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研究課題名（和文）Dynamic Resource Allocation for 5G Green HetNet

研究課題名（英文）Dynamic Resource Allocation for 5G Green HetNet

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研究成果の概要（和文）：上りリンク単入力多出力(SISO)シングルキャリア周波数分割多元接続(SC-FDMA) におけるユーザーのスケジューリングと資源ブロック(RB)配分問題について研究 している．まず，SIMO SC-FDMAシステム信号伝送のための解析モデルを示した．ユーザーのスケジューリング関する簡素なアルゴリズムを設計するために、ユーザーの受信相関アレイと上りリンクSIMO SC-FDMAシステムの周波数効率(SE)の関 係性を示した．我々の研究結果によれば、システムに8つの資源ブロックと18の ユーザーが存在する場合、提案スケジューリング法によってSE特性が約10%向上する。

研究成果の概要（英文）：We studied the user scheduling and resource block (RB) allocation problem in uplink single input multiple output (SIMO) single carrier frequency division multiple access (SC-FDMA) system. An analytic model for SIMO SC-FDMA system signal processing was first presented. In order to design a low complexity algorithm for user scheduling, we first showed the relationship between the user's received array correlation and the uplink SIMO SC-FDMA system spectral efficiency (SE). Our results show that the proposed scheduling technique improves the total SE for about 10% when an optimum number of 8 RBs is considered with 18 users in the system. Moreover, we proposed similar algorithm which is capable of controlling the system fairness as well. Finally, we further developed our model for the case of imperfect channel state information (CSI) by introducing a pilot signal structure. Simulation results show that our a algorithm improves the SE considerably, even under imperfect CSI conditions.

研究分野：無線通信

キーワード：resource allocation　fairness　5G　uplink　scheduling

1．研究開始当初の背景

Information and communication technology (ICT) has significantly paved the way for a life with higher standards and quality. However, by current trends, ICT data traffic (mainly caused by Video transmission) is expected to increase 1,000 fold by 2020 and we will have at least 50 billion Internet-capable devices by that time. Due to this increased demand for bandwidth, we are running out of radio space sooner than expected and this is an alarm for a breakdown which may affect the nation's economy. For instance, smaller industries are dependent for wireless-enabled technologies, for their products and services. If a solution is not found for this high demand of bandwidth, instead of the flourishing of the new commercial opportunities, we'll witness a closing down. This is why 5G is so important, even before 4G has taken off. Unlike its predecessors, 5G does not only look for improving speed of data rates, but also tries to establish sustainability and making a global digital life a possibility.

2．研究の目的

In this project we pursue two goals; (1) Designing robust radio resource management (RRM) modules for next generation 5G mobile communications, (2) Optimizing the RRM modules from energy-consumption point of view. With the rapid growth of wireless industry and related infrastructure, the demand for bandwidth is increasing exponentially and the initial works for designing the next generation (5G) mobile communications which accommodates a higher capacity has started. On the other hand, Energy is becoming a scarce resource and the need to optimize energy consumption in all industries as well as wireless industry is apparent. This project aims at addressing these issues by designing energy-efficient RRM modules for 5G heterogeneous networks (HetNet).

3．研究の方法

(1) We studied the user scheduling and resource block allocation problem in uplink single input multiple output (SIMO) single carrier frequency division multiple access (SC-FDMA) system. An analytic model for SIMO SC-FDMA system signal processing at the transmitter and receiver was first presented. Later, we used this model to derive the users' signal to interference noise ratio (SINR) and then the system spectral efficiency. In order to design a low complexity algorithm for user scheduling, we first showed the relationship between the user's received array correlation and the uplink SIMO SC-FDMA system spectral efficiency. Then we argued that grouping the users based on their received array correlation can improve the overall spectral efficiency, while keeping the scheduling algorithm less complex without the need for performing a full search. For instance, our results show that our proposed scheduling technique improves the total spectral efficiency for about 10% when an optimum number of 8 resource blocks is considered with 18 users in the system.

(2) Moreover, we proposed similar algorithm which is capable of controlling the system fairness as well. However, this algorithm works for the scenarios with no multi-user interference (MUI) in the system.

