Deep Neural Network-based Fingerprinting Localization for 5G NR mmWave Small-Cell

Suah Park*, Minsoo Jeong*, Hyeonjin Chung*, Hongseok Jung*, Hye-Kyung Jwa†, Jeehyeon Na†, and Sunwoo Kim*

*Department of Electronic Engineering, Hanyang University, Seoul, South Korea

†Electronics and Telecommunications Research Institute, Daejeon, South Korea

Email: *{paksua1031, qwjms, hyeonjingo, hssjung, remero}@hanyang.ac.kr, †{hkjwa, jhna}@etri.re.kr

***Abstract*—In this paper, we propose a fingerprinting-based localization method in the 5G millimeter-wave (mmWave) small-cell channel. The proposed method uses measurements that do not require additional processes to collect, such as synchronization signal-reference signal received power (SS-RSRP) used for synchronization between the user and base station in 5G communication and transmitter (TX) beam ID data as fingerprint data. With the collected data and a deep neural network (DNN)-based pattern matching model, we evaluate the localization performance in 5G small-cell environments. As a result, the proposed method achieves localization root-mean-squared-error (RMSE) of $2.76\,\mathrm{m}$, which can be applicable to the actual small-cell environment.**

I. Introduction

5G communication uses millimeter-wave (mmWave) signals in the 20-100 GHz frequency band to support high data rate and low transmission latency requirements compared to 4G LTE communication [1]. However, Due to the high carrier frequency band characteristics, large path losses occur, which leads to narrower coverage compared to long-term evolution (LTE) communications. Therefore, 5G mmWave communications are generally used in small-cells within a 250-meter radius. In particular, the high frequency and wide bandwidth characteristics of mmWave signals enable precise localization in small-cell environments. Thus, various 5G signal-based precise localization research has been studied actively [2], [3].

Localization technologies are composed of geometric and fingerprint methods. Geometric localization typically uses methods such as trilateration and triangulation. The authors in [4]–[6] propose a localization method that utilizes various parameters (e.g. time of arrival (ToA), time difference of arrival (TDoA), angle of arrival (AoA)) measured in 5G NR signals. However, traditional methods have localization performance uncertainty due to none-light-of-sight (NLOS) transmission. In contrast, the fingerprint methods focus on the features of the 5G signal for localization. The methods use a database constructed by measurements such as the received signal strength indicator (RSSI), and channel state information (CSI) [7], [8]. Among these, CSI-based localization algorithms have attracted relatively because CSI can represent detailed channel information such as multipath effects [9], [10].

Nevertheless, most wireless devices still find it difficult to collect accurate information for CSI in the real world functionally. Hence, we propose a localization method to avoid this problem using the synchronization signal-reference signal received power (SS-RSRP) and transmitter (Tx) beam ID in 5G communication. The SS-RSRP is the information reported to the base station when the secondary synchronization signal (SSS) is transmitted. Thus, it does not require any additional process to measure the data. Additionally, simulations demonstrate that precise localization is possible in 5G mmWave small-cell environments.

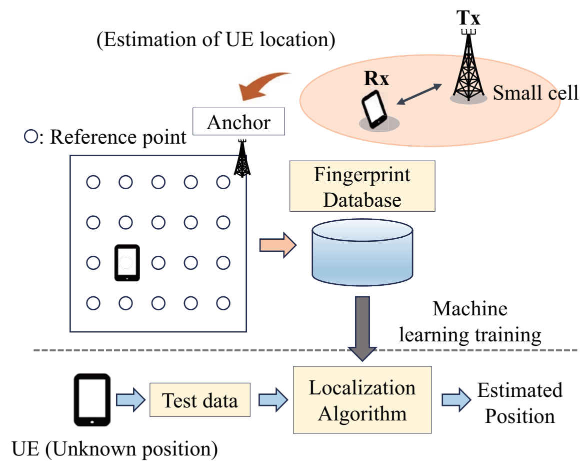


Fig. 1. Fingerprinting localization scenario in 5G small-cell

II. Channel environment

In this section, we present the cluster delay line (CDL), one of the 5G NR-based channels used for simulation shown in Fig. 1. The CDL channel model is described in the third generation partnership project (3GPP) technical report (TR) 38.901 and uses a maximum bandwidth of 2 GHz within the 0.5-100 GHz band [11]. Wireless signals in the real world are multipath propagation due to scattering, diffraction, and reflection from obstacles. The multipath signals are refracted by scatterers and distributed into subpath. Moreover, subpath can be clustered around specific time delay and angular spread. Fig. 2 shows an example of a simple CDL channel, where two clusters have distributed with sub-paths and the power profile regarding impulse response.

