A Noble Probabilistic RF Fingerprinting Method by Using Multiple MNO's Cellular Signals on Smart Watch

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Abstract

In order to accurately locate a target device in an unspecified wide-area environment where GNSS is not possible, improving cell-based positioning technology is very important. However, the existing cell- based positioning technology had limitations in improving performance because it had to utilize only the positioning information provided from the base station of one MNO registered with a SIM card. To overcome this problem, in this paper, we propose a noble algorithm to estimate cell measurements from multiple MNOs using the spatial similarity of SRN. In addition, we tried to improve the performance of RF fingerprinting using a robust feature ("positioning infrastructure matching number") that is not affected by RSS. As a result of the experiment, it was confirmed that by augmenting multiple MNOs, the availability and precision of cell positioning improved by 15. 3% and 31. 2%, respectively, compared to using a single MNO.

Keywords

RF fingerprinting, Multiple MNOs, Smart Watch

1. Introduction

In order to improve location availability and accuracy when requesting emergency rescue in GNSS shadow areas, it is most important to improve the performance of positioning technology using base stations, the most common communication infrastructure. Existing cell-based positioning technology including GSM/LTE/5G/6G [1][2][3][4] traditionally utilizes Cell-ID, ToA, TDoA, AoA, etc., but the multipath of base station signals in dense urban areas and the installation of multiple repeaters to improve call quality deteriorate positioning performance. Meanwhile, Location Fingerprinting (or RF Pattern Matching) patterns the reception characteristics of base station signals that reflect the complex positioning environment in dense urban centers and reflects them in the Location DB, enabling relatively improved positioning. However, in terms of network, due to the nature of the base station as a wide area network, the installation density is lower than that of Wi-Fi and beacons, and as a result, the number of base stations that can be received by the terminal is small. Additionally, in terms of terminals, smart watches usually have fewer base stations (especially neighboring cells) than smartphones at the same point, so a larger base station positioning error may occur.

In this paper, in addition to the directly measured signal reception information from the MNO base station identified by the SIM card in the commercial terminal, the signal reception information from the base stations of other nearby MNOs is additionally estimated to increase the number of available base stations and improve the DOP to reduce the positioning error. Suggest ways to improve. The core principle is to use the signal fingerprint of the unlicensed band (Wi-Fi, BLE, etc.) that can be commonly received by commercial terminals as a kind of spatial identifier, and to use the signal fingerprint of the unlicensed band (LTE/5G/6G, etc.) that has the maximum similarity to the spatial identifier. Other MNO's base station signal reception information is indirectly estimated. In order to accurately determine

IPIN-WCAL 2025: Workshop for Computing & Advanced Localization at the Fifteenth International Conference on Indoor Positioning and Indoor Navigation, September 15–18, 2025, Tampere, Finland

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the maximum similarity, a separate matching DB needs to be created in the form of a combination of unlicensed and licensed band signal fingerprints. However, unlike the general Location Fingerprinting DB, accurate labeling of collected location information is not required, so user participation is required for each location request. Easy construction is possible. In addition, this matching DB can be updated in real time when base stations are added/changed/moved, and is very advantageous in ensuring personal privacy due to non-collection of location information.

To verify the performance of the proposed method, a comparative positioning test was conducted for each terminal (smart watch and smartphone) indoors in 50 buildings densely located in an urban environment, and the presence or absence of enhancement of the cellular signal of another company's MNO and the presence or absence of a combination of positioning resources that can be received were examined. The positioning performance was analyzed.

2. How to estimate multiple MNO's cell signals

In Figure 1, "As-Is" represents a general positioning system currently utilizing a single MNO's base station. At this moment, the target device acquires one serving cell and multiple neighboring cells based on cell measurement values, but the number of available cells is very limited. Especially in suburban or rural environments with few MNO subscribers, in the worst case there may be coverage of several kilometers and only one available cell. In this case, regardless of the type of observation information (time, distance, angle, etc.), there is few algorithm that can improve positioning accuracy. To overcome this problem, To-Be in Figure 1 shows a method to improve base station positioning performance by estimating base station signals of multiple MNOs, increasing the number of available base stations and improving DOP. If cell measurement information of multiple MNOs can be estimated from a target device equipped with a single MNO SIM card, this has a similar effect to improving DOP using multi constellation of GNSS or improving positioning performance using Centroid of multiple Wi-Fi AP locations.

