Practical Resource Scheduling in Massive-cell Deployment for 5G Mobile Communications Systems

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***Abstract*—This paper proposes the first practical resource scheduling that increases system throughput in massive-cell deployment for 5G mobile communications systems. In 5G systems, the best combination of a huge number of antennas and user equipment for communications should be decided in the scheduling. The proposed scheme searches for the suitable combination without exhaustive search and accelerates calculation of system throughput for each combination. The scheme quickly obtains the combination for which the scheduling achieves higher system throughput, and thus the scheduling can be done within the required period. Simulation and experimental measurements show that the system throughput obtained is about seven times higher than for the conventional scheme. The proposed scheme enables a future practical 5G system.**

Keywords—5G mobile communications systems, resource scheduling, massive-cell deployment, hardware acceleration

I. Introduction

In downlink radio communications systems, resource scheduling assigns user equipment (UE) to each antenna. For efficient communications and improved overall system throughput, scheduling that decides the suitable combination of antennas and UEs is needed [1, 2].

In the fifth generation of mobile communications systems (5G), in order to increase system throughput, a huge number of antennas will be deployed in ultra-high density by allowing cell overlap [Fig. 1(b)] [3]. In the 5G system, radio transmission with these antennas will be intensively controlled at a central unit. When the numbers of antennas and UEs are 32 and 256, respectively, which is based on a 5G-system model in mobile and wireless communications enablers for the twenty-twenty information society (METIS) [4], the number of combinations of antennas and UEs reaches approximately 10^{76}. The scheduling in the ultra-high-density antenna deployment has to decide the best combination from this explosive increase of possible combinations.

Nevertheless, the scheduling period is limited to 1 ms in long-term evolution (LTE) specifications [5]. Thus, the scheduling must complete a huge amount of calculation to decide the best combination within the required period.

Before the 5G system [Fig. 1(a)], conventionally, exhaustive search can be applied to decide the combination in scheduling. The search can be done by software because the scheduling assigns UEs to only one antenna [6, 7]. On the other hand, in the 5G system, a high-performance calculator, such as a CPU with more than 10^{70} million instructions per second, will be needed to complete the search within the required period. It will be impossible to complete it with exhaustive search. If the scheduling decides the combination with exhaustive search, the search will have to be abandoned when the required period is expired. However, with this conventional scheme, the suitable combination cannot be found, and higher system throughput cannot be obtained. It will be difficult to increase the system throughput within the required period in the 5G system. Consequently, the performance of the 5G system cannot be drawn out sufficiently.

To overcome this issue, we propose a practical scheme that obtains the combination for which the scheduling achieves higher system throughput within the required period. The scheme searches for the suitable combination with a small amount of calculation. In addition, we devised an implementation scheme that accelerates the calculation of the system throughput for each combination search. These schemes can optimize the combination within the required period.

II. Proposed Scheme

Our proposal consists of a search scheme and an implementation scheme. The search scheme finds the suitable combination that achieves higher system throughput by iterating processing for improving the combination. In order to increase the number of iterations for improving the combination, the implementation scheme accelerates calculation of the system throughput for a combination during the search. As shown in Fig. 2, the conventional scheme needs longer processing time to obtain the combination that achieves higher system throughput. In contrast, the system throughput is quickly improved in the proposed scheme. The combination that achieves higher system throughput is obtained within the required period. The details of the schemes are described below.

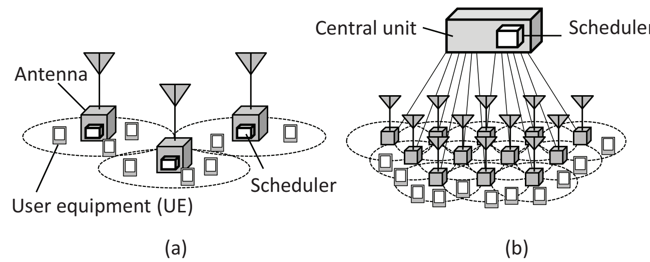

Fig. 1. Illustrations of antenna deployment (a) before the 5G system, and (b) in the 5G system (massive-cell deployment).

