USE OF AGPS CALL DATA RECORDS FOR NON-GPS TERMINAL POSITIONING IN CELLULAR NETWORKS

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Abstract: This paper presents a novel method of user terminal positioning in cellular networks. A pattern matching technology based on received-signal-strength (RSS) from the pilot channels of cell towers has been the most popular network-based positioning method. In response to a position request, a terminal measures RSSs of pilot channels from surrounding cell towers and then the terminal's RSS pattern is compared with a pattern database to find the most correlated one which indicates the position of the terminal. Although the pattern matching method can provide accurate positioning, its database construction and maintenance require a high overhead of periodic labor-intensive pattern collection. In this paper, we propose to exploit the call data records (CDRs) that are uploaded by Assisted Global Positioning System (AGPS) terminals as inputs to the pattern database, which removes or reduces the pattern collection overhead. In AGPS systems, terminals measure satellite signals and cellular network parameters (such as RSS) and relay them to the cellular infrastructure, which in turn calculates the terminal position using both that satellite and cellular network data. The proposed AGPS CDR based pattern matching method takes advantage of the increasing number of AGPS terminals in service: non-AGPS terminals can obtain more precise positioning results in areas where more AGPS calls are generated (e.g. hotspots). To do so, we analyze the characteristics of RSS patterns and AGPS CDRs. Based on the analysis, a pattern-distance metric and an AGPS CDR based pattern matching system are proposed and their performances are evaluated by examining field data of several urban downtown areas of Seoul, Korea. We obtain promising results: the position of the user terminal can be estimated with the accuracy (or, positioning error) at the level of 96.5m and 149.8m for the 67% and the 95% confidence interval, respectively.

1 INTRODUCTION

[1]The geographic position of a user terminal is valuable and critical information to provide ubiquitous/intelligent services such as location-based emergency terminal service. Many researchers and engineers have made great efforts to obtain accurate user terminal position information with or without Global Positioning System (GPS).

Although GPS is able to provide excellent position accuracy, position fixes require lines of sight (LOS) to multiple satellites, long first fix time (at least 30s), and high processing power. Assisted GPS, or AGPS (Djuknic, 2001), is a technology that uses an assistance server in a cellular infrastructure to cut down the time needed to fix the position. In AGPS systems, the terminal, being limited in processing power, communicates with the assistance server that has high processing power. In response to position queries, AGPS terminals measure satellite signals and cellular network parameters (such as RSS) and relay them to the assistance server. The server uses those data to calculate the position of the terminal and send the calculated position back to the terminal. In urban areas, however, AGPS does not work (like GPS) under heavy tree cover or indoors where the terminal cannot receive a sufficient number of satellite signals. Moreover, equipping a terminal with AGPS module raises terminal production cost. That's why some proposed positioning technologies exploit the inherent radio parameters of the cellular network rather than relying on GPS technologies.

The network parameters open up several possibilities for positioning methodology. Simply, every cellular system provides some information identifying the serving cell (Cell-ID) enabling a coarse-grained

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[1] Korea patent pending.

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position estimate. For more accurate positioning, a number of proposed solutions have utilized the propagation delay, time-difference-of-arrival (TDOA), antenna orientation or received-signal-strength (RSS). The propagation time (or time-of-arrival) to the cell tower is only available in TDMA systems and UMTS. And in cases without LOS view between the transmitter and the receiver, the distance from the propagation time is overestimated. TDOA among several cell towers could be measured and the terminal position can be obtained by solving the hyperbolic system. Hyperbolic systems require time synchronization among cell towers, which is feasible not in GSM and UMTS but in only CDMA networks. Additional hardware can compensate for the time asynchrony but raises costs. The hyperbolic systems also suffer from the inaccurate TDOA measurements mainly caused by the near-far problem: Idle Periods in Downlink (IPDL) is proposed to mitigate the problem while it costs downlink capacity and additional complexity (3GPP, 2002). The information of sector antenna orientation and angle opening can be used to increase the positioning accuracy. Many service providers, however, do not maintain the information of each sector antenna. And radio waves may arrive from outside the opening angle due to antenna side lobes, reflections, and diffractions especially in dense urban areas.

