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Avoid Intersections Collisions Algorithm for V2V Communications

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Abstract

Road intersections represent one of the most complex configurations encountered when traversing road networks. A high percentage of accidents occur at these locations. In- addition increasing number of vehicles makes the number of accidents and collisions increase in a dangerous way specially in high way roads, many researches on that topic has been made on the recent technologies to reduce the number of accidents, if we come up with a way that enables cars to communicate with each other, and each car sends data about it, such as its location, speed and direction in which it will travel, this will facilitate movement and reduce collisions. In this research paper, we will propose to present communication protocols between cars and each other through intersections, as well as between cars and the surrounding environment, through short-range wireless communications that coordinate movement between cars and prevent collisions.

Related work

In what follows, we review the existing work on the adoption of V2V and V2I communication in traffic management algorithms as considerations of V2V and V2I in [1], the authors here describe a legacy algorithm for an intelligent traffic management system applied to automatic regulation of traffic at intersections. The application of the legacy algorithm enables the intelligent intersection to accommodate vehicles, in a low percentage, not equipped or with faulty V2V and V2I communications. The developed intelligent traffic management techniques, which are based on a spatiotemporal reservation scheme, aim to minimize accidents, traffic congestion and consequently the environmental costs of road traffic. The performance of three intelligent traffic management algorithms applied to road intersections, round about sand crossroads, are analyzed. Compared with traditional traffic management techniques.

Another topic which is related to ours which is Basic safety message (BSM) or heartbeat message is periodically broadcast by each vehicle on the road, conveying vehicle's instantaneous position and driving state. The vehicular communication network enables the fast exchange of BSMs with neighboring vehicles which assists drivers in acquiring the local driving environment and maneuvering promptly in case of any potential hazard. Such message is exceptionally crucial for vehicles at road intersection to avoid collisions. Authors here in [2], propose a novel BSM broadcast scheme using random linear network coding (NCB-RI) to address the message dissemination at road intersection. Considering each BSM packet broadcast occupies one broadcast slot, their objective is to reduce the required number of broadcast slots

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and lower the total transmission time for exchanging all BSMs among the studied vehicles. The coding overhead caused by the random linear network coding is further deducted by using coefficient seeds. In addition to the efficient monitoring of vehicles which need time for smooth traffic flow. Vehicle collision detection and congestion control are prime challenges to be met. Many technologies are in action for collision free traffic. Pertaining to this, vehicle collision prediction system based on VANET is proposed which ad-dresses the issue of collision avoidance. It uses Intelligent Control Unit (ICU) and Vehicle to Vehicle communication to predict the collision probability at highway intersection. In [3], authors implemented a scheme at open street map, on location of interest and makes use of warning system based on collision probabilities. Simulation results show the collision probability for near crash, no crash and crash.

1- Introduction

An intersection is defined as a road junction where two or more roads meet. According to the available statistical data concerning vehicle accidents in USA and Japan, approximately 50% of car accidents occur at intersections which are currently managed by stop signs and traffic lights, in order to address these areas at intersections, connected safety-communication systems are being introduced [4], Vehicle-to-vehicle or vehicle-to-infrastructure are traditional linked security communication systems by some protocols which are the Third-Generation Partnership Project (3GPP) which implements effective message distribution to multiple users over a geographical area at a well-made granularity. While the fourth generation is denominated Long-Term Evolution (LTE). It is a progression of the UMTS that increases the capacity and speed using a different radio interface together with core network improvements. The main aim of all the cited standards is to reduce the connection times and to extend the transmission range, allowing proper operation in conditions of high mobility and vehicular density. In the transport research field, the primary purpose of these technologies is the improvement of road safety at intersections, trying to prevent any dangerous situations [5]. Our focus in this paper is to introduce a new collision detection algorithm for intersections and improve our V2V-based intersection management protocol. The rest of this paper is organized as follows. Section 2 presents the collision detection algorithm for intersections (CDAI) which have been used in our new intersection protocol. Section 3,4 provides an overview on vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) and road side unit (RSU). Section 5, 5.1 represents our problem statement and problem solving, section 5.2 represents an algorithm for prevention of collisions at intersection using RSUs and in section 6 we make a comparison between the two schemes.

