Towards Safer Roads:
An Efficient VANET-based Pedestrian Protection Scheme

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Abstract— **About 1.2 million people lose their lives on roads yearly due to accidents despite the emerging and uprising technology in contemporary vehicles. In addition, 4.4 million people were seriously injured and required medical attention in crashes last year. By employing Vehicle-to-Pedestrian (V2P) communication between drivers and vulnerable road users,fewer casualties are likely to occur and roads are expected to be much safer. In this paper, we propose a lightweight scheme to protect vulnerable road users based on communication between smartphones and on-board units installed in vehicles. Initially, the signal strength is used to estimate the distance between vehicles and pedestrians and predict the occurrenceof a collision. Since signal strength alone can result in false alarms, we propose a collision detection algorithm to confirma collision. The algorithm is run on both sides; the driversand vulnerable road users to give appropriate and real-time warnings of a potential accident/collision. Vehicles and road users exchange their Global Positioning System (GPS) locations using Dedicated Short Range Communications (DSRC). The algorithm constructs a vector representing the vehiclepath and uses efficient and simple mathematical operationsto determine if there is a possibility of collision or not. Our scheme contributes to the safety applications of vehicular ad hoc networks. Our experiment's results confirm that the proposed scheme can effectively detect collisions with minimum computation overhead.**

Keywords— Collision detection, Safety applications, Vehicular ad hoc networks, Vehicle to pedestrian communication, Vulnerable road users component.

I. INTRODUCTION

The Global status report on road safety published by the World Health Organization (WHO) highlights that the number of annual road traffic deaths has reached 1.35 million. Daily, almost 3700 people are killed globally in road crashes and more than 50% of those killed are pedestrians, cyclists, or motorcyclists [1]. According to the European Commission report "Traffic Safety Basic Facts 2018", an estimated number of 5000 persons are killed yearly in the European Union and the highest accidents exposure occurs in urban areas [2]. A report published by Ward's Magazine shows a rough estimate of the number of running vehicles now to be 1.2 billion and estimates that this number will soar to 1.7 billion in 2035 [3]. With the increase in the number of vehicles on roads, many concerns regarding road safety are on the rise, and more accidents, road fatalities, and causalities are expected [4]. The National Highway Traffic Safety Administration (NHTSA) recently published a fatality analysis report that shows the number of pedestrians killed in traffic crashes to be around 6200 in 2018 and 2019. Unfortunately, NHTSA confirms that a pedestrian is killed every 85 minutes it crashes. Table I presents more detailed statistics about pedestrian deaths in the US in the period from 2015 to 2019 [5]. Since 1996, various pedestrian safety schemes have been proposed using the latest technological developments and advances. For example, the giant car manufacturer Volvo introduced an automatic brake system to avoid potential collisions and to increase pedestrian safety [6]. However, the adequacy of such developments is still a matter of debate. Recently, a 49-years-old cyclist woman was hit by an Uber transport self-driving vehicle belonging to Tesla, causing a fatal accident [7]. We attribute the causes of such a deadly accident to relying solely on sensors to detect surroundings. It is clear that even with all the innovative measures/precautions taken by the car manufacturers, pedestrian safety is yet far from being fully achieved.

TABLE I. STATISTICS OF PEDESTRIAN FATALITIES IN THE US ONLY [5]

Year	Fatalities	Pedestrian Fatalities	Pedestrian Deaths
2015	35,092	5,376	15%
2016	37,461	5,987	16%
2017	37,133	5,977	16%
2018	36,835	6,374	17%
2019	36,096	6,205	17%

