Towards Vehicle-Assisted Adaptive Wireless GeoMesh Network for Smarter Cities

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***Abstract*—Recent development in low-power wireless networks enables us to deploy IoT (Internet of Things) devices in an entire city with low maintenance and management cost. However, since such IoT devices cannot have fine-grained location sensors, such as GPS, types of applications with the IoT devices must be limited. This paper proposes a method of fine-grained location estimation for IoT devices in low-power wireless networks, specifically Wi-SUN (Wireless Smart Utility Network). We leverage public vehicles, which go around over an entire city almost everyday with mounting a GPS sensor and Wi-SUN link. The vehicular devices are used to collect GPS data for learning the relationships between the radio strength measured at Wi-SUN stations and the locations of IoT devices. With the learned data, we expect to estimate the fine-grained location of a Wi-SUN device.**

***Keywords*–Wi-SUN; Localization; Vehicular Network.**

I. Introduction

The increasing concentration of the world's population in urban areas places the cities in a spotlight. Indeed, on 2% of the earth's surface, cities actually use 75% of the world resources [1]. These aspects inevitably make the cities important actors for the world's sustainable development strategy. Especially in developed countries including Japan, problems on people (e.g., continuousely increasing aging population and weakened links of communities) and problems on city infrastructure (e.g., worn roads, bridges and buildings) in urban areas are considered as one of the biggest social problems. Moreover, cities must have tenacious and dependable functionalities against big disasters, such as earthquakes or typhoons. To solve these problems, ICT (Information and Communication Technologies) have to be more integrated and leveraged to support urban life for citizens, municipalities and businesses. Especially, IoT technology and networks to support IoT are promising ways to enhancing both awareness of cities' contexts and responsiveness of activities.

Recent development in wireless ad-hoc network technologies offers several practical protocols, such as WiFi, Bluetooth, Zigbee, Wi-SUN [2], LoRa [3] and SIGFOX. Compared to networks as fixed infrastructure, ad-hoc networks have advantages of flexibility and adaptability. Especially, in this research, we focus on low-power communication protocols, such as Wi-SUN and LoRa, because low-power consumption is one of the key requirements for easy maintenance and management of IoT deployed in a city. To get the benefit of low-power consumption, IoT devices should not have a high power-consuming location sensors, such as GPS (Global Positioning System). However, fine-grained location information is indispensable to support various smart cities applications.

In this paper, we propose a fine-grained location estimation method in Wi-SUN mesh networks. To achieve the goal, we leverage public vehicles to collect fingerprint of radio strength measured at Wi-SUN stations and ground-truth GPS coordinates for location estimation. Public vehicles, such as garbage trucks, move around over an entire city almost everyday. Therefore, we can obtain timely relationships between radio strength and GPS locations, and adapt the relationship for Wi-SUN devices to estimate locations accurately. The contributions of the paper are as follows:

- Addressing the problem for fine-grained location estimation in wireless mesh network with low-power consumption protocols.
- Proposing a method to improve the location estimation accuracy by leveraging public vehicles.

The rest of the paper are organized as follows. Section II introduces Wi-SUN mesh networks and the location estimation problem. We describe our proposed approach for location estimation in Section III. Section IV makes a brief review of related work. Finally, we conclude the paper in Section V.

II. Location estimation problem in wireless mesh networks

This section firstly introduces Wi-SUN, the adopted wireless communication protocol. Then, we discuss the location estimation problem in Wi-SUN mesh networks.

A. Wi-SUN

Wi-SUN, short for Wireless Smart Ubiquitous Network, is a wireless specification using IEEE802.15.4g in PHY layer and IEEE802.15.4e in MAC layer. Wi-SUN is designed to meet the requirements for M2M/IoT communication, such as low cost, low power consumption, autonomous operation. Compared to other LPWA (Low Power and Wide Area) protocols, such as LoRaWAN or SIGFOX, Wi-SUN supports up to 300 Kbps bandwidth, and forms not only star topology but also mesh topology called Wi-SUN FAN (Field Area Network). These features allow for multiple and redundant connection paths with high network performance compared to other LPWA protocols, so that it provides a reliable IoT network service for smart cities.

In our project, we will deploy a wireless mesh network with Wi-SUN FAN in Fujisawa city, Japan. In Fujisawa, like in all the other cities in Japan, emergency municipal

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radio communication stations are installed about every 200 meters for public announcement of emergency information, such as evacuation. We integrate those stations and Wi-SUN FAN networks to provide a communication network covering the entire city. Figure 1 maps the locations of all the radio communication stations in Fujisawa city. The communication range of Wi-SUN is around 500 meters, therefore, deploying Wi-SUN base stations to the stations forms a practical wireless mesh network over the entire city.

