

Cell Selection for Range Expansion with Almost Blank Subframe in Heterogeneous Networks

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Abstract—To encourage data offloading in heterogeneous networks, range expansion techniques have been introduced in LTE-Advanced system. By adding a positive bias in cell selection process, more users can select picocells as their serving cells even the picocell is not of the strongest signal. Also, to protect offloaded users from severe macrocell interference, a specific subframe called almost blank subframe (ABS) is introduced. Since macrocell is kept silent during ABSs, the offloaded users can be allocated without strong macrocell interference within ABSs. It is noted that the offloaded user's average data rate highly depends on the amount of ABSs rather than the bias value because the scheduling opportunities of offloaded users are limited within ABSs. And from the user's point of view, the cell which is expected to give high data rate should be selected as a serving cell. In this paper, we propose a cell selection scheme based on expected user data rate which is a function of the ABS ratio. Simulation results show that the performance of our proposed cell selection scheme can improve average user rate and increase the number of offloaded users as the ABS ratio increases.

I. INTRODUCTION

The growing needs of multimedia applications require high-speed data transmission with low latency in wireless networks. In accordance with these expanding demands, there are extensive investigations to make progress in the next generation broadband wireless communication systems. Especially, heterogeneous networks have been considered as a promising solution to maximize area spectral efficiency by taking advantage of improved spatial reuse [1],[2]. In heterogeneous networks, in addition to well-coordinated high-power macrocells, low-power cells such as pico, femto, and relays are underlaid in a macrocell area. However, transmit power difference between macro and low power nodes (e.g., picocell) is large enough to the users connected to the picocell suffering from severe interference by a macrocell, which is one of major problems in heterogeneous networks [3]. In addition, due to the large transmitting power difference, the number of users connected to the picocell is limited. Generally, the increasing number of users served by a picocell can bring significant performance gain through cell splitting, even it is not the cell with the strongest received power. Therefore, range expansion schemes are introduced to increase coverage of a picocell by adding a positive bias to their measured signal-strength during cell selection [4],[5]. In order to obtain more offloading effect, a larger range expansion bias needs to be

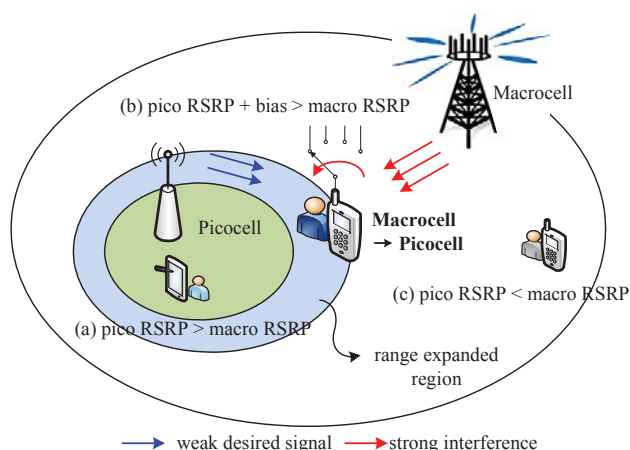


Fig. 1. Cell selection with range expansion in heterogeneous network

used [6]. However, since users located in the range expanded picocells might experience the bad link quality, the offloaded users require a mechanism to be kept from severe macrocell interference. In order to mitigate cross-tier interference, enhanced inter-cell interference coordination (eICIC) techniques that leave certain macrocell subframes blank are considered in 3rd Generation Partnership Project (3GPP) Long Term Evolution Advanced (LTE-Advanced) system [7],[8],[9]. Since only reference signals are transmitted through the blanked subframes, it is called almost blank subframe (ABS). Therefore, the users in range expanded region are scheduled within ABS to avoid strong cross-tier interference. Then, the remaining normal subframes (hereafter referred to as non-ABS) are allocated to the users closely located to the picocells and macrocells. Therefore, when a large bias value is used for more offloading effect, more subframes need to be kept silent to protect offloaded users. In other words, if the ratio of ABS to non-ABS (hereafter referred to as ABS ratio) is low, average data rate of the offloaded users might be lower due to heavily loaded users within ABSs. Therefore, the ABS ratio is one of important factors to be considered in cell selection process when range expansion is applied. Generally, the ABS ratio can be established by the macrocell based on the condition of the cell area including picocells (e.g., bias values, load of

each cell, the number of picocells, and so on). However, the bias value for range expansion can be varied independently among picocells according to condition of each picocell (e.g., load condition, location of picocell, and so on). Therefore, there may exist disproportion between the ABS ratio and a bias value of each cell. From user's point of view, however, the ABS ratio is more important than the bias value, since average user rate is varying according to the ABS ratio rather than the bias value. Therefore, in this paper, we propose a cell selection scheme based on expected user rate which is a function of the ABS ratio. By comparing the expected data rate of target cells, the users can select their serving cells which are expected to give higher data rate regardless of the bias value.

