Reliability of VANET Bicycle Safety Applications in Malicious Environments

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***Abstract*— This paper presents a bicycle safety application that aims to reduce accidents due to the so-called Right Hook Conflict, where a right-turning vehicle causes a crash with an adjacent bicycle. It is based on the same technologies introduced for accident avoidance for motor vehicles in the context of connected vehicles. The bicycle safety application uses information that is exchanged in periodic beacon messages emitted by all vehicles, including bicycles. This wireless vehicle-to-vehicle communication is however vulnerable to malicious jamming attacks. A bicycle safety application algorithm is presented that is capable of mitigating against such attacks, as well as message loss due to natural phenomena. The algorithm was analyzed in terms of accuracy and application reliability. Its effectiveness was evaluated based on real-world field experiments using commercial equipment installed in the vehicles and bicycle.**

***Index Terms*—VANET, connected vehicles, vehicle-to-vehicle, V2V, vehicle-to-bicycle, safety applications, bicycle safety, jamming attack**

I. Introduction

A key objective of Intelligent Transportation Systems is to increase safety and reduce accidents. One of the most recent considerations is accident reduction through safety applications (SA) in the context of connected vehicles. Here, traffic participants use vehicle-to-vehicle (V2V), and vehicle-to-infrastructure (V2I) communication to distribute status information to surrounding vehicles. This is achieved using Onboard Units (OBU) and Road Side Units (RSU) that are installed in each vehicle and the infrastructure, respectively. The safety applications use the information to predict and alert the driver to potential hazards. Whereas significant research has considered motorized vehicles, little research has focused on the special needs for bicycles, e.g., addressing the so-called Right Hook, which is a common source of accidents where a right-turning vehicle causes a crash with a bicycle to its right. The drivers of the turning vehicles are mostly unaware of the bicycle to its right [1]. In this research bicycles have the same communication capabilities as vehicles, as they are equipped with mobile OBUs.

The two main technologies for V2V and V2I communication are Dedicated Short Range Communication (DSRC) [4], and Cellular Vehicle-to-Everything (C-V2X), as promoted by the Third Generation Partnership Project (3GPP). Whereas cellular network communication generally includes base stations, C-V2X communication can be directly between vehicles in a Device-to-Device (D2D) fashion [2]. This research uses the more mature DSRC technology, but the general issues discussed are expected to have similar implication in C-V2X.

II. Background and Related Work

The communicating nodes in V2V and V2I implement a Vehicular Ad Hoc Network (VANET). VANETs are similar to Mobile Ad Hoc Networks (MANET), but they consider short message exchanges and a fast changing network topology. Communication is assumed to be based on DSRC, which operates in a dedicated bandwidth of 75 MHz at 5.9 GHz [3]. One of the seven DSRC channels, i.e., Channel 172, is assigned to safety applications. It is used to broadcast the Basic Safety Message (BSM), which is the most important beacon message broadcast by each vehicle every 100ms [4]. Each BSM contains information related to the sender's Global Positioning System (GPS) position, and additional information like position accuracy, speed, heading, steering wheel angle, transmission and break status. This information is used by the safety applications executing in each vehicle's OBU.

In [5] safety applications and their associated crash scenarios are identified. We will describe SA from the viewpoint of a Host Vehicle (HV), which receives BSMs from Remote Vehicles (RV). When specific event information received in the BSM from an RV suggests a critical situation, the driver of the HV is issued an alert. An example of an SA is the Emergency Electronic Brake Lights (EEBL), which aims at avoiding rear-end collisions. When a vehicle brakes hard it broadcasts a so-called *hard-braking event* in its BSMs. An HV receiving such event from the RV's BSM can issue an alert to the driver, e.g., if its position is at a relevant distance behind the RV in the same lane. This is particularly helpful when the driver's line of sight to the initiating RV is obstructed, e.g., due to fog, snow, or other vehicles. Other SA address forward collision warning, blind spot warning, or situations where it is not safe to enter an intersection due to a potential crash with an RV in the intersection. In the safety applications considered in [5] bicycles play only a peripheral, limited role. However, bicycles have unique characteristics. They often drive at lower speeds, occupy limited space in the right lane, and are frequently overlooked by the drivers of vehicles. Most importantly, bicyclists are much more vulnerable and susceptible to injuries in an accident, e.g., a right hook collision.

