

An Intelligent Architecture for Issuing Intersection Collision Warnings

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ABSTRACT:

According to NHTSA (National Highway Transportation Safety Administration), approximately 2 million crashes (30 percent of all crashes) occur at intersections every year causing over 6,700 fatalities and significant number of serious injuries. Radar and infrared technologies can be used to detect impending rear-end and lane-change collisions. However, impending intersection collisions cannot be detected using radar and infrared technologies, because these technologies require line-of-sight communications. Wireless communications do not require line-of-sight. Thus, using wireless communication technologies, the vehicles can inform each other about how far they are from the intersection. This paper presents an intelligent architecture for issuing intersection collision warnings using a wireless communication technology, an in-vehicle processor and a vehicle detecting system. An intersection has a wireless unit called the Intersection Traffic Controller (ITC). This ITC keeps broadcasting a message all the time. Each vehicle communicates with the ITC in real time to let the ITC know about its current location. The ITC then includes this information in its message. The current technology will allow us to build such an intelligent architecture in a cost effective manner. This paper presents the detailed description of the architecture along with the communication protocol and requirements for real-time operation of the system.

Key words: Collision avoidance, collision warning and wireless communications.

1. INTRODUCTION

There have been major improvements in vehicle safety since the 1960's. The introduction of safety features such as seat belts, air bags, crash zone, lighting and new vehicle structures has dramatically reduced the rate of crashes, injuries and fatalities. The fatality rate per hundred million miles traveled has fallen from 5.5 to 1.7 in the period from mid-1960s to 1994 [1]. However, in spite of these impressive improvements, according to NHTSA each year in the United States, motor vehicle crashes still account for a staggering 40,000 deaths, more than three million injuries, and over \$130 billion in

financial losses. All of these safety features are either static or passive. They act to minimize collision damage or give the driver visual assistance or warning at specific geographic areas.

With recent advance in sensing, computing, and communication technologies, new driving assistance systems such as night vision and collision warning systems (CWS) have been designed, tested, and deployed [1, 2, 3, 4, 5]. While night vision systems simply provide visual assistance to drivers in dark environment, collision warning and avoidance systems generally exhibit some intelligence. Despite the fact that intersection collision accounts for almost 30% of all crashes, intersection collision avoidance systems received less attention than the forward collision avoidance systems [3, 6]. The reason, besides the fact that the intersection collision problem is more complicated than rear-end crash, is the limitation of the radar technology, the most widely used object sensing method in vehicle collision avoidance systems. Most radar systems require line-of-sight for object detection. This renders ineffective collision warning/avoidance system that requires line-of-sight for threat detection.

The present technologies that are being investigated to avoid intersection collisions are differential global positioning systems (DGPS), electronic compasses, roadside sensors, etc. There are several disadvantages of these technologies. For example, the GPS signals have some errors and in some areas, especially in downtown areas with very tall buildings, the signals may not be detected. The roadside sensors may not detect some vehicles if there are multiple lanes on the road.

This paper presents an intelligent architecture for issuing intersection collision warnings. Wireless communications do not require line-of-sight. Thus, using wireless communication technologies, the vehicles can inform each other about how far they are from the intersection. In our proposed technique an Intersection Traffic Controller (ITC) is installed at the intersection that broadcasts the status of the intersection and communicates with the vehicles approaching the intersection. Vehicles cooperatively share the critical information with the ITC for collision anticipation, i.e., location, velocity, acceleration, etc and achieve threat

detections. The location of the vehicle is determined by using the sensor in the vehicle and the magnetic strips paved on the roads, a barcode or using the RF method. By sharing the information between vehicles and the ITC, each vehicle is able to predict potential hazard. This system requires minor support infrastructure.

The rest of this paper is organized as follows. Background material, including the previous work done on the intersection collision avoidance system is presented in Section 2. Our proposed technique for Issuing Intersection Collision Warnings is presented in Section 3. Our proposed techniques for determining Road number, Lane number and distance from intersection are presented in Section 4. System requirements, in terms of protocol, bandwidth and memory size, for our proposed technique are presented in Section 5, and the conclusions are presented in Section 6.

