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Dynamic Almost Blank Subframe Assignment Method with Power Control Subframe for User Fairness

Masayoshi Ozawa and Tomoaki Ohtsuki
Keio University, 3-14-1, Hiyoshi, Kohokuku, Yokohama, 223-8522, Japan
Email: ozawa@ohtsuki.ics.keio.ac.jp, ohtsuki@ics.keio.ac.jp

***Abstract*—In long term evolution (LTE), heterogeneous network (HetNet) is constructed to increase network capacity. In HetNet, low transmit power base stations (BSs) such as femto-BSs are deployed in an indoor within the coverage of macro cells. Since BSs are close to each other in HetNet, indoor or cell-edge users are likely to experience outage due to inter-cell interference. Therefore, almost blank subframe (ABS) techniques emerge as inter-cell interference mitigation technique in time region. One of the conventional ABS techniques is dynamic ABS assignment, which is able to adapt to interference circumstances to protect the cell-edge users more. In the dynamic ABS assignment method, a BS dynamically allocates ABS to its subframe based on surrounding circumstances. However, the resource utilization of BSs decreases, because the number of ABS assignments increases in the dense BS deployment. This results in low sum rate. In addition, if the number of ABS assignments increases, user fairness becomes impaired due to the difference of the number of users which each BS serves. In this paper, we propose a dynamic ABS assignment method with power control subframe to improve sum rate and user fairness together. Each BS receives feedback from surrounding BSs and users, and chooses its subframe assignment based on the received feedback. Simulation results show that the proposed method improves the sum rate and user fairness compared with the conventional dynamic ABS assignment method, while achieving a similar user outage ratio.**

Keywords*—*Long term evolution, Heterogeneous network, Almost blank subframe, Femto base station

I. Introduction

Recently, wireless data traffic is increasing due to the widespread usage of smart phones and other wireless devices. Long term evolution (LTE) [1] was formulated to address this situation. In LTE, we use orthogonal frequency division multiplexing (OFDM) at downlink to allow data to be directed to multiple user equipments (UEs) and to exploit the frequency diversity properties of wireless channel. Figure 1 shows an overview of the basic resource assignment unit in LTE. The minimum unit is resource element (RE). Each RE is set to control region, data region or cell-specific reference signal (CRS). A resource block (RB) is 7 (OFDM symbols) × 12 (subcarriers) REs. Two consecutive RBs in time region constitute the basic unit for the UE scheduling. The unit is called subframe.

In addition, heterogeneous network (HetNet) is considered as the technique for improving network capacity. In HetNet, the base station (BS), of which transmit power is lower than that of macro BS (MBS) is deployed in an indoor area suffering from wall loss in the macro cell area. The low power BSs cover the areas that MBS cannot. For example, we know that femto BS (FBS) with low transmit power is deployed in the indoor area. Also, it has been shown that 50% of all voice calls and over 70% of all data traffic are from indoor areas [2]. Thus, HetNet is effective for accommodating those traffic from indoor so that the network capacity increases. However, one of the major drawbacks of HetNet is the existing interference between MBS and FBS, or among FBSs because they are placed close to each other.

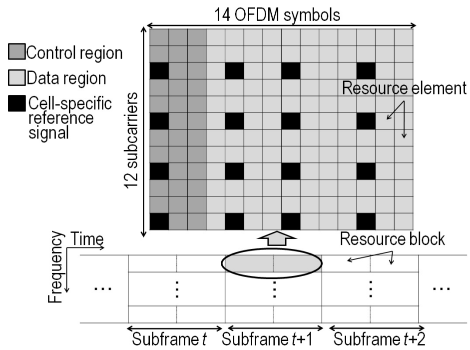

Fig. 1. Basic resource assignment unit in LTE.

One of the inter-cell interference mitigation techniques used in time region is almost blank subframe (ABS) [3], [4]. In the general ABS techniques, a BS does not interfere with the surrounding BSs by assigning ABS to its subrame and the stop of transmission during the subframe. For example, an FBS stops the transmission during ABS, and as a result the macro user equipment (MUE) in the indoor is not affected by the strong interference from the FBS. On the other hand, a subframe for the protection of UEs from strong interference is called *protected subframe* (PS). In other words, MBS assigns PS to protect the MUE while the FBS assigns ABS to stop its transmission. However, these ABS techniques in [3], [4] do not suppress the interference between FBSs, because all FBSs have the same subframe assignment.

