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

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***Abstract*—This paper proposes a Safety-Aware Navigation App for pedestrian protection app in vehicular networks. This application gives a collision warning to both vehicles and pedestrians. This application realizes a mobile computing service for the road safety where vehicles themselves or mobile devices (e.g., smartphones and tablets of drivers or passengers in vehicles) play a role of both cloud server and cloud client. This paper describes how the application controls the sleeping schedule for saving smartphone battery energy in vehicular networks.**

I. INTRODUCTION

Recently, mobile cloud computing has been introduced [1], regarding mobile devices (i.e., smartphones and tablets) as both cloud clients and cloud servers. These mobile devices perform sensing around the environments as mobile sensors and play a role of intermediate servers as computing nodes or storage nodes. This new paradigm for cloud computing will be expected to generate many useful services in many network areas, such as cellular networks, social networks, mobile ad hoc networks, vehicular networks, personal & body networks, and mission critical networks. This paper focuses on the mobile cloud computing in vehicular networks for smart road services. The target applications are driving safety, navigation efficiency, and location-based services in road networks.

In this paper, we propose a Safy-Aware Navigation App (called SANA) for the pedestrian protection in road networks. Our SANA uses vehicular cloud computing as a branch of mobile cloud computing [1]. SANA can prevent the pedestrians from colliding with vehicles when people cross the 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. 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 SANA Collision Prediction Procedure and Energy-Efficiency Scheduling through Filtering for Collision Prediction. Note that this paper focuses on the road safety service for pedestrian protection in our early work [3].

The remaining of the paper is constructed as follows. Section II summarizes related work. Section III describes the problem formulation for SANA. Section IV explains the delay modeling for vehicle and pedestrian. Section V describes our SANA for road safety, such pedestrian protection. Section VI discusses further research issues for SANA. Finally, Section VII concludes the paper along with future work.

II. RELATED WORK

Nowadays, cloud computing has been realized and popularly used for a variety of Internet services in both industry and academia. Cloud computing makes companies process their batch-oriented tasks through servers interconnected via networks in the scalable and elastic way [4]. As one of leading solution companies for cloud computing systems, VMware allows companies to run their own private cloud systems through the product of vCloud Suite [5]. Amazon runs Amazon Web Services (AWS) cloud service [6]. AWS provides cloud infrastructure for small businesses or persons according to the load of tasks with the corresponding charge for temporary lease of computing and storage resources. Google and Apple also support various mobile services for mobile devices via their own cloud [7], [8].

The advent of mobile cloud computing is due to the popularity of mobile devices (e.g., smartphone). Now mobile devices can run not only cloud client Apps, but also cloud servers or proxies as mobile cloud [1]. The boundary of cloud clients and servers has broken down. By being aware of user patterns and environment contexts, mobile devices can change their role dynamically to maximize the satisfaction of mobile users. Mobile devices can offload the task load of the cloud systems for other mobile devices as an intermediate cloud. This new paradigm will open new fascinating services in various networks, such as home networks, personal & body networks, social networks, cellular networks, mobile ad hoc networks, vehicular networks, and mission critical networks. In this paper, we focus on the mobile cloud computing for the road safety in vehicular networks.

Recently, vehicular networks have been intensively researched in various aspects, such as data forwarding schemes and Media Access Control (MAC) protocols. Data forwarding schemes are categorized into Vehicle-to-Infrastructure (V2I) data forwarding and Infrastructure-to-Vehicle (I2V) data forwarding. For the V2I data delivery, vehicular traffic statistics (e.g., vehicle inter-arrival time and average vehicle speed) are used in VADD [9]. In addition to the vehicular traffic statistics, vehicle trajectory (i.e., navigation path) is effectively in TBD [10] to improve forwarding performance in a privacy-preserving manner. For the I2V data delivery, the vehicle trajectory of a destination vehicle is used in TSF [11] along with the vehicular traffic density. This multihop I2V data delivery has more challenge than the multihop V2I data delivery because the destination vehicle keeps moving over time, so a target point should be selected appropriately as a rendezvous point for the packet and destination vehicle. This target point selection is performed through the estimation of the destination vehicle's travel delay and the packet delivery delay. For the efficient data sharing among a multicast group of vehicles, TMA [12] is developed to extend the idea of TSF [11] considering the multiple target points for the multicast group vehicles. For the MAC protocols in vehicular networks, LMA [13] is a vehicle-to-vehicle (V2V) MAC protocol for the driving safety, using directional antenna and vehicle trajectory for the efficient wireless channel coverage. WPCF [14] is an efficient V2I and I2V MAC protocol using Point-Coordination Function (PCF) for wireless channel access, which proposes WAVE PCF where WAVE stands for Wireless Access in Vehicular Environments.

