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Reliability and survivability of vehicular ad hoc networks: An analytical approach ☆

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ABSTRACT

Vehicular ad hoc network (VANET) is a technology that facilitates communication between vehicles by creating a 'mobile Internet'. The system aims at ensuring road safety and achieving secured commutation. For this reason, reliability and survivability of the network become matters of prime concern. Reliability and survivability of the network is immensely dependent upon the hardware and channel availability. This paper, primarily focuses on the reliability and survivability of VANET as a function of reliable hardware and channel availability. The reliability of the vehicles and the road side equipment is investigated using reliability block diagrams. The survivability of the network, with respect to reliable hardware and channel availability is explored using Markov chains and Markov reward model. Considering that the communication between the vehicles may take place directly (i.e., *vehicle-to-vehicle* (V2V)) or through the road side equipment (i.e., *vehicle-to-roadside* (V2R)), the evaluation is ascertained for both V2V and V2R communications methodology, in terms of network reliability, connectivity and message lost due to unreliable hardware or channel availability. The technique of hierarchical modeling is adopted for the same. The results are also verified against simulation.

1. Introduction

Vehicular ad hoc network (VANET) is a technology that uses moving cars as nodes in a network to create a mobile network [1]. The primary goal of VANET is to increase safety, ameliorate congestion, reduce pollution and thereby conserve resources. Of late, the military has used VANET for detection systems and vehicular tracking. Hence the reliability and survivability of VANET in the event of adverse situations is a matter of prime concern.

Communication in VANET is primarily between the vehicles, also referred to as the 'On Board Units' (OBUs), since they are equipped with 'On Board Equipment' which enables communication between them [2]. Communication between the OBUs begins with the registration of the OBUs with the network through roadside equipment primarily installed in the light poles, traffic light signals etc.. The roadside infrastructure into which this equipment is installed are called 'Road Side Units' (RSUs). If the communication between the OBUs continues through the RSUs then it is called *vehicle-to-roadside* (V2R) communication otherwise it is known as *vehicle-to-vehicle* (V2V) communication. This is illustrated in Fig. 1.

In this paper, the reliability and survivability of VANET are explored as a function of reliable hardware and channel availability, for both V2V and V2R communications. In the next section, we first explore the research work accomplished in this field. Thereafter, a reliability analysis of the hardware involved in communication is conducted in Section 3 using reliability block diagram (RBD). The reliability of the network is also evaluated for different topologies that may exist in a VANET. In Section 4, connectivity and message loss due to channel unavailability and hardware failure is studied. This analysis is conducted for both V2V and V2R communications using Markov reward model (MRM) [3–5]. In Section 5, the impact on message loss in the V2V and V2R communications is analyzed. The paper is concluded in Section 6 together with a summary of the results obtained.

2. Background work

Reliability and survivability of complex systems has always been a matter of concern [6,7]. The importance of reliability and survivability analysis is reflected in planning, accessing risk, uncertainties and proposing maintenance strategies [8,9]. Several studies have been made to explore connectivity and dependability

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of VANET. Ref. [10] summarizes the recent attempts made to explore and enhance the reliability of VANET in terms of the successful transmissions. Reliability of VANET is discussed in terms of packet reception rate, packet delivery ratio, OBU successful packet delivery probability and the effective range. It also proposes stochastic modeling as an efficient modeling technique for examining the same, analytically. Ref. [11] examines connectivity as a function of traffic load. It also presents algorithms for analyzing connectivity, independent of the traffic load, but based on distance from destination. However, we observe that reliability and survivability of VANET has not been explored as a function of reliable hardware and channel availability.

Further, in [12], connectivity using bond percolation model and Bolloba's model is investigated. Quantitative relationship among network connectivity, vehicle density and transmission range is analyzed and minimum transmission range to achieve good network connectivity is obtained for a given vehicle density. Ref. [13] explores V2V communication analytically, under the collision avoidance scheme. The main contribution of the paper lies in the analytical derivation of optimal channel access probability, transmission range and the rate at which the OBUs should transmit in order to avoid collision and therefore connect successfully. While the two research articles focus on connectivity, the reliability of the hardware involved in communication is ignored. In comparison, we propose to analyze the impact of reliable hardware and channel availability on connectivity.

The dynamism of VANET environment is studied using a fluid dynamic model in [14]. Connectivity amongst the OBUs is examined under different traffic conditions. Ref. [15] analyzes packet level performance in VANET under variant traffic scenarios. Ref. [16] deals with message delivery. The paper analyzes the successful delivery of the messages assuming priority. Ref. [17] simulates VANET in real city scenes, i.e. for different vehicle distribution and GPS data transmissions.