A dynamic ABS assignment method which is one of the ABS assignment methods, is an effective way to adapt to interference environments. In the prior work [5], each BS allocates PS, ABS, or non-protected subframe (NS) to its subframe based on the received feedback from the surrounding BSs and UEs. Therefore, none of the femto user equipments (FUEs) as well as the MUE is affected by the interference from surrounding FBSs. However, in the dense BS networks, sum rate decreases because the number of ABS assignments is increased to protect a lot of UEs. In addition, if the number of ABS assignments increases, the user fairness becomes impaired because of the difference of the number of UEs which each BS serves.

In this paper, we propose a dynamic ABS assignment method with power control subframe (PCS) where transmit power is controlled so that the utilization of BS increases, while suppressing the number of outage UEs. As a result, the proposed method increases the sum rate performance. In addition, we improve UE fairness, because each BS decides its subframe assignment considering the number of the connecting UEs served by each BS of surrounding. Compared with the conventional dynamic ABS assignment method, the proposed one improves both the sum rate and UE fairness, while achieving the similar UE outage ratio.

The rest of this paper is organized as follows. In Section II, we show our system model. In Section III, we explain the proposed dynamic ABS assignment method in detail. In Section IV, we describe simulation model and parameters. In Section V, we show that our method is superior to the other conventional ones by computer simulation results. In Section VI, we conclude the paper.

II. System Model

The system model is described based on the prior dynamic ABS assignment method [5]. We consider a HetNet in which FBSs using the same frequency are deployed in the coverage of the macro cell. Also, we assume that all BSs in the network are synchronized. UEs can distinguish among signals received from the surrounding BSs in their vicinity with the help of CRSs. Hence, UE u calculates reference signal received power (RSRP) [6] from BS b as follows.

$$R_{u,b} = P^{\mathrm{CRS}} G_{u,b}, \tag{1}$$

where P^{CRS} denotes constant CRS transmit power and $G_{u,b}$ is the channel gain including the effects of path loss and shadowing between BS b and UE u. The CRS is transmitted even if the BS assigns ABS to its subframe. Therefore, UE periodically receives CRS from the surrounding BSs. The UE feeds back the RSRP information received from the surrounding BSs to its connecting BS. However, the UE can transmit a limited number of RSRPs, because it is not able to measure the received power from all BSs in the network. BS b calculates the UE u's signal to interference plus noise power ratio (SINR) with limited feedback (RSRP) from UE u as follows.

$$\gamma_u = \frac{R_{u,b}}{\Sigma_{m \in M_u} R_{u,m} + \Sigma_{f \in Fu} R_{u,f} + \eta}, \tag{2}$$

where m and f represent MBS and FBS, respectively. M_u and F_u are the set of interfering MBSs and FBSs, respectively which cause strong interference to UE u, and η accounts for thermal noise. The calculated SINR at the BS is not an exact SINR, because this is calculated based on the limited RSRP information.

In this system model, we assume that each BS transmits with a subframe pattern consisting of 4 subframes. Also, PS is assigned to one subframe in the subframe pattern to protect cell-edge UEs, and other ones are set as NS or ABS.

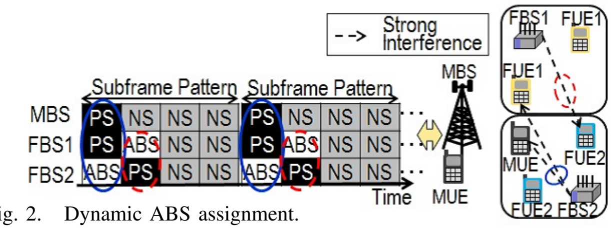

Fig. 2. Dynamic ABS assignment.

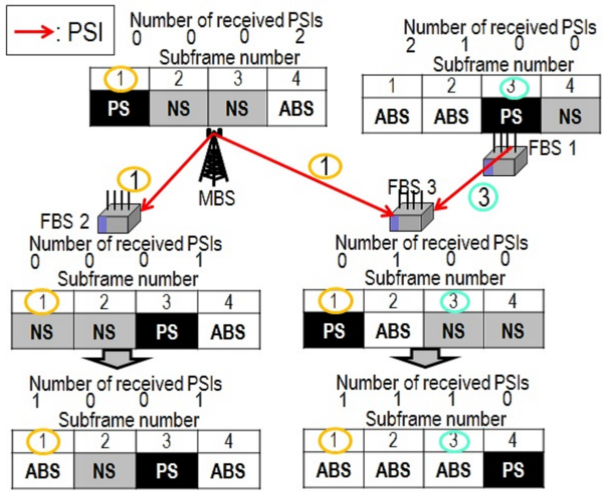

Fig. 3. An example of PSI transmission.