(3) We further developed our model for the case of imperfect channel state information (CSI) by introducing a pilot signal structure for uplink. This method uses interpolation to estimate the channel. Simulation results show that our algorithm improves the spectral efficiency considerably, even under imperfect CSI conditions.

(4) At the next step, we further developed other efficient channel estimation techniques, employing channel sparsity characteristics.

(5) Finally, in an effort to improve the energy-efficiency, we proposed a joint opportunistic ON/OFF switching (OOFS) & dynamic channel allocation algorithm (JOFS-DCA) for downlink HetNet. A non-cooperative game is formulated between the base stations (BSs) and then, a distributed algorithm is proposed to decide about the ON/OFF status of the BS or the level of its transmission power. In the next step, UEs decide which BS to connect to, i.e., the UE association problem. Each UE chooses the target BS considering both the RSS and averaged load of all BSs. Finally, each BS employs a distributed channel segregation method to choose a channel based on its look-up table. This look-up table is formed based on the level of co-channel interference (CCI) that each BS senses on different channels. After each BS' channel is decided, then an orthogonal division multiple access (OFDMA) scheme is used to transmit to the UEs in downlink. Simulation results are provided to evaluate

the performance of the proposed algorithm in terms of average BS energy consumption and throughput.

In the following, we are going to elaborate more on some of the results that we obtained in (1) and (5).

4．研究成果

(1) Research Result Summary for RRM Study for Uplink SIMO SC-FDMA

Table 1: Simulation Parameters

Transmitter	
Data modulation	QPSK,
Number of RBs	$\Delta = 1:8$
FFT/IFFT size	$N_c = 256$
Total Number of users	$U = 1:16$
Total Transmit SNR	$E_s/N_0 = 0:20$ dB
Transmit Pwr. Control	Slow TPC
Channel	
Fading type	Frequency-selective block Rayleigh
Power delay profile	$L = 16$-path uniform power delay profile
Time delay	$\tau_{u,l} = l$, $l = 0:L-1$
Receiver	
Number of receive antennas	$N_r = 1:8$
Equalization Type	MMSE-FDE

The simulation parameters are summarized in Table 1. A block transmission and QPSK data modulation is considered. We assume an L=16-path frequency-selective block Rayleigh fading channel with uniform power delay profile. The transmit timing is asynchronous among different users, but is kept within the CP. The correlated receive antenna diversity reception using $N_r = 1:8$ is assumed. First, we consider ideal channel estimation and use a slow transmit power control for all users.

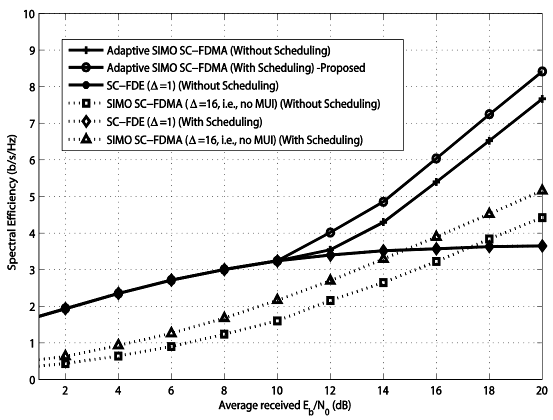

Fig. 1: Spectral efficiency *vs* average received SNR for different resource allocation scenarios and $N_r = 4$, $U = 16$.

Figs. 1 shows the spectral efficiency as a function of average received SNR for different scheduling and RA schemes. Our proposed adaptive scheme is compared with two extreme cases, i.e., SC-FDE ($\Delta = 1$) and pure SIMO SC-FDMA ($U = \Delta$), with and without the DOC-based scheduling technique. As we can see our proposed adaptive scheme, which jointly selects the RB size and schedules the users, has the dominant performance for SNRs over 10dB. However, it has a similar performance with SC-FDE for SNRs below 10dB. By comparing SC-FDE and SIMO SC-FDMA ($U = \Delta$), we observe that SC-FDE has a better performance only for SNRs below 18dB, and for SNRs over 18dB its performance degrades due to increased MUI.

