ETRI Journal, Volume 40, Number 1, February 2018
http://onlinelibrary.wiley.com/journal/10.4218/(ISSN)2233-7326

Investigation of Open-Loop Transmit Power Control Parameters for Homogeneous and Heterogeneous Small-Cell Uplinks

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In Long Term Evolution (LTE) cellular networks, the transmit power control (TPC) mechanism consists of two parts: the open loop (OL) and closed loop. Most cellular networks consider OL/TPC because of its simple implementation and low operation cost. The analysis of OL/TPC parameters is essential for efficient resource management from the cellular operator's viewpoint. In this work, the impact of the OL/TPC parameters is investigated for homogeneous small cells and heterogeneous small-cell/macrocell network environments. A mathematical model is derived to compute the transmit power at the user equipment, the received power at the eNodeB, the interference in the network, and the received signal-to-interference ratio. Using the analytical platform, the effects of the OL/TPC parameters on the system performance in LTE networks are investigated. Numerical results show that, in order to achieve the best performance, it is appropriate to choose $\alpha_{\text{small}} = 1$ and $P_{\text{o-small}} = -100$ dBm in a homogenous small-cell network. Further, the selections of $\alpha_{\text{small}} = 1$ and $P_{\text{o-small}} = -100$ dBm in the small cells and $\alpha_{\text{macro}} = 0.8$ and $P_{\text{o-macro}} = -100$ dBm in the macrocells seem to be suitable for heterogeneous network deployment.

Keywords: 5G, HetNet, Interference, Open-loop power control, Small cell.

I. Introduction

Long Term Evolution (LTE) was introduced in the Release 8 specification of the Third Generation Partnership Project (3GPP), in order to accommodate the high-data-rate and low-latency requirements for cellular networks. Owing to the rapid increase in mobile broadband traffic, the need for network densification has become vital for radio access networks [1]. With additional network nodes per unit area, the distance between the eNodeB and the user equipment (UE) can be minimized, which results in a link-budget improvement [2].

One of the major challenges in the LTE network is intracell and intercell interference. For homogenous small-cell deployment, several interference mitigation schemes have been proposed in [3]–[5], which mostly focus on the downlink. For the uplink, the interference should be emphasized since it crucially impacts the network performance. For heterogeneous network (HetNet) deployment, the interference scenario becomes more complex owing to large differences between the transmit powers of the macrocell and small-cell layers. Therefore, intercell interference management plays a key role in HetNet performance [6].

Most LTE networks adopt a frequency reuse factor of unity. Therefore, the network is prone to intercell interference. Thus, the 3GPP standard introduced transmit power control (TPC) to enable power control in both the downlink and uplink for LTE [7]. In particular, the precise control mechanism for the UE uplink

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Manuscript received Sept. 15, 2017; revised Nov. 20, 2017; accepted Nov. 30, 2017.

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https://doi.org/10.4218/etrij.2017-0191

pISSN: 1225-6463, eISSN: 2233-7326

transmission power is emphasized to mitigate the adverse impact of interference on the network performance [8]. Uplink TPC is initiated at the UE on the basis of the information in the downlink configurations by the eNodeB. There are two parts of the TPC mechanism in an LTE uplink, that is, the open loop (OL) and closed loop (CL). OL/TPC determines the initial power settings of the network, whereas CL/TPC aims to correct the errors in OL/TPC configurations. That is, OL/TPC compensates for the path loss and shadowing. Meanwhile, CL/TPC tends to mitigate fast fading [9].

Most cellular networks consider OL/TPC because of its simple implementation and low operation cost. Therefore, in this work, only OL/TPC is taken into account. The 3GPP specification defines the UE transmit power P_{Tx} (dBm) for an LTE-A uplink as [10]:

$$P_{\text{Tx}} = \min\{P_{\max}, 10\log 10M + P_{\text{o}} + \alpha \cdot \text{PL} + \Delta mcs + f(i)\}. \tag{1}$$

- $P_{\max}$ is the maximum allowable transmit power for the UE.
- M is the number of physical resource blocks (PRBs). For simplicity, M is set to 1 in this study.
- P_{o} is a cell/UE-specific parameter. P_{o} is assumed to be cell-specific in this study.
- α is the path-loss compensation factor.
- PL is the path loss between the UE and the serving eNodeB.
- Δmcs and $f(i)$ are the CL/TPC parameters defining the modulation and coding scheme and closed-loop correction, respectively, as defined in the 3GPP standards. While analyzing the OL/TPC, Δmcs and $f(i)$ are assumed to be zero.

