Proposal of Enhanced Cell Range Expansion for Heterogeneous Mobile Networks

Kentaro Yoda and Hiroyuki Otsuka

Graduate School of Engineering, Kogakuin University,
1-24-2, Shinjuku-ku, Tokyo, 163-8677 Japan
e-mail: cm23076@ns.kogakuin.ac.jp

***Abstract*—This paper proposes an enhanced cell range expansion (CRE) technique that assigns different CSOs to UE according to UE's connection ratio to each picocell in HetNets. We first describe the algorithm and connection sequence of the proposed CRE technique. Then, we show the average and 5-percentile user throughput for the proposed CRE in comparison with conventional CRE using system-level computer simulations. From these results, we confirmed that the proposed CRE improve the 5-percentile user throughput while maintaining the average user throughput compared with that of conventional CRE.**

Keywords—mobile communication, heterogeneous networks, cell range expansion, personal picocell scheme, UE's connection ratio, system-level computer simulations

I. INTRODUCTION

Fifth-generation (5G) mobile systems have been diffused in many countries to increase system capacity and peak data rates, achieve low latency. 5G is also expected to support "Internet of things (IoT)" services where 5G can accommodate a huge number of IoT terminals. Two types of 5G mobile systems have been approved by the third-generation partnership project (3GPP) standards body. One is called as 5G with non-standalone (NSA) operation which enables 5G deployments using existing the fourth-generation (4G) mobile systems. Another type is called as 5G with standalone (SA) operation which provides a complete 5G with a 5G core network. Currently, almost all of the 5G are operated as 5G NSA which focuses on enhanced mobile broadband [1]–[5].

Heterogeneous networks (HetNets) are effective way to increase system capacity, i.e., can meet the requirements for a huge number of mobile data traffic. HetNets are composed of a macrocell operated by high-power base station (BS) and picocells operated by low-power pico-BS within the same coverage. Therefore, 5G NSA in a sense is the same configuration as HetNets. Specifically, HetNets using picocells operating at millimeter wave band have attracted a lot of attention to achieve higher user throughput, because the available amount of signal bandwidth of the picocell is enormous.

HetNets deployment should ensure that the picocells serve enough UE even though the transmit power of pico-BS is a rather small compared to that of macro-BS. The cell range expansion (CRE) technique for picocells is one way to do that. The CRE can virtually expand the picocell coverage through the use of a positive cell selection offset (CSO) for the downlink reference-signal received power (RSRP) from the picocell [6–10]. The cell selection in HetNets environments is carried out for UE based on the comparison between the downlink RSRPs from the macrocell and picocell. In the CRE operation, a positive CSO is added to the downlink RSRP from the picocell, therefore, CRE can allow more UE to access the picocell. However, the CRE has one drawback that the received signal-to-interference plus noise ratio (SINR) of UE forced to connect the picocell is worsen. Consequently, the user throughput of the UE in the CRE zone may worsen.

To overcome this drawback, we have proposed a personal picocell scheme using adaptive control CRE that can provide different CSOs for UE [11–15]. In [11], we proposed an adaptive control CRE using cumulative distribution function (CDF) of downlink SINRs from the macrocell, and presented the improvement of user throughput by the proposed method in co-channel HetNets using a 2 GHz band. In [14], we demonstrated the improvement of user throughput by the adaptive control CRE in HetNets composed of macrocell using a 2 GHz band and picocells using a 3.4 GHz band.

In this paper, from a very different perspective, we propose an enhanced CRE based on the adaptive control CRE that assigns different CSOs to UE according to UE's connection ratio to each picocell. The conditions of HetNets in this paper also are different from those of the previous work as shown in [11], [14], where HetNets are composed of macrocell using a 2 GHz band and picocells with a wide bandwidth using a 4.5 GHz band.

This paper is organized as follows. In Section II, we show the algorithm and connection sequence of the proposed CRE in HetNets. In Section III, we demonstrate the average and 5-percentile user throughput of the proposed CRE in comparison with those of conventional CRE using system-level computer simulations. Finally, we conclude our work in Section IV.

