Two-Stage Beam Index Estimation Method Using Spectrum Sensing in Local 5G

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***Abstract*—With the proliferation of local 5G systems, we consider expanding coverage by allowing a certain level of interference to solve the coverage reduction problem. At this time, identical frequency interference occurs between adjacent systems. As a method to suppress the resulting interference, we consider beam control utilizing spatial multiplexing. Here, it is necessary to know where the beams of adjacent systems are pointing, but this is difficult because local 5G systems operate autonomously. This paper verifies a method that estimates the beam index of adjacent systems by performing spectrum sensing using the local terminal and base station and capturing beam directionality in three dimensions.**

***Index Terms*—Local 5G, Beamforming, Convolutional Neural Network (CNN)**

I. INTRODUCTION

In recent years, Local 5G has attracted considerable attention as an autonomous wireless system capable of achieving communication performance comparable to that of fifth-generation mobile communications [1]. In Japan, when multiple Local 5G systems share the same frequency, regulations require that the amount of radio leakage outside the deployment premises be kept below a specified level to mitigate mutual interference between systems [2]. However, a challenge remains in that sufficient signal power is often unavailable near the edges or boundaries of the premises, resulting in areas where communication services cannot be provided. To address this issue, methods have been investigated that expand the service area by controlling co-channel interference (CCI) generated by leaked signals outside the premises [3] [4].

In Local 5G, beamforming using array antennas enables concentrated radiation of radio waves in specific directions. Thus, spatial multiplexing is employed to form beams in directions different from those of Adjacent systems. As a result, high-throughput communication can be achieved by both mitigating mutual CCI and securing high transmit power. To avoid beam overlap, it is essential to identify the beams used by Adjacent systems in advance. However, among autonomously operated Local 5G systems, there is no established mechanism for exchanging communication parameters between base stations, making it difficult for Adjacent base stations to obtain beam index information used to determine beam directions. Therefore, estimating the beam index selected by Adjacent Local 5G base stations acting as interference sources is necessary. Although the beam index could theoretically be identified by demodulating pilot or control signals, this would require demodulators compatible with arbitrary Local 5G systems, making reliable identification challenging. In addition, packet demodulation from leaked signals of Adjacent systems requires high received signal power, which may make demodulation infeasible for devices located outside the service area. Thus, a robust method for identifying beam indices that does not rely on data demodulation is essential.

In this study, assuming frequency sharing among multiple Local 5G systems, we propose a method that estimates beam indices by detecting the signal power leaked from Adjacent Local 5G base stations. In the proposed method, the received signal strength indicator (RSSI) for each beam used by an Adjacent Local 5G base station is observed at both the terminal and base station of the target system, and classification using these observations enables estimation of the beam index used by the Adjacent system.

Various methods for estimating beam directions have been widely studied. Conventional approaches include methods based on time-of-arrival (TOA) and direction-of-arrival (DOA) estimation, such as the MUSIC algorithm, ESPRIT, and compressed sensing (CS) [5] [6]. Although these methods can achieve highly accurate localization, they impose high computational load and require multidimensional nonlinear optimization and management of large antenna arrays, posing constraints for practical deployment. In contrast, the proposed method avoids complex nonlinear optimization and estimates beam directions solely from terminal-side RSSI measurements.

Although prior studies have estimated beam directions using terminal-side measurements, their performance in tilt classification is limited when relying only on horizontal power distributions [7]. In contrast, the proposed method introduces elevated observation points, allowing three-dimensional characterization of power distributions and improving estimation accuracy.

Through real-world experiments using Sub-6 GHz signals and simulations based on the collected data, we evaluate the beam-index estimation accuracy of the proposed method and demonstrate its effectiveness.

II. System Model

As shown in Fig. 1, each Local 5G system consists of a star-type cellular configuration in which a single base station deploys its service area and supports communication for multiple wireless terminals. We assume two cellular systems our system and an Adjacent system operating autonomously. Each system defines the area in which terminals requiring communication support are located as its own premises. Unlike conventional Local 5G systems, radio leakage outside the premises is allowed to the extent necessary to support terminals located within the premises as effectively as possible. Under the assumption that appropriate CCI mitigation techniques are applied between the two systems, the same frequency is shared. To observe the CCI required for CCI control, terminals in our system measure the RSSI to capture the power of leaked signals transmitted by the base station of the Adjacent system.