It is necessary to mention the role of the path-loss compensation factor. For $\alpha = 1$, the path loss is "fully compensated." For lower values of α, the path loss is only "partially compensated" and called fractional power control (FPC). Specifically, $\alpha = 0$ indicates "no power control." A higher value for α results in an increase in the transmit power and consequently higher intercell interference, which is mainly caused by the cell edge users. A lower value of α results in a decrease in the transmit power and thus reduces interference by the cell edge user, but it may degrade the performance. In this study, the parameters α and P_{o} are both assumed to be cell-specific, although the standard allows P_{o} to also be UE-specific. However, the 3GPP specification does not specify how to set these parameters to achieve proper network performance.

In the literature, many studies have been carried out regarding the OL/TPC parameters in homogenous LTE and HetNet scenarios. Reference [11] described LTE uplink power control and analyzed its impact on the system performance. For a homogenous macrocell environment, a path-loss compensation factor α_{macro} of 0.8 was selected as the optimum value for FPC. However, the optimum value needs to be revisited in a homogeneous small-cell environment because of the cell size reduction. Reference [12] proposed an improved open-loop power control scheme for the LTE uplink, which applied a different value of α_{macro} for each group of users experiencing similar channel conditions. However, such an approach may not be feasible since the path-loss compensation factor is cell-specific in the LTE standard [10]. In [13], the impact of the selection of the OL/TPC parameters on the network congestion in subway areas was described, where the proper tuning of the parameters was able to provide congestion relief. Our previous work [14] analyzed the impacts of α_{small} and $P_{\text{o-small}}$ on the UE transmission power for a homogenous small-cell network, where a higher value of α_{small} can be chosen, such as 0.9 or 1.0, since the UE transmit power becomes smaller than that in the macrocell case, as the path loss decreases with the reduction in the cell size. Therefore, in this study, we further extend the analysis to homogenous small-cell network deployment.

For HetNet deployment, a UE-specific TPC algorithm was proposed in [15], where the interference was computed by the ratio of the UE-specific average interference to the average eNodeB interference. In [16], the impact of the OL/TPC parameters on the performance of LTE UL in a HetNet environment including the cell range extension for a picocell was analyzed. A brute-force search was applied to determine the optimum PC parameters without investigating their tendency in both homogeneous and HetNet environments. Additionally, the same fractional path-loss compensation factor was suggested for macrocell and picocell layers. That is, the same settings for both layers were considered. Reference [17] presented a detailed survey of power control schemes for an LTE uplink. However, it focused only on the selection of the value of α. Furthermore, the same value of $\alpha = 0.7$ was assumed for both macrocells and small cells. It is necessary to consider different values of α for small cells and macrocells, as a higher value of α may be selected for the small cells [18]. In addition, [19] analyzed the different values of P_{o} for macrocells and small cells, where –90 dBm and –70 dBm were selected for the macrocell and small cell, respectively. However, the same value of $\alpha = 0.7$ was assumed for both macrocells and small cells. Therefore, it is necessary to investigate the impact of the simultaneous variation in both α and P_{o} on the network performances. Even though the uplink OL/TPC was described in a technical document [10], the specific value was not known. Thus, from the viewpoint of implementation, it is very important to know the information of parameter values such as α and P_o.

To the best of our knowledge, setting the parameter values for the UL OL/TPC in terms of both α and P_o has not been intensively investigated. Additionally, such initial parameter settings are essential for network operators. Therefore, in this work, the impact of the OL/TPC parameters is investigated for both homogeneous small-cell and HetNet environments. Furthermore, for the OL/TPC in a HetNet, it is essential to analyze the individual and combined impacts of the variations in the macrocell and small-cell parameters on the network performance. A mathematical model is derived in order to compute the transmit power at a UE, the received power at an eNodeB, the interference in the network, and the received signal-to-interference ratio (SIR). By using this analytical platform, the OL/TPC parameters for the LTE networks are calculated. The rest of this paper is organized as follows. Section II presents a network model and its performance analysis. Section III presents the numerical results. Finally, Section IV concludes the paper.