In this paper, with the emergence of mobile cloud computing and vehicular networks, we will design the architecture of vehicular networks for SANA. For the vehicular networks, we will propose an organization of network systems consisting of TCC, RSUs, and RNs and the V2I/I2V/V2V data forwarding schemes. For the smart road services, we will suggest a feasible design of road safety services, such as pedestrian protection service through the interaction between mobile devices and the vehicular cloud.

III. Problem Formulation

In this section, we describe our vehicular network architecture and then list up assumptions for SANA and other smart road services [3].

A. Vehicular Network Architecture

Vehicular networks consist of the following system components:

- Traffic Control Center (TCC) [15] is a management node for vehicular cloud systems. As a trusted entity, TCC maintains the trajectories of vehicles for the location management for the data delivery toward the vehicles. These vehicle trajectories are not exposed to other vehicles for privacy concerns. In I2V data delivery, TCC determines which RSU will be the packet source node to deliver the packets to the moving destination vehicle(s) as shown in Fig. 1. It is assumed that TCC and RSUs are interconnected with each other through a wired network.
- Road-Side Unit (RSU) [16] is a wireless node interconnecting vehicular ad hoc networks and a wired network. RSU has Dedicated Short Range Communications (DSRC) [17], storage, and processing capability to forward packets from TCC to packet destination vehicles, as shown in Fig. 1. For the cost effectiveness, RSUs are *sparsely deployed* into the road network and are interconnected with each other through the wired network or wirelessly (as Mesh Network) [18]. Each RSU installation with power and wired network connectivity can cost as high as US$5,000 [19].