Compared to the above-mentioned parameters, RSS is the commonly available basic parameter for all types of wireless cellular systems. Shadowing and multipath fading, however, make RSS an unreliable metric to estimate the exact transmitter-receiver distance. Moreover, the RSS-to-distance function (propagation model) is highly affected by environment/system specific factors such as height of surrounding buildings, walls and operation RF frequency. Thus, rather than RSS-based triangulation, RSS database pattern matching algorithm is in use. It overcomes the above-mentioned problems by using a database built from measurements or predictions. The position of the terminal is then determined by comparing the terminal's RSS measurements to the database entries and finding the best-matching position. Making appropriate measurements over wide cellular network areas is very expensive and therefore not considered applicable. Moreover, the change of cell towers' locations, antenna angles, and surrounding buildings mandates frequent update of the database. Thus, the pattern matching approach is more practical by wireless LAN based small-area/indoor positioning services. Prediction data, on the other hand, can be obtained from wave propagation simulation tools and remove the database maintenance overhead. Accurate prediction, however, requires precise 3-D maps over large areas and accurate/detailed network parameters including antenna loss, height, tilt, transmission power, etc., which are not commonly and easily obtained. And the maps and parameters also require frequent update.

In this paper, we propose to exploit the call data records (CDRs) uploaded by Assisted Global Positioning System (AGPS) terminals as inputs to the pattern database, which removes or reduces the pattern collection overhead. The characteristics of RSS patterns and AGPS CDRs are analyzed and reflected in designing a pattern-distance metric and pattern matching system, respectively. The main contributions of this paper are:

- Database cost reduction: we show that the AGPS CDRs can be utilized to build and maintain a pattern database for positioning of non-AGPS terminals.
- Pros and cons of the use of the AGPS CDRs
    - As the number of AGPS users increase, non-AGPS terminals obtain more accurate position results. It means that non-AGPS terminals can obtain more accurate positioning results in the area where more AGPS calls are generated (position information of non-AGPS terminals will be requested much more frequently).
    - Absence of AGPS CDRs in indoor areas may reduce the coverage of pattern matching positioning area. However, we show that indoor positioning by the proposed method is possible even with outdoor AGPS CDRs.
- The analysis of RSS pattern characteristics: we design a pattern-distance metric based on the analysis.

The performance of the pattern-distance metric and the AGPS CDRs based pattern matching system are evaluated by examining the field data of urban downtown area of Seoul, Korea. Field trials provide promising results: the position of a user can be estimated with the accuracy at the level of 96.5m and 149.8m for the 67% and the 95% confidence interval, respectively.

The remainder of this paper is organized as follows. In the next section, we present related work. Section 3 introduces the proposed pattern matching localization, and Section 4 details the proposed pattern distance metric. In Sections 5 and 6, experimental results and concluding remarks are given.

2 RELATED WORK

Cell-ID, time-difference-of-arrival (TDOA), GPS are the traditional localization methods in cellular networks (3GPP, 2002), (Djuknic, 2001),(Zhao, 2002). In Cell-ID systems, the position of user terminal is determined as the position of serving cell tower. This method is simple and applicable to every cellular network, but it offers only coarse-grained position information because the cell area is typically wide. TDOA uses the time difference of the radio signal propagation to estimate the distance between the user terminal and the adjacent cell towers. By using these distance data, TDOA triangulates the position of the user terminal. This method can provide a more accurate position than the Cell-ID method, but its application is limited to synchronized networks or it introduces an additional hardware cost to measure the asynchronity. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to calculate the position, the velocity and the time; accuracy of GPS is fairly high. By attaching a GPS receiver on a user terminal, GPS can be employed in cellular networks. However, GPS is not available in indoors or deep urban canyons, because it requires LOS to satellites. In cellular networks, on the other hand, AGPS is used to reduce the time required to find the position of the user terminal.