MATLAB provides a 5G toolbox to create the channel environment for 5G NR communication systems [12]. The simulations use a CDL model that is similar to the real-world channel using MATLAB. Furthermore, the simulation and

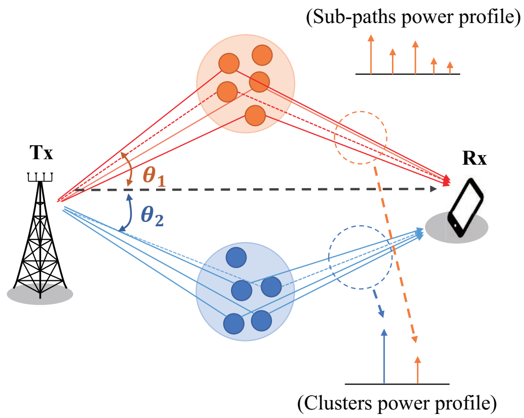


Fig. 2. An example of CDL with two clusters: θ_is represent the angle of departure (AoD) each cluster for the LOS departure direction.

localization performance will be compared by implementing a scattering multiple-input multiple-output (MIMO) channel provided by MATLAB [13].

Scattering-MIMO is designed in a propagation channel where the signal radiates from the Tx array and is reflected from scatterers to the Rx array. With the two channel models, the received signals can get as follows.

$$\mathbf{r}(\mathbf{t}) = \mathbf{W}^r(\mathbf{H}\mathbf{W}^t\mathbf{s}(\mathbf{t}) + \mathbf{n}(\mathbf{t})), \quad (1)$$

where $\mathbf{r}(\mathbf{t})$ is the received signal, $\mathbf{W}^r$ is the weight value for the steering vector for the Rx beam, and $\mathbf{W}^t$ is the weight value for the steering vector for the Tx beam. The $\mathbf{H}$ is the channel matrix, and $\mathbf{n}(\mathbf{t})$ is the channel noise value, which assumes white Gaussian noise $\sim \mathcal{N}(\mathbf{0}, \mathbf{1})$ whose mean is $\mathbf{0}$ and variance is $\mathbf{1}$. In this simulation, $\mathbf{s}(\mathbf{t})$ is a synchronization signal block (SSB) to collect the SS-RSRP and Tx beam ID.

III. DNN-Based Fingerprinting Method in Small-Cell Environment

In this session, we describe the method of fingerprinting localization in small-cell environment with 5G mmWave.

A. Channel Design

We build a channel environment using MATLAB to be similar to real-world communications. The carrier frequency of the CDL channel is 28.5 GHz and considers a light-of-sight (LOS) environment with 12 clusters. The angle of the LOS signal in the subpath is the angle of the straight-line distance between the receiver (Rx) and Tx, and the middle angle of the NLOS cluster is set randomly according to the Gaussian distribution $\sim \mathcal{N}(\mathbf{0}, \mathbf{1})$. In the scattering MIMO channel, we set the same carrier frequency as CDL and the number of scatterers to 5. Also, the location of each scatterer was randomized.

B. Measurement Collection

The simulation environment is a two-dimensional environment $100 \times 100\,\mathrm{m}^2$ with 361 reference points (RPs) as Rx and four anchors as Tx shown in Fig. 3. In addition, 30 test points (TPs) are used in the simulation evaluation. The antenna size is 8, with 16 beams each assigned to 16 SS bus