II. PROPOSED CRE

A. Configurations of HetNets and CRE

Figure 1 shows a typical HetNet combined with a macrocell served by a macro-BS and picocells served by each pico-BS. Picocells are primarily added in hot spots with considerable UE, including indoor areas. HetNet can improve the system capacity and increase generally user throughput because the total amount of radio resources in HetNets are increased. It is important for UE to determine which access is better to communicate with the macro- or pico-BSs, which is referred to as cell selection. UE is normally connected to a cell with a stronger downlink RSRP. Therefore, the connection ratio of the macro-BS is greater than that of the pico-BS because the transmission power of the macro-BS is larger than that of the pico-BS. CRE technique is very effective for increasing the connection ratio to the pico-BS by adding a positive CSO for the downlink RSRP from the pico-BS, as shown in Fig. 1. In this case, the picocell coverage appears to be wider as an "extended picocell" for the UE. Conventional CRE provides a fixed CSO for all UE, i.e., the size of the extended picocell is same among all picocells.

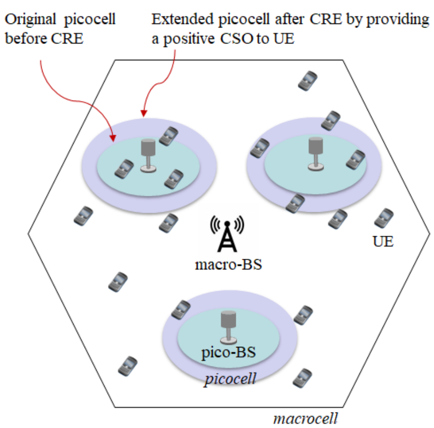


Fig. 1. Configurations of HetNet and CRE.

B. Personal picocell scheme using adaptive control CRE

Figure 2 illustrates a personal picocell scheme using adaptive control CRE which can form an independent extended picocell seen from each UE. This is based on the idea that the picocell coverage should be independent of each UE, even though the picocells are located at same microcell or macro-sector. This idea is executed by providing different optimal CSO to each UE. One of useful ways is to provide a positive high CSO for UE with lower downlink SINR from macro-BS to encourage the connection to pico-BS, and conversely to provide a positive low CSO for UE with higher downlink SINR to maintain the connection to macro-BS.

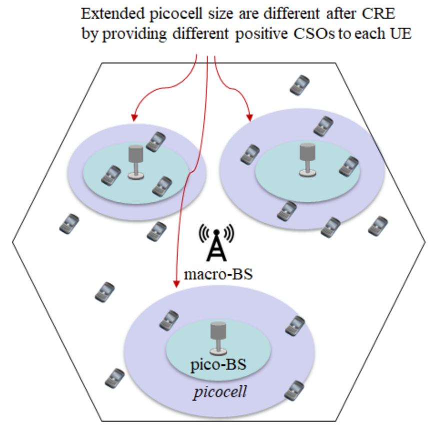


Fig. 2. Example of adaptive control CRE.

C. Proposed CRE using UE's connection ratio to each picocell

Figure 3 shows the principle of adaptive control CRE using the UE's connection ratio to picocells in each macro-sector. When the connection ratio to picocells for macro-sector *1* is R_1, CSO_1 is applied to UE located within macro-sector *1*. In this case, the R_1 is calculated using the number of UE connected to multiple pico-BSs within the macro-sector *1*. When the connection ratio to picocells for macro-sector *2* is R_2, CSO_2 is applied to UE located within macro-sector *2*. Like these, CSO is determined for each macro-sector.

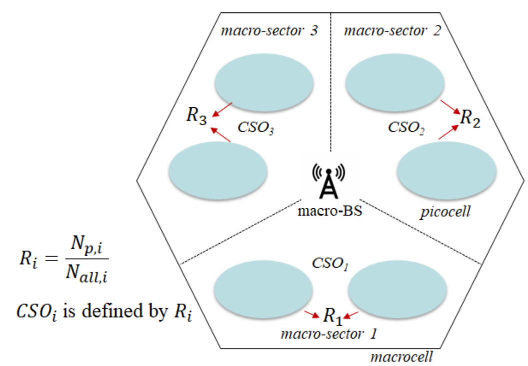


Fig. 3. CRE using UE's connection ratio to picocells in each macro-sector.

