SANA: Safety-Aware Navigation Application for Pedestrian Protection in Vehicular Networks

Taehwan Hwang[1] and Jaehoon (Paul) Jeong[2(✉)]

[1] Department of Digital Media and Communications Engineering, Sungkyunkwan University, Suwon, Gyeonggi-Do 440-746, Republic of Korea
taehwan@skku.edu

[2] Department of Interaction Science, Sungkyunkwan University, Suwon, Gyeonggi-Do 440-746, Republic of Korea
pauljeong@skku.edu

Abstract. This paper proposes a Safety-Aware Navigation Application (SANA) for pedestrian protection in vehicular networks. Because the distracted walking by the smartphone usage in a street or crossroad usually causes road accidents and casualties, it is necessary to design an energy-efficient safety service for a smartphone to warn a pedestrian of possible danger. SANA provides smartphone users with such a safety service. This service calculates the collision possibility that is modeled from the travel delay (i.e., moving time from a position to another position) of both a vehicle and a pedestrian. It also generates an alarm to warn both the vehicle and pedestrian that are relevant to a possible collision. It considers the encounter time of the vehicle and pedestrian for maximum sleeping time to save energy. This paper proposes a scheduling algorithm for optimizing such a sleeping time, considering the filtering of irrelevant smartphones to minimize false positive alarms. The results of the simulation prove that our SANA outperforms legacy schemes in terms of energy consumption and alarm delay (i.e., time difference between the expected alarm time and the actual alarm time).

Keywords: Smartphone · Alarming · Safety app · Collision prediction · Energy saving · Scheduling

1 Introduction

Recently, smartphones have been popularly used by people for various applications (e.g., text messaging, voice calling, email, and web surfing) in road networks. This can cause the collision between pedestrians and vehicles by distracted walking and driving. In 2012, 4,743 pedestrians were killed in traffic crashes in the United States, and another 76,000 pedestrians were injured [1]. This statistics indicates one crash-related pedestrian death every 2 h, and a pedestrian injury every 7 min.

To the best of our knowledge, this paper is the first smartphone-based alarming system called Smartphone-Assisted Navigation Application (SANA) for

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pedestrian protection. The proposed alarming system is designed to ensure the safety of pedestrians with minimal disturbance, while minimizing smartphone energy consumption. In particular, we choose a way of providing effective visual or audio alarm for texting users or music-listening users while walking in streets. The proposed alarming system consists of two-level alarms, such as pre-warning and warning. A pre-warning is an additional warning before a warning is generated in order that a pedestrian can react to a warning promptly to avoid an accident. After the delivery of the pre-warning, a warning is delivered to the pedestrian for accident avoidance. In this paper, we design this two-level alarming system and evaluate our design in terms of energy consumption and alarm delay.

In this paper, we focus on the reduction of energy consumption and alarm delay in our SANA alarming system. The frequent updates of GPS location improve the synchronization, but also cause worse energy efficiency and shorten battery life [2]. To achieve the high synchronization and energy-efficiency simultaneously, this paper provides collision prediction procedure and energy-efficiency scheduling through filtering for collision prediction. SANA can prevent the pedestrians from colliding with vehicles when they cross a street. To prevent this collision, SANA gives a warning to both a vehicle and a pedestrian as soon as they arrive in the range of the safety distance. To give a successful warning, SANA needs frequent updates of GPS location for high synchronization of both vehicles and pedestrians. Note that this paper is the enhanced version of our early paper with simulation-based evaluation [3]. The contributions of this paper are as follows:

- An architecture for smartphone-based alarming system. A pedestrian's smartphone communicates with a driver's smartphone via road-side unit (RSU) in Dedicated Short Range Communications (DSRC) [4] for alarming service.
- A probability model for travel delay and collision. The travel delays of a pedestrian and a vehicle are modeled with Gamma distribution. The collision probability of a pedestrian and a vehicle is computed based on Gamma distribution.
- A scheduling algorithm for DSRC communications for energy efficiency. The scheduling algorithm performs the filtering for irrelevant smartphones from possible collisions and determines working and sleeping time for communications between the smartphones of a pedestrian and a driver.