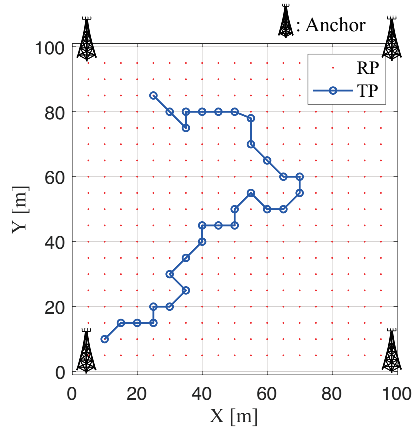


Fig. 3. Labeled fingerprints collected at various RPs

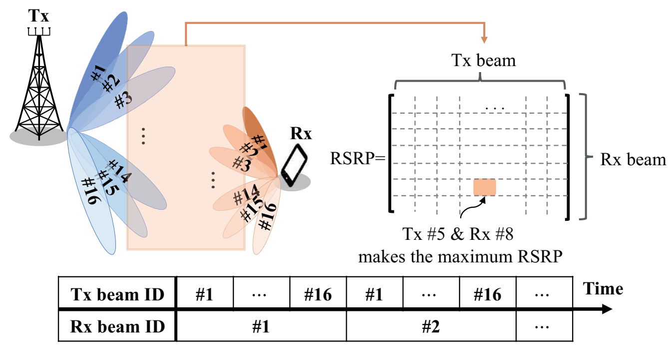


Fig. 4. Labeled fingerprints collected at various RPs

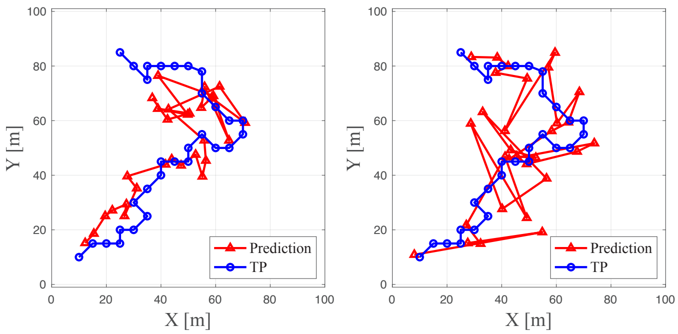
signals. The SSB signal is used in 5G NR for transmit/receive synchronization and receiving network information, as well as being transmitted periodically. This signal is generated with a signal block length of 64. Fingerprinting data for localization is collected during the beam sweeping steps, where the maximum SS-RSRP and the corresponding Tx beam ID are measured, as shown in Fig. 4. This process is performed for each anchor and RP. The data is gathered eight times at each anchor and RP, and two times at TP.

C. Deep Learning Training and Testing

The DNN-based fingerprinting localization method is performed in two steps: offline and online steps. In the offline step, the data collected by the RPs and real locations input the DNN model and construct a radio map. The online step provides test data to the trained model to estimate the user's location. The DNN model is trained by matching the input SS-RSRP and Tx beam ID to locations. The parameters of the DNN model for training are shown in Table. I. Moreover, before training, the SS-RSRP is normalized for enhanced estimation accuracy. At the end of this process, the data is scaled to the interval [0, 1].

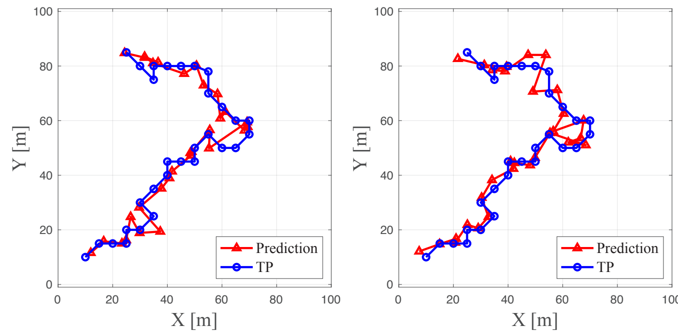
TABLE I. Measurement campaigns parameter in DNN model

Parameter	Setting
Number of hidden layers	3
Size of hidden layers	400
Activation function	ReLU
Optimizer	Adam
Inter reference point distance	5 m



(a) CDL channel (b) Scattering-MIMO channel

Fig. 5. Estimated positions in CDL and scattering-MIMO channel with SS-RSRP



(a) CDL channel (b) Scattering-MIMO channel

Fig. 6. Estimated positions in CDL and scattering-MIMO channel with SS-RSRP and Tx beam ID

IV. Simulation results

In this section, we present the simulation results in the scattering-MIMO and CDL channel environments. Fig. 7 shows the overall localization performance with SS-RSRP and Tx beam index measurements in two channel models by root-mean-squared-error (RMSE). Fig. 5 shows the localization performance when the fingerprint database consists of only SS-RSRP measurements. With the use of the CDL channel and the Scattering MIMO channel, proposed method shows RMSE $9.41\,\mathrm{m}$ and $10.75\,\mathrm{m}$ localization performance respectively. Since the DNN-based localization model could not accurately distinguish the data patterns collected from different locations, the localization performance decreased. Fig. 6 shows the localization performance when the fingerprint database consists of both SS-RSRP and Tx beam index measurements. With the use of the CDL channel and the Scattering MIMO channel, RMSE $2.76\,\mathrm{m}$ and $2.83\,\mathrm{m}$ results are confirmed, respectively. It is confirmed that the proposed method can accurately estimate the location, by including the angular information between anchors and the user.

