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Hardware Prototype Design for Real-Time Collision Detection and Prevention Application of VANET

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Abstract— Real-time embedded system design of Vehicular Ad hoc Network (VANET) application is discussed. Expansion of Internet of Things (IoT) has led to the presence of sensors and internet integration in most everyday objects. This paper describes the implementation of small-scale intra-vehicular and inter-vehicular VANET prototype with wireless sensor communication link for real-time collision prevention and detection. VANET technology is therefore, emerging as a new system to improve the safety of car drivers and passengers alike. Cars fitted with suitable sensors can display warnings about impending collisions due to over-speeding or rash driving as well as communicate with other vehicles through roadside infrastructure to detect accidents out of the visible range of drivers. Due to dynamic network topology of cars, it becomes difficult to deploy VANET system on a large-scale. In this paper, the implementation and working of a small-scale real-time VANET system prototype with three mobile nodes and one stationary node is achieved to enable future development and deployment.

Index Terms— Collision Detection, Collision Prevention, Radio Modules, Ultrasonic Sensors, Vehicular networks, Wireless Sensor Networks, ZigBee.

1 Introduction

1.3 million people die in road accidents every year around the world and is the major reason of death amongst young people in the age group of 15-24 [1]. It is predicted to become the fifth leading cause of loss of human life unless suitable action is taken to counter the estimates [1]. Most crashes are due to minute mistakes and inattention of drivers and their failure to respond swiftly in face of potentially fatal situations. Hence, using new technology to enhance safety of drivers and passengers has become the need of the hour.

Mobile Ad hoc network (MANET) is made up of an assembly of wireless mobile nodes that move randomly within a network and can communicate with each other anywhere without any centralized infrastructure [2]. It has already been employed in military battle fields, classroom, law enforcement, etc [2]. Vehicular Ad hoc Network (VANET) is a mobile ad hoc network where vehicles act as mobile nodes [3]. VANET utilizes two types of communication, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication. Hardware infrastructure for VANET employs On-Board Units (OBUs) and Roadside Units (RSUs). V2V communication enable vehicles fitted with OBUs that are equipped with various application-specific sensors to communicate information to each other without any centralized infrastructure. V2I communication enables the vehicles (specifically OBUs) to communicate with stationary infrastructure i.e. RSU, which is usually responsible for creation of the radio network for communication. If the cars leave the network coverage of one roadside infrastructure, they enter the network created by another infrastructure, if present, and start communicating with vehicles within that particular network range [4]. Wireless sensor network (WSN) communication link is embedded in VANET. It is a collection of nodes in a network that can sense the external and internal environment and communicate the required information to a single base station [4]. These wireless nodes have sensors, fast computational capability, wireless trans receiver and a power supply [5].

VANET provides all the features of MANET which makes it attractive for Intelligent Transport Systems (ITS) including self-organizing topology, reduced power consumption and huge network environment [6]. Its applications can be broadly divided into safety applications and commercial applications. Safety applications include accident warning system, road condition warning system, signal violation warning system, etc while commercial applications include internet access, music download, weather information, traffic information [6]. VANET is impossible without an appropriate routing protocol to adequately address the dynamic topology restraints that makes it difficult to be deployed. Many routing protocols have been designed and implemented to successfully simulate MANET, VANET and other wireless ad hoc networks. The most successful is the AdHoc On Demand Vector Routing Protocol (AODV) which is a demand-based routing protocol [6]. AODV finds a node with the help of another node if not in range and uses Route Request Messages (RREQ) and Route Reply Messages (RREP) [6].

This paper highlights the implementation of real-time Vehicular Ad hoc Network with Wireless Sensor Network prototype for collision prevention and detection. It employs an infrastructural unit to create a network to enable wireless communication between itself and the cars within its network range. In this prototype, cars are attached with OBUs fitted with appropriate sensors and other peripherals. When distance between vehicles fall below a certain safe threshold value within a network, vehicles communicate with each other via the radio link and warning system gets activated in vehicles to help prevent collision. Similarly, vehicles communicate to the RSU within their network to notify if they have been involved in an accident with some other vehicle. RSU broadcasts this message to all the vehicles within its coverage area to avoid further possible escalation if drivers are blindsided and out of visibility range of the accident. RSUs are repeated after certain distances in the roads when the network range becomes weak to provide uninterrupted service**.**