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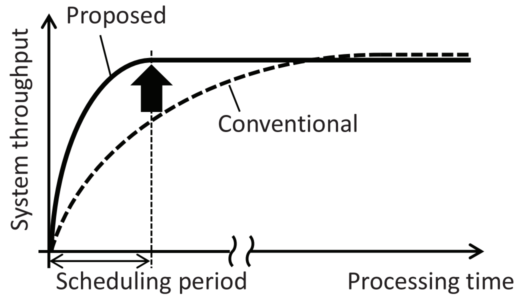

Fig. 2. Effectiveness of the proposed schemes.

A. Search scheme

In general, the UEs having the highest throughput are simultaneously chosen for all antennas when the scheduler searches for a combination, and the system throughput for the combination is calculated. In the proposed search scheme, the UE having the highest throughput is chosen only for one antenna, and the system throughput for the combination is calculated. Then, UEs are chosen for other antennas additionally. This choosing of the UE is carried out one by one by other antennas. In this way, the best UEs are assigned to antennas so that the system throughput always increases. The combination can be approximated to the suitable combination by iterating this assignment of UEs, and the system throughput is improved.

Figure 3 shows the procedure for deciding the combination in the proposed search scheme. First of all, all antennas are set to the blank, which means the radio transmission is stopped. Then, one of the antennas is selected. In the case shown in Fig. 3(a), antenna A is selected. In order to select the UE to which antenna A transmits the data, the throughputs of each UE are calculated. In this case, the throughputs of UE#1, UE#2 and UE#3 are calculated, and these three throughputs are compared. In this example, UE#2 has the highest throughput. Then, UE#2 is provisionally selected for antenna A, and the combination is updated.

Next, antenna B is selected. In the case shown in Fig. 3(b), in order to select the UE for antenna B, the system throughputs are calculated with the interference power from antenna A taken into account. The throughput of UE#2 may be changed because the interference power from antenna B is changed. When UE#4 is chosen, the system throughput is calculated by summing the throughput of UE#2 and that of UE#4. With the same calculation as above, the system throughput is calculated by summing the throughput of UE#2 and that of UE#5. These two system throughputs are compared, and the highest system throughput is obtained when antenna B transmits the data to UE#4 in this example. Then, UE#4 is provisionally selected for antenna B, and the combination is updated.

In this scheme, all antennas are selected one by one. This UE selection for each antenna is carried out sequentially to other antennas until the system throughput for the combination is no longer improved. In the case shown in Fig. 3(c), antenna A is selected again, and the throughputs of UE#1, UE#2 and UE#3 are calculated again because the interference powers from antenna B and antenna C are changed.

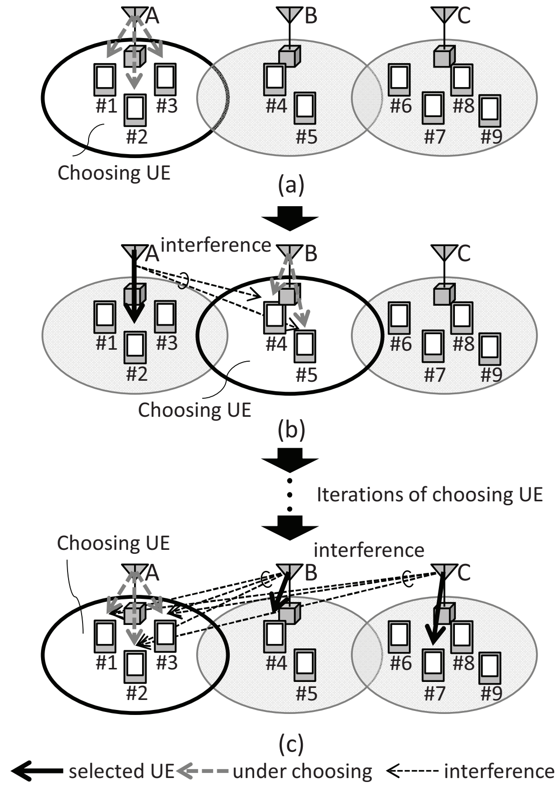

Fig. 3. Procedure for deciding the combination in the proposed search scheme in cases where (a) antenna A is selected, (b) antenna B is selected, and (c) antenna A is selected again.