Pattern matching localization method is proposed to overcome the limitations of traditional methods (Bahl, 2000), (Laitinen, 2001), (Ahonen, 2003), (Borkowski, 2005). Under the pattern matching method, a user terminal measures the radio signal pattern, and then, seeks for the most similar pattern in the pattern database, which consists of the radio signal patterns gathered at the specified positions a priori. In this way, the position of the user terminal is estimated. (Bahl, 2000) proposes a pattern matching method for wireless local area networks, while (Laitinen, 2001), (Ahonen, 2003), (Borkowski, 2005) employ the pattern matching in cellular networks.

Under the pattern matching method, because the signal pattern database should be updated periodically in order to adapt to the ever-changing radio environment, the maintenance cost is significant. Accordingly, a number of research efforts have been made to reduce the maintenance cost. (Zhu, 2005), (Roos, 2002) employ the radio signal propagation model to predict the radio signal patterns at the specific positions. Measured field data can complement the radio signal propagation model: it therefore reserves accuracy of the signal pattern database with a low pattern database maintenance cost. This prediction method is orthogonal to our proposed AGPS CDR base method, thus, they can be used together with our method. Accurate propagation modeling, however, requires precise 3-D maps over large areas and detailed network parameters including antenna loss, height, tilt, transmission power, etc. (Smailagic, 2002), (Lim, 2006) propose special algorithms exploiting spatial correlation of patterns in wireless LAN environments. Although they are proved to work well in indoor wireless LAN systems, we observed that it is inappropriate to apply them to cellular network systems because of cellular systems' larger cell coverage and more dynamic radio environment than those of small-area wireless LAN systems.

3 PATTERN MATCHING LOCALIZATION

3.1 Basic Pattern Matching System

Figure 1 depicts the basic pattern matching system architecture. In basic pattern matching systems, operators use dedicated measurement terminals and collect signal patterns at positions (whose positions are already known) in advance. And the patterns are stored in the signal pattern database. Signal patterns at a position may vary with the change of radio propagation environment or cell planning. Therefore, operators are required to periodically measure signal patterns to maintain the signal pattern database up-to-date. We call a collected signal pattern stored in signal pattern database as a *seed*. That is, the seed is the entry in the signal pattern database. On the other hand, we call a signal pattern in a position request from a terminal as a *sample*.

In order to determine the position of a user terminal, the user terminal first measures the signals from surrounding cell towers, and sends the sample pattern to the infrastructure to find the most correlated pattern which is used to estimate the position where the terminal's pattern is measured.

Collecting seed patterns over the wide area of the cellular network is labor-intensive work. Suppose we collect seeds at every 50 m grid point in $1km^2$ range, 400 times of measurement are needed, and in case of $5km^2$ urban area range, 10,000 times. Furthermore, operators should measure seed patterns periodically to maintain the database up-to-date. Moreover, in order to obtain the more accurate position fix, the more and the denser seed patterns are needed. Therefore, we propose a novel pattern matching system to automate the construction of the signal pattern database.

3.2 Proposed Pattern Matching System

The proposed AGPS CDR based pattern matching architecture is illustrated in Figure 2. In the proposed system, we make use of the CDRs uploaded by AGPS terminals as seed patterns for positioning non-AGPS terminals. In general, AGPS is accurate within 50 meters when users are indoors if GPS signals are received and 15 meters when they are outdoors (Djuknic, 2001), so that we can leverage the AGPS result as the actual position of a terminal. An