The remaining of the paper is constructed as follows. Section 2 describes our design of SANA for pedestrian safety. Section 3 presents energy consumption modeling for operations in wireless communication and GPS devices. Section 4 shows safety performance modeling of alarm delay. Section 5 evaluates the performance of SANA in terms of energy consumption and alarm delay. Finally, Sect. 6 concludes the paper along with future work.

2 The Design of SANA

In this section, we explain our design of SANA for pedestrian protection. The pedestrian protection is very important to reduce the fatality around school zones

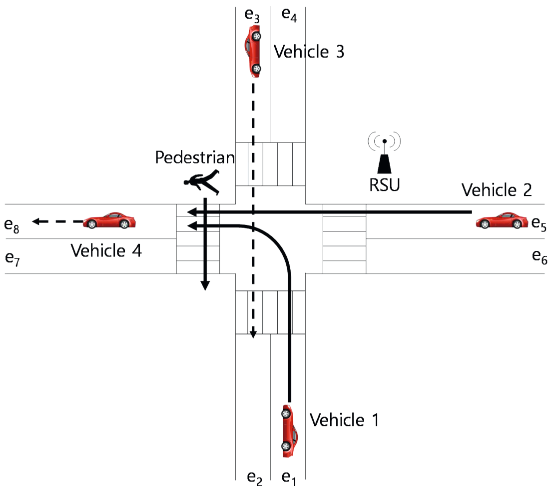


Fig. 1. Efficient collision prediction by vehicle filtering

and downtown streets. Nowadays most of people are carrying a smartphone as either a pedestrian or driver every day.

The pedestrian protection can be performed through the communication between the smartphones of a pedestrian and a driver when the vehicle approaches the pedestrian. If two smartphones share their trajectories and motion vectors, we can expect the possibility that the pedestrian and the vehicle will collide with each other. When the vehicle may hit the pedestrian just in a couple of seconds, SANA can give alarm to both the pedestrian and the driver so that they can avoid a collision. Figure 1 shows the situation that the pedestrian can be hit by Vehicle 1 or Vehicle 2. Pedestrian protection can be achieved by the collision prediction of a vehicle and a pedestrian. We can predict collision by modeling the travel delay of the vehicle and the pedestrian, as discussed in Sect. 2.2.

2.1 SANA Collision Prediction Procedure

For the collision prediction between a pedestrian and a vehicle, we assume the reliable interaction between the pedestrian's smartphone and the driver's smartphone through communication infrastructure. It is assumed that one Navigation Clients are running on the pedestrian's smartphone and the driver's smartphone. Also, Navigation Agent is running on an RSU as a middle cloud [5] near the pedestrian in order to reduce the interaction delay between Navigation Clients. Navigation Client and Navigation Agent can communicate with each other by the cellular link through 4G-LTE [6] or vehicular communication link based on DSRC [4]. The procedure for pedestrian protection is as follows:

1. As Navigation Client, a vehicle or pedestrian with navigator periodically (0.1 s) reports to a nearby Navigation Agent its location, direction, and speed during its travel from its source to its destination.

2. Navigation Agent maintains location and motion vector matrices for the pedestrians and vehicles in a target road network graph to predict the possible collision in the graph.
3. With these matrices, Navigation Agent computes the collision probability for a pair of pedestrian and vehicle, considering the trajectories of the pedestrian and the vehicle along the road segments in the target road network.
4. For each pair with a high collision probability, Navigation Agent delivers the emergency message to the vehicle and the pedestrian. This emergency message must be delivered in a very short time (e.g., 0.1 s).
5. When receiving this notification from Navigation Agent, Navigation Client immediately shows it to the relevant pedestrian and the driver to react to the dangerous situation promptly.
6. If Navigation Client escapes from the dangerous situation, it repeats Steps 1 through 5 for the pedestrian protection with Navigation Agent. In this pedestrian protection, it is important to minimize false negative and false positive. Otherwise, the pedestrian can be in a danger by the misleading guidance.

