Abstract

The NOTICE architecture is a new concept in Vehicular Ad-Hoc Networking (VANET) that aims at providing automated notification of traffic incidents on highways in order to reduce congestion and improve overall traffic safety. The basic component of NOTICE is a system of sensor belts that collect information from passing cars through a wireless radio link. An indicator of performance for the NOTICE system is the incident detection time which depends on various parameters among which we note the vehicle speed, the time required by communicating radios for connection setup and information exchange, the amount of information to be transmitted, or the radio technology employed. In this paper we present a numerical performance study of the NOTICE system with realistic values of these parameters in an attempt to provide some basic specifications for the physical layer of the system.

1. Introduction

VANET and vehicular communications have generated increasing interest for the research community lately, and they are regarded as a major component of intelligent transportation systems (ITS). We note that VANET is not purely an ad-hoc network since the data transmission occurs not only through ad-hoc based vehicle-to-vehicle (V2V) communications but also through infrastructure based vehicle-to-infrastructure (V2I) communications. In V2V communication, individual vehicles are responsible for forwarding and disseminating information toward the region of interest, and individual vehicles rely on messages received from other vehicles on the road. V2V communication needs the position, direction and identity of the vehicle in order to route the information towards the region of interest which makes it vulnerable to attacks from malevolent traffic participants. A potential approach in countering malicious attacks would be to use V2I communications and keep a record of the identity of participating vehicles using some infrastructure units. However, this approach compromises the privacy of traffic participants and requires also installation of expensive infrastructure along the road. This limits the VANET scalability and alternative approaches to deal with both security and privacy in VANET have been explored [4–6].

The NOTICE architecture [1] was proposed recently as an alternative to addressing both security and privacy issues in vehicular communications by using short range transmission at low power. In the NOTICE system a given vehicle details like position or identity are unknown to the other vehicles and communication takes place through a system of sensor belts embedded in the roadway that collect information and provide driver notification in case of highway incidents. The information collected is related strictly to the traffic conditions and does not disclose the identity of the traffic participant. A related approach using different infrastructure is discussed in [2] where magnetic sensors are deployed along both sides of the road for information collection and dissemination.

In our paper we focus on parameters of the NOTICE system that affect the incident detection time, which are the time required to establish the wireless connection between a sensor belt and a vehicle passing over it and the time needed to transmit the data between vehicle and the belt, and present a numerical investigation of how these times are influenced by the traffic density, the average speed of the vehicles, and data rate at which the vehicle and belt transceivers operate. We note that the actual speed of the vehicle determines the time that the two radios (inside the vehicle and on the sensor belt) have available to make a successful communication and these should be correlated with the radio technology used in the implementation.

The paper is organized as follows: we present a brief description of the NOTICE system in Section 2 followed by an analysis of the incident detection time when not all vehicles are able to exchange information with belts in Sec-
Figure 1. Sketch of communication between a car and a sensor belt in NOTICE.

Figure 2. Sketch of timing diagram for car-to-belt communication in NOTICE.

2. The NOTICE System: A Brief Review

According to [1] the NOTICE architecture assumes that vehicles are equipped with a tamper-resistant Event Data Recorder (EDR) designed to store basic information about the vehicle’s movement (lane changes, speed variation, specific driver input about road conditions, etc.) which will be exchanged with sensors embedded in a belt in the roadway at some given distances. In order to confirm an event related to a traffic incident a given belt aggregates information reported by multiple vehicles to report the incident and alert traffic participants as vehicles cannot usually alert each other directly about incidents. Information flow in the NOTICE system is based upon the following communication scenarios:

2.1. Communication between a car and a given belt

This scenario is described schematically in Figures 1–2 and starts when the sensor belt determines that a vehicle has arrived (using a pressure sensor that is activated by the front wheels of the vehicle).

As soon as the belt senses a vehicle passing over, a radio transceiver on the belt will attempt to establish communication with #1 transceiver in the vehicle by sending a short range “HELLO” message with low transmit power. The vehicle has only limited time available to respond with an acknowledgment message “ACK” to the “HELLO” message from the belt. If the belt does not get the acknowledgment from the vehicle it will not attempt further communication with that vehicle. Upon successful handshaking between belt and vehicle a wireless radio link is established with #2 transceiver in the vehicle and information/data will be exchanged using symmetric key encryption technique as discussed in [1]. The transmission power/range available for the information/data exchange will be higher than that used in handshaking so that a longer time interval is available for data exchange than for handshaking.

2.2. Communication between adjacent sensor belts

Two adjacent belts on the same lane do not directly communicate with each other but may exchange information using passing vehicles as carriers. This scenario assumes that one belt is uploading information for the next belt to a passing car using belt-to-car communication as described above and that the car should communicate this information to the next belt. Assuming successful communication between cars and belts the information travels from one belt to the other with the speed of vehicle in this scenario. Belts on opposite sides of highways will be connected by direct-wired connection under the median of the road, and side-by-side belts in different lanes of a road also will not be able to communicate directly each other.

2.3. Car to car communication

The NOTICE system is designed to minimize V2V communication as much as possible in order to support security and privacy awareness. However there are some instances where V2V communication is desirable for timely dissemination of information. For example, when a message-carrying vehicle is unable to reach a belt to transmit the traffic information uploaded from its latest communication with a previous belt due to congestion or other factors the vehicle will forward its traffic information to the vehicles which are in front of it and are heading towards the next belt.
In this case the information flow will occur using multi-hop or single-hop communication to the destination belt.