The combination is always updated so that the system throughput increases. This increases the system throughput monotonically as the number of iterations increases. In addition, in the ultra-high-density antenna deployment, inter-cell interference from neighboring antennas becomes high. When the system throughput for the combination is calculated, the inter-cell interference is taken into account so that the scheduling decides the combination that enables its suppression. Consequently, the scheme can increase the system throughput and simultaneously suppress the inter-cell interference.

Figure 4 shows a flow chart of the search. In this search scheme, the system throughput is calculated every time a UE is chosen. This system-throughput calculation is iterated until all UEs are chosen for the selected antenna. This calculation is carried out sequentially to other antennas until the required period is expired. The combination obtained when the required period is expired is the suitable combination. The radio transmission is executed based on the decided combination.

In this scheme, antenna is selected from N antennas, and UE is selected from M UEs for the selected antenna. This UE selection is repeated during the scheduling period by selecting antenna one by one. Thus, the number of iterations can be formulated as

$$N*M*L \tag{1}$$

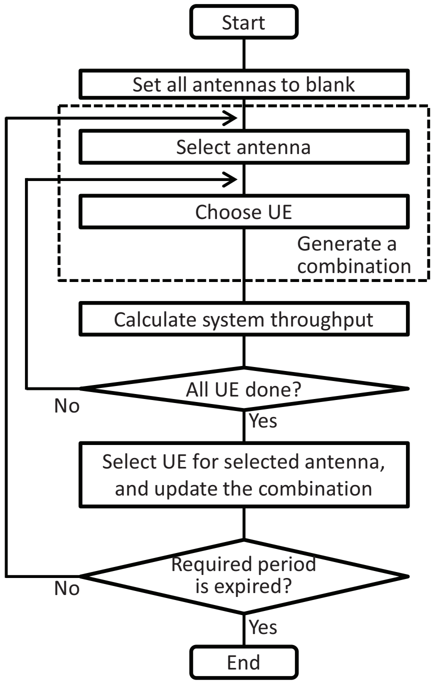

Fig. 4. Flow chart of the search.

where N, M, and L are the numbers of antennas, UEs, and repetitions, respectively. When all antennas are selected once, the number of repetitions is incremented. According to Eq. (1), when N, M, and L are 32, 256, and 7, respectively, the number of searched combinations is approximately 10^4. The number of iterations is dramatically reduced to a number that can be calculated in practice. With this search scheme, the search that obtains higher system throughput within the required period can be realized.

B. Implementation scheme

As shown in Fig. 4, the system throughput has to be calculated every time a UE is chosen in this search scheme. The system throughput TH_{sys} is calculated by summing the throughputs of all UEs as

$$TH_{sys} = \sum_{m=1}^{M} W \log_2\left(1 + SINR_{n,m}\right) \quad (2)$$

where W denotes transmission bandwidth and $SINR_{n,\ m}$ represents the received signal power to interference power and noise ratio of UE m served from antenna n. $SINR_{n,\ m}$ is calculated by summing the interference powers from the other antennas as

$$SINR_{n,m} = \frac{P_{n,m}}{\sum_{i=1,\, i\neq n}^{N} P_{i,m} + \eta} \quad (3)$$

where $P_{n,m}$ denotes the received signal power of UE m served from antenna n and η denotes noise power. According to investigation by software-based scheduling, this system-throughput calculation accounts for more than 90% of the processing time to execute the search.

Conventionally, scheduling is executed on a CPU with software. On the other hand, in the 5G system, it will be difficult to execute a huge amount of calculation on a CPU with software. Therefore, we devised a hardware implementation scheme so that calculation is accelerated and the number of iterations increases.

