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Interference Aware Fractional Frequency Reuse using Dynamic User Classification in Ultra-Dense HetNets

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ABSTRACT

Small-cells in heterogeneous networks are one of the important technologies to increase the coverage and capacity in 5G cellular networks. However, due to the randomly arranged small-cells, co-tier and cross-tier interference increase, deteriorating the system performance of the network. In order to manage the interference, some channel management methods use fractional frequency reuse(FFR) that divides the cell coverage into the inner region(IR) and outer region(OR) based on the distance from the macro base station(MBS). However, since it is impossible to properly measure the distance in the method with FFR, we propose a new interference aware FFR(IA-FFR) method to enhance the system performance. That is, the proposed IA-FFR method divides the MUEs and SBSs into the IR and OR groups based on the signal to interference plus noise ratio(SINR) of macro user equipments(MUEs) and received signals strength of small-cell base stations(SBSs) from the MBS, respectively, and then dynamically assigns subchannels to MUEs and small-cell user equipments. As a result, the proposed IA-FFR method outperforms other methods in terms of the system capacity and outage probability.

☞ keyword : 5G, OFDMA, heterogeneous network, fractional frequency reuse, interference management, dynamic user classification

1. Introduction

Addressing the increasing mobile data demand and speed in 5G cellular networks is an important issue[1]. Small-cell is one of the solutions to this problem. Small-cells with low power, low cost and low coverage can be installed indoors and in hotspot areas to handle the mobile data demands of dense users[2]. Small-cells can be individually installed in the macrocell coverage without any design. However, the use of small-cells indiscriminately in heterogeneous networks (HetNets) in which macro base station(MBSs) and small-cell base stations(SBSs) are overlapped increases the effect of interference due to insufficient frequency resources, resulting in deterioration of system performance[3].

Interference management in HetNets with ultra-dense small-cells is particularly important. The main cause is cross-tier interference, resulting in performance degradation due to ultra-dense distribution of the SBSs that use the same channel as the existing macrocell user equipments(MUEs). As a method of managing cross-tier interference, it is fractional frequency reuse(FFR) method in which subchannels are divided and used[4].

The FFR method is a method of dividing a macrocell locally and partially dividing all available subchannels to reduce the effect of interference. In the FFR method, the available channels are divided between users near the inner region(IR) of the cell and users at the outer region(OR) of the cell. Many researchers have proposed resource reuse schemes with the FFR method to mitigate interference in the conventioal cellular networks(CCNs) and HetNets. In [5] and [6], the macrocell of CCNs is devided into the IR and OR based on the distance with a distance ratio of 0.63 and 0.65, respectively. In [7], the macrocell has three regions, i.e., inner, intermediate, and outer regions, while in [8], optimal subchannels are allocated to MUEs and small-cell user equipments(SUEs) after dividing the MUEs and SUEs into the IR and OR in the distance based FFR of HetNets. All of these methods are proposed the optimal FFR by using the distance of the macrocell locally. However, the method of using the distance has difficulty in practically accurate measurement. In addition, the MBS of the CCN divides

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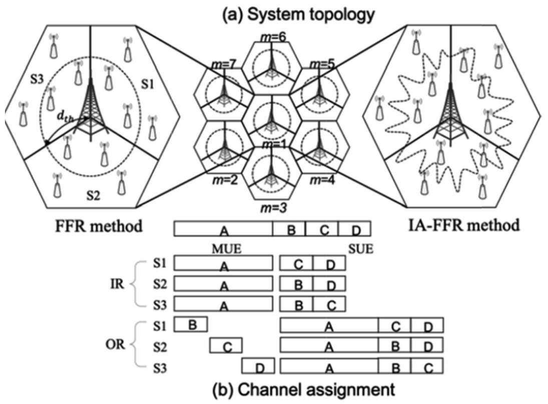


(Figure 1) System topology and channel assignment

MUEs into the IR and OR using the signal-to-interference plus noise ratio(SINR) and received signal strength(RSS) from the serving MBS for MUEs in [9] and [10], respectively. However, SBSs are installed indoors and thus SBSs in HetNets with FFR also need a grouping method to divide them into the IR and OR in a good way instead of the distance way.