Within the premises of our system, terminals are uniformly distributed, and among them, those located in the half of the premises facing the Adjacent base station perform Spectrum Sensing. Since the Adjacent system transmits radio waves concentrated in a specific direction through beamforming, terminals located in the beam direction detect high RSSI values, whereas terminals outside that direction observe lower RSSI values. Consequently, the RSSI varies depending on the beam index, allowing us to obtain the spatial RSSI distribution corresponding to the terminal locations. Furthermore, an additional observation point is set at a certain height-such as at our base station-where Spectrum Sensing is also performed. This enables three-dimensional characterization of the beam direction.

III. Proposed Method

First, the concept of the proposed method is illustrated in Fig. 2. The proposed method consists of two stages: horizontal classification and vertical classification. The procedure first groups the beams according to the horizontal direction, followed by classification of the vertical beam direction. Through these two steps, it becomes possible to estimate a single beam even from a beam set that combines both horizontal and vertical directions. The detailed procedure is described below.

A. Before System Operation

First, the procedure before system operation is described. As shown in the Fig.3, RSSI data required for estimation are collected in this phase. At this stage, the beams used by the Adjacent base station are assumed to be known, and the corresponding data are observed. This allows the acquisition of data for all beams used by the Adjacent base station. The data observed at the terminals are converted into images and used to train a convolutional neural network (CNN) [7]. Meanwhile, for the data measured at our base station, the median value is calculated for each beam and stored.

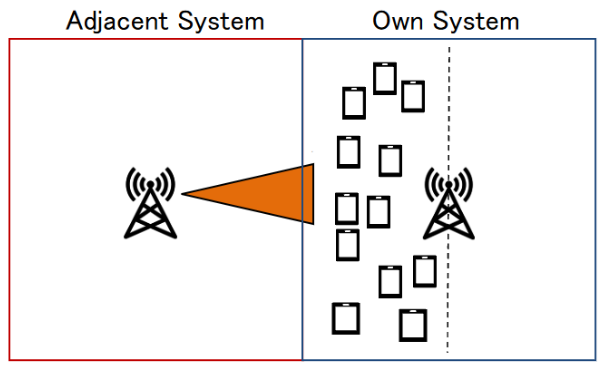

Fig. 1. System Model

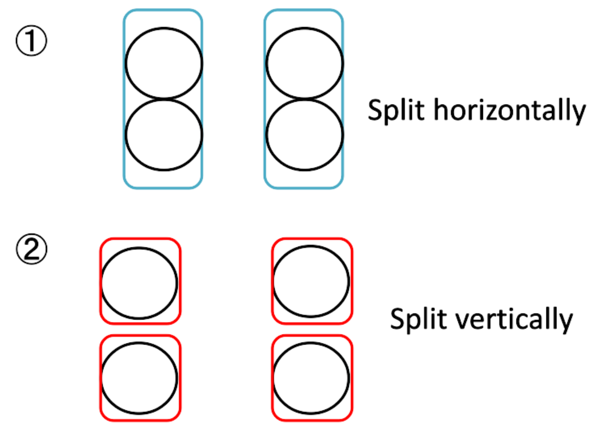

Fig. 2. Overview of the Proposed Method

B. During System Operation

Next, the estimation phase during system operation is described. As shown in the Fig.4, new Spectrum Sensing is performed at the timing when the beam of the Adjacent base station needs to be estimated. Using the data obtained from the terminals, a single image is generated, and the horizontal direction is estimated by the trained model. Subsequently, vertical classification is performed according to the estimated horizontal direction. As an example, consider the case in which the horizontal direction is estimated to belong to group α. The mean squared error (MSE) is calculated between the observed RSSI values and the median RSSI of each beam belonging to the horizontal group α. The MSE values obtained at each