Figure 5 shows a block diagram the circuit based on the scheme. The circuit comprises three parts: a combination-generation part that outputs the combination of antennas and UEs, a system-throughput-calculation part, and a combination-decision part that decides the combination by comparing the system throughput for each combination. The system-throughput-calculation part consists of plural throughput-calculation blocks that output the throughputs of the UEs in parallel. The throughput-calculation blocks are provided with the same number of antennas. The UE information memory stores calculation conditions of the UE throughput. The throughput-summation block outputs the system throughput by summing the throughputs of the UEs.

The proposed implementation scheme assigns each throughput-calculation block to an antenna. Throughputs of the UEs in the combination generated by the combination-generation block are calculated at the throughput-calculation blocks. With UE information stored in the memory, UE throughputs are calculated. Then, the system throughput is calculated by summing the throughputs of all UEs in the combination. In this scheme, the throughputs of the UEs are simultaneously calculated at the throughput-calculation blocks. So, the circuit executes the search at high speed, and this increases the number of iterations within the scheduling period. Furthermore, the circuit scale can be minimized by optimizing a parallel number for the same number of antennas.

More specifically, the search scheme only changes one of the UEs in the combination. The combination-generation block informs each throughput-calculation block of the selected antenna. The UE information for the chosen UE is read from the memory. The UE information is updated only at the throughput-calculation block assigned to the selected antenna. At the throughput-calculation block assigned to the selected antenna, the UE throughput is calculated with the updated UE information. On the other hand, at the throughput-calculation block assigned to the un-selected antenna, UE throughput is calculated with the retained UE information. When one of the UEs in the combination is changed into a different UE, the

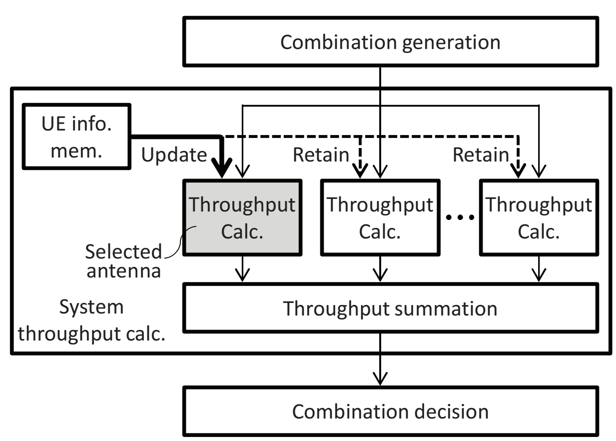

Fig. 5. Circuit block diagram.

inter-cell interference is changed. All UE throughputs need to be calculated at all throughput-calculation blocks.

Figure 6 shows the timing chart. The number of times the UE information is read from the memory is minimized by using the characteristic of the combination generation in the search scheme. The combination-generation block only changes the UE for the selected antenna; it does not change UEs for the other antennas. As a result, the UE information is updated only for the throughput-calculation block assigned to the selected antenna. The other throughput-calculation blocks use the UE information retained in each throughput-calculation block. The scheme realizes parallel processing by setting all the UE information needed to calculate the system throughput with minimized memory readout. Thus, the circuit executes the search at high speed and the scheme increases the number of iterations within the scheduling period.

III. Performance Evaluation

In order to evaluate the performance of the proposed schemes, we carried out system-level simulations and experimental measurements. Then, we evaluated the system throughput obtained within the scheduling period.

A. *Effectiveness of implementation scheme*

Generally, the scheduling is executed on a CPU with software. In order to increase the number of iterations for improving the combination, the system-throughput calculation is accelerated by hardware in the implementation scheme. Increasing the number of iterations improves the system throughput because the system throughput can be improved by iterating the UE selection. To verify the number of iterations within the scheduling period, we measured the processing time spent for the search scheme. Then, we compared the number of iterations with the proposed scheme and software-based scheduling.

The proposed implementation scheme described in section II.B was implemented on a field-programmable gate array (FPGA) (Xilinx, Virtex7) at the clock frequency of 100 MHz. The processing time was measured with the FPGA. The software-based processing time was measured with a general purpose processor (Intel, Core i5) at the clock frequency of 2.67 GHz.