(2) Research result summary for energy-efficiency RRM in downlink HetNet

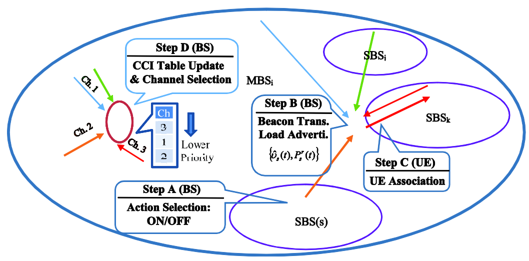

Fig. 2: System model for the energy efficiency improvement in HetNets through distributed RRM technique.

We consider the downlink transmission in a heterogeneous network. Fig. 2 shows the system model, which consists of a set of BSs, $\mathcal{S} = \{1,\ldots,S\}$. We assume only one macro base station (MBS), $s = 1$ which encompasses a variable number of small base stations, $\mathcal{S} = \{2,\ldots,S\}$. A total number of X users, $\mathcal{X} = \{1,\ldots,X\}$ are available in the system. We assume a total of C available channels, $\mathcal{C} = \{1,\ldots,C\}$.

In Steps A, ON/OFF status of the BS is decided based on a game theoretic algorithm. Step B involves beacon transmission and load advertisement in which each BS periodically broadcasts the beacon signal on the selected channel. In Step C, users decide to which BS they want to connect to, based on the received power and estimated load of each BS which they receive during Step B. Later at step D, the instantaneous CCI power $I_{BS(s)}(t;c)$ is measured at BS(s) on the cth channel ($c = 0:C-1$). We use the first order filtering to compute the average CCI power. The average CCI power $\bar{I}_{BS(s)}(t;c)$

computed at s th BS on the c th channel at time t is given by

$$\bar{I}_{BS(s)}(t;c) = (1-\beta)\cdot I_{BS(s)}(t;c) + \beta\cdot\bar{I}_{BS(s)}(t-1;c), \quad (1)$$

where β denotes the forgetting factor. Using the average CCI powers on all available channels, the CCI table (Table 2) is updated for all available channels ($c = 0 : C-1$). The channel having the lowest average CCI power is selected as

$$\mathrm{C}(s,t) = \operatorname*{argmin}_{c\in \mathrm{C}} \bar{I}_{BS(s)}(t;c), \quad (2)$$

which is used until the next CCI table updating time t+1. The averaging interval of the first order filtering is given as 1/(1- β). If a too small β is used, averaging is not enough and the measured average CCI power varies like the instantaneous CCI power. Therefore, the channel reuse pattern varies at every CCI table updating time. Hence, $\beta \approx 1$ is recommended. In this paper, β =0.95 is used for the computer simulation.

Table 2: CCI Table at the BS(s)

Ch. #	Avg. CCI Pow.	Priority
#1	$\bar{I}_{BS(s)}(t;1)$	2
#2	$\bar{I}_{BS(s)}(t;2)$	1
...	$\bar{I}_{BS(s)}(t;3)$	...
#C	$\bar{I}_{BS(s)}(t;4)$	n

Two benchmarks are considered for comparison purposes. First is a baseline approach, in which all BSs are always on. Second is the energy-efficient ON/OFF switching algorithm without any channel allocation scheme. Fig. 3 and Fig. 4 show the average energy consumption per BS for different numbers of UEs for $S = 2$ BSs and $S = 25$ BSs, respectively. The number

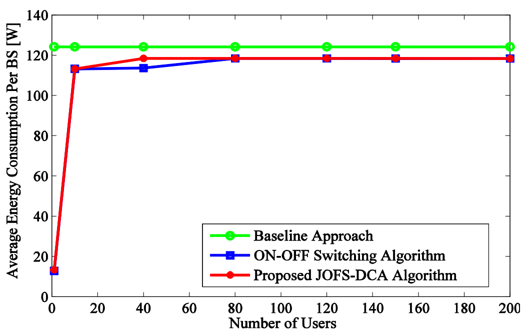

Fig. 3: Average energy consumption per base station for different number of UEs and $S = 2$ BSs and $C = 4$.