Figure 2 shows an example of subframe pattern assignment in dynamic ABS assignment. The indoor MUE and cell-edge FUE 1 receive strong interference from the FBS 2. Similarly, the cell-edge FUE 2 receives strong interference from the FBS 1. Therefore, the FBS 2 allocates ABS to the first subframe in the subframe pattern to protect the indoor MUE and cell-edge FUE 1. In a similar manner, the FBS 1 allocates ABS to the second subframe in the subframe pattern to protect the cell-edge FUE 2. In the third and fourth subframes, each BS can be used for cell-center UE without any strong interference. Also, FBSs cannot restrict the subframes usage of MBS, because MBS has higher priority than FBSs in HetNet. Hence, MBS does not assign ABS to its subframe and can use all subframes as active. In general, the resource of MBS will be strictly limited if MBS uses ABS, because MBS serves a lot of UEs compared with FBS.

To achieve dynamic ABS assignment, each BS sends PS indicators (PSIs) denoting its PS position (number) in the subframe pattern to its surrounding FBSs. Figure 3 shows an example of PSI transmission. Each FBS receives PSIs from the surrounding BSs and changes the current PS position to the subframe with minimum number of the PS position numbers denoted by the PSIs. In other words, the subframe pointed by the least received PSIs in the subframe pattern is set as PS. Herewith, a lot of UEs are protected, because the subframes pointed by more PSIs are set as ABS. For remaining the subframes, if the PSIs point to the subframe, ABS is assigned to it. Then, if the PSIs do not point to the subframe, NS is assigned to it.

Next, we explain the transmission of PSI. Each BS calculates the UE u's SINR γ_u in PS using eq. (2) based on the limited RSRP information from UE u, and the calculated SINR should be higher than a specified SINR threshold. If γ_u is lower

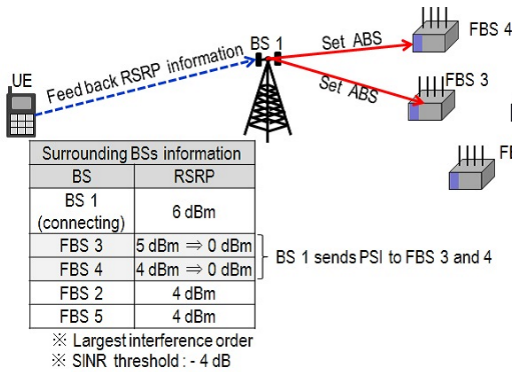

Fig. 4. An example of selection of interfering FBSs.

than the SINR threshold, it can be increased by removing the largest interfering FBS in the interfering FBS set F_u in eq. (2). In other words, if the most dominant interfering FBS does not transmit, γ_u would be improved. Each BS selects strong interference FBSs from the interfering FBS set F_u until γ_u becomes higher than the threshold value. Then, the BS sends PSIs to the selected FBSs to improve UE u's SINR. We show an example of the selection of strong interfering FBSs in Fig. 4.

III. Proposed Method

We propose a dynamic ABS assignment method consisting of two proposed techniques : a power control subframe as well as a PSI transmission selection based on the number of the connecting UEs of surrounding FBSs. In this section, we first describe each technique individually. Next, we explain the general flow of the proposed method.

A. Power Control Subframe

The first technique is power control subframe (PCS). In the conventional method, each BS selects strong interference FBSs from the interfering FBS set until UE's SINR becomes higher than the SINR threshold to protect outage UE. Then, the BS sends PSI to the selected FBSs and they assign ABS to their subframe. However, the conventional ABS assignments result in low sum rate, because the resource of BSs is restricted. In the proposed method, last selected FBS assigns PCS to its subframe to improve sum rate, while the UE does not experience outage. During the PCS, The last selected FBS can transmits data with the transmit power that does not cause any UE outage. To achieve this, PSI includes the transmit power information to which the selected FBS should set as new transmit power.