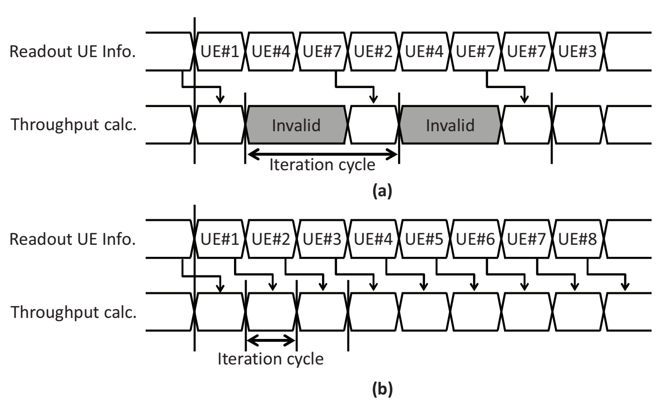

Fig. 6. Timing chart in the circuit (a) without proposed search scheme, and (b) with proposed search scheme.

Figure 7 shows the processing time per iteration. As seen in the figure, the processing time per iteration measured with the proposed scheme is 10 ns. The software-based processing time per iteration is 596 ns. The circuit executes the search scheme about 60 times faster than software-based scheduling. These results show that the proposed implementation scheme accelerates the system-throughput calculation.

From these results, the number of iterations within the scheduling period of 1 ms in the proposed scheme is 100000 and that in software-based scheduling is 1679. These results show that the number of iterations in the proposed scheme is about 60 times larger than in software-based scheduling. Since the implementation scheme increases the number of iterations, the search scheme can increase the number of UE selections for improving the combination. Therefore, the system throughput can be further improved with this implementation scheme.

B. *Effectiveness of search scheme*

1) *Simulation setup*

The performance of the proposed search scheme was evaluated in practical conditions based on the small cell scenario in LTE specifications [8]. Table I shows the simulation conditions. In the simulation conditions that assume the ultra-high-density antenna deployment, 32 single antennas are uniformly distributed in a circle with a radius of 155 meters. The minimum distance between antennas is 20 meters.

2) *Reduction of the number of searched combinations*

It is important to obtain the combination with a small number of iterations even if the number of antennas increases. To verify that the combination is obtained in the ultra-high-density antenna deployment, we compared the number of searched combinations.

Figure 8 shows the dependence of the number of searched combinations on the number of antennas. As seen in the figure, the number of all combinations increases exponentially as the number of antennas increases. On the contrary, with the proposed scheme, the number of searched combinations slightly increases as the number of antennas increases. When the number of antennas is 32, the number of searched

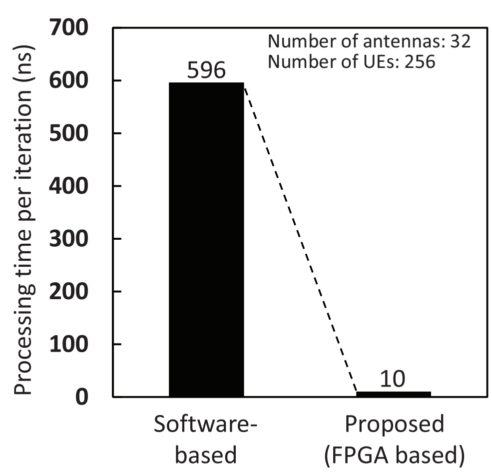

Fig. 7. Processing time per iteration measured with software-based processing and proposed scheme.

TABLE I. SIMULATION CONDITIONS

Parameter	Value
System bandwidth	10 MHz
Carrier frequency	3.5 GHz
Transmission power	30 dBm
Number of antennas	32
Number of UEs	256
Antenna deployment	Uniform in a circle with a radius of 155 m
Min. inter-antenna distance	20 m
Antenna height	10 m
UE distribution	Uniform in a circle with a radius of 155 m
Antenna height at UE	1.5 m
Traffic model	Full buffer
Propagation loss	Line of sight: $22.0\log_{10}(R) + 38.9$ dB Non-line of sight: $36.7\log_{10}(R) + 36.8$ dB For 3.5 GHz, R in meter.
Fading model	Rayleigh fading
Shadowing standard deviation	8 dB
Noise figure	9 dB
Thermal noise power density in dBm/Hz	-174

combinations is reduced by 10^{-71}. These results show that the proposed search scheme is superior in reducing the number of searched combinations in the ultra-high-density antenna deployment.