In this paper, we propose a lightweight scheme to protect vulnerable road users based on Vehicle-to-Pedestrian (V2P) communication. Our objective is to give warnings to both the drivers and vulnerable road users in a timely manner to take precautions that contribute to safer roads. We assume that users on road own a smartphone that is able to run a mobile application. Initially, smartphones establish a Wi-Fi hotspot and on-board units attempt to connect to them. Each Vehicle measures the signal strength to estimate how far a road user is from itself. The signal strength is directly proportional to the distance between the vehicle and the smartphone. However, depending solely on signal strength is not a sufficient method to confirm a collision since we show that it may result in false collision alarms. Therefore, we propose a collision detection algorithm that is run on both sides; the drivers and vulnerable road users to give appropriate and real-time warnings of a potential accident collision. Vehicles and road users exchange their Global Positioning System (GPS) locations using Dedicated Short Range Communications (DSRC). The algorithm constructs a vector representing the vehicle's path and a circle to represent a pedestrian position. Then, we run lightweight calculations to confirm or debunk the possibility of collision occurrence. The scheme can run without the need for a server between the driver and the pedestrians so that latency and reaction time needed to avoid inevitable accidents are both minimized. If a potential collision is confirmed, the smartphone should ring out as an alert in a mobile application of the vulnerable road user. The drivers receive a similar warning(s) from the on-board unit so that they can apply brakes/change their directions and take appropriate actions. The scheme is an integral component to be used with sensors to overcome their shortages and maximizes the safety of both drivers and vulnerable users. Pedestrians and vulnerable road users are used interchangeably throughout this paper.

The remainder of the paper is organized as follows. In Section II, we discuss the related work. The network model and our proposed scheme are described in section III. The implementation and simulations are conducted in section IV.

Finally, conclusions and future work are presented in section V.

II. RELATED WORK

A considerable amount of research work is directed towards the protection of vulnerable road users due to the increased number of fatalities on roads. On-board sensors, automatic emergency brakes, and image processing to analyze perceived images and videos are all countermeasures to decrease the number of accidents on roads. However, on-board sensors are prone to catastrophic failures due to many reasons such as adverse weather conditions, darkness, and contamination of the vehicle sensors. A smartphone-based scheme called PAWS that utilizes a smartphone application and an optional low-power embedded wearable headset mounted with an array of microphones for localization was proposed in [8]. The scheme consists of three modules; car detection, localization, and users' alerting and warning modules. Their main idea is to extract features from the surrounding audio samples and run a Random Forest classifier for car detection. However, a headphone is required to run this scheme. Roadside Light Detection and Ranging (LiDAR) sensors are installed on roads to facilitate the development of safer transportation infrastructure. LiDAR sensors can provide three- dimensional scans of an observed area and distinguish between vehicles, and pedestrians. Since LiDAR sensors can determine the interactions among the various users of a road, store road statistical data, they can be of crucial importance for many road safety applications [9], [10], [11].

A low-cost scheme called WiSafe that uses Wi-Fi to prevent collision with pedestrians is proposed in [12]. WiSafe is compatible with 802.11 a/b/g/n and can work with smartphones and wearable devices. Moreover, WiSafe can use cellular communication and utilizes 2G/3G and 4G to transmit information between pedestrian and vehicle. The scheme establishes a communication channel between the vehicles and the pedestrians. However, the results of the WiSafe experiment have shown that concrete buildings can degrade the efficiency of the scheme [12].

Saha et. al. [13] proposed a Wi-Fi, 5G/LTE based protection scheme, which combines new technologies such as 5G and Wi-Fi to protect vulnerable road users. Vulnerable road users should carry an accelerometer and gyroscope sensor for accurate determination of headings and location. Using GPS technology, there was an attempt to create a warning system with 5G on-board information exchange. However, a failure of 33% is observed in experiments on 3 cm pavement. Dahlia et. al. [14] proposed a study to improve pedestrian safety in black spots using communication between vehicles and body sensors (Wireless Body Area Networks (WBANS)). Examples of wireless body area network devices are new generation smart watches, fitbits, and phones. These small scale devices exchange location information with Road Side Units (RSUs) and then RSUs forwards this information to passing vehicles. Pedestrians can be better protected when vehicles are aware of their locations.

III. AN EFFICIENT VANET-BASED PEDESTRIAN PROTECTION SCHEME

In this section, we present our network model and proposed scheme to protect road users from accidents.

A. Network Model

Our network model is depicted in Fig. 1 and its components are as follows.

Smartphone: The smartphone belongs to vulnerable road users. Vulnerable road users include pedestrians, cyclists, or children crossing intersections and people with disabilities. A designated mobile application is installed and runs on a smartphone to perform the following tasks:

1) Establishing hotspots to allow vehicles to connect to them.
2) Running a collision detection algorithm that consists of lightweight mathematical operations.

   The phone is equipped with GPS and can communicate using cellular communications and dedicated short range as well.

Vehicles: The network consists of vehicles moving at different speeds and trajectories. Vehicles are equipped with on-board units that can run programs, communicate using cellular and dedicated short range communications.