We show an example of PCS in Fig. 5. The UE connecting with BS 1 feeds back RSRP information to BS 1. The BS 1 should send PSI to its surrounding FBSs to protect the UE, because the UE's SINR (- 11 dB) is lower than the SINR threshold (- 4 dB). The BS 1 selects the largest interfering FBS until the SINR at the UE becomes higher than the SINR threshold. Thus, the FBSs 3 and 4 are selected in Fig. 5. Then, the BS 1 sends PSI to the FBSs 3 and 4, and they set ABS to their subframes as in the conventional method. On the other hand, in the proposed method, the FBS 3 sets ABS and the FBS 4 sets PCS to protect the UE connecting with BS 1, and to increase the resource utilization of FBS 4. The last selected FBS 4 decreases its transmit power based on the

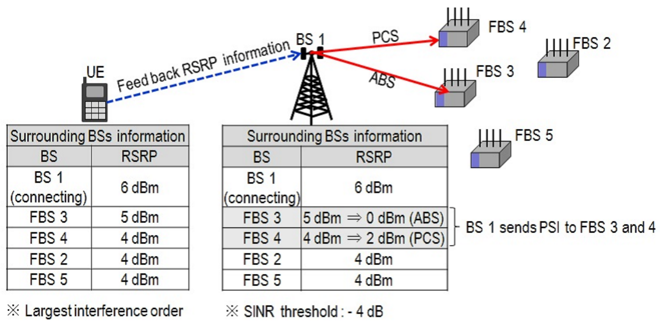

Fig. 5. Power control subframe.

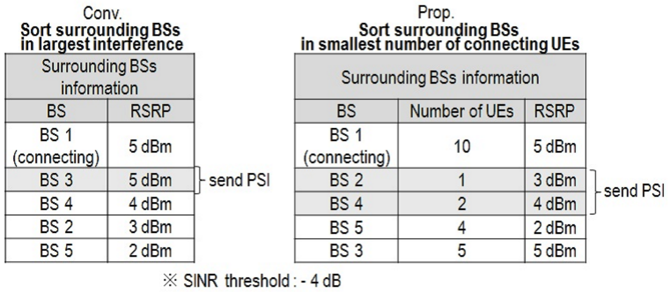

Fig. 6. PSI transmission selection based on the number of the connecting UEs of surrounding FBSs.

transmit power information of PSI sent by BS 1 so that the UE's SINR is equal to the threshold SINR. As a result, the UE does not experience outage and the FBS 4 can communicate with UEs connecting with it under low transmit power during the subframe to which the FBS 4 assigns PCS.

B. PSI Transmission Selection based on Number of Connecting UEs of Surrounding FBSs

The second technique is PSI transmission selection based on the number of the connecting UEs of surrounding FBSs. We explain the second technique with Fig. 6. In the conventional method, UE measures RSRP from the surrounding BSs and feeds back it to serving BS. If the UE's SINR is lower than the SINR threshold, the BS selects the largest interfering FBS until the UE's SINR becomes higher than the SINR threshold. On the other hand, in the proposed method, the BS selects the FBSs with the smallest number of connecting FUEs until the UE's SINR becomes higher than the threshold SINR to improve UE fairness. In large number of connecting UEs, each UE is assigned a few resources. In contrast, each UE is assigned a lot of resources in small number of connecting UEs. Therefore, a BS serving a small number of UEs assigns ABS while a BS serving larger number of UEs does not assign ABS to improve UE fairness. To achieve this technique, we assume that each UE can measure the number of connecting UEs from surrounding BSs besides RSRP.

C. Flow of Proposed Method

We explain the flow of the proposed method in Fig. 7. First, BS decides a subframe pattern. BS sets PS to the subframe with the minimum number of the PS position numbers denoted by the PSIs in subframe pattern. For the remaining subframes, if PSIs point to the subframes and the transmission power denoted by the PSI is not 1 mW (0 dBm), PCS is assigned and the BS changes the transmission power to the value denoted by PSI during the PCS. If PSIs point to the subframes and

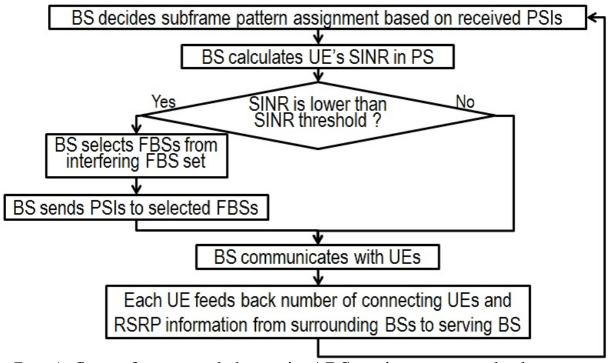

Fig. 7. A flow of proposed dynamic ABS assignment method.