II. Network Model and Performance Analysis

We assume two scenarios for the small-cell uplink. One is a homogeneous small-cell network, and the other is a HetNet. We analyze the performance for both scenarios in terms of the UE transmit power, eNodeB received power, interference, and received SIR.

1. Homogenous Small-Cell Scenario

This section considers homogenous small-cell deployment, where 19 small cells are uniformly distributed, as shown in the network in Fig. 1. The analysis is focused on the uplink for the central small cell surrounded by two tiers of small cells. In order to analyze the performance, the fluid model in [20] is employed. At the eNodeB, omnidirectional antennas are modeled to provide network coverage in each cell. The small cell radius is $R = 200$ m in the network range of $R_{\text{nt}} = 1{,}000$ m. Generally, a uniform UE distribution is assumed for the analysis of the OL/TPC settings in the network [21] since it provides a better insight for modeling and analyzing the network [22]. Therefore, the UE distribution is assumed to be uniform in the small-cell area [23]. The performance of the OL/TPC is analyzed in terms of the parameters α and P_o.

A. Transmit and Receive Powers

For the homogenous small-cell environment, the uplink transmit power $P_{\text{Tx-small}}$ (dBm) is given by

$$P_{\text{Tx-small}} = P_{\text{o-small}} + \alpha_{\text{small}} \cdot \text{PL}, \tag{2}$$

where $P_{\text{o-small}}$ is P_o for the small cells, and α_{small} is α for the small cells. The received power $P_{\text{Rx-small}}$ (dBm) at the eNodeB can be derived from (2):

$$\begin{aligned} P_{\text{Rx-small}} &= P_{\text{Tx-small}} - \text{PL} = P_{\text{o-small}} + \alpha_{\text{small}} \cdot \text{PL} - \text{PL} \\ &= P_{\text{o-small}} + (\alpha_{\text{small}} - 1) \cdot \text{PL}. \end{aligned} \tag{3}$$

Note that we focus on the free-space model for path-loss estimation [24]. The mathematical expression for the free-space model is given as

$$\text{PL} = 32.45 + 20\log_{10}(r) + 20\log_{10}(f_{\text{MHz}}), \tag{4}$$

where r is the distance from the UE to the eNodeB in meters, and f_{MHz} is the operating frequency. Equation (4) can be rewritten in order to calculate the distance from the UE to its serving eNodeB when the corresponding path loss and frequency values are known:

$$r = \log_{10}^{-1}\left(\text{PL} - 20\log 10(f_{\text{MHz}}) - 32.45\right)/20. \tag{5}$$

B. Interference

In Fig. 1, the central small cell with a radius of R is surrounded by two interfering rings at a distance of $2nR$ ($n = 1, 2$). The network size is expressed as

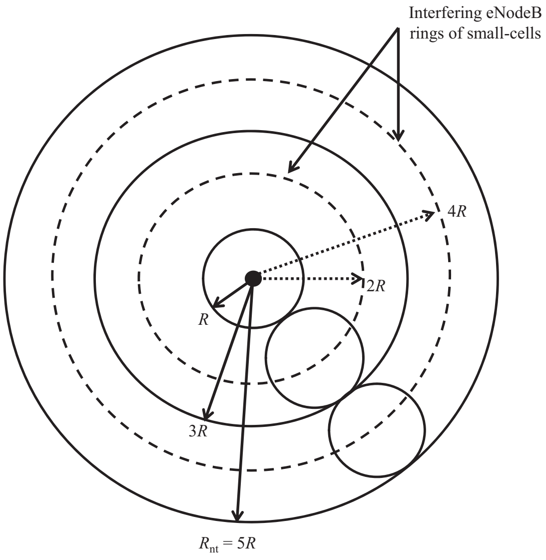

Fig. 1. Fluid model for homogenous small-cell deployment.

$R_{\text{nt}} = (2N_{\text{i}} + 1)R$, where N_{i} represents the number of interfering rings. In this paper, two interfering rings are assumed. Note that the first ring of interfering cells is located between R and $3R$, and the second ring exists between $3R$ and $5R$.