In [6] a bicycle safety application for non-malicious environments addressing right hook collisions was presented. It

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was shown that SA reliability $R(t)$ was directly related to the probability that at least one BSM indicating an event was received by an HV, before its was too late for the driver of the HV to react. $R(t)$ is defined as the probability that a system functions up to specifications during the entire time interval $[0, t]$ [10]. This can also be expressed in terms of unreliability $Q(t) = 1 - R(t)$. Specifically, SA unreliability $Q(t)$ is the probability that during the time interval $[t_{event}, t_{react}]$ all messages are lost, where t_{event} is the time of the event, e.g., hard-braking event used by EEBL, and t_{react} is the latest time before an alert is too late for the HV driver to react.

The loss of a BSM can be due to benign reasons like environmental signal degradation, or the so-called shadowing effect. However, we additionally assume malicious act as the source of message omissions. One way to attack wireless communication is by using jamming. Different types of jammers, ranging from constant jammers to intelligent jammers, were address in [11], and a hybrid jammer, immune to Packet-Delivery-Ratio (PDR) detection mechanisms, was shown in [12]. This research does not restrict itself to any specific jammer type, but simply assumes that message loss due to jamming will occur.

The aforementioned Right Hook [1] is shown in Figure 1. In this scenario the bicycle is traveling in the right lane, e.g., a bicycle lane. Assume the truck in the left lane has the intention of turning right. The right hook conflict zone, RHC Zone, is the area where potential right hook accidents may occur. To avoid such accident, a driver needs to receive an alert to the potential accident before time t_{react}. Given the reaction time T_{react}, any alert after t_{react} comes too late. As summarized in [6], the reaction time of a bicyclist is approximately 1 second [7], the combined perception and brake reaction time is 2.5 seconds [8], and the reaction time of a truck driver, the driver's time to initial steering, is about 1.7 seconds [9]. In the RHC Zone timing is critical due to the fact that distances between the bicycle and the truck may be extremely short, as both may even be right next to each other.

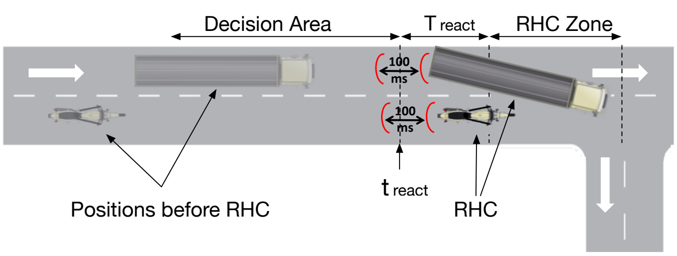

Fig. 1. Typical Right Hook Conflict

III. SA Prediction Algorithm

The bicycle safety application uses a prediction algorithm that is capable of mitigating against jamming attacks. The description to follow will be from the viewpoint of the truck.

When BSMs from a bicycle, known to the truck from previous BSMs, are not received in a timely manner, the position of the bicycle needs to be estimated. This projection will be based on Dead Reckoning [13], which calculates the estimated position of the bicycle based on the last known position. This requires information like the speed and the last recorded coordinates, available from the last received BSM, and computed last recorded bearing. The time elapsed since the last received BSM and the bearing are computed locally.

Let $Lat(B)$, $Long(B)$ and $Lat(T)$, $Long(T)$ denote the geographical coordinates for the bicycle and truck respectively, and $\Delta_{Long(TB)}$ $\Delta_{Lat(TB)}$ or $\Delta_{Long(BT)}$ $\Delta_{Lat(BT)}$ their respective differences in longitude and latitude. When it is necessary to indicate whether coordinates are in degree or radian, a d or r will be added in parenthesis, e.g., $Lat(B[d])$ indicates the latitude of a bicycle in degree, and $Lat(T[r])$ latitude of a truck in radian.

