Implementation of VANETs Using FPGA-based Hardware Test-Bed Approach for Intelligent Transportation System

Syed Waqar Alam, Bilal Muhammad Khan

***Abstract* --- Vehicular Ad-hoc Network (VANET) is a very active and demanding research field in recent days that plays a vital role in road safety applications. This develops a communication network between vehicles travelling on roads for inter-vehicular direct communication within their radio range. Respective road-side units (RSUs) also needs to be installed for indirect communication between vehicles which are out of radio range of each other. This paper presents VANET with its classifications and the protocol that is being used in detail. The simulation scenarios describe behavioral models for each classification and propose a hardware test-bed approach by simply incorporating respective verilog codes on any FPGA chip as per hardware requirement. This develops a small and simple kit at very basic level to connect our required sensors, burn the coding on FPGA and get the response as verification before going for real-time implementation in road traffic environment. This makes this safety critical application even safer. The futuristic approach opens the door for researchers to go with hardware approach for real-time traffic environments with this added advantage of hardware re-configurability that can be implemented accordingly.**

***Index Terms* – Communication, FPGA, Intelligent Transport System, Test Bed, VANET**

I. INTRODUCTION

The world of communication systems has emerged itself mostly from wired domain to wireless domain. However, wired domain is still playing an active role, shifting towards wireless domain provides many benefits in terms of infrastructure-less architecture, low cost installments, remote management and low power consumption. Staying in the same domain, a new area of research which is very much under consideration during recent years is Vehicular Ad-hoc Networks (VANETs) [1, 7]. Vehicular ad-hoc networks (VANETs) is capable of playing a vital role to transform our local road transportation system into an “Intelligent Transportation System”.

This highlights the requirement to develop road safety applications for people travelling via road transportation system so as to decrease the root cause of death toll and number of injuries due to accidents occurring in various parts of the world.

VANET in a much broader aspect, is considered as a special type of MANET [4, 6] (Mobile ad-hoc network) in which vehicles or its surrounding units are considered as wireless nodes. Vehicles in the scenario of VANET move freely as they are supposed to be in real-time traffic environment and the communication between them is mobile. Enabling a vehicle to communicate via VANET with other vehicles on the roads or with nearby road-side units (RSUs) to convey its information to the vehicles outside it’s radio range will assist a driver in a much better way to choose the right path for his vehicle. This makes sure of all the security measures after gathering exact transport information from its surroundings for a safer drive and prevents deadly road accidents. This justifies such type of VANET implementation as a major cause to save human life as well as huge investment in terms of vehicles and infrastructure.

In this paper, our proposed simulation results for VANETs are extracted by generating and implementing Verilog code using Xilinx ISE Suite. Xilinx ISE Suite as a simulation tool for this paper provides us an approach to go towards hardware implementation straight ahead. It gives a platform to incorporate Verilog code on a single FPGA chip which acts like a test-bed model by connecting respective sensors at its I/O ports. This test-bed will help the developer to verify the scenarios and its respective response first on a small hardware kit developed before going for real-time implementation in traffic environment.

The motivation beside implementing FPGA based approach instead of normal microcontroller is to achieve increased processing performance (due to FPGA’s parallel processing mechanism), optimized power requirements, cost reduction (on a larger scale), remote access and obviously runtime hardware reconfigurability for real-time applications [8].

However, if one focuses on current available approaches for VANETs, Table-I shows some of the VANET simulators and their respective response parameters that are obtained from them [9]. The current approaches deliver deviation in parametric values, however, the proposed approach point towards a better reconfigurable hardware architecture that must be capable of addressing the drawbacks obtained from current ones.

In further layout of this paper, section II gives the brief introduction of the protocol that is being used for VANET. Moreover, VANETs classification is presented in the third section, simulation scenarios are explained in the fourth section, futuristic approach in the fifth one followed by the conclusion of the paper.

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TABLE 1. Comparison of Vanet Simulators [9]

Simulators	GloMoSim	NS-2	QualNet
Signal to Noise Ratio Calculation	Cumulative	Difference in two signals	Comulative
Signal Reception	SNRT, BER	SNRT	SNRT, BER
Fading	Rayleigh Ricean	No	Rayleigh Ricean
Path Loss	Free space, Two Ray	Free Space, Two Ray	Free Space, Two Ray, ITM (Irregular Terrain Model).
Support for multiple wireless technology	Yes	No	Yes

II. THE PROTOCOL – 802.11p (WAVE)

While working in the domain of VANETs, the protocol that is preferably being used is IEEE 802.11p [2]. This protocol is for wireless communication is an extended form of WLAN standard of IEEE 802.11, having similarities with IEEE 802.11a in terms of physical layer with Orthogonal Frequency Division Multiplexing (OFDM) & with IEEE 802.11e in terms of MAC (Medium Access Control) layer for QoS [11] [12]. IEEE 802.11p is also named as Wireless Access in Vehicular Environments (WAVE).