2.2 Travel Delay and Collision Probability

In this section, we model the travel delay and collision probability of a vehicle and pedestrian on a road segment. We assume that road statistics are available, such as the average travel delay μ and the travel delay standard deviation σ of the vehicle and pedestrian. We also assume that the travel delays of vehicles and pedestrians follow the Gamma distributions such that $P \sim \Gamma(\kappa_p, \theta_p)$ and $V \sim \Gamma(\kappa_v, \theta_v)$ [7–9]. Figure 2 shows the distributions of pedestrian delay P and vehicle delay V. Every node notifies RSU of its current position, and RSU gets the μ and σ value of a road segment from Trafic Control Center (TCC) [10] periodically. To predict the collision on a crosswalk, the travel delay from the current position to a crosswalk is required. Let δ_{ped_i} be the travel delay that the pedestrian i will move from its current position to the entrance of the next crosswalk and δ_{veh_j} be the travel delay that the vehicle j will move from its current position to the border of the next crosswalk. The travel delay δ to the next crosswalk of the node can be calculated with the ratio of its current position (i.e., offset from the entrance of the road segment) x $[m]$ to the length l $[m]$ of the road segment. Because we know the average travel delay μ $[s]$ of the road segment, we can calculate the travel delay δ $[s]$ as follows:

$$\delta = (1 - \frac{x}{l}) \cdot \mu. \tag{1}$$

If a pedestrian and a vehicle are expected to arrive at the same time, the collision probability must be high. Let $T_{collision}$ be the duration that the collision may happen. We can compute the collision probability of the pedestrian i and the vehicle j as $P_{ped_i,veh_j} = P[\delta_{veh_j} - T_{collision} \leq \delta_{ped_i} \leq \delta_{veh_j}]$. Assuming that the pedestrian travel delay distribution and the vehicle travel delay distribution are independent of each other, the collision probability P_{ped_i,veh_j} is computed as follows:

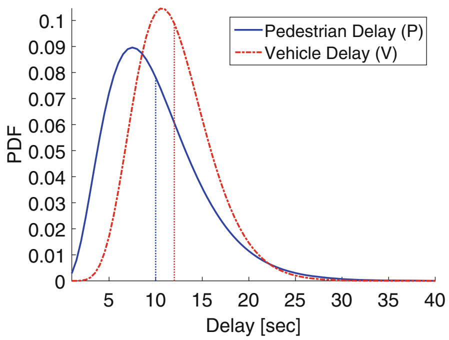


Fig. 2. Distibutions of pedestrian delay and vehicle delay

$$P_{ped_i,veh_j} = P[\delta_{veh_j} - T_{collision} \leq \delta_{ped_i} \leq \delta_{veh_j}] = \int_0^{\infty} \int_{v-T_{collision}}^{v} f(p)g(v)dpdv, \quad (2)$$

where $f(p)$ is the probability density function (PDF) of the pedestrian travel delay, and $g(v)$ is the PDF of the vehicle travel delay. We will consider that the pedestrian and the vehicle will be safe when the collision probability $P_{ped,veh}$ is less than 80 %. So far, we have explained the collision probability based on the road statistics and the trajectory information. In the next section, we will design an energy-efficient scheduling using the collision probability discussed in this section.

2.3 Energy-Efficient Scheduling through Filtering

A key idea for energy-efficient scheduling is to filter out irrelevant vehicles for a specific pedestrian. This filtering lets RSU compute an optimal sleeping schedule of a pedestrian's smartphone for the message exchange via vehicular communications, such as V2I. From Fig. 1, Vehicles 1 and 2 are relevant to Pedestrian in that they can collide with Pedestrian. However, Vehicles 3 and 4 are irrelevant to Pedestrian, so they are filtered out in the computation of the sleeping periods of Pedestrian.

In Fig. 3, since Vehicle 1 is relevant to Pedestrian, the work and sleep schedule of Pedestrian's smartphone is computed considering the encounters with RSU and vehicles. At time t_1, Pedestrian communicates with RSU for the duration δ to get its work and sleep schedule for collision prevention and smartphone energy saving. At time t_2, Pedestrian communicates with Vehicle 1 to exchange the location and direction information to prevent possible collision. Therefore, the work and sleep scheduling for Pedestrian's smartphone can be performed with the trajectories and mobility characteristics (e.g., speed and direction) of the pedestrians and vehicles. Also, for the work and sleep schedule for vehicles, the same procedure can be applied with the algorithm discussed in this section.

