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Vehicular ad-hoc network simulations of overtaking maneuvers on two-lane rural highways

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ABSTRACT

The objective of this paper is to evaluate the effectiveness of a dedicated short-range communication (DSRC)-based wireless vehicle-to-vehicle (V2V) communication system, called the *overtaking assistant*, devised for improving safety during overtaking (also referred to as passing) maneuvers on two-lane rural highways. Specifically, the paper examines the influence of vehicular kinematics (vehicle speeds, accelerations and distances), driver behavior (drivers' perception/reaction time and overtaking rate), and DSRC characteristics (power settings, communication range, packet errors, sensor errors, and estimation inaccuracy) on the effectiveness of DSRC systems in predicting unsafe overtaking maneuvers. To this end, the paper utilizes a microscopic traffic simulator called VEhicles In Network Simulation (VEINS) that supports the simulation of wireless communication protocols in Vehicular Ad-hoc NEtworks (VANETs). 18,000 overtaking maneuvers – with roughly 10,000 collision maneuvers – were simulated to consider heterogeneity in vehicular kinematics, driver behavior, and DSRC performance. The *overtaking assistant* predicts whether a collision will occur and warns the driver before the maneuver begins. A descriptive analysis followed by a multivariate analysis (using binary discrete outcome models) of the simulated data reveals that the majority of collisions that could not be detected were due to the vehicles being out of communication range for the communication power settings used in the simulation. Packet errors, or failed communications, at a rate of up to 50% did not have a significant influence on the ability to detect collisions. These results suggest that the most important step in paving the way toward advanced driver assistance systems for rural highway overtaking maneuvers is to broaden the communication range of DSRC devices.

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1. Introduction

The National Highway Traffic Safety Administration (NHTSA)'s annual crash statistics indicate that two-lane rural highways witness a disproportionately high number of fatal crashes. In particular, although only 19% of the US population lives in rural areas, 54% of the traffic fatalities occur on rural highways (see FHWA, 2015; NHTSA, 2014). Many of these fatality-causing collisions occur during the passing maneuver on two-lane highways when vehicles attempt to overtake slower moving vehicles ahead. Among the primary reasons behind these collisions are driver errors, including inattention or distraction, misperception of sight distances, illegal passing, and excessive speeds. Despite the implementation of various design solutions and traffic control strategies, such crashes continue to dominate traffic fatality statistics.

Historically, the focus of highway safety has been geared toward implementing passive safety systems (such as airbags and road barriers) that attempt to reduce the severity of crash outcomes. With the advancement of technology, however, efforts have expanded to design advanced driver assistance systems, or ADAS, that attempt to proactively anticipate and prevent crashes. For example, features such as forward collision warning, blind spot detection, lane departure warning, and adaptive cruise control are becoming more prevalent and popular in new vehicle models. However, the development of an *overtaking assistant* – an ADAS that determines whether a gap is considered safe for overtaking, given the trajectory information of the vehicles in the vicinity – has yet to be realized. One particular task of the overtaking maneuver -- determining the location of oncoming traffic (i.e., traffic in the opposite lane) – is not a task that radars, lasers, or cameras have been able to achieve successfully, mainly because the reported detection ranges of these sensors are shorter than the safe overtaking sight distances (or passing sight distances) recommended in the transportation literature (see Hegeman et al., 2005; Harwood et al., 2008; Delphi, 2009; Velodyne, 2016).

An alternative solution is to use wireless connected vehicle technologies, such as dedicated short-range communication (DSRC) systems, to prevent collisions. Connected vehicle research in the US suggests that 81% of all annual crashes can potentially be addressed by vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems (United States Department of Transportation, 2015). These technologies rely on wireless communication networks that enable the anticipation of driving situations (i.e., positions, speeds, and acceleration of different vehicles within range of the situation, along with distances between vehicles) at a level of coverage and fidelity that is not feasible with human perception or even with technologies such as radars, cameras, or in-vehicle sensors. Such information can potentially be used to develop accurate collision warning and avoidance systems aimed at assisting overtaking maneuvers.

While wireless communication technologies have the potential to enhance safety during the passing maneuver, most existing studies (see for example Rabadi and Mahmud, 2007; Yang et al., 2011; Joerer et al., 2014a) have focused on the use of these technologies for urban driving situations (such as roadway intersections) and not on overtaking assistance. This paper attempts to fill this gap by undertaking an assessment of the potential benefits and challenges of using DSRC-based wireless communication systems in the context of overtaking maneuvers on two-lane rural highways. In doing so, the impacts of two broad factors are considered: (a) driver perception-reaction (PR) behavior and vehicular dynamics (speeds and accelerations of different vehicles involved) and (b) DSRC performance. In this paper, DSRC performance refers to the accuracy, efficiency, timeliness and robustness of data transmission among vehicles. The tasks of gathering information (through on-vehicle sensor measurements) to communicate, and of synthesizing communicated information to create a full picture of the present and projected future states of all vehicles, are also considered as dimensions of DSRC performance. Heterogeneity in driver PR time, vehicular dynamics, and DSRC performance that lead to alternate overtaking situations is explicitly accommodated in the analysis.

The paper assesses the potential of wireless communication technologies to assist in overtaking maneuvers using a Vehicular ad-hoc network (VANET) simulator. Such simulators have become the preferred tool for evaluating emerging vehicle safety technologies, offering many advantages over the traditional method of collecting field data. Foremost among these is that it is not feasible to use existing field data when penetration rates for the technologies being assessed are too low or even non-existent (as in our case). VANET simulators, on the other hand, combine a network simulator – with built in network functionality that adheres to DSRC standards for communication among vehicles, as well as between vehicles and infrastructure – with a traffic simulator that allows for flexibility in the design of roadway scenarios and the scalability to support large traffic flows. The specific VANET simulator used here is the VEhIcles in Network Simulator (or VEINS; see Sommer et al., 2011) that supports the simulation of wireless communication protocols in vehicular ad-hoc networks. VANET simulations are run, and the resulting simulated data are analyzed using both descriptive analysis and discrete choice models.

The rest of this paper is structured as follows. The next section outlines related work in the area of overtaking maneuver safety. Section 3 focuses on the design of the collision warning system (called an *overtaking assistant*) simulated in this paper, along with the assumptions made for simulating rural highway overtaking maneuvers (and collisions). Section 4 presents and describes the simulated data, along with a descriptive analysis of the performance indicators of the *overtaking assistant*. Section 5 presents a statistical analysis of the simulated data, using discrete outcome models, and discusses significant findings. Section 6 concludes the paper with recommendations to improve DSRC-enabled driver assistance systems for rural overtaking maneuvers and future research directions.