The algorithm structure for estimating multiple MNO's cell is shown in Figure 2.

In the first stage, the target device that received the positioning request scans measurable information such as Cell, W-Fi, BLE, and barometric pressure for RF composite positioning. At this time, cell measurement information is limited to the measurement values of the MNO registered in the SIM card.

In the second step, the measurement information for complex positioning scanned from multiple target devices subscribed to different MNOs is stored in the Multiple Cell Matching DB on the server. In this process, the exact collection location is not necessary.

In steps 3 and 4, the Cell measurement value of other MNOs with maximum similarity is estimated by comparing the Short-Range Node (e.g. Wi-Fi, BLE, etc.) list measured in the target device with the Short-Range Node list in the Multiple Cell Matching DB. In particular, Short Range Nodes are currently installed in dense urban indoor environments and have a smaller communication range than Cells, and can show high spatial similarity when multiple nodes are combined. Therefore, if there is a list of Short-Range Nodes in the unlicensed band that can be commonly measured by the target device regardless of the MNO, the cell measurement values of other MNOs that can be measured directly without changing the current SIM card can be estimated.

In step 5, the final multiple cell measurement is created by combining the cell measurement value of one MNO measured directly by the target device and the cell estimate value of other MNOs.

3. Hybrid RF fingerprinting using RSS agnostic feature

Figure 3 shows the location server structure in which the Hybrid RF Fingerprinting algorithm is implemented using the cell measurement information of the multiple MNOs proposed above.

Similar to the general fingerprinting method, it is largely divided into offline stages for creating a location database and online stages for real-time positioning.