In this paper, we propose a new interference-aware FFR(IA-FFR) method using dynamic user classification for MUEs and SBSs in HetNets. In the proposed IA-FFR method, MUEs and SBSs are divided into the IR and OR by using their SINR with an SINR threshold and the RSS from the serving MBS for MUEs and SBSs, respetively. Through simulation results, we show that the SINR and capacity of MUEs are increased, and the outage probability of MUEs is decreased.

The structure of this paper is as follows. Section 2 introduces the system model in HetNets and Section 3 proposes the IA-FFR method with dynamic user classification. Section 4 shows the simulation results thorugh comparision with the previous distance-based FFR mothods. Finally, the conclustion is presented in Section 5.

2. System model

We consider the donwlink of a cellular network with othogonal frequency division multiple access and frequency division duplex(OFDMA-FDD). Fig. 1 shows the system model and channel assignment method in HetNets with FFR. We consider 7 hexagoanl macrocells with 3 sectors, i.e., S1, S2, and S3. A set of M MBSs $M = |\mathbf{M}|$, $\mathbf{M}$={1,2,⋯,M}, is located in the center of each cell, and a set of N MUEs, $N = |\mathbf{N}|$, $\mathbf{N} = \{1,2,\ldots,N\}$ is randomly located within the cell coverage. A Set of S small-cells $S = |\mathbf{S}|$, $\mathbf{S} = \mathbf{S} = \{1,2,\ldots.,S\}$, is also randomly located within the macrocell coverage, and each small-cell serves one SUEs. Fig. 1-(b) describes the channel assignment for MUEs and SUEs. A set of K subchannels, $K = |\mathbf{K}|$, $\mathbf{K} = \{1,2,\ldots,K\}$, is divided into four subchannel groups, i.e., A, B, C, D. The MBS assigns group A, $\left\lfloor \frac{3K}{6} \right\rfloor$ subchannels, to its MUEs in the IR of all sectors while group B, C and D, i.e. each group has $\left\lfloor \frac{K}{6} \right\rfloor$ subchannels, to its MUEs in the OR of S1, S2 and S3, respectively. On the other hand, SBSs in S1, S2 and S3, allocate group (C,D), (B,D) and (B,C), each SBS has $\left\lfloor \frac{2K}{6} \right\rfloor$ subchannels, to their SUEs in the IR while group (A,C,D), (A,B,D) and (A,B,C), each SBS has $\left\lfloor \frac{5K}{6} \right\rfloor$ subchannels, to ther SUEs in the OR, respectively.

In order to evaluate the system performance, we first calculate the SINR of MUEs and SUEs. Let γ_{mn}^{k} denote the SINR of MUE n served by MBS m at subchannel k in dB. γ_{mn}^{k} can be expressed as

$$\gamma_{mn}^{k} = \frac{G_{mn}^{k} A(\theta) \omega_{mn}^{k}}{\sigma_N^2 + \sum_{\forall i \in \mathrm{M}\setminus\{m\}} G_{in}^{k} A(\theta) \omega_{in}^{k} + \sum_{\forall s \in S} G_{sn}^{k} \omega_{sn}^{k}}, \quad (1)$$

where $G_{mn}^{k} = P_{mn}^{k} L_{mn}$ in which P_{mn}^{k}, L_{mn} and $A(\theta)$ are the transmission power of subchannel k, path loss and azimuth antenna pattern between MBSm and MUEn in dB, respectively. Let ω_{mn}^{k} is an indicator variable, ω_{mn}^{k}=1 if MBS m allocate subchannel k to MUEn, and 0 otherwise. Let σ_N^2 is the white noise power. $A(\theta)$ can be expressed as

$$A(\theta) = \mathrm{A_g} - \min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right], -\pi \le \theta \le \pi, \quad (2)$$

where $\mathrm{A_g}$ and A_m are the maximum antenna gain and maximum attenuation in dB, respectively, while θ_{3dB} is 3dB beamwidth[11].