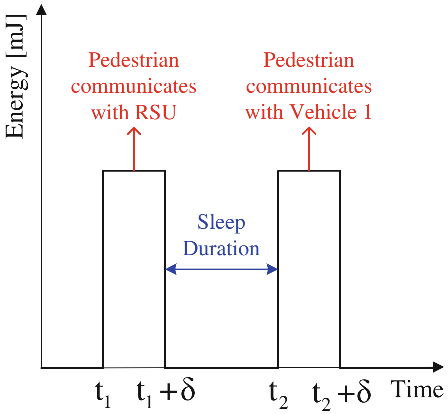


Fig. 3. Communication scheduling

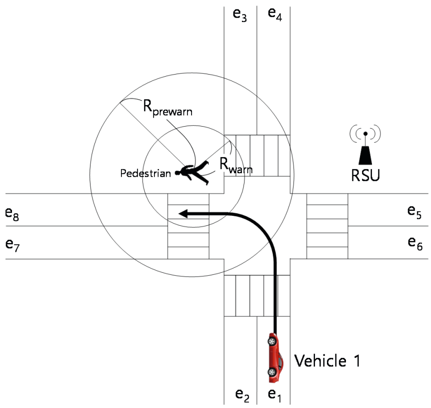


Fig. 4. Pedestrian protection area

2.4 Definition of Pedestrian Protection Area

In SANA, a pedestrian's smartphone will get warning messages from an RSU when it encounters a vehicle soon. These warning messages are generated when the vehicle enters an area including the pedestrian. In this paper, this area for warning message generation is defined as pedestrian protection area. This pedestrian protection area consists of the following two types of areas: (i) Warning area and (ii) Pre-warning area.

Definition 1. (Warning Area). *Let **Warning area** be the area around a pedestrian through which a vehicle can reach the pedestrian in safety time (e.g., 2 s). That is, the safety time is defined as the time taken for the vehicle to be able to hit the pedestrian from the perimeter of the warning area. The safety time depends on the speed of the vehicle and the safety distance for pedestrian protection. Most nations in Europe commonly say 2 s rule as the safety time [11]. SANA also uses 2 s as the safety time. If a vehicle enters the **Warning area**, SANA will give a warning message to both the pedestrian and the vehicle for pedestrian protection.*

Definition 2. (Pre-warning Area). *Let **Pre-warning area** be the area around a pedestrian which a vehicle toward the pedestrian can reach the perimeter of the area for the pedestrian in safety time (e.g., 4 s). A pre-warning message is defined as a message to warn the pedestrian of a possible collision in advance before the generation of a message for the warning area. It must be delivered at the twice of the safety time before the vehicle may hit the pedestrian. That is, the vehicle and pedestrian should be alarmed before 4 s away from the estimated collision time. If SANA has predicted a vehicle to enter the **Pre-warning area**, SANA will schedule the pedestrian's smartphone to exchange the location with the vehicle and give a pre-warning to both the pedestrian and the vehicle. This additional pre-warning can let the pedestrian and the driver recognize the actual warning corresponding to the warning area in a prompt and reliable way [12]. Figure 4 shows the protection areas whose outer circle is Pre-warning area and whose inner circle is warning area.*

Table 1. Average additional energy cost of various DSRC and GPS activities

Variable	Description	Test Value
E_e (J/sec)	Additional energy cost of establishing a connection	10.00
E_i (J/sec)	Additional energy cost of maintaining the IDLE mode	8.83×10^{-1}
E_s (J/sec)	Additional energy cost of maintaining the SLEEP mode	4.20×10^{-2}
E_d (J/byte)	Additional energy cost of downloading data in IDLE mode	7.50×10^{-6}
E_u (J/byte)	Additional energy cost of uploading data in IDLE mode	8.70×10^{-6}
E_g (J/sec)	Additional energy cost of maintaining GPS	1.43×10^{-1}
E_a (J/sec)	Additional energy cost of changing from SLEEP mode to IDLE mode	8.00×10^{-3}

2.5 Collision Prediction Algorithm

In this section, we present the collision prediction algorithm for pedestrians and vehicles. The collision prediction algorithm is based on the travel delay model. The RSU gathers the mobility information from nodes in the road network. Based on the collision probability suggested in Sect. 2.2, the collision prediction algorithm works as follows:

1. RSUs are deployed near crosswalks. The TCC [10] gives each RSU its location information, adjacent road segments, and vehicular traffic statistics (e.g., the average travel delay μ and travel delay deviation σ of its adjacent road segments).
2. A node i (e.g., vehicle or pedestrian) sends its current location to RSU to get the safety information including collision probability at a crosswalk.
3. The travel delay (δ_{ped_i} or δ_{veh_i}) will be calculated by RSU. The method to compute the travel delay is presented in Sect. 2.2. RSU tells the node its travel delay to the next crosswalk.
4. The collision probability will be calculated by RSU. RSU uses two different $T_{collision}$'s that are 2 s for the warning area and are 4 s for the pre-warning area, respectively. The method to compute the collision probability is presented in Sect. 2.2. RSU will calculate all collision probabilities between the node i (i.e., pedestrian) and the other nodes (i.e., vehicles), and then select the maximum collision probability.
5. RSU gives the travel delay and the collision probability to the node i.
6. The node i is regarded as safe, if the collision probability is less than 80 %.
7. The node i is in the pre-warning area, if the probability collision is equal to or greater than 80 % and $2 < \delta_{ped_i} \leq 4$ (or $2 < \delta_{veh_i} \leq 4$).
8. The node i is in the warning area, if the probability collision is equal to or greater than 80 % and $0 \leq \delta_{ped_i} \leq 2$ (or $0 \leq \delta_{veh_i} \leq 2$).

3 Energy Consumption Modeling

In this section, we present the energy cost for the activities of wireless communication and GPS. We refer to these energy cost values from several measured results of other analyses [13,14]. We also present a simple model for total energy consumption in simulation time. For an energy consumption model, our vehicular networks need the energy parameters of DSRC. In the real world, the graph of DSRC wireless energy consumption has complex values. Since this work focuses on energy efficient scheduling, we assume that the set of modes consists of Establishment, IDLE, and SLEEP. Furthermore, the energy consumption value has its average value for each mode. In each mode, the additional energy consumption is required for download, upload, GPS operation, and mode change. We assume that the wireless module of smartphone needs additional energy to transit the current mode to SLEEP or IDLE. We refer to the measured results of power consumption from the reports of the related analyses [13,14]. The average value of each state is presented in Table 1. We have built simple energy models for wireless communication, assuming three modes, Establishment, IDLE, and SLEEP. Additionally, we need to consider the energy for each mode such as, download, upload, GPS operation, and mode change, as shown in Table 2. The total power consumption in the simulation time is the sum of power consumptions to maintain modes and additional processing as follows:

$$P_{total} = P_e + P_i + P_s + P_d + P_u + P_g + P_a. \tag{3}$$

The energy consumption is one of performance metrics to evaluate the scheduling method. SANA is compared with two baselines, such as always-awake and duty-cycle. In the next section, we will present the method to measure the safety performance of the scheduling in vehicular networks.

Table 2. Parameter values for energy consumption of mobile node

Variable	Description
T_e (sec)	Time of establishing a connection
T_i (sec)	Time of maintaining IDLE mode
T_s (sec)	Time of maintaining mode
N_d (byte)	Data size of downloading data
N_u (byte)	Data size of uploading data
T_g (sec)	Time of maintaining GPS
T_a (sec)	Time of changing SLEEP mode to IDLE mode
P_e ($= E_e \cdot T_e$) (J)	Total energy consumption for establishing a connection
P_i ($= E_i \cdot T_i$) (J)	Total energy consumption for maintaining the IDLE mode
P_s ($= E_s \cdot T_s$) (J)	Total energy consumption for maintaining the SLEEP mode
P_d ($= E_d \cdot N_d$) (J)	Total energy consumption for downloading data in IDLE mode
P_u ($= E_u \cdot N_u$) (J)	Total energy consumption for uploading data in IDLE mode
P_g ($= E_g \cdot T_g$) (J)	Total energy consumption for maintaining GPS
P_a ($= E_a \cdot E_a$) (J)	Total energy consumption for changing to IDLE mode in SLEEP mode
P_{total} (J)	Total energy consumption of simulation time