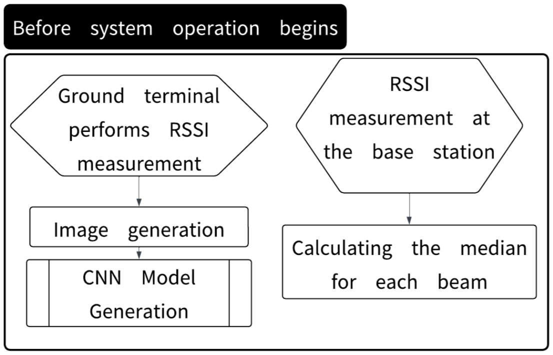

Fig. 3. Flowchart of the Two-Stage Estimation(Before Operation)

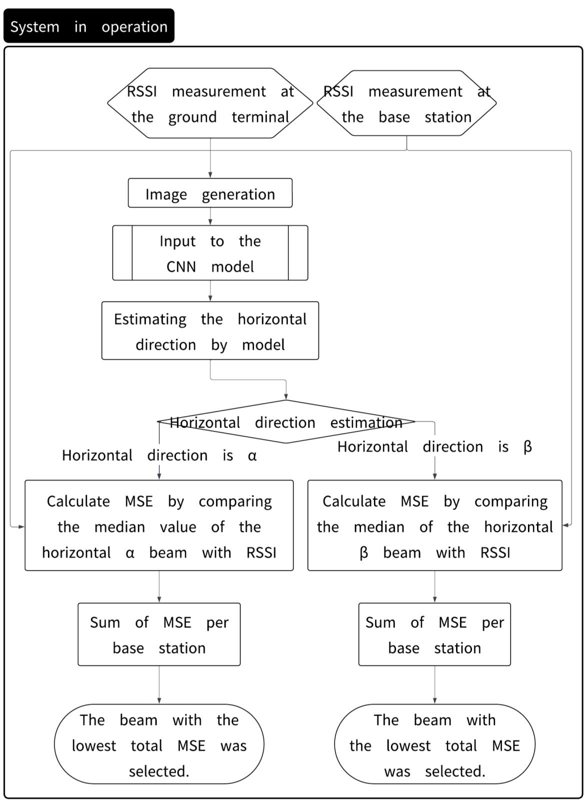

Fig. 4. Flowchart of the Two-Stage Estimation(During Operation)

observation point are then summed, and the beam with the smallest total MSE is selected as the final estimation result. Through this procedure, a single beam can be estimated from a set of beams with different horizontal and vertical directions.

IV. Experimental Equipment

We conducted real-world experiments to collect the RSSI data required to validate the proposed method. In the experiment, a transmitter was configured using a test experimental station and a horn antenna. As beam transmission directions, four beam patterns were generated by combining two vertical angles-10° and -50°-with two horizontal directions-south and east. The transmission frequency was 5.0185 GHz, and the transmit power was 30 dBm. The installation height of the transmit antenna was 11 m, the assumed receive antenna height for terminals was set to 2 m, and the assumed receive antenna height for our base station was set to 12 m.

TABLE I
Experimental Parameters in the Real-World Measurement

Item	Transmitter	Receiver
Center Frequency	5.0185 [GHz]	5.0185 [GHz]
Transmit Power	30 [dBm]	-
Beam Direction	Vertical: 10°, $-50°$ / Horizontal: South, East	-
Antenna Type	Horn Antenna	Omnidirectional Antenna
Antenna Height	11 [m]	2 [m] (UE) / 12 [m] (Base Station)
Measurement Method	-	RSSI Measurement Using a Spectrum Analyzer
Measurement Locations	-	Along a Specified Route + 2 Fixed Points (Assumed Base Stations)