2 Embedded Architecture Of VANET Prototype

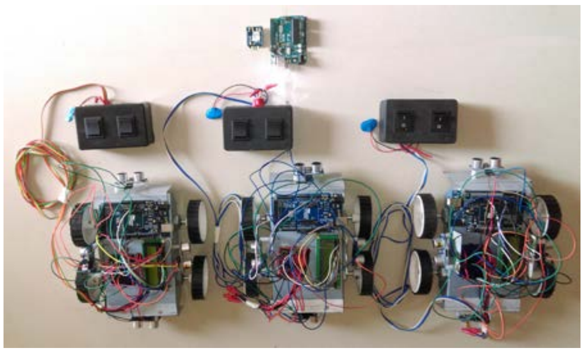

Fig. 1. VANET Prototype with one RSU and three OBUs

This hardware design approach of the miniature real-time VANET prototype for collision prevention and detection application is achieved with three mobile nodes and a single stationary node. This prototype employs cars or the three mobile nodes fitted with OBUs and one RSU or stationary node, mimicking infrastructural unit to form the proposed VANET system. The mobile nodes are manual robots designed with micro controllers and are controlled by human intervention (wired remotes) to closely resemble cars. The stationary node or the infrastructural unit of the prototype is designed using the same micro controller as the mobile nodes and plays a very important role in the whole system architecture. Although, centralized infrastructure is not essential for VANET, this prototype has a dedicated RSU for V2I communication.

2.1 On-Board Unit

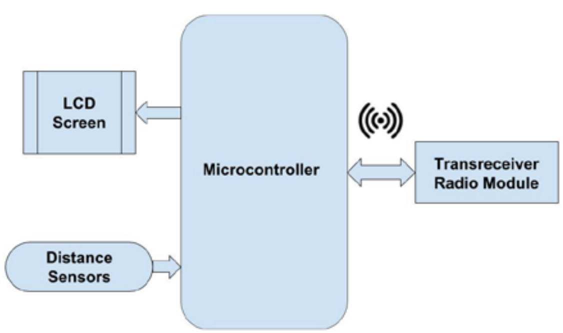

Fig. 2.

Three mobile nodes or cars are designed for this prototype. These cars are equipped with a single OBU. The OBU comprises of ATmega 1280 micro controller as processor and XBee S2B trans receiver radio module which helps create a mesh radio network between cars and the stationary infrastructure unit. The cars are fitted with four ultrasonic ranging sensors to monitor inter-vehicular distance in only four major directions - front, back, left and right, for ease of operation of our prototype. Ultrasonic sensors provide 2cm to 400cm of non-contact measurement with a ranging accuracy of up to 3mm. Modern cars could be equipped with many such sensors for full-proof operation. As modern cars are already equipped with display units, 16x2 LCD is provided on these OBUs to display warning messages or any other information with V2V communication and information about collisions if any, within the network range of RSU due to V2I communication.

2.2 Roadside Unit

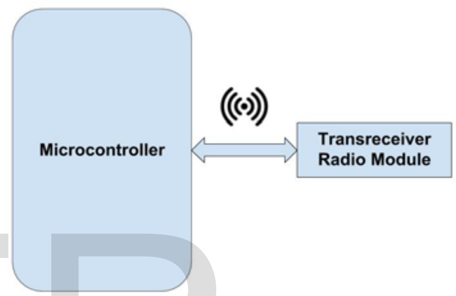

Fig. 3.

A single stationary node or RSU comprises of ATmega328P and trans receiver radio module XBee Pro S2 to create a network between itself and the three mobile nodes equipped with OBUs for collision detection application of prototype VANET. In this design approach, RSU is only utilized for the creation of network and information broadcast. This network is established between the infrastructure and the mobile nodes when any of the mobiles nodes come within the network range of the RSU. Further development can enable the utilization of information collected by RSU to be used for various other communication and technology services like weather analysis and information, weather prediction, internet, traffic information systems, Global Positioning System (GPS), internet music, internet calls, emergency services, etc within vehicles through wireless communication [7].

2.3 Radio Network

As this prototype deals with small distances as compared to real-life traffic scenario, XBee trans receiver radio modules are used in OBUs and RSU. XBee Series 2 Pro module provides a radio power of 6.3Mw, indoor range of 140 feet and outdoor range of 4000ft. XBee modules are based on ZigBee protocol, which is an industry standard protocol for Low Rate Wireless Personal Area Network (LR-WPAN) of multiple wireless nodes via serial data transmission, making it slow but easy to configure. The XBee supports both an AT (Attention Sequence) and an API (Application Programming Sequence) Mode for sending and receiving data at the controller.