2. BACKGROUND MATERIALS RELATED TO INTERSECTION COLLISION AVOIDANCE SYSTEM

The new vision for intelligent transportation system is based on information management and availability, connectivity and system control and optimization – in short, the creation of an integrated national network of transportation information. The information to be gathered, managed and distributed includes real-time information on the physical state of the infrastructure, how it is being built, used, maintained and kept secure. Some of the previous work and key entities of Intelligent Transportation System (ITS) are mentioned here briefly.

Collision Avoidance Systems:

Crash Statistics data, collected by the NHTSA (National Highway Traffic Safety Administration) show that 88% of rear end collisions are caused by driver inattention and following too closely [1]. Studies show that an additional one-second warning could reduce the crash rate by 50-90%. The passive safety technologies such as safety belt, and air bag cannot reduce the crash costs significantly.

The development of active collision warning and driver assistance systems is a significant step in this direction. The active collision avoidance systems use technologies such as radar, wireless ad hoc networking, DSRC to warn the driver of an imminent collision. This gives the necessary time to the driver for taking remedial action and reduces the probability of a crash. Some of the proposed systems also use inter-vehicle communications to exchange dynamic information about each other and make crash avoiding maneuvers. Such an architecture has been proposed in our previous work [7].

Rural intersection collision avoidance:

Rural Intersection Decision Support [8] uses a suite of advanced traffic monitoring and communication technologies, to track vehicles approaching the intersection. Human-factors and cognitive psychology are used to design and evaluate ways of communicating relevant information to the driver waiting to cross.

- Surveillance: Rural IDS will build on previous work, using advanced sensing technologies and digital map systems developed by the Intelligent Vehicles Laboratory at the University of Minnesota.
- Computation: Vehicle locations will be tracked and trajectories computed in real time as vehicles approach the intersection.
- Driver interface: A driver-centered analysis of the intersection crash problem was performed by the ITS Institute's **Human FIRST** Program to derive a candidate set of infrastructure-based driver interfaces based on human factors design principles.

BATTELLE Intersection Collision Avoidance System:

Battelle [9] is supporting a federal project to develop specifications for a system that would help drivers avoid intersection collisions. The goal of the project is to develop a system that will alert drivers to a potential crash situation as they approach an intersection. Or, if necessary, the system can assume control of a vehicle if the driver is unable to respond in time.

The equipment in the vehicle could include sensors of several varieties - microwave, laser, radar, or video imaging systems - as well as computers and communications equipment. Potential infrastructure equipment might include intersection surveillance sensors and road-to-vehicle transponders. These systems should consider such parameters as velocity, heading, acceleration of the subject vehicle, presence/configuration of the traffic light, signal light phasing, and the dynamic state of other vehicles in the vicinity of the intersection.

Driver Safety Support Systems for intersection collision prevention:

This system [10] aims to prevent collision at intersections without signal lights and without clear view ahead. This system also provides a mechanism for issuing a message to the vehicle about the condition of the signals whether they are about to turn red, so that the driver does not speeds up in order to cross the intersection at the yellow light. It essentially uses image detectors to detect the approaching vehicles and infrared beacons to transmit this information to the vehicles. Warning messages are given to the vehicle's embedded unit that will have wireless capabilities. Such system have the limitation of weather, because in cases of snow or heavy rain, the control unit might get an error message or false signal from the camera.

Dedicated Short Range Communications (DSRC):

5.9 GHz DSRC (Dedicated Short Range Communications) is a short to medium range communications service that supports both public safety and private operations in roadside-to-vehicle and vehicle-to-vehicle communication environments. Dedicated Short Range Communications (DSRC) allows high-speed communications between vehicles and the roadside, or between vehicles, for ITS; it has a range of up to 1,000 meters [11]. Potential DSRC applications for public safety and traffic management include:

- Intersection collision avoidance
- Approaching emergency vehicle warning
- Vehicle safety inspection
- Transit or emergency vehicle signal priority
- Electronic parking payments
- Commercial vehicle clearance and safety inspections
- In-vehicle signing
- Rollover warning
- Probe data collection
- Highway-Rail intersection warning.

In our earlier work, we developed a technique for secured inter-vehicle communication. A brief description of our earlier work is presented in the following subsection to make the readers familiar with the technique for developing a secure inter-vehicle network. After that, in Section 3 of this paper, we present the technique for building the intersection collision avoidance system.

