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이종 네트워크를 위한 Almost Blank Subframes의 성능 분석

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Analytical Evaluation of Almost Blank Subframes for Heterogeneous Networks

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요약

이종 네트워크 환경에서 이종셀 간 간섭 제어를 위해 Almost Blank Subframes (ABS)이 제안 되었다. ABS에서는 서브프레임에 대한 자원 할당을 하지 않음으로써 동일 채널 간섭을 줄일 수 있다. 기존 연구에서는 ABS 기술의 성능 평가를 위한 수학적 모델링이 제안되지 않았다. 본 논문에서는 ABS 기술에 대한 수학적 모델을 제시하였다. 분석을 위한 가정에서 OFDMA 기반의 다중 반송파 (multi carrier) 시스템을 가정하였고, large-scale 페이딩을 가정하였다. 성능 평가로써 effective SINR에 대한 누적분포함수를 나타낸다. 시뮬레이션과 분석에 대한 결과 비교를 통해 수학적 모델에 대한 정확도를 보인다.

Key Words : exponential effective SINR, heterogeneous networks (HetNet), inter-cell interference coordination (ICIC), co-channel interference (CCI), almost blank subframes (ABS).

ABSTRACT

In heterogeneous networks, the almost blank subframes (ABS) for inter-cell interference coordination (ICIC), which can be protected from the CCI due to unutilized subframes (i.e., ABS) is proposed. However, the analytical model for ABS-based systems has not been fully studied yet. In this paper, we derive a new analytical model to evaluate the performance of ABS-based systems. In an analytic model, we assume that each carrier in multicarrier systems, such as in OFDMA, is subject to large-scale fading, which is independent of other carriers. As a performance measure, we present the cumulative distribution function (CDF) for the effective SINR. We show the accuracy of the analytical model via simulation results.

Ⅰ. Introduction

Heterogeneous networks (HetNet) are promising systems for achieving substantial gains in coverage and capacity as compared to macro-only networks. In a heterogeneous network, low-power nodes consisting pico-, femto-, and relay nodes are placed throughout a macro cell layout, and they are placed generally in an unplanned manner. Among these low-power nodes,

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the introduction of pico-nodes is important in order to accommodate efficiently high-volume traffic in local areas, and enhance the overall system capacity. However, by the difference transmission power, the number of UEs connected to the pico-node is much smaller than that for the macrocell, which results in inefficient resource utilization[1]. To solve this problem, it is beneficial for the UEs to bias the handover criteria so that the UEs select the pico-node more frequently[2,3,11]. Although this technique overcomes problem with inefficient resource utilization, the UEs connected to the pico-node suffer interference from the aggressor macro cell, since the received signal power of the macro cell is higher than that of the connected pico-nodes for such UEs. Hence, pico-node deployment requires the use of an inter-cell interference coordination (ICIC) technique such as almost blank subframes (ABS)[4].

In the ABS technique, some resource elements (REs) of the pico-node can be protected from the co-channel interference (CCI) due to unutilized subframes (i.e., ABS) of the macro base station (BS). ABS was introduced in 3GPP Rel-10 (the first LTE-Advanced release) and its performance has been evaluated in previous work[1, 4, 5]. However, earlier investigations of the ABS scheme heuristically addressed, showing the performance of the ABS scheme only in simulations.

In this paper, we establish an analytical model for evaluating the performance of a subframe of the pico-node corresponding to the ABS of the macro BS. By using the ABS technique, even if most REs of pico-node do not suffer from interference, some REs are still affected owing to common reference symbol (CRS) transmissions from the macro BS. In this case, because the performance of a subframe of the pico-node corresponding to the ABS of the macro BS depends on the existence of interference signals on the REs, it is necessary to apply the effective signal to interference plus noise ratio (SINR) method[6]. We consider the cumulative distribution function (CDF) of the exponential effective SINR, $\mathrm{SINR}_{\mathrm{eff}}$, as a performance measure. This is because $\mathrm{SINR}_{\mathrm{eff}}$ provides accuracy within a few tenths of a decibel, even when interference is included[7]. We evaluate the accuracy of the proposed analytic model via comparison with simulation results.