1) ZigBee Protocol and Communication

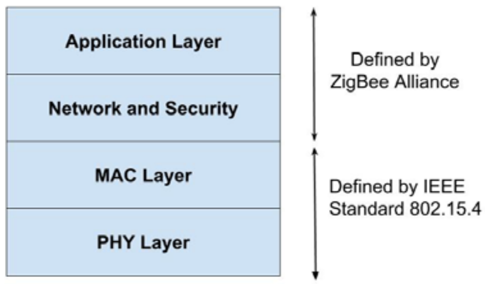

Fig. 3. ZigBee Protocol Stack

This protocol corresponds to IEEE 802.15.4 standard and have spread spectrum techniques in the 2.4 GHz band, known as the industrial, scientific, and medical (ISM) band. It defines specifications for LR-WPAN with 16 channels and 2 MHz bandwidth for devices that operate within 10m and consume low power. ZigBee can meet a wide variety of industrial needs than due to its long-term battery operation, self-organization, multi-hop, greater useful range, flexibility in a number of dimensions, and reliability of the mesh networking architecture [8]. The Universal Asynchronous Receiver/Transmitter (UART) controller for serial communications takes 14 bytes of data and transmits the individual bits in a sequence and the bits are assembled into bytes at the destination by a second UART [9]. The incoming data from remote module typically includes: source address, destination address, error checking values, and other pertinent information needed by the protocol [9].

Coordinator, routers and end devices are the three main ways that a device can act in a ZigBee network. The coordinator is responsible for creating a network and therefore, every network must have at least one coordinator. It performs all the activities of a router, in addition to its own special activities such as selecting a PAN ID, security mode, etc. The routers serve as transmitters or receivers and responsible for routing traffic [10]. It can also go to sleep. The end devices send or receive data to/from the routers or the coordinator and can also send or receive information from other end devices [10]. It does not route traffic and do not go to sleep.

In addition to the above classification, a LR-WPAN network also has a full-function device (FFD) and a reduced-function device (RFD). Coordinators and routers are FFDs. End Devices act as RFDs. The FFD can operate in three modes serving as a PAN coordinator, a coordinator, or a device and can talk to RFDs or other FFDs, while an RFD can talk only to an FFD [8]. After activation of an FFD for the first time, it may establish its own network and become the PAN coordinator [8]. Only one of many FFDs acting as coordinators can be the overall PAN coordinator, which may have greater processing resources than any other device in the PAN [8]. In this VANET prototype system, RSU acts as the only coordinator and the three OBUs acts as the routers.

2) AT Command

Attention Sequence (AT) Mode, also called Transparent Mode, is used for only simple transmission and reception of required encapsulated serial data [9]. The AT commands are used for configuration, so that one node can communicate with its destination node [9].

3) API Programming Mode

This prototype uses API mode for communication of serial data. In Application Programming Interface (API) Mode, the message packet or API Frame is encoded with destination address, types of packet, and checksum value. The command parameter is given one by one, and each command needs a waiting time. However, in the API Mode, all the required command parameters can be used to configure an XBee RF module at a single time, thus, providing reliability and less energy consumption [9]. API operation mode enables many operations such as configuration of the XBee module itself, configuration of remote modules in the network, data management and transmission to multiple destinations, receive success/failure status of each transmitted RF packet and identify the source address of each received packet [11].

4) Mesh Network

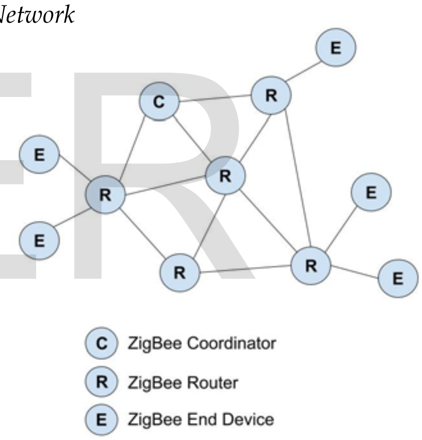

Fig. 4.

There are four major types of network topology for the ZigBee communication protocol, pair topology, star topology, tree topology and mesh topology. This VANET prototype system employs Mesh topology. A mesh network consists of at least three nodes, with at least one coordinator. This type of network is more flexible and reliable than other topologies because if one node in this network fails, the other remaining nodes can carry out transmission of message packets [9].