Synchronization Server: The server is connected to the Internet to be available for both vehicles and vulnerable road users.

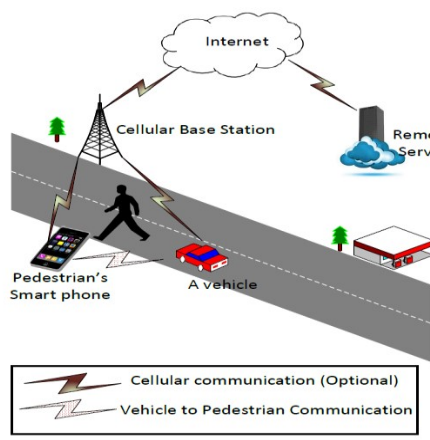

Fig. 1. Our Network Model.

We use the server to synchronize data signalstrength data read by the vehicle with the vulnerable road users. Our scheme can run efficiently without the need for the server. This is because werely on the signal strength and an efficient algorithm to detect collisions. The server has large storage and computation capabilities, and can be used in other situations mentioned later.

Our objective is to warn both drivers and pedestrians with a reasonable distance and time, if there is a possibility of a collision, in order for them to take the appropriate actions. Moreover, we aimto keep the scheme's cost at its minimum to be availablefor the public. Therefore, no special devices need to be installed in vehicles or worn by the road users to run the scheme. We make use of the availability of smartphones with almost every person nowadays. Our scheme consists of two phases; preliminary signal strength road users' protection phase, and an efficient independent collision detection phase. The two phases are explained in subsections B and *C*, respectively.

B. Signal Strength based Vulnerable Road Users Protection

The smartphones of road users establish a Wi-Fi hotspot. On-board units installed in smart vehicles sniff available Wi-Fi networks and attempt to connect to them. When vehicles connect to a pedestrian's hotspot, the signal strength is measured to estimate the distance between itself and the road user. If the signal strength for a specific hotspot increases and exceeds a certain threshold, the scheme should execute the next phase which is an efficient independent collision detection algorithm explained in section C. The signal strength is directly proportional to the distance between the vehicle and the smartphone's hotspot. Fig. 2 depicts the steps run by the vehicle and the smartphone to detect a potential collision. Vehicles should be able to establish hotspots to allow pedestrians to measure the signal strength and predict collision as well. However, if a vehicle cannot establisha hotspot due to a hardware or software malfunctiona synchronization server can be used. A vehicle sends a warning message to the synchronization server if it detectsa collision. Road users' smartphones connect to the server to get warnings if they have access to cellular communication.There is a tradeoff between the efficiency of the scheme andthe time needed to connect to the server. If the pedestrian does not have access to the synchronization server, onlythe vehicle's driver is warned about the collision. While the increase of the signal strength indicates a shorter distance between road users and a vehicle, it does not necessarily mean that a collision will occur. This scenario is depicted in Fig. 3. In order to avoid false alarming, we run the efficient and independent collision detection phase.

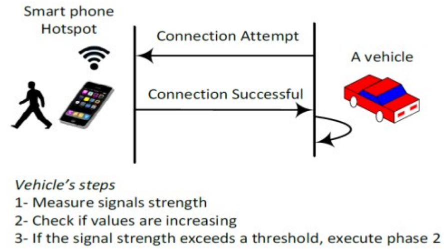

Fig. 2. Vehicles connect to smartphones hotspots and measure thesignal strength to predict the possibility of collision occurrence.

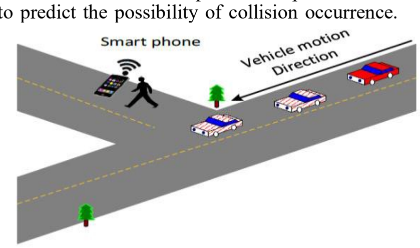

Fig. 3. A situation that triggers a false collision alarm whendepending solely on signal strength. Although the signal strengthis increasing, the pedestrian is safe and there is no sign of any collision.

