Outdoor Wi-Fi RSSI Map Construction Based on Crowdsourcing and Simulation

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Abstract—**In order to maintain certain quality of Wi-Fi services even in the congested, uncoordinated ISM bands in urban areas, mobile Wi-Fi clients (i.e. smartphones of pedestrians and vehicle passengers) must be intelligent to carefully choose appropriate access points (APs). For such purpose, Wi-Fi radio map would be of great help to them to make proper AP selections (e.g. vertical handover) along with their movement. However, crowdsourcing-based approaches require a large number of volunteers to monitor and report signals on streets, and war driving is too coarse for accurate map construction in complicated urban building environment. In this research, we propose a Wi-Fi radio map construction mechanism using both crowdsourcing and highly-precise simulation. Once some cooperative smartphone users collect Wi-Fi beacon data with RSS information, it estimates "tx-tile" for each AP, which is "virtual" transmission source on a wall of the building where AP is inside. Then using this tx-tile with estimated tx-power, it executes online Wi-Fi radio propagation simulations with 3D city models to complement RSS information in many other areas that are not covered by the limited number of cooperative users.**

I. INTRODUCTION

The Japanese government has a national policy of enhancing Wi-Fi availability by the Tokyo Olympic in 2020. This is mainly because Wi-Fi can be a monetary-cost-effective solution for foreign tourists. For the realization of the world's highest level ICT environment, the Ministry of Internal Affairs and Communications issued an action plan, called "SAQ2 JAPAN Project" in June 2014. Likewise, Softbank Group Corp. provided nationwide 400,000 APs (Access Points) for foreigners. The movement toward increasing availability and usability of Wi-Fi in public areas have become more active. In addition, Wi-Fi has also been important as alternative infrastructure of low-cost smart city foundation. For example, in Barcelona, the information from the urban infrastructure like street light illuminance, human flow and noise levels is aggregated through a Wi-Fi-based platform. Therefore Wi-Fi is now becoming indispensable infrastructure.

However, in urban areas, Wi-Fi APs have been deployed densely to increase spatial coverage, which leads to a chaotic and disorderly environment. For such dense Wi-Fi environment, many efforts have been dedicated to increase the performance. For example, the IEEE802.11ax task group reports that Wi-Fi throughput can be nearly doubled using Dynamic Sensitivity Control (DSC) and Transmit Power Control (TPC) [1]. Our research group has been developing the channel selection technique for autonomous and efficient frequency reuse of each AP with the IEEE802.11a/g/n architecture [2]. This approach is based on the measurement of IEEE802.11 MAC frames, the highly-precise Wi-Fi simulation, and machine learning technique. Besides those researches that consider the throughput improvement of single AP, it is necessary to take the impact of multiple APs into account. For example, interference signals from surrounding APs are likely to incur the performance degradation of clients at the edge of Wi-Fi cells. Careless selection of APs in horizontal handover causes serious quality degradation or disconnection, which finally affects TCP throughput. As seen, to provide a certain quality even in crowded, unconditioned ISM bands in the city, Wi-Fi clients should intelligently select appropriate APs.

Wi-Fi radio map is a promising way of allowing the clients the fast recognition of the surrounding APs and their signal intensity. Recently, the rapid spread of smartphones has made Wi-Fi beacon data sensing much easier [3], [4]. In these approaches, radio information observed by smartphones is stored in a database with geographical coordinates, and the information is used to provide Wi-Fi radio conditions to Wi-Fi clients. However, the naive crowdsensing approaches that simply map the observed signal strength with SSID onto the 2D coordinates have several drawbacks. Most significantly, crowdsensing generally requires a number of cooperative users to cover wide region of urban city, but recruiting them is not easy. Designing and deploying incentive mechanisms is not always successful.

In this resarch, we present a Wi-Fi radio map construction method [5]. Similar to several existing approaches, proposed method rely on a crowdsourcing approach where smartphone users help to collect Wi-Fi beacon data. This method assume most of APs are inside the buildings in urban environments. To construct Wi-Fi radio map outdoors based on RSS reports from those cooperative users, it is necessary to estimate the exact AP position inside building, which often difficult due to several factors. Therefore, this scheme estimates "tx-tile" for each AP, which is a "virtual" transmission source as if the AP is on the wall of the building in which the AP exists. Then using this "tx-tile" and estimated tx power, it executes online Wi-Fi radio propagation simulations with 3D city models to complement RSS information of uncovered areas.

