

Reliability and Safety/Integrity Analysis for Vehicle-to-Vehicle Wireless Communication

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ABSTRACT

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications are gaining increasing importance in automotive research and engineering domains. The novel communication scheme is targeted to improve driver safety (e.g., forward collision warnings) and comfort (e.g., routing to avoid congestion, automatic toll collection, etc.). Features exploiting these communication schemes are still in the early stages of research and development. However, growing attention to system wide infrastructure - in terms of OEM collaboration on interface standardization, protocol standardization, and government supported road/wireless infrastructure - will lead to popularity of such features in the future. This paper focuses on evaluating reliability and safety/integrity of data communicated over the wireless channels for early design verification. Analysis of a design can be done based on formal models, simulation, emulation, and testing. The first two are preferred choices over the latter two for early verification, as both formal models and simulation provide rapid verification with high repeatability, fast turnaround time, high control, and high flexibility. Though formal models and simulation may provide lower realism, they help in narrowing down alternatives by discarding outliers. In this paper, we focus on three analysis techniques for early verification/analysis of wireless channels: formal state transition modeling, simulation of the protocol, and hazard and risk assessment. The first two techniques have been considered in several earlier works - in particular, the paper focuses on Markov Chain modeling of the protocol behavior, and simulation of the protocol in ns2. We use both techniques for analyzing a representative vehicle-to-vehicle communication system and present a comparison of the techniques from the outcome of the analysis. The third technique, hazard and risk assessment (H&RA) approach based on ISO/DIS 26262, has attracted a lot of attention for

automotive safety/integrity analysis - however, to the best of our knowledge, the approach has not been widely used with perspective to V2V communication. By applying the H&RA approach to wireless systems, hazards are identified, controls and mitigations are proposed, and safety goals are determined. The controls and mitigations as well as the safety goals will provide requirements on the reliability of the wireless channels and on the communication network architecture.

INTRODUCTION

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications are gaining increasing importance in automotive industry. Communication will be based on the IEEE 802.11p standard ([30, 31]), an approved amendment to the IEEE 802.11 standard to add wireless access in vehicular platforms. The wireless communication, also known as Dedicated Short Range Communications (DSRC), is performed over a dedicated channel; in the US, 75 MHz at 5.9 GHz has been set for the purpose. The focus of DSRC is to have connected cars to assist in driving and to increase safety. [Figure 1](#) shows vehicles moving on road while communicating with each other - the shared information may include vehicle conditions (e.g., velocity), road conditions (e.g., slope), and traffic conditions (e.g., accident).

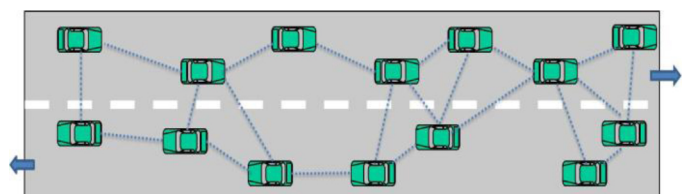


Figure 1. Vehicle-to-Vehicle (V2V) Communication

The communication is not limited to vehicle-to-vehicle information; the protocol can be used for vehicle-to-infrastructure communication schemes like vehicle-to-utilities (e.g., automatic toll payment), vehicle-to-road (e.g., warning on traffic light), vehicle-to-maintenance (e.g., searching for gas stations), vehicle-to-owners (e.g., diagnostic update via cell phone), or vehicle-to-commerce (e.g., targeted local advertisement) (Figure 2).



Figure 2. Vehicle-to-Infrastructure (V2I) Communication

DSRC communication is being targeted for safety applications (e.g., post crash notification, cooperative collision warning, etc.), convenience applications (e.g., congested road notification, parking availability notification, etc.), and commercial applications (e.g., remote vehicle personalization, diagnostics, etc.). Refer [1] for detailed discussion on such possible applications. The applications may also require different types of communication - e.g., unicast vs. broadcast, event-driven vs. periodic, download vs. streaming, etc. In summary, the applications (e.g., “360 Degree” Wireless Collision Warning System) are expected to provide a “sixth sense” to the driver (Figure 3) for better and safer driving experience.



Figure 3. “360 Degree” Wireless Collision Warning System

Given the increasing importance of V2V/V2I communication, a holistic framework for performance

analysis of wireless channels is of prime importance. Designers need methods and tools for objective evaluation and comparison of automotive ECS (Electronic Control System) architectures to select the most suitable alternative. [2] identifies a set of key top level metrics to compare ECS architectures; the metrics evaluate an architecture based on hard real-time behavior (timing, safety, reliability, etc.), ability to accept change (e.g., flexibility, scalability, etc.), ability to reflect consumer demands (e.g., fuel efficiency, maintainability, etc.), compatibility to legacy designs (e.g., alignment, complexity, etc.), and monetary cost. In this paper, we focus on reliability and safety-integrity analysis of data communicated over DSRC channels. The objective of the paper is to reflect on the common approaches to compute reliability/safety/integrity of data communicated over DSRC channel, to use the techniques to analyze representative system design, and to compare/evaluate/ analyze outcomes of such analyses.