Figure 2 presents the fluid model for the interference calculation. The UE density of ρ_{ue} is assumed to be uniform in each cell such that $\rho_{\text{ue}} = 1/(\pi R^2)$. Consider a UE u scheduled by the central small cell eNodeB b. From (3), the received power at eNodeB b from UE u is written as

$$p_{\text{Rx-small},u} = p_{\text{o-small}} \cdot pl_{u,b}^{\alpha_{\text{small}}-1}, \tag{6}$$

where $p_{\text{o-small}}$ (mW) is the target received power, and $pl_{u,b}$ is the path loss between UE u and eNodeB b. Since the frequency reuse factor is assumed to be one, UE u suffers external interference due to one UE per PRB in each neighboring cell. Therefore, the small-cell interference expression is approximated by

$$I_{\text{small}} = \int_{R}^{R_{\text{nt}}} \int_{0}^{2\pi} \rho_{\text{ue}} p_{\text{o-small}} pl_{u,b}^{\alpha_{\text{small}}} pl_{u,b}^{-1} r dr d\theta, \tag{7}$$

where u, b designates UE u scheduled by eNodeB b. Moreover, the path loss pl can be expressed in terms of the path gain pg where $pg = 1/pl$. In this work, we assume that the path loss is only dependent on the distance r between the UE and the eNodeB. Therefore, the path gain can be given as

$$pg_{u,b}(r) = \mathrm{A} r^{-\eta}, \tag{8}$$

where A is a constant and $\eta = 3.5$ is the path-loss coefficient. Consider user v scheduled by eNodeB c, which is located on the first ring of the interfering small cells at a distance $r \in [R; 2R]$ from eNodeB b. Figure 2 clearly shows that user v is located at a distance of $2R - r$ from eNodeB c. The interference offered by the small area $2\pi r dr$ around UE v is $\rho_{\text{ue}} p_{\text{o-small}} A^{-\alpha_{\text{small}}} (2R - r)^{\alpha_{\text{small}}\eta} \mathrm{A} r^{-\eta} 2\pi r dr$. Similarly, if UE v is located in the region of the first interfering ring, that is, $r \in [2R; 3R]$, it is at a distance $r - 2R$ from eNodeB c. Hence, the interference offered now by the small area $2\pi r dr$ around UE v can be estimated to be $\rho_{\text{ue}} p_{\text{o-small}} A^{-\alpha_{\text{small}}} (-2R + r)^{\alpha_{\text{small}}\eta} \mathrm{A} r^{-\eta} 2\pi r dr$. Therefore, the generalized expression for the interference offered by the nth interfering ring to the central small cell can be given as

$$\begin{aligned} I_{n,\text{small}} = {} & 2\pi \int_{(2n-1)R}^{2nR} \rho_{\text{ue}} p_{\text{o-small}} A^{-\alpha_{\text{small}}} (2nR - r)^{\alpha_{\text{small}}\eta} \mathrm{A} r^{-\eta} r dr \\ & + 2\pi \int_{2nR}^{(2n+1)R} \rho_{\text{ue}} p_{\text{o-small}} \mathrm{A}^{-\alpha_{\text{small}}} (-2nR + r)^{\alpha_{\text{small}}\eta} \mathrm{A} r^{-\eta} r dr. \end{aligned} \tag{9}$$

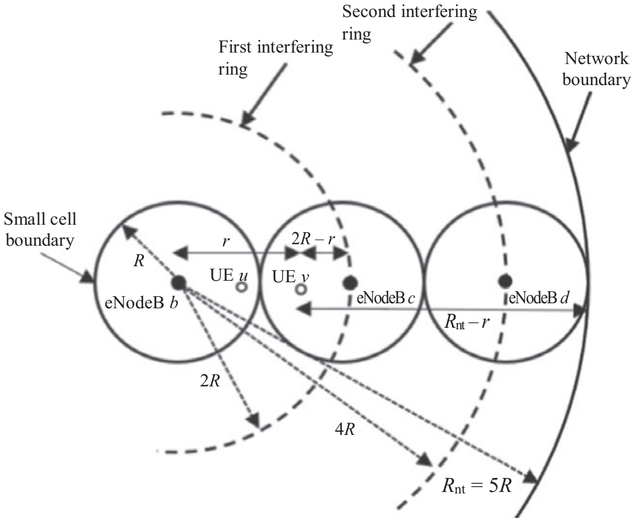

Fig. 2. Fluid model for the interference calculation.