Taking a step further, we propose an enhanced CRE using the UE's connection ratio to picocell for each picocell, as shown in Fig. 4. When the connection ratio to picocell *1* within macro-sector *2* is $R_{1,2}$, $CSO_{1,2}$ is applied to UE located around pico-$BS_{1,2}$. When the connection ratio to picocell *2* within macro-sector *2* is $R_{2,1}$, $CSO_{2,2}$ is applied to UE located around pico-$BS_{2,2}$. Thus, CSO is determined for each picocell, even though multiple picocells are located within the same macro-sector.

Figure 5(a) shows the algorithm and connection sequence of the proposed CRE using the UE's connection ratio to each picocell.

In this paper, two different CSOs (CSO_{high} and CSO_{low}) are used for simplicity, although it would be ideal for each UE to provide each CSO. The γ is the threshold of $R_{k,j}$, where $R_{k,i}$ is the connection ratio to pico-$BS_{k,i}$ within macro-sector i, as shown in Fig. 5(b). If $R_{k,i}$, is less than γ, CSO_{high} is assigned to UE around pico-$BS_{k,i}$ in the macro-sector i. If $R_{k,i}$, is greater than γ, CSO_{low} is assigned to UE around pico-$BS_{k,i}$.

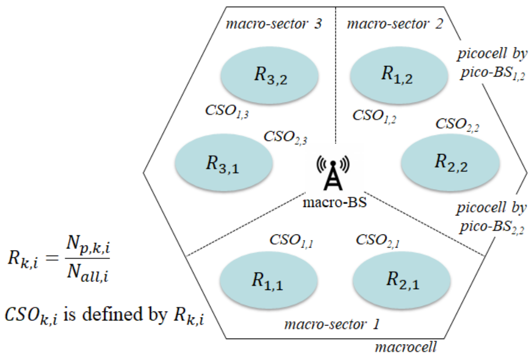
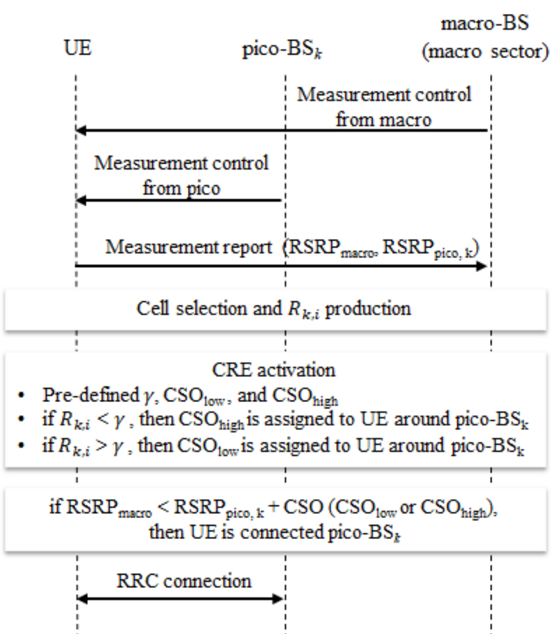
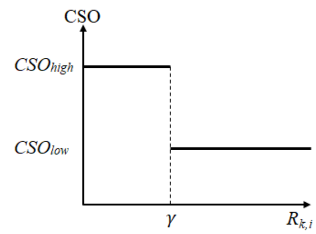


Fig. 4. Proposed CRE using UE's connection ratio to each picocell.



(a) Connection sequence between macro/pico-BSs and UE



(b) How to decide CSO_{high} and CSO_{low}

Fig. 5. Algorithm and connection sequence of the proposed CRE.

III. Simulation Results

A. Simulation conditions

In this paper, system-level computer simulations are executed to evaluate the user throughput of the proposed CRE using the UE's connection ratio for each picocell. The primary simulation parameters are listed in Table I. The carrier frequencies used in the macro- and pico-BSs are 2 and 4.5 GHz, respectively. The system bandwidth of the macro- and pico-BSs are assumed to be 10 and 100 MHz, respectively. The number of UEs is 30 per macro-sector. The UE layout is based on a cluster distribution in which 2/3 of the number of UEs are deployed nearby the pico-BSs and the rest are uniformly deployed within the macro-sector. 32 types of modulation and coding scheme (MCS) indexes incorporating 1024-QAM are used to transmit data in the downlink [15], [16].

