Safety-Silence Tradeoff Equation in Various Traffic Conditions

SVSU FACULTY-LED UNDERGRADUATE RESEARCH

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ABSTRACT

In vehicular ad-hoc networks every 10 ms vehicles broadcast "heartbeat" messages, basic safety messages (BSMs) which include precise location coordinates. Vehicles use each other's coordinates to avoid crashes, but eavesdroppers might use the same information for tracking or stalking. To confuse eavesdroppers, some privacy researchers recommend silent periods, spans of time during which vehicles cease transmissions. To what extent do silent periods impair safety? This research applies the Safety-Silence Tradeoff Equation, which estimates the probability of a crash given the proportion of vehicles transmitting BSMs in a region, to a range of vehicle traffic conditions.

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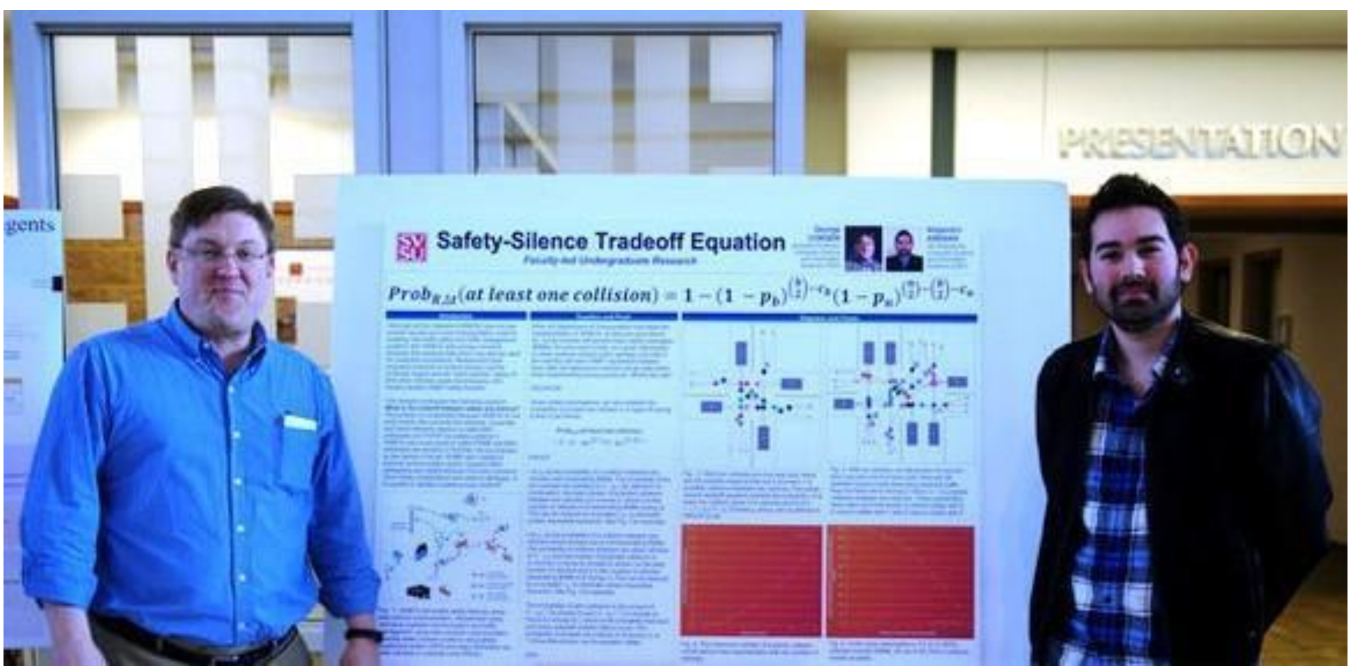

FIGURE 1: GEORGE CORSER AND ALEJANDRO ARENAS AT SVSU UGRP SYMPOSIUM (APRIL 7, 2014)

FACULTY REPORT

Research Results

The purpose of this research was to conceptualize and to simulate the performance of vehicle network protocols in various traffic scenarios. The measurable result was to be an equation, a formalization and quantification of the relationship between safety/security, network/application service quality/efficiency and availability, and privacy, i.e. anonymity of motorists. This would be called the Safety-Silence Tradeoff Equation. Ideally, the research would also result in a paper publication prepared for submission to an IEEE-sponsored conference.