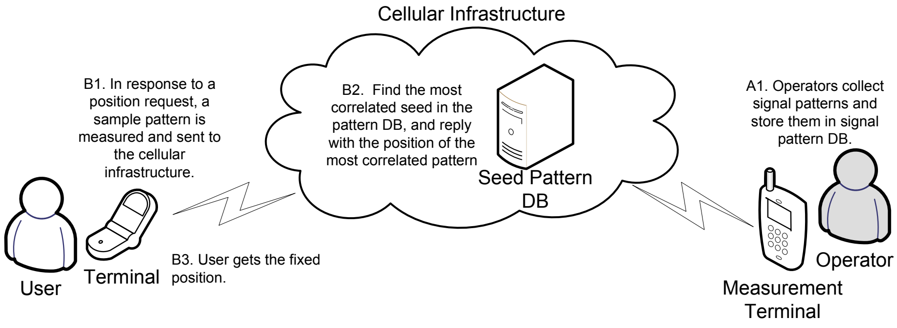

Figure 1: Basic pattern matching architecture. Process A is the pattern database construction process, and process B is the user terminal positioning process.

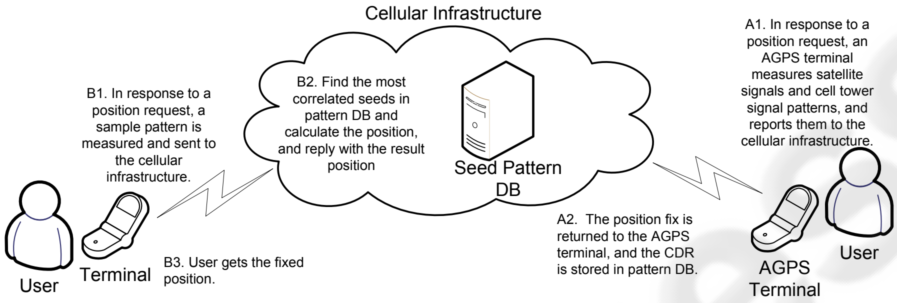

Figure 2: AGPS CDR based pattern matching architecture. Process A is the pattern database construction process using AGPS user terminals, and process B is the user terminal positioning process.

AGPS CDR includes the call time as well as the signal pattern and an AGPS positioning result (3GPP2, 2001). From the CDMA (IS-95) system of the company A in Korea, we have obtained this log data without any modification on the system. In this way, we are able to construct and maintain a pattern database at low cost.

In some cases, the size of the seed pattern database may be too large to manage, since the number of AGPS terminals is increasing and many users exploit AGPS for the location based service. Then, the database lookup time and, eventually, position fix time will increase. In this case, we can reduce the time by doing spatial and temporal filtering for the incoming CDRs. For example, we can designate regional databases for each area unit, and each database maintains CDRs generated from its assigned area. When we choose candidate seed patterns from the database to compare with the sample pattern, we can filter out old seeds. We can also consider the specific time interval (a day of the week, a time in a day) at which the sample and seed patterns are measured in choosing most appropriate seed patterns in a manageable size.

On the other hand, in a particular area, or a particular cellular network where AGPS terminals are generating calls not so frequently, there may not be sufficient number of seeds in the pattern database. In this case, the seeds should be accumulated in the pattern database for a long time to offer required accuracy in that area. This incurs a question on the seed valid time. We investigate this question: how long the seed is valid, by using two sample sets of 55-day difference, which is somewhat long time if we consider the rapid change of outdoor radio environment especially in urban area. We collected the seed set on Dec. 15, 2005, and used two sample set: one was measured on Dec. 15, 2005, and the other on Feb. 8, 2006. The seeds and samples were collected from about 100 spots of downtown area of Seoul (near the *Gangnam station*, one of the most crowded areas in Korea, with many high buildings) and the area size is approximately $1km \times 1km$. The result error dis-

Table 1: The result error distances (m) on the time variation. This table shows the mean positioning accuracy and the accuracies (in meters) for the 67% (1 sigma) and 95% (2 sigma) confidence interval, respectively.

Measurement date of sample	Mean	1 Sigma	2 Sigma
12/15/2005	87.7	110	169
2/8/2006	93.2	121	196

Table 2: An example of RSS pattern (unit: dBm).