2- Collision Detection at Intersections

In [6], the author defines the Intersection area as a perfect square box which has predefined entry and exit points for each lane connected to it. The intersection area is considered as a grid which is divided into small cells. Each cell in the intersection grid is associated with a unique identifier. Figure 1 shows an intersection with two lanes entering the intersection grid from all four directions We make the following assumptions. Each vehicle has access to the digital map database that provides road and lane information. Intersections are identified by unique identifiers (IDs) on this map. Intersections have well defined approach and exit lanes. Vehicles also have access to a global positioning system (GPS) with locally generated Radio Technical Commission for Maritime (RTCM-104) correction to obtain Real- Time Kinematic (RTK) solution in order to achieve reliable lane-level vehicle positioning. Such GPS augmentation can be made available by local base stations or through commercial service providers.

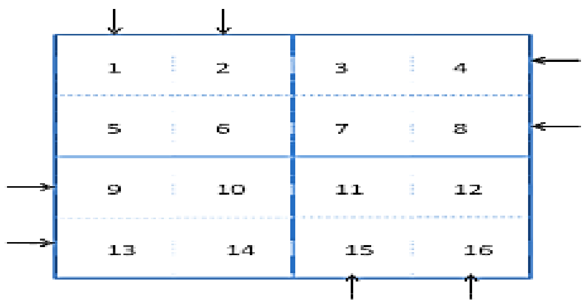


Figure 1, Intersection grid divided into small cells

In the context of intersection, we define the Current Road Segment (CRS) as the road segment that the vehicle is currently moving on before it enters the intersection area, and the Next Road Segment (NRS) is the road segment that the vehicle will move in after crossing the intersection area. We use an offline table

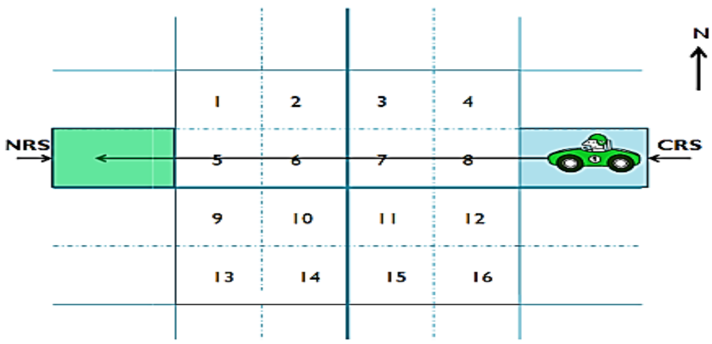


Figure 2, Illustration of TCL, CRS & NRS

which we refer to Trajectory Cell Table (TCT) to determine the cell that will be occupied by the vehicle while crossing the intersection area. TCT uses CRS, NRS as inputs and lane number and returns a list of cell numbers which will be referred to as Trajectory Cell List (TCL), TCL is sorted based on the order of cells along the vehicle's trajectory. For example, in figure 1, a vehicle is attempting to enter the intersection area from east and exiting from west, based on CRS, NRS and current lane, the vehicle uses TCT to update TCL dynamically, in this case TCL value will be [8, 7, 6, 5].

In order to update the Trajectory Cells List (TCL) accurately, each vehicle should be aware of the current cell it is occupying inside the intersection grid. As we mentioned before, all vehicles are equipped with GPS devices and have access to the digital map database as well as the intersection's coordinates. Therefore, each vehicle is able to use this information to map the current GPS coordinates to its current cell number. The current cell number will be then used to update the TCL and will be broadcast to surrounding vehicles as part of the basic safety message (BSM). To update the TCL, each vehicle determines its current cell number using GPS to map to cell number. If the vehicle detects that it has not entered the intersection box, it does not modify the TCL. In this case, the TCL contains the full list of cell numbers which will be occupied by the vehicle while crossing the intersection area. If the vehicle is inside the intersection box, then it uses the current cell number and modifies the TCL as follows. As the trajectory cells list is sorted, using the current cell number, the vehicle can tell which cells have already been crossed and what the next cells along its trajectory are. So, the vehicle updates the TCL by removing cell numbers that have been completely passed and the new TCL contains the current cell number and the remaining cells of the trajectory. Figure (2) shows an example, wherein a vehicle is crossing the intersection, and updating the TCL based on its location outside or inside the intersection grid.