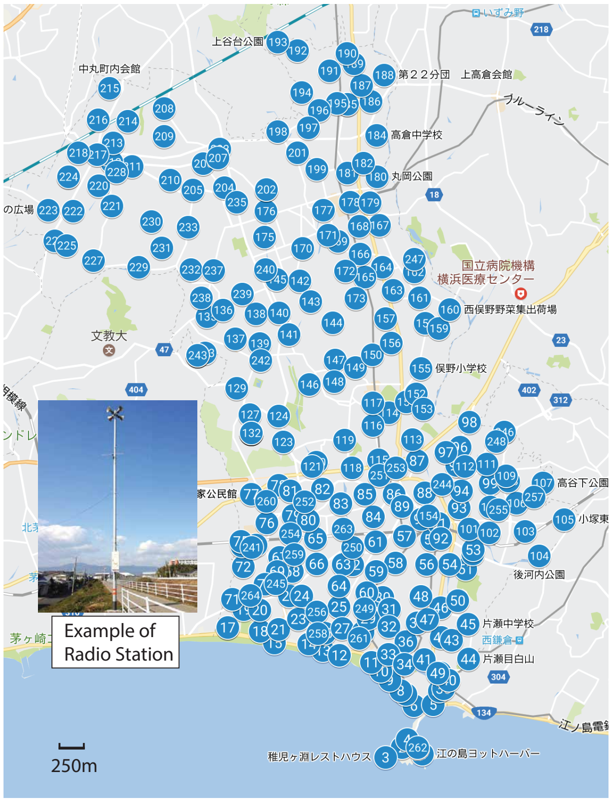


Figure 1: Locations of emergency municipal radio communication stations in Fujisawa city, Japan

B. *Location estimation in Wi-SUN mesh network*

The location is an important information for many application scenarios in Wi-SUN and other LPWA protocols. One of the typical use cases is to watch over elderly people of dementia; when an elderly is abnormally wandering away from home, a sensor device with Wi-SUN beacon attached to him, will detect the abnormality and let care-workers and families know his locations. Similar applications are also useful for young children or pets.

Usually, the location of a device in Wi-SUN network is estimated through identifying which Wi-SUN station is closest to the device. However, this only estimates the device's location as a radius of about 200 meters. This granularity is too wide when targeting people to be watched over for protection. To estimate accurate locations, triangulation can be adapted by measuring Wi-SUN device's RSSI (Received Signal Strength Indication) at multiple Wi-SUN stations, the locations of which are known. However, since signal strength varies greatly in different environmental conditions (e.g., weather, season and so on), detailed relationships between RSSI and the locations should be updated timely. This limitation makes the estimation of accruate locations very difficult, because there is no suitable model to updating the relationship in an entire city. We propose an approach to solve the problem in the next section.

III. Improve Estimation with Public Vehicles

In this section, we first describe the architecture of the proposed system and then introduce the idea of vehicle-assisted location estimation and the automotive sensing platform to be adopted in our research, respectively.

A. *Overview of the proposed system*

As shown in Figure 2, we will implement in this research a system that consists of self-developed Wi-SUN edge devices, Wi-SUN base stations and vehicular devices with GPS receiver and Wi-SUN module. The Wi-SUN edge devices will be attached to users, e.g., young children, the elderly and pets. The base stations will be deployed to emergency municipal radio communication stations of Fujisawa city. The devices broadcast signals periodically or when requested by base stations. If a base station is in the vicinity of a edge device, it will be able to measure the RSSI of the edge device. Via the collaboration of multiple base stations, it is envisioned that locations of the edges devices can be estimated via triangulation. The vehicular devices will be installed into garbage trucks of Fujisawa city and collect GPS data of their locations to assist the location estimation of base stations.