3 VANET APPLICATION SCENARIO

VANET can be used for various applications for human safety and comfort. This system focusses on Collision Avoidance and Collision Detection application of VANET.

3.1 Collision Prevention

Fig. 6. Collision Prevention: Warning Messages are displayed on the Display Screen of Vehicles A and B

Mesh network is formed between the OBUs of vehicles to channel vehicle-to-vehicle (V2V) communication. Supposedly, as seen from Figure 6, the inter-vehicular distance between vehicle A and vehicle B becomes less than a minimum preset threshold value from any of the given four major directions i.e. Left, Right, Front and Back, warning messages sent to one from the other OBUs will be displayed on the OBUs of both vehicles A and vehicle B to caution the drivers to slow down immediately to avoid any potentially fatal and dangerous situation.

3.2 Collision Detection

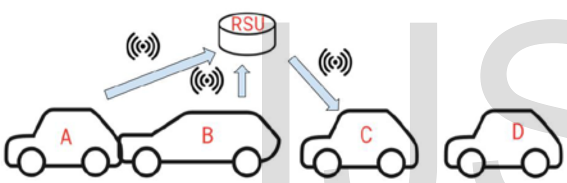

Fig. 7. Collision Detection: Accident Notification Messages are displayed on the Display Screen of Vehicle C

Roadside RSU creates hybrid network between itself and the three OBUs to facilitate vehicle-to-infrastructure (V2I) communication. In case of an accident between vehicles within the network range of a particular RSU, it will be notified of this event from the OBUs of the affected cars and the RSU, in turn, will broadcast this message to all the other vehicles in the network through their OBUs. This helps the drivers to take precautionary measures in case of limited visibility. As seen from Figure 7, RSU is notified about the collision that has taken place between vehicles A and B by the OBUs of both the vehicles. The RSU, in turn, notifies vehicle C about this collision. Vehicle D has not been notified as it is out of the network range of the RSU.

4 Implementation

This VANET prototype system comprises of non-autonomous mobile robots with 250 rpm motors and manually controlled with wired switchboards to simulate regular cars and to be able to closely quantify human perception limitations. These mobile robots are fitted OBUs. The single RSU is kept at a certain distance from the mobile nodes to successfully emulate the system in a real-time environment. The system code is written in C language in Arduino IDE.

4.1 XCTU Configuration in API Mode

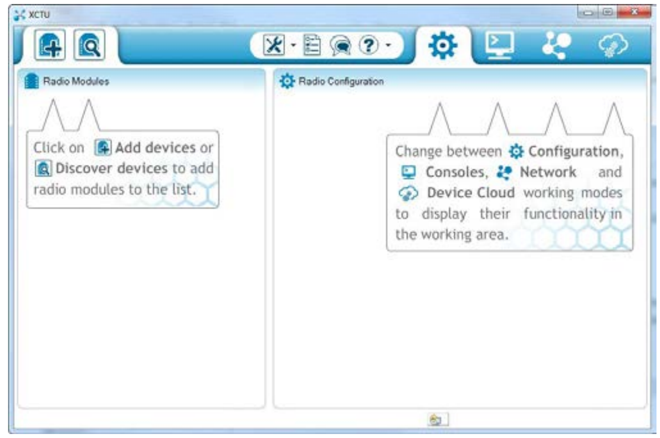

Fig. 8. XCTU Interface

The XBee wireless trans receiver modules are configured with Configuration and Test Utility (XCTU) Software. 3 types of addresses are assigned to the wireless trans receiver XBee modules to uniquely identify them. The modules are identified in the network with a unique 4-bit serial number (MAC Address) address or identifier. The address of the destination must be known to send message from source to destination. A 16-bit address is dynamically assigned to each radio by the coordinator when it sets up a network and is unique only within the given network. Finally, each XBee radio can be assigned a text called the node identifier. Each ZigBee network creates a virtual network and labels it with a 16-bit Personal Area Network (PAN) address. All the communicating radios must be in the same frequency or channel to receive messages. When the ZigBee coordinator picks a network PAN address, it checks over all the available channels and picks a single one for that network's conversations. All the radios in that network must use the same channel. By default, XBee radios handle channel selection automatically.