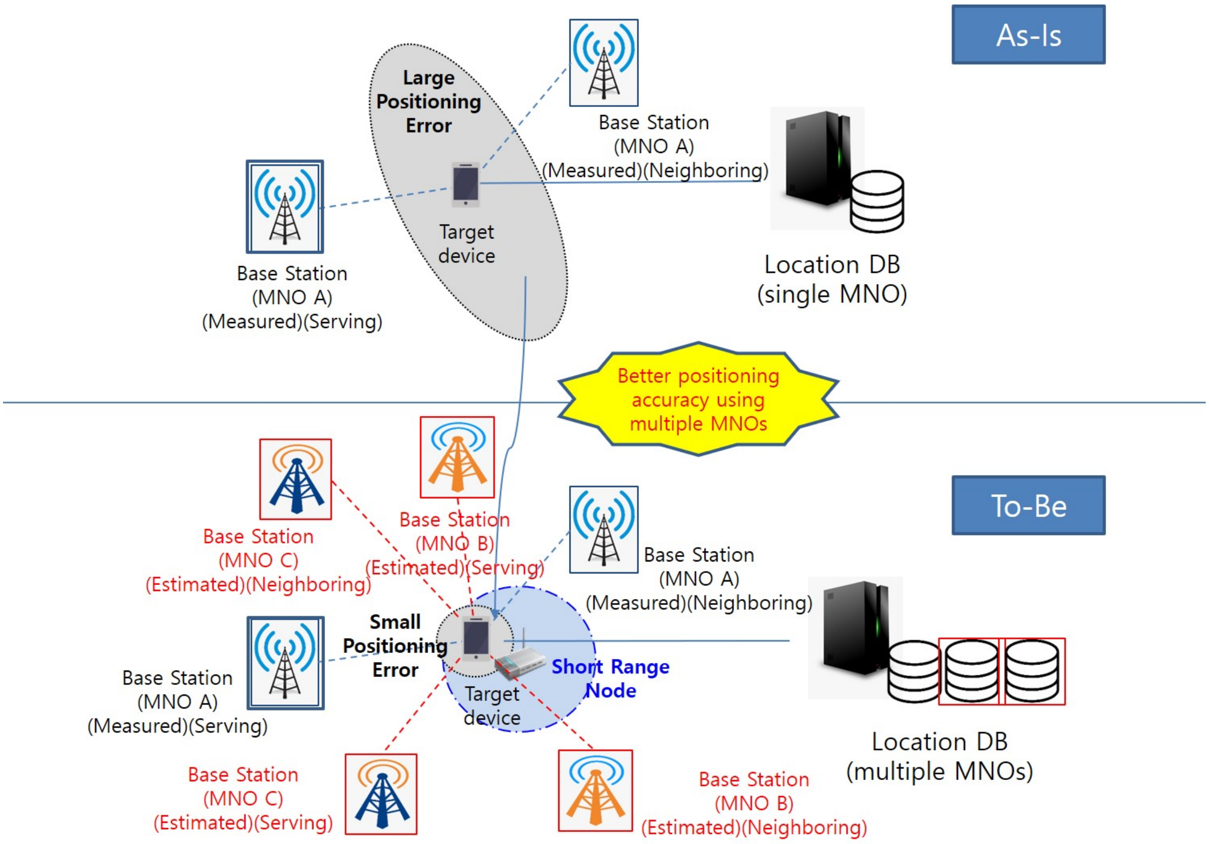

Figure 1: Concept of how to estimate multiple MNO's cell measurements

3.1. Offline phase (data collection and location DB creation)

In order to acquire collected data for creating the location DB, we manufactured a dedicated collection device for vehicles outdoors. The device saves not only multiple MNOs (3 companies), but also Wi-Fi, BLE, barometric pressure, and GNSS in time synchronization, and automatically transmits previously acquired data to the collection server every time the vehicle is started through the LTE Cat M1 communication method.

Meanwhile, indoors, a positioning verification app is installed on user terminals subscribed to various MNOs, and measurement information and collection locations for hybrid positioning are collected in real time every time the self-developed Location API is called. At this time, the collection location is marked on the map by the user or uses location information provided by the mobile OS(Android).

Utilizing all of the indoor and outdoor collected data, a Grid-based Location DB is created by determining a specific collection period and location. The single grid spacing is 25m, and the resolution is set to half of the indoor positioning requirements(50m) of the US FCC.

3.2. Online phase (Hybrid positioning procedure)

In step 1, when PSAP requests positioning, the target device provides measurement information for complex positioning to the Location Server.

In step 2, based on the input value, the cell measurement information of the multi MNO is estimated by comparing it with the multiple cell matching DB. If the corresponding value does not exist, the cell measurement information of a single MNO within the input value is used. In addition to cells, short-range node and sensor measurement information uses input values as is.

Step 3 calculates the location of the final target device through RF fingerprinting operation that compares the measurement information estimated in Step 2 with the Location DB. However, in this paper,

