Frequency Spectrum Sharing of Time Scheduling and Adaptive Beam Forming for Local 5G System

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Abstract—**Private 5G (local 5G), which allows operators to provide 5th generation mobile communications, is attracting attention as a cellular system that allows operators to provide their own communication services. However, due to limited frequency bands, appropriate control of co-channel interference (CCI) is required to share frequency resources. Effective CCI control is required assuming autonomous base station operation. In this paper, we focus on the fact that the vertical beamforming direction of a base station tracks mobile terminals, and show that CCI can be effectively suppressed by appropriately designing the time schedule that allocates communication rights to each terminal.**

I. Introduction

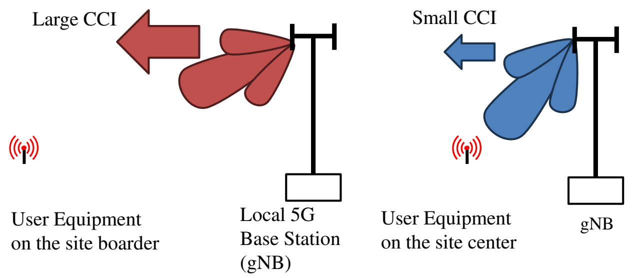
In recent years, attention has focused on Private 5G (or Local 5G) as a cellular system that enables businesses operating factories and other facilities to deploy base stations and achieve the communication performance of the fifth-generation mobile communication standard (5G)[1]. Unlike 5G operated by communication carriers, it allows businesses to establish unique communication performance tailored to their specific needs. This enables them to independently deploy communication infrastructure designed to enhance their productivity.

In Japan, the frequency bands available for use as Local 5G are limited. The frequency band known as Sub-6GHz is particularly constrained. If numerous businesses deploy their own Local 5G systems, assigning independent frequency resources becomes difficult. Therefore, sharing the same frequency becomes essential [2]. In multi-cell deployments like those by communication operators, coordinated operation between base stations can effectively suppress Co-channel Interference (CCI) that occurs during frequency sharing. However, in Local 5G, coordination between base stations is impossible if they belong to different operators. Consequently, operators must independently manage CCI control.Consequently, Japan's Radio Law mandates that operators suppress radio waves leaking onto other operators' premises below specified thresholds [3]. These thresholds are set extremely low to prevent interference with other operators' communications. This necessitates designing systems to ensure received power levels remain below noise levels even within premises, inevitably creating out-of-coverage areas.Particularly at site boundaries, dead zones inevitably occur due to signal power degradation. Consequently, Local 5G faces the challenge of having a narrow service area and limited applications.

Therefore, this study investigates a method to control CCI in Local 5G using base station beamforming and time scheduling that allocates communication rights to terminals. The base station is assumed to employ beamforming capable of controlling vertical directivity, with the main lobe tracking the terminal's position.Consequently, when a terminal is located at a site boundary far from the base station, the beam becomes shallow, leading to significant signal leakage to adjacent operators. Therefore, by focusing on terminal movement and applying a resource allocation method that guides terminals from the site boundary toward the site center, CCI can be suppressed. However, under this time-based scheduling for determining communication rights allocation, CCI occurrence is unavoidable for static terminals lingering at the site boundary.Therefore, this paper defines a relaxation condition where the average CCI power over a fixed time window must fall below a threshold value as the criterion for CCI affecting adjacent operators. This approach allows for the occurrence of instantaneous CCI while also creating periods with low CCI, thereby maintaining overall communication performance.This study evaluated changes in throughput performance based on average CCI power through real-world experiments using commercial Local 5G equipment. It discussed the validity of the threshold value as an acceptable limit based on the relationship between average CCI power and communication performance. Furthermore, computer simulations established a time scheduling method based on terminal movement predictions[4][5], demonstrating superiority over existing methods in terms of throughput and terminal communication opportunities.