This research produced the first equation for such a relationship.

$$\boldsymbol{Prob_{R,\Delta t}(at\ least\ one\ collision) = 1 - (1 - p_b)^{\binom{b}{2} - c_b}(1 - p_u)^{\binom{n}{2} - \binom{b}{2} - c_u}}$$

Please refer to the draft paper (an external document) to see the definitions of the equation's terms.

The project was designed to be completed in the time allotted, so except for the final submission of the paper (due in July), the project is complete.

Student Learning Outcomes

The role of the undergraduate student, Alejandro Arenas, was essential. He prepared the visualizations and acted as a sounding board for discussions, both of which led to the development of the equation and preparation of the simulations and the paper. The student was to learn how to apply hands-on technical programming skills to a real-world problem: analyzing vehicle privacy protocols. The programming skills are well within the skill limits of an undergraduate programmer. Prior to working on this project Alejandro did not have the ability to analyze research parameters (for example: communication range of antennae, density of vehicles, distances between vehicles, etc.).

Today, Alejandro can see (a) how to set up a vehicle simulation program, (b) how to tweak the parameters to test the limits of the protocols and (c) how to document and write up the research in a proper scholarly fashion. To accomplish these three results, Alejandro prepared a range of visualizations for the project, mostly using MS-Visio. By discussing the problem with the lead researcher, he helped conceptualize the problem which was eventually formed into an equation and verified in simulation. Some of the software tools Alejandro used or touched on were MS-Visio, MS-Word Equation Editor, MS-PowerPoint, Matlab and C++.

Alejandro's learning outcomes were measured using Bloom's Taxonomy. The participant was examined to determine if he was advancing from the "remembering" and "understanding" levels and moving toward the "applying", "analyzing" and "evaluating" levels. It may take years to be able to creatively conceptualize new research problems and solutions; this level of mastery was not achieved. However, iIt is the assessment of this faculty that the participant now has a solid understanding of the combinatorics involved in evaluating vehicle crash scenarios that might be more likely in the absence of vehicle-to-vehicle ad-hoc network communications. Alejandro's detailed observations and his prepared visualizations represent his most important contributions to the project and to the advancement of scholarship. He is rightly now the co-author of a scholarly paper pending publication.

Budge t Performance

The budget called for $1000 toward student work hours at $9 per hour. The actual number of hours used were 95.5 hours, or $859.50.

Final Thoughts

Not all research lends itself to collaboration, especially collaboration with people who do not have a deep foundation in the research field. However, this project allowed faculty to publish with an undergraduate co-author who helped conceptualize and more thoroughly document the work. The overall effort might be more aptly characterized as “undergraduate-assisted faculty research” rather than “faculty-led undergraduate research,” however, it was not always clear where one ended and the other began.

This was the PI’s first grant. The research project produced a paper and was delivered on time and within budget. The work also contributed directly and significantly to the long term research goals of this faculty. The student was exposed to graduate level research activities. All in all, SVSU appears to have been well served by this effort.

STUDENT REPORT

Knowledge Gained

The main things I learned were:

1. **Diagramming.** I learned how vehicle networks are supposed to prevent car crashes and how turning them off might increase the chances of car crashes. I learned how diagramming intersections where cars might crash in to each other can help people figure out the risk, the probability of a crash.
2. **Research Paper Writing.** I learned how to write a research paper, at least the basic parts of what's in a research paper. I attended a presentation by Professor Corser hosted by the ACM, an SVSU RSO, on March 18, 2015 on the topic, "how to write a research paper." Professor Corser did most of the writing up of the paper, but I did the diagramming. We also talked over how we could mathematically explain the probabilities of cars crashing in to each other by using a thing called the "Safety-Silence Tradeoff Equation." This equation is the main contribution of the paper.
3. **Research Presentation.** How to do a poster presentation. Professor Corser and I presented a poster of the work at SVSU UGRP SYMPOSIUM on April 7, 2015.

Take a look at the diagrams below. These are two of the diagrams I made (with Prof. Corser's help).