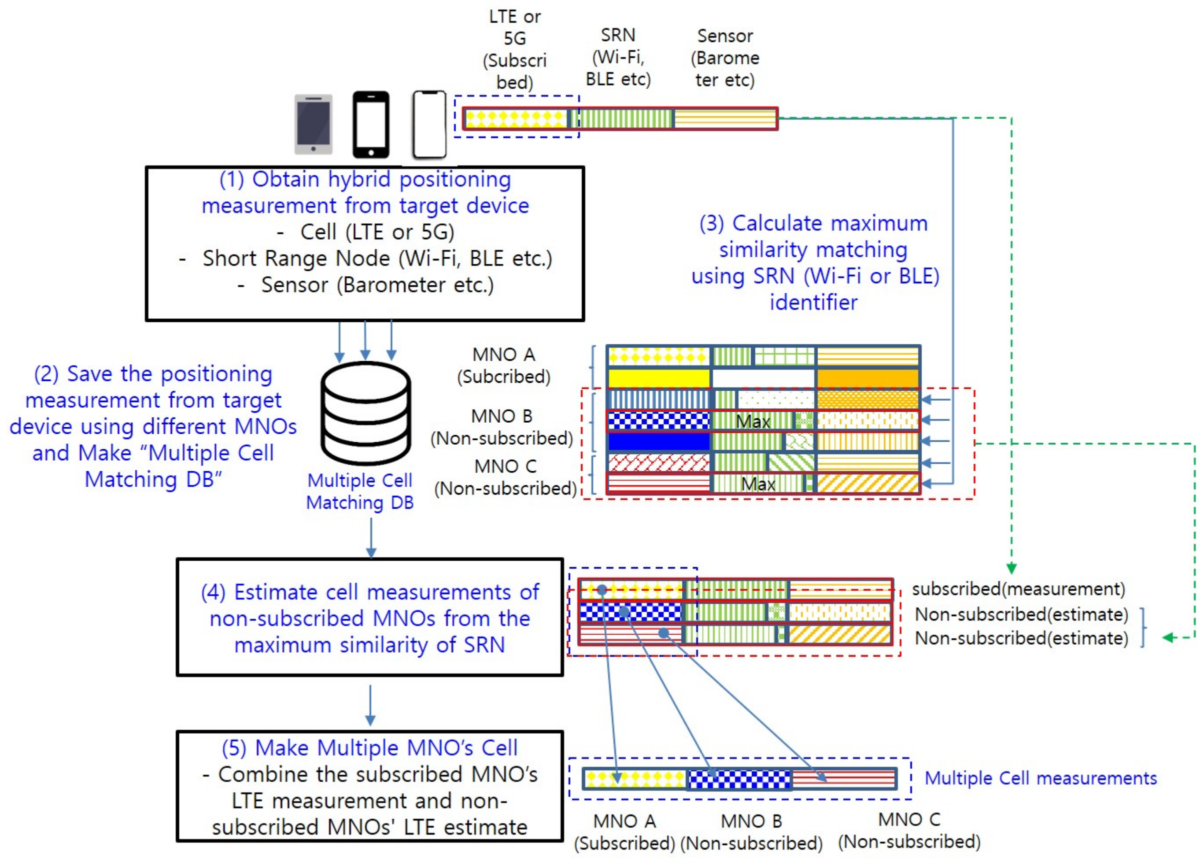

Figure 2: Detailed algorithm structure to estimate multiple MNO's cell measurements

instead of the Grid with the minimum sum of euclidean distance of RSS (Received Signal Strength), the Grid with the maximum "positioning infrastructure matching number" without using RSS is calculated as the optimal location.

The reason is to overcome the problem of large positioning errors occurring due to large signal power attenuation inside and outside the building when comparing the Location DB generated from collected data(outdoor-oriented) with positioning measurement information(indoor-oriented).

Of course, if RSS is collected repeatedly and sufficiently from an unspecified number of buildings indoors, it can help improve positioning performance. However, due to the nature of emergency location purposes, obtaining reliable collected data for places that are difficult to predict is not cost and time-efficient. It's unrealistic.

In summary, this paper proposes a method of reinforcing cell measurement information of multiple MNOs, thereby strengthening feature discrimination by improving the "positioning infrastructure matching number" and seeking to improve positioning performance through "DOP" improvement.

The detailed "positioning infrastructure matching number" is defined as a random variable as in equation (1), and the final target device's location is calculated through equation (2).

Each location infrastructure is an independent event but the measurement information for fingerprints is different for each location infrastructure. However, by standardizing it with a generic indicator called "matching number," it is very easy to combine each location infrastructure.

The random variable X for hybrid Localization is defined as follows.

$$X_{\text{hyb}} = X_{\text{Cell}} + X_{\text{WiFi}} + X_{\text{BLE}} \tag{1}$$

where X_{Cell}, X_{WiFi} and X_{BLE} is random variable for matching number between UE measurements and Location database of Cell, WiFi and Bluetooth Low Energy respectively.