(a)

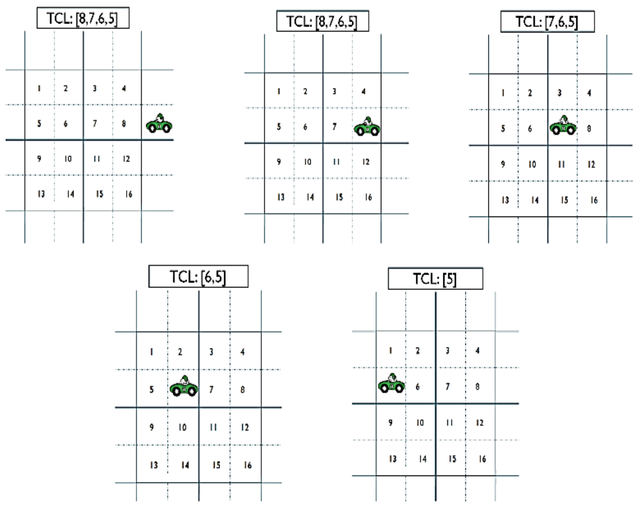


Figure 3, Sequence of updating the TCL

The author claims that a collision occurs inside the intersection area if two or more vehicles have time and space conflicts. In other words, vehicles get to a potential collision if they have overlapping (Arrival-Time, Exit-Time) intervals and they occupy at least one common cell along their trajectories through the intersection. If any of these conditions is false, then there will be no conflicts and vehicles can continue along their trajectories safely.

Our Collision Detection Algorithm for Intersections (CDAI) runs on all vehicles, using the information obtained from received safety messages, which are broadcast by surrounding vehicles. The algorithm uses the Trajectory Cells Lists of the sender and the receiver of the safety messages and by comparing the two lists, it determines if there is any common cell along their trajectories while crossing the intersection. If a potential collision is detected by CDAI, the algorithm returns the first conflicting cell number which we refer to as the Trajectory-Intersecting Cell (TIC).

Figures 4 (a, b) show two scenarios in which two vehicles are inside the intersection area at the same time but they have no TIC as they do not occupy any common cell along their transaction inside the intersection grid. In this case, both vehicles can cross the intersection at the same time without any collision. As illustrated in Figures 5 (a, b), a potential collision may occur when two vehicles are going to be inside the intersection at the same time and having cell conflict.

Figure 5 (b) shows a scenario in which one vehicle is approaching the intersection from the east and attempting to exit to the west, while the other vehicle is entering from the south and also exiting to the west. These two vehicles share more than one intersection cell (cell number 6, 7 and 5) along their trajectories through the intersection area. In such cases where there are multiple conflicting cells, the CDAI returns the first TIC, which is cell number 7 for this example.

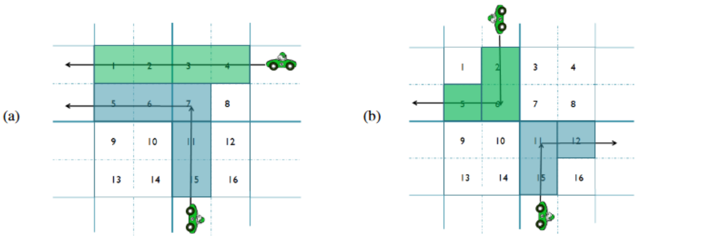


Figure 4, Example scenarios in which no space conflict occurs at the intersection