The total interference offered to the central small cell can be approximated as

$$I_{\text{small}} = \sum_{n=1}^{N_{\text{i}}} I_{n,\text{small}}. \tag{10}$$

C. Received SIR

The received SIR for user u can be obtained by dividing (6) by (10):

$$\text{SIR}_{\text{Rx},u} = \frac{p_{\text{Rx-small},u}}{I_{\text{small}}}. \tag{11}$$

2. HetNet (Small Cell/Macrocell) Scenario

This section considers HetNet deployment, where all of the parameters are the same as those of the homogeneous small scenario, except for the additional consideration of the macrocell ranging to 1,000 m. Figure 3 shows the network model for HetNet deployment. The small cells are assumed to be uniformly distributed in a macrocell. Table 1 summarizes the system parameters for both the homogeneous small-cell and HetNet scenarios.

A. Transmit and Receive Powers

In the HetNet deployment, the uplink UE transmit and eNodeB received powers in the small cells are the same values as those in the homogenous small-cell deployment

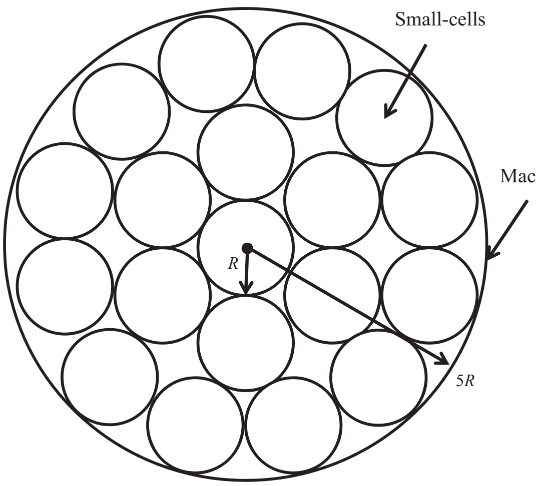

Fig. 3. Fluid model for HetNet deployment.

Table 1. System parameters.

Parameter	Homogenous small network	Heterogeneous network
Number of cells	19 small cells	19 small cells, 1 macrocell
Cell radius	Small-cell radius R = 200 m	Small-cell radius R = 200 m, Macrocell radius = $5R$ = R_{nt} = 1,000 m
UE distribution	Uniform distribution	
Path-loss model	Free-space model, PL = 32.45 + 20log10(r) + 20log10(f_{MHz})	
Antenna type at eNodeB	Omnidirectional antenna	
Path-loss compensation factor ‘α’ range	α_{small} = 0.7, 0.8, 0.9, 1	α_{small} = 0.7, 0.8, 0.9, 1 α_{macro} = 0.8, 0.9, 1
P_{o} range (dBm)	$P_{\text{o-small}}$ = –60, –70, –80, –90, –100	$P_{\text{o-small}}$ = –60, –70, –80, –90, –100 $P_{\text{o-macro}}$ = –60, –70, –80, –90, –100

(see (2) and (3)). Therefore, we additionally consider the macrocell case. For the macrocell, the uplink UE transmit power $P_{\text{Tx-macro}}$ (dBm) is given by

$$P_{\text{Tx-macro}} = P_{\text{o-macro}} + \alpha_{\text{macro}} \cdot \text{PL}. \tag{12}$$

The received power $P_{\text{Rx-macro}}$ (dBm) at the eNodeB is

$$P_{\text{Rx-macro}} = P_{\text{o-macro}} + (\alpha_{\text{macro}} - 1) \cdot \text{PL}. \tag{13}$$

B. Interference

For the HetNet deployment, only one macrocell is under consideration. Therefore, the interference experienced by the central small cell due to the macrocell can be formulated from (7) by

$$I_{\text{macro}} = p_{\text{o-macro}} pl_{v,b}^{\alpha_{\text{macro}}} pl_{v,b}^{-1}. \tag{14}$$

The total interferences in the HetNet environment can then be given as

$$I_{\text{HetNet}} = I_{\text{macro}} + I_{\text{small}}. \tag{15}$$

C. Received SIR

The received SIR for user u in the HetNet environment can be obtained by dividing (6) by (15):

$$\text{SIR}_{\text{Rx},u} = \frac{p_{\text{Rx-small}}}{I_{\text{HetNet}}}. \tag{16}$$

The impacts of noise and shadowing are not considered in this analysis. If the impacts of shadowing and noise need to be included, the variation presented in [25] can be expected.