Secure inter-vehicle communication:

To build a secure inter-vehicle wireless network, every vehicle must be equipped with a wireless device to communicate with the neighboring vehicles as well as with the Intelligent Transportation Towers (ITTs). An ITT will be responsible for authenticating the vehicles when the vehicles will come within the range of the ITT. An intelligent vehicle will have three different types of wireless links: 1) a link for the in-vehicle wireless network, 2) a link for inter-vehicle wireless network, and 3) another link for the vehicle to ITT communications. When a vehicle is manufactured, at that time a wireless device will be installed in it. At the time of installing the wireless device, a set of keys will be given to the device. A copy of these keys will also be kept in a secure central server. Different vehicles will be given different sets of keys. These keys will be securely kept in the central server. If the secure central server of a particular vehicle is going to be maintained by the manufacturer of that vehicle, then every auto company will have its own central server. Authorized organizations will be able to access the keys of a vehicle by using the vehicle's ID (VID) number. If the auto companies maintain the central

servers, then the VID of a vehicle will indicate which server to go to for accessing the keys.

3. PROPOSED INTELLIGENT ARCHITECTURE FOR ISSUING INTERSECTION COLLISION WARNINGS

In this section of the paper, we present a technique for issuing intersection collision warnings. This technique requires that every vehicle must be equipped with a wireless device to communicate with the Intersection Traffic Controller (ITCs). We are assuming that all intersections are installed with an ITC, and all roads of the intersection are equipped with a mechanism to determine the road number, lane number and distance from the intersection as mentioned in Section 4. We are also assuming that all vehicles are capable of detecting the road number, lane number and distance from the intersection. The ITC broadcasts the condition of the intersection using messages. A message contains all the dynamic information about that particular intersection. For example, the message indicates how soon the traffic light will change from its current state to the next state, whether the vehicle can take a left turn, whether any vehicle has violated the traffic signal, etc. Figure 1a shows the functions performed by the ITC.

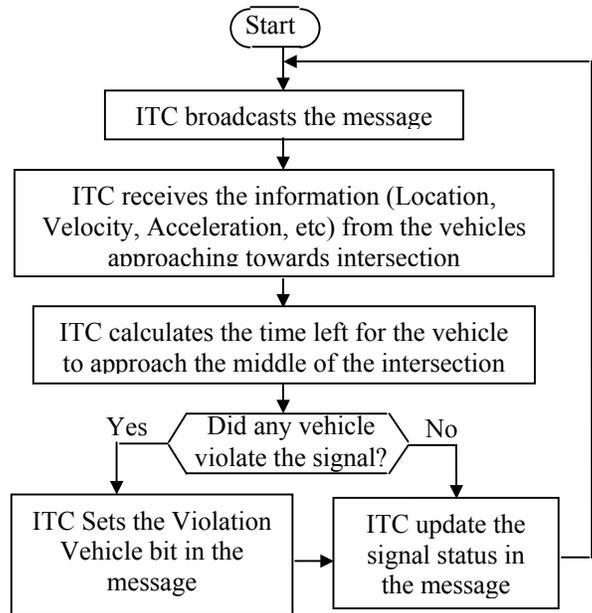


Figure 1a. Tasks performed by the Intersection Traffic Controller (ITC)

The ITC also receives the information from the vehicles approaching the intersection. As a vehicle approaches an intersection, using the infrastructure system present at the intersection the vehicle's onboard computer knows on which road number, lane number it is present and the distance from the intersection. The vehicle receives its speed and acceleration from the in-vehicle network. This information is sent to the ITC through Dedicated Short Range Communication (DSRC) using the specific message format as mentioned in Section 5.1. The

vehicle's onboard computer receives the broadcasted messages from the ITC and checks the information in the message that corresponds to the road number and lane number of the vehicle. From the message, the vehicle's on board computer determines whether the signal at the intersection is green, yellow or red and the time left for the signal to change from its current state to the state. The on board computer calculates the time left for the vehicle to reach the intersection and checks whether the vehicle can pass the intersection without violating the traffic signal. From the message, the vehicle's on board computer knows if any other vehicle has violated the traffic signal. If any vehicle violates the traffic signal, the on board computer issues pre warning to the driver indicating that a vehicle has violated the traffic signal. Figure 1b shows the algorithm executed by the onboard computer of a vehicle for issuing the intersection collision warning.