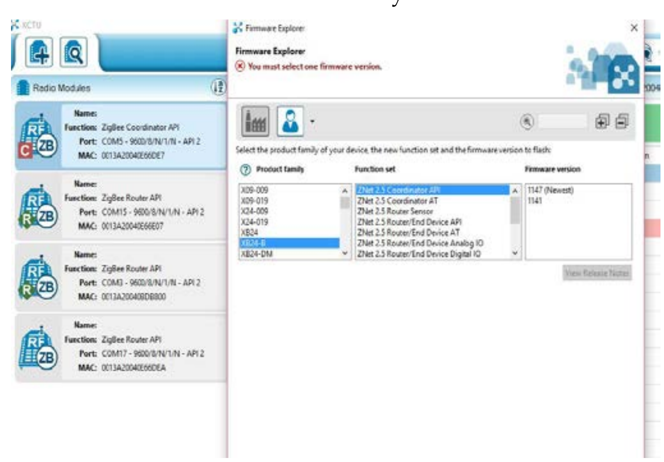

Fig. 9. XBee Modules Configuration

In this VANET prototype system, RSU is configured as the coordinator and the three OBUs are configured as the routers. RSU acts the overall PAN coordinator.

The steps are:

1. Connect the OBU XBee module to the PC with serial adapter to configure them.
2. Search for radio modules and select the USB port where the XBee radio has been connected. For USB ports to be recognized, appropriate USB drivers are installed (CP210x Silicon Drivers).
3. The following default XBee setting must be configured: Baud=9600, Data=8-bit, Parity=None, Stop bits=1, Flow control=None, Local echo=On
4. For the modules to communicate with each other, all of them must have common PAN ID and Channel.
5. For OBUs, the XBee Pro S2B RF modules are configured in the ZigBee Router API mode and updated with latest firmware version of XBP24-ZB.
6. Select DH=0000 and DL=FFFF. This is because the packets from OBU are broadcast and it communicates with all the nodes in the network.
7. Select API enable as API=1 which means API has no escaped characters.
8. 'Write' these Parameters.

Repeat the steps for the remaining two OBU modules. For configuration of RSU, in step 5, select ZigBee Coordinator API mode.

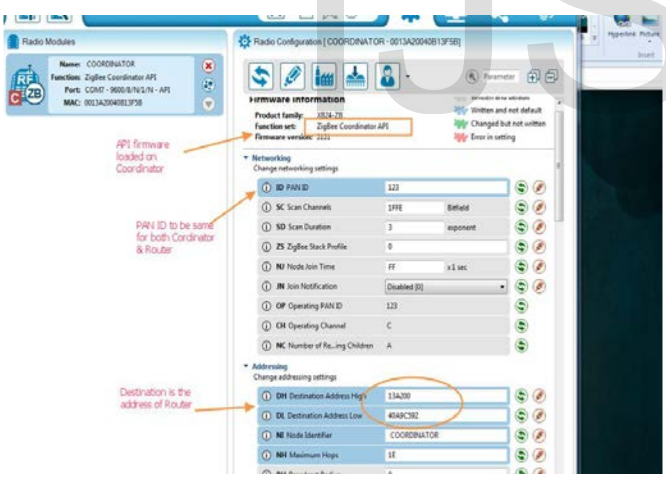

Fig. 10. XBee Settings for Coordinator API

After successful configuration of the OBU and RSU modules as Router API and Coordinator API respectively, API frames can be generated with the help of API frame generator provided by XCTU. If the frame is correctly generated, response message is displayed on the console. API mode of communication generates packets which are not human friendly as opposed to AT mode of communication of ZigBee Protocol. But this mode provides extra reliability and security to the packets such as checksum for error detection The API mode of communication also gives an option of viewing the network formed between the modules communicating with each other.

4.2 Working

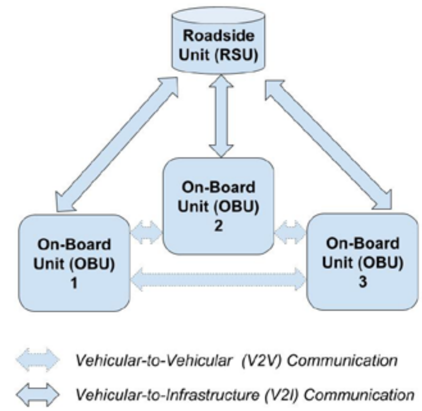

Fig. 11. Working Design of VANET Prototype

The XBee trans receiver module present in the Roadside Unit or RSU is configured to be in the Coordinator API mode of ZigBee protocol using XCTU software tool. XBee modules present in OBUs are configured to Router API mode of IEEE 802.15.4 standard. API has been chosen over AT mode as connected cars system will typically involve more than two mobile nodes and API mode provides much better functionality than AT mode in such a scenario. These wireless modules present in RSU will broadcast data packets to all On-Board Units or OBUs simulated as cars within its network range. Although only one RSU is used in this scenario, in real-time, once an OBU falls out of range of a particular RSU, it will be picked by another RSU within this new network range of the OBU. The RSU in this system is capable of broadcasting warning messages in case of accidents that have already happened to ensure that cars out of visual range can be forewarned of such events and avoid any other complications. RSU embodies the V2I communication of VANET application.