III. Numerical Results

In this section, analyses of the OL/TPC performance of the homogeneous small-cell and HetNet deployments are presented. For both scenarios, the network performance is quantified in terms of the UE transmit power, the received power at the eNodeB, and the received SIR. It would be beneficial for the UE to transmit with the lowest power, maintaining an acceptable level of the received SIR.

1. Homogenous Small-Cell Scenario

When $P_{\text{o-small}}$ is kept constant and the path-loss compensation factor α_{small} is varied from 0.7 to 1.0 in the homogenous small-cell deployment, the UE transmit power is analyzed as a function of the distance using (2). $P_{\text{o-small}}$ is set to –100 dBm since further decreases in $P_{\text{o-small}}$ may result in a received signal power below the dynamic range and thus an unacceptable received SIR at the eNodeB [26].

Figure 4 indicates that for α_{small} = 1.0, the transmit power becomes the maximum value, while as α_{small} decreases, it decreases. This shows that the FPC decreases the UE transmit power; thus, it decreases the interference to the other cells. In addition, the UE transmit power increases with the distance from the eNodeB. The impact

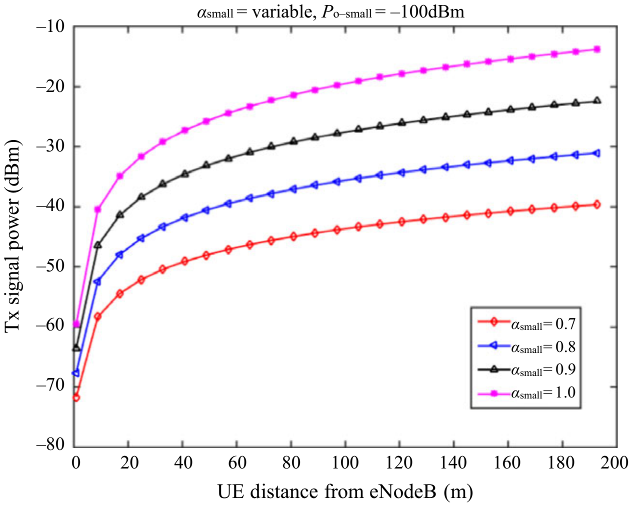

Fig. 4. UE transmit power versus the distance as a function of α_{small} in the homogenous small-cell deployment.

of variation in $P_{\text{o-small}}$ on the UE transmit power is analyzed when α_{small} = 1.0. Figure 5 shows that the transmit power increases at a higher value of $P_{\text{o-small}}$. Note that the transmit power becomes flat around a distance of 140 m when $P_{\text{o-small}}$ = –60 dBm since the UE transmit power is limited to 23 dBm. A comparison of Figs. 4 and 5 shows that the variation in α_{small} results in a variation in the UE transmit power of around 25 dBm; meanwhile, the variation in $P_{\text{o-small}}$ results in a variation of around 38 dBm. Furthermore, the UE transmit power ranges from –80 dBm to –10 dBm for the variation in α_{small}, and it ranges from –60 dBm to 30 dBm for the variation in $P_{\text{o-small}}$. Therefore, it is necessary to find the proper combination of OL/TPC parameters that may optimize the network performance.

Next, both α_{small} and $P_{\text{o-small}}$ are varied. Figure 6 shows that the parameter set of α_{small} = 1 and $P_{\text{o-small}}$ = –100 dBm results in the lowest UE transmit power. We can deduce that the optimum OL/TPC parameter set is a lower $P_{\text{o-small}}$ value and higher α_{small} value. By using (3), the received power at the eNodeB is plotted as a function of α_{small} and $P_{\text{o-small}}$ in Fig. 7. Note that for α_{small} = 1 and $P_{\text{o-small}}$ = –100 dBm, the received power at the eNodeB is the same regardless of the distance since the path loss is fully compensated. It is clear that the impact of the parameter set is more influential when the UE is close to eNodeB. In order to calculate the received SIR at the eNodeB, the interference generated in the network is calculated according to (10). Figure 8 shows the interference levels as a function of different values of $P_{\text{o-small}}$ and α_{small}. This shows that a lower value of $P_{\text{o-small}}$ results in less interference. Note that as α_{small} increases, the interference increases since the FPC no longer provides benefits.