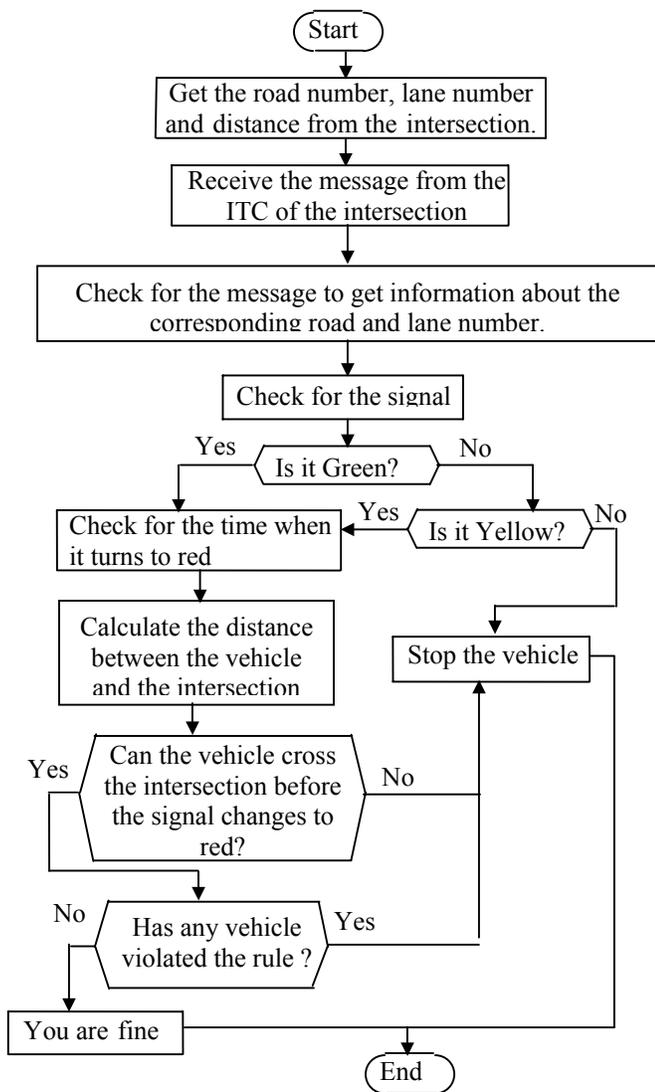


Figure 1b. Tasks performed by vehicle's onboard computer

4. PROPOSED TECHNIQUES FOR ROAD NUMBER, LANE NUMBER AND DISTANCE

FROM THE INTERSECTION DETECTION SYSTEM

In our proposed architecture, the vehicle's on board computer gets the information about the road number and the lane number on which it currently is in motion. We are still in the process of doing research for developing a high speed sensor technique which is capable of delivering the information about road number, lane number and the distance from the intersection to the vehicle's onboard device. The following subsections show a brief description of these techniques.

4.1. BARCODE SYSTEM:

In this technique, we propose to put a barcode on the road using paint on the road. Each lane in the road would be bar-coded and would contain information such as road number and lane number. The bar-code will also indicate its distance from the intersection. The bar-code technique will require that each vehicle have a light source embedded in its chassis. The disadvantage of this system is that in snow, heavy rain or dust the system might behave erroneously.

4.2. RF METHOD:

In this technique, we make the use of a four to five low power very short range Radio Frequency (RF) transmitters. These devices would be embedded in the road. The devices would be located sequentially one after another on the road in order for them to create a very narrow band of electromagnetic field. Each of these devices will transmit at frequency F and each lane in the road would have an array of such transmitters at a unique frequency, say F1, F2, F3, F4 for lane 1,2, 3 and 4, respectively. As soon as a vehicle comes in the range of these devices, the vehicle would detect a narrow beam of signal and would know that since it is the strongest signal in the lane, the messages contained in this signal is for that particular lane on which the vehicle is moving. For the messages, the vehicle will know the road number, lane number and its distance from the intersection.