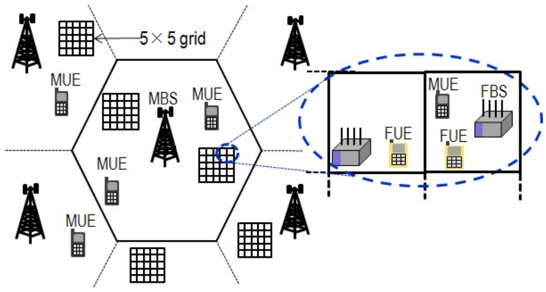

Fig. 8. Network model in simulation.

the transmission power denoted by the PSI is 1 mW (0 dBm), ABS is assigned. NS is assigned to other subframes to which the PSIs do not point. After the decision of the subframe pattern assignment in the subframe pattern, BS calculates UE's SINR in the PS based on RSRP information from the UE. If the calculated SINR is lower than the SINR threshold and it would be higher than the SINR threshold by selecting the interfering FBSs in the interfering FBS set and sending PSIs to them, the BS selects the FBSs with the smallest number of connecting UEs in the interfering FBS set until the calculated SINR becomes higher than the SINR threshold. Next, BS sends PSI to the selected FBSs and communicates with connecting UEs according to the subframe pattern. After that, UE can measure RSRP and the number of connecting UEs from limited surrounding BSs (including serving BS) and feeds back those information to the serving BS.

IV. Simulation Setup

The simulation parameters are taken from [7] and [8], and they are summarized in TABLE I. Also, the simulation model is shown in Fig. 8. MUEs are randomly deployed in the simulation area and they are associated with the MBS from which they receive the highest power. FBSs are deployed in 5×5 grid [7]. The 5×5 grid means a square building consisting of 25 regularly arranged square apartments. Every apartment has an FBS with a certain deployment probability. FUEs are randomly distributed within the apartment, if FBS is deployed in the apartment. Full-buffer transmission is assumed in such a way that every BS assigns all the available data resources during all the active subframes (except ABS) to their served UEs. In addition, the positions and shadowing values of the BSs and UEs are assumed to remain unchanged. Subframe pattern includes 4 subframes and a subframe length is 1 ms. In LTE, the minimum required SINR to decode the control channels is –6 dB [9]. Considering bias value (2 dB), we set

TABLE I. Simulation parameters.

Number of subframes patterns	15 (60 subframes)
Distance between MBSs	500 m
System bandwidth	10 MHz
MBS Tx power	46 dBm
FBS Tx power	20 dBm
MBS shadowing std. dev.	8 dB
FBS shadowing std. dev.	10 dB
MUEs per macro cell	30
5×5 grid per macro cell	3
FBS deployment probability	0.2 or 0.4
FUEs per FBS	$1 \sim 6$
Fading model	No fast fading
Number of Tx and Rx antennas	1
Number of received power from BSs UE can measure	7 BSs
SINR threshold (required + bias)	$-6 + 2$ dB

–4 dB as an threshold SINR. The scheduler at BSs always allocates RBs to the UEs during the subframe with round robin scheduling. Also, we assume that each UE can measure information from the surrounding 7 BSs (a serving and six interfering BSs).

We evaluate the UE outage ratio, the sum rate of FUE, and the fairness index of FUE in this paper. Since the proposed and conventional methods apply ABS to only FBSs, MBS uses all resources as active. Thus, we do not evaluate the sum rate of MUE and the fairness index of MUE, because for both metrics the proposed and conventional methods have almost the same performance. The UE outage ratio represents the number of UEs who experience SINR lower than the required SINR during all subframes in the last subframe pattern. The sum rate of FUE is the sum of the connecting FUEs' capacity per FBS. To evaluate UE fairness, we use Jain's fairness index [10]. Fairness index takes a value from 0.0 to 1.0, and the larger value of fairness index means the higher fairness. In other words, the fairness index of 1.0 means that sum rate of UEs is completely equal to each other. The fairness index is represented as follows

$$F = \frac{\left(\sum_{i=i}^{K} x_i\right)^2}{K \sum_{i=i}^{K} x_i^2}, \qquad (1 \le i \le K), \tag{3}$$

where K denotes the number of UEs and x_i represents the capacity of UE i.