II. System Model

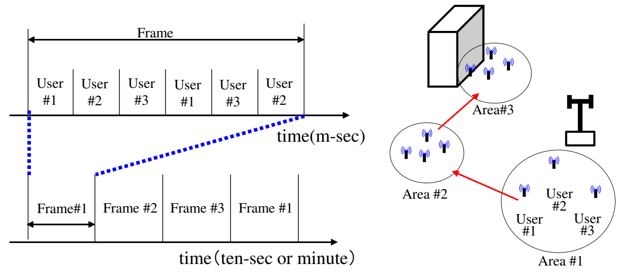
This study assumes a cellular system where a single base station establishes communication with multiple wireless terminals. In Local 5G, operators can deploy cellular systems anywhere by installing base stations. Each base station provides communication services according to the operator's unique operational policies. Since multiple cellular systems share the same frequency band, Co-channel Interference (CCI) occurs.To maintain communication quality between systems, operators establish mutual agreements setting CCI tolerance standards. CCI fluctuates over time due to multipath fading. Additionally, building obstructions cause CCI attenuation or amplification within specific distance segments.For this CCI tolerance standard, a fixed time interval was assumed, and the average CCI over that interval was set as the permissible interference level. This is because cellular systems possess a high capability to suppress CCI through spatial signal processing and retransmission techniques, and are considered capable of sufficiently mitigating high CCI occurring over short time durations due to fading.Furthermore, since quality standards at



(a) Tilt up for supporting the access of user equipment on site boarder

(b) Tilt down for supporting the access of user equipment on site center

Fig. 1. Image of Relationship between CCI and Angle of Beamforming



(a) Time format

(b) Spatial Division Image (Area)

Fig. 2. Assumption and Frame of Proposed Time Schedule

the transport and application layers are expected to be strongly influenced by the average CCI over a fixed time interval, an averaging criterion was adopted.Furthermore, propagation path loss models are used to predict CCI. The reference location for interference is the property boundary of the adjacent operator. The CCI at the property boundary is calculated using the propagation path loss model, considering the base station's transmit power and antenna gain. The average value of this calculated CCI over a fixed time interval is defined as the average CCI power, and the condition is that the average CCI must be kept below the allowable value.

The base station is assumed to have spatial directivity and can three-dimensionally set azimuth directions with high directivity gain. The capability to dynamically control antenna directivity is termed beamforming. Beamforming is assumed to dynamically control the directivity angle to achieve high beam gain for the terminal. Figure 1 an example of the relationship between beamforming azimuth and terminals. When a terminal is located at the operator's property boundary, which corresponds to the cell boundary, the terminal is distant from the base station, resulting in a shallow vertical beamforming angle. Conversely, for terminals near the base station, the vertical beamforming angle becomes steep.In the former case, antenna gain increases in the far-field direction. Consequently, CCI leaking outside the cell increases. Conversely, a steeper vertical angle suppresses CCI. This relationship establishes a linkage between the terminal's position when establishing communication with the base station and the beamforming angle, resulting in CCI varying according to the terminal's location.

To manage communication connections with multiple terminals, the base station employs a time schedule that plans the timing of communication establishment opportunities. This time schedule determines when each terminal establishes communication with the base station. In existing time scheduling, the base station collects Channel State Information (CSI), which determines the communication quality between the base station and the terminal, and designs the time schedule based on the CSI state.CSI varies over time, and when terminals are spatially separated, these variations are independent. The base station compares the CSI for each terminal and establishes a time schedule for determining communication with terminals based on sparsity, which considers the CSI state and its occurrence probability. As a result, communication can be established when the communication state is favorable. This is called user diversity.

Many existing scheduling methods have been verified to maximize user diversity gain. However, when assigning communication to terminals far from the base station, the beamforming angle becomes shallow, increasing CCI. Designing a schedule that establishes long-term communication for terminals far from the base station (i.e., terminals near the site boundary) risks exceeding the average CCI threshold set for the system.If the average CCI threshold is exceeded, transmission is stopped to prevent exceeding the average value. This results in reduced opportunities for terminals to establish communications and decreased system throughput.

III. Proposed Time Schedule Design

Figure 2 illustrates the proposed time scheduling concept. The proposed method employs a two-stage time scheduling approach. First, the time span used to calculate the average CCI is defined as a frame. Then, the time span obtained by dividing the frame into equal intervals is defined as a slot. Frames and slots switch at intervals ranging from tens of seconds to milliseconds.Therefore, assuming a terminal moves at walking speed, it will travel approximately tens of meters within one slot time. Consequently, the building shadowing conditions change, altering the shadowing effect. Furthermore, since the frame duration is on the order of tens of seconds, it is assumed that a terminal moving at walking speed can traverse the operator's premises for a sufficiently long period. The proposed time scheduling design accounts for this extended terminal movement.