of channels for the proposed algorithm is $C = 4$ in all scenarios. We observe that the proposed algorithm and ON/OFF switching one have considerably higher EE than the baseline approach but their performance is quite identical for lower number of (density) of BSs. However in more dense

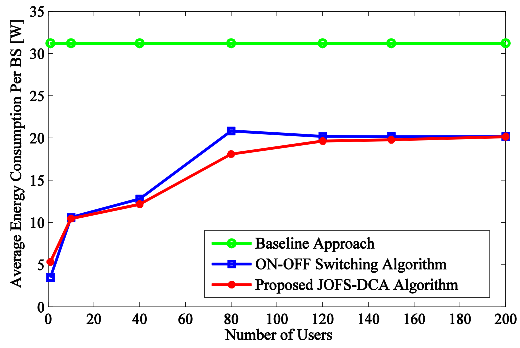

Fig. 4: Average energy consumption per BS for different number of UEs ($S = 25$ BSs and $C = 4$).

scenarios ($S = 25$ BSs), the proposed algorithm slightly outperforms the only ON/OFF switching algorithm for moderate number of connected UEs in the system. Maximum improvement is about 12%.

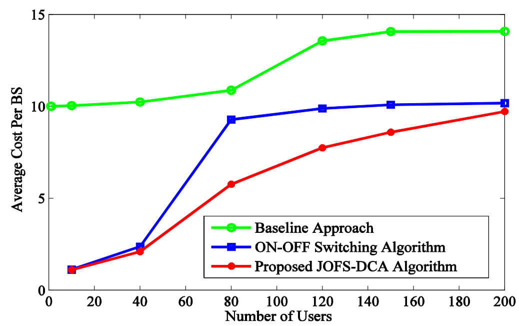

Fig. 5: Average cost per base station for different number of UEs and $S = 25$ BSs and $C = 4$.

Fig. 5 shows the average cost (i.e., Energy consumption + Load) per BS for different number of UEs, $S = 25$ BSs and $C = 4$. When both power consumption and load are taken into consideration, the proposed algorithm shows substantial improvement, compared to the two other

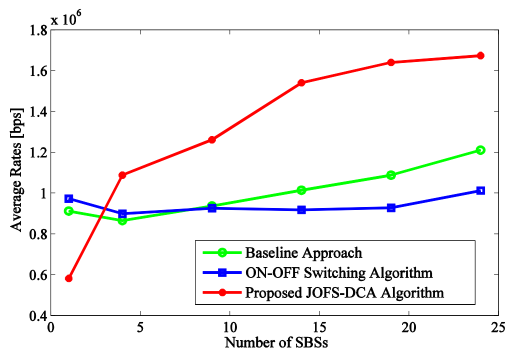

Fig. 6: Average throughput per BS for different number of base stations ($X = 100$ UEs and $C = 4$).

algorithms.

Finally, Fig. 6, compares the average throughput per BS for different number of BSs. Again the proposed algorithm significantly outperforms the two other algorithms.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

①雑誌論文（計４件）

- G. Gui, A. Mehbodniya and F. Adachi, "Sparse LMS/F algorithms with application to adaptive system identification", Wiley Wireless Communications and Mobile Computing, doi: 10.1002/wcm.2453, Dec. 2013.
- A. Mehbodniya, K. Faisal, Kang. K. Yen and F. Adachi, "Wireless network access selection scheme for heterogeneous multimedia traffic", IET Networks, vol.2, no.4, pp.214-223, Dec. 2013
- A. Mehbodniya, S. Aissa and F. Adachi, "Efficient Resource Utilization for Heterogeneous Wireless Personal Area Networks", IEICE Transactions on Communications, vol. E96-B, no. 6, pp.1577-1587, Jun. 2013.
- A. Mehbodniya, K. Faisal, Kang. K. Yen and F. Adachi, "A Fuzzy Extension of VIKOR for Target Network Selection in Heterogeneous Wireless Environments", Elsevier Physical Communication, Volume 7, pp. 145-155, June 2013.