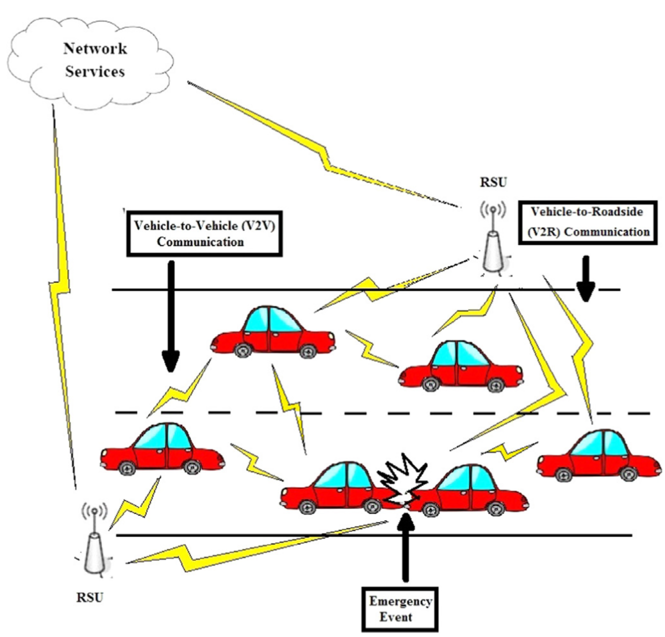

Fig. 1. VANET communication architecture.

In these articles, we observe that the reliability of hardware and channel availability is immensely ignored in comprehending the performance of VANET [1,18,19]. Hence, we propose to analyze the reliability and survivability of VANET, in terms of network reliability, connectivity and message loss, as function of the reliable hardware and channel availability. Several methodologies are implemented to study the reliability and improve survivability of various systems. In this paper, the analysis is conducted using RBDs, Markov chains and the MRM technique [20,5], for both V2V and V2R communications.

3. Reliability

A reliable communication in VANET is dependent upon reliable hardware involved in communication. Reliability is defined to be the ability of a system or component to perform its required functions under stated conditions for a specified period of time. In this section, the reliability of OBUs and RSUs are explored using RBDs.

3.1. OBU [21]

An OBU is composed of several modules and sensors that are responsible to collect the necessary information to be provided to the driver. Below, we mention the modules and sensors that compose the basic architecture of an OBU:

- *Main Control Unit* (*MCU*): An OBU contains a MCU bus, for the connection and coordination amongst its peripheral devices. The reliability of the MCU, at time *t*, shall be denoted by $R_{MCU_{VS}}(t)$.
- *General positioning system* (*GPS*): It allows the OBU to receive and transmit the location of the OBUs. The reliability of the GPS communication module, at time *t*, shall be denoted by $R_{GPS_{VS}}(t)$.
- *Dedicated Short-Range Communications* (*DSRC*) *Unit*: DSRC unit is responsible for communications between an OBU and RSU or OBU and OBU. In this unit, all DSRC configuration information is encapsulated to enable appropriate communication. The reliability of the DSRC unit, at time *t*, shall be denoted by $R_{DSRC_{VS}}(t)$.
- *Ethernet Controller*: The DSRC module utilizes Ethernet for communication to the host device, in this case the OBU. The GPS and Ethernet controllers (DSRC communication) make it possible to gather the information from these devices and thus enable the full capabilities of our collision warning algorithms. The reliability of the ethernet controller, at time *t*, shall be denoted by $R_{EC_{VS}}(t)$.
- *System Operations and Warning Indicators*: These are actually a part of the cabin user interface, i.e., the interface through which the user operates the OBU. The interface is also responsible for displaying warnings being received from the RSU or satellite with regard to traffic conditions. The reliability of the system operations and warning indicators, at time *t*, shall be denoted by $R_{SO_{VS}}(t)$ and $R_{WI_{VS}}(t)$, respectively.

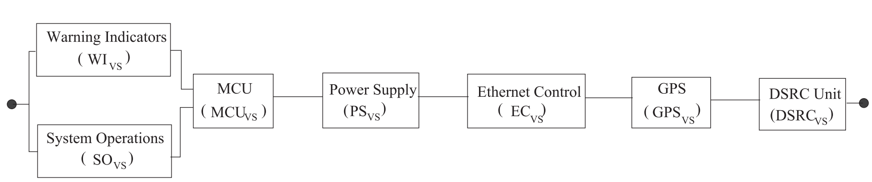

Fig. 2. RBD of an OBU.