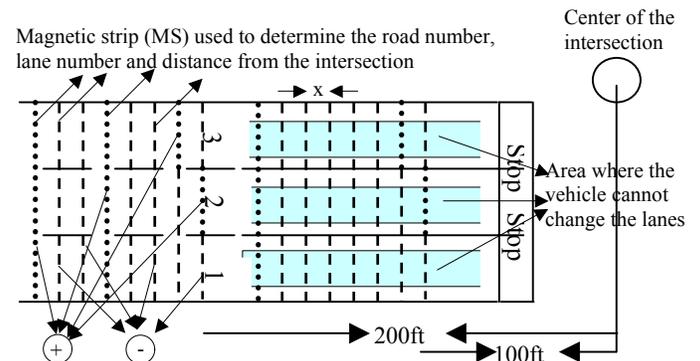
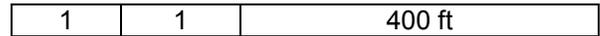


Figure 2. Magnetic strips placed on Road No 3 with three lanes at predefined distances.



4.3. MAGNETIC STRIPS:

Each road has multiple sets of magnetic strips placed at some predefined distances from the intersection. These sets of strips are arranged in such a way that they carry information like distance from the intersection, road number and lane number. The first two strips carry the road number information and the next two strips carry the information of distance from the intersection. The last four strips carry the lane number information. By sensing the fields of the magnetic strips, the magnetic sensor of a vehicle detects where the vehicle is with respect to road number, lane number and distance from the intersection. Figure 2 shows how the magnetic strips are arranged for road number three with three lanes. The magnetic strips with dot “.” symbols create positive magnetic fields and magnetic strips with dash “-” symbols create negative magnetic fields. When a vehicle passes over these strips, the vehicle’s sensor detects a positive pulse when it goes over a dot symbol magnetic strip and a negative pulse when it goes over a dash symbol magnetic strip. The bit coding for a positive pulse is one and for a negative pulse is zero. Table 1a, 1b, 1c show the bit coding and decoding for road number, lane number and distance from the intersection.

4.4 ITEMS TO BE STUDIES TO DETERMINE THE BEST VEHICLE DETECTION SYSTEM.

Study has to be done on the advantages and disadvantages of the techniques discussed in section 4.1, 4.2 and 4.3. We are under the process of developing a two gauss magnetic strength at a distance of 12 inches from the magnetic strip and see whether the sensors can detect this field without an error.

5. PROTOCOL AND SYSTEM REQUIREMENTS FOR BUILDING ICAS

In this section, we present the format of the ITC to vehicles and vehicles to ITC messages. We also provide an estimate of memory and bandwidth requirements for an Intersection Traffic Controller (ITC). The memory and bandwidth requirements have been determined for the worst-case scenarios. In order to determine the memory requirements of an ITC, we have assumed that the intersection has a maximum of 16 roads and each road has a maximum of 16 lanes.

Table 1a: Bit coding and decoding for Road number

Bit Coding for Road number				Road Number
0	0	0	0	1
0	0	0	1	2
0	0	1	0	3
⋮	⋮	⋮	⋮	⋮
1	1	1	0	15
1	1	1	1	16

Table 1.b Bit coding and decoding for Lane number

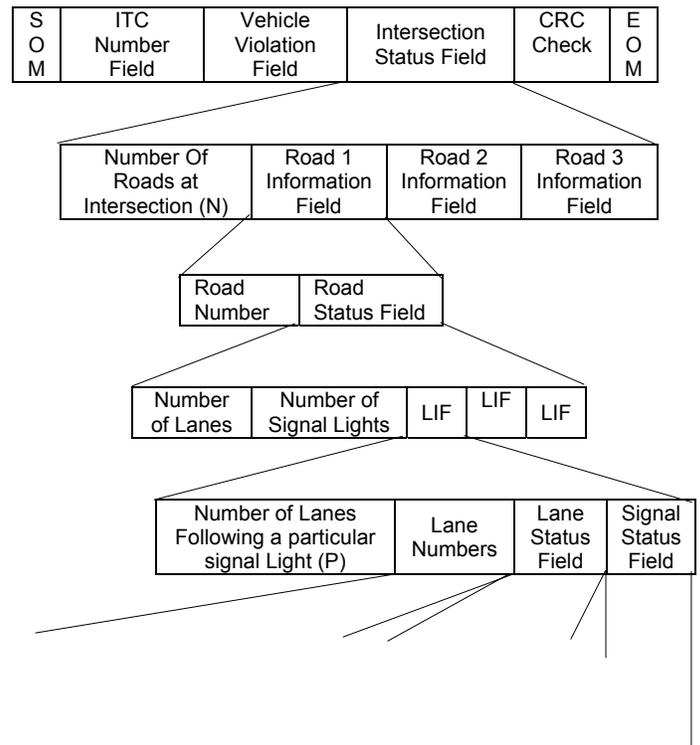
Bit coding for Lane Number				Lane Number
0	0	0	0	1
0	0	0	1	2
0	0	1	0	3
⋮	⋮	⋮	⋮	⋮
1	1	1	0	15
1	1	1	1	16