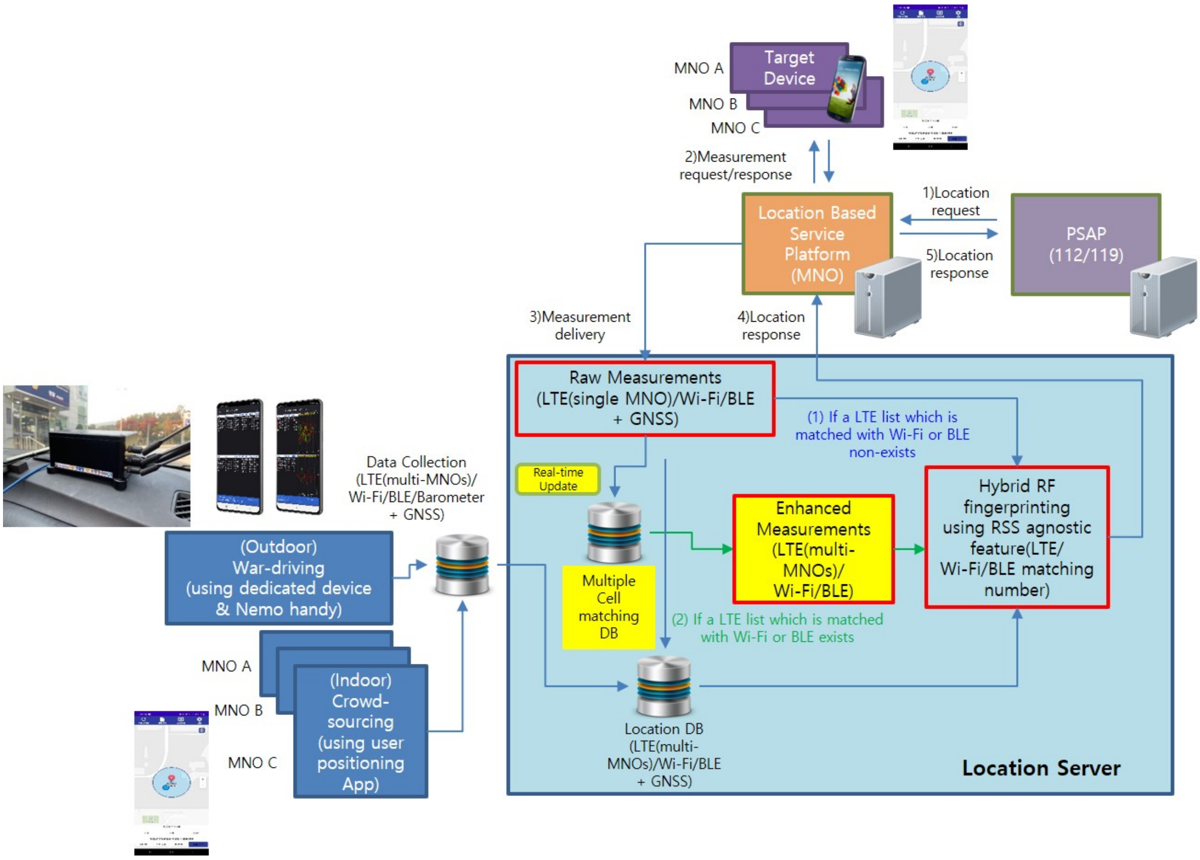

Figure 3: Location server architecture for Hybrid Positioning using multiple MNOs' cell measurement

The final target device's location is calculated as follows.

$$\hat{L}^k = \underset{L_k}{\text{argmax}} X_{hyb} \tag{2}$$

where L_k, is the location of kth grid in Location database.

4. Experimental Settings

The test environment to verify the above proposed algorithm is indoors in 50 buildings located in downtown Daejeon, Korea. The test site is equipped with three MNOs' LTE base stations, and has multiple Wi-Fi and a small number of BLE beacons.

Positioning tests were conducted five times on three terminals (three MNOs) of the same model at each location. To compare the positioning performance of smartwatches and smartphones, three test devices, Samsugn Galaxy Watch 5 and Samsung Galaxy S10, were used.