C. Efficient and Independent Collision Detection

Initially, vehicles and pedestrians' smartphones exchange their GPS locations, and the vehicles' speeds using V2P communication as shown in Fig. 4. Our technique requires at least the most recent two GPS locations of a vehicle. Using the most recent coordinates, it is a straightforward task to construct a line that represents the path of the vehicle. A vulnerable road user is located at the center of a virtual circle where the radius of the circle is a configurable parameter. We employ the circle-line intersection from analytic geometry to detect the collision as shown in Algorithm 1. There is a trade off between the value of the radius and falsealarms. For example, if the radius is very large, Algorithm1 will return collision detection while there is no collision to occur and no hazard for the pedestrians. The value of the pedestrian's radius is crucial for the efficiency of the proposed scheme. In Fig. 5, we show three different outputs of Algorithm 1 in the context of a pedestrian- vehicle collision. Two scenarios of interest represent apotential collision when the vector representing the vehicles' path is either interesting or a tangent to the pedestrian's circle. The third scenario will not trigger an alarm since the vector does not collide with the pedestrian's circle.

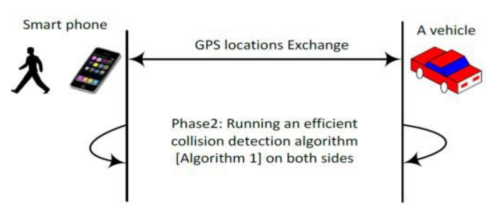

Fig. 4. Phase 2 objective is to ensure a potential collision after execution of phase 1, an efficient algorithm to detect a collision is run on both sides.

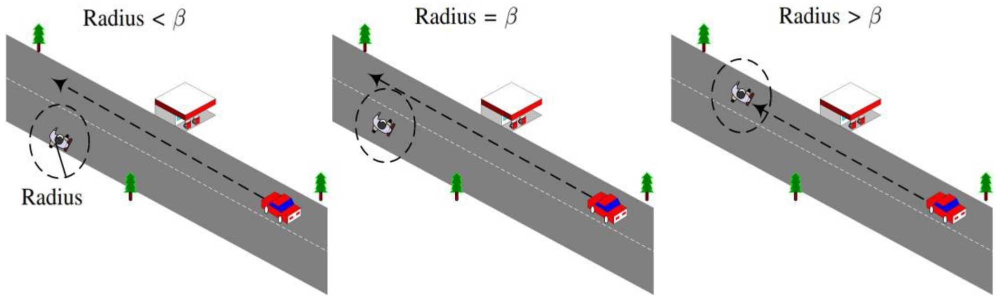

Fig. 5. Three different scenarios of pedestrian vehicle collision detection according to the proposed collision algorithm

Algorithm 1 Efficient Collision Detection Algorithm

Inputs : Radius of Circle , Pedestrian locatioi $(Pedestrian_X, Pedestrian_y)$, Most recent GPS coordinates of a Vehicle (x_1, y_1) , (x_2, y_2)
while true **do**
  $a = y_2 - y_1$
  $b = x_1 - x_2$
  $c = a \cdot x_1 + b \cdot y_1$
  $\beta = \frac{|(a \cdot Pedestrian_x)+(b \cdot Pedestrian_y)+c|}{\sqrt{a^2+b^2}}$
  if Radius $\geq \beta$ **then**
    Potential_Collision = true
    Issue_Appropriate_Warning()
  end if
end while

IV. SIMULATION

In this section, we test the performance of our proposed scheme. Simulation setup and simulation results are presented in sections A and B, respectively.

A. Simulation Setup

The efficient and independent collision detection phaseis implemented using python 3.6 on a Kali Linux 64- bit operating system running on Intel Core i7-7700, 2.80 GHz with 16 GB RAM. In order to generate test data, we generate a topography using OpenStreetMap (OSM) and vehicular movement traces randomly using SUMO [15].The topography's dimension is about 0.87 1.5 km area which resembles the campus area around Sam Houston State University in Huntsville, TX, USA. We varied the number of vehicles to be 200, 400, 600, 800, and 1000 vehiclesto assess the performance in different traffic scenarios, and the radius of the pedestrians was set to 1 meter. We used the following metrics to assess our scheme as follows.

- **Collision Detection Algorithm execution time:** The time needed by the smartphone/vehicle to compute the steps in Algorithm 1 for a different number of vehicles/smartphones.
- **Stopping Distance & Time:** Given a collision warning, we derived an equation to measure the time needed to stop and the distance covered by the vehicle at differentspeeds.
- **Total Time to avoid a Collision:** This is the execution time of Algorithm 1 to detect a potential collision added to the driver's reaction time *in average 2.3 seconds accordingto Table II* added to the time needed to stop the vehicle after the driver presses the brakes. The total time is directly proportional to the velocity of the vehicle.

