Cooperative Pedestrian Safety Framework using 5G-NR V2P Communications

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***Abstract*—Over the past several years, there has been a growing focus on research aimed at decreasing the rising number of pedestrian fatalities in traffic accidents. Advances in Vehicle-to-Pedestrian (V2P) communications have opened up new possibilities for improving pedestrian safety, but these potential solutions have yet to be thoroughly explored. This paper outlines a cooperative pedestrian safety framework (CPSF) for non-signalized pedestrian crossings that leverages 5G-NR V2P communications to warn both pedestrians and drivers. The framework also considers the limited battery power of pedestrian equipment. According to the results of the analysis and evaluation, the proposed CPSF significantly reduces the occurrence of vehicle-pedestrian collisions while conserving battery power, making the road safety framework more feasible.**

Keywords—Pedestrian safety, V2P communications, Battery consumption, 5G-NR C-V2X

I. Introduction

There have been many injuries as well as fatalities as a result of the growing number of collisions between cars and pedestrians in recent years. Despite continuous efforts to decline the number of accidents on the roads, the risk of casualties among pedestrians is still higher [1]. They are largely vulnerable due to issues such as distracted driving, inadequate pedestrian infrastructure, vehicle speed, and age-mobility challenges [2]. Ensuring the safety of pedestrians in their day-to-day commute is yet a challenging issue.

Few earlier studies have developed vehicle-to-pedestrian (V2P) collision avoidance systems using vehicular networks to solve this problem. One of the ways to connect pedestrians to vehicular networks is by using their smartphones [3]. However, the smartphone's limited battery capacity does not allow it to adopt the efficient methods that have been suggested for vehicle-to-vehicle (V2V) scenarios. As the pedestrian smartphone and the vehicle must continuously provide location updates at a very brief interval in order to anticipate collisions, transmitting periodic messages can quickly deplete the battery of a smartphone.

V2P based safety solutions mostly rely on 802.11p [4][5] or Cellular Vehicle to Everything (C-V2X) [6][7] for communication technology. However, the study shows that C-V2X technology performs better in safety applications because of its larger coverage area, reliability, robustness, and interoperability, promising a significant reduction in pedestrian casualty in the near future [8]. Therefore, C-V2X based V2P solutions have gained increased attention to improve pedestrian safety.

This paper proposes a method to develop a cooperative pedestrian safety framework (CPSF) that utilizes 5G-NR V2P communications to alert pedestrians and drivers in order to reduce traffic accidents while considering the battery power constraint of pedestrian user equipment (UE). The specific contributions of this paper are the following:

- We analyze different designs of safety systems to decrease the battery usage of pedestrian UE.
- We propose a cooperative alert beaconing method that reduces the number of beacon transmissions while maintaining the effectiveness of the safety framework.
- To minimize the risk of accidents involving vehicles and pedestrians, we suggest a technique that involves notifying both vehicles and pedestrians to increase the safety framework's efficiency.

This article is organized into six sections. After this introduction, section II presents the related works on pedestrian safety systems. Section III explains the model and overall working process of the framework. The settings related to simulations and experiments are described in section IV. In section V, the outcomes of the experiments are presented and discussed. Finally, conclusions are drawn in section VI.

II. Related Works

The European Telecommunication Standard Interconnects (ETSI) introduces two safety messages that can be exchanged between road users for reliable connection and safety applications. The first one is the Decentralized Environmental Notification Message (DENM), which is transmitted to nearby road users in case there is an emergency, and the second message is the Cooperative Awareness Message (CAM), which is transmitted periodically to exchange the state information among the road users. Authors of [7][9] considered the CAM message format for providing pedestrian information to vehicles in a periodic manner. They considered the 0.1s (100ms) interval for periodic messages according to the standard. 5G-NR technology considered in this work provides specific quality of service (QoS), which is sufficient to support 0.1s latency [8].

There are three types of communication between vehicles and pedestrians: direct, indirect, and hybrid. Vehicles and pedestrians communicate with one another directly using the direct mode of communication. Authors of [10] employ a direct form of communication to test proposed access methods using radio equipment in the real field for the V2P system. The indirect mode of communication, on the other hand, entails vehicles and pedestrians communicating with each other over a network of infrastructure. For example, a cloud computing-based V2P system is proposed in [9] that makes use of indirect way of communication to improve pedestrian safety in obstructed visibility and bad weather conditions. A hybrid mode of communication uses both direct connection between

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vehicles and pedestrians as well as indirect communication through infrastructure. Examples of such communication mode can be found in [11] that prevents pedestrian accidents using a coarse-grained positioning by leveraging intermittent Global Positioning System (GPS) information and mobile sensing data. Among these modes, a direct connection should perform fastest as it can communicate immediately without any intermediate link. Due to the lower communication latency, this mode is ideal for safety applications. That is why this paper utilizes a direct communication mode for the proposed framework. However, to make use of this mode, all the devices must use the same kind of communication technology.