5. Experimental Results

5.1. Effect of multiple MNOs on LTE only positioning performance

From Table 1, the base station positioning test results when applying multiple mno are analyzed as follows. For reference, the algorithm that applies this multiple MNOs is not limited to a specific mobile network, but an LTE network was used for verification.

- Positioning availability: When applying multiple MNOs, the positioning success rate (i.e. the ratio of the number of successful position information calculations to the total number of position

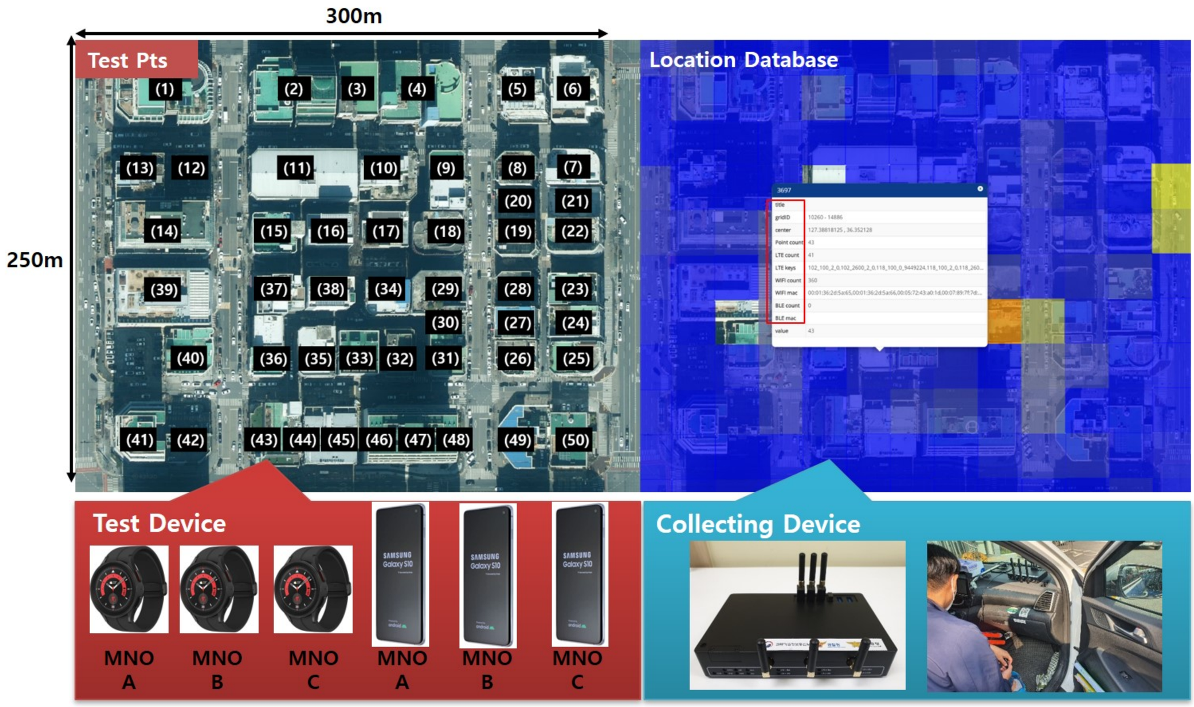

Figure 4: Test points and devices(Left) and Location Database and collecting device(Right) at the experimental site

requests) based on all terminals increases from 85.87 to 99.00 percent. The reason for the low positioning success rate when applying single MNO is the failure of matching LTE measurement information and location DB. In the case of LTE, in order to improve accuracy in this algorithm, successful matching of "LTE matching number" must match not only LTE PCI but also EARFCN (E-UTRA Absolute Radio Frequency Channel Number) and serving/neighboring status etc. Therefore, in the case of a base station supporting LTE CA (Carrier Aggregation) in the test area, positioning failure may occur if the variable LTE channel characteristics in the Location DB are not reflected through sufficient data collection. However, in the case of multiple MNOs, there is a possibility of matching from other MNOs, so the possibility of location failure can be reduced despite the test area where the location DB was created with little collected data.

