Signal Dragging: Effects of Terminal Movement on War-Driving in CDMA/WCDMA Networks

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Abstract. In cellular networks, the signal pattern reported by a mobile terminal has been the major source for localization. In this paper we show how the signal pattern is affected by the terminal movement such as the speed and the moving direction in CDMA/WCDMA networks. When the mobile terminal is moving, its signal pattern tends to contain more signals from base stations positioned opposite of the terminal's moving direction than signals from base stations positioned in the forward. We call this phenomenon *"signal dragging"*. If the signal dragging prevails, it naturally provides a useful hint for figuring out the movement of a terminal, e.g., direction. We also show that the accuracy of the localization algorithm based on pattern matching varies greatly depending on the terminal movement. Based on these experimental results in commercial networks we suggest the practical data collection procedure, e.g., the war-driving, should consider the terminal movement. Otherwise the use of war-driving data can be harmful.

1 Introduction

[1]Recent advances in ubiquitous computing applications and location-based services (LBSs) have necessitated the network-based localization of mobile terminals. The cellular phones and many other hand-held mobile devices become the core of LBS applications such as E-911, location-aware information search, and car navigation. Although GPS provides fairly accurate location estimates in open areas, its applicability becomes very limited where line-of-sight (LOS) paths to four or more satellites are not guaranteed: for example, indoor areas, narrow street canyons of urban areas, and deep mountain valley. GPS also requires additional hardware equipments on mobile terminals, which increases manufacturing cost.

To overcome the limitation of GPS, academia and industrial communities have made great efforts for the network-based localization technologies especially for the mobile terminals in cellular networks. Every base station (BS)

[1] This work was supported in part by MIC & IITA through IT Leading R&D Support Project and the Brain Korea 21 project of Ministry of Education, 2007, Korea.

J. Hightower, B. Schiele, and T. Strang (Eds.): LoCA 2007, LNCS 4718, pp. 211–227, 2007.

broadcasts its own identifier (Cell-ID), which enables the mobile terminal to estimate its position roughly. For more precise positioning, a number of proposed solutions have utilized the propagation delay, time-difference-of-arrival (TDOA) [20] [22], antenna orientation or received-signal-strength (RSS). Without the LOS path between a transmitter and a receiver, the distance calculated from the propagation time can be erroneous. TDOA localization requires time synchronization among BSs, which is not fulfilled in GSM and UMTS but only in CDMA networks. The orientation and the angle opening of sector antenna can be used to increase the positioning accuracy. Many service providers, however, do not maintain the orientation, opening and tilting information of each sector antenna.

Compared to the above mentioned parameters, the RSS is commonly available parameter for all types of wireless networks. Many localization techniques proposed for cellular networks such as pattern matching (PM) [7] [10], particle filter [17] [18] [19], (weighted) centroid [6] [8], and Cell-ID [23] depend on the RSS information. In the PM localization system, for example, signal patterns are measured a priori over the entire service area and stored in a pattern database. The position of the terminal is then determined by comparing the terminal's currently reported signal pattern to the database entries and finding the best-matching location.

In this paper, however, we show that *the movement context of a mobile terminal highly affects its signal pattern, eventually the performance of some RSS-based localization systems.* From our WCDMA and CDMA measurement data obtained from two metropolitan cities: Seoul, Korea and Seattle, USA, we have observed that signal patterns measured at the same position can be highly deviating depending on the movement context such as direction and speed. In particular, our major finding is the *"signal dragging"* phenomenon: when the mobile terminal is moving, its signal pattern tends to contain more signals from the BSs positioned opposite of the terminal's moving direction than signals from BSs positioned in the forward direction. This finding indicates the caveats of using war-driving data [5]. When the accuracy of a localization system is evaluated through benchmark tests, test data set is normally obtained by war-driving: we drive a car around the test area with mobile terminals and other measurement equipments. The signal patterns for the pattern database are normally measured by war-driving, too. When a terminal requests its localization to the pattern matching system, the terminal may be stationary or moving in the opposite direction of the war-driving car, which can generate unexpectedly poor localization performance. Therefore the use of war-driving data not considering the movement context of a terminal can be harmful.

Our contributions are the following: (i) we investigate how the movement of a terminal affects its signal pattern and why this signal dragging happens, (ii) we show how localization accuracy is affected by the terminal's movement, and (iii) we demonstrate some applications of this finding: the direction of a moving terminal can be roughly estimated with only one current signal pattern without any signal pattern history.

This paper is organized as follows: Section 2 describes the concept of the signal dragging and its error metric. Section 3 and 4 present the properties and implications of the signal dragging, respectively. Section 5 explains why the signal dragging occurs from a technical perspective. Section 6 outlines related work, and we conclude in Section 7.