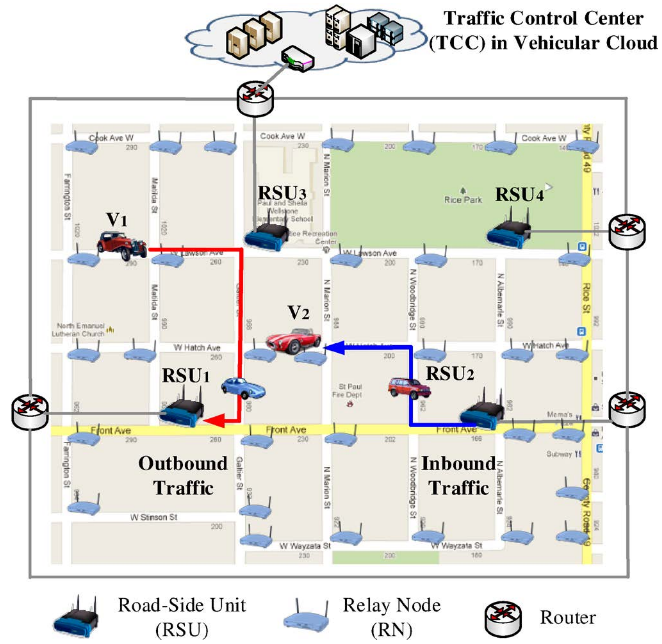


Fig. 1. Vehicular Network Architecture for SANA Service

- Relay Node (RN) [11] is a wireless stand-alone node as a temporary packet holder for the store-and-forward of packets toward an intended direction in the road network. RN has the capability of DSRC communications, storage, and processing capability, but does not have the wired network connectivity for the cost saving, as shown in Fig. 1. This means that RNs do not have the direct, wired connectivity to either RSUs or TCC to save deployment cost. Also, it is assumed that RNs are not wirelessly connected to each other. However, in the case where RNs are wirelessly connected, we can regard the road segments among them as wirelessly covered by a Mesh Network consisting of those RNs. With a small number of RSUs, RNs are used to perform the reliable data delivery from RSU to the other RNs corresponding to the target points (i.e., packet destinations) by using intermediate vehicles as packet carriers, moving on road networks, as proved in our early work TSF [11]. One RN is assumed to be deployed at each intersection for the reliable forwarding, but we can handle the case where some intersections do not have their own RNs [11] by TSF.
- Vehicles have mobile devices (such as smartphones and tablets) or their dedicated on-board computers. As mobile sensors, vehicles can measure travel delay for each road segment along their travel path. For VANET, vehicles have DSRC device [17] along with other wireless communications devices, such as WiFi, WiMAX, 3G, and 4G-LTE [20]. A smart vehicle has various devices for smart road services, such as mobile devices (e.g., smartphone and tablet), internal and external cameras, wireless communications devices (e.g., DSRC, 4G-LTE, 3G, WiFi, and WiMAX), accelerometer, gyroscope, and vehicle computer. It is announced that major vehicle vendors (such as GM

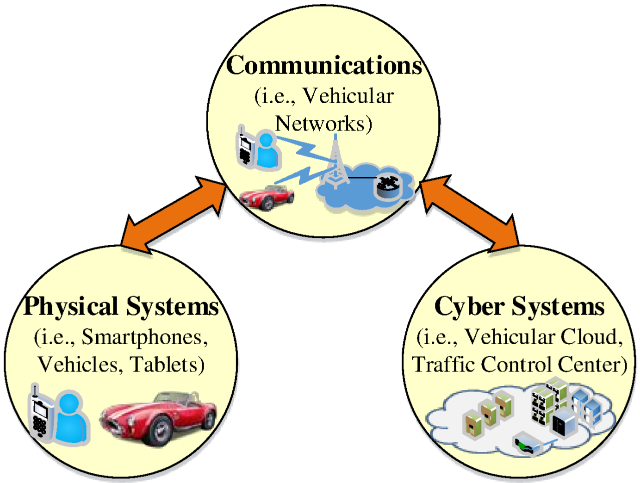


Fig. 2. Vehicular Cyber-Physical Systems

and Toyota) are planning to release vehicles with DSRC devices [21]. These DSRC vehicles play a role of packet forwarders and packet carriers until they can forward packets to a relay node or packet destination vehicle.

B. The Concept of Vehicular Cyber-Physical Systems

In this subsection, we formally define Cyber-Physical Systems (CPS) and Vehicular Cyber-Physical Systems (VCPS) and specify the target applications in VCPS.

Definition III.1 (CPS: Cyber-Physical Systems)**.** *Let **CPS** be the systems that are integrated by Physical Systems (following physical laws in continuous time domain) and Cyber Systems (following discrete mathematics in discrete time domain) via Communications.*

Definition III.2 (VCPS: Vehicular Cyber-Physical Systems)**.** *Let **VCPS** be the systems that are integrated by Physical Systems in Road Networks and Cyber Systems in Vehicular Cloud via Wireless and Wired Communications, as a subset of CPS.*

As shown in Fig. 2, VCPS consists of Physical Systems (e.g., Vehicles, Smartphones, and Tablets), Cyber Systems (e.g., Traffic Control Center), and Communications (e.g., Vehicular Networks).

The VCPS takes advantages of the characteristics of road networks to design vehicular networks and services [10]–[12], such as (i) Predictable vehicle mobility, (ii) Road network layout, (iii) Vehicular traffic statistics, and (iv) Vehicle Trajectory. First, for Predictable vehicle mobility, vehicle moves along roadways with bounded speed. Second, for Road network layout, road network layout can be represented as a road map that can be reduced to a road network graph. Third, for Vehicular traffic statistics, vehicle inter-arrival time and average vehicle speed can be measured per road segment and average waiting time for traffic signal can be measured per intersection. Last, for Vehicle trajectory, vehicles follow the routes provided by GPS-based navigation systems for efficient driving. These characteristics are very important assets to design the vehicular networks (e.g., data forwarding schemes and media-access control protocols) and the vehicular services (e.g., interactive navigation and pedestrian protection). In next sections, considering these characteristics, we will show the delay modeling for mobile nodes (i.e., vehicle and pedestrian) and also a VCPS application called SANA.