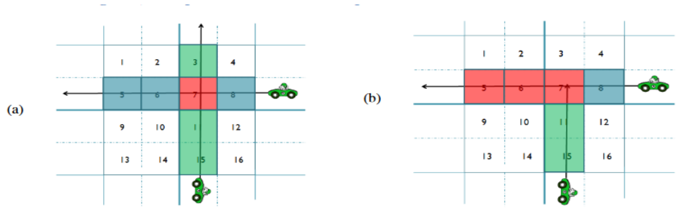
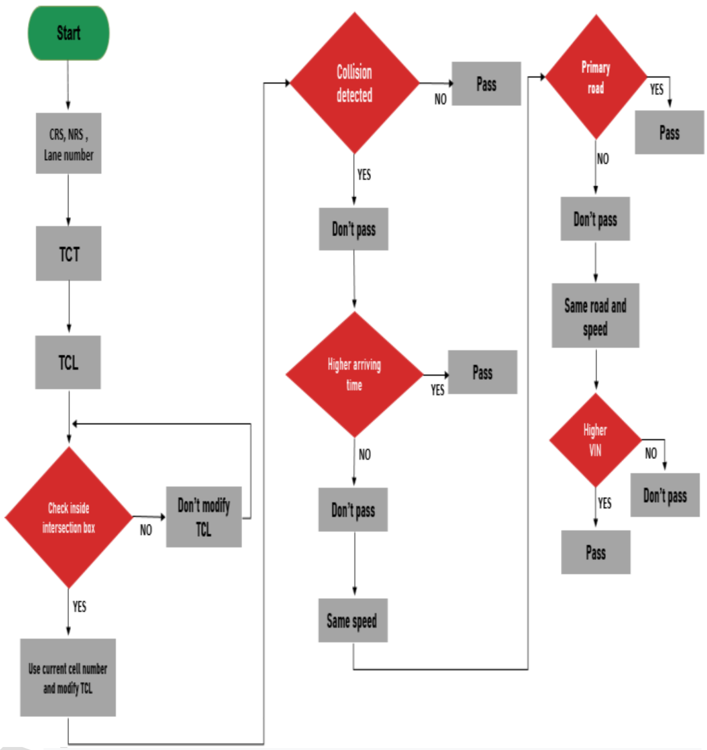


Figure 5, Example scenarios of space conflict

In the case that a potential collision is detected by CDAI, the "first come, first served" (FCFS) algorithm is used to assign priorities to vehicles. Based on FCFS, a vehicle, which gets to the entrance of the intersection with a lower arrival time value, gets to cross the intersection before other vehicles with higher arrival times. To avoid any deadlock situation, in which two or more vehicles have the same arrival time, tie-breaking rules apply. If vehicles arrive at an intersection at the same time, our priority policy assigns higher priorities to vehicles entering the intersection using primary roads than vehicles arriving from secondary roads. If these still result in a tie among vehicles, the vehicle with a higher Vehicle ID Number (VIN) will have a higher priority and gets to cross the intersection grid first. The VIN is unique for each vehicle.

Algorithm for prevention collisions at intersections

- As a vehicle is moving, TCT uses CRS, NRS, Current Lane number as inputs to obtain TCL.
- Then the vehicle checks if it's inside intersection area or not, if it's inside, it uses the GPS device occupied inside it to have the access to the digital map data base, therefore each vehicle is able to use this information to map the current GPS coordinates to the current cell number which will be then used to update TCL while it's moving.
- If a potential collision is detected by CDAI, the First Come First Served algorithm (FCFS) is used to assign priorities where it assigns the priority of passing to the vehicle which arrives first to the intersection area.
- If the two vehicles arrive at the same time, so priority policy assigns the priority of passing to the vehicle that that arrives to the intersection area from a primary road than that arriving from a secondary road.



Algorithm to avoid collisions using v2v technology.

Variables: Vehicle A, Vehicle B
Input: CRS, NRS, Lane number.
Output: TCL.

Start

```
if (Vehicle A is inside intersection
box) {
        modify TCL
}

else {
        don't modify TCL
}

if (Vehicle A and Vehicle B inside intersection area) {
        don't pass
}
else {
        pass
}
//Higher arriving time
if (speed of vehicle A > speed of vehicle B) {
Vehicle A pass first}
else {
Vehicle B pass first}

//Same speed
else if (Primary Road) {
        pass
}
```

```
else {
        don't pass
}
//Same speed and road
else if (Higher VIN) {
        pass
}
else {
        don't pass
}
```

4- Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I)

In V2V technology consists of wireless data transmissions between motor vehicles. The primary purpose of this communication is to prevent possible accidents, allowing vehicles in transit to transfer data on their position and their speed within an ad-hoc mesh network [7]. The latter uses a decentralized connection system, which may provide either a fully connected mesh topology or a partially connected mesh topology (Figure 6). In the first case, each node is connected directly toothers in the network. In the second case, some nodes can be connected to all the others, while the remaining ones are attached only to those with which they frequently exchange most of the data. By exploiting this network topology, the nodes of a mesh network can exchange messages and information with neighboring nodes to which they are directly connected (only one hop, in the case of totally connected network), or they can choose one of the different paths available to reach the destination (multi-hop, in the case of a partially connected network). This topology also increases the robustness of the network structure. In fact, in case of collapse or temporary malfunction of a node, the routes are recalculated within the forwarding tables to reach all destinations.