We assume areas defined by dividing the range covered by base stations into fixed zones. Each area is defined as a range where shadowing conditions are nearly identical, roughly corresponding to the size of obstructing objects like buildings or partitions. Within this area, radio wave attenuation is equivalent, and the signal fluctuates due to fading. Terminals within an area are grouped together, and a time scheduling scheme is designed to assign communication establishment rights to these groups.

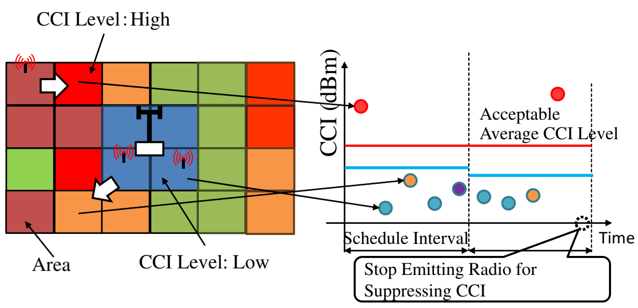


Fig. 3. Proposed Time Schedule

In the proposed time schedule, the smallest time unit is defined as a slot, and communication establishment is determined per slot. Furthermore, communication establishment is not assigned to individual terminals but rather to groups of multiple terminals existing within the area.The group assigned the communication right then determines the final communication establishment when terminals within the group notify the base station of their CSI. Consequently, multiple terminals competitively establish communications within the slot time, enabling user diversity. However, compared to existing time schedules, the number of terminals competing for use is limited, resulting in reduced user diversity gains.

Next, CCI to adjacent systems is used as the criterion for assigning the right to establish communication. Here, it is assumed that the base station's beamforming is oriented toward the direction where the main lobe's maximum gain is achieved relative to the area's center of gravity. Consequently, the antenna gain from beamforming at the adjacent system's site boundary is determined, enabling the calculation of CCI. Here, terminal usage within the operator's network is assumed to involve planned moving objects, such as robots. Consequently, the operator knows the location of these moving objects in advance. As shown in Figure 3, when the area where the terminal exists can be identified, the beamforming direction is determined, thereby fixing the magnitude of the CCI to the adjacent system. The time schedule is established based on this determined CCI.

The proposed time schedule shown in Figure 3 utilizes information about the future location of the moving object to predict the area where it will be present.Based on the estimated predicted area, the CCI generated when beamforming is set is calculated, assuming communication is established. A time schedule is then designed to allocate communication rights to each slot such that the average CCI within the frame time remains below a certain threshold. This approach achieves CCI suppression by allocating communication rights to terminals near the base station when terminals at site boundaries, which typically experience high CCI, move closer.Furthermore, establishing long-term plans over fixed time intervals ensures consistent communication opportunities, preventing skewed access among terminals. Conversely, this approach can also be utilized for establishing exclusive communication for specific terminals at the operator's discretion. In such cases, it enables the estimation of communication usage time within the permissible average CCI threshold, allowing for communication quality prediction tailored to application requirements.

TABLE I
PARAMETERS FOR EXPERIMENTAL EVALUATION

Parameters	Value	
Center Frequency	4.8	GHz
Bandwidth	100	MHz
Transport Protocol	UDP	
Measurement Time	60	sec
Transmit Power of gNB1(Target of Measure)	20	dBm
Transmit Power of gNB2 (Resource of CCI)	-3,0,5,10,15,17,20,25,30	dBm
Antenna High of gNB	2.5	m
Antenna High of UE	1	m
Time Slot Pattern in TDD	MIXED (DDDSUUDDDD)	

The authors have previously advanced the establishment of time scheduling that improves terminal communication establishment opportunities (fairness) based on CCI to adjacent systems. These time scheduling results have demonstrated the effects of suppressing CCI between adjacent systems and improving fairness. However, the communication performance achieved specifically throughput remains unclear.Furthermore, the system throughput relative to the permissible average CCI threshold, established through prior inter-operator agreements, remains unclear. This paper clarifies the achievable throughput when considering CCI occurrence through computer simulation. It also quantitatively evaluates throughput fluctuations caused by CCI using actual Local 5G equipment, thereby clarifying the necessary CCI suppression effect.