On the other hand, let γ_{st}^{k} denote the SINR of SUE t served by SBSs at subchannel k in dB. γ_{st}^{k} can be expressed as

Algorithm 1: Proposed IA-FFR method

Input: $\forall m \in \mathbf{M}$, $\forall n \in \mathbf{N}$, $\forall s \in \mathbf{S}$, $\forall t \in \mathbf{T}$, Γ_{mth}, Γ_{sth}
Output: $\forall m \in \mathbf{M}$, $\forall n \in \mathbf{N}$, $\forall s \in \mathbf{S}$, $\forall t \in \mathbf{T}$, $\forall k \in \mathbf{K}$, ω_{mn}^{k}, ω_{st}^{k}
Initialization: $\alpha_{mn}=0$, $\beta_{mn}=0$, $\forall m \in \mathbf{M}$, $\forall n \in \mathbf{N}$, $\forall s \in \mathbf{S}$, $\forall t \in \mathbf{T}$, $\forall k \in \mathbf{K}$

// Classify MUEs according to SINR of MUEs
for m=1 **to** M
  for n=1 **to** N
    Calculate Γ_{mn} according to (6)
    Set α_{mn} according to (7)
  end for
end for
// Classify SBSs according to SNR of SBSs
for m=1 **to** M
for s=1 **to** S
    Calculate Γ_{ms} according to (8)
    Set β_{ms} according to (9)
  end for
end for
// Allocate subchannels to MUEs
for m =1 **to** M
  for n=1 **to** N
    if $\alpha_{mn} == 1$ **then**
      MBS m allocate $\left\lfloor \frac{3K}{6N_{IR}} \right\rfloor$ subchannels to MUE n
    else
      MBS m allocate $\left\lfloor \frac{K}{6N_{OR}} \right\rfloor$ subchannels to MUE n
    end if
  end for
end for
// Allocate subchannels to SUEs
for s=1 **to** S
  for t=1 **to** T
    if $\beta_{ms} == 1$ **then**
      SBS s allocate $\left\lfloor \frac{2K}{6} \right\rfloor$ subchannels to SUE t
    else
      SBS s allocate $\left\lfloor \frac{5K}{6} \right\rfloor$ subchannels to SUE t
    end if
  end for
end for

$$\gamma_{st}^{k} = \frac{G_{st}^{k}\omega_{st}^{k}}{\sigma_N^2 + \sum_{\forall j \in S\setminus\{s\}} G_{jn}^{k}\omega_{jn}^{k} + \sum_{\forall m \in M} G_{mt}^{k} A(\theta)\omega_{mt}^{k}}, \tag{3}$$

where $G_{st}^{k} = P_{st}^{k} L_{st}$ in which P_{st}^{k}, L_{st} is the transmission power of subchannel k, path between SBS s and SUE t in dB, respectively. Let ω_{st}^{k} is an indicator variable, $\omega_{st}^{k} = 1$ if SBS s allocate subchannel k to SUE t, and 0 otherwise.

Through γ_{mn}^{k} and γ_{st}^{k}, the capacity of MUE n served by MBS m, C_{mn}, can be expressed as

$$C_{mn} = W \sum_{\forall k \in K} \omega_{mn}^{k} \log_2(1 + \gamma_{mn}^{k}), \tag{4}$$

where W is the bandwidth of a subchannel in Hz.

Finally, the capacity of SUE t served by SBS s, C_{st}, can be expressed as

$$C_{st} = W \sum_{\forall k \in K} \omega_{st}^{k} \log_2(1 + \gamma_{st}^{k}). \tag{5}$$

3. Proposed IA-FFR method

In this section, we propose a new IA-FFR method with dynamic user classification using the SINR and RSS for MUEs and SBSs, respectively. First, in the proposed IA-FFR method, MUEs calculate their SINR while SBSs measure their RSSs from the MBS. Then, they transmit the information to the serving MBS.