In Fig. 9, the received SIR is calculated using (11) for the homogenous small-cell deployment. This shows that the parameters of α_{small} = 1 and $P_{\text{o-small}}$ = –100 dBm give a constant received SIR e around 4 dB. In addition, it shows that for the other values of α_{small} and $P_{\text{o-small}}$, the SIR becomes larger when the UE is near the eNodeB and becomes smaller when the UE is far from the eNodeB. Note that there is a crossing point at a distance of around 40 m. This means that when the distance is closer than 40 m, the signal power is more dominant than the

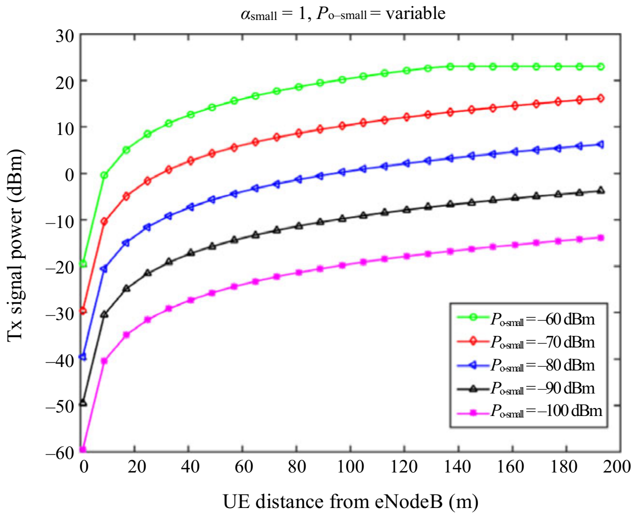

Fig. 5. UE transmit power versus the distance as a function of $P_{\text{o-small}}$ in the homogenous small-cell deployment.

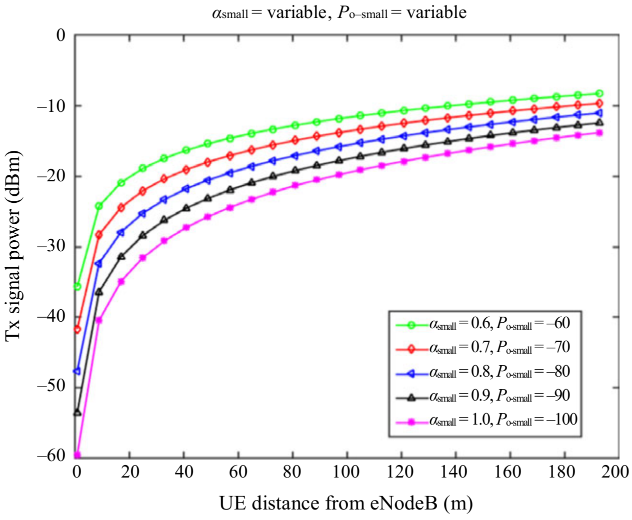

Fig. 6. UE transmit power versus the distance as a function of α_{small} and $P_{\text{o-small}}$ in the homogenous small-cell deployment.

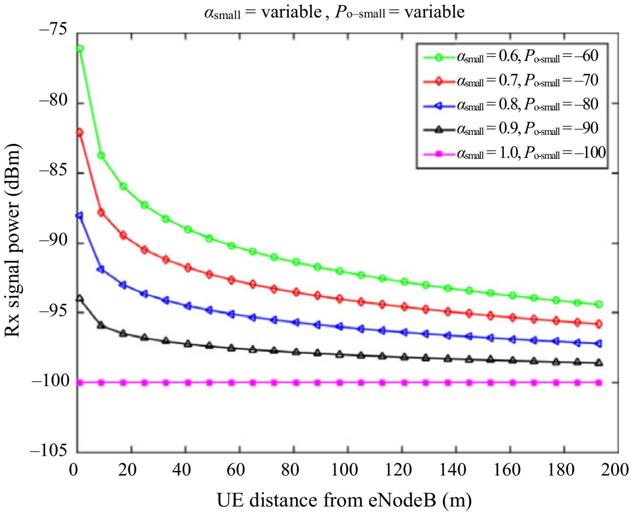

Fig. 7. eNodeB receive power versus the distance as a function of α_{small} and $P_{o\text{-}small}$ in the homogenous small-cell deployment.