2 The Effect of Movement

In this section, based on our measurement data, we show how the movement of a terminal affects the signal pattern reported.

2.1 Signal Pattern Data

To prepare and perform a handover, a mobile terminal continuously measures signal strengths from both the serving BS that communicates with and other surrounding BSs. The serving BS also informs the mobile terminal of a list of adjacent cells which it should monitor. Mobile terminals automatically reports the signal pattern to the network when performing a location update procedure.[2] This signal pattern normally consists of many pairs of a BS identifier and its RSS value ([BS ID, RSS]). Thus, the signal pattern information is continuously maintained by a terminal and is accessible by a localization module in a mobile terminal.

When we seek to investigate network characteristics or to optimize the cell planning of the network, signal patterns are measured normally through war-driving. Especially if we perform the network-based localization without the help of GPS, signal patterns are the only source of information to estimate the terminal's position. Therefore understanding the characteristics of signal patterns is crucial for the localization and the network management.

Our signal pattern data used in this paper includes WCDMA measurements in Seoul, Korea and Seattle, USA; and CDMA measurements in Seoul, Korea. We used the Inno Wireless OPTis-S diagnostic module attaching SiRF3 chipset based GPS devices and mobile terminals, LG SV900 for CDMA measurements and Samsung W120 and LG CU500 for WCDMA measurements. Fig. 1 shows the measurement area in Seoul, in which we collected WCDMA data sets.[3] The positions of BSs are depicted by circles and given by operators; thus, they are fairly accurate. However, seven more BSs have been deployed in the area of Fig. 1 after we got the BS position database from the operator, which contribute to the experimental errors to some extent.

[2] This report is called *Network Measurement Report (NMR)* in a GSM network and NMR in GSM only contains the records of up to six or seven strongest signal strength measurements.

[3] We also have and use another WCDMA data sets measured in Seoul at different times.

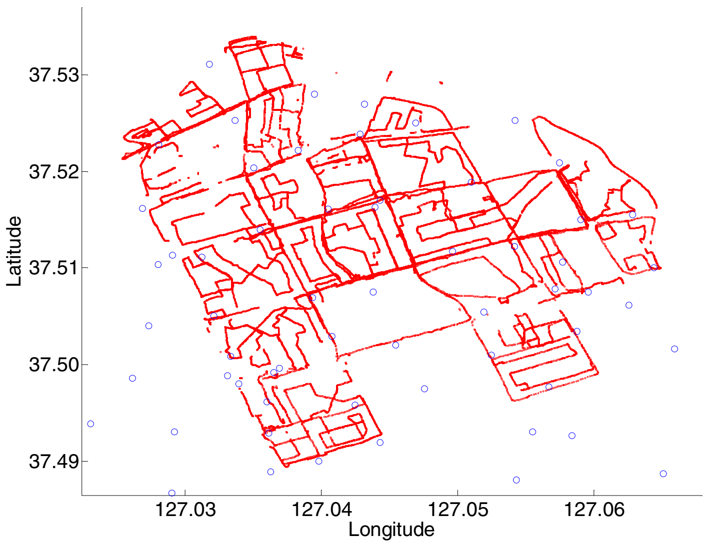


Fig. 1. The measurement area in Seoul, Korea, about $25km^2$

2.2 Signal Dragging

From our large data sets, we realized that a moving mobile terminal tends to retain signal information of old BSs than newly appearing BSs. In other words, when the mobile terminal is moving, its signal pattern information tends to contain more signals from BSs positioned opposite of the terminal's moving direction than the signals from BSs positioned in the forward direction. Fig. 2 illustrates the situation where the "*signal dragging*" phenomenon occurs. A mobile terminal is receiving signals from six BSs while the user of the mobile terminal is moving northeast-ward. The terminal's signal pattern contains four signals from the backward BSs but contains only two signals from the forward BSs.

To show the signal dragging phenomenon more effectively, we draw vectors (white arrows in Fig. 2) stemming from the mobile terminal's position to individual BSs' positions; each vector is called a BS vector. Then we sum the BS vectors to calculate the sum vector, which is illustrated by the dark gray arrow pointing toward the southwest direction in Fig. 2. Because more backward BSs are included in the signal pattern than forward ones, the sum vector tends to point toward the opposite direction of the terminal's moving direction. Thus, if we reverse the sum vector, the resulting direction vector is likely to point toward the moving direction of the terminal as described.