3) *Improvement of system throughput*

The proposed search scheme iterates the UE selection so that the system throughput increases. To verify that the system throughput can be improved as the number of iterations increases, we compared the system throughput obtained by the proposed scheme with that of the conventional scheme that abandons calculation when the scheduling period expires.

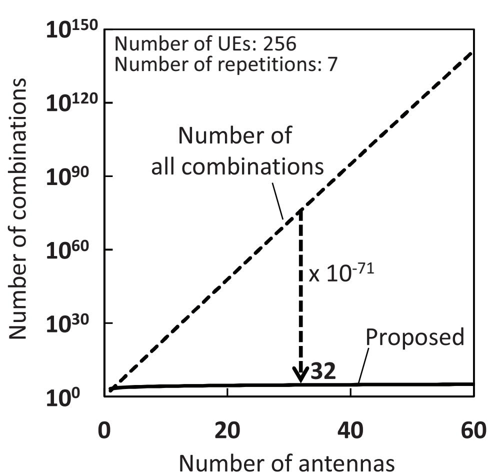

Fig. 8. Dependence of the number of combinations on the number of antennas.

Figure 9 shows the dependence of the system throughput per resource element group (REG) on the number of iterations. As seen in the figure, the system throughput obtained by the proposed scheme monotonically increases as the number of iterations increases. The suitable UE is chosen every iteration in the proposed search scheme. As a result, the system throughput monotonically increases. The better combination can be obtained as the scheduling period becomes long, and the highest system throughput is obtained even if the scheduling abandons calculation when the scheduling period expires.

C. *System throughput*

In order to verify that the proposed scheme obtains the combination for which the scheduling achieves higher system throughput within the required period, we evaluated the system throughput. The dependence of the system throughput on the scheduling period and number of antennas were simulated. In these simulations, 10000 cases for antennas and UEs deployment were examined.

Figure 10 shows the dependence of the average system throughput per REG on the scheduling period. As seen in the figure, the combination that achieves higher system throughput is obtained within the scheduling period of 1 ms in the proposed scheme. At the scheduling period of 1 ms, the average system throughput for the combination obtained by the proposed scheme is about seven times higher than the conventional scheme. Furthermore, the combination that achieves higher system throughput is obtained faster than 1 ms. This indicates that the combination can be obtained even when the scheduling period is shortened.

Figure 11 shows a histogram of the system throughput per REG in order to verify that the proposed scheme is effective in any antennas and UEs deployments. As seen in the figure, the system throughputs obtained by the proposed scheme are higher than the those obtained by the conventional scheme on all combinations.

Figure 12 shows the dependence of the average system throughput per REG on the number of antennas. As seen in the figure, the average system throughputs obtained by the proposed scheme are higher than for the conventional scheme

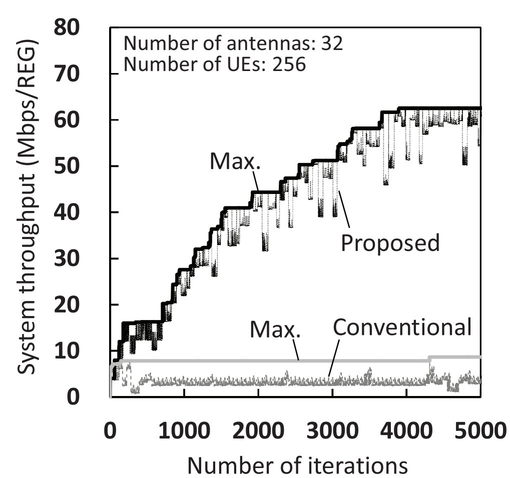

Fig. 9. Dependence of the system throughput per REG on the number of iterations.