Since the calculations are using polar equations and the coordinate points from the OBUs are in geographical degree form, one needs to convert from degree to radian to get the polar coordinates. The Bearing (Azimuth) [14] starts from north clockwise $0° - 360°$. It is denoted by $\beta_{TB[d]}$ and is determined using the truck and bike coordinates as shown in Equation 1, which was derived from [15]

$$\beta_{TB[d]} = \tan^{-1}\left\{\frac{\sin(\Delta_{Long(TB)})\cos(Lat(B))}{\cos(Lat(T))\sin(Lat(B)) - \gamma}\right\} \quad (1)$$

with $\gamma = \sin(Lat(T))\cos(Lat(B))\cos(\Delta_{Long(TB)})$

Next, the Haversine Formula of [16] is used to calculate the distance, d_{TB}, between the truck and the bike:

$$d_{TB} = 2r_{earth}\sin^{-1}\left\{\sin^2\left(\frac{\Delta_{Long(TB)}}{2}\right) + cos(Lat(B))\,cos(Lat(T))\,\sin^2\left(\frac{\Delta_{Lat(TB)}}{2}\right)\right\}^{1/2} \quad (2)$$

where r_{earth} is the earth's radius in meters. Let $C_T(t)$ be the clock value of the truck at real time t [in ms]. Furthermore, let $C_T(t_{rec(B)})$ be the recorded time of the truck's clock when the last BSM of the bike was received. Based on the bicycle's velocity v_B from its last BSM, the truck can estimate the bike's distance, d'_B, traveled in any direction since the last BSM was recorded. If the speed of the truck v_T is less than or equal to the average approaching right-turn speed, i.e., there is no deceleration, d'_B is calculated using

$$d'_B = v_B\,[C_T(t) - C_T(t_{rec(B)})] \quad (3)$$

One needs to find the time the truck will take to reach a speed less than or equal to that of an average truck about to make a right turn. Based on [17] v_{RT} was determined as 10 m/s. We use the maximum truck deceleration, denoted by a_T^{-1}, which is $0.8m/s^2$ [18]. The difference in speed between the truck and the average truck's speed on approaching to right-turn, Δv_T, is $\Delta v_T = v_T - v_{RT}$.

How much will the bicycle have moved by the time the truck will have reached its right-turn-approaching speed? The truck's estimated time to reach this turning speed is $T_{ToReachTurnSpeed} = \Delta v_T / a_T^{-1}$. The time the bicycles is moving unobserved by the truck (due to jamming) is the time that has passed since the truck received the bicycle's last BSM, $C_T(t_{rec(B)})$, plus $T_{ToReachTurnSpeed}$. Thus the bicycle will move for a duration of

$$T_{BikeMoving} = [C_T(t) - C_T(t_{rec(B)})] + \frac{\Delta v_T}{a_T^{-1}} \tag{4}$$

and its projected distance covered is

$$d'_B = v_B \, T_{BikeMoving} \tag{5}$$

To find the bike's angular distance ratio, α_B, under consideration of the earth curvature, d'_B is divided by the earth radius [in km], $\alpha_B = \frac{d'_B}{6371}$. The estimated latitude and longitude of the bicycle are:

$$EstLat(B[r]) = \sin^{-1}\left\{ \sin(Lat(T))\cos(\alpha_B) + \cos(Lat(T))\sin(\alpha_B)\, \cos(\beta_{TB}) \right\} \tag{6}$$

$$EstLong(B[r]) = Long(T) + \tan^{-1}\left\{ \frac{\sin(\beta_{TB})\, sine(\alpha_B)\, \cos(Lat(T))}{\cos(\alpha_B) - \sin(Lat(T))\sin(Lat(B))} \right\} \tag{7}$$

The latitude and longitude of the truck are calculated analogously, except its time base is $T_{ToReachTurnSpeed}$ rather than $T_{BikeMoving}$. The Minimum Stopping Sight Distance from [19] is used to find the bike's stopping distance as

$$S = \frac{V^2}{254(f \pm G)} + \frac{V}{1.4} \tag{8}$$

where V is its velocity [in km/h], f is the coefficient of friction (which is 0.32 for dry condition), 1.4 is the distance of the bicyclist's eye above the pavement, and G is the grade. Note: since a flat road is assumed, G can be neglected. Now, d_{TB} from Equation 2 is compared with S from Equation 8. A driver alert should be issued if $S \geq d_{TB}$.