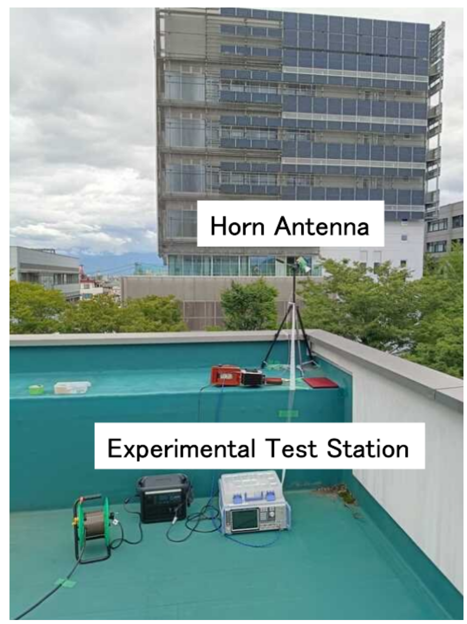

Fig. 5. Transmitter

For Spectrum Sensing at the terminals of our system, measurements were conducted along designated routes using a spectrum analyzer. To emulate Spectrum Sensing at our base station, measurements were performed at two observation points.

V. Beam Estimation Accuracy Results

We evaluated the accuracy of the proposed method through simulations using real-world measurement data. Fig. 7 illus-

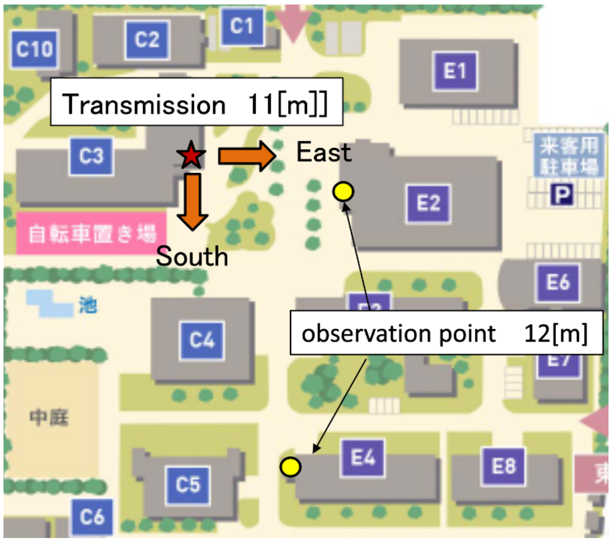

Fig. 6. Geometric Relationship Between the Transmitter and Receiver Locations

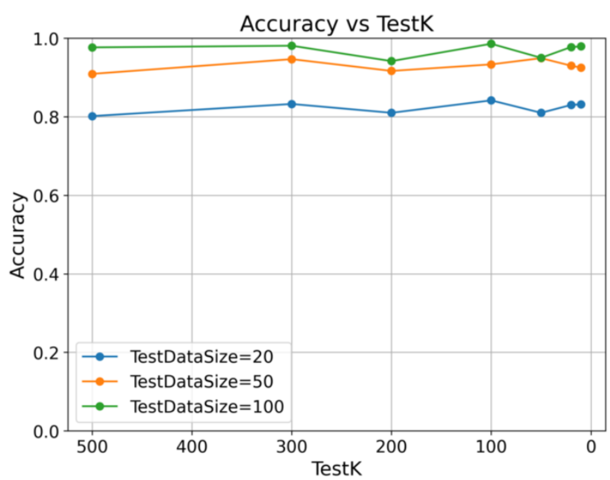

Fig. 7. Accuracy of the Two-Stage Beam Index Estimation Method

trates the accuracy of the two-stage beam index estimation. TestDataSize represents the number of terminal-side samples required during estimation, and the horizontal axis TestK represents the number of samples required for base-station-side measurements. The graph shows that the accuracy is almost unaffected by TestK, while it improves progressively as TestDataSize increases. Among the tested conditions, collecting 100 data samples at the terminals and 500 samples at the base station enabled the method to achieve an accuracy of approximately 97%.