We compare the proposed method with a "No ABS" case that does not use ABS, a "FP (Femto Partitioning) [5]" in which the MBS assigns "NS, PS, NS, PS" to its subframe pattern and the FBS assigns "NS, ABS, NS, ABS" to its subframe pattern, and the conventional one [5]. In addition, we also compare the proposed method with the conventional one [5] considering the two proposed techniques, so that we clearly see the effect of each of them. For comparative methods, "Conv. + PCS" denotes the conventional method with the

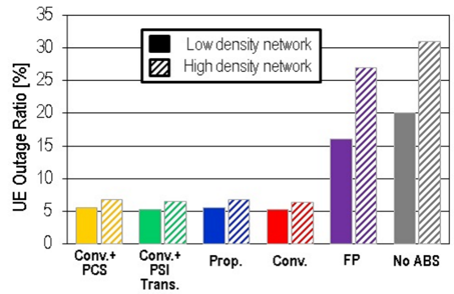

Fig. 9. UE outage ratio.

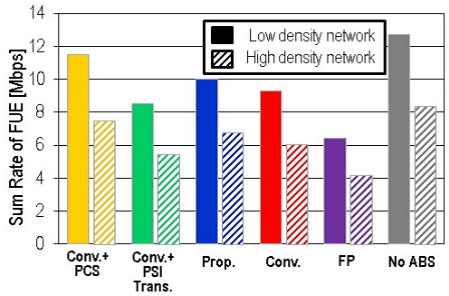

Fig. 10. Sum rate of FUE.

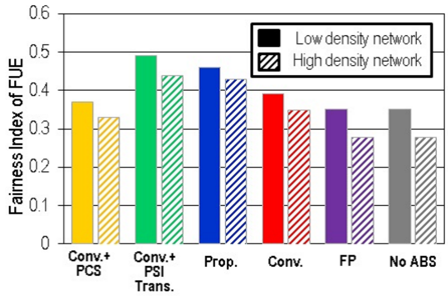

Fig. 11. Fairness index of FUE.

first proposed technique (power control subframe). Similarly, "Conv. + PSI Trans." is the conventional method with the second proposed technique (PSI ransmission selection based on the number of the connecting UEs of suroundding FBSs).

V. Simulation Result

We simulate under both low and high density networks. In low density network, the FBS deployment probability is 0.2, and that is 0.4 in high density network.

Figure 9 shows the UE outage ratio. "No ABS" does not reduce inter-cell interference from FBS to MUE, while "FP" does. The conventional method reduces the interference from FBS not only to MUE but also to FUE, this results in low UE outage ratio. The UE outage ratio of "Conv. + PCS" slightly increases compared with that of the conventional ones, because the resource utilization of FBSs increases due to PCS. As a result, the proposed method also slightly increases the UE outage ratio. However, this gap is considerably small. In the high density network, the UE outage ratio becomes high compared with that in the low density network. This is because it becomes difficult to protect all outage UEs due to the increase of FUEs.

Figure 10 shows the sum rate of FUE. "No ABS" achieves the highest the sum rate of FUE, because of using all subframes as active. Compared with "No ABS", the sum rate of FUE of "FP" is almost half, because FBSs use only half subframes in all subframes. The sum rate of FUE of "Conv. + PCS" is higher than that of the conventional one, because "Conv. + PCS" decreases the number of ABS assignments and increases the usage time of subframes because of PCS. However, that of "Conv. + PSI Trans." is lower than that of the conventional one, because BS selects interfering FBSs with the smallest number of connecting UEs as the interfering FBS set until UE's SINR becomes higher than the threshold value. In other words, more FBSs assign ABS or PCS, compared with the number of ABS and PCS assignments on the selection of largest interfering FBS. In the high density network, the sum rate of FUE is decreased compared with that in the low density network. This is because the interference from surrounding BSs increases due to the increase of FBSs.

Figure 11 shows the fairness index of FUE. The proposed method and "Conv. + PSI Trans." improve the fairness index of FUE by between 0.7 and 1.0 compared with that of the conventional one. This is because BS selects interfering FBS with the smallest number of connecting UEs as the interfering FBS set. In the conventional one, UE fairness is not considered and BS selects the largest interfering FBS as the interfering FBS set. In the high density network, the fairness index of FUE is decreased compared with that in the low density network. This is because the number of FBSs and FUEs in the network increases.

VI. Conclusion

In this paper, we proposed a dynamic almost blank subframe assignment method with power control subframe to improve the sum rate and user fairness. Each base station (BS) receives feedback from the surrounding BSs and users, and decides its subframe assignment based on the feedback. The proposed method adopts two new techniques. First, a power control subframe is applied to increase the sum rate, and second, a subframe assignment based on the number of connecting UEs of each BS to improve user fairness is proposed. Through computer simulation, compared with the conventional dynamic ABS assignment methods, the proposed methods were shown to improve the sum rate and user fairness, while achieving a similar user outage ratio.

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