Location	RSS from cell 1	RSS from cell 2	RSS from cell 3	RSS from cell 4
(37.5085, 127,0335)	-4.43	-7.23	-10.22	-20.46

tance of our proposed method is shown in Table 1. The mean error of former sample set (with 'fresh' seeds) is 87.7 m, while that of the latter sample set (with '55-day-old' seeds) is 93.2 m. Despite of the 55 day gap between the two sets, the positioning accuracy results do not make a considerable difference. This demonstrates that the duration of the seed validity could be very long than our presumption. Therefore, when AGPS terminals are generating calls not so frequently, we can store seeds in the pattern database for a long time to maintain the density of seeds in the pattern database.

The basic pattern matching picks up only one seed (and its measurement position) in determining the position of a sample pattern. Consequently, the result of the basic pattern matching will become unstable as the variations of the radio signals increase (due to slow fading and fast fading). In order to mitigate the effect of the variations, we select multiple seeds and use them together in determining the position of user terminals. We introduce a metric of the pattern distance, which will be detailed in Section 4, and select multiple seed patterns in terms of the pattern distance. We then estimate the centroid of the selected seeds as the position of a user terminal. The field trial test in Section 5 shows that this centroid method exhibits with less deviating positioning results.

4 PATTERN DISTANCE METRIC

We define a radio signal pattern as a set of the received-signal-strengths (RSSs) of adjacent cell towers (Table 2). User terminals commonly measure the RSS of the pilot channel to determine when to handoff to other cells, or to control transmit power in any cellular network, i.e., GSM, CDMA, WCDMA networks.

Before designing a pattern distance metric, we analyze the characteristics of RSS patterns. First we look at the distribution of RSS values measured from one cell tower as illustrated in Figure 3. X, Y, and Z axes represent latitude, longitude, and RSS value in dBm, respectively. Circular points indicate measurement locations. In Figure 3, as the user terminal goes far from the cell tower, the measured RSS value

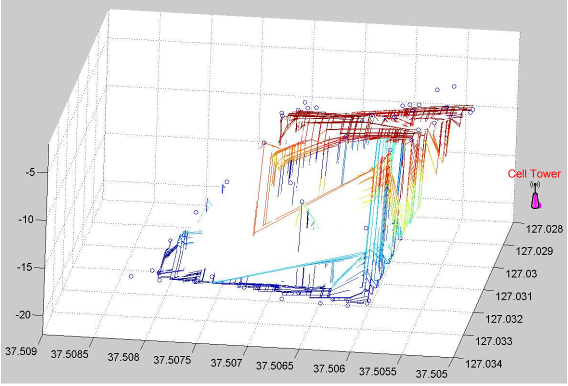

Figure 3: Signal strength at various positions received from a cell sector antenna. Cell tower is at (37.50504, 127.02527).

decreases while the RSS values measured near the cell tower are not decreasing fast. Although there are some fluctuation of RSS values due to slow and fast fading, in general, the difference between two RSS values measured at two positions increases in proportion to the distance between the positions. With these characteristics of the RSS, we reach the following observation.

- **Observation 1.** In general, as the distance between two measurement positions increases, the difference between the two measured RSS values increases. The pattern distance metric should reflect the difference between RSSs of two patterns (i.e., a seed and a sample), then eventually indicate the distance between the two measurement positions.

Therefore, in order to take RSS difference into an account to pattern distance metric, we use the Euclidean distance as follows.

$$\sqrt{\sum_{k=1}^{n}(RSS_{A_k} - RSS_{B_k})^2}.$$

where n is the number of RSSs in two patterns and RSS_{A_k} is the k^{th} RSS value of the pattern A and RSS_{B_k} is the k^{th} RSS value of the pattern B.