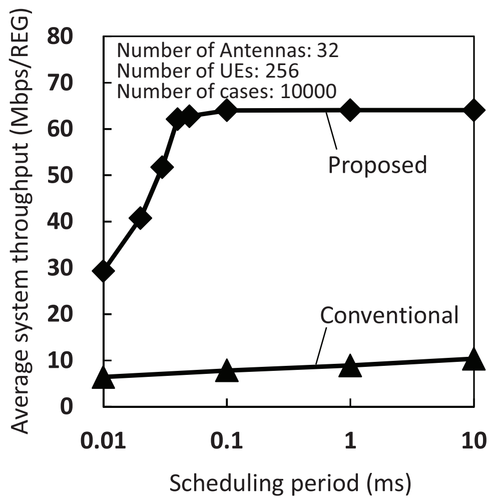

Fig. 10. Dependence of the average system throughput per REG on the scheduling period.

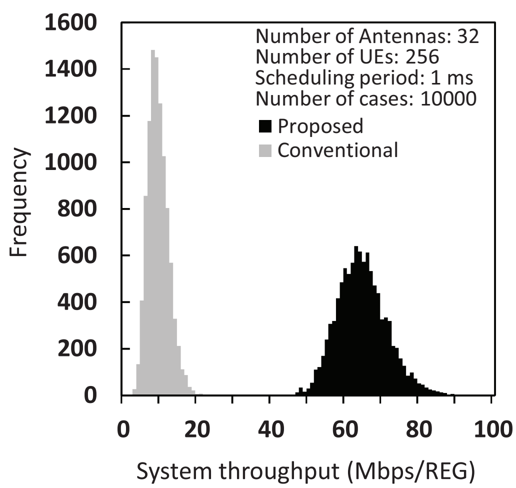

Fig. 11. Histogram of the system throughput per REG.

at all numbers of antennas. In addition, when the number of antennas is more than 32, the proposed scheme obtains higher system throughput within the scheduling period of 1 ms.

These results show that the proposed scheme improves the system throughput by seven times within the scheduling period of 1 ms when the numbers of antennas and UEs are 32 and 256, respectively. Furthermore, the proposed scheme can be applied in a system with more than 32 antennas and with the required scheduling period of shorter than 1 ms.

IV. Summary

In this paper, in massive-cell deployment, we proposed a practical resource scheduling that obtains higher system throughput within the scheduling period of 1 ms. Our proposal consists of a search scheme and an implementation scheme. The search scheme finds the suitable combination with a small number of iterations for improving the combination. As a result, the number of searched combinations is reduced by 10^{-71} when the numbers of antennas and UEs are 32 and 256, respectively.

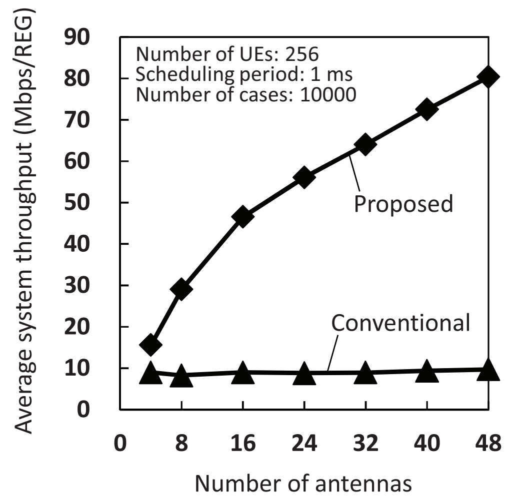

Fig. 12. Dependence of the average system throughput per REG on the number of antennas.

The implementation scheme performs the calculation of system throughput 60 times faster than software-based scheduling. This increases the number of iterations for improving the combination in the search scheme. Consequently, with these two schemes, the system throughput is about seven times higher than for the conventional scheme. Furthermore, the combination can be optimized in a period shorter than 1 ms, and obtained in a system with more than 32 antennas. The proposed scheme performed practical resource scheduling in massive-cell deployment for the 5G system for the first time. Although the proposed scheme was evaluated with single antennas, the scheme might be applicable to multi-input multi-output antenna systems. The scheduling with the proposed scheme enables a practical 5G system.

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