IV. Travel Delay Modeling

In this section, we model the travel delay of vehicle and pedestrian on a road segment and an End-to-End (E2E) travel path, such as vehicle trajectory and pedestrian trajectory. Note that this delay modeling originates from our early work TSF [11].

A. Travel Delay on Road Segment

Let $G = (V, E)$ be a road network graph where V is a set of intersections and E is a set of directed road segments. It is proved that the travel delay of one vehicle over a fixed distance in light-traffic vehicular networks follows the Gamma distribution [11] [22]. Thus, the travel delay through a road segment i in the road network is defined as *link travel delay* d_i such that $d_i \sim \Gamma(\kappa_i, \theta_i)$ where κ_i is a shape parameter and θ_i is a scale parameter [23].

To calculate the parameters κ_i and θ_i, the mean μ_i and the variance σ_i^2 can be used for the link travel delay d_i on the given road segment $e_i \in E$ [23]. The traffic statistics of μ_i and σ_i^2 are available from commercial navigation service providers (e.g., Garmin [24]). Let the mean of d_i be $E[d_i] = \mu_i$ and the variance of d_i be $Var[d_i] = \sigma_i^2$. Thus, the formulas for κ_i and θ_i are as follows [23]:

$$\theta_i = \frac{Var[d_i]}{E[d_i]} = \frac{\sigma_i^2}{\mu_i} \quad (1)$$

$$\kappa_i = \frac{E[d_i]}{\theta_i} = \frac{\mu_i^2}{\sigma_i^2} \quad (2)$$

In addition to the above mathematical model for link delay distribution on a road segment, our delay modeling can accommodate empirical measurements for the distribution of link delay. These empirical measurements can be performed by the periodical reports of mobile devices of vehicles or pedestrians (passing through a road segment or walking in a street) to the RSU taking charge of the road segment. Thus, a more accurate link travel delay distribution allows for a more accurate E2E travel delay distribution in the following subsection.

B. Travel Delay on End-to-End Path

The End-to-End (E2E) travel delay in a road network can be modeled with the link delay model in Section IV-A [11]. As the link travel delay is modeled as the Gamma distribution of $d_i \sim \Gamma(\kappa_i, \theta_i)$ for road segment i, the E2E travel delay can be modeled with a sum of Gamma distributions of the link delays. Assume that as shown in Figs. 3(a) and 3(b), for two contiguous edges (e.g., e_1 and e_2) in a given E2E travel path, the *intersection waiting delay* from the first edge (e.g., e_1) to the second edge (e.g., e_2) is included in the first link travel delay (e.g., d_1).

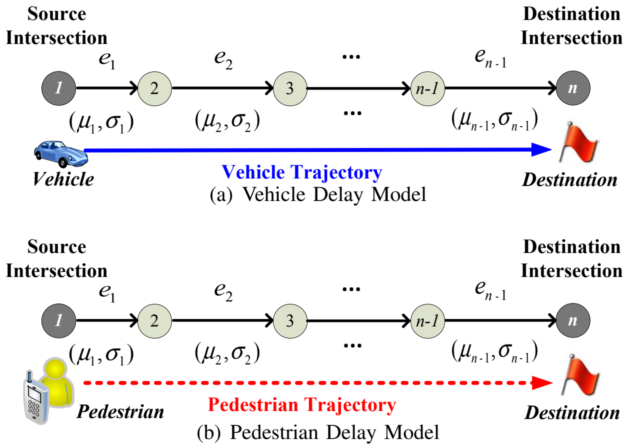


Fig. 3. Travel Delay Models for Vehicle and Pedestrian

Given an E2E travel path, it is assumed that the link travel delays of different road segments for the path are independent. With this assumption, the mean (or variance) of the E2E travel delay is approximately calculated as the sum of the means (or variances) of the link travel delays for the links along the E2E path. Assuming that the travel path consists of $n-1$ road segments, the mean and variance of the E2E travel delay D are computed as follows:

$$E[D] = \sum_{i=1}^{n-1} E[d_i] = \sum_{i=1}^{n-1} \mu_i \tag{3}$$

$$Var[D] = \sum_{i=1}^{n-1} Var[d_i] = \sum_{i=1}^{n-1} \sigma_i^2 \tag{4}$$

With (3) and (4), the E2E travel delay D is approximately modeled as a Gamma distribution as follows: $D \sim \Gamma(\kappa_D, \theta_D)$ where κ_D and θ_D are calculated using $E[D]$ and $Var[D]$ using the formulas of (1) and (2). Note that if a more accurate distribution for the E2E path is available from the measurements or another mathematical model, our travel delay model can use this distribution for the E2E travel delay estimation.

So far, we have explained our delay model for a mobile node's travel delay. In next section, we will design one smart road service called SANA using the delay models discussed in this section.

V. The Design of Safety-Aware Navigation App

In this section, we explain the design of Safety-Aware Navigation App (SANA) for pedestrian protection. The pedestrian protection is very important to reduce the fatality around school zones and downtown streets. Nowadays most of people are carrying a smartphone as either pedestrian or driver every day. This pedestrian protection can be performed through the communication between the smartphones of a pedestrian and a vehicle's driver when the vehicle approaches the pedestrian. If two smartphones share their trajectories and motion vectors, it is feasible to tell the possibility that the pedestrian and the vehicle will collide by some mistake caused by either the

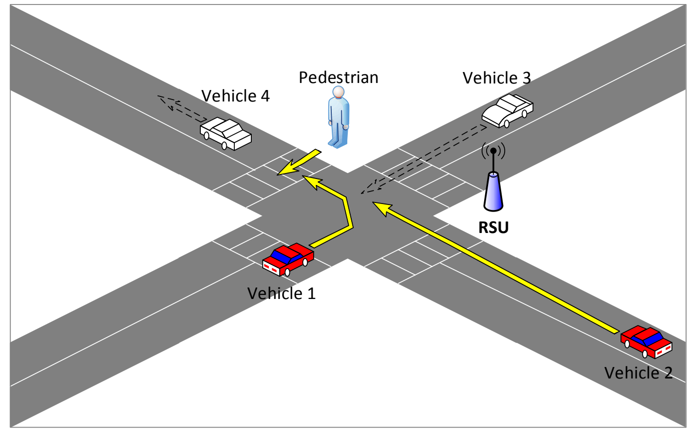


Fig. 4. Collision Prediction through Vehicle Filtering

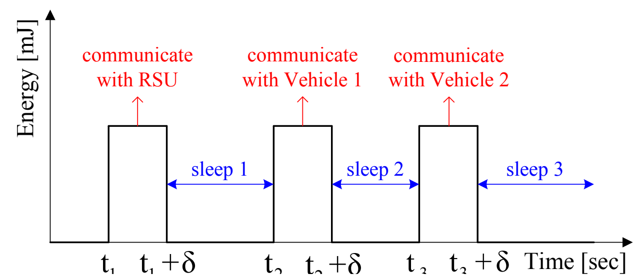


Fig. 5. The Communication Device Scheduling of Pedestrian's Mobile Device

pedestrian or the driver. When the vehicle is going to hit the pedestrian just in a couple of seconds, the smartphone of the driver will be able to notify that of the pedestrian in the form of either voice or vibration.