The rest of this paper is organized as follows. The system model is described in Section II. Cell selection scheme based on the ABS ratio is proposed in Section III. In Section IV, simulation results are provided to demonstrate that the proposed schemes increase overall system throughput and the number of users associated to the picocells. Section V draws conclusions.

II. SYSTEM MODEL

Consider the downlink data transmission of the two-tiered cellular network, where picocells are distributed within a macrocell coverage. To encourage that more users select picocells as their serving cells, range expansion is considered by adding a positive bias value in cell selection process. As explained in Section I, we employ time-domain eICIC scheme to mitigate inter-tier interference, where the macrocell keeps silence for specific subframes (i.e., ABS) to protect offloaded users. Therefore, picocells can send data to their users in range expanded region using the ABS without strong macrocell interference. Then, remaining subframes (i.e., non-ABS) are utilized for users closely located to picocells as well as for macrocell users. Fig. 2 shows a scenario when 50% of macrocell subframes are silenced for the ABS (i.e., $\alpha = 0.5$). In other words, macrocells do not allocate any users in even subframes, but only in the odd subframes while users connected to picocells are allocated in both subframes. This implies that offloaded users can be protected from co-channel macrocell interference within even subframes. Therefore, scheduling opportunities for the offloaded users might be varied according to the ABS ratio. If the ABS ratio is low, scheduling opportunities of offloaded users is also reduced. Thus, the ABS ratio is one of important factors to be considered in cell selection process when the range expansion scheme is applied.

In a conventional maximum signal cell selection scheme, a user i selects its serving cell with the maximum reference signal received power (RSRP).

Max RSRP :

$$j^* = \arg \max_{j \in \mathcal{M} \cup \mathcal{P}}, RSRP_{j,i}, \quad (1)$$

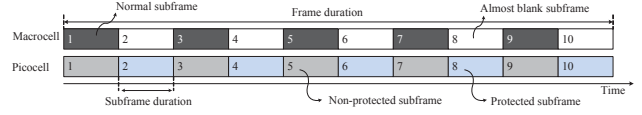


Fig. 2. Example of almost blank subframes for range expansion in heterogeneous network [3].

where $\mathcal{M}$ and $\mathcal{P}$ is the set of macrocells and picocells, respectively. Since the transmit power of a macrocell is much higher than that of a picocell, probability that users select picocells as their serving cells is low, which reduces cell splitting gain in heterogeneous networks. Therefore, to encourage users to select picocells as their serving cells, a positive bias value is introduced to the cell selection process. Max RSRP+bias :

$$j^* = \arg \max_{j \in \mathcal{M} \cup \mathcal{P}} \{RSRP_{j,i} + bias_j\}, \quad (2)$$

where $bias_i$ is the offset value of a picocell for cell range expansion, where 0 is for the macrocell and $x(x > 0)$ is for picocell. Intuitively, as the bias value increases, the number of users associated to picocells is increased. However, although the user selects a picocell because of a high bias value, if the ABS ratio is low, expected data rate through the selected picocell might be lower than that of the macrocell. In other words, if a user decides to stay in a macrocell regardless of the bias, the user might have more chances of scheduling than picocells because of the large portion of non-ABS and strong received signal strength. Therefore, from the user's point of view, the ABS ratio is more important than the bias value in terms of average user rate. Thus, we take the ABS ratio into consideration in cell selection process to improve expected user data rate regardless of the bias value.

III. PROPOSED CELL SELECTION SCHEME

In this section, we propose a cell selection scheme based on the ABS ratio. Since the data rate of users are proportional to the scheduling opportunities of target cell, the cell which might be expected to give high data rate than other cells should be selected as their serving cells regardless of the bias value. When user i selects macrocell m at subframe n , the signal-to-interference plus noise ratio (SINR) of user i can be represented as

$$\gamma_{m,i}(n) = \frac{h_{m,i}(n)p_m(n)}{I_i^m(n) - h_{m,i}(n)p_m(n) + I_i^p(n) + \sigma_i^2}, \quad (3)$$

where

$$I_i^m(n) = \sum_{m=1}^{\mathcal{M}} h_{m,i}(n)p_m(n) \quad (4)$$

$$I_i^p(n) = \sum_{p=1}^{\mathcal{P}} h_{p,i}(n)p_p(n). \quad (5)$$

$h_{m,i}(n)$ and $h_{p,i}(n)$ are the channel coefficients at the subframe n from macrocell m and picocell p to the user i ,

respectively. $p_m(n)$ and $p_p(n)$ are the transmit power of macrocell m and picocell p at subframe n , respectively. σ_i^2 is noise power of user i . $I_i^m(n)$ and $I_i^p(n)$ are the sum of interferences from macrocells and picocells, respectively.