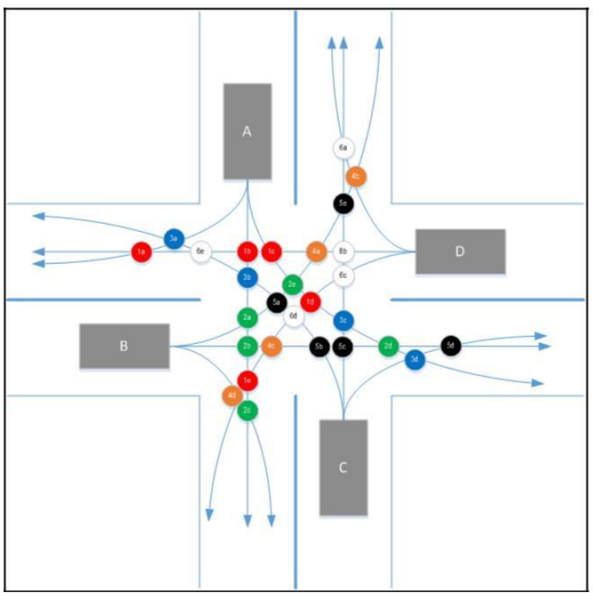

FIGURE 2: INTERSECTION OF TWO TWO-LANE ROADS

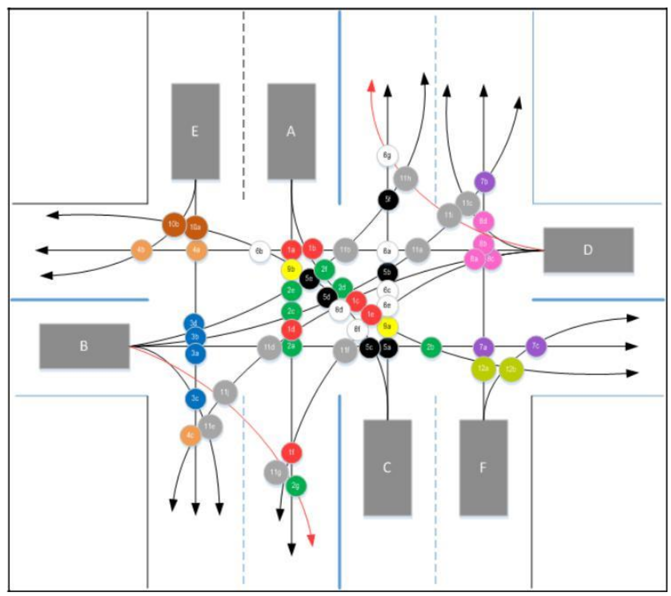

FIGURE 3: INTERSECTION OF TWO-LANE AND FOUR-LANE ROADS

Figure 2 shows an intersection of two two-lane roads. Think of it as a four-way stop. There are four cars, labeled A, B, C, and D, starting at top and labeling counterclockwise. With four cars there are six possible pairs which might crash into each other, AB, AC, AD, BC, BD and CD. Each colored dot in the diagram represents a possible crash location between a specific pair of cars. For example, each green dot indicates a possible crash location between AB, that is, between car A and car B. So even though there are only two cars, there are five possible places for them to crash in that intersection. But there are only four places where car A might crash with car C, as shown by the blue dots. If we assume every dot has an equal probability of being a crash, then there is a bit higher probability of a crash between AB than a crash between AC because there are more possible crash locations.

Figure 3 shows an intersection of one four-lane road and one two-lane road. With six cars there are fifteen possible pairs which might crash into each other, AB, AC, AD, AE, AF, BC, BD, BE, BF, CD, CE, CF, DE, DF, and EF. Note there are ten possible crash locations for BD (light gray dots), but only two for CE (dark brown dots). Also note there are no possible crash locations for AE, CF and EF. In this case we have to reduce the number of pairs by those three, so the possible pairs where crashes could occur are only twelve, not fifteen. This is just an assumption. Of course it is possible that there could be a crash between especially AE or CF because they are right next to each other. A crash between EF would be a real long shot, though, because they are so far away from each other.

Feelings about Experience

I am an international student so the only work I can do is work-study or certain internships. I can't apply for jobs at regular companies because I only have a student visa, not a work visa. This opportunity gave me a chance to financially support my studies while also contributing to SVSU's research. I feel pretty great about that!