Table 1c:Bit coding and decoding for Distance from intersection

Distance Coding		Distance from Intersection
0	0	100 ft
0	1	200 ft
1	0	300 ft

5.1. PROTOCOL:

The ITC plays a vital role in the Intersection Collision Avoidance System (ICAS). The main purpose of the ITC is to broadcast the condition of the intersection for the traffic crossing the intersection. The messages to be broadcasted should have a specific format so that all the vehicles can understand easily. The length of the message varies depending upon the number of roads, lanes and signal lights present at an intersection. The message will have to be broadcasted in the form of packets. Figure 3a shows an overview of the message format that is to be broadcasted by an ITC.



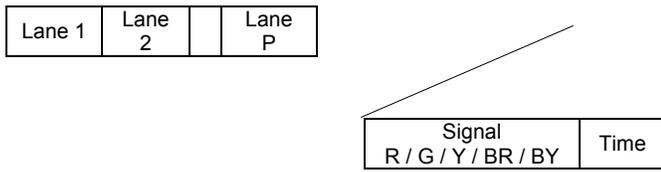


Figure 3a: An overview of the ITC message format.

All messages begin with a Start of Message (SOM) field. This serves to identify the beginning of a message. The second field in the message is always the ITC field, which contains 16-bit ITC number field. This field is used to identify the intersection. The third field in the message is the vehicle violation field. This field contains one bit, which is used to determine whether any vehicle has violated the traffic signal.

Field number four is called the Intersection status field. This is a variable length field. The first four bits are used to specify the number of roads present at the intersection. Following these four bits are road information fields. The number of road information fields depends upon the number of roads present at the intersection.

The Road information field is again divided into a 4-bit road number field and a road status field. The length of the road status field depends upon the number of signal lights and lanes present on a particular road. The first part of the Road Status field is the number of lanes field, which is four-bit wide. This field specifies the number of lanes present on a particular road. The second field is the number of signal lights field, which contains two bits. This field specifies the number of signal lights present for a particular road. Following the number of signal lights field is the lane information field. The lane information field is of variable length. This field is repeated depending upon the number of signal lights present on a road.

The lane information field is divided in to four sub fields. The first sub field contains four bits. This field specifies the number of lanes following a particular signal light. The second sub field specifies the lane numbers of the road following the respective signal light. The third sub field is lane status field, which contains four bits. These four bits are L bit, T bit, R bit and U bit, which specifies whether the vehicles on a particular lane can go left, through, right or make a U turn, respectively or not. The last sub field is the Signal Status field, which has two fields. The First field is the signal field which is of three bits and specifies the signal status i.e. whether the signal is red, green, yellow, blinking yellow or blinking red and the second field is the time field which contains 32 bits, specifying the time left for the signal change.

Following the Intersection status field is the CRC field. It consists of 16-bit Cyclic Redundancy Check code, which allows the receivers to verify the correctness of the received message. The final field of the message is the

End Of Message (EOM) field,

L	T	R	U
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 which serves as the end of the message.

S	Vehicle			Distance		E
O	Road	Velocity	Acceleration	from the	CRC	O
M	No			intersection		M

Figure 3b: Format of the vehicle to ITC message.

Figure 3b shows the format of the message that is to be received by the ITC from the vehicles approaching towards the intersection. The first field is the Start Of Message (SOM) field, which serves to identify the beginning of a message. The second field is of four bits specifying the road number of the vehicle. The third field contains 12 bits, and it specifies the velocity of the vehicle. The fourth field contains 16 bits, and it specifies the acceleration of the vehicle. Following the acceleration field is the Distance field, which has 16 bits to specify the distance from the intersection. The next field is the CRC field. It consists of a 16-bit Cyclic Redundancy Check code, which allows the ITC to verify the correctness of the received message. The last field is the End of Message (EOM) field.