The rest of this paper is organized as follows. In Section II, the ABS technique and system model are described. The analytical method to calculate the performance measures of interest is derived in Section III. In Section IV, analytical results are verified with simulation results for all the performance measures of interest and performance analysis is conducted. Section V concludes this paper.

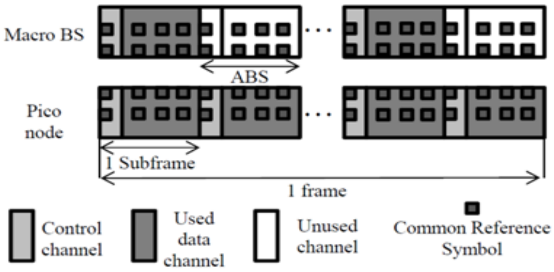

Fig. 1. Protected subframes by the ABS technique

Ⅱ. Almost Blank Subframes and System Model

2.1. Heterogeneous Networks (HetNet) and Almost Blank Subframes (ABS)

The LTE system is based on orthogonal frequency division multiple access-frequency division duplex (OFDMA/FDD). In LTE down link, the one frame consists of 12 subframes, where each subframe consists of one control and one data region, as shown in Fig. 1. In LTE-based HetNet, the only difference between the pico-node and the macro BS is that the transmit power of the pico-node is lower than that of the macro BS. Its transmit power ranges from 250mW to approximately 2W in outdoor deployments[4]. The ABS of an LTE Rel-10-based HetNet is enabled through an X2-interface for the coordination of resources used for scheduling data traffic. In HetNet scenario, the macro BS does not schedule data traffic while transmitting CRSs in order to provide legacy support to reduce the interference created by the macro BS, on ABS[8], as shown in Fig. 1. The number of CRSs mapped to a subframe corresponds to the number of antenna ports, where 8 CRSs per antenna port are mapped to a subframe. Thus, some REs in a data channel of the pico-node are protected by the ABS of the macro BS, while other REs suffer from interference by CRSs of the macro BS.

2.2. System Modeling

For LTE-based HetNet, we assume that there are *M* REs in one subframe and consider the channel model consisting of a path-loss component and a log-normal shadowing component[9]. The transmit power of the pico-node is given by P_p. The path loss exponent is given by α, the shadowing effect and the noise power are given by *L* and *N*, respectively. The set of macro BS is ***Z***, i.e. each BS uses the m-th sub-carrier as the UE and transmits with power P_m. We denote the distance between the macro BS_z and the UE by R_z. We assume that the natural logarithm of *L* is a Gaussian with mean zero and standard deviation σ, and noise power is an exponentially distributed with N_0B, where N_0 and *B* are noise power spectral density and the bandwidth of a sub-carrier, respectively.

The associated $SINR_m$ on the *m*-th sub-carrier is given as

$$SINR_m = \frac{P_p r^{-\alpha} L}{I_z + N}, m = 1, ..., M, \quad (1)$$

where for the macro BS set ***Z***,

$$I_z = \sum_{z \in Z} P_m R_z^{-\alpha} L, \quad (2)$$

where shadow fading is assumed to be independent across REs and independent of the transmitter and receiver position. In what follows, we assume that the random variable for the natural logarithm of *L* is statistically independent. In the above expression, we assume that the pico-node to the UE is at a distance *r*. Thus, the conditional distributions for the natural logarithm of powers received at the UE are a Gaussian distribution with mean of $\ln\left(P_p r^{-\alpha}\right)$ and standard deviation σ for the desired power, and a Gaussian distribution with mean of $\ln\left(P_m R_z^{-\alpha}\right)$ and standard deviation σ for the interference power, respectively.

