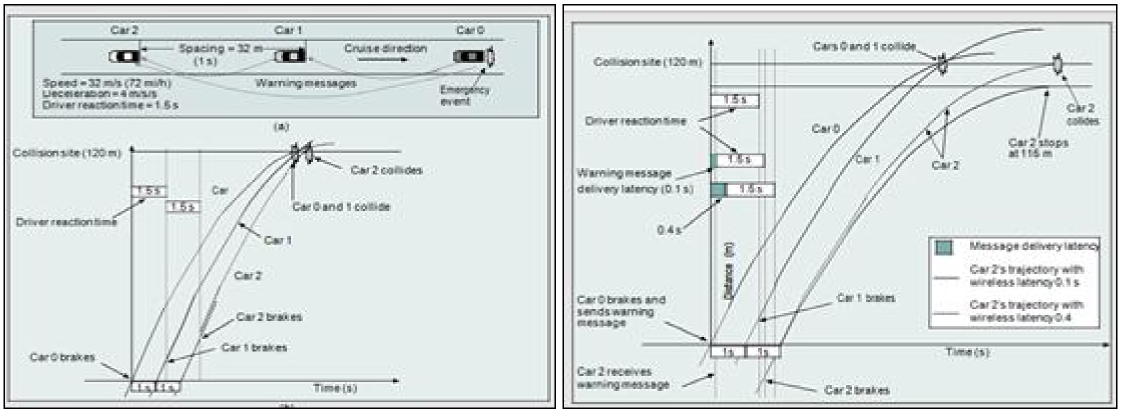


Figure 10: Model for chain car collisions: a) a three-car highway platoon
b) Chain car collisions when drivers react only on the tail light of the car ahead
&
Figure 11: Model for chain car collisions: a) a three-car highway platoon
b) Chain car collisions when drivers react only on the tail light of the car ahead

Two conclusions can be made from the above scenario. First, using a high-speed wireless communication network, it is possible to design CCA systems that can improve highway safety by avoiding chain collisions. Second, reliable and fast warning message delivery is a crucial requirement for -such CCA systems to be able to leverage the underlying networking infra-structure.

5. Cluster-Based Risk-Aware Cooperative Collision Avoidance System: [3]
This is C-RACCA system, which consists of adequate solutions to address the short comings of traditional CCA model by dynamic clustering procedure to formulate clusters of vehicles.

5.1. Shortcomings of the Traditional CCA Systems
In traditional CCA systems [17], upon an emergency situation, a vehicle in the considered platoon dispatches warning messages to all other vehicles behind it. A recipient takes into account the direction of the warning message arrival with respect to its directional bearing and decides whether to pass the message to other vehicles or not. Indeed, the message will be ignored if it comes from behind. To ensure a platoon-wide coverage, the message is transmitted over multiple hops. However, this approach leads to the following two problems: 1) generation of a large number of messages, which literally flood the VANET, and 2) generation of redundant messages (originated from different vehicles) pertaining to the same emergency event. Consequently, message collisions are more likely to occur in the access medium with the increasing number of vehicles in the platoon.

5.2. Dynamic Clustering of Vehicles
Prior to a detailed description of the envisioned clustering mechanism, it is essential to point out a number of assumptions regarding the considered VANET environment, as listed in the following.
1) To accurately estimate the current geographical location, each vehicle in the platoon consists of global positioning systems (GPSs) or similar tracking modules. It should be noted that the knowledge pertaining to the real-time coordinates of the vehicular nodes is an assumption made by most protocols and applications. Indeed, this is a reasonable enough assumption pointed out by Boukerche *et al.* [18] because the GPS receivers can easily be deployed on vehicles. However, as VANETs are evolving into more critical areas and becoming more reliant on localization systems, there may be certain undesired problems in the availability of GPS in certain scenarios (e.g., when the vehicles enter zones where GPS signals may not be detected, such as inside tunnels, under-ground parking, and so forth). Indeed, there exist several localization techniques, such as dead reckoning [19], cellular localization [21], and image/video localization [22], that may be used in VANETs so that this GPS limitation may be overcome. In addition, GEOCAST [20], which is one of our earlier developed protocols, may be used so that it is still possible to support some vehicles, which have lost GPS signals, or do not have GPS on board, to learn from the other vehicles and position themselves.