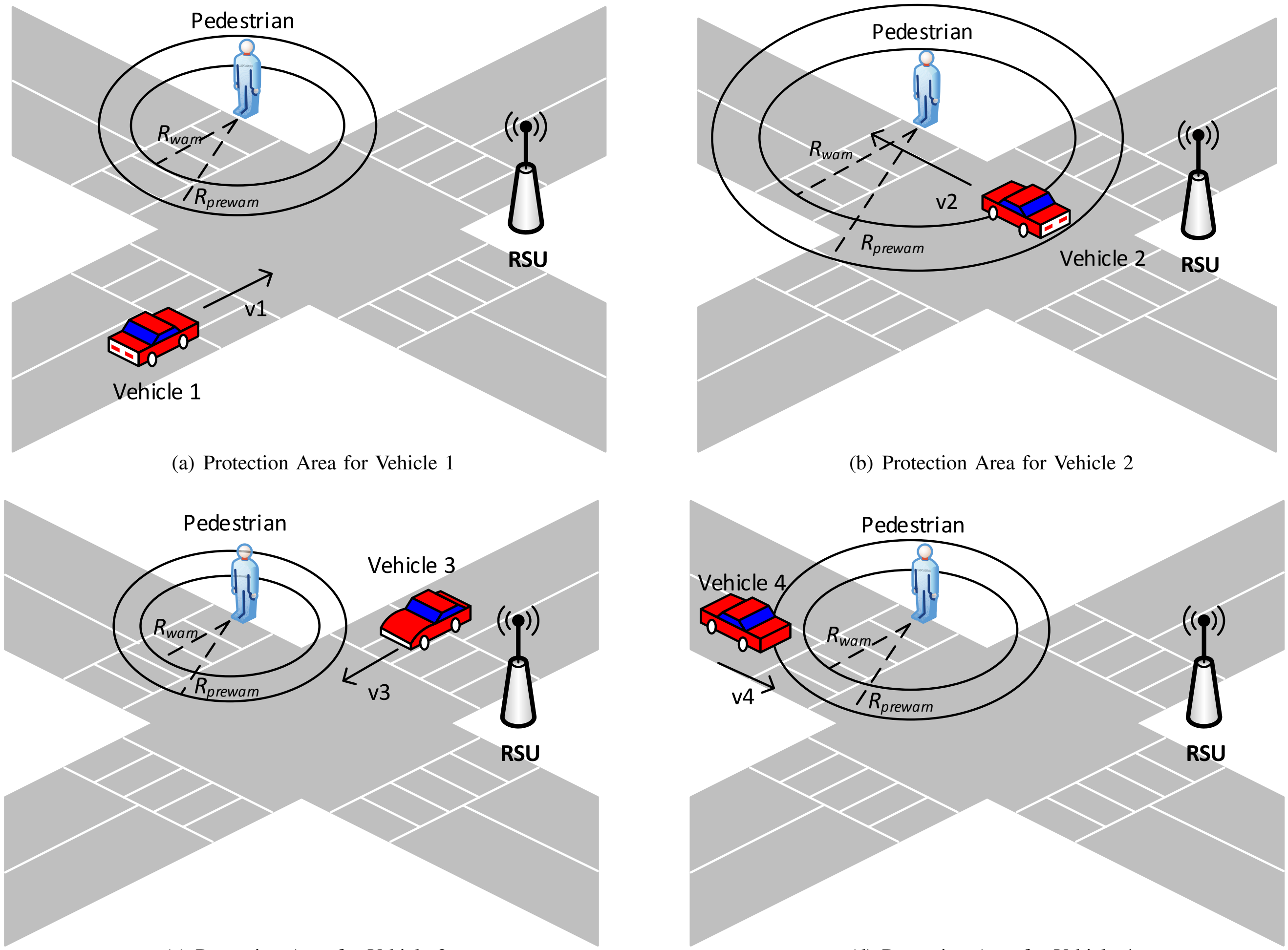
Fig. 4 shows the pedestrian protection by the collision prediction of a vehicle and a pedestrian with the vehicle and pedestrian trajectories. This collision prediction can be performed by the delay modeling of the vehicle travel and the pedestrian travel, as discussed in Section IV.