Similarly, when user i selects picocell p , it can have SINR represented as

$$\gamma_{p,i}(n) = \frac{h_{p,i}(n)p_p(n)}{I_i^m(n) \cdot \delta_m(n) + I_i^p(n) - h_{p,i}(n)p_p(n) + \sigma_i^2}, \quad (6)$$

where δ is an indication function. i.e., If n is an ABS, $\delta_m(n) = 0$, otherwise, $\delta_m(n) = 1$. Therefore, the SINR of picocell can be represented by

$$\gamma_{p,i}(n) = \begin{cases} \gamma_{p,i}^{\text{ABS}}, & \text{if } n \text{ is ABS,} \\ \gamma_{p,i}^{\text{nonABS}}, & \text{otherwise.} \end{cases} \quad (7)$$

Then, expected data rate when the user selects the macrocell can be formulated as

$$E\{R_i^m\} = (1 - \alpha) \log_2(1 + \gamma_{m,i}), \quad (8)$$

where α is the ABS ratio of the macrocell. Similarly, expected data rate when the user selects the picocell can be written by

$$E\{R_i^p\} = (1 - \alpha) \log_2(1 + \gamma_{p,i}^{\text{nonABS}}) + \alpha \log_2(1 + \gamma_{p,i}^{\text{ABS}}). \quad (9)$$

After comparing expected data rate of each cell, the user selects the cell which is expected to give higher expected data rate as

$$j^* = \arg \max_{j \in \mathcal{M} \cup \mathcal{P}} E\{R_i^j\}. \quad (10)$$

From (8), (9), the probability that the user selects picocell as its serving cell is increased as the ABS ratio increases. Therefore, if the ABS is low, the user may select the macrocell regardless of the bias value. For the sake of simplicity, if we focus on the strongest interference from cross-tier, the expected rate can be represented as

$$E\{R_i^{m'}\} = (1 - \alpha) \log_2 \left(1 + \frac{\text{SNR}_{m',i}}{\text{SNR}_{p',i} + 1} \right) \quad (11)$$

$$E\{R_i^{p'}\} = (1 - \alpha) \log_2 \left(1 + \frac{\text{SNR}_{p',i}}{\text{SNR}_{m',i} + 1} \right) + \alpha \log_2(1 + \text{SNR}_{p',i}), \quad (12)$$

where

$$m' = \arg \max_{j \in \mathcal{M}} \text{RSRP}_{j,i}, \quad (13)$$

$$p' = \arg \max_{j \in \mathcal{P}} \text{RSRP}_{j,i}. \quad (14)$$

$\text{SNR}_{m',i} = \frac{h_{m',i}p_m'}{\sigma_i^2}$ and $\text{SNR}_{p',i} = \frac{h_{p',i}p_p'}{\sigma_i^2}$ is signal-to-noise ratio (SNR) of user i from the macrocell and picocell, respectively. After some manipulations, cell selection criterion (10) can be simplified by

$$\text{SNR}_{p',i} > (\text{SNR}_{m',i} + 1)^{1-\alpha} - 1. \quad (15)$$

TABLE I
SYSTEM PARAMETERS

Parameter	Value
Cell Layout	7 macrocells, 6 picocells per macrocell
User number	20 per macrocell (uniformly distributed)
Inter-site Distance	500m
Pathloss (macrocell)	$L=128.1+37.6\log_{10}(R)$, R in km
Pathloss (picocell)	$L=30.6+36.7\log_{10}(R)$, R in m
Log-Normal Shadowing	standard deviation : 6dB (macrocell) 4dB (picocell)
eNB transmit power	46dBm
Pico transmit power	30dBm
Fading	Rayleigh fading
Thermal Noise Density	-174 dBm/Hz
ABS ratio	0.2 (2:8), 0.5 (5:5) (ABS : normal subframe)
Bias value for RE	6dB, 12dB
Scheduling	Proportional fairness (PF)