For reliability analysis, this paper focuses on the metric *packet delivery ratio* (PDR) which measures the fraction of packets that have been successfully received over the channel to the total number of packets that have been transmitted. There are several conventional techniques that are available for computing/assessing the PDR. The techniques can be broadly classified as formal modeling, simulation, emulation, and test bed implementation. The formal modeling technique usually models the state transition behavior, and captures the general behavior of the state transition systems. The simulation technique records the change in the systems’ parameters as different events occur - the events are generated randomly to reflect environment behavior. The emulation technique [28, 29] tries to model the system components in software and hardware, and execute the system to analyze the behavior. The test bed [27] implementation technique implements the actual hardware in the real environment, and analyzes traces to estimate patterns. The first two techniques are high-level which means they are repeatable, flexible and scalable but may not reflect reality very accurately. The fourth technique reflects reality accurately but is not repeatable, flexible, and scalable. The third technique is in the middle. In this work, we focus on techniques that can be applied to early design verification, when detailed hardware model (either as hardware prototype or software stack required by emulation) or actual hardware (required by test bed implementation) is not available. However given that both formal analysis and simulation are high level, the risk of using any single technique may be high - given that the risk lies in the model, comparing the results across two techniques will provide greater confidence in the results. For our work, we selected two widely used approaches for each technique - Markov Chain modeling for formal analysis and ns-2 based simulation. Comparing the results of these two approaches, we evaluate how the two models can be used in tandem for early design verification for wireless communication.

Given that the systems would be used for safety application, safety analysis need to be performed. In automotive industry ISO/DIS 26262 is the rising standard for such analysis. However to the best of our knowledge there is no open publication on the use of ISO/DIS 26262 process for analyzing wireless applications. In this work, we used hazard and risk assessment (as prescribed by ISO/DIS 26262) and analyzed potential use to wireless application. The paper presents the analysis and the outcome of the analysis for representative wireless applications.

Overview: The next section presents the DSRC protocol. The following two sections provide the aspects of simulation, and Markov Chain modeling analysis for DSRC with reference to related work. The section “Analysis Comparison” provides the outcome of the two analysis techniques to representative data sets and comparison between the two techniques. The following section presents safety-integrity analysis for wireless data based on ISO/DIS 26262 hazard and risk assessment.

PROTOCOL

In this section, we discuss a brief overview of the protocol; refer [30, 31] for detailed discussion on unicast and broadcast protocols. If a message is ready to be transmitted, then the channel is checked. If the channel is sensed busy, then the sender needs to perform a backoff procedure. The node computes the backoff window length (the length of the window is chosen randomly from an initial allowable window size C_{win}) and the node waits for a Distributed Inter Frame Space (DIFS) interval. The backoff counter is started at the end of the DIFS. The node monitors the channel for discrete time interval known as slot time (set by the protocol). If there is channel activity within a slot, then the backoff counter process is suspended - once the medium is idle for a DIFS period, the backoff procedure resumes. If there is no activity during the slot interval, then the backoff counter is decremented. When backoff counter reaches zero, the message is transmitted. If the channel is not busy, then the node monitors the channel for DIFS interval. If the channel becomes busy within (or at the end) the DIFS interval, then the node performs a backoff. If the channel is not busy within and at the end of the DIFS, then the node transmits the message. After transmission a new backoff is performed even if there is no other frame waiting to be sent to prevent channel capture.

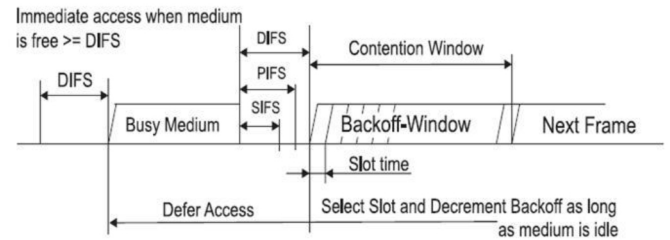


Figure 4. Illustration of Basic Access Method for Scheduling Packet Transmissions (© 1999 IEEE, reprinted from IEEE 802.11 master document, 1999 version [31])

The throughput or reception rate for broadcast protocol may suffer from the following:

- Hidden Terminal- a receiving vehicle may be within range of two transmitting vehicles both of which are outside the transmit range of each other; this can cause packet collision and lost data (which impact throughput).
- Consecutive Freeze Process - under saturated condition, a transmit node may “hog” the channel by selecting zero backoff window.

Note that both the above situations exist in unicast and broadcast protocols; however the lack of acknowledgement makes the situations worse for the broadcast scheme. The automotive environment can bring in other challenges like

- Mobility - the vehicles are almost continuously moving which may mean that they are moving from range of one vehicle to another which will affect packet drop rate;
- Channel Fading - given the traffic, infrastructure, and road condition, ideal channel scenarios would not hold, and it gets difficult to efficiently model channel fading which is needed to compute accurate packet drop ratio;
- Number of cars and distribution - higher the car density, higher would be the number of vehicles trying to transmit at the same time causing higher number of packet collisions;
- Number and type (priority access, arrival rates, etc.) of messages - depending on origin of signals, messages will be created with varying rates; also, depending on urgency and importance, messages will be assigned different priorities which will detect different access mechanism to MAC; these factors need to be accounted for accurate modeling of delay and throughput. Depending on data arrival rate, the channel can either work under saturated condition (data is always ready to be transmitted at each node) or unsaturated condition (data may not be always available at nodes).

Any analysis for the DSRC broadcast protocol needs to account the above. For a formal model, one needs to account for each of the perspectives. For simulation, one needs to