Let Γ_{mn} denote the SINR of MUE n served by MBS m. Γ_{mn} can be expressed as

$$\Gamma_{mn} = \frac{G_{mn}}{\sigma_N^2 + \sum_{\forall i \in \mathrm{M}\setminus\{\mathrm{m}\}} G_{in}}, \tag{6}$$

where $G_{mn} = P_{mn} L_{mn} A(\theta)$ in which P_{mn} is the transmission power of a subchannel for MUEs in the IR. Let α_{mn} denote an indicator variable, $\alpha_{mn} = 1$ if MUE n is served by MBS m in the IR, and 0 otherwise. α_{mn} can be expressed as

$$\alpha_{mn} = \begin{cases} 1 & \text{if } \Gamma_{mn} \geq \Gamma_{mth} \\ 0 & \text{otherwise} \end{cases}, \tag{7}$$

where Γ_{mth} is a given target SINR threshold in dB for classifying MUEs in the IR or OR.

Second, Γ_{ms} denote the RSS of SBSs served by MBS m in dB. Γ_{ms} can be expressed as

$$\Gamma_{\mathrm{ms}} = \frac{G_{ms}}{\sigma_N^2}, \tag{8}$$

where $G_{ms} = P_{ms} L_{ms}$ in which P_{ms} is the transmission power for SBSs in the IR. Let β_{ms} denotes an indicator variable, $\beta_{ms} = 1$ if SBS is classified in the IR, and 0 otherwise. β_{mn} can be expressed as

(Table 1) System parameters

Parameter		Value
Cellular layout		Hexagonal grid, 3 sectors per cell
Inter site distance		500m
Carrier frequency		2GHz
System bandwidth		10MHz
MBS(SBS) transmit power		46dBm(10dBm)
Number of MUEs per sector		30
Number of SUE per SBS		1
Number of SBS per sector		100,200,300
path loss model	MBS-MUE	$15.3+37.6\log_{10} d$[11]
	SBS-SUE	$38.46+20\log_{10} d$[11]
Shadowing standard deviation		8dB
Wall-penetration loss		10dB[12]
Minimum distance MBS-SBS		35m
Minimum distance SBS-SUE		20cm
Threshold of MUE(Γ_{mth})		-5, 0 5dB
Threshold of SBS(Γ_{sth})		115, 117.5, 120dB

$$\beta_{mn} = \begin{cases} 1 & \text{if } \Gamma_{ms} \geq \Gamma_{sth} \\ 0 & \text{otherwise} \end{cases}, \tag{9}$$

where Γ_{sth} is a given target RSS threshold in dB for classifying SBSs in the IR or OR.

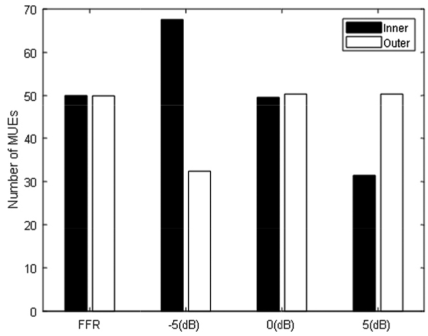
After classifying MUEs and SBSs into the IR and OR, the MBS and SBSs allocate subchannels to their MUEs and SUEs using subchannels assigned to the IR and OR, respectively. Let $N_{\mathrm{IR}} = \sum_{\forall n \in N} \alpha_{mn}$ and $N_{\mathrm{OR}} = N - N_{\mathrm{IR}}$ denote the number of MUEs in the IR and OR, respectively. MBS*m*allocate $\left\lfloor \frac{3K}{6/N_{IR}} \right\rfloor$ and $\left\lfloor \frac{K}{6/N_{OR}} \right\rfloor$ subchannels to each MUE in the IR and OR. SBS s allocate $\left\lceil \frac{2K}{6} \right\rceil$ and $\left\lceil \frac{5K}{6} \right\rceil$ subchannels to each SUE in the IR and OR. The proposed method based on the SINR of MUEs and RSS of SBSs is described in Algorithm 1.