Next, we examine the tendency of misclassification using the confusion matrix. Fig. 8 shows the number of misclassifications when TestDataSize = 50 and TestK = 500. The results correspond to simulations in which each beam was estimated 500 times. The beam index numbers are defined as follows: 1 for South-10°, 2 for South-50°, 3 for East-

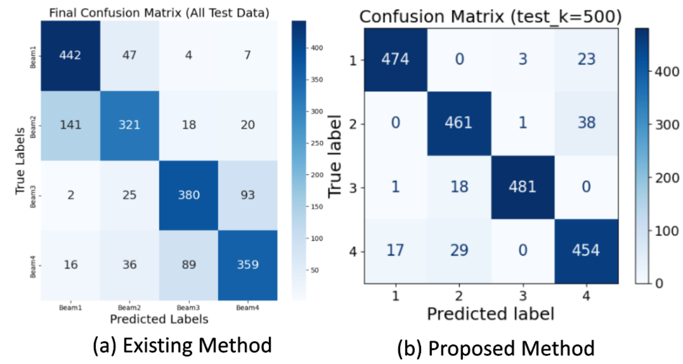

Fig. 8. Misclassification Matrix

50°, and 4 for East-10°. As a result, beam indices 1 and 2 are never misclassified with each other, and likewise, no misclassification occurs between 3 and 4. This indicates that vertical classification is performed with 100% accuracy. In existing methods, the classification accuracy in the vertical direction has been a major issue, and the improvement of vertical classification accuracy has significantly contributed to the overall performance. By dividing the estimation method into two stages, the proposed approach successfully resolves the previous issue of insufficient vertical classification accuracy.

VI. Conclusion

In this paper, we proposed a method for estimating the beam index of Adjacent cells using Spectrum Sensing, with the aim of suppressing Adjacent-cell interference and improving frequency utilization efficiency in local 5G systems. The proposed method employs a two-stage structure in which the horizontal beam direction is first estimated, followed by vertical-direction classification. This design improves the vertical beam identification accuracy, which has been a challenge for conventional methods. We constructed an experimental environment and acquired RSSI data by switching the beam direction among four patterns. By conducting simulation evaluations using this real-world data, we confirmed that the proposed method can achieve a certain level of identification accuracy under appropriate conditions. These results demonstrate that the proposed approach operates effectively in realistic environments and that beam-index estimation based on Spectrum Sensing is sufficiently feasible.

Acknowledgment

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References

[1] M. Yoon, J. Seo and K. Cho, "An efficient network operation automation scheme using network status information for local 5G networks," 2023 14th International Conference on Information and Communication Technology Convergence (ICTC), Jeju Island, Korea, Republic of, 2023, pp. 1447-1449. communication;

[2] H. MURAKAMI, K. ISHIZU, H. Kawasaki, K. IBUKA, S. FILIN, T. MATSUMURA, and F. Kojima, "Current Status and Future of Local 5G" IEICE Communication Magazine, pp.246-253, 2020.

[3] H. MURAKAMI, H. SAWADA and T. MATSUMURA, "Interference Analysis for Spectrum Sharing of Multiple Local 5G gNBs by Different Operators in a Building," 2022 25th International Symposium on Wireless Personal Multimedia Communications (WPMC), Herning, Denmark, 2022, pp. 164-169.

[4] "Guidelines for Local 5G Deployment" in Ministry of Internal Affairs and Communications (MIC), Japanese, Dec. 2019, [online] Available: $https : //www.soumu.go.jp/main_content/000659870.pdf$.

[5] R. Xue, H. Liu and Z. Liang, "A Joint Solution Method of Orthogonal Matching Pursuit and Improved Harris Hawk Optimization for 5G Positioning," 2024 IEEE 7th International Conference on Electronic Information and Communication Technology (ICEICT), Xi'an, China, 2024, pp. 99-103, doi: 10.1109/ICEICT61637.2024.10671356.

[6] A. Abdelbari and B. Bilgehan, "A Novel DOA Estimation Method of Several Sources for 5G Networks," 2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE), Istanbul, Turkey, 2020, pp. 1-6, doi: 10.1109/ICECCE49384.2020.9179306.

[7] Mitsuhashi, H., Takyu, O., and Akimoto, K., "Experimental Evaluation of Beam Index Estimation Using Spectrum Sensing in Local 5G,"International Conference on Emerging Technologies for Communications (ICETC 2025), Osaka, Japan