②[学会発表（計 29 件）

- R. Yoneya, A. Mehbodniya and F. Adachi," A Base Station on/off Algorithm for Energy-Efficient HetNet", RCS IEICE Tech. Rep., vol. 114, no. 254, pp. 207-212, Keio University, Tokyo, Japan, 17th Oct. 2014.
- G. Guan, S. Kumagai, A. Mehbodniya and F. Adachi, "Two are Better than One: Adaptive Sparse System Identification using Affine Combination of Two Sparse Adaptive Filters", in Proc. of the IEEE (VTC-Spring), 18-21 May 2014, Seoul, Korea.
- A. Mehbodniya and F. Adachi, "Radio Resource Management for Next Generation", in Proc. IEICE Information and Com. Tech. Forum (ICTF), 28-30 May 2014, Poznan, Poland.
- A. Mehbodniya and F. Adachi, "Fairness-Capacity Tradeoff for SC-FDMA/SDMA Transmission Scheme", IEICE Tech. Rep., vol. 113, no. 456, RCS2013-333, pp. 163-167, Waseda University, 3rd March 2014.
- A. Mehbodniya and F. Adachi, "Radio Resource Management for Next Generation Wireless Networks", IEICE Tech. Rep., vol. 114, no. 8, RCS2014-17, pp. 91-94, Nagoya Inst. of Tech., 18th April 2014.
- A. Mehbodniya and F. Adachi, "Imperfect channel estimation and its effect on uplink FDMA resource management", IEICE Tech. Rep., vol. 114, no. 86, RCS2014-49, pp. 99-103, Okinawa, 17th June 2014.
- G. Guan, A. Mehbodniya and F. Adachi, "Bayesian Sparse Channel Estimation and Data Detection for OFDM Communication Systems", in Proc. of the IEEE (VTC-Fall), 2-5 September 2013, Las Vegas, USA.
- G. Guan, A. Mehbodniya and F. Adachi, "Adaptive Sparse Channel Estimation for Time-Variant MIMO Communication Systems", in Proc. of the IEEE (VTC-Fall), 2-5 September 2013, Las Vegas, USA.
- G. Guan, A. Mehbodniya and F. Adachi, "Sparse Channel Estimation for MIMO-OFDM Amplify-and-Forward Two-Way Relay Networks", in Proc. of the IEEE (VTC-Fall), 2-5 September 2013, Las Vegas, USA.
- G. Guan, A. Mehbodniya and F. Adachi, "Least Mean Square/Fourth Algorithm for Adaptive Sparse Channel Estimation", in Proc. of the IEEE (PIMRC'13), 8-11 Sept. 2013, London, UK.
- G. Guan, A. Mehbodniya and F. Adachi, "Adaptive Sparse Channel Estimation Using Re-Weighted Zero-Attracting Normalized Least Mean Fourth", in Proc. of the IEEE Int. Comm. Conf. in China (ICCC), 12-14 Aug. 2013, Xian, China.
- G. Guan, S. Kumagai, A. Mehbodniya and F. Adachi, "Variable is Good: Adaptive Sparse Channel Estimation using VSS-ZA-NLMS Algorithm", in Proc. of the IEEE Intern. Conference on wireless comm. and signal proc. (WCSP), 24-26 Oct. 2013, Hangzhou, China.
- A. Mehbodniya, W. Peng and F. Adachi, "An adaptive multiuser scheduling

and chunk allocation algorithm for uplink SIMO SC-FDMA", Communications (ICC), 2014 IEEE International Conference on, vol., no., pp.2861, 2866, 10-14 June 2014. doi: 10.1109/ICC.2014.6883758。

- A. Mehbodniya, T. Iwata, F. Adachi, "A Tunable Multiuser Grouping and Chunk Allocation Algorithm for Controlling Fairness-Capacity Tradeoff in SC FDMA/SDMA Transmission", Vehicular Tech. Conference (VTC Spring), 2014 IEEE 79th , vol., no., pp.1,5, 18-21 May 2014. doi: 10.1109/ICC.2014.6883758.