- Positioning accuracy: Even though multiple MNOs are applied, it does not meet the US FCC indoor positioning accuracy standards (50m, 80 percent error), but when compared, the positioning accuracy was greatly improved by 31.2 percent from 154m to 106m.

Table 1
Positioning Method Performance

Positioning method	Device	50% error (m)	80% error (m)	Positioning Success rate (%)	Positioning Success rate with 50-meter error (%)
LTE only (Single MNO)	SM-R925(W)	93	154	85.33	19.69
	SM-G973U1(P)	94	154	87.60	21.30
	Total (W&P)	93	154	85.87	20.50
LTE only (Multiple MNOs)	SM-R925(W)	54	107	99.20	46.80
	SM-G973U1(P)	50	104	99.00	50.88
	Total (W&P)	51	106	99.00	49.02

5.2. Effect of multiple MNOs on Hybrid positioning performance

From Table 2, the results of the Hybrid localization test when applying multiple MNOs are analyzed as follows.

- Positioning availability: During hybrid positioning, only measurement values such as Wi-Fi and BLE are added, the same positioning availability was analyzed as LTE only positioning test.

- Positioning accuracy: When applying multiple MNOs, the positioning success rate with 50 meter error was improved by about 21.60 percent from 78.80 to 95.82 percent based on total devices. This represents a position error level of 35m when converted to the US FCC indoor positioning accuracy standard (50m, 80 percent error).

Table 2
Comparison of Positioning Methods by Error Metrics and Success Rates

Positioning method	Device	50% error (m)	80% error (m)	Positioning Success rate (%)	Positioning Success rate with 50-meter error (%)
Hybrid (Single MNO)	SM-R925 (W)	24	54	85.33	78.75
	SM-G973U1 (P)	23	53	86.40	78.86
	Total (W&P)	23	53	85.87	78.80
Hybrid (Multiple MNOs)	SM-R925 (W)	15	34	99.20	93.28
	SM-G973U1 (P)	20	35	100.00	95.82
	Total (W&P)	18	35	99.66	94.55

5.3. Effect of device type on positioning performance

From Table 1 and Table 2, it can be seen that when applying the proposed algorithm, smart watches do not experience significant performance degradation compared to smartphones in terms of positioning availability or accuracy, regardless of the positioning method. This means that the proposed algorithm can guarantee more robust positioning performance by using "matching number" as a feature instead of using RSS, which is sensitive to noise, even if there is variability in measurement information due to device diversity.

6. Conclusion

This paper proposes a noble probabilistic RF fingerprinting by using multiple MNO's cellular signals. The method proposes new approaches to estimate multiple MNO's cell measurements from short-range node's spatial similarity. Through this, we attempted to improve positioning performance by reducing DOP of multiple cell measurements. Additionally, hybrid RF fingerprinting using RSS agnostic feature is designed to mitigate positioning errors due to collecting environments' mismatch (between Location DB and device measurements). Especially by using not RSS but matching numbers, the measurement combination for hybrid positioning could be facilitated.

Experimental results show that the positioning success rate was confirmed to be improved by about 15.3 percent and positioning accuracy was improved by 31.2 percent, in case of LTE-only positioning technology when using multiple MNOs. In addition, when applied to hybrid positioning technology, it was confirmed that approximately 94.55 percent of the indoor positioning requirements of the US FCC were satisfied. Finally, robustness to device diversity was confirmed through comparison of positioning performance between smart watches and smart phones.

Acknowledgments

Identification of funding sources and other support, and thanks to individuals and groups that This work was supported by Protection Technology for Socially vulnerable individuals Program(www.kipot.or.kr) funded by Korean National Police Agency(KNPA, Korea) [Project Name: Development of an Integrated Control Platform for Location Tracking of Crime Victim based on Low-Power Hybrid Positioning and Proximity Search Technology / Project Number: RS-2023-00236101]

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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