4. Simulation results

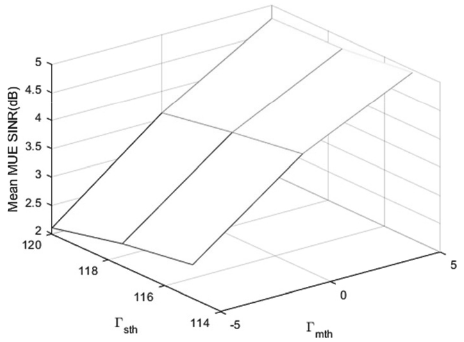
In this section, we use Monte Carlo simulation to evaluate the user's SINR, capacity and outage probability performance of the proposed method. We compare the proposed method with three different methods, i.e., frequency reuse factor(FRF)3 and FFR, for performance comparison[6,7]. The numbers of subchannels for each MUE is $\left\lfloor \frac{K}{3N} \right\rfloor$ in the FRF3 method, respectively. Furthermore, the numbers of subchannels for each SUE is $\left\lfloor \frac{4K}{6/N} \right\rfloor$ in the FRF3 method, respectively. The FFR and proposed methods are $\left\lfloor \frac{3K}{6/N_{IR}} \right\rfloor$ and $\left\lfloor \frac{K}{6/N_{OR}} \right\rfloor$ subchannels for MUEs in the IR and OR while $\left\lceil \frac{2K}{6} \right\rceil$ and $\left\lceil \frac{5K}{6} \right\rceil$ subchannels for SUEs in the IR and OR. The FFR uses distance classifiacation for IR and OR by d_{th} 0.65 times the radius of the MBS[6]. In order to analysis with the proposed method in various ways according to the threshold, we experiment with treshold value Γ_{mth} of MUEs from -5 to 5dB and treshold value Γ_{sth} of SBSs from 115 to 120dB. Finally, in order to compare the FFR and the proposed method in the same environment, the proposed method uses threshold Γ_{mth}=0 dB and Γ_{sth}=117.5 dB, respectively. Detailed system parameters are summarized in Table 1.

Fig. 2 and 3 show the number of MUEs and SBSs divided into IR and OR according to the threshold in the proposed method. In Fig. 2, it shows the change of the number of MUEs in the IR and OR of the proposed method according to the SINR threshold Γ_{mth}. The FFR method is divided by the distance $\mathrm{d_{th}}$ and shows a number of about 50%:50%, while in the proposed method, it can be seen that the number of MUEs in the OR increases as the threshold value Γ_{mth} increases. In Fig. 3, it shows the change of the number of SBSs in the IR and OR of the proposed method according to the SINR threshold Γ_{sth}. The FFR method is divided by the distance $\mathrm{d_{th}}$ and shows a number of about 50%:50%, while in the proposed method, it can be seen that the number of SBSs in the OR increases as the threshold value Γ_{sth} increases.

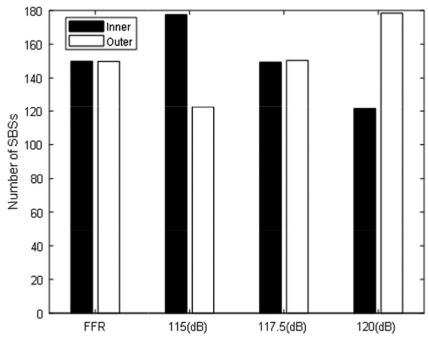
Fig. 4 and 5 show the mean MUE and SUE SINR according to the two thresholds Γ_{mth} and Γ_{sth} in the proposed method. In Fig. 4, when Γ_{mth} is 5dB and Γ_{sth} is 120dB, it shows the highest SINR. This is because, as the Γ_{mth} increases, the MUE belongs to an OR having relatively less influence of interference, and as the Γ_{sth} increases, the cross interference between the SBS and the MUE decreases. In Fig. 5, when Γ_{sth} is 115dB, it shows the highest SINR. This is because as the Γ_{sth} decreases, the SUE belonging to