Fig. 3 shows that signal dragging occurs in a real driving user's circumstance. The two axes indicate the latitude and longitude, the squares are the ground truth (GT) position of a moving user, and the circles are the positions of BSs in the example area. The arrows in Fig. 3 indicate the direction estimation vector which corresponds to the reverse of sum vector (black arrow) in Fig. 2. The length

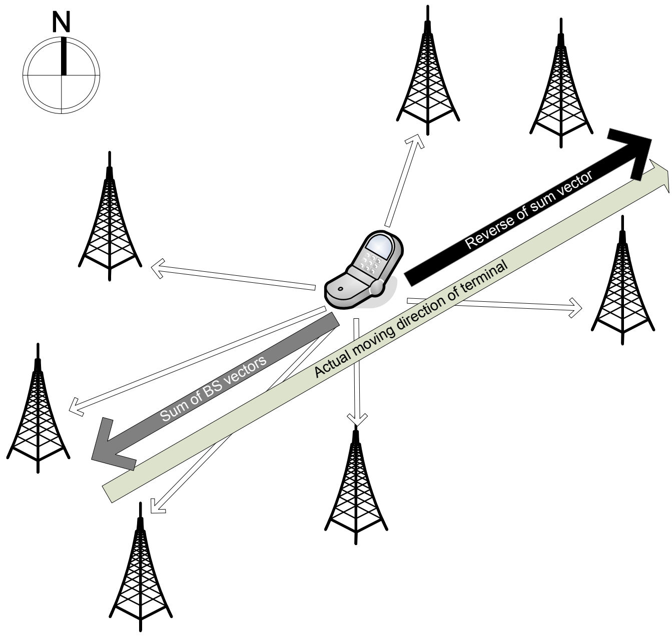


Fig. 2. A descriptive picture of the signal dragging phenomenon

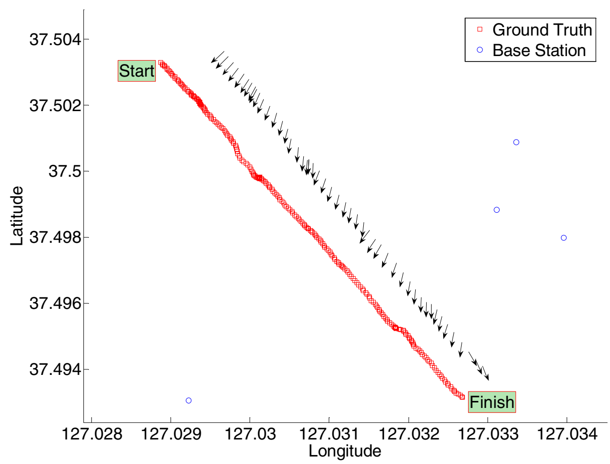
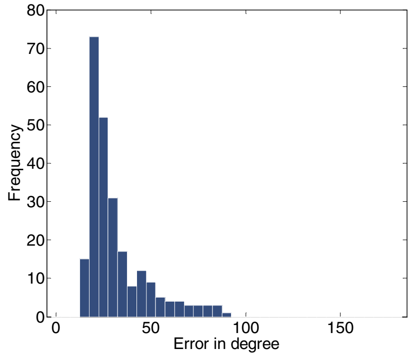
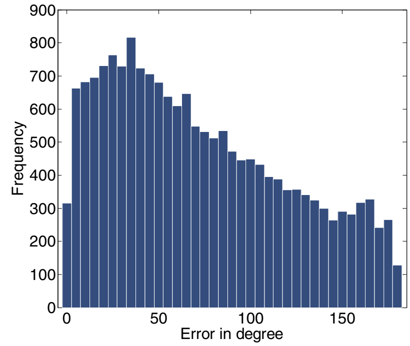


Fig. 3. An actual example of the signal dragging phenomenon from WCDMA data of Seoul, about $0.8km^2$

of all BS vectors are equalized before being summed up to remove the weighted effect of distant BSs. And the length of the sum vector is also equalized before plotting because this helps us figure out the estimated direction more easily.



(a) SDEM distribution of the trajectory in Fig. 3, mean 31.5, median 25.8



(b) SDEM distribution of the trajectory in Fig. 1, mean 72.6, median 64.0

Fig. 4. SDEM distributions

Each arrow plotted corresponds to one GT spot estimating the current moving direction of the user.[4] Thus, if the direction of arrows matches the actual moving direction, we can say that the signal dragging phenomenon occurs notably.

Signal Dragging Error Metric (SDEM). As an intuitive metric indicating whether the phenomenon has occurred as expected or not, we can use the angular difference (absolute value) between two vectors, the actual user direction vector (i.e., difference of two consecutive ground truth (GT) positions) and the estimated direction vector (the arrows on the map in Fig. 3). We call this absolute angular difference as *Signal Dragging Error Metric (SDEM)*. Using the mean of the SDEMs at all user's position on the map, we can tell that the signal dragging phenomenon in the interested area has shown its efficacy as long as the mean value is less than 90 degrees. If the mean value is near to 90 degrees, there is no relation between the terminal's movement and the geometric distribution of BSs in the terminal's signal pattern at all. If the mean is bigger than 90 degrees, we can tell that more forward BSs tend to be contained in the signal pattern rather than the backward BSs on average: the opposite of signal dragging. Recall that the direction estimation vector is the reverse of the sum vector.