II. APPROACH

Fig. 1 shows the system overview. This system assumes utilization of crowdsourcing and collects Wi-Fi beacon observation data in urban areas from cooperative users using

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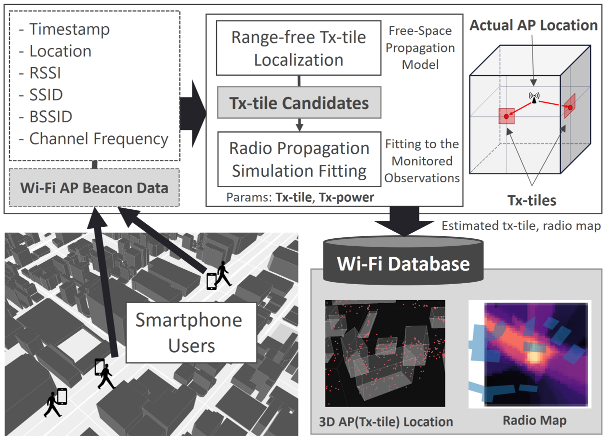

Fig. 1. System Overview

smartphones. The observation application installed on the smartphone performs Wi-Fi channel scan at regular intervals. The scanned point is called *observation point*, and data obtained at each observation point is called *observation data*. Each observation data contains SSIDs, MAC addresses, RSS, channels by beacon advertisement from APs. The application periodically sends collected data to the cloud server and based on these data, the our methods estimate the AP location and generate the radio map for each AP. The Wi-Fi database is constructed in the following three steps; (i) estimate tx-tile candidates using the observation data for each AP, (ii) estimate the location of each tx-tile by fitting the simulated RSS values to the observed RSS values, and (iii) determine the transmission power of tx-tiles for final calibration.

Basically, tx-tile candidates are determined by range-free localization from multiple observation points. We consider the maximum range of beacon transmission from an AP, and consider the sphere centered at an observation point with the maximum transmission range using the free-space propagation model. The model calculates RSS in free space without obstacles between the transmitter and the receiver.

In the second step, we select one tx-tile for each wall from the tx-tile candidates in the first step. For this purpose, we execute several simulations using different tx-tiles and select the best one that gives the best-fit simulation to the actual observations.

In the third step, we estimate the transmission power of the tx-tile. As in the second step, we execute several simulations with different transmission power using the txtile estimated in the second step and select the radio map with the least error. Then we adopt this map as the Wi-Fi radio map of the AP.

III. EVALUATION

We evaluated our method in Osaka University campus environment. We installed 5 APs near the windows of department buildings and collected observation data at 297 points around those buildings using a smartphone, and then, we estimate obtain "tx-tile" and the radio map of each AP. The average localization error was $14.2\,\mathrm{m}$. The positional error in the horizontal direction was $6.7\,\mathrm{m}$, and the positional error in the vertical direction was $11.7\,\mathrm{m}$. We also evaluated the precision of the radio map. We compared actual RSSI and estimated RSSI on the radio maps. At 21 of the 30 samples, the error remained within $\pm 5\,\mathrm{dBm}$.

Moreover, we built the system of large-scale crowdsensing and radio map construction, which includes the smartphone application for crowdsourcing, simulation fitting engine and 3D radio map visualization application. Using this system, we constructed Wi-Fi RSS maps in the area of $5\,\mathrm{km}^2$ of Osaka City [6]. The number of total observation points was 42,022, and the number of observed APs was 78,170. The result showed the simulated RSS samples that the RSS errors were $10\,\mathrm{dBm}$ or smaller were about 80%.

IV. CONCLUSION

We proposed a Wi-Fi database construction method. This low-cost constructible database can be used for many purposes such as autonomous AP selections by Wi-Fi clients and autonomous channel selection by APs. 3D radio map visualization application of our system also could help Wi-Fi service providers to optimize channels and locations of their APs in the urban area. In addition, we also built a smartphone application testbed system [7] using this Wi-Fi database.

In future work, we will consider the method to control client's Wi-Fi connection which prevent degradation of application QoS (Quolity of Service), combining our Wi-Fi database which can be constructed easily and users' behavior estimation and prediction.

ACKNOWLEDGMENT

Many thanks to my supervisor Teruo Higashino and Hirozumi Yamaguchi for their support and valuable comments.

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