Positioning System for Subway Lines and Stations Using Cellular Tower IDs

Go Matsubara*, Hiroshi Kanasugi**, Jun Kumagai*, Ryosuke Shibasaki*
*Center for Spatial Information Science, **Earth Observation Data Integration and Fusion Research Initiative
The University of Tokyo
Tokyo, Japan

Abstract—People movement analysis within indoor and underground environments has been attracting attention from several fields. However, indoor positioning remains uncertain and various kinds of methodologies have been employed. In particular, Wi-Fi positioning has become popular in a mobile environment. However, the insufficiency of databases associating Wi-Fi access points (APs) with their actual positions, in addition to their movability and easy-to-replace features, sometimes causes the database to indicate unusual positions at great distances from the actual location. This prompted us to focus our study on the stability of the cell tower information obtainable from the mobile phone network, and the network availability along subway lines and in stations. In this research, we created databases containing tables that list the subway stations and their corresponding cell tower IDs in the Tokyo and Nagoya areas. We subsequently used this database to develop a positioning system and verified the extent to which it could accurately detect the stations by conducting feasibility experiments.

Keywords—cellular tower signals; positioning underground; subway line; indoor positioning systems; smartphone

I. INTRODUCTION

People movement analysis within indoor environments, for example in commercial facilities and traffic facilities such as railway stations, is attracting attention in terms of optimizing facility design and preparing for disaster response; therefore, demand for positioning in indoor and underground environments has been expanding. However, indoor positioning remains uncertain and has employed various kinds of methodologies such as Wi-Fi access points (APs) or Cell-ID based positioning [1][2], pedestrian dead reckoning (PDR) [3], and the indoor messaging system (IMES) (pseudo-GPS) [4]. In particular, positioning with the aid of information from Wi-Fi APs has become popular in recent years because existing facilities such as Wi-Fi hotspots can be directly re-utilized without installing additional equipment.

Although Wi-Fi positioning can detect a location accurately within 10 cm under ideal conditions, sometimes it indicates unusual positions extremely far away from the actual location. This is caused by the insufficient accumulation of data associating a Wi-Fi AP with actual positions. In addition, since a Wi-Fi AP can be easily replaced and people have recently started using mobile Wi-Fi, the database containing Wi-Fi APs needs to be updated more frequently to improve the accuracy.

Additionally, the standard Wi-Fi positioning API on a smartphone usually returns only the position values. With respect to people movement analysis and application development, the attribute information of the associated facility would be more useful than the position values.

In this study, we focused on the stability of cell tower information, i.e., the cell tower ID (Cell-ID) and Location Area Code (LAC), neither of which are changed easily once a cell tower is established. In addition, in Japan, the mobile network is now available in any areas, even indoors and underground. Although the subway is a common transportation in the urban areas of Japan, detecting people movement along subway lines and in stations has not been considered significantly. Therefore, this paper describes the detection of subway lines and stations with the use of mobile phone Cell-IDs and the results.

First, we created a database containing the stations and their corresponding Cell-IDs in the Tokyo and Nagoya regions. Next, we developed a positioning system specified for each subway line that provides not only the coordinates but also the name of the station and subway line. We expect it to improve the user experience of train transfer navigation systems.

Moreover, we evaluated the accuracy of our positioning system by carrying out feasibility experiments. The results showed that the size of the mapping database is relatively small, and that all the data can be included in the application. Therefore, our solution facilitates positioning without requiring any network connection. On the other hand, the application sometimes failed to identify the station correctly because the cellular signal reached stations beyond those we expected.

II. EVALUATING OF PREINSTALLED POSITIONING SYSTEM

As mentioned in the previous section, the preinstalled Wi-Fi positioning sometimes indicates the unusual positions. In order to observe this phenomenon, we made a sample Android application using Wi-Fi positioning that refers to Google’s databases. Then, we evaluated whose accuracy.

We conducted two experiments in different areas. Firstly, we traveled on the Tokyo Metro Chiyoda line from Kitasenju station to Yoyogi-uehara station (a total of 17 stations) while using the Wi-Fi positioning function of the API of a smartphone subscribing to the service provided by docomo.
every 5 minutes (Fig. 1). Next, we traveled on the Nagoya city subway visiting all the stations while using the positioning function of the API every 10 seconds.

In both cases, we detected some points that could be considered noise (A) on the trajectories. When creating the databases by mapping the Wi-Fi AP to the coordinates, we occasionally detected signals from mobile Wi-Fi APs, such as tethering smartphones. The presence of these APs in the databases might be the source of noise. These two sets of results led us to conclude that the database of the Wi-Fi positioning system provided by Google is not well organized.