The mean SDEM of the trajectory data in Fig. 3 is 31.5 degrees while the median is 25.8 degrees. Therefore we can say that the signal dragging is apparent. The mean SDEM evaluated on the entire trajectory in Fig. 1 is 72.6 degrees and the median is 64.0 degrees. Even the mean SDEM is less than 90 degrees, we may need to further investigate the detailed distribution of the metric values. The SDEM distribution of the data set of Fig. 3 is given in Fig. 4.(a), in which no SDEM over 90 degrees is observed. Fig. 4.(b) shows the SDEM distribution of the entire trajectory of Fig. 1. In this distribution, almost two-third of SDEM values

[4] We draw only a half of the total arrows corresponding to GT spots in the figure to have enough spacing between adjacent arrows so that each arrow can be shown clearly.

are less than 90 degrees but also significant amount of spots show inconsistent results. Note that the median SDEM is normally smaller than the mean SDEM. This implies more number of data lie below the mean value. The reason why the average SDEM is bigger in Fig. 1 is because the trajectory and the change of moving direction is more versatile in Fig. 1, which will be explained in section 3.

In our experiments, the user GT positions are obtained by GPS and, in turn, the user moving directions are calculated from the GPS records. Because GPS position estimation is also erroneous especially in urban areas, the actual user direction we use can be erroneous. In order to reduce the effect of GPS error on SDEM, we exclude signal pattern records that are measured when the user is almost stationary. For example, in this paper, if the instant speed of the user computed from the two consecutive GPS records is less than 10km/h, the signal pattern record is excluded.

3 Properties of Signal Dragging

In this section, we enumerate interesting factors which affect the signal dragging phenomenon: speed, direction change, and BS arrangement.

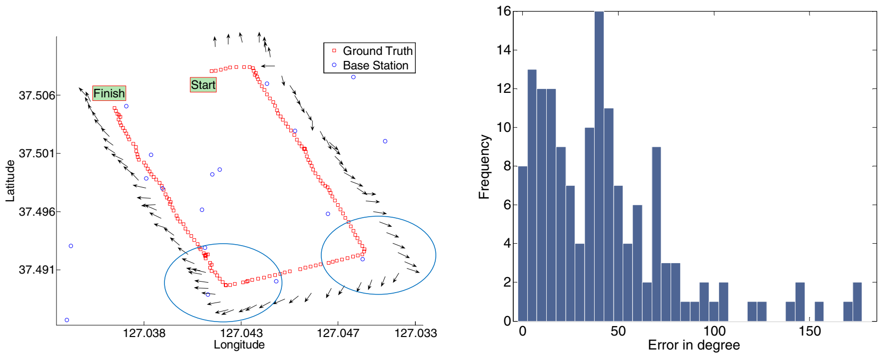
Correlation with Speed

The speed of a mobile terminal affects the degree of signal dragging. In order to observe the relation, we compute the correlation coefficient between the terminal's moving speed (calculated from two consecutive GPS records) and the $(180 - SDEM)$.[5] When we test the straight trajectory data set of Fig. 3 whose average speed in km/h and deviation is 31 and 12 each, the correlation coefficient is 0.48. We argue this is sufficient to say that the moving speed of terminal is positively correlated to the effect of signal dragging. In other words, as the terminal moves faster, the signal dragging becomes more notable. Here, we exclude signal patterns with the screening threshold 4km/h instead of 10km/h in order to see the correlation between speed and signal dragging more vividly.

Direction Change

Fig. 5.(a) shows the rectangular shaped trajectory of one of our WCDMA data sets measured in Seoul, Korea, while the SDEM distribution of the data set is shown in Fig. 5.(b). As shown in the two corners marked by ovals in Fig. 5.(a), *when the mobile terminal turns its direction, the direction estimation arrows gradually converge to the changed direction of the terminal after some delay.* The arrows finally catch up with the terminal's direction as the terminal moves on the straight road about 500 meters after the turn in this example. Thus, if the terminal changes its direction frequently, the SDEM value tends to increase. The best case happens when the terminal moves in a straight line for a sufficient time as shown in Fig. 3.

[5] Because SDEM increases as the effect of signal dragging decreases, we subtract the calculated SDEM from 180 degrees to compute the correlation coefficient.