A. SANA Collision Prediction Procedure

For the collision prediction between a pedestrian and a vehicle, we articulate the interaction between the pedestrian's smartphone and the vehicle's smartphone through the vehicular cloud. It is assumed that one Navigation Client is running on the pedestrian's smartphone and the vehicle's smartphone, respectively and that Navigation Server is running on the vehicular cloud as a cloud server. Also, Navigation Agent is running on an RSU nearby the pedestrian for the safety in order to reduce the interaction delay between Navigation Client and Navigation Server as a middle cloud [1]. The communications between Navigation Client and Navigation Agent can be performed by the cellular link through 4G-LTE/3G or vehicular data delivery scheme (e.g., TSF [11]) based on DSRC [17].

The procedure for pedestrian protection is as follows:

1) As Navigation Client, a vehicle or pedestrian with navigator periodically reports its location, direction, and speed to Navigation Server in TCC via adjacent



(a) Protection Area for Vehicle 1

(b) Protection Area for Vehicle 2

(c) Protection Area for Vehicle 3

(d) Protection Area for Vehicle 4

Fig. 6. Pedestrian Protection Area consisting of Warning Area and Pre-warning Area

RSUs during its travel from its source to its destination.

2) Navigation Server 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 Server computes the collision probability for a pair of pedestrian and vehicle, considering the pedestrian trajectory and the vehicle trajectory along the road segments in the target road network.
4) For each pair with a high collision probability for accident avoidance, Navigation Server delivers the emergency message to the vehicle and the pedestrian in the pair in the form of voice or vibration. This emergency message delivery must be performed within a short threshold (e.g., 0.1 second).
5) When receiving this notification from Navigation Server, Navigation Client immediately reacts to it by generating a special voice message or sound along with a special vibration to let the relevant pedestrian and the driver react to the dangerous situation promptly.
6) If Navigation Client goes out of the dangerous situation, it repeats Steps 1 through 5 for the pedestrian protection with Navigation Server.

In this pedestrian protection, it is important to minimize false negative and false positive for the collision between a vehicle and a pedestrian. Otherwise, the walking and driving will have a lot of inconvenience by the misleading guidance.

B. Energy-Efficient Scheduling through Filtering for Collision Prediction

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. 4, 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. 5, since Vehicles 1 and 2 are relevant to Pedestrian, the work and sleep schedule of Pedestrian's mobile device is computed considering the encounters with RSU and vehicles. At time t_1, Pedestrian communicates with RSU for the duration δ to get work and sleep schedule for collision prevention and smart phone energy saving. At time t_2 and t_3, Pedestrian communicates with Vehicle 1 and Vehicle 2 to exchange the location and direction information to prevent possible collision, respectively. Therefore the work and sleep scheduling for Pedestrian's mobile device 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 appled using the algorithm discussed in this section.

C. 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 V.1 (Warning Area)**.** *Let **Warning area** be the area around a pedestrian through which a vehicle can reach the pedestrian in at most time Δt. That is, Δt is the time taken by the vehicle to hit the pedestrian from the perimeter of the warning area. Δt depends on the speed of a vehicle and the safety distance for pedestrian protection. If a vehicle enters the **warning area**, SANA will give a warning message to both pedestrian and the vehicle for pedestrian protection.*

Definition V.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 warning area for the pedestrian in at most time α. A pre-warning message is a message to warn beforehand the generation of a message for the warning area. It must be delivered at time $\alpha + \Delta t$ before the vehicle hits the pedestrian where Δt is the time taken for the vehicle to hit the pedestrian from the perimeter of the warning area and α is the user-defined pre-warning interval corresponding to the gap between the pre-warning area and the warning area. If SANA has predicted a vehicle to enter the **pre-warning area**, SANA will wake the pedestrian's mobile device to exchange the location with the vehicle and give a pre-warning to both pedestrian and the vehicle before giving them a warning for pedestiran. This pre-warning can let the pedestian and the driver recognize the actual warning corresponding to the warning area in a prompt and reliable way [25].*