Impact on Future

I took CIS-255 from Professor Corser. When I heard he was interested in doing some research and needed a (paid) student assistant, I applied. I still have not decided my long term career or anything but now that I have seen what it is like to do research work, I am definitely more likely to go to graduate school.

PENDING PUBLICATION (EXTERNAL DOCUMENT)

Please find the current draft of the publication as a PDF included with this document.

Screenshot of First Page

Safety-Silence Tradeoff Equation: Effect of Privacy Protocols on Vehicle Collisions

George P. Corser, *Student Member, IEEE*, Alejandro Arenas, Huirong Fu, *Member, IEEE*

Abstract—**In vehicular ad-hoc networks (VANETs), Basic Safety Messages (BSMs) would be transmitted by all vehicles every 100ms in order to help prevent traffic accidents. Because BSMs may expose vehicle locations to wireless surveillance, to thwart eavesdroppers, some privacy researchers recommend silent periods, spans of time during which vehicles cease transmissions. But silent periods impair safety provided by BSMs. This paper quantifies this tradeoff, presenting the Safety-Silence Tradeoff Equation, and showing an inverse exponential relationship between the proportion of vehicles transmitting BSMs and the proportion of potential collisions between vehicles unprotected by BSMs.**

Index Terms—**silent period, safety, mathematics of privacy, computational privacy**

I. Introduction

In vehicular ad-hoc networks (VANETs), wireless communications called Basic Safety Messages (BSMs) would be transmitted in order to help prevent crashes between vehicles. Accurate global positioning systems (GPS) installed in each vehicle would provide precise location data for BSMs. Every fraction of a second, each vehicle could compute future positions of its neighboring vehicles and avoid impending collisions. In this way VANETs may one day prevent injuries, reduce insurance costs, and may also reduce transportation costs by enabling new traffic management systems.

But VANETs raise privacy concerns because they would transmit data which may also be used for unwanted surveillance. Researchers have proposed protocols to protect against surveillance, but many protocols require periodic "silent periods," spans of time when vehicles cease transmissions, thereby disabling VANET safety benefits.

This research addresses the following question: What is the tradeoff between safety and silence?

The safety-silence tradeoff problem is important because society values both safety and privacy. Without a measure for the tradeoff it is difficult for individuals and policymakers to make effective compromises between the two.

The problem is complicated because VANETs do not work exactly like conventional networks. Corporate and home networks, for example, depend on static MAC addresses and TCP/IP, but safety systems in VANETs use new protocols in which MAC addresses are dynamic—they can be changed by the vehicle in transit. In the United Stated the new protocols are part of Dedicated Short Range Communications (DSRC) / Wireless Access in Vehicular Environments (DSRC/WAVE). WAVE Short Message Protocol (WSMP) was created to improve communication speed. Dynamic MAC addressing was added specifically to enable privacy protocols.

The authors of this paper are not aware of any prior methods to compute this tradeoff in vehicular contexts. There are some works on the mathematics of privacy [15] and computational privacy [14], but they do not include discussions of the relationship between safety and silent periods. VANET privacy research is an emerging area of study, so this may be the first paper to present a mathematical formula for the tradeoff.

The primary contribution of this paper is the presentation and proof of the Safety-Silence Tradeoff Equation. Also included are illustrations and examples of applications of the equation.

The rest of this paper is organized as follows. Section II presents background for the VANET privacy problem, establishing the necessity of silent periods. Section III presents mathematical analysis and proof. Section IV presents an illustration and Section V discusses practical considerations. Section VI presents results of simulations to evaluate performance of the equation. Section VII concludes the paper.

II. Background

VANETs depend on vehicles each having access to accurate Global Positioning System (GPS) data. Vehicles transmit their positions to each other using vehicle-to-vehicle (V2V) communications. Vehicles may communicate with application servers, such as Location Based Services (LBS) via wired roadside units (RSU) using vehicle-to-infrastructure (V2I) communications. See Fig. 1. However, as far as their effect on safety is concerned, silent periods are relevant only within V2V communications.

Among the earliest and most cited papers [1] in the field of vehicular ad hoc network privacy are recommendations that privacy protection schemes include silent periods. Recent work has suggested privacy protocols be executed at "social spots" such as traffic lights and intersections [16].

These and other recommendations were founded partly on the results of seminal work in mix zones [2]. Silent periods and mix zones operate together. Vehicles cease transmitting

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