A. Basic BSA Algorithm for Malicious Environments

The bicycle safety application that implements dead reckoning is shown in Figure 2. It overcomes the limitations in the algorithm described in [6], which was only suitable for a benign environment. Now we consider DoS attacks, such as jamming. The shaded area to the right shows the algorithm's behavior if a BSM is received. It is similar to the benign-case algorithm in [6]. If a BSM from a new bicycle is receive, this bike is registered. Next the OBU's time of BSM reception, t_{last}, is recorded. This time serves as a reference for bicycle BSM omissions, e.g., due to jamming or shadowing. It is used for dead reckoning when messages are not received. If the trucks blinker is set, indicating the intention to turn right, a blinker flag is included in its BSMs, which is used by the bicycle safety application. Next the distance between the two vehicles, d_{TB}, and the minimum stopping distance S are calculated. If S is less than d_{TB}, then it is safe to turn. Otherwise an alert needs to be issued.

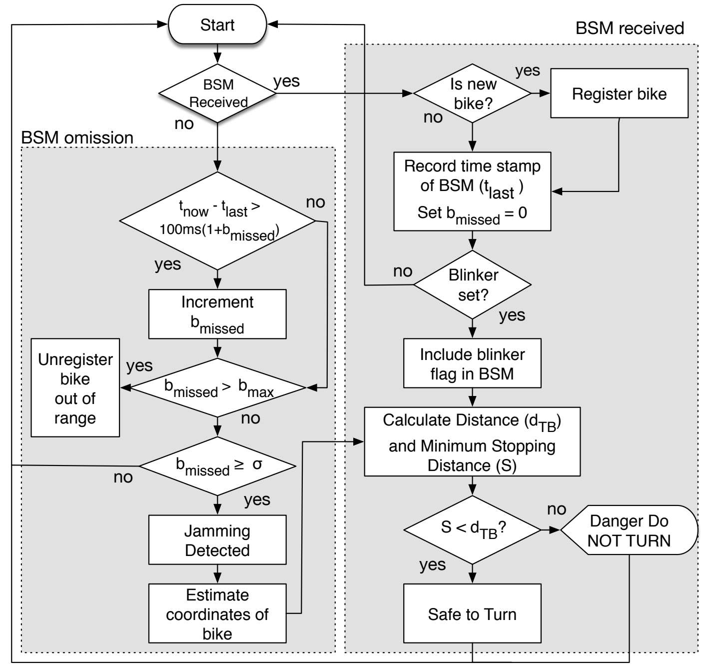

Fig. 2. BSA Flowchart from the viewpoint of one bicycle

The case when no BSM was received is shown in the left area of Figure 2. An omission is detected if no BSM is received within the BSM inter-arrival time of approximately 100ms. Omission counter b_{missed} keeps track of the number of consecutively missed BSMs. A predetermined b_{max} specifies the threshold of omissions before the bicycle should be unregistered. This avoids tracking bicycles that are no longer relevant, e.g., they are out of range or the units have been shut down. When a BSM is received from a bicycle, the counter b_{missed} is reset.

In [20] it was argued that BSM's older than 500ms, 5 BSM intervals, should be considered outdated. We assume that if the number of missed BSM's has not reached this threshold σ, i.e., if $b_{missed} < \sigma = 5$, then the omissions do not pose immediate threats. Otherwise, we assume a DoS is ongoing. Given the knowledge of the bicycle's last position and velocity, as well as the time that has expired since then, the bicycle's coordinates can be estimated as shown in Subsection III. This initiates the transition to the part of the algorithm that determines if the bicycle's position could pose a danger in the RHC-zone, i.e., if $S \geq d_{TB}$, in which case an alert should be issued.