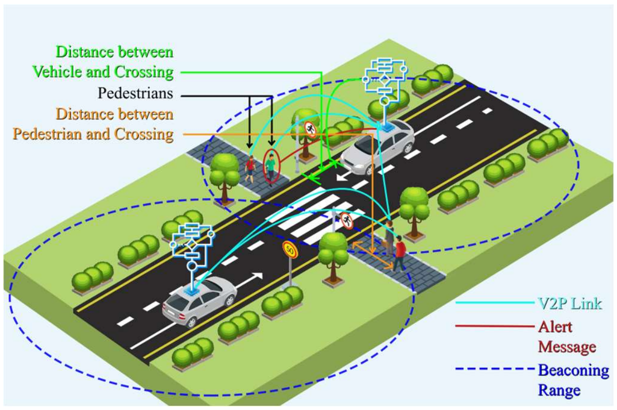

Fig. 1. The system model of CPSF.

The mechanisms to engage pedestrians in V2P communication can be divided into active and passive groups. A pedestrian is considered to be actively participating when its UE sends periodic updates on the pedestrian's location, speed, etc. [6][7]. On the contrary, if the UE only listens to the messages from a vehicle on-board unit (OBU) and/or when UE sends a reply only when it detects the message from an OBU, this type of participation may be called passive participation. The methodology in [11] utilizes passive participation to develop a mobile sensing-based collision warning service for pedestrians. Active communication can result in more UE-battery usage [7] and network congestion because of periodic messages. At the same time, it may continue beaconing even after a vehicle is no longer considered a danger, e.g., the vehicle has already driven away from the pedestrian. Therefore, this type of system may need to use mechanisms to optimize pedestrian transmissions. In this paper, the pedestrians participate using a passive communication mechanism as the UE sends the update when it receives a beacon from the vehicle.

If the V2P systems rely on an indirect communication mode, then an information processing unit connected to the network is responsible for carrying out detection, tracking, and prediction tasks [12][13]. If required, then the information processing unit notifies the vehicle and the pedestrian through infrastructure for necessary action. However, in the case of direct communication mode, either the pedestrian's smartphone or the vehicle's specialized processing unit, or both, must act as the information processing unit. This paper avoids excessive battery use of UE by proposing a method where most of the processing work is assigned to the vehicle. Pedestrian UE only determines whether it is close to the pedestrian crossing by using Global Positioning System (GPS) data.

III. Cooperative Safety Scheme

This method considers a non-signalized pedestrian crossing to improve the pedestrian safety of urban areas, as illustrated in Fig. 1. It assumes that pedestrians cross the road by determining the presence of traffic in the approaching lanes. The vehicles also reduce speed or stop if they notice the pedestrians are about to cross the road. The state information of the vehicles and pedestrians is shared through V2P link under the assumption of perfect communication performance. It is also assumed that position of the pedestrian crossing is known to both pedestrian UE and the vehicle. In the proposed CPSF, a vehicle assesses the risk of collision by taking the distance from the pedestrian crossing and its current speed into consideration. When it finds the situation to be unsafe, it alerts both the pedestrian and the driver so that a collision can be avoided.

A. Cooperative Alert Beaconing

It is necessary to decrease the number of beaconing in safety systems to reduce UE-battery power depletion resulting from periodic messages. With 5G-NR V2X, road users can communicate with one another within 200 meters while maintaining more than 90% reliability [14]. That is why most of the previous research works assume that road users start beaconing once it is within a beaconing range (R_b) of 200 meters. However, it takes a much shorter distance for a passenger car to stop, even if it is driving at high speed. So, it is appropriate to begin beaconing within a narrower range in order to decrease the number of beacons while effectively alerting other road users. In order to quantify the safe range to start beaconing, this work defines the distance required for a