Because RSSs of the points at the same distance from a cell tower are similar (as shown in Figure 3), if a pattern (sample or seed or both of them) contains only one RSS measurement value from one cell, the pattern with a single RSS may appear at a number of positions. In that case, the picked-up position of the most correlated seed based on the above metric may be far from the position of the sample pattern. However, as the number of RSS values from different cells increases, an RSS pattern will have a fewer number of candidate positions. In addition to Observation 1, we come to another observation.

Table 3: An example of hole RSS. (unit : dBm).

	RSS from cell 1	RSS from cell 2	RSS from cell 3	RSS from cell 4
Pattern A	-3.42	-5.23	*hole*	-16.78
Pattern B	-6.23	-13.25	-8.43	*hole*

- **Observation 2.** Let S_A and S_B denote the set of cells whose pilot signals are received by user A and user B, respectively. As the number of cells in their intersection increases, we can say that the similarity (the distance between A and B) between two patterns becomes more substantial. Therefore, comparing two patterns, we need to consider the number of cells common in the two patterns.

Patterns may have RSSs from a different set of cells. Let us take an example of Table 3, in which pattern A has RSSs from cell 1, cell 2, and cell 4, and pattern B has RSSs from cell 1, cell 2, and cell 3. In this example, we cannot calculate Euclidean distance between patterns A and B. We call the RSS from the cell whose RSS is measured by only one pattern (not in the other pattern) as *hole*. In the example of Table 3, the pattern A contains a RSS from cell 4 but the pattern B does not: the RSS entry of cell 4 is a hole in pattern B. Likewise, the RSS entry of cell 3 is a hole in pattern A. As we have observed, if the number of holes of a pattern pair is large, the two patterns' measurement positions are far apart.

In order to calculate the Euclidean distance between them, we assign a certain constant value to holes: *hole RSS*. Through an experiment given in Section 5, we find that a constant somewhat lower than the smallest RSS in the pattern database (also in the sample patterns) is appropriate for the hole RSS. According to Observation 2, we should give some penalty to holes, and the proposed hole RSS method gives penalty by assigning a small value to the hole: as the hole RSS becomes smaller, a distance metric value becomes larger.

We have tested our proposed metric by observing the correlation coefficient between the pattern distance metric and the actual geographic distance. High coefficient value (close to one) indicates the proposed pattern distance metric reflects the actual geographic distance well. From the data set (both seed and sample) of section 5, all possible pattern pairs are examined: we calculate the correlation coefficient between the vector of pattern distance metric and the vector of geographic distance (between measurement positions). The results show that a promising value of a coefficient of 0.7.

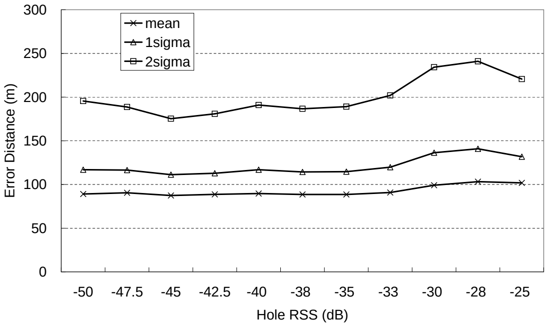

Figure 4: Experiment result with various hole RSS. 1 sigma means the accuracy for the 67% confidence interval and 2 sigma means the accuracy for the 95% confidence interval.

The another application of the proposed distance metric is to infer confidence level of a position fix. If the sample and the picked-up most correlated seed has a small pattern distance metric, the measurement position of the seed patten is close to the sample measurement position, i.e., the position fix is accurate with a high probability.

5 EXPERIMENTAL RESULTS

We have performed extensive experiments with data gathered from the commercial CDMA network of the company A in the urban area of Seoul, Korea. The gathered data sets are as follows.[2]

- **Seed pattern database:** The pairs of the position and the signal pattern were gathered by the CDRs uploaded by AGPS terminals in the urban area (near the *Gangnam station*) of Seoul. The area size is $1km \times 1.8km$, and we obtained seed patterns of 283 positions in that area.
- **Sample data set:** We measured signal patterns at 30 points in the area covered by the signal pattern database. We measured 5 samples at one point, indoors/outdoors separately at the same point [3]; 300 samples in total were measured. We retrieved the real latitude and longitude of each point using the digital map, which enabled us to calculate the error distances of localization results.