V. Conclusion

In this paper, we proposed a DNN-based fingerprinting localization method in 5G mmWave small-cell environments. Proposed method was evaluated in two 5G NR channel environment. In addition, SS-RSRP and Tx beam ID, which do not require an additional collection process, are used as fingerprints. Through the several simulation, we achieved localization RMSE $2.76\,\mathrm{m}$ in NR CDL channel. Simulation results demonstrate that the proposed method is applicable to the actual small cell environment. In the future, we hope that this research will be applied to real-world 5G small cells so that high-precision positioning results can be utilized in many fields.

ACKNOWLEDGEMENTS

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government(MSIT) (No. 2018-0-01659, 5G Open Intelligence-Defined RAN (ID-RAN) Technique based on 5G New Radio)

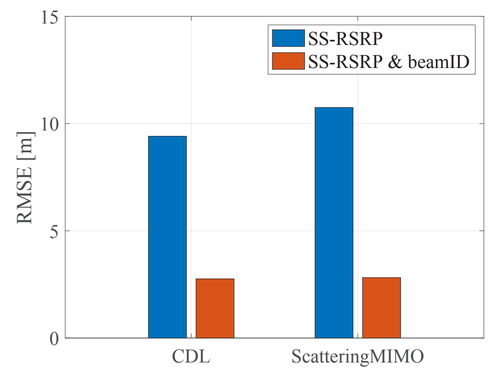


Fig. 7. RMSE for simulation evaluation

References

[1] M. Shafi *et al.*, "5G: A tutorial overview of standards, trials, challenges, deployment, and practice," *IEEE J. Sel.*, vol. 35, no. 6, pp. 1201–1221, 2017.

[2] A. Shahmansoori *et al.*, "Position and orientation estimation through millimeter-wave MIMO in 5G systems," *IEEE Trans. Wirel. Commun*, vol. 17, no. 3, pp. 1822–1835, 2018.

[3] L. Chen *et al.*, "Carrier phase ranging for indoor positioning with 5G NR signals," *IEEE Internet Things J.*, vol. 9, no. 13, pp. 10 908–10 919, 2022.

[4] G. Celik and H. Celebi, "TOA positioning for uplink cooperative NOMA in 5G networks," *Phys. Commun.*, vol. 36, 2019.

[5] Q. Liu, R. Liu, Z. Wang, and Y. Zhang, "Simulation and analysis of device positioning in 5G ultra-dense network," in *proc. Int. Wireless Commun. Mobile Comput. Conf. (IWCMC)*, 2019, pp. 1529–1533.

[6] E. Y. Menta *et al.*, "On the performance of AoA–based localization in 5G ultra–dense networks," *IEEE Access*, vol. 7, pp. 33 870–33 880, 2019.

[7] M. Gucciardo, I. Tinnirello, G. M. Dell'Aera, and M. Caretti, "A flexible 4G/5G control platform for fingerprint-based indoor localization," in *proc. IEEE Conf. Comput. Commun. Workshop (INFOCOM WKSHPS)*, 2019, pp. 744–749.

[8] J. Gante, G. Falcão, and L. Sousa, "Enhancing beamformed fingerprint outdoor positioning with hierarchical convolutional neural networks," in *proc. IEEE Int. Conf. Acoust., Speech, Signal Process. (ICASSP)*, 2019, pp. 1473–1477.

[9] Q. Li, X. Liao, M. Liu, and S. Valaee, "Indoor localization based on CSI fingerprint by siamese convolution neural network," *IEEE Trans. Veh.*, vol. 70, no. 11, pp. 12 168–12 173, 2021.

[10] Y. Ruan *et al.*, "Hi-Loc: Hybrid indoor localization via enhanced 5G NR CSI," *IEEE Trans. Instrum. Meas.*, vol. 71, pp. 1–15, 2022.

[11] 3GPP, "Study on channel model for frequencies from 0.5 to 100 GHz," 3rd Generation Partnership Project (3GPP), Technical Report (TR) 38.901, Jan. 2020, version 16.1.0. [Online]. Available: http://www.3gpp.org/\-DynaReport/\-38901.htm

[12] MATLAB, "nrCDLchannel, version 9.14.0 (R2023a)," https://kr.mathworks.com/help/5g/ref/nrcdlchannel-system-object.html.

[13] ——, "Scattering MIMO channel, version 9.14.0 (R2023a)," https://kr.mathworks.com/help/phased/ref/scatteringmimochannel.html.