(a) WCDMA trajectory in Seoul, Korea, about $3.5km^2$

(b) SDEM distribution, mean 42.8, median 37.8

Fig. 5. Vector convergence at the change of direction

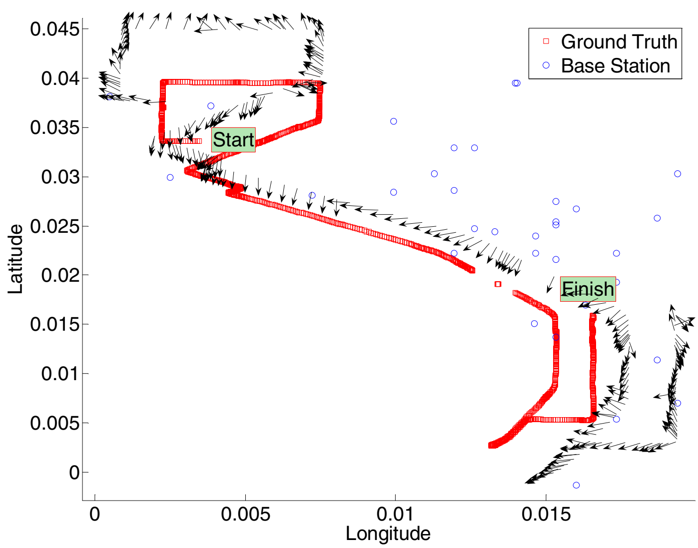
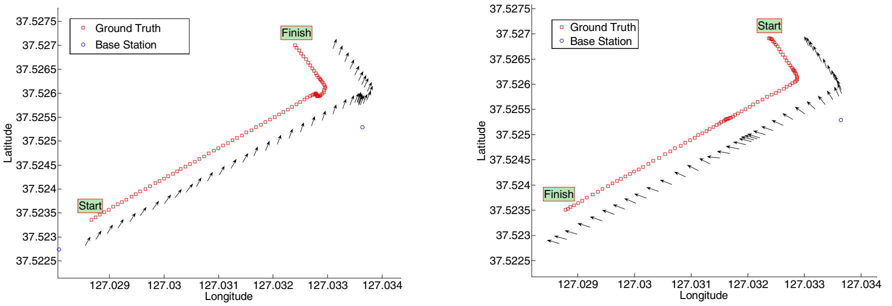


Fig. 6. The effect of uneven BS arrangement (WCDMA data in Seattle, USA, about $8.4km^2$)

We have observed a similar effect of direction change and vector convergence from many other data sets whose trajectories contain direction changes followed by straight lines. Those data sets include measurements from not only Seoul but also from Seattle, USA.

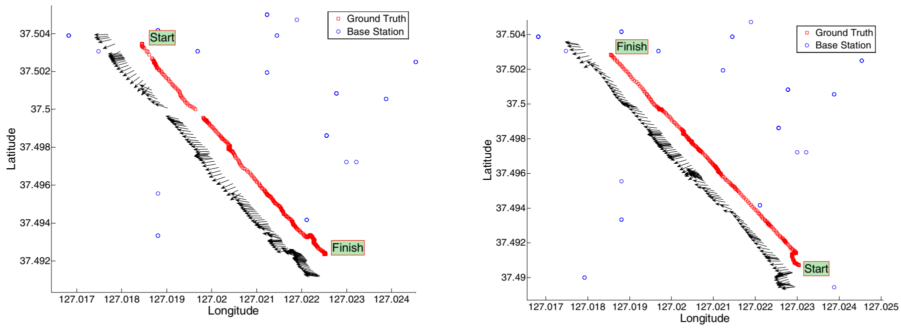
From the way how a mobile terminal updates and maintains its signal pattern, we may find the factors that attribute this convergence delay. The section 5 will convey the technical backgrounds of CDMA and WCDMA systems related to this issue.



(a) Initial direction, SDEM mean 48.4, median 40.1

(b) Reverse direction, SDEM mean 88.8, median 64.0

Fig. 7. Two directional WCDMA data sets in Seoul, about $0.2km^2$



(a) Initial direction, SDEM mean 107.7, median 111.5

(b) Reverse direction, SDEM mean 68.5, median 64.0

Fig. 8. Two directional CDMA data sets in Seoul, about $0.8km^2$

Arrangement of BSs

Another interesting property is observed in Fig. 6[6]. The white area at the left bottom of the map indicates a sea in which there is no base stations. Reminding the way the arrows are drawn, if the terminal is located on the seaside, the sum vector can only indicate to the inland despite of the terminal's movement. If we reverse the sum vector, the final direction vectors will eventually point toward the sea. This specific arrangement of BSs became the major contribution to SDEM of this data set of Fig. 6 whose mean value is 79.3 degrees and the median is 65.8 degrees.