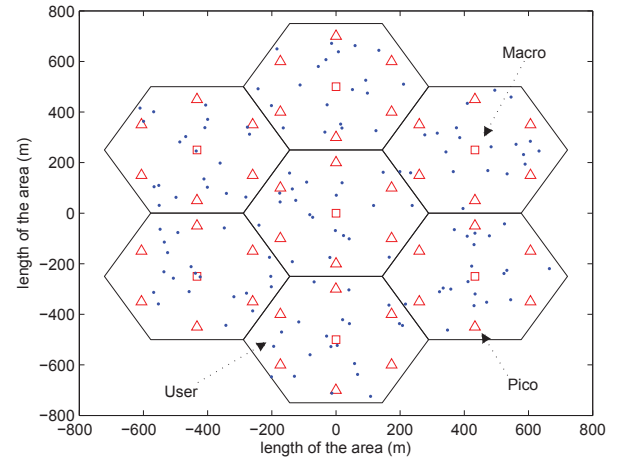


Fig. 3. Network topology of the simulation scenario

IV. SIMULATION RESULTS

To verify the performance of the proposed cell selection scheme, heterogeneous networks consist of macrocells and picocells are considered as illustrated in Fig. 3. In each macrocell area, 6 picocells are deployed with a distance of 2/5 ISD (inter-site distance) far from the macrocell. Users are uniformly distributed within the macrocell area. Each cell is equipped with a single omni-directional transmit antenna. 6dB and 12dB bias values are considered for cell range expansion. To show the performance according to ABS ratio, 20% and 50% subframes are blanked for ABS, which is denoted by $\alpha = 0.2$ and 0.5, respectively. The parameters in the simulations are summarized in Table I.

Although there are many kinds of diverse cell selection schemes such as proportional fairness based cell selection [10] and reference signal received quality (RSRQ) based cell selection [11], we evaluate the performance of RSRP based cell selection scheme (Max RSRP) and RSRP plus bias based cell selection scheme (Max RSRP+bias) for simplicity, and the Max RSRP cell selection scheme is considered as a

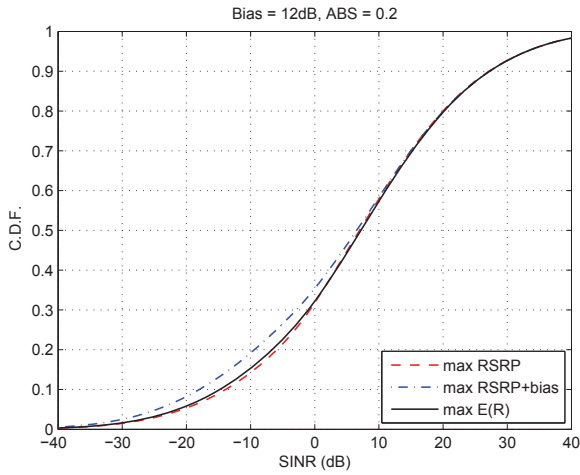


Fig. 4. Comparison of CDF of SINR with bias 12dB, ABS ratio 0.2

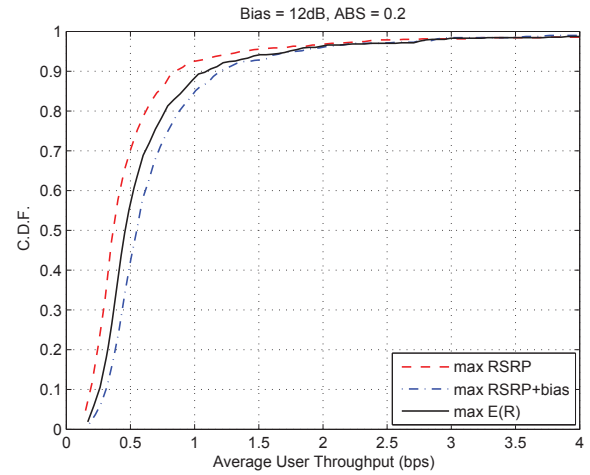


Fig. 6. Comparison of CDF of average user throughput with bias 12dB, ABS ratio 0.2