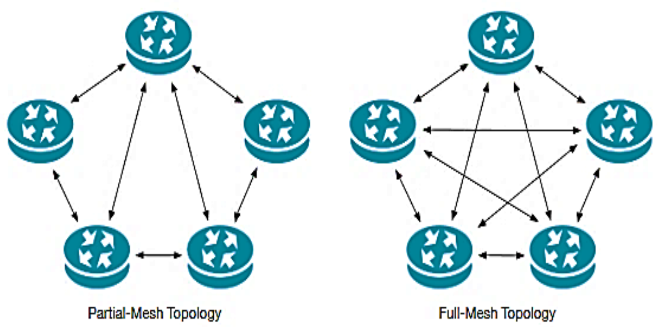


Figure 6, Mesh topologies

Depending on how the technology is developed, the driver of a vehicle can receive a warning in the event of an accident risk or the vehicle itself can independently take preventive actions, such as emergency braking, if it is designed to carry out safety interventions [8]. It is expected that V2V communications will be far more effective than current embedded systems designed by the Original Equipment Manufacturer (OEM) since, to date, the vehicle safety is entirely dependent on the functionality of onboard sensors, cameras, and radars [9]. The system reacts to any dangerous situations based on specific parameters detected by these devices placed on the vehicle. Typically, the main examined parameters are the travel speed, the distance from an obstacle or the presence of a vehicle in the blind spot. However, although the used technologies are increasingly reliable, the calculation errors should not be underestimated. On the contrary, V2V communication protocols will improve the performance in the security field, since, by making all the vehicles close to interact each other, they will help the car in danger (for instance, driver's sleep, a component malfunction, obstacle in the lane, and so on) to undertake a more effective choice to solve the emerging problem. Therefore, the primary purpose of each node forming part of the mesh network will be the data collection to guarantee good security to itself and its neighbors.

The V2V technology, thanks to the cooperation with these already existing security systems, will yield efficient management of possible pitfalls in the roadways all over the world. The new Intelligent Transport Systems (ITSs) will employ data from V2V communication to enhance traffic management, allowing vehicles to also communicate with road infrastructures, such as traffic lights or signs [5].

Unlike the V2V communication model, which allows the exchange of information only among vehicles, the V2I enables vehicles in transit to interface with the road system. These components include RFID readers, traffic lights, cameras, lane markers, street lamps, signage, and parking meters [10]. Commonly, V2I communications are wireless, bidirectional, and similarly to V2V, using Dedicated Short-Range Communication (DSRC) frequencies to transfer data [11]. This information is sent from the elements of the infrastructure to the vehicle, or vice versa, through an ad-hoc network. In the ITS, V2I sensors can acquire infrastructural data and provide travelers with real-time advice, sending information on road conditions, traffic congestion, any accidents in the roadway, the presence of construction sites and the availability of parking spaces. Likewise, traffic supervision and management systems can use the data collected from the infrastructure and vehicles to set variable speed limits and adjust the Signal Phase and Timing (SPAT) to achieve fuel savings and facilitate traffic flows [12]. The hardware, software, and firmware that make communication between vehicles and infrastructure reasonable are a fundamental starting point for the development of autonomously driven cars.

When V2I is the only available communication interface, each OBU autonomously transmits collected data through the cellular system either after a given time out or when a certain amount of data has been collected. If also V2V and V2R communications can be exploited, information can be exchanged also between vehicles and between vehicles and roadside units (RSUs). In this case, OBUs communicate one with each other exchanging information and aggregating redundant data referring to the same road segment; with V2Rthey also perform transmissions to RSUs whenever possible. Both the aggregation of information and the transmission through RSUs allow to reduce the V2I load toward the control center, thus saving the limited capacity of the cellular network and the related costs [13].