In the data sets measured in Seoul, we have observed the similar effect of uneven (or biased) arrangement of BSs. For example, if the terminal is located

[6] The absolute latitude and longitude values are replaced by the relative values due to the operator's request.

on the riverside or on the boundary of urban/rural area, the arrangement of BSs surrounding the terminal is highly biased toward inland or urban area. On the contrary, as the arrangement of BSs is closer to uniform, the signal dragging phenomenon tends to be more notable. *Thus, the arrangement of BSs and the geographical environment greatly affects the efficacy of signal dragging phenomenon.*

Now, we may want to know how much the moving direction of a terminal causes signal dragging despite of the influence of BS arrangement. Fig. 7 and Fig. 8 show the both effects of moving direction and BS arrangement. We measure signal patterns twice on the same road (using same measurement equipments) with two different driving directions opposite each other. For convenience, we denote one direction as *initial direction* and the other direction as *reverse direction*. If estimation arrows point toward the terminal's direction in both trajectories, we can say that the signal dragging is apparent and the influence of BS arrangement is weak. In the example of Fig. 7, arrows in both directions tend to point the direction the terminal moves toward; however, the efficacy of signal dragging in the reverse direction (Fig. 7.(b)) is not so apparent, because more BSs are placed in bottom right of the trajectory than in upper left, though most BS positions are not shown in the map.

On the contrary, the two-way direction test results in Fig.8 with CDMA measurements show one example where signal dragging hardly happens due to the uneven arrangement of surrounding BSs. The arrows in Fig.8.(a) and Fig.8.(b) are similar despite of their opposite moving directions. Although the arrows in both trajectories are similar, the signal patterns of each direction are different enough to affect localization performance. We will discuss the difference in section 4.

4 Implications of Signal Dragging

In this section, we further investigate the implications and the applications of the signal dragging with a number of example data sets.

4.1 Pattern Matching (PM)

In PM systems [7] [9] [10] operators collect signal patterns from a number of selected points in the service area and store them in a pattern database: we call a signal pattern in the pattern database as a *seed*. Based on the assumption that the signal pattern at a certain point is stable temporally and spatially, the position of a terminal is determined by comparing the terminal's current signal pattern (*sample*) to the database entries and finding the best-matching location.

To see if there exists a difference in the performance of the positioning algorithm by the movement context, we perform PM experiments using the collected signal patterns in both directions (initial and reverse) of the same road. The seed and the sample pattern data are collected in the areas in Fig. 7 (WCDMA) and Fig. 8 (CDMA). A complete description on the pattern distance metric and other

PM parameters can be found in [9]. We have total four kinds of data sets for each direction and each radio network (WCDMA and CDMA). We performed eight different PM experiments using one directional data as seeds and another directional data as samples for each radio network as the results shown in Table 1. In the case that the directions in measuring the seed and the sample data are same, the location error is much smaller than that of the case that the directions are different. This means the signal pattern can be very different depending on the moving direction in war-driving.

Table 1. 95 percentile PM errors using different seed and sample data

Seed by Sample	WCDMA (meter)	CDMA (meter)
Initial by Initial	97.87	86.71
Initial by Reverse	202.80	197.33
Reverse by Reverse	54.86	74.58
Reverse by Initial	115.30	271.21

4.2 Centroid Family

The centroid family contains three localization algorithms: centroid, weighted centroid, and cell ID. The centroid algorithm generates the resulting position as the middle point of BSs whose pilot signals are in the signal pattern regardless of the RSS value of each BS. Whereas the cell ID algorithm simply returns the position of the reference BS. In case of the weighted centroid algorithm we compute the RSS weighted average of the given BS positions in a signal pattern as explained in [8].

Table 2. 95 percentile error results of centroid family algorithms

Data	Centroid (meter)	Weighted Centroid (meter)	Cell ID (meter)
WCDMA Initial	325.37	454.44	462.85
WCDMA reverse	326.56	427.62	527.01
CDMA Initial	2103.77	412.15	274.16
CDMA reverse	1623.28	502.55	335.13

Table 2 shows the localization errors of the centroid family algorithms using the same data set in PM. We can see the similar error results in both directions irrelevant of the type of centroid algorithms, which is in contrast to the PM error results. The reason why the PM and the centroid family shows different results is that the PM algorithm is based on the similarity between the signal patterns of seeds and samples but the centroid family algorithms calculate the position of a terminal only using the current signal pattern; the centroid family algorithms do not need to compare the signal patterns. From these results we can say that the pattern database should be constructed with various terminal movement contexts considering the direction and the speed.