Fig. 6 shows the protection areas whose outer circle is pre-warning area and whose inner circle is warning area. In Fig. 6(a), the pre-warning area's radius (denoted as $R_{prewarn}$) corresponds to time $\alpha_1 + \Delta t_1$ such that $R_{prewarn} = (\alpha_1 + \Delta t_1) \cdot v$ for vehicle speed v. The warning area's radius (denoted as R_{warn}) corresponds to time Δt_1 such that $R_{warn} = \Delta t_1 \cdot v$. The radii of these areas depend on the vehicle's speed and the safety distance for pedestrian protection. SANA will compute these areas according to the position and direction of each vehicle, and determine whether the vehicle is located within the areas of the pedestrian. In Fig. 6, four cases of the vehicles are described to show how SANA will operate according to the vehicle's speed and location. In the case of Vehicle 1, the vehicle is not within neither warning area nor pre-warning area, so SANA will make the pedestrian's mobile device sleep. In the case of Vehicle 2, the vehicle is within the warning area, so SANA will give a warning to both the pedestrian and Vehicle 2. In the case of Vehicle 3, the vehicle is not within the pre-warning area, but it will pass through the pre-warning Area soon, so SANA will wake up the pedestrian's mobile device, and then prepare for a pre-warning for both pedestrian and Vehicle 3. In the case of Vehicle 4, the vehicle is within the pre-warning area, SANA will wake up pedestrian's mobile device and give a pre-warning to both pedestrian and Vehicle 4.

VI. Research Issues

In this section, we discuss further research issues for VCPS and how to evaluate performance. We have the following research issues for VCPS including SANA:

- To realize the VCPS, we need to consider system-level design of vehicular cloud systems. For example, for the interactive navigation service, we decompose the tasks and roles of Navigation Client and Navigation Server.
- In VCPS, mobile devices promptly need to select wireless link among the available wireless links, such as DSRC, 3G, 4G-LTE, and WiFi. A switching mechanism among the multi-links is required as a vertical handover. Also, a horizontal handover for the same wireless links should be supported in a seamless way.
- For the interactive navigation service, we need to measure vehicular traffic statistics with mobile devices. Thus, we need to design the measurement functions for vehicle's average speed and speed deviation per road segment using the mobile devices.
- For the pedestrian protection, we need to track the mobility of the mobile nodes (i.e., vehicle and pedestrian). To track the pedestrian, we can implement the motion prediction using the accelerometer and gyroscope in smartphones. Since the accurate motion prediction is important to prevent collision between the vehicle and the pedestrian, the algorithm of the mobile node tracking should be well-designed and implemented in a solid way.
- Autonomous dynamic system reconfiguration for VCPS is required to *self-adapt the VCPS* according to the changes of task loads and the available resources in cloud clients and cloud servers, such as the computing power and storage capacity in the cloud servers and the battery consumption rate or battery budget in mobile devices. For these scalable and elastic cloud services, the VCPS should be *self-adaptive systems* under highly dynamic environments in the real world.
- Networking and connectivity mechanisms should be self-adaptive for the effective battery consumption for mobile devices. Since the mobile devices (e.g., smartphones) have high energy drain rate for interactive cloud services (e.g., pedestrian protection) due to the frequent communications with the vehicular cloud infrastructure nodes, such as RSUs and RNs. For these interactive cloud services, service processes can be

decomposed into multiple parts that are collaboratively performed in mobile devices, RNs, RSUs, and TCC in order to minimize the energy consumption in the mobile devices.

- The tasks in VCPS are time-critical, so the performance of VCPS should be evaluated in realistic settings. For the performance evaluation of SANA, we will build our models in a vehicle/pedestrian mobility simulator called SUMO [26] and a network simulator called OMNeT++ [27].

VII. Conclusion

In this paper, we proposed our design of Safy-Aware Navigation App (called SANA) using vehicular cloud for the road safety. For the communications among mobile devices in road networks, vehicular networks need to support multiple wireless communications, such as DSRC, 3G/4G-LTE, WiFi, and WiMAX. With these multiple wireless links, the vehicular networks consist of Traffic Control Center (TCC), Road-Side Units (RSUs), Relay Nodes (RNs), and Mobile Devices (e.g., vehicles, smartphones, and tablets). 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. As future work, we will investigate the system-level design of vehicular cloud computing for our SANA service. That is, we will design and implement cloud server, cloud client, and smartphone App in vehicular cloud systems for our SANA service.

VIII. Acknowledgment

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