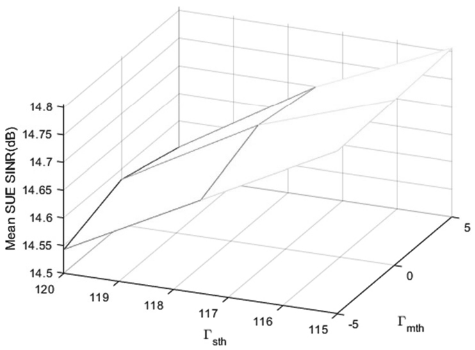
(Figure 2) Number of MUEs in the IR and OR



(Figure 4) Mean MUE SINR of the proposed method



(Figure 3) Number of SBSs in the IR and OR



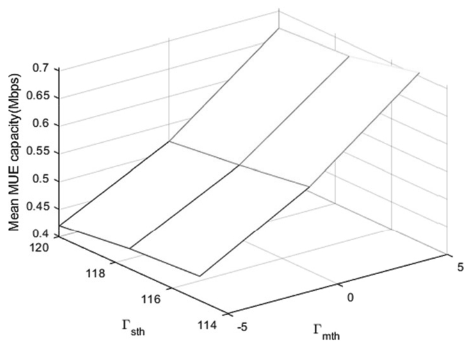
(Figure 5) Mean SUE SINR of the proposed method

the IR increases, and the amount of interference from the MBS decreases.

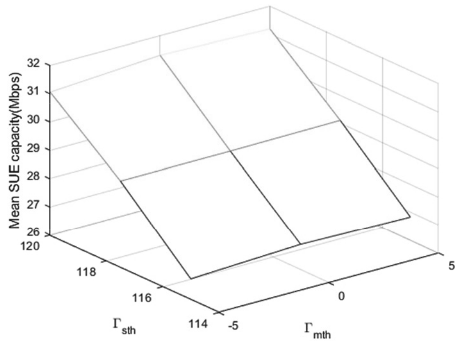
Fig. 6 and 7 show the mean MUE and SUE capacity according to the two thresholds Γ_{mth} and Γ_{sth} in the proposed method. In Fig. 6, when Γ_{mth} is 5dB, it shows the highest SINR. This is because the SINR increases as the MUE interference amount decreases, as shown in Fig. 4. In Fig. 7, unlike the previous Fig. 5, mean SUE capacity shows the highest value when Γ_{sth} is 120dB. This is because even though the SINR is low, the amount of resources used increases as the Γ_{sth} increases.

Fig. 8 and 9 are shows comparing mean MUE and SUE SINR with other methods when the threshold values of the proposed method are Γ_{mth}=0dB and Γ_{sth}=117.5dB, respectively. In Fig. 8, FRF3, which has the least effect of interference, shows the higher performance than the FFR. The proposed method shows higher performance than the FFR as the number of SBS increases. And the proposed method shows similar performance to FRF3 from 100. This is a result that occurs because the number of MUEs and SBSs in IR and OR are different depending on the threshold value Γ_{mth}=0dB and Γ_{sth}=117.5dB. The proposed method shows numbers of UEs and SBSs configuration similar to FFR through two threshold, but improves performance because UEs with better SINR are welcomed. In Fig. 9, the FRF3 with the least cross interference shows higher performance than the FFR based method. In the FFR based methods, the resources used by SBSs in the IR and OR are same and show similar performance because the number of SBSs is kept similar.

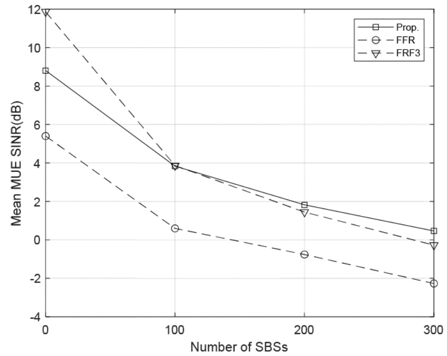
Fig. 10 and 11 are shows comparing mean MUE and SUE capacity with other methods when the threshold values of the proposed method are Γ_{mth}=0dB and Γ_{sth}=117.5dB, respectively. In Fig. 10, the resource usage of MUEs in FRF3 is the lowest, it shows the lowest performance. The proposed method uses the same resources for MUEs as the FFR method, but has better performance. This is because the MUEs of the proposed method through thresholds are