The higher the vehicle's velocity, the more time needed to stop because the vehicle runs a longer distance. The drivers' reaction time to different incidents on roads can vary in different situations and from person to person. For example, the reaction time to recognize that the traffic light has changed is different from the time required to press the breaks pedal in emergencies. We define the driver's reaction time to be the time needed to decide to continue or brake, and if stopping is the driver's decision, then it includes engaging the brake (i.e. removing foot from the accelerator and pressing brake).

In [16], the reaction times of the drivers vary between 0.7 to 3 seconds and are shown in Table II [17]. For realistic results, we consider the average driver's reaction time which is 2.3 seconds. In algorithm 2, we compute the total time needed by a vehicle to stop in more details.

TABLE II. STATISTICS OF THE MOST RECENT REACTION TIMES OF DRIVERS IN CRASH AVOIDANCE RESEARCH [17]

Time	Description
0.7 Second	The fastest driver's reaction time
1.0 Second	Old standard reaction time
1.5 Seconds	Common reaction time based on experiments
2.0 Seconds	Common reaction time based on experiments
2.3 Seconds	Average reaction time
2.5 Seconds	California State Standard
3.0 Seconds	National Safety Council (NSC) and UK Standard

Algorithm 2 Calculating the total time required to stop a vehicle in case of a potential collision is detected.

Current velocity of vehicle (currentvelocity), coefficient of friction between the tires and the roadway (ω), acceleration due to gravity (g) , time required to react/response to an emergency (ReactionTime), collsion detection algorithm execution time (Execution time)
if potential_collision_detected = true **then**
    $ReactionTime = 2.3$
    $\omega = 0.8$
    $g = 9.81$
    $StopDistance = \frac{currentvelocity^2}{2(\omega \cdot g)}$
    $AverageSpeed = \frac{(currentvelocity)}{2}$
    $StopTime = \frac{(StopDistance)}{AverageSpeed}$
    TotalTime = ExecutionTime + ReactionTime + StopTime
end if

B. *Experimental Results*

- Collision Detection Algorithm execution time: Fig. 6 presents the time required to run our efficient detection algorithm with a different number of vehicles. Ouralgorithm is lightweight and scalable. For example, it only needs 26.1ms to compute the algorithm for1000 surrounding vehicles. These results prove that theproposed scheme can scale well even in large cities with high traffic densities.

- Stopping distance & time: To calculate the distance covered by vehicles before a stop, we use Newton's Law that is shown in equation 1 where v is the vehicle's velocity and ω is the coefficient of friction and g= acceleration due to gravity.

$$d_{stop} = \frac{v^2}{2 \times \omega \times g} \qquad (1)$$

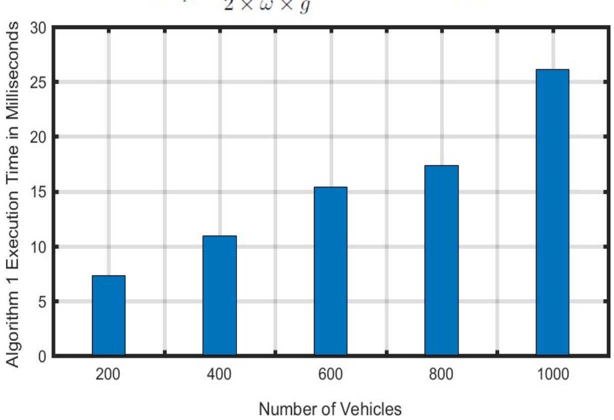

Fig. 6. Execution time of Collision Detection Algorithm 1 in milliseconds with different numbers of vehicles.