The 802.11p MAC method is based on carrier sense multiple access (CSMA) [5] [13], where nodes listen to the wireless channel before sending. If the channel is busy, the node must defer its access and during high utilization periods. This could lead to unbounded delays. However, its physical layer is mainly concerned with the reliability of the system. The protocol uses channel bandwidth of 10MHz in 5.9GHz band (5.85-5.925GHz), having data rates from 3Mbps to 27 Mbps.

Moreover, Table II gives a comparative analysis of performance parameters for MAC layer of 802.11 and Ad hoc MAC. [14, 15].

TABLE 2. Comparative analysis of 802.11 and AD HOC MAC [14. 15]

Performance parameters for MAC	802.11	AD HOC
Basis	CSMA/CA	RR-ALOHA
Maturity of implementation	Mature and still evolving	Medium
Real-time performance capability and QoS	Small	Medium
Mobility	Medium → High	Medium
Broadcasting reliability	No	Yes
Synchronization with time	Not required	Mandatory

III. CLASSIFICATION OF VANETs

VANETs are mainly classified into two main categories, i.e. “Vehicle to Vehicle (V2V) Communication” and “Vehicle to Infrastructure (V2I) Communication”. However, there is a third type of model as well which is known as hybrid communication and is considered as “Vehicle to Vehicle to Infrastructure (V2V2I) Communication” [3].

A. V2V Communication

In V2V communication, a central entity (like an access point in WLAN standard) is not required as the means of communication between vehicles travelling on the roads. This clearly indicates that the mobile vehicles travelling freely on the road can directly communicate with each other or may form a small group to send & receive information to other nodes using different routing algorithms. As multiple vehicles may be there in such communication scenario, the routing protocols that allows the information exchange between the nodes may form a multi hop network. During communication in the scenario of V2V communication, the exchange of information in accurate time with reduced latency is very important being time-sensitive, else may result as a serious loss. Considering few of the scenarios in terms of examples, a V2V communication may give emergency brake lights warning by informing the vehicle when the driver of vehicle moving ahead apply sudden brakes. In case of close distance scenario, it may generate a warning message to avoid forward collision. When two vehicles moving from blind spots reaches an intersection, it generates a warning message of vehicle detection when both the nodes come within the radio range of each other to avoid any undesired incident.

B. V2I Communication

The V2I communication allows communication between a vehicular mobile node and a static road side unit (RSU) to exchange the information globally on large scale. Direct communication between a vehicle and RSU for information exchange formulates a single hop network. Then the RSU can broadcast the gathered information globally so that the information regarding vehicles from one part of the city can be shared with other part of city by first having V2I communication and then I2V communication (here I is representing infrastructure, as road side unit and V as vehicular node).

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As an example if there is blockage of road in certain part of city, then the vehicle moving on the same road will definitely face congestion issues. However, this vehicle can send this blockage information to the RSU present within its radio range using V2I communication. The respective RSU may broadcast this information globally using I2I communication and the information is finally delivered to other vehicles willing to follow the same route having blockage using I2V communication.

C. V2V2I Communication

This third type is a hybrid one combining V2V and V2I communication formulates V2V2I communication. In this case, one communicating vehicle is considered as "master vehicle". This master vehicle can exchange information with other vehicles as well as RSUs that are in radio range simultaneously.

IV. SIMULATION SCENARIOS

Table III present the parametric values used for 802.11p protocol. A comprehensive simulation analysis is done for three cases as discussed above and the implementation of these scenarios are presented in this section which shows the practical demonstration of VANETs on hardware platform using Xilinx ISE Suite to get their respective timing diagrams as simulation results.

TABLE 3. Parametric Values for 802.11p

Parameters	**802.11p values**
Channel bandwidth	10 MHz
Data rates	3 to 27 Mbps
Slot Time	16 µs
SIFS time	32 µs
Preamble length	32 µs
Air propagation time	<4 µs
CWmin	15
CWmax	1023

Case I. For V2V nodes

In this scenario two vehicular nodes "v1" and "v2" are considered which are travelling on the same path.

When both the vehicular nodes come within the radio range of each other, "v1" receives positive edge of clock. At this positive edge, "v1" gets high and then transmits this high to "v2" on the next clock cycle showing V2V communication and indicating the driver of "v2" that the distance between both the vehicles is close enough, this enforces node v2 to take precautionary steps to avoid any possible collision. Figure 1 shows the data flow of V2V scenario.