IV. Experimental Evaluation

Verification was conducted using commercial local 5G equipment. The device parameters are as shown in Table I. Two base stations connect communications to their respective terminals, sharing the same frequency band.GPS-based time synchronization was established, ensuring identical timing and scheduling for time slots in Time Division Duplexing (TDD). Consequently, when one system was transmitting downlink, the other system was also transmitting downlink. Thus, CCI was emitted by the base station and received by the terminal of the other system. This study evaluates communication performance by measuring throughput and other metrics on the downlink of one system.

The figure 4 shows the experimental setup. Two base stations were deployed indoors with a short distance between them. The wireless environment between base stations and between base stations and terminals is line of sight. One base station is designated as the interfering base station, and the performance of the communication system at the other base

Fig. 4. Overview of Experimental Environment

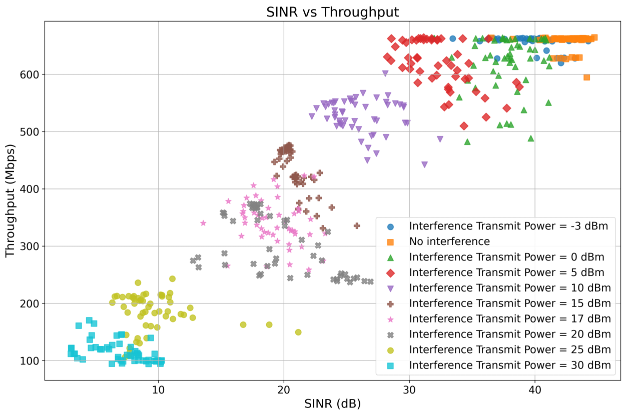


Fig. 5. Results of Experimental Evaluation

station is evaluated. Evaluations are conducted by controlling the interference power by switching the transmit power of the interfering base station.The horizontal and elevetional direction antenna [6] is used in this experiment.

Figure 5 shows the achieved throughput when varying the transmit power of the interfering base station. The horizontal axis represents the received signal-to-interference-plus-noise ratio (SINR) at the terminal in the interfered-with system. The vertical axis shows the achieved throughput. Throughput is averaged over fixed time intervals. The figure indicates that while achieved throughput exhibits fluctuations, it tends to decrease as transmit power increases.Since the transmit power is considered to determine the average received interference power, setting the average CCI as the frequency sharing criterion between systems allowed us to determine the average throughput and its fluctuation range. These results can be used as preliminary numerical values representing the achievable communication performance of each base station, enabling applications to determine whether they meet the required quality of service for the provided application.

V. Simulation Evaluation

Figure 6 shows the evaluation environment. A straight line is drawn between two base stations, assuming terminal movement along this line in a round-trip motion. The site boundary is set at half the distance of this line, dividing

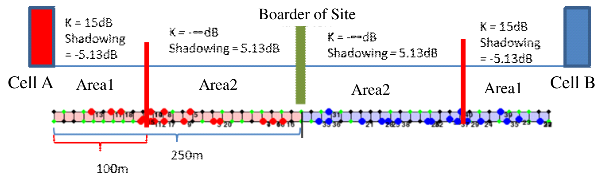


Fig. 6. Evaluation Environment in Computer Simulation

TABLE II
Simulation Parameters

Parameters	Value	Parameters	Value
Number of UEs	20	Beam Forming Model	3GPP(Angle wide of Half power 10 deg.) [6]
Measurement Periods	1000s	Time interval	Every 5 sec.
Center Frequency	4.9[GHz]	Propagation Model	Umi-streetcanyon-LOS
Higher Level (gNB,UE)	(10[m],1.5[m])	Proposed Time Scheduling	Wors Case Level: -85[dBm]
Speed of UE	1.5[m/s]	Fading Model	Nakagami-m [7]
Transmit Power	20[dBm]		

the service area. This paper assumes two areas, with different communication path models in each area. Shadowing is modeled as fixed power attenuation.Furthermore, referencing literature, the diversity gain achievable based on the number of competing users was modeled as the gain expansion value at an outage probability of 0.9. The Signal-to-Interference-plus-Noise Ratio (SINR) was calculated, and throughput was derived from Shannon's information capacity theorem.For the time schedule, the conventional method was considered, where communication opportunities were assigned to terminals based on the Proportional Fairness (PF) policy, taking into account the CSI of all users within the service area. In this case, if the average interference to the adjacent base station exceeded the threshold value, transmission was suppressed by not establishing communication during the time interval used to calculate the average interference power, ensuring the threshold was not exceeded.The communication time schedule for the proposed method was designed based on a literature-based approach. It predicts future interference based on terminal movement forecasts and allocates communication rights to each terminal such that the average interference remains below the threshold value. The table II shows the parameters used in this experiment.