4- Overview on Road Side Unit (RSU)

Roadside unit (RSU). A Roadside Unit is a DSRC transceiver that is mounted along a road or pedestrian passageway. An RSU may also be mounted on a vehicle or is hand carried, but it may only operate when the vehicle or hand carried unit is stationary. Furthermore, an RSU operating under this part is restricted to the location where it is licensed to operate. However, portable or hand-held RSUs are permitted to operate where they do not interfere with a site-licensed operation. A RSU broadcasts data to OBUs or exchanges data with OBUs in its communications zone. An RSU also provides channel assignments and operating instructions to OBUs in its communications zone, when required [14].

5- Problem Statement

Our main aim of this research is to prevent collisions between vehicles at intersections, we have discussed CDAI that arranges the movement of vehicles inside intersection area. Authors in [15] claims that the availability of propagating of real time traffic information via v2v communication is one of the critical bottlenecks, forwarding collision warning applications based on v2v need the information regarding how quickly a warning can be propagated to a vehicle in addition to accident warning applications that needs information to reach as many vehicles as possible in the local transportation network. So, without knowing the information propagation characteristics such as connectivity, transmission, distance, time delay and coverage, it's difficult to successfully implement those applications based on v2v technology. Similarly, in CDAI algorithm if the vehicle failed to estimate an accurate TCL and broadcasted it to the surrounding vehicles or if it failed to calculate the accurate distance to the intersection area and if a delay occurs while broadcasting, all these limitations can cause a collision.

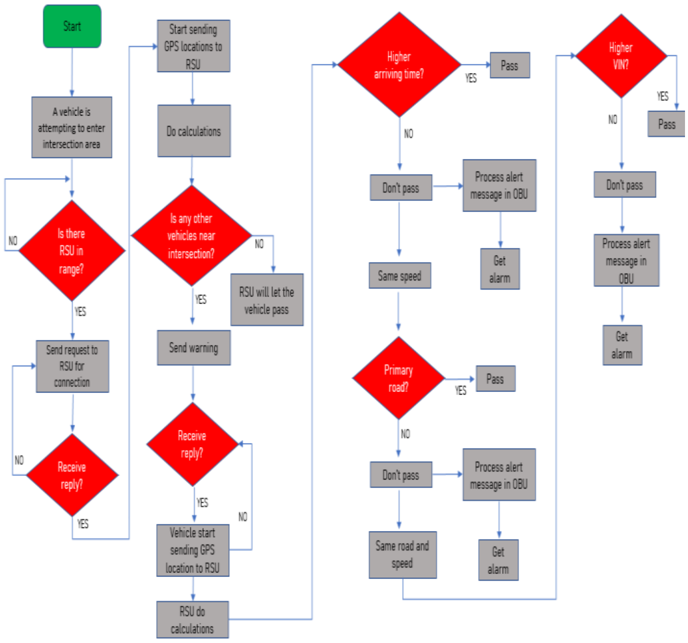
5.1- Problem Solving

To solve this problem, we must find a way to make communication stable between vehicles. So, in [16], authors agreed on that by the help of VANETs (which is formed by vehicles that are equipped with wireless communication devices such as IEEE 802.11p, positioning systems as GPS devices and digital maps), vehicle will be enabled to communicate with each other within the same radio transmission range, it also allows vehicles to connect to RSUs which is connected to the internet forming a fixed infrastructure that offers them the capability of communicating with each other and with roaming vehicles. RSUs support cooperative and distributed applications in which vehicle and RSUs work together to coordinate actions and to share several types of information. The RSU wired and wireless backbone network can be used to bridge network partitions in the VANET. The basic motivation behind using RSUs is that RSUs are a fixed infrastructure, it's much easier to send a packet to a fixed near target than to a remote moving object, also the delay of sending a packet through the fixed RSU network will be much less than through the VANET, that may delay the packet at intermediate nodes or even lead to dropping it. Our case is a vehicle which is attempting to enter the intersection area (assume a transmission range if 250-500m). So, to prevent collision it needs to be connected to an RSU which will let this vehicle be connected to the other vehicle through this shortrange wireless channel. Each vehicle is connected with a positioning system (GPS device) which is already popular in new cars and will be common in the future, also assuming that vehicles will be equipped with a digital map which provides street map and static object location such as location of RSUs. Each vehicle frequently sends to the nearest RSU beacons that contain the current location, speed, direction and timestamp.