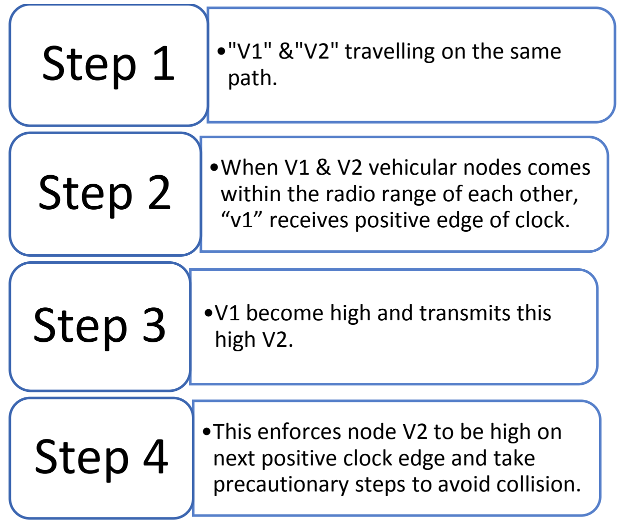

Fig. 1 Data flow of V2V scenario

The results are shown in Figure 2 as timing diagram obtained from ISim simulator of Xilinx ISE Suite by simulating its behavioral model.

Fig. 2 V2V simulation scenario using ISim simulator of Xilinx ISE Suite

Case II. For V2I nodes

In this scenario one mobile vehicular node denoted by "V" and the other one is the road side unit or infrastructure unit denoted by "I" is considered.

The vehicular node "V" needs to transmit its information globally so that the vehicles travelling in other parts of city may utilize it in an effective way. For this purpose, when "V" comes within the radio range of a road side unit "I", it receives positive edge of clock (as in the previous case) and gets high. Then "V" transmits this information to "I" on the next positive edge showing V2I communication to transmit this information globally as desired.

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Figure 3 shows the data flow of V2I scenario.

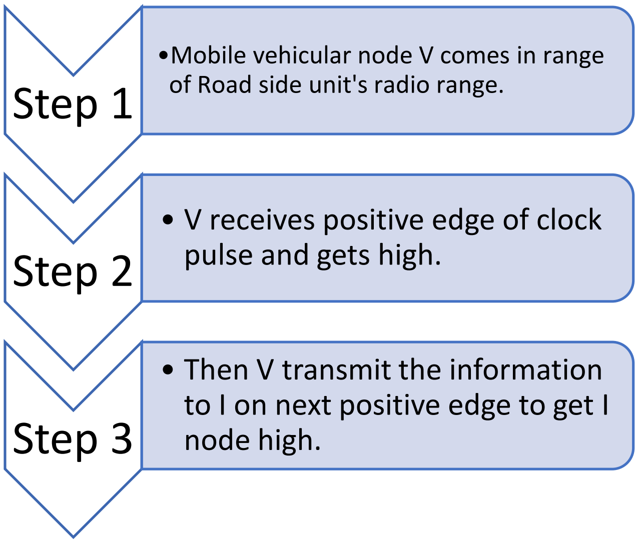

Fig. 3 Data flow of V2I scenario

The results of hardware timing diagram can be seen from Figure 4.

Fig. 4 V2I simulation scenario using ISim simulator of Xilinx ISE Suite

Case III. For V2V2I nodes

In case of hybrid model (V2V2I communication), a master vehicular mobile node will interact with other units in a way as discussed above. Using such type of hybrid models may contribute in reducing infrastructure in the sense of less number of RSUs being used as the communication to other vehicles is also being done by master vehicle itself.

In this model we consider in total 4 nodes having 1 master node, 2 vehicular mobile nodes and 1 RSU. According to scenario whenever there is any accident or blockage in any of the lanes on road and our master vehicular node is also following the same path, the vehicle (1st vehicular node) being the victim of that incident will transmit a 'high' to master node indicating V2V communication between the two. Once the master vehicle receives 'high' signal pulse, it will relay this information to the vehicle which is following the master (2nd vehicular node) indicating V2V communication again so that they may avoid that incidental route if they wish to and at the same time to the nearest RSU indicating V2I communication to transmit it globally.

Figure 5 shows the data flow of V2V2I scenario.