Choice of Hole RSS: First, we have performed an experiment to determine the appropriate value of the hole RSS. We figured out under which value it shows the best accuracy, varying the hole RSS from -50 dB

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[2] In our experiments, the CDRs contain the SINR values (Ec/Io) from the adjacent cell towers, and we have used the SINR values as signal pattern instead of the RSS.

[3] For example, samples were measured inside and outside of a building entrance with a distance of several meters, or measured under the roof and on the roof of a building.

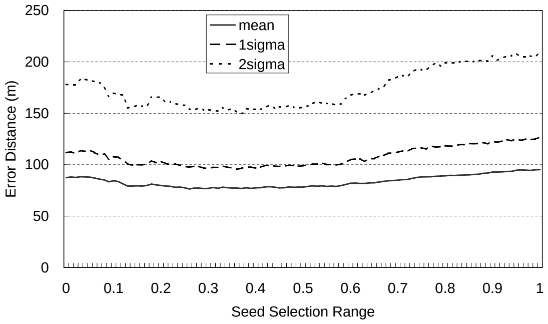

Figure 5: Experiment result with various seed selection range.

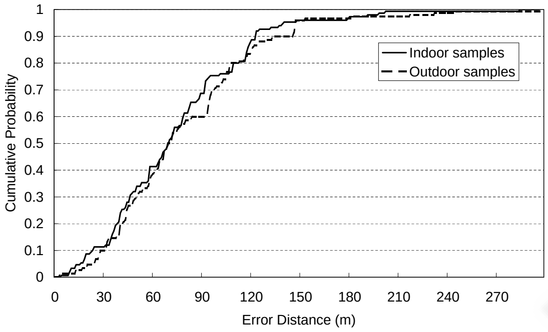

Figure 6: Cumulative distribution function (CDF) accuracy of proposed pattern matching that used with indoor and outdoor samples separately. Hole RSS is -45 dB and seed selection range is 0.37.

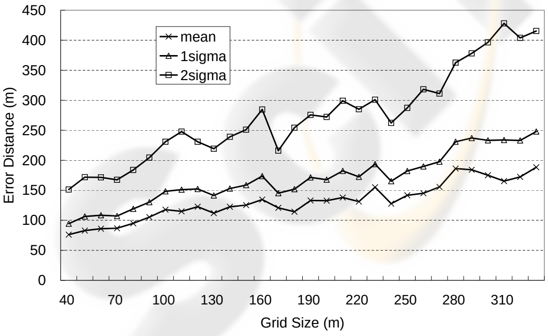

Figure 7: Experiment result with various grid size (seed density). Hole RSS is -45 dB and seed selection range is 0.37.

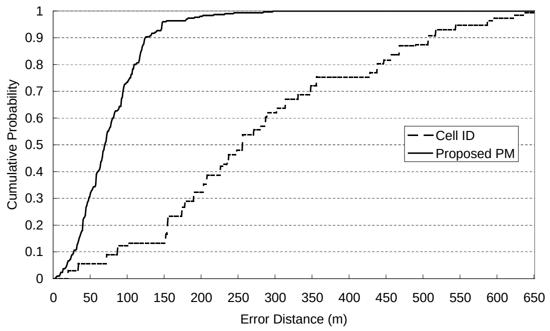

Figure 8: Cumulative distribution function (CDF) accuracy of proposed pattern matching and Cell ID method. Hole RSS is -45 dB, and seed selection range is 0.37, and all seeds are used.

to -25 dB. Figure 4 shows that, with -45 dB of the hole RSS, we can achieve the best accuracy; in this case, the mean error distance is 87.4 m and 2 sigma (the accuracy for the 95% confidence interval) is 175.2m. In our experiment environment, the minimum RSS that a user terminal can detect is around -32 dB: -45 dB is somewhat lower value than the minimum RSS. From this result, we can infer that the somewhat lower value than the minimum RSS which a user terminal can detect is eligible when applying our proposed method to other wireless networks.