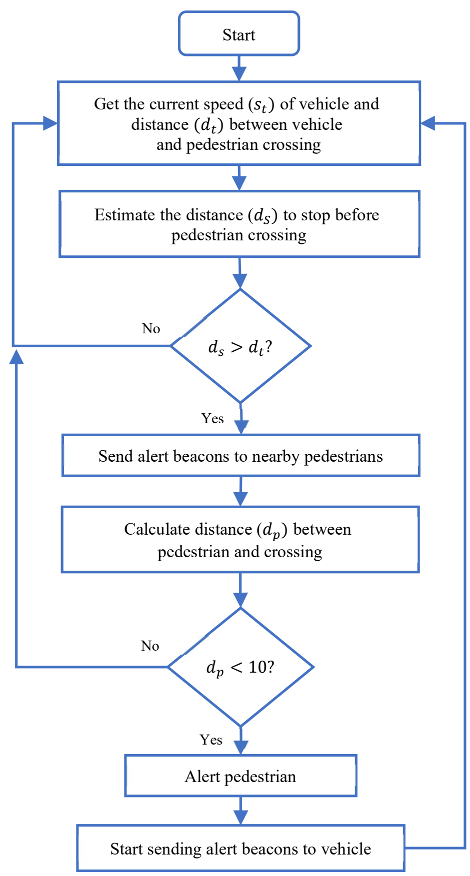

Fig. 2. Flowchart of the CPSF algorithm.

driver to detect the pedestrians on the crossing or near the crossing using Decision Sight Distance (DSD). According to [15], the distance, d to recognize a potential threat, to select an appropriate speed, and to complete the required maneuver safely, can be defined by equation (1).

$$d = 0.278VT + 0.039\, V^2/r_d \qquad (1)$$

Where V is the speed limit of the road, T is the time to make decisions and maneuver the vehicle safely, and r_d is deceleration rate of the vehicle. A vehicle can begin evaluating the risk of the situation once it is d meters away from the pedestrian crossing. Although this work assumes the vehicles drive within the speed limit, it also studies the effectiveness of the framework if the speed limit is violated. In order to alert road users in risky situations, CPSF algorithm is proposed, as illustrated in Fig. 2. If the algorithm detects a collision risk, the vehicle starts sending beacons to pedestrians UE. The UE then determines the position of the pedestrian and the distance from the crossing. If the pedestrian is near the crosswalk, i.e., the distance d_p is less than 10 meters, UE alerts the pedestrian and starts sending beacons at i intervals to the incoming vehicle. These beacons inform and alert the driver of the pedestrian's location and intention. At this point, the driver can activate the brake to slow down or maneuver safely to mitigate the collision risk.

TABLE I. LIST OF SIMULATION PARAMETERS

Parameters	Description	Value
L x W	Dimension of vehicle	4.5 m x 1.8 m
r_a	Acceleration rate of vehicle	1.5 m/s^2
r_d	Deceleration rate of vehicle	3.4 m/s^2
s_p	Maximum walking speed of pedestrians	5 km/h
n_v	Number of vehicles per hour	600, 900, 1800
n_p	Number of pedestrians per hour	150
V	Speed limit of road	50 km/h
T	Reaction and decision-making time	9.1 s [16]
i	Beacon interval	0.1 s
R_b	Beaconing range	200 m
TTC	Time to Collision	1.0 s

B. Risk Assessment Algorithm

It is not necessary for the pedestrian UE to continue beaconing if the vehicle is deemed risk-free. If the vehicle is moving at such a slow speed that it can stop easily before the pedestrian crossing or if it is past the pedestrian crossing, it can be considered risk-free. That is why this method identifies a situation to be risky if a vehicle does not decrease its speed even after crossing DSD. This means the driver did not notice the pedestrian on the crossing or at the edge of the crossing. However, this could also mean that there is no pedestrian on the crossing and there is no risk of collision. To distinguish between these two situations, the algorithm first determines the distance d_t between pedestrian crossing and the current position of the vehicle using the GPS coordinates. The distance is calculated by the Haversine distance equation [16]:

$$d_t = Rc \qquad (2)$$

where

$c = 2atan2\left(\sqrt{a}, \sqrt{(1-a)}\right)$, $a = sin^2\left(\frac{\Delta\varphi}{2}\right) + cos\varphi_1 \cdot cos\varphi_2 \cdot sin^2(\Delta\lambda/2)$, $\Delta\varphi = \varphi - \varphi_v$ and $\Delta\lambda = \lambda - \lambda_v$.

In equation (2), the symbol R represents the Earth's radius. The variables φ and λ are the latitude and longitude of pedestrian crossing, while φ_v and λ_v stand for latitude and longitude of a vehicle at time t. After that, the distance d_s to stop the vehicle is calculated using equation (3) given the vehicle's speed s_t at time t.

$$d_s = {s_t}^2/2r_d \qquad (3)$$

As illustrated in Fig.2, if the value of d_s is greater than d_t, the algorithm identifies the situation as risky and proceeds with the beaconing sequence, as discussed in the earlier section.