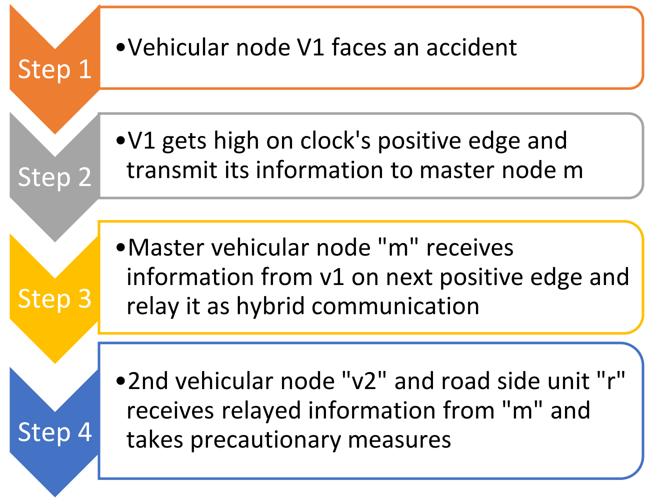

Fig. 5 Data flow of V2V2I scenario

Figure 6 shows the timing diagram of this scenario. In this case, labelled "v1" is the vehicle facing accident. At positive edge of clock, v1 gets high and sends the information to "m" which is our master vehicular node in the next clock cycle. Then the master node relays this information to "v2" which is the other vehicular node and "r" which is our RSU simultaneously.

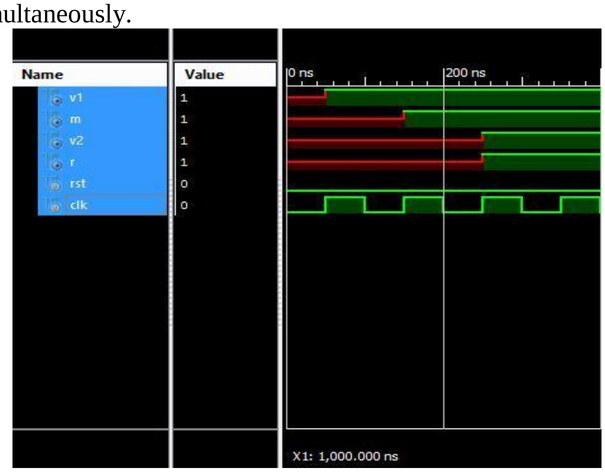

Fig. 6 V2V2I simulation scenario using ISim simulator of Xilinx ISE Suite

The above presented timing diagrams are obtained via ISim simulator of Xilinx ISE Suite as mentioned earlier after implementing and simulating the behavioral models for respective programs using Verilog coding technique.

In case of reset for each case, all the parameters will set themselves to low. This connects us with an approach towards FPGA based hardware test-bed.

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As the timing diagrams presented for each simulation scenario clearly shows the behavioral response, this provides ease to the developer to simply incorporate their Verilog coding on a single FPGA chip and connect the required sensors as peripherals on I/O ports that needs to be implemented on real-time hardware. One important thing that needs to be clear is that instead of dealing with the protocols for VANETs, the timing diagrams presented in this paper shows the implementation response for hardware using Xilinx ISE feature. The duty cycle for synchronous clock can be set by the developer in his verilog code as per hardware requirement to get the response of the overall system as fast as required. In these particular cases, clock changes are being occurred at 50ns, so we may observe the response at each positive edge of clock accordingly. Once the response is tested and verified on this simple and small development kit, the developer may go for its implementation in real-time traffic environment. The system that'll be developed using this approach will have a flavor of hardware reconfigurability. This clearly means that if our developer wishes to upgrade the hardware in future or add any additional feature, he need not to replace whole hardware or any component in terms of processor or FPGA chip etc., but simply reprogram the current one.

V. CONCLUSION

We proposed a simple approach in this paper using reconfigurable hardware test bed development in a much easier way. The proposed approach is not restricted to use a particular FPGA of a specific company. A developer can design its hardware image for required cases of VANET using Verilog on his desired FPGA. The same chip can be reprogrammed very easily for upgradation purpose if the user wants to add any additional feature in his vehicular network. Furthermore, extracting and implementing useful results from research under the area of VANETs will contribute much in terms of safety critical applications to improve vehicular transportation systems and provide its transformation in a new dimension.

On the other hand, this approach also saves time opting from dedicated application specific software tools for VANETs [9] like SUMO, VANETMobiSim, GrooveSim etc which somehow may restrict to perform user define operations in user friendly OS and have their own limitations.

VI. FUTURISTIC WORK

For real-time implementation as a futuristic approach, FPGA based hardware [10, 16] will provide on-chip reconfigurable hardware capable of facilitating vehicular ad-hoc networks (VANETs). The communication reliability using such hardware will be quite better due to parallel processing capability of FPGA. This hardware needs to be installed as a part of electronic section in each vehicle as well as for road side units (RSUs) that are looking forward for respective communication. For the multiple node scenarios, i.e. there will be multiple vehicles/RSUs and so as multiple on-chip reconfigurable VANET hardware installed with each node. Therefore, the communication between them will be done in similar manner.

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