Table2a: A list of parameters used in the message format of an ITC

Parameter	Description
LIF	Lane Information Field
N	Number of roads at the intersection
P	Number of lanes that follow a particular signal
L	Left (0—Left turn; 1—NO left turn)
T	Through (0—Through; 1—No Through)
R	Right (0—Right turn; 1—No Right turn)
U	U Turn (0—U Turn; 1—NO U Turn)
G	Signal is Green (000)
Y	Signal is Yellow (001)
R	Signal is Red (010)
BY	Signal is Blinking yellow (011)
BR	Signal is Blinking red (100)

5.2. MEMORY REQUIREMENT:

The memory required by the ITC to store the information of the vehicles approaching towards the intersection is in the order of some Kbytes. The ITC has to store the vehicles' road number, velocity, acceleration and distance from the intersection. To store each vehicle's information, the ITC needs four bytes of memory. Consider there are N Roads at an intersection. Each road has L_n number of lanes, and each lane has X number of vehicles that are sending messages to the ITC. The total memory required by the ITC can be expressed as

$$M = 4NL_n X \text{ bytes.}$$

Table 2b: memory required from an ITC

From Table 2b it is seen that for 16 roads with 16 lanes and 5 vehicles per lane, the maximum memory required by an ITC is 1.25 Kbytes. In addition to this memory, some memory is needed by ITC to keep the intersection information and run the program for maintaining the updated information. The size of this additional memory is fixed and doesn't depend on the number of vehicles approaching towards the intersection.

5.3. BANDWIDTH REQUIREMENT:

An ITC will have to broadcast (in real time) the information of the approaching vehicles and change of traffic signals to all the vehicles approaching towards the intersection. The ITC has to broadcast the message once in every 10 milliseconds so that the vehicles receive the updated signal information and keep track of the situation at the intersection. Let us assume that a particular intersection has N number of roads with L_n lanes and each lane has S signal lights. Each signal light requires 42 bits and each lane requires 4 bits to specify the lane number. Four bits are required to mention road number and six bits are required to mention the number of lanes and signal lights present on a road. The number of bits required to specify the information of one road is $(42S + 4L_n + 10)$ bits. To specify the information of N roads, the number of bits required by the intersection status field is $N(42S + 4L_n + 10)$. The SOM and EOM field requires 32 bits. ITC field requires 20 bits. The violated vehicle information field requires one bit. The CRC field requires 16 bits. Apart from the intersection status field, we require additional 69 bits. The total length of the message that is to be broadcasted by the ITC is $N(42S + 4L_n + 10) + 69$

Table 2c shows the bandwidth requirement from an ITC. From Table 2c it is seen that for 16 roads with 16 lanes and 4 signal lights per road, the bandwidth needed from an ITC is 48.1 Kbytes/sec, i.e 384.8 Kbits/sec, which can be obtained using DSRC technology which has a data rate of 6,9,12,18,24 and 27 Mbps with 10 MHz channels [11].

Table 2c: Bandwidth required from an ITC.

Number of Roads (N)	Number of Lanes per Road (L_n)	Number of signal states per Road (S)	Length of the message in bytes	Bandwidth Required in Kbytes/sec
3	2	1	31.125	3.039
3	3	2	48.375	4.724
4	3	2	61.625	6.018
4	4	3	84.625	8.260
16	16	4	492.625	48.10

From the above analysis, it becomes clear that using today's technology we can build ITCs with sufficient memory, in order to keep the information of all the vehicles coming towards the intersection. Today's

Number of Roads (N)	Number of Lanes per Road (L_n)	Number of vehicles on each Lane (X)	Memory in Kbytes
3	2	1	0.023
3	3	2	0.070
4	3	2	0.093
4	4	3	0.187
16	16	5	1.25

technology will also allow us to build ITCs with sufficient bandwidth capabilities to support the intersection collision avoidance.

6. CONCLUSIONS

In this paper, we presented the architecture for issuing the intersection collision warning system. We provided detailed description of the message format to be broadcasted. We also investigated the feasibility of implementing the Intersection Traffic Controller (ITC) using the current technology. There are still numerous challenges to be studied including the performance of the system that will enable a vehicle to determine the road and lane number on which it is moving, and its distance from the intersection.

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