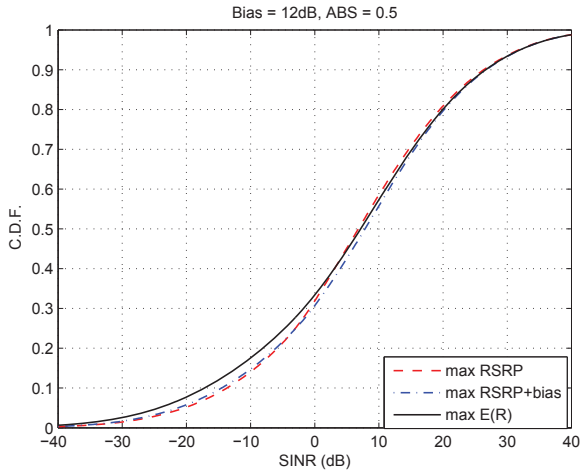


Fig. 5. Comparison of CDF of SINR with bias 12dB, ABS ratio 0.5

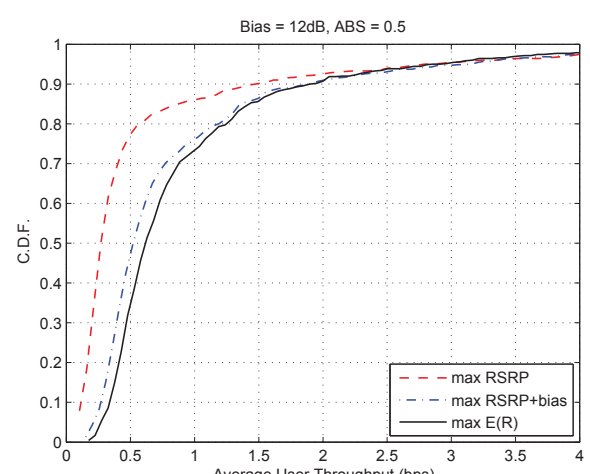


Fig. 7. Comparison of CDF of average user throughput with bias 12dB, ABS ratio 0.5

baseline cell selection scheme in our simulation. In order to measure the performance gain, the following performance metrics are defined. Cell average spectrum efficiency is the cell throughput per 1Hz for one macrocell including 6 picocells. Cell edge spectrum efficiency is 10% user throughput of all users connected to the macrocell and picocells. To quantify the offloading effect, the percentage of users associated to picocells is measured.

Fig. 4 and Fig. 5 show the C.D.F. (Cumulative Distribution Function) of downlink SINR according to different ABS ratio, with the comparison of existing Max RSRP, Max RSRP+bias, and the proposed cell selection scheme. Since Max RSRP+bias scheme selects the picocell even it is not the cell with the strongest received power, the measured SINR is the worst among the other schemes when the ABS ratio is low. When the ABS ratio is low, the offloaded user might have low expected data rate, the number of offloaded users is limited

by the proposed scheme. However, as the ABS ratio increases, more users are offloaded to the picocells by our proposed scheme while the other schemes are not affected by ABS ratio, which results in the worst SINR in Fig. 5. However, as shown in Fig. 6 and Fig. 7, the performance of average user throughput for the proposed scheme outperforms the other schemes accordingly by increasing the ABS ratio. Simulation results are summarized in Table. II.

V. CONCLUSIONS

In this paper, a cell selection scheme is investigated for range expansion in heterogeneous networks. When the range expansion scheme is applied to encourage more users to select picocells as their serving cells by adding a positive bias, the almost blank subframe is inevitable to protect offloaded picocell users from macrocell interference. Since the scheduling

TABLE II
SIMULATION RESULTS

Parameters	Max RSRP (baseline)	Max RSRP+bias	Max E{R}	Max RSRP (baseline)	Max RSRP+bias	Max E{R}
	Bias = 6dB, ABS = 0.2			Bias = 6dB, ABS = 0.5		
Cell average spectrum efficiency (bps/Hz/cell)	2.0972	2.4049 (+14.7%)	2.4370 (+16.2%)	2.0653	2.5319 (+22.6%)	3.0949 (+49.9%)
Cell edge spectrum efficiency (bps/Hz)	0.1481	0.1771 (+19.6%)	0.1792 (+21%)	0.0882	0.1183 (+34.2%)	0.2241 (+254%)
UE associated to pico cells (%)	11.1%	20.5%	21.2%	11.7%	21.5%	50.0%
	Bias = 12dB, ABS = 0.2			Bias = 12dB, ABS = 0.5		
Cell average spectrum efficiency (bps/Hz/cell)	2.0497	2.5652 (+25.2%)	2.3652 (+15.4%)	2.0320	2.8605 (+40.8%)	3.0792 (+51.5%)
Cell edge spectrum efficiency (bps/Hz)	0.140	0.1905 (+36.6%)	0.1683 (+20.7%)	0.0864	0.1638 (+190%)	0.2079 (+241%)
UE associated to pico cells (%)	12.9%	37.9%	23.8%	12.2%	37.7%	52.1%

opportunity of the offloaded picocell users is highly dependent on the ABS ratio, the ABS ratio should be considered to guarantee the expected user rate when the user selects its serving cell. From the observation, we propose a cell selection scheme to select the serving cell based on expected user rate which is a function of the ABS ratio. Simulation results show that the performance of the proposed cell selection scheme can be significantly improved in terms of average user rate and the number of offloaded users as the ABS ratio increases.

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