4.3 Direction Estimation

If the signal dragging phenomenon prevails, the signal pattern shows directional characteristics to a certain degree. We can leverage this directivity to find out the terminal moving direction: the direction estimation vector which is the reverse of the sum vector. As described in subsection 2.2, we have drawn BS vectors stemming from the terminal's true position (GT) and calculated the SDEM. The GT position of a terminal, however, may not be available to users in real application scenarios. If a terminal is equipped with GPS, we can use GPS results as GT positions. Otherwise, we should use the result of network-based localization algorithms as an alternative for the GT in calculating the SDEM. To see the applicability of signal dragging, we arbitrarily employ the RSS-based weighted centroid algorithm among the centroid family to find out the position of a terminal instead of GT. The mean and median SDEM of the area in Fig. 1 is 73.9 degrees and 65.6 degrees each. Comparing with the result of the GT based SDEM (mean 72.6, median 64.0), this proves the applicability of direction estimation.

To the best of our knowledge, this is the first work to show the possibility of direction estimation of mobile terminals without depending on previous records (history) of terminal positions. Only one single instance of a signal pattern currently available at the terminal is needed for direction estimation.

5 Technical Reasons of Signal Dragging

In order to understand why the signal dragging phenomenon happens from a technical perspective, we need to investigate the characteristics of cellular network systems we used. In this section, we overview the basics about CDMA and WCDMA systems focusing on the logical channel structure and the pilot set management policy. Based on these backgrounds we will discuss the technical reasons why the signal dragging occurs.

5.1 Basics of CDMA and WCDMA Systems

We start this section from the basics of IS-95 CDMA and CDMA2000 standards which are used for the mobile telecommunications employing the code division multiple access (CDMA) scheme. For the communications between the BS and the mobile station (MS), there are two kinds of links, the forward link from the BS to the MS and the reverse link from the MS to the BS. We are interested in the forward link because the signal information from the BS is delivered to the MS through this link. The forward link consists of a pilot channel, a synchronization (sync) channel, a number of paging channels, and traffic channels. The pilot

CDMA signal transmitted by a BS provides a reference for all MSs around. Its broadcast period is 26.66 ms due to the fixed chip rate. The pilot signals from all BSs are based on the same pseudo-random binary sequence, but each BS is identified by a unique time offset of its pseudo-random binary sequence. The MS processes the pilot channel to find the strongest pilot signals to decide when to perform handoff. Once the MS identifies the strongest pilot offset, it examines the signal on its sync channel which is locked to the pseudo-random binary sequence signal on the pilot channel and obtains the information pertinent to this particular BS. The MS now attempts to access the paging channel and listens for system information. After the acquisition of the paging channel, it listens to the assigned paging channel and is able to receive and initiate the calls.

The paging channel is subdivided into paging channel slots. In non-slotted mode in which the MS is not saving power, the MS monitors all slots on a continuous basis, thus paging and control data for the MS can be received in any of the paging channel slots. In slotted mode, the MS can stop or reduce processing activities to save battery power during the slots in which the paging channel is not monitored. The MS can specify its preferred slot cycle using the SLOT_CYCLE_INDEX field in control messages. The length of the slot cycle, in units of 1.28 seconds, is given by the two to the power of SLOT_CYCLE_INDEX. As an example, if the MS selects the SLOT_CYCLE_INDEX as two, the slot cycle becomes four meaning $1.28 * 4 = 5.12$ seconds.

The pilot channels of the BSs identified by the MS, as well as other pilot channels relayed by the serving BS are continuously categorized by the MS into four groups.

- Active Set: Contains the pilots whose paging or traffic channels are actually being monitored or used.
- Candidate set: Contains the pilots that are not currently in the active set. However, these pilots have been received with sufficient signal strength to indicate that the associated forward traffic channels could be successfully demodulated.
- Neighbor Set: Contains the pilots that are likely candidates for idle handoff. The member BSs are specified in the control or paging channel message from the BS.
- Remaining set: Contains all possible pilots in the current system, excluding pilots in the active, candidate, or neighbor sets.

The pilot channels of the BSs move among sets by the basis of the signal strength, the expiration timer, and the set capacity. The signal pattern information we obtain is from received signal powers of the pilot signals of the BSs in the above sets. The more detailed explanation can be found in [14], [15], and [16].

Wideband CDMA is a type of 3G cellular network designed to achieve higher speeds and support more users compared to the older 2G networks. The similar channel structure mentioned above is also employed in WCDMA. The primary and secondary synch channel and the common pilot channel are downlink channels which carry no user data but perform the similar role as those of CDMA. The cell search procedure is based on these three fundamental physical layer signaling channels available in every cell. The primary synch channel is used to detect the presence of cells and to give information about each cell's slot timing. The secondary synch channel serves as a means of detecting the frame start timing of cells. Other various channels for the cell broadcast and the data traffic are designed. Also the set of monitoring cells are maintained for the soft handover. Like the slotted mode in CDMA, the discontinuous reception (DRX) mode is supported in WCDMA. The MS may use DRX in an idle mode in order to reduce power consumption. When DRX is used the MS needs only to monitor one page indicator in one paging occasion per DRX cycle. The detailed specifications can be found in [11], [12], and [13].