IV. Experimental Results

The algorithm of Figure 2 was implemented using an ARADA LocoMate Classic OBU for the truck, and an ARADA LocoMate ME, a battery powered small OBU mounted on the bicycle. Experiments were conducted using a data rate of 3Mbps, 23 dBm transmitter power, and 100ms BSM spacing, in open space and close proximity of OBUs.

Many experiments were conducted with the truck's speed approaching the right turn less and more than the turning speed of $v_{RT} = 10$ m/s from [17]. Due to space limitations we

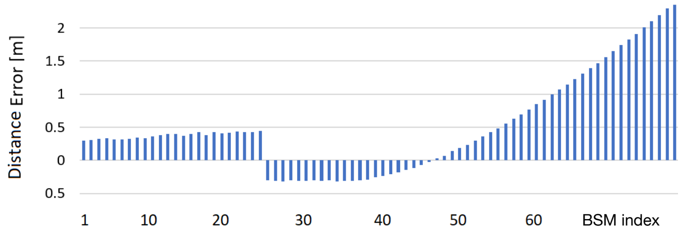

Fig. 3. GPS error with 4m fixed distance between vehicle and bicycle. Truck speed is less than turning speed.

can only present one typical experiment conducted in open space. Figure 3 shows GPS errors, which is the calculated distance between both antennas, d_{TB}, using Equation 2 minus the actual known OBU distance. The GPS antennas of the vehicle and bicycle were spaced at a distance of 4 meters, i.e., the vehicle and the bicycle were driving next to each other at that exact distance. The x-axis represents BSM time slots, here referred to as BSM indices. Jamming started at 29, i.e., after 2.9s. The prediction algorithm started when b_{missed} reached σ. A sub-meter GPS error was observed most of the time. Only several seconds after jamming started did the error slightly grow, as expected due to dead reckoning errors.

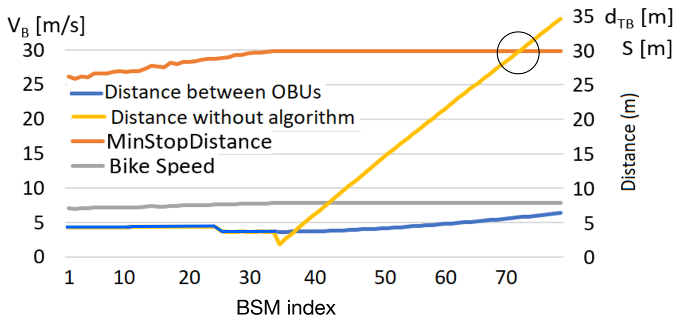

Fig. 4. Graphs for speed less than turning speed.

Figure 4 shows the calculated distance between OBUs, and the minimum stopping distance from Equation 8, as it relates to the bicycle speed, which in this case was equal to the truck's speed. The blue graph shows the distance calculated by the algorithm up to jamming, and dead reckoning after its detection. The yellow line indicates what would happen without the algorithm, in which case the safety application would fail when the calculated OBU distance is falsely interpreted to be greater than the minimum stopping distance. This is the case when the two graphs cross, as marked by the circle. Thus, without the algorithm a jammer could cause the safety application to fail, potentially giving an attacker the power to cause an accident.

V. Conclusions

This paper presented a bicycle safety application to address right hook conflicts. The underlying algorithm can overcome the impact of BSM omissions, as the result of natural phenomena or malicious act, by applying dead reckoning. Using commercial OBUs, it was demonstrated that jamming attacks could be mitigated by the proposed algorithm, thereby avoiding potential dangerous scenarios where attackers could produce accidents. Field experiments in open space showed that sub-meter GPS accuracy was achieved. Further results of ongoing research in urban environments and more comprehensive testing are expected to be published separately.