In the case of Tokyo, we failed to obtain any coordinates in some areas (B). When we called the API while the train was moving, it was difficult to obtain the coordinates. This suggested that we would have to call the API more frequently to avoid a blind zone. In the case of Nagoya, in which case we called the API every 10 seconds, we succeeded in obtaining coordinates in all of the stations; however, the batteries of our smartphones were depleted after 1 hour.

III. METHODOLOGY

In this study, we tried to develop a positioning system specifically for subway lines without incurring additional costs. Moreover, we tried to provide not only the coordinates but also the station names and the names of subway lines.

We focused on the advantages of Cell-ID positioning. Because cellular signals reach farther than the other signals, we assumed that we might be able to receive the signals anywhere in the subway shaft. This approach would also accelerate the positioning process compared to the other methods. In addition, as cellular specifications are the same all over the world, we expect to facilitate the expansion of our service to other areas.

A. Cellular network environment

Cellular carriers set up their cellular network towers (cell-towers) at specific intervals in the subway shafts to enable cellular services in all the subway lines. Fig 2 illustrates the relative location of selected stations and the cell towers that provide coverage in this area. Certain cell-towers cover multiple stations (e.g., 68730882), and some stations contain multiple cell-towers (e.g., three cell-towers could be found at the Nakamura-nisseki (H05) station). According to cellular network specifications, each cell-tower broadcasts specific information: the Mobile Country Code (MCC), Mobile Network Code (MNC), Cell-ID, and Location Area Code (LAC). As these specifications are the same all over the world, each cell-tower in the world can be uniquely identified if these four parameters are provided.

B. Creating the database of Cell-IDs and stations

We collected the Cell-IDs from all the subway lines in the Tokyo and Nagoya areas by creating an Android application that records the Cell-ID and LAC sent from the cell-towers.

We traveled along each subway line and collected the Cell-IDs in the Tokyo and Nagoya areas following the procedure listed below in Mar. 2016 and from Dec. 2016 to Jan. 2017.

2) Adjust the clocks of the smartphones accurately.
3) Board the train.
4) Travel to the next station.
5) Disembark from the train.
6) Record the Cell-ID, LAC, and timestamp
7) Walk the entire length of the platform.
8) Repeat 3) to 7) by completing a round trip on each line.

The experimental areas covered 13 lines with 274 stations in Tokyo, and 6 lines with 100 stations in Nagoya (the number of stations includes multiple entries for stations where multiple subway lines cross). The targeted cellular carriers were docomo, au (without CDMA), and SoftBank.

C. Creating the positioning system

We implemented a positioning system specifically for subway lines on Android smartphones. The application refers to the database created in section III-B.

IV. EXPERIMENTS AND RESULTS

In this section, we describe the results of the experiments we conducted to create and verify the database.

A. Creating a database

When collecting the Cell-IDs, in some areas, the Cell-ID changed as frequently as every 10 seconds, and in other areas,
the Cell-ID remained unchanged, even for a few minutes. We found around 1,500 unique Cell-IDs in the Tokyo area for 274 stations of the docomo network, and almost 300 unique Cell-IDs in the Nagoya area for 100 stations for each cellular carrier. TABLE I shows the result for the Higashiyama line in Nagoya using the au network. Some Cell-IDs were detected at multiple stations: no.68730883 (@) was found at Takabata, Hatta, and Iwatsuka stations.

Figure 3 shows the percentage of short- and long-range Cell-towers and the number of stations receiving their signals. For example, 65% of SoftBank’s cell-towers are short-range towers. On the other hand, the au network operates some long-range cell-towers of which the signal can even reach six stations. We can assume au implemented facilities to relay the signals.

B. Result of positioning

We examined our positioning application by traveling along the Asakusa line from Oshiage to Gotanda station using the docomo network. It showed that our app could indicate the correct stations prior to arriving at those stations, even without Wi-Fi positioning (TABLE II).

In the case of Nagoya, we defined the app status below. While the train was stationary at the station (from the moment the doors opened until they closed): Success: the app indicated the correct station at all times (†). Success at times: the app could indicate the correct station even for a moment (††). Fail: the app indicated the incorrect station at all times (×). The results were different depending on the particular cellular carrier network. TABLE III contains the result for the Higashiyama line. The app indicated the correct station for 20 out of 22 stations and for 19 out of 22 stations with the docomo and SoftBank networks, respectively. On the other hand, with the au network, the app tended to indicate the previous stations. In the whole Nagoya area, the app achieved success for approximately 60% of the stations within the docomo network, approximately 50% with au, and approximately 90% with SoftBank.