5.2- Modified algorithm for prevention collisions at intersections using RSUs

- System starts with a vehicle is attempting to enter intersection area.
- The vehicle checks for available RSUs in range.
- If yes, the vehicle sends a request for the RSUs to connect with it.
- If the vehicle receives an acknowledgement (reply), it starts sending the GPS location to the RSU.
- Then RSU do some calculations based on the data received from the vehicle.
- Then RSU checks if there is any vehicle near intersection area or not.
- If there is no vehicle near the intersection area, RSU will let the vehicle pass.
- If RSU found that there is another vehicle is attempting to enter the intersection area at the same time. RSU will send a warning message to this vehicle to stop.
- The vehicle sends an Ack to RSU that it received the warning.
- The vehicle will send the GPS location to the RSU.
- RSU chooses between the two vehicles to pass depending on the same parameters of the last flowchart.
- If a vehicle arrives to the intersection before the other vehicle.
- RSU will let it pass and stop the other vehicle and process alert message to OBU.
- If the two vehicles arrive at the same time but one from a primary road and the other from a secondary road.
- Then RSU will give the priority to the one which comes from primary road and stop the one which come from secondary road and process alert message to OBU.

- If the two vehicles come from primary road or secondary roads and arrive to intersection area at the same time.



- Then RSU will give the priority of passing to the vehicle that have higher VIN (Vehicle Identity Number), and stops the vehicle of lower VIN and process alert message to OBU.

Algorithm to avoid collisions using RSUs.

```
            Variables: Vehicle A,
Vehicle B, RSU S.
            Input: CRS, NRS, Lane
number.
            Output: TCL.
            Start
            //Vehicle is attempting to
enter intersection area.
            if (S is within the area
of A){
         A send request to S to
connect
            }
            /*A start sending GPS
location for connection
            and do some calculations*/
            if (S detect any vehicle B
is attempting to enter
intersection area) {
              S send warning to these
    vehicles
            }
            else {
              S will let A pass
            }
            if (S recieve a reply){
              Vehicle B start sending
    GPS location to S
            }
                // S will do calculations
based on last V2V algorithm
            //Higher arriving time
            if (speed of vehicle A >
speed of vehicle B) {
            Vehicle A pass first}
            else {
            Vehicle B pass first}

            //Same speed
            else if (Primary road) {
     pass
            }
            else {
     don't pass
            }
            //Same speed and road
            else if (Higher VIN) {
     pass
            }
            else {
            don't pass
            }
```

5- Comparison between the two algorithms

Collision prevention using CDAI	Collision prevention using RSU
Communication is done between vehicle with another vehicle to broadcast Basic Safety Messages (BSM) [6].	Communication is done between vehicle and RSU and viceversia [16].
Vehicle broadcast it's information as location, speed and position to the surrounding vehicles using GPS device equipped inside it [6].	RSU asks vehicle to send it's information as location, speed and position using GPS device equipped inside it [16].
Vehicles by the help of CDAI control it's passage inside intersection area using priority policy [6].	RSU controls the passage of vehicles inside intersection area using priority policy [16].
Vehicles can access a digital map database which allows it to map surrounding vehicles inside intersection area [6].	Vehicles can access a digital map database which allows it to map fixed infrastructures as RSUs as well as vehicles [16].

Conclusion

In this paper, a collision avoidance at intersection system based on V2V communication was proposed. By using CDAI protocol that arranges the movement of vehicles inside intersection area based on the information each vehicle shares with the neighboring vehicle. After collecting information from neighboring vehicles, CDAI decides the vehicle that is allowed to pass under certain road conditions which are: FCFS, primary or secondary roads and higher arriving time. A modification was made on that system as it has some limitations existing a bottleneck in propagating of real time information, where forward collision warning applications based on V2V need the road traffic information regarding how quickly a warning can be propagated to the other vehicle, therefore any shortening can lead to an accident. The modified system enhances the movement of vehicles inside intersection area. By the help of VANETs, vehicles that are equipped with GPS devices and digital maps can map neighboring RSUs within the transmission range, these vehicles will be enabled to communicate with each other by connecting with RSUs, these RSUs are connected with internet forming a fixed infrastructure enabling stability in exchanging information between vehicles and RSUs.

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