3. Incident Detection Time

The incident detection time is the time needed by a sensor belt to determine that a traffic incident has occurred. This is influenced by various parameters like the spatial density of the vehicles in traffic (cars/km) or how conservative the belt inference mechanism is, and is investigated under different scenarios in [1]. However, the analysis in [1] assumes that all vehicles arriving to a sensor belt do establish a communication link with the belt and exchange information. However, this may not always be the case as some of the vehicles may fail to establish a successful connection with the belt.

When only a fraction of the vehicles are able to exchange information with the belts the time needed by the system to detect an incident will be affected, and we performed simulations to evaluate how the mean incident detection time varies when the probability of successful connection between cars and belt is no longer ideal and equal to 1. We used the same traffic simulator as in [1] which is based on the car following model in [11] and the Intelligent Driver Model (IDM) [9]. We have simulated an 8 km four-lane highway with two lanes in each direction, with initial vehicle speeds in the range of 30 m/s (67.5 mph) which may increase or decrease to maintain some parameters on the road such as safety distance for example. Cars also may change lane and bypass each other when possible.

Results of this experiment are shown in Figure 3 and we note that in the case of moderate traffic flow (1200 cars/hour per lane) the mean incident detection time for 0.8 probability of successful connection between cars and belt is around one minute and is only about 10% higher than the detection time in the ideal case when successful connection probability is equal to 1. Moreover, the detection time is still around one minute for probability of successful communication equal to 0.7. In the case of sparse traffic flow (600 cars/hour per lane) we note that the mean detection time when probability of successful communication equals 0.8, is only 7% more than the detection time at a perfect situation.

From these results we conclude that even with 80% successful car-to-belt communication the NOTICE system can still detect a traffic incident in around one minute.

4. A Simulation Analysis of the Car-To-Belt Communication Process

Results presented in the previous section have shown that the NOTICE system is capable of detecting incidents in reasonable time even when not all cars are able to exchange information with the belt. We note that successful data exchange between vehicle and belt requires that a wireless radio link be successfully established and that the amount of information to be exchanged be successfully transmitted. The former requirement is influenced by the time available for connection setup and handshaking while the latter is affected by the data rate at which the car and belt transceivers operate, which determines the time needed for the actual data transmission. These time requirements, which are indicated on the car-to-belt communication diagram sketched in Figure 2, depend on the speed with which the vehicle is moving, and their influence on successful data exchange in the car-to-belt communication will be investigated in this section.

In our study we focus on a single belt in one lane of the highway and we look at the probability of successful handshaking and data exchange between belt and passing cars. We assume that the number of cars that pass over the belt has a Poisson distribution with rate equal to the traffic flow, and that their speeds are independent and identically distributed (i.i.d) having a normal probability density function with given mean and variance [7, 8, 10]. We consider moderate and sparse traffic and for practical considerations we use a truncated version of the normal distribution to avoid dealing with negative numbers or values very close to zero that covers the range given by the mean of the distribution ± 3 standard deviation intervals containing approximately 99.8% of the entire distribution.
4.1. Connection Setup and Handshaking Stage

As it has already been mentioned the first requirement of a successful data exchange is that a connection be established between belt and the passing vehicle. In order to have this condition satisfied the vehicle must acknowledge the belt’s “HELLO” message before getting out of the range of the low-powered connection setup transceiver, and the probability of successful handshaking is given by the probability that the distance traveled by the vehicle at its current speed, from the time it activates the belt and receives the “HELLO” message to the time its “ACK” message is received by the belt, is less than the 1 m range covered by the handshaking radios.

In order to study variation of the probability of successful connection setup and handshaking we perform simulation experiments for moderate traffic (1,200 cars/hour/lane) and sparse traffic (600 cars/hour/lane). In the first experiment we keep the average speed of the car constant and vary the time available for handshaking. Results of this experiment are presented in Figure 4 from which we note that, as expected, the probability of successful connection remains above 0.9 for all speed values below 65 mph.

4.2. Data Exchange Stage

After connection between the belt and a passing car has been successfully established, the actual information is exchanged: the passing car downloads its traffic information to the belt and/or uploads any eventual information that the current belt wants to transmit to the upcoming belt. In order for the information exchange to be successful the data rate of the second transceiver must support transmission of the entire information while the car is within its 3 m range, which according to Figure 1 implies a travel distance of 6 m for the passing car. Thus, the probability of successful data exchange is given by the probability that the time required to transmit the information at the data rate supported by the second transceiver is less than the time in which the car travels over the 6 m implied by the range covered by the second transceiver.

Results of this experiment are presented in Figure 5 and we note that, as expected, the probability of successful connection remains above 0.9 for all speed values below 65 mph.
between belts and passing cars is above 0.8 and implies a probability of success larger than or equal to 0.9 for both these events implies that the probability of connection between a belt and a passing car is obtained by multiplying their corresponding probabilities. Thus, a probability of success larger than or equal to 0.8 and implies a reasonable incident detection time of about one minute or less.

We conclude our remarks by noting that the desired probabilities of successful connection and data exchange of 0.9 are satisfied by transceivers which have a connection time of 45 ms or less and support data rates of 300 kbps or higher. From this perspective inexpensive wireless systems such as ZigBee [3] may be good candidates for the physical layer of the NOTICE system.

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References