TABLE I. Primary Simulation Parameters

Parameter	macro-BS	pico-BS
Cell layout	Hexagonal grid, 19 cell sites, 3 sectors per site	4 picos per macro-sector
Carrier frequency	2.0 GHz	4.5 GHz
System bandwidth	10 MHz	100 MHz
Cell radius (ISD)	289 m (500 m)	–
Tx Antenna height	32 m	10 m
Tx power	46 dBm	19 dBm
Tx antenna gain	14 dBi	5 dBi
Tx antenna downtilt	15 deg.	0 deg.
UE distribution	2/3 clustered distribution, 30 UEs per sector	
Scheduling algorithm	Proportional Fairness	
Traffic model	Full buffer	
Link adaptation	32 MCS (QPSK to 1024-QAM)	

B. User throughpt of proposed CRE

Figure 6 shows the average and 5-percentile user throughput of the proposed CRE using the UE's connection ratio to each picocell compared with those for the conventional method. In the conventional method, seven kinds of CSO are set, CSO = 0, 3, 6, 9, 12, 15, and 18 dB. The proposed CRE (Proposal) uses adaptive control CRE with the parameters of $\gamma = 0.125$, $CSO_{low} = 9$ dB, and $CSO_{high} = 18$ dB. The blue bar shows the average user throughput, and the yellow bar shows the 5-percentile user throughput.

The average user throughput decreases according to an increase of the CSO from 0 to 18 dB, although the 5-percentile user throughput increases. The reason of this phenomenon is that the increase of the number of UE in the CRE zone may degrade user throughput, and that UE with poor user throughput connected to macro-BS is connected to pico-BS by CRE. However, the proposed CRE can solve such kinds of trade-off problems, i.e., improve the 5-percentile user throughput while maintaining the average user throughput compared with those of conventional method, as shown in Fig. 6. Compared with a CSO of 9 dB, the proposal can improve 5-percentile user throughput by two times approximately, although the average user throughput slightly decreases.

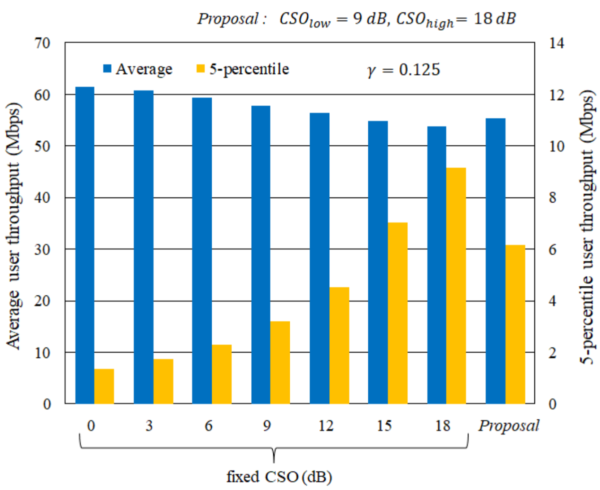


Fig. 6. Average and 5-percentile user throughput of proposed CRE compared with the conventional CRE.

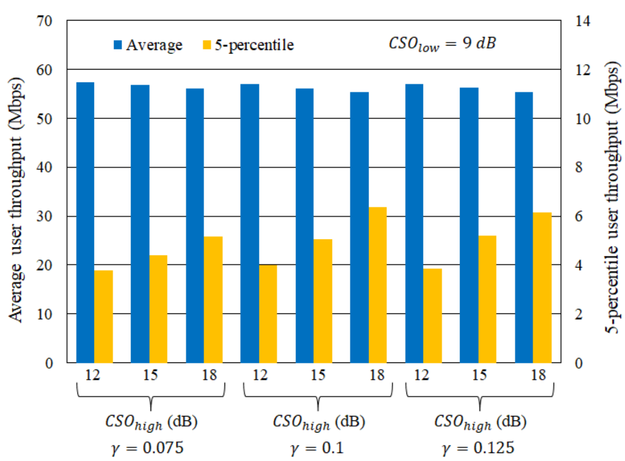


Fig. 7. Average and 5-percentile user throughput of proposed CRE versus γ as function of CSO_{high}.

Figure 7 shows the average and 5-percentile user throughput of the proposed CRE versus γ as function of CSO_{high} of 12, 15, and 18 dB. The behavior for user throughput against γ and CSO_{high} is the same. Thus, considering both the average and 5-percentile user throughput, the parameters of $CSO_{low} = 9$ dB and $CSO_{high} = 18$ dB are the best for the γ of around 0.1.