5.2 Why the Signal Dragging Occurs, a Technical Perspective

From the information in the previous section, we can find out the reasons why the signal dragging happens.

First, the difficulty of synchronizing with a newly found BS makes the mobile terminal hard to recognize forward BSs. As we have discussed earlier, the pilot signal is broadcast by the BS every 26.66 ms. This inevitably induces delay time in reading the pilot signal from a newly found BS, which may be positioned in the forward direction with a higher probability than the backward direction. After the terminal gets the pseudo noise (PN) code from the pilot channel, it will need more time to get the PN offset from the sync channel. In addition, if the terminal is moving fast, the multipath fading effect occurs severely interfering the terminal from receiving the intended signals.

Second, if the mobile terminal is working in a slotted mode, it updates its signal pattern information with relatively long update interval time which is calculated from the SLOT_CYCLE_INDEX parameter. As explained in the previous subsection, the terminal becomes awake based on the slot cycle. From our CDMA measurement data, we found that SLOT_CYCLE_INDEX is set to be 2 in the CDMA terminal used in our measurements. In other words, the update interval of signal patterns measured in a slotted (idle) mode was about 5 seconds, which is similar to $1.28 * 2^2 = 5.12s$ as explained in the previous subsection.

The third reason of the signal dragging is that the mobile terminal tends to keep the acquired signal pattern information even after the corresponding BS's pilot channel is not detected any more. Once the terminal obtains the necessary information of BSs, it saves and manages the information according to the pilot set handling policy. Even the pilot signal strength of a BS in the active set is weakened below a certain threshold, the pilot information is not excluded from the four sets instantly but lowered the set position to candidate or neighbor or remaining set. Moreover in slotted mode, the slot cycle also contributes to the delayed discard of an old weak signal.

6 Related Work

There has been studies trying to predict the movement context of a user from the signal pattern. The movement context can be the location, direction, speed, and acceleration. The location context has been the primary concern of the academia and the industry, and the practical level of accuracy satisfying the E911 requirements are achieved using different algorithms [6] [7] [8]. Many people tried to guess the mobility status of a user from signal patterns in GSM and WiFi systems [2] [3] [4]. The basic idea is that the signal pattern varies more intensively as the terminal moving speed increases. This idea is consistent with our findings in that the signal patterns are varied by the movement context such as the speed or the moving direction. In order to extract the movement context, two are more signal patterns are compared, thus they need some history of signal patterns. But our work differs in the sense that the movement context can be extracted even from a single instance of a signal pattern.

M. Kim et al. [5] points out the hazards of using war driving trace data. According to their work, if we just drive and collect signal patterns, we may not be able to get sufficiently accurate AP position data for the subsequent localization. Even their work is based on WiFi, we argue that the same thing can happen in the cellular networks too. Due to the difficulty of getting the BS database from the provider, the researchers often build their own database, so called virtual network database [1] [6]. We point out that the errors of the localization is not just from the incorrect virtual network database but also from the mismatching movement context between the time of war-driving and that of the subsequent localization.

Many studies on the metropolitan scale localization have been done in GSM networks [1] [6] [7] or in WiFi networks [4] [21]. But we have performed our whole experiments in CDMA and WCDMA networks. The experimental results in this paper can help others understand the different properties of the CDMA/WCDMA networks.

7 Conclusion and Future Work

We have revealed that there is a significant relationship between the signal pattern and the terminal movement context. The signal patterns are very important sources for the localization, tracking, and network measurement applications. Thus understanding the nature of the signal pattern is essential for the better services. We have shown that the signal dragging occurs as an influence of the terminal movement context using CDMA/WCDMA test data in two cities. We defined an intuitive signal dragging error metric to quantify the extent of the signal dragging. Using this metric and its distribution, we exhibited how the factors affect the signal dragging. The signal dragging phenomenon illustrated how to augment the current methodology of collecting signal patterns, especially the war-driving. There can be limitations or hazards of using war-driving data without the movement context at the time of war driving. We have shown that the PM accuracy can be greatly influenced by the terminal movement context whereas the accuracy of centroid family algorithms is not affected. We suggest that we record the movement context as well as the signal patterns so that we can improve/analyze the localization accuracy. The signal dragging phenomenon itself also provides a useful direction context of the terminal, which can be a useful source of the terminal context. On the other hand, we described why the movement context of a mobile terminal influences the signal patterns based on the CDMA/WCDMA specifications.

Our work is, to our knowledge, the first analysis on the effect of the movement context on the signal patterns. We are planning to perform more experiments in various radio environments such as WiFi and GSM.

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