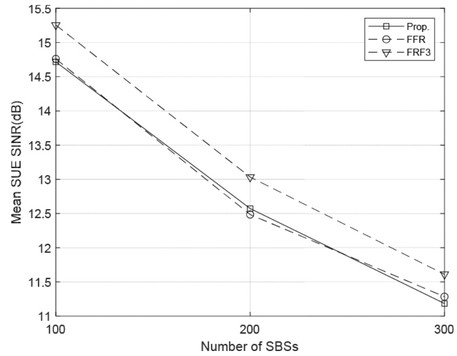
(Figure 6) Mean MUE capacity of the IA-FFR method



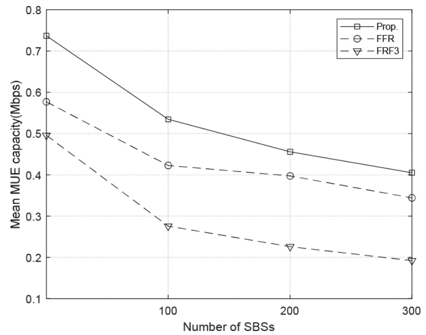
(Figure 7) Mean SUE capacity of the IA-FFR method



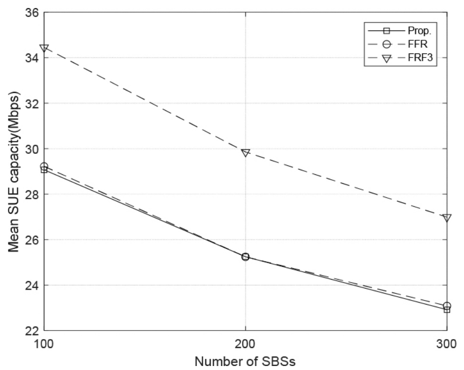
(Figure 8) Mean MUE SINR



(Figure 9) Mean SUE SINR



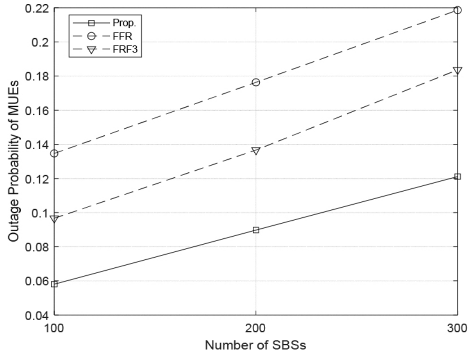
(Figure 10) Mean MUE capacity



(Figure 11) Mean SUE capacity

provided with better SINR. In Fig. 11, the FRF3 method shows the highest value since it has the lowest cross-tier interference. As shown in Fig. 9, the proposed method shows similar performance in capacity as the SINR of SUE is similar to that of FFR and the number of SBSs is similar.

Fig. 12 shows the outage probability of MUE according to the number of SBSs. The FRF3 method shows lower outage probability performance than FFR, because the interference effect is the least. As the number of SBSs increases, the proposed method shows lower probability than other methods because this proposed method classifies MUEs with better SINR at the thresholds. Additionally, the



(Figure 12) Outage probability of MUEs

outage probability of SUEs is excluded because all methods havavalues close to 0.

5. Conclusion

This paper proposes a new IA-FFR method with the dynamic user classification for MUEs and SBSs. In the proposed IA-FFR method, the MBS groups MUEs and SUEs into the IR and OR through the SINR of MUEs and RSS of SBSs through the MBS, respectively. It is more measurable that uses information through SINR of MUEs and RSS of SBSs than distance-based FFR methods, which are information that cannot be measured in previous studies. In the proposed IA-FFR method, MUEs and SBSs are dynamically included in the IR and OR through the SINR of MUEs and RSS of SBSs, respectivley. This lowers the probability of the MUE's outage compared to the existing methods, and improves the SINR and capacity for MUEs. For future research, we are planning to study a dynamic resource assignment method for MUEs and SUEs with considering co-tier and cross-tier interference in HetNets.

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