References

[1] M. Jannat, D. S. Hurwitz, C. Monsere, K. H. Funk II, "The role of driver's situational awareness on right-hook bicycle-motor vehicle crashes," Safety Science, vol 110, pp 92-101, 2018.

[2] F. Jameel, et. al.,"A Survey of Device-to-Device Communications: Research Issues and Challenges," IEEE Communications Surveys & Tutorials, Vol. 20, No. 3, Third Quarter 2018.

[3] "Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems - 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Spec.", ASTM E2213-03, 2010.

[4] J. B. Kenney, "Dedicated Short-Range Communications (DSRC) Standards in the United States," Proc. of the IEEE, Vol. 99, No. 7, pp. 1162-1182, 2011.

[5] *Vehicle Safety Communications-Applications (VSC-A) Final Report*, DOT HS 811 492 A. U.S. DoT, NHTSA. September 2011.

[6] Mohammad Baqer, and Axel Krings, "On the Reliability of VANET Safety Applications for Bicycles," to appear in proc. IEEE International Conference on Connected Vehicle and Expo (ICCVE) 2019.

[7] M. Figliozzi, N. Wheeler, and C. M. Monsere, "Methodology for estimating bicyclist acceleration and speed distributions at intersections," Transportation Research Record:Journal of the Transportation Research Board, vol. 2387, pp. 66-75, 2013.

[8] Wisconsin Bicycle Facility Design Handbook. Wisconsin Department of Transportation, Madison, January 2004.

[9] McGehee D. V., et.al. ,"Driver Reaction Time in Crash Avoidance Research: Validation of a Driving Simulator Study on a Test Track." Proc. 14th Triennial Congress of the International Ergonomics Association, pp. 320-323, Santa Monica, CA, 2000.

[10] W. B. Johnson, "Design and Analysis of Fault-Tolerant Digital Systems," Addison-Wesley Publishing Company, New York, 1989.

[11] K. Pelechrinis, M. Iliofotou, S.V. Krishnamurthy, *Denial of Service Attacks in Wireless Networks: The Case of Jammers*, Communications Surveys & Tutorials, IEEE , Vol.13, No.2, pp.245-257, 2011.

[12] S. Hussein, et.al., "A New Hybrid Jammer and its Impact on DSRC Safety Application Reliability," in proc. 7th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), Vancouver, BC, Canada, pp. 1-7, 2016.

[13] Randell C., Djiallis C., Henk L."Personal Position Measurement Using Dead Reckoning," Proceedings of the Seventh International Symposium on Wearable Computers, Oct. 2003, pp 166-173, New York, USA, 2003.

[14] Monmonier, M. "Viewing azimuth and map clarity," Annals of the Assocation of American Geographers Vol 68(2): pp 180-195 Jun 1978.

[15] Ben Gardiner, Waseem Ahmad, Travis Cooper, "Collision Avoidance Techniques for unmanned Aerial Vehicles," Auburn University, National Science Foundation, 08-07-2011.

[16] Chopde, N., and Nichat, M. "Landmark Based Shortest Path Detection by Using A* and Haversine Formula." International Journal of Innovative Research in Computer and Communication Engineering. Vol.1, Issue 2: 298-302. 2013.

[17] Schattler K, Hanson T, Maillacheruvu K. Effectiveness Evaluation of a Modivied Rightturn Land Densign at Intersections. Civil Engineering Studies, 2016;(16013).

[18] A. K. Maurya and P. S. Bokare, "Study of deceleration behavior of different vehicle types," International Journal for Traffic and Transport Engineering, vol. 2, no. 3, 2012.

[19] General design factors, Mn/DOT Bikeway Facility Design Manual, Chapter 5, March 2007, pp.123-136.

[20] X. Ma, X. Yin, and K.S. Trivedi, *On the Reliability of Safety Applications in VANETs*, Invited paper, International Journal of Performability Engineering Special Issue on Dependability of Wireless Systems and Networks, 8(2), March 2012.