- A. Mehbodniya, W. Saad, F. Adachi, R. Yoneya, I. Guvenc, "Energy-Efficient radio Resource Management for Next Generation Dense HetNet", The 5th International Conference on Energy Aware Computing Systems & Applications (ICEAC), 24-26 March 2015, Cairo, Egypt.

- A. Mehbodniya and F. Adachi, "Imperfect channel estimation and its effect on uplink FDMA resource management", **電子情報通信学会無線通信システム研究会** (RCS), 2014 **年** 06 **月** 17-19 **日**, **那覇市/沖縄県青年会館**

- A. Mehbodniya and F. Adachi, "A Distributed Sleep Mode and Bandwidth Allocation Algorithm for Improving Energy-Efficiency in Dense HetNet", **電子情報通信学会無線通信システム研究会** (RCS), 2015 **年** 03 **月** 4-6 **日**, **東京都/東京工業大学**.

- A. Mehbodniya, K. Temma, R. Sugai, R. Yoneya, F. Adachi, "A Hybrid Algorithm for Optimization of Base Station Power Consumption and Throughput Improvement", **電子情報通信学会無線通信システム研究会** (RCS), 2015 **年** 03 **月** 4-6 **日**, **東京都/東京工業大学**.

- R. Yoneya, A. Mehbodniya, F. Adachi, "A Novel Handover Algorithm with Load Balancing for Next Generation HetNet", **電子情報通信学会無線通信システム研究会** (RCS), 2015 **年** 03 **月** 4-6 **日**, **東京都/東京工業大学**.

- R. Yoneya, A. Mehbodniya, F. Adachi, "A Novel Joint Handover and Base Station Sleep mode Algorithm in HetNet", **電子情報通信学会無線通信システム研究会** (RCS), 2015 **年** 01 **月** 22-23 **日**, **岡山大学**.

- R. Sugai, K. Temma, A. Mehbodniya, F. Adachi, "A Study on Interference-Aware Channel Segregation for HetNet Using Time- and Frequency-Division Channels", **電子情報通信学会無線通信システム研究会** (RCS), 2015 **年** 03 **月** 4-6 **日**, **東京都/東京工業大学**.

- A. Mehbodniya," Energy-Efficient Resource Allocation for 5G", tutorial presented at 2014 International Conference on Computer, Information, and Telecommunication Systems, CITS 2014, 7th Aug. 2014, Jeju Island, Korea.

- A. Mehbodniya," Energy-Efficient Radio Resource Management for Dense HetNet", tutorial presented at 2014 International Telecomm. Symposium (ITS), 17th Aug. Sao Paulo, Brazil.

- A. Mehbodniya and F. Adachi, "Energy-Efficient Resource Allocation for Next Generation Wireless Networks", tutorial presented at 2014 European Signal Processing Conference (EUSIPCO 2014), 1st Sept. 2014, Lisbon, Portugal.

- A. Mehbodniya, I. Guvenc and F. Adachi, "Hyper-Dense Heterogeneous Wireless Networks", tutorial presented at IEEE (VTC-Fall), 14th Sept. 2014, Vancouver, Canada.

- I. Guvenc, A. Mehbodniya and F. Adachi, "Towards Energy-Efficient Hyper-Dense Wireless Networks with Trillions of Devices", 2015 IEEE wireless communications and networking conference (WCNC), 9th Mar. 2015, New Orleans, USA.

- A. Mehbodniya, "Dynamic Resource Allocation for 5G Green HetNet", keynote at the 2nd International Conference on Electrical, Electronics, Computer Engineering and their Applications, 11th Feb. 2015, Manila, Philippines.

- A. Mehbodniya, "Dynamic Resource Allocation for 5G Green HetNet", keynote at The International Conf. on Advanced Technologies for Communications (ATC), 15th Nov. 2014, Hanoi, Vietnam.

- A. Mehbodniya, "Dynamic Resource Allocation for 5G Green HetNet", invited talk ECE department, University of Victoria, Canada, 16th Sept. 2014.

６．研究組織

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