Let the joint probability density function (PDF) for the position of an UE in a pico cell is $f_p(r,\theta)$. It is

$$f_p(r,\theta) = r/\left(\pi r_0^2\right), 0 \le r \le r_0, 0 \le \theta \le 2\pi, \quad (3)$$

where r_0 is the radius of the pico cell. Then for a given that (r,θ), distance between an UE and the macro BS_z,

$$R_z = \sqrt{r^2 + D_z^2 - 2rD_z\cos\theta}, \quad (4)$$

where D_z is the distance between the pico-node and the macro BS_z.

Ⅲ. Modeling of Exponential Effective SINR

In order to evaluate the performance, we use the CDF of $SINR_{eff}$, $F_{e,SINR}$, that depends on the set of *M* SINRs into a unique value, $SINR_{eff}$ such that $F_{e,SINR}(\gamma) = \Pr[SINR_{eff} \le \gamma]$. $SINR_{eff}$ can be formulated as

$$SINR_{eff} = -\beta \ln\left(\frac{1}{M}\sum_{m=1}^{M} e^{-SINR_m/\beta}\right), \quad (5)$$

where β depends on the coding scheme and the number of coded bits in a block, and $SINR_m$ is the associated SINR on the *m*-th RE[6].

To evaluate the statistics of SINR$_{eff}$ in (5), using the total probability law, we can re-formulate (5) as follows

$$\begin{aligned} & SINR_{eff} \\ & = \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} -\beta \ln\left(\frac{1}{M}\sum_{m=1}^{M} e^{-\gamma_m/\beta}\right) \\ & \times f_{SINR}^{1}(\gamma_1)d\gamma_1 \cdots \times f_{SINR}^{M}(\gamma_M)d\gamma_M \end{aligned} \tag{6}$$

where γ and f_{SINR}^{m} are the random variable and the PDF for SINR of *m*-th sub-carrier, respectively. Hence, in order to compute f_{SINR}^{m}, we need to first obtain the conditional CDF of SINR for *m*-th sub-carrier, $F_{SINR}^{m}(\gamma_m|r,\theta,R_z)$. It then is

$$F_{SINR}^{m}(\gamma_m|r,\theta,R_z) = \Pr\left[\frac{P_p r^{-\alpha} L}{I_z + N} < \gamma_m\right], \tag{7}$$

where (r,θ) is the position of an UE in a pico cell, R$_z$, represents the set of the distance between the UE and interfering BS$_z$.

After applying the natural logarithm manipulations to (8), it can be expressed as

$$\begin{aligned} & F_{SINR}^{m}(\gamma_m|r,\theta,R_z) \\ & = \int_{0}^{\infty}\int_{0}^{\infty}\left\{1 - Q\left[\frac{\ln\gamma_m + \ln(i_z + n) - m_s}{\sigma_z}\right]\right\} \\ & \times f_{I_z}(i_z)di_z f_N(n)dn \end{aligned} \tag{8}$$

where *Q*() is the Q-function, m_s and σ_s are mean and standard deviation for the natural logarithm of the desired signal power, respectively. $f_{I_z}()$, then, is the log-normal distribution with mean m_{I_z} and standard deviation σ_{I_z} for the interfering signal power sum of the set ***Z*** and whose mean and standard deviation can be obtained by using Yeh and Schwartz's algorithm[10]. Lastly $f_N()$ is the exponential distribution for noise power.

As mentioned above, for *m*-th sub-carrier, SINR$_m$ is associated with the existence of interference signals received from interfering BS$_z$. The approximation is applied to the case that the interference occurs. In general, since the interference power is stronger than noise power, we approximate $I_z + N \approx I_z$ and (8) is can be expressed as

$$F_{SINR}^{m}(\gamma_m|r,\theta,R_z) = \Pr\left[\frac{P_p r^{-\alpha} L}{I_z} < \gamma_m\right]. \tag{9}$$