4 Safety Performance Modeling

The safety performance is a key indicator to evaluate the scheduling method in our vehicular networks. To avoid the collision between a pedestrian and vehicle, RSU gives the pre-warning and warning to both the pedestrian and vehicle. We can guarantee the safety when the alarm message is delivered to smartphones in time. Thus, we use the delay of alarm message as a safety performance metric. In the ideal case, a mobile node i receives a pre-warning at $T_{prewarn_i}$ and a warning at T_{warn_i}, if there is no delay of alarm. In the real world, the pre-warning and warning are received with delay. The delayed pre-warning is received at $t_{prewarn_i}$ and the delayed warning is received at t_{warn_i}. The delay time of pre-warning $\delta_{prewarn_i}$ and the delay time of warning δ_{warn_i} calculated, respectively, as follows:

$$\begin{aligned} \delta_{prewarn_i} &= t_{prewarn_i} - T_{prewarn_i}, \\ \delta_{warn_i} &= t_{warn_i} - T_{warn_i}. \end{aligned} \tag{4}$$

The total alarm delay of a node is δ_{alarm_i}. The total delay of all nodes is δ_{total} in the simulation time. If the number of nodes is n, δ_{alarm_i} and δ_{total} can be calculated as follows:

$$\begin{aligned} \delta_{alarm_i} &= \delta_{prewarn_i} + \delta_{warn_i}, \\ \delta_{total} &= \sum_{i=1}^{n} \delta_{alarm_i}. \end{aligned} \tag{5}$$

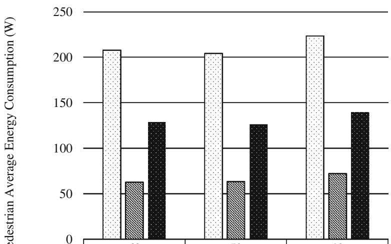
We will use the total delay of all nodes δ_{total} as a safety performance metric in Sect. 5.3.

5 Performance Evaluation

In this section, we evaluate the performance of SANA in terms of the energy consumption and the average alarm delay. We compare SANA with two baselines, such as Always-On and Duty-Cycle. Always-On is a scheduling scheme where a mobile node sends an RSU its location information every 0.1 s. Always-On can achieve the best safety performance, but it consumes the battery most quickly. Duty-Cycle is a scheduling scheme to allow a mobile node to work according to a fixed period. The refresh period of Duty-Cycle in our simulation is 0.3 s which means that a mobile node wakes up every 0.3 s and sleeps after finishing its work. However, if either a warning or pre-warning message is delivered from RSU, the mobile node does not sleep until it gets a safety message from RSU. Our simulation map has 200 m-by-200 m area. We evaluate the impact of vehicle speed on the performance as we set the maximum vehicle speed limit to 40, 50 and 60 km/h. The maximum pedestrian speed is 2 km/h. Four crosswalks exist on an intersection. We assume that the pedestrian and vehicle start to move at different road segments. Our simulation increases the vehicle inter-arrival time from 10 s to 60 s by 5 s. The pedestrian inter-arrival time is 10 s constantly. The simulation time is 1,000 s. We assume that the communication range of RSU can cover whole area of the target road network.

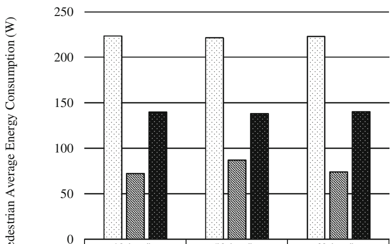
5.1 Simulation Design

In this section, we present how the simulation is implemented for SANA. The simulation of SANA is implemented in Veins [15] which is an open source framework for Inter-Vehicular Communication (IVC) simulation in a data network simulator called OMNeT++ [16], cooperating with a road network simulator called SUMO [17] via Traffic Control Interface (TraCI). This allows for the bi-directionally coupled simulation of road traffic and network traffic. The movement of vehicles in SUMO is reflected in the movement of nodes in OMNeT++ via Veins.