V. DISCUSSIONS

In this section, we discuss and motivate the results we obtained with the method.

A. Features

1) Advantages

Speed: because signals from cell-towers cover larger areas than other signals such as those of Wi-Fi or Bluetooth, this method is able to detect the stations before the trains reach them.

Stability: the cell-towers are not easy to be moved or removed once they are established, thus we do not need to maintain the databases as frequently as for Wi-Fi positioning.

Low-cost and generic technology: as this method uses only standard smartphones and existing facilities, we can easily expand the service areas, even to foreign countries or other facilities such as shopping malls located underground, by collecting information about the Cell-IDs without the additional costs for establishing new dedicated devices or facilities.

Small database: each database record only contains the Cell-ID and the station codes; therefore, the size of the database does not exceed 20 KB for each carrier in one city. This makes it possible to include all of the data within the application and to detect the position without network access, unlike standard Wi-Fi positioning systems. It is advantageous for users of Internet meter rate charging systems.

<table>
<thead>
<tr>
<th>Station</th>
<th>Cell-ID</th>
<th>Station</th>
<th>Cell-ID</th>
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<tbody>
<tr>
<td>Takabata</td>
<td>68730883</td>
<td>Nakamura-nisseki</td>
<td>68730882</td>
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<tr>
<td>Hatta</td>
<td>68730883</td>
<td></td>
<td>71810819</td>
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<tr>
<td>Iwatsuka</td>
<td>68730883</td>
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<td>68730881</td>
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<td></td>
<td>68730882</td>
<td>+ Honjin</td>
<td>68730881</td>
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<td></td>
<td>68730881</td>
<td>* Kamejima</td>
<td>68730881</td>
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<table>
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<tr>
<th>TABLE II. RESULT FOR ASAKUSA LINE</th>
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<tbody>
<tr>
<td>Station</td>
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<tr>
<td>---------</td>
</tr>
<tr>
<td>Oshiage</td>
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<td>Honjo-azumabashi</td>
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<td>Asakusa</td>
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<td>Sengakuji</td>
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<td>Takanawadai</td>
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<tr>
<td>Gotanda</td>
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Additional properties: unlike the positioning systems of standard smartphones, we collected the Cell-ID information for each of the subway lines individually; therefore, this application is able to detect not only the simple coordinates but also other properties such as the names of the station and subway line.

2) Disadvantages
Low accuracy of coordinates: because signals from cell-towers have a long reachable distance, this method returns only the station level coordinates at best (from several kilometers to dozens of kilometers).

Low accuracy areas: we found the signals from cell-towers to reach longer distances than we expected. In some areas, we failed to identify the correct station from among the listed stations. In such areas, we would have to refer to other indexes.

3) Use case
Based on these features, we consider this method useful for developing transfer guide systems. On the other hand, for systems that require high-accuracy coordinates, such as indoor navigation systems, this method is not suitable.

B. Detection rate for each carrier
We found the success rates of positioning to depend on the cellular carriers.

docomo: the app indicated the correct stations with a success rate of 60-70%. However, in areas with long-range cell-towers, the success rates dropped.

au: in all areas, the app tended to indicate the previous stations and at stations crossed by multiple subway lines, the app could not determine the correct subway lines. We can assume that this carrier installed certain facilities that relay the signals.

SoftBank: in the majority of areas, the app could indicate the correct stations. This suggests that the signals from each cell-tower only reached a short distance. In addition, an accurate score was obtained not only for station detection but also for train line detection. The research found that it was possible to detect train lines located on different floors by receiving signals from cell-towers on those floors.

VI. CONCLUSIONS
In this study, we developed a smartphone positioning system specified for subway lines because the preinstalled positioning functions were insufficiently accurate. First, we created databases to associate the stations with Cell-IDs. Next, we developed an application capable of indicating the name of a station and subway line based on the received Cell-ID information. Lastly, we conducted experiments to verify the accuracy of the app on the Tokyo and Nagoya subway systems.

We found the accuracy of this application to differ for each cellular carrier. The carrier that made use of cell-towers with limited coverage areas in a higher density arrangement, i.e., of which the signals could reach only one station, produced a high success rate. On the other hand, in the case of carriers that employ signal relay facilities, this method could not detect the correct stations and therefore we have to consider using a method that would additionally use indexes other than Cell-IDs to select listed stations. In terms of stability, cell-towers are not easily moved or removed once they are established, thus it would not be necessary to maintain the databases as frequently as for Wi-Fi positioning.

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REFERENCES