OBUs are capable of tracking the position of nearby vehicles. There are four ultrasonic ranging sensors attached to all the mobile nodes in the network. The Ultrasonic Sensor sends out a high-frequency sound pulse and then measures the time taken by the echo sound pulse to reflect back [11]. One sensor opening transmits ultrasonic waves and the other receives them [12]. The speed of sound is approximately 341 meters per second in air. The ultrasonic sensor uses the following mathematical equation calculate the ranging distance:

$$\text{Distance} = \frac{\text{Time} \times \text{Speed of Sound}}{2}$$

Here Time = the time between when an ultrasonic wave is transmitted and when it is received.

Division by 2 is done because the sound wave travels to the object and then comes back. [12]. These sensors continuously monitor the inter-vehicular distance between the mobile nodes in front (F), back (B), left (L) and right (R) directions.

They measure the corresponding distance between other nodes in the network with respect to itself. These distances will be continuously displayed on the LCD present on the OBU. For the sake of our application, we assume a particular minimum preset threshold value of 12 centimeters as inter-vehicular distance to be maintained between the three mobile nodes for collision avoidance and prevention. When the distance between two successive nodes crosses 12 centilitre, the XBee RF modules present in the OBUs of these two cars communicate with each other and warn each other of impending collision if proper precautions are not undertaken by both drivers such as slowing the vehicle down, etc. This is the V2V communication of our VANET system for collision prevention and avoidance. The OBU can interact with other OBUs as well as RSU. Message packets are unicast. The XBee modules will lead the effective transmission and reception of packets between the mobile nodes.

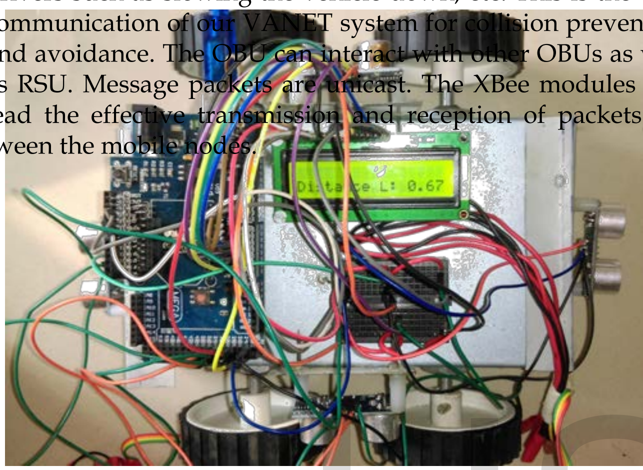

Fig. 12. On-Board Unit (OBU) prototype showing Inter-Vehicular distance in the Left (L) direction

When vehicles are involved in an accident, their OBUs, if undamaged, informs the RSU within its network range about the collision. Warning messages are displayed on the LCD of the the other OBUs present in the same network when RSU wants to inform all the cars about the unfortunate incident that has happened within the network range of the collided mobile nodes. Other nodes outside of the network will not be disturbed. This type of information transfer to all the cars connected in the network is called broadcast transfer of information and is the V2I communication of our VANET system for collision detection. This plays a pivotal role as it prevents further damage when other vehicles are caught unaware of any collisions. As ZigBee has a range of 10-30 meters, RSUs are repeated after some distance so that when the mobile nodes move out of the network of one RSU, it will be connected with another RSU. But this prototype only deploys one RSU.

5 Conclusion and Future Work

This century might just witness the birth of exciting new technologies from driver less cars to flying cars but the safety limitations of these technologies has led to cautious pace of development. Separate incidents of loss of human life due to driver less cars have led to renewed interest in connected cars with human drivers for safety and comfort applications. Constraints in large-scale deployment of VANET is the cause of large scale simulation of VANET networks but hardly any hardware implementation. This paper has presented a small-scale real-time hardware implementation of VANET with four nodes. Further development to this prototype with increased number of nodes and additional applications with real-time environment conditions is required for large scale deployment and use.

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