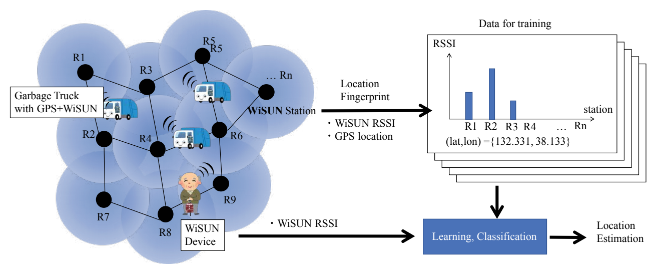
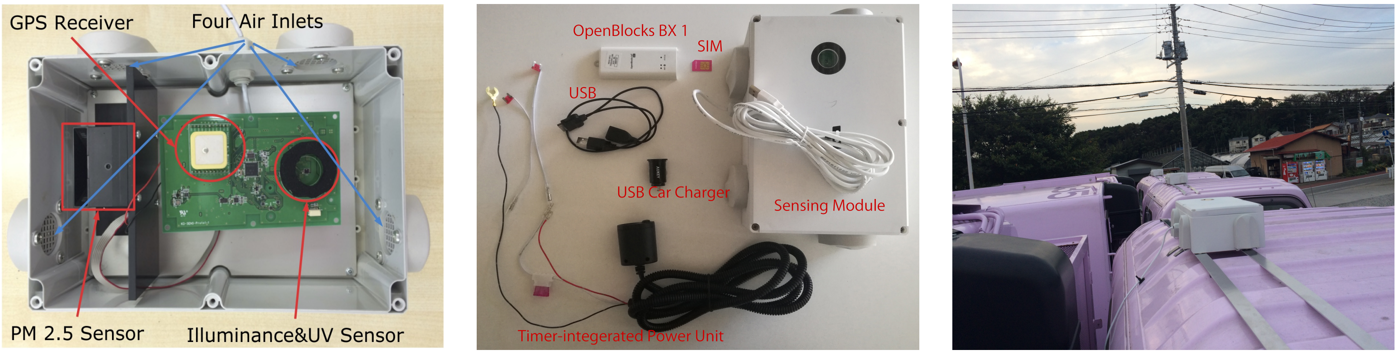


Figure 2: System overview

B. *Vehicular-assisted location estimation*

In outdoor environment, the propagation of wireless signals may be affected directly or indirectly by weather, seasons, buildings and so on, so that the wireless signal strength (RSSI) would be variable over time. In this research, we propose to use public vehicles, like buses, taxi cars or garbage trucks, equipped with GPS and Wi-SUN module, to enhance the accuracy of location estimation at the base stations. In particular, these vehicles will broadcast their locations, i.e., GPS coordinations, as they move around in the city. The base stations in the vicinity of these vehicles will receive these GPS data and also measure the corresponding RSSI of these signals transmitted from the trucks. The GPS data and RSSI data will be further analyzed to find the relationship between locations and wireless signal strength, which in turn can be used to improve the location estimation of our system. It is notable that since public vehicles typically roam around over their cities almost everyday, so timely update can be expected.



(a) (b) (c)

Figure 3: Sensor node of Cruisers.

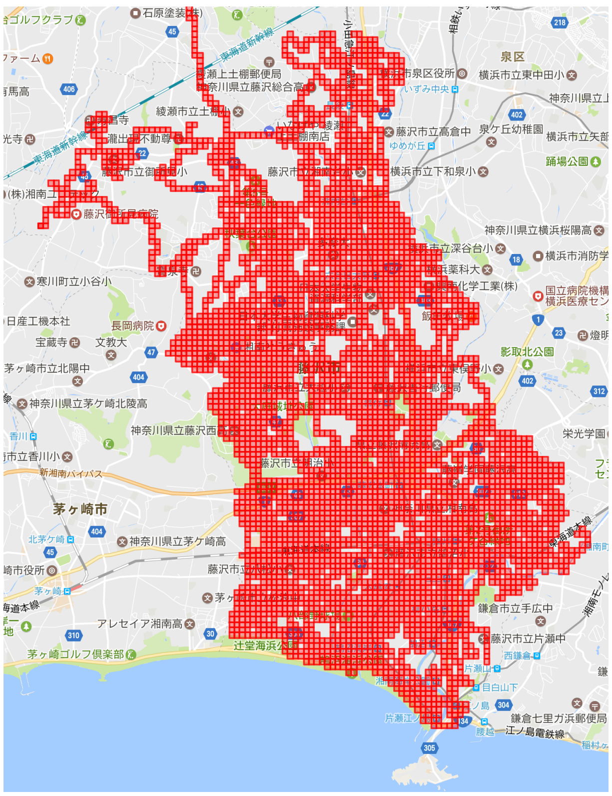


Figure 4: The coverage of Cruisers. The size of a cell is set to $100m \times 100m$. A cell is marked with red color if a truck of Cruisers visits the grid at least once per three days.

C. Cruisers: an automotive sensing platform

In our past research, an automotive sensing platform called Cruisers has been deployed to garbage collection trucks in Fujisawa. The Cruisers platform will be used in this research to serve as the host of vehicular devices. As shown in Figure 3, a sensing module containing a GPS receiver and environmental sensors are developed and installed on the roof of garbage trucks. The sensor data are read by the small computer with embedded 3G connectivity, called OpenBloks BX1, and sent to backend servers over a carrier network.