The table III shows achievable communication opportunities, average throughput, and the Gini coefficient indicating fairness for various average interference threshold values. Here, the Gini coefficient is a measure evaluating the fairness of communication opportunities among terminals; a value of 0 indicates fairness, while 1 indicates a dominant user monopolizing communication opportunities.The figure shows that with existing methods, communication opportunities significantly decreased as the average interference threshold increased. This occurs because average interference exceeds the threshold during the time schedule, preventing communication establishment. In contrast, the proposed method ensures

TABLE III
SIMULATION RESULTS

(a) Conventional

Acceptable Average CCI (dBm)	Opportunities of Access of UEs (Max: 200)	Average Sector throughput (Mbps)	Gini Coefficient
-80	199/200	826	0.494
-85	99/200	381	0.338
-90	30/200	129	0.34

(b) Proposed

Acceptable Average CCI (dBm)	Opportunities of Access of Ues (Max: 200)	Average Sector throughput (Mbps)	Gini Coefficient
-80	200/200	993	0.431
-85	197/200	987	0.417
-90	139/200	740	0.257

communication opportunities at a rate of 1.0 even when the average interference threshold is low. The Gini coefficient remains below 0.2 as long as the threshold is -85dBm or higher.The proposed method avoids assigning communication rights to terminals located at site boundaries where transmit-interference is high. Furthermore, since terminals move, those at site boundaries also migrate toward the cell center. By assigning communication rights during this migration, communication rights can be granted without increasing transmit-interference. The average throughput is approximately doubled compared to the existing method, achieving high throughput.

VI. CONCLUSION

This study established a method to improve the time scheduling for determining communication rights allocation to terminals as a means to mitigate same-frequency interference when sharing the same frequency in autonomous cellular deployment for Local 5G. Through real-device experiments, throughput affected by same-frequency interference was quantitatively evaluated, clarifying the relationship between the average power level of same-frequency interference and communication performance.Furthermore, simulation evaluations demonstrated that designing time scheduling based on terminal movement prediction suppresses the expansion of interference caused by shallow beams when terminals are near site boundaries. It also revealed that actively assigning communication rights to terminals near base stations effectively suppresses same-frequency interference and increases throughput accordingly.Future work will focus on clarifying the interference suppression effect for planned terminal movements corresponding to actual usage and the robustness against errors in terminal movement prediction.

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REFERENCES

[1] M. Wen et al., "Private 5G Networks: Concepts, Architectures, and Research Landscape," in IEEE Journal of Selected Topics in Signal Processing, vol. 16, no. 1, pp. 7-25, Jan. 2022.

[2] 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

[3] S. Tomida, K. Mizutani and H. Harada, "Radio Protection Area Estimation Methods for Spectrum Sharing-based 5G System," 2021 IEEE 18th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 2021, pp. 1-4.

[4] T. Nanjo, O. Takyu and K. Akimoto, "Resource Allocation Algorithm Utilizing Interference Prediction in Local 5G Environments," 2025 Sixteenth International Conference on Ubiquitous and Future Networks (ICUFN), Lisbon, Portugal, 2025, pp. 156-159.

[5] T. Nanjo and O. Takyu, "Modified Resource Allocation Algorithm Based on Co-Channel Interference Prediction in Local 5G Environments," 2025 Asia Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC), Singapore, Singapore, 2025, pp. 1761-1766.

[6] Sector Antenna (GS00229) producted by DENGYO Japan https://solutions.den-gyo.com/product01_003

[7] 3GPP TR 36.873 v12.2.0 table 7.1-1 Antenna modelling parameters

[8] M. K. Simon and M-S. Alouini, Digital Communication over Fading Channel,-A Univied Approach to Perforamnce Analysis-, John Wiley & Sons, Inc. 2000.