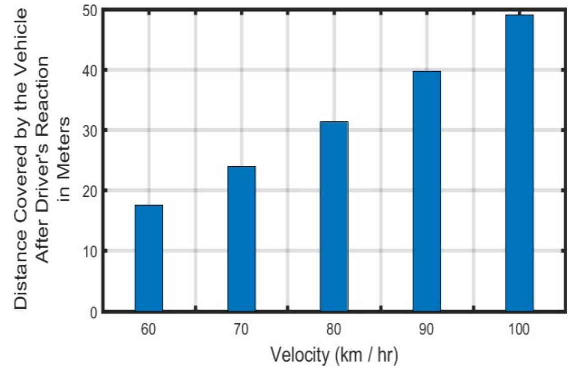

Fig. 7. Stopping distance in meters at different vehicles' speeds

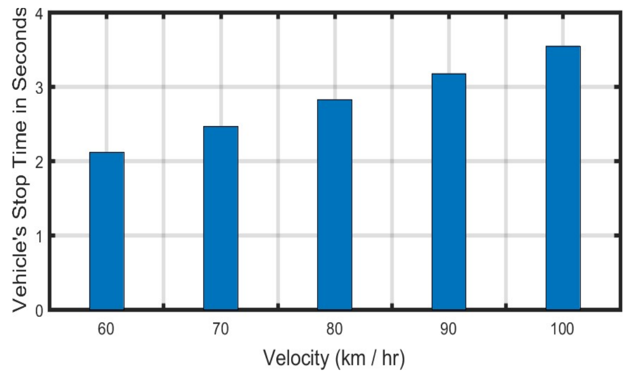

Fig. 8. Stopping times in seconds at different vehicles' speeds.

Fig. 7 illustrates the distance covered by the vehicles at different speeds. It is clear that the higher the speed, the longer the distance needed by the vehicle to stop. In order to have a better understanding, we use the stopping distance equation to calculate the time needed by the vehicle to stop. In equation 2, we calculate the average speed where Velocityinitial is the speed of the vehicle when the driver reacts to the collision detection warning (presses brakes) and Velocity_final=0 where the vehicle stops. We derive equation 3 to calculate the time to stop. Fig. 8 shows the stopping time after the drivers' reaction. It shows that it takes about 3.5 seconds to stop a vehicle running at 100 km/h while it takes 2.6ms only to give a warning to the driver. Our scheme execution time is negligible to the vehicle's stop when its speed is high.

$$averagespeed = \frac{Velocity_{initial} + Velocity_{final}}{2} \qquad (2)$$

$$StopTime = \frac{AverageSpeed}{d_{stop}} \qquad (3)$$

- Total time to stop a vehicle and prevent an accident: Fig. 9 shows the total time needed by a vehicle to detect a collision and stop. This time is calculated by considering the algorithm execution time added to the driver'sreaction time, in addition to the time needed by the vehicle to stop. According to our calculations, it should take about 4 seconds when the number of vehicles between 200 and 1000 vehicles. As shown in Fig. 9, the time of execution is almost the same when we increase the number of vehicles from 200 to 1000 which shows the scalability of our scheme.

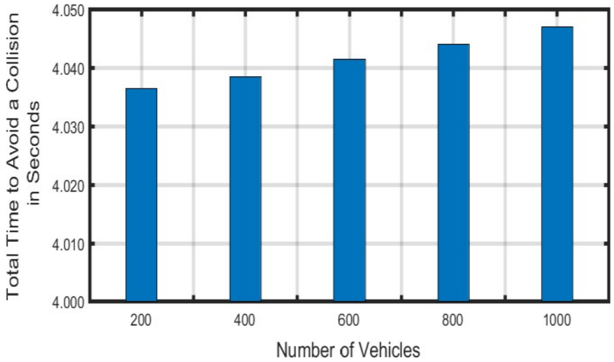

Fig. 9. Total Time to stop a vehicle with different number of vehicles

V. CONCLUSIONS AND FUTURE WORK

In this paper, we proposed a lightweight scheme to protect vulnerable road users to mitigate the uprising on-road casualties. The proposed scheme is based on communication between vulnerable road users' smartphones and onboard units installed in vehicles. Different from other schemes that focus on warning drivers only, our schemecan warn both drivers and road users. Our scheme employs smartphones and consists of two phases to detect a potentialcollision. Smartphones establish hotspots where vehicles attempt to connect to them and estimate the distance based on measuring the signal strength. In the second phase, an efficient algorithm is used to detect collisions on both sides; the vehicle and the road users. The proposed scheme certainly contributes to the safety applications of vehicular ad hoc networks by protecting vulnerable road users. Our evaluations and simulation show that it can effectively detectcollisions with minimum computation overhead.

We plan to extend this work by measuring the false positives which could potentially trigger alarms although the pedestrian is safe. Most importantly, the privacy of pedestrians and drivers will be addressed by encrypting the exchanged GPS locations. The cost of privacy in terms of the computation delay will be investigated.

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