By applying the natural logarithm manipulations to (9), it can be rewritten as

$$\begin{aligned} & F_{SINR}^{m}(\gamma_m|r,\theta,R_z) \\ & = \int_{0}^{\infty}\left\{1 - Q\left[\frac{\ln\gamma_m + \ln(i_z) - m_s}{\sigma_z}\right]\right\} \\ & \times f_{I_z}(i_z)di_z \end{aligned} \tag{10}$$

For the case that the interference do not occur, in (8), $f_{I_z}(0) = 1$ and we have

$$\begin{aligned} & F_{SINR}^{m}(\gamma_m|r,\theta,R_z) \\ & = \Pr\left[\frac{P_p r^{-\alpha} L}{N} < \gamma_m\right] \\ & = \int_{0}^{\infty}\left\{1 - Q\left[\frac{\ln\gamma_m + \ln(n) - m_s}{\sigma_z}\right]\right\} \\ & \times f_N(n)dn \end{aligned} \tag{11}$$

Finally, using the total probability law, for (9) and (11), we can get the CDF of SINR$_m$, F_{SINR}^{m}, as follows

$$\begin{aligned} & F_{SINR}^{m}(\gamma_m) \\ & = \int_{0}^{r_0}\int_{0}^{2\pi} F_{SINR}^{m}(\gamma_m|r,\theta,R_z) f_p(r,\theta)drd\theta \\ & = \int_{0}^{r_0}\int_{0}^{2\pi} \Pr\left[\frac{P_p r^{-\alpha} L}{I_z + N} < \gamma_m\right] f_p(r,\theta)drd\theta \end{aligned} \tag{12}$$

From (12), f_{SINR}^{m} can be obtained as a function of γ_m. Substituting each PDF of SINR for REs into (6), we can express $F_{e,SINR}$ as a function of γ and M.

Ⅳ. Numerical Results

In this section, we present Monte-Carlo simulation results and compare them with our analysis for the $SINR_{eff}$ statistic. To validate our analysis, we developed a simulation program with MATLAB and performed 500 independent simulations. We consider the interference scenario with one macro-cell in which one pico-node is deployed because the pico-node usually has one dominant interfering macro BS[4]. We assume that the data channel has 132 REs including CRSs in one subframe, and the numbers of CRSs according to the number of antenna ports 1, 2 and 4, are 8, 16 and 24, respectively. We assume that the bandwidth of a subcarrier is 15 kHz, and M, α and β are 5, 3 and 1, respectively. Additional system parameters for simulation and analysis are set as shown in Table 1[8]. In Fig. (2) and Fig. (3), the curves are numerically obtained from the equations given in the preceding analysis, whereas the symbols indicated the corresponding simulation results.

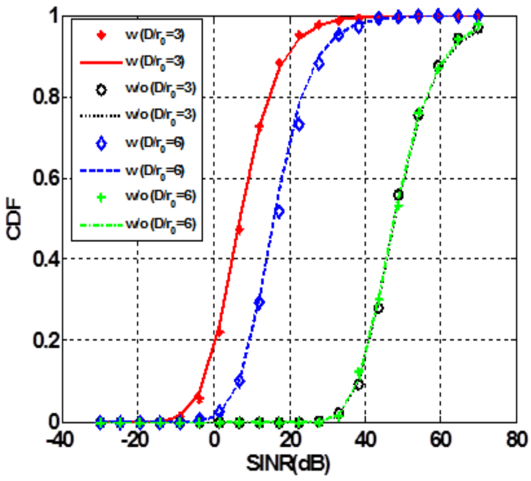

Fig. 2. Example of F^m_{SINR} for the existence of interference according to D/r_0.