IV. CONCLUSION

In this paper, we proposed an enhanced CRE technique that assigns different CSOs to UE according to UE's connection ratio to each picocell in HetNets. We described the algorithm and connection sequence of the proposed CRE technique using two different CSOs (CSO_{high} and CSO_{low}). Then we demonstrated the average and 5-percentile user throughput for the proposed CRE in comparison with conventional CRE using system-level computer simulations. From these results, we confirmed that the proposed CRE can improve the 5-percentile user throughput while maintaining the average user throughput compared with that of conventional CRE.

This work was supported in part by JSPS KAKENHI Grant Number JP21K11874, Grant-in-Aid for Scientific Research (C). This work was also supported in part by 6G-IOWN Promotion Department, NTT DOCOMO INC., Japan.

REFERENCES

[1] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. K. Soong, and J. C. Zhang, "What will 5G be?," *IEEE J. on Select. Area Commun.*, vol. 32, no. 6, pp. 1065-1082, June 2014.

[2] D. Soldani and A. Manzalini, "Horizon 2020 and beyond; On the 5G operating system for a truly digital society," *IEEE Veh. Tech. Mag.*, vol. 10, no. 1, pp. 32-42, March 2015.

[3] T. Nakamura, A. Benjebbour, Y. Kishiyama, S. Suyama, and T. Imai, "5G radio access: Requirements, concept and experimental trials," *IEICE Trans. on Commun.*, vol. E98-B, pp. 1397-1406, Aug. 2015.

[4] 3GPP TR 23.501, "System architecture for the 5G system (5GS)," Release 15, June 2018.

[5] 3GPP TS 38.101-4, "5G NR User equipment radio transmission and reception; Performance requirements," Release 15, Sept. 2019.

[6] I. Guvenc, "Capacity and Fairness Analysis of Heterogeneous Networks with Range Expansion and Interference Coordination," *IEEE Commun. Letters*, vol. 15, issue 10, Oct. 2011.

[7] E. Dahlman, K. Dimou, S. Parkvall, and H. Tullberg, "Future wireless access small cells and heterogeneous deployments," in *Proc. ICT2013*, May 2013.

[8] S. S. Sun, W. Liao, and W. T. Chen, "Traffic offloading with rate-based cell range expansion offsets in heterogeneous networks," in *Proc. WCNC*, April 2014.

[9] M. Thurfjell, M. Ericcson, and P. d. Bruin, "Network Densification Impact on System Capacity," in *Proc. VTC2015-Spring*, May 2015.

[10] P. Tian, H. Tian, J. Zhu, L. Chen and X. She, "An adaptive bias configuration strategy for range extension in LTE-Advanced heterogeneous networks," in *Proc. ICCTA* 2011, May 2011.

[11] K. Kikuchi and H. Otsuka, "Proposal of Adaptive Control CRE in Heterogeneous Networks," in *Proc. PIMRC*2012, pp. 910-914, Sept. 2012.

[12] K. Kikuchi and H. Otsuka, "Parameter optimization for adaptive control CRE in HetNet," in *Proc. PIMRC*2013, NET47, Sept. 2013.

[13] K. Fujisawa, F. Kemmochi, and H. Otsuka, “Personal-cell scheme using adaptive control CRE for multicarrier HetNets,” in *Proc. VTC2019-Fall*, 8B-5, Sept. 2019.

[14] K. Fujisawa, F. Kemmochi, A. Yoneyama, and H. Otsuka, “Personal picocell scheme using adaptive control CRE in heterogeneous mobile networks,” *J. of Sensor and Actuator Networks*. vol. 9, no. 4, pp. 1-15, Oct. 2020.

[15] K. Fujisawa, F. Kemmochi, and H. Otsuka, “Performance of adaptive control CRE against cluster size for UE layout in multiband HetNetss,” in *Proc. WSCE2020*, Session 3, no. S1022, pp. 1-5, Oct. 2020.

[16] T. Yasaka, K. Yoda, S. Suyama, and H. Otsuka, “Throughput performance of denser mobile networks incorporating fiber-optic relay nodes,” in *Proc. APWCS2022*, WVR1-5, August 2022.