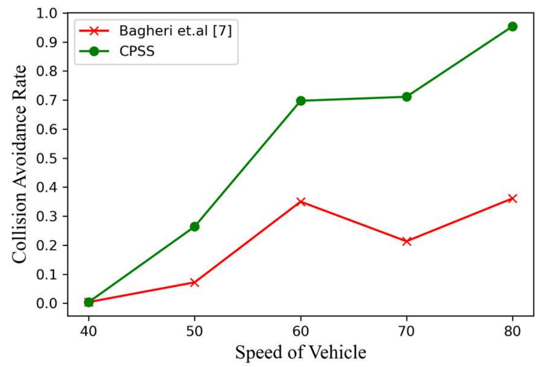

Fig. 3. Collision avoidance rate for different driving speeds.

IV. EXPERIMENTAL SETTINGS AND SIMULATION PROCEDURES

The model of the pedestrian crossing and the traffic simulation is created in Simulation of Urban MObility (SUMO) [17]. The two-way lanes are 1000 meters, and the pedestrian walking paths are 100 meters in length, respectively. In experiments, vehicles are characterized by their dimensions (L x W) as well as their acceleration rate (r_a) and deceleration rate (r_d). The vehicles and pedestrians with maximum walking speed (s_p) are generated randomly via embedded tools. However, the same random seeds have been used to reproduce the vehicles and pedestrians for the purpose of comparison. To simulate light, medium, and heavy traffic flow with different numbers of vehicles (n_v) are used. The collision between vehicles and pedestrians is determined by Time to Collision (TTC), which measures the time remaining until a collision occurs between two objects. Table I summarizes the simulation parameters and their values used for experiments and evaluation. To estimate the effectiveness

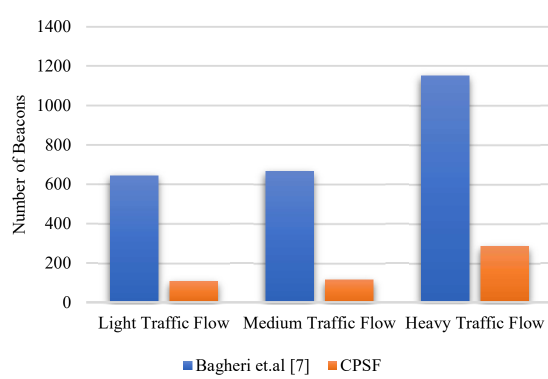

Fig. 4. Average number of beacons transmitted by UE in different traffic conditions.

of the safety framework, this work measures the collision avoidance rate of CPSF and compares it with the method presented in [7] that sends alerts to vehicles only. Experiments are carried out for different values of s_t which are within and beyond the speed limit to see the performance under regular situation as well as speed violation.

V. REUSLTS AND DISCUSSIONS

The performance of the proposed framework for different driving speeds is depicted in Fig. 3. It indicates that when the CPSF alerts both the pedestrians and drivers, it outperforms the current practice, which only alerts the driver. This means that when both pedestrians and drivers receive alerts, the system is more efficient in ensuring the safety of pedestrians crossing the road. For an instance, the implementation of CPSF and driving at a speed of 50km/h can result in an increase of approximately 20% in collision avoidance rates. Moreover, the data also suggests that the CPSF can be effective in situations where speed limits are being violated. This illustrates the versatility and effectiveness of the system in enhancing road safety in various scenarios. However, when driving speeds are below 40 km/h, the collision avoidance rate is relatively low. This is because, at lower speeds, vehicles have more time to react to potential hazards and make adjustments to avoid collisions. As a result, collisions are rarely recorded at these slow speeds, and the collision avoidance rate is nearly nonexistent. It is important to note, however, that while low speeds can reduce the risk of accidents, they can also negatively impact traffic flow and cause congestion. In this study, the impact of the CPSF on the battery usage of pedestrian UE is evaluated by comparing it to the existing system based on the average number of beacons transmitted by the pedestrian UE to alert vehicles as illustrated in Fig. 4. It is evident that, compared to existing research work, CPSF requires less number of beacons to alert vehicles. For instance, in heavy-volume traffic, approximately 25% of beacons are needed to alert the vehicles, compared to the current system. This will reduce the battery usage of pedestrian UE while ensuring the safety of crossing the roads.

VI. CONCLUSIONS

This paper presents a method for creating a cooperative pedestrian safety framework (CPSF) that leverages 5G-NR V2P communications to warn both pedestrians and drivers, with the aim of reducing traffic accidents. The framework also takes into account the limited battery power of the equipment used by pedestrians. Initially, we analyze different technologies and components of safety system architecture to establish a method that is more practical and suitable for pedestrians. After that, the paper explains the method to develop and evaluate the method. Based on the simulation results, the framework effectively lowers the collision rate between vehicles and pedestrians by nearly 20% while lessening the battery usage by decreasing the number of beaconing. In the future, we aim to study more diverse yet realistic scenarios and explore other methods to enhance the framework for better performance and reliability.

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