Table 1. System parameters

Parameters	Pico-node	Macro BS
Shadowing standard deviation	3dB	4dB
Cell radius	100m	1000m
Tx power	100mW (20dBm)	40W (46dBm)
System bandwidth	10Mhz	
Noise density (N_0)	-174dBm/Hz	

In Fig.2, F^m_{SINR} is plotted for different interference condition and (D/r_0). In this figure, (w) and (w/o) denote the CDF with and without interference, respectively. Via numerical examples, we find that the results of our analysis closely approximate those of simulations. From (9), we observe that when interference occurs, it has a greater impact on the performance than noise does

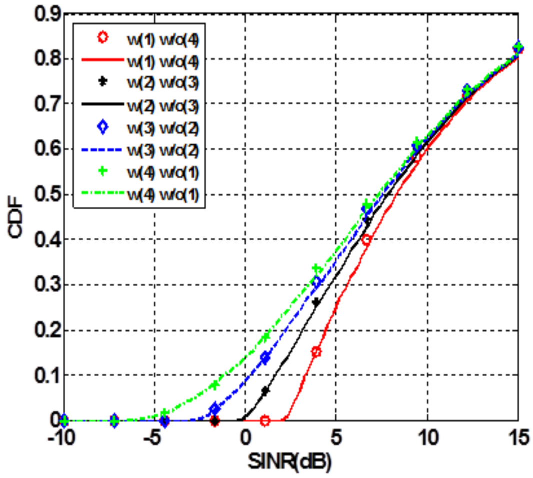

Fig. 3. $F_{e,SINR}$ with respect to the number of REs with/without interference (D/r_0).

As expected, when (D/r_0) increases, the performance of $SINR_m$ with interference increases. In case of without interference, regardless of (D/r_0), these performances are similar, since there is no interference from the macro BS.

In Fig. 3, $F_{e,SINR}$ is plotted under various interference conditions. The ratios of the number of REs with interference to those without interference are 4:1, 3:2, 2:3 and 1:4, when D/r_0=3. We find that the analytical result from the proposed model agrees with the simulation result. It is also observed that the curve of $F_{e,SINR}$ strongly depends on these ratios. For example, when the interference condition is 1:4, the curve of $F_{e,SINR}$ is close to the curve without interference shown in Fig. 2, while the curve of $F_{e,SINR}$ for the interference condition of 4:1 closely matches the curve with interference shown in Fig. 2.

In Fig. 4, we consider an interference scenario, and the numerical results are presented for $F_{e,SINR}$ for a subframe of a pico-cell corresponding to the ABS of a macro cell. In this figure, we find that the interference introduced by the data channel increases with an increasing number of antenna ports. For example, when the SINR is 5dB, $F_{e,SINR}$ for the number of the antenna ports 1, 2 and 4, is 0.05, 0.2 and 0.26, respectively. On the whole, the performance of a subframe for a pico-node corresponding to the ABS of a macro BS improves, as confirmed in Fig. 4.

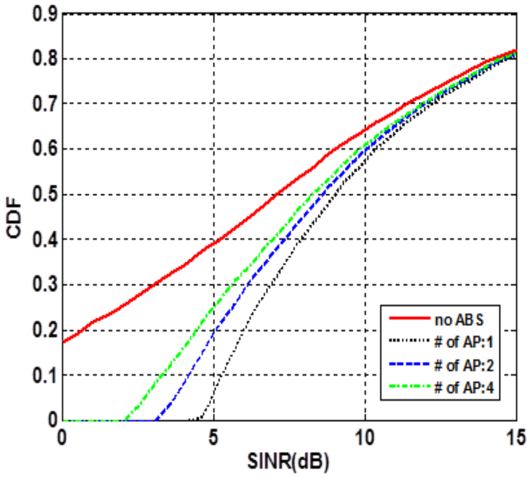

Fig. 4. $F_{e,SINR}$ with respect to the number of antenna ports of macro cell (1, 2, 4).

V. Conclusion

In this paper, a statistical model of the effective SINR for the analytical performance evaluation of ABS-based heterogeneous networks has been developed. We have shown that the effective SINR statistics obtained by the proposed analytical model agrees with the simulation results. In the evaluation, ABSs are employed to protect the subframes in the pico-node from severe interference from the macro BS. Although we have only shown an example of a two-cell interference scenario in this paper, the proposed model can be applied for the performance evaluation of heterogeneous networks using ICIC techniques in a multi cell environment.

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