	60	50	40
Always-On	207.77	204.13	223.33
Duty-Cycle	62.56	63.24	72.08
SANA	128.62	125.93	139.63

Fig. 5. Pedestrian average energy consumption per vehicle inter-arrival time

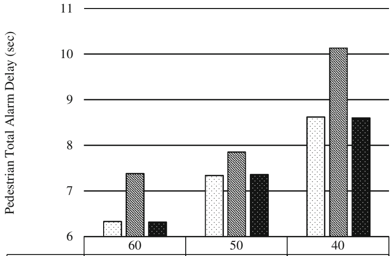


	40 km/hr	50 km/hr	60 km/hr
Always-On	223.33	221.29	222.68
Duty-Cycle	72.08	86.95	73.98
SANA	139.63	138.05	140.06

Fig. 6. Pedestrian average energy consumption per vehicle maximum speed

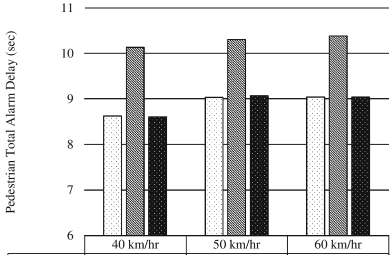
5.2 The Impact of Energy Consumption

In this section, we investigate the impact of vehicle inter-arrival time and vehicle maximum speed on energy consumption. Figures 5 and 6 show the energy consumption of three scheduling schemes according to vehicle inter-arrival time and vehicle maximum speed, respectively. Always-On consumes battery most quickly. In Fig. 5, the longer inter-arrival time vehicles have, the less energy the pedestrian node consumes. This is because the longer inter-arrival time means less traffic, so the number of vehicles which should communicate with a pedestrian decreases. For example, as shown in Fig. 5, for the vehicle inter-arrival time of 40 s, Always-On consumes 223.33 W, Duty-Cycle consumes 72.08 W, and SANA consumes 139.63 W. SANA reduces only 63 % of the energy consumption to the Always-On. In Fig. 6, we can see that the energy consumptions of both Always-On and SANA are not affected by vehicle maximum speed, but that of Duty-Cycle is a little affected. Thus, Duty-Cycle is the most energy-efficient scheme from the simulation result.



	60	50	40
Always-On	6.33	7.34	8.62
Duty-Cycle	7.38	7.85	10.13
SANA	6.32	7.36	8.60

Fig. 7. Pedestrian total alarm duration per vehicle inter-arrival time



	40 km/hr	50 km/hr	60 km/hr
Always-On	8.62	9.03	9.04
Duty-Cycle	10.13	10.30	10.38
SANA	8.60	9.07	9.04

Fig. 8. Pedestrian total alarm duration per vehicle maximum speed

5.3 The Impact of Alarm Delay

In this section, we investigate the impact of vehicle inter-arrival time and vehicle speed on alarm delay. Figures 7 and 8 show how the alarm delay of pedestrian is related to each scheduling scheme. Always-On is the safest scheme from the simulation result in terms of alarm delay. For example, as shown in Fig. 7, for the vehicle inter-arrival time of 40 s, Always-On has 8.62 s delay, Duty-Cycle has 10.13 s delay, and SANA has 8.60 s delay. SANA reduces 15 % of the alarm delay of Duty-Cycle. Duty-Cycle is the most dangerous scheme from the simulation result, even though it is most evergy-efficient. Therefore, from the simulation results, it can be concluded that SANA can provide a promising pedestrian protection service in the optimization of both energy consumption and alarm delay.

6 Conclusion

In this paper, we proposed our design of Safety-Aware Navigation Appplication (called SANA) for road safety. For road safety, DSRC will be common communication technology in vehicular networks. In this paper, we investigate a pedestrian protection application running in smartphones with DSRC or 4G-LTE device. To design our SANA service framework, we first described our delay modeling for a mobile node's travel delay. We then explained our energy-aware SANA service for pedestrian protection. SANA makes RSU gather the mobility information of nearby mobile nodes. RSU can predict the collision among nearby mobile nodes. With the prediction, RSU can schedule the working time of mobile nodes to reduce energy consumption. The scheduling is performed to minimize the alarm delay for the pedestrian safety. As future work, we will enhance our collision prediction algorithm in order to reduce false positive and false negative alarms for a more reliable alarming service.

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