Effect of multiple top seeds: Next, we have figured out the effect of seed selection when determining the position of a user terminal. The basic pattern matching uses only the most similar seed (top seed), and determines the position of that seed as the user terminal's position. However, because of the momentary fluctuation of the radio signal caused by shadowing, the result of the basic pattern matching is not stable. This is the reason why we propose to exploit several similar seeds when estimating the position of a user terminal in the previous section. We perform an experiment, varying the seed selection range based on the top seed metric. The seed selection range will be denoted by S. Let m be the top seed metric, then we will consider the positions of the seeds whose metric is less than $m \times (1+S)$. Then we determine the position of a user terminal as the centroid of those seeds. We use -45 dB as the hole RSS in all following experiments.

Figure 5 shows the error distances with varying the value of the seed selection range. When the seeds are selected within the appropriate seed selection range, the accuracy of the result is better than that of the case that only top seed is selected, i.e., when the seed selection range is zero. From the graph, we find that the accuracy of the result is the best when the seed selection range is 0.37, in which case, the mean error distance is 76.8 m and the 2 sigma result was 149.8m.

In particular, the 2 sigma result shows more improvement (180m to 150m) while the mean value exhibits relatively small improvement (90m to 77m): this centroid method decreases the deviation, and thus, has a stabilization effect.

Indoor vs. outdoor: Throughout the previous experiments, we have used the mixture of both the indoor and the outdoor samples. Now, we test whether our proposed pattern matching is suitable for the indoor samples. Figure 6 shows the cumulative distribution function (CDF) accuracy of our proposed pattern matching with indoor and outdoor samples separately. Although the indoor samples are usually collected from several meters inside from building entrances and do not include deep basement samples, it shows almost the same accuracy values in both indoor and outdoor samples, from which we could conclude our proposed pattern matching is suitable for both the indoor and the outdoor samples.

Effect of seed density: The accuracy of our proposed pattern matching shows some dependency on the density of the seeds (the number of seeds in the seed database per unit area). Through experiments, we examine the relation between the density of seeds and the accuracy of our method. In the experiment, we divide a range into grids, and leave only one seed in a grid. Figure 7 shows the experiment result. As the grid size increases, the accuracy of the proposed pattern matching method becomes lower. Particularly, above 70 m of the grid size, the accuracy of our proposed pattern matching decreases rapidly. Hence, in our proposed pattern matching, the appropriate density of seeds has to be maintained to achieve the high accuracy.

Comparison with Cell-ID: Finally, we have compared the accuracy of our proposed method with the Cell-ID method. Figure 8 shows the cumulative distribution function (CDF) accuracy of our proposed pattern matching and Cell-ID method. As Figure 8 shows, the accuracy of our proposed pattern matching is much higher than Cell-ID method.

6 CONCLUSION

In this paper, we have proposed a novel pattern matching localization method for the cellular network, by exploiting the CDRs uploaded by AGPS terminals as inputs to the pattern database. We have analyzed the characteristics of RSS patterns from AGPS CDRs, and designed the pattern-distance metric and the new pattern matching method using that metric. The proposed positioning method reduces the pattern collection overhead by automating the construction of the RSS pattern database. The experiment results demonstrate that 1) the accuracy of the proposed positioning method is much higher than that of the Cell-ID method 2) the proposed AGPS CDR based method works well for indoor users as well as for outdoor users 3) the density of seed patterns is closely related to the positioning accuracy. For the future work, we will investigate how to leverage other GPS-free positioning methods together with the proposed AGPS CDR based pattern matching method.

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