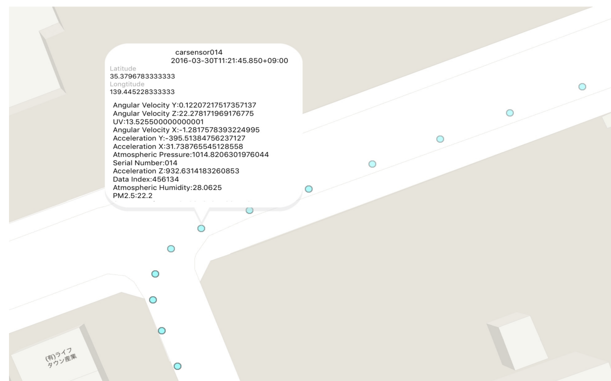


Figure 5: Fine-grained sensing of Cruisers

The city operates 140 garbage trucks for waste collecting and 66 of them have been equipped with the platform by June, 2017. The garbage trucks provide a good coverage on Japanese cities, since the garbage collecting system in Japan works in a daily and door-to-door fashion. In Japan, each house/mansion maintains at least one garbage container located in a nearby roadside. Following the schedule made by local government, residents will throw their family waste to the container in the early morning of each *collecting day* (i.e., the days, typically weekdays, that garbage collecting trucks come to collect waste). Meanwhile, the garbage collecting trucks operated by local governments are organized to visit these containers successively to collect house waste.

Based on the GPS data accumulated from Cruisers, it has been shown that a wide coverage can be achieved [4]. Figure 4 shows the Cruisers' coverage performance. In Figure 4, the urban area of the city are divided into a grid of $100m \times 100m$. A cell is marked with red color if a truck of Cruisers visits the grid at least once per three days. Since we haven't fully deployed the platform to all the garbage trucks, we mainly cover the southern part of the city. The Cruisers-attached trucks visit all the residents' houses in the southern part, implying it covers the area where residents' activities are held. Additionally, with the platform, a fine-grained data collection can be achieved as shown in Figure 5. The sensory data are sent to the backend servers in 100Hz. Supposing a truck is

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driving at 40km/h, the 100Hz sensing will give us a set of sensor data for each 11.1cm.

IV. Related work

The recent progress in ICT like IoT, 5G and LPWA has inspired a number of wireless mesh network applications in smart cities. In [5], the authors proposed a wireless mesh sensor network based on WiFi and discussed its applications in smart grid, agriculture and environment protection. While WiFi provides a high bandwidth, its high energy consumption hinders its application in power-limited scenarios. A routing protocol was proposed in [6] to use Bluetooth devices to construct wireless mesh networks. Simulation was also conducted in [6] to show how the proposed protocol outperforms conventional routing schemes like blood routing in terms of energy consumption. A data collecting scheme using frame aggregation of Wi-SUN was proposed in [7] to improve the data aggregation efficiency of a WSN of smart meters. It is notable that compared with mature wireless networking technologies, like WiFi and cellular communication, LPWA technologies like Wi-SUN, LoRa and SIGFOX achieve long range communications as well as low power consumption, making them promising options for smart cities.

Node positioning is a fundamental problem in power-limited wireless networks where a GPS module is not practical due to its high power consumption. While node positioning has been widely explored in wireless sensor networks [8] and cellular networks [9], node positioning in Wi-SUN networks remains a not well investigated area. On the other hand, WiFi-based approach has also been proposed to enhance GPS service in indoor environment [10]. It is envisioned that while the methods and experience obtained from previous research are helpful, the wireless radiation in the proposed network will be more sensitive to environment factors like weather, so that new estimation methods are required to address these issues. Finally, how to effectively utilize vehicular nodes to improve the estimation accuracy is also an interesting problem.

Automotive sensing is a novel sensing technology where sensors are installed into vehicles to utilize vehicles' mobility to conduct urban sensing. Besides our work [4][11], a couple of applications have also been proposed in the literature. In [12], the authors equipped nuclear radiation sensors to agricultural vehicles to detect nuclear pollution on farmland at Fukushima, where a nuclear leakage accident occurred after the Great East Japan earthquake. The authors of [13] used smartphones stood on the dashboard of a car to detect good view of flowering cherries along roadside. An on-demand air quality monitoring system using public vehicles was proposed in [14], where the authors studies how to adapt the monitoring behavior of sensors in order to accumulate sufficient information of air with a relatively few number of vehicles.

V. Conclusion

The paper propose a method to estimating fine-grained locations in Wi-SUN mesh networks. To solve unstable RSSI in outdoor environment, we propose to leverage sensorized public vehicles for collecting relationships between RSSI and GPS locations. By providing accurate locations, various applications will be inspired. As the first step, we have developed an automotive sensing platform called Cruisers. We will implement and delpoy all the components of the system, and evaluate its location estimation accuracy and feasibility in Fujisawa city. Through our research, vehicles should play an important role not only in wireless mesh network but also to support fine-grained location estimation. Thus, our study will open up a new networking model of vehicle-integrated functional city networks to support various smart city applications.

Acknowledgment

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