- To facilitate communications, two distinct wireless channels are considered to exchange signaling messages to formulate vehicles' clusters and to issue/forward warning messages, respectively.
- Each vehicle is assumed to be capable of estimating its relative velocity with respect to neighboring vehicles. In addition, it is also considered to be able to compute, via adequately deployed sensors, intervehicular distances.
- When a vehicle receives a warning message, it can estimate the direction of the message arrival, i.e., whether the received warning originated from a vehicle from the front or the rear.
- Each vehicle is considered to have knowledge on its maximum wireless transmission range, which is denoted by T_r. A vehicle constantly uses this parameter to update its current transmission range R.

5.3. Example of Three Clusters

Fig. 12 portrays an example of three such clusters. As depicted in this figure, a vehicle may act as a special node, i.e., as a cluster head (CH) or a subcluster head (SCH), or may merely drive as an ordinary vehicle (OV). In case of forming a CH, the vehicles are voluntarily required to consistently advertise for the cluster while maintaining and up-dating their respective cluster tables. On the other hand, the first SCH node is selected as the last vehicle that is reachable by the CH. Indeed, the SCH node may be used to define a subsequent SCH entity (i.e., the last vehicle reachable from this SCH node), and so forth. SCH nodes are in charge of relaying packets (e.g., emergency warning messages) from either a CH or from SCHs in front to other vehicles within the same cluster that lie outside the CH's (or the front SCH's) transmission range. In addition, a SCH also aggregates information from OVs within its reach and relays them to the CHs/SCHs in front. It should be noted that it is a rare case to have a cluster containing a large number of SCHs. In such case, the cluster size will be significantly large, and vehicles will be more likely moving at very low speeds. Thus, chain collisions will not happen in such case. Finally, OVs comprise the ordinary members in the cluster that perform no specific task.

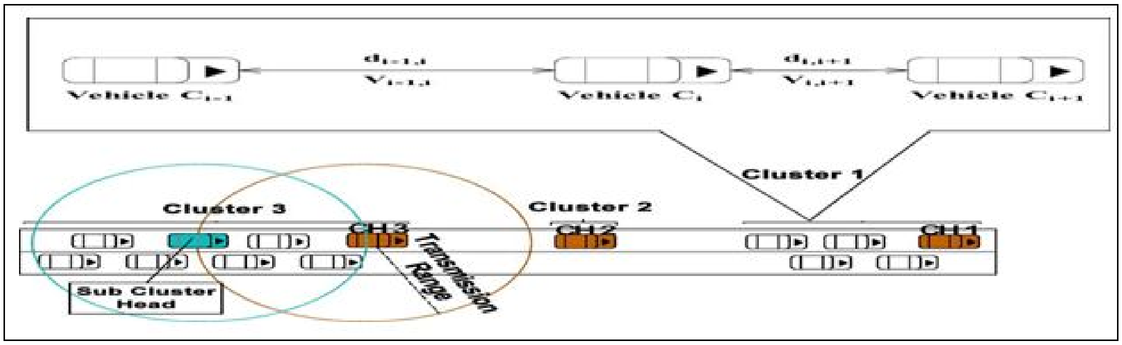


Figure 12: Examples of three clusters

6. Conclusion

Thus in this paper we provide an idea of what is VANET its architecture and its applications with highway cooperative collision avoidance (CCA), which is an emerging vehicular safety application using the IEEE- and ASTM-adopted. Also show the short comes of CCA and provide a C-RACCA i.e. Clustered Based Risk Aware Collision Avoidance System. This paper intention was to show the necessity and importance of VANET for the populated and developed countries to adopt this methodology.

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