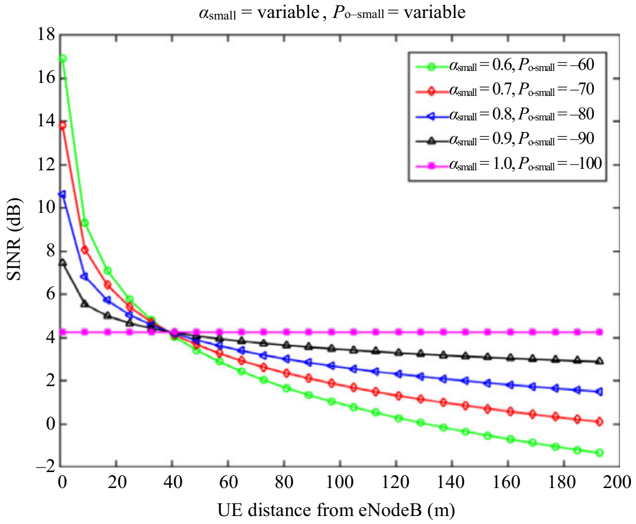

Fig. 9. SIR versus the distance as a function of α_{small} and $P_{o\text{-}small}$ in the homogenous small-cell deployment.

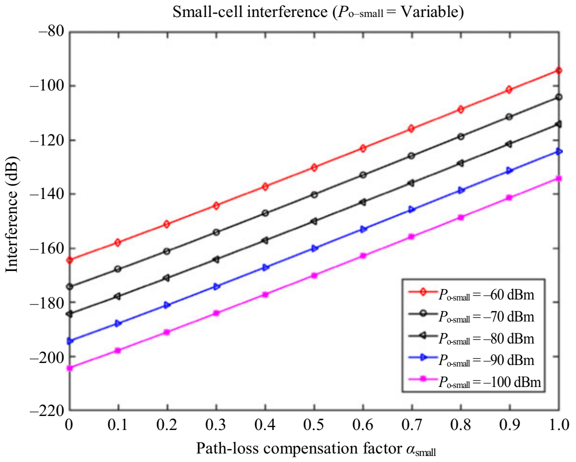

Fig. 8. Interference versus α_{small} as a function of $P_{o\text{-}small}$ in the homogenous small-cell deployment.

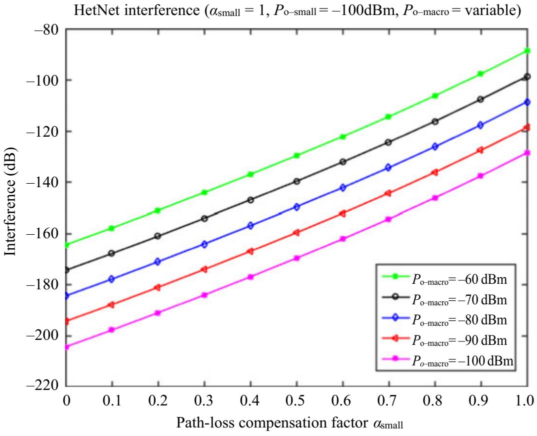

Fig. 10. Interference versus α_{macro} as a function of $P_{o\text{-}macro}$ in the HetNet.

interference power. Meanwhile, as the UE approaches the cell edge, the interference becomes the dominant factor. Such a tendency diminishes as α_{small} increases and $P_{o\text{-}small}$ decreases.

2. HetNet (Small Cell/Macrocell) Scenario

In the HetNet environment where small cells coexist with macrocells, it is expected that the small cells carry most of the traffic load, and the macrocells support the backbone network. Therefore, in this study, we focus on the optimization of the performance of the small cells. The interference is now calculated for the macrocell according to (14) since it has been analyzed for the small cell. Figure 10 presents the HetNet interference as a function of α_{macro} and $P_{o\text{-}macro}$ using (15) when $\alpha_{small} = 1$ and $P_{o\text{-}small} = –100$ dBm. This indicates that when α_{macro} is small, such as zero, almost the same interference results. However, when α_{macro} becomes larger, the interference increases. This confirms that the FPC is influential in macrocell environments. Figure 11 analyses the impacts of variations in α_{small} and $P_{o\text{-}small}$ on the received SIR in the HetNet when $\alpha_{macro} = 1$ and $P_{o\text{-}macro} = –100$ dBm. Comparing Figs. 9 and 11, the macrocell interference degrades the SIR performance since the SIR distribution from –2 dB to 17 dB is changed to the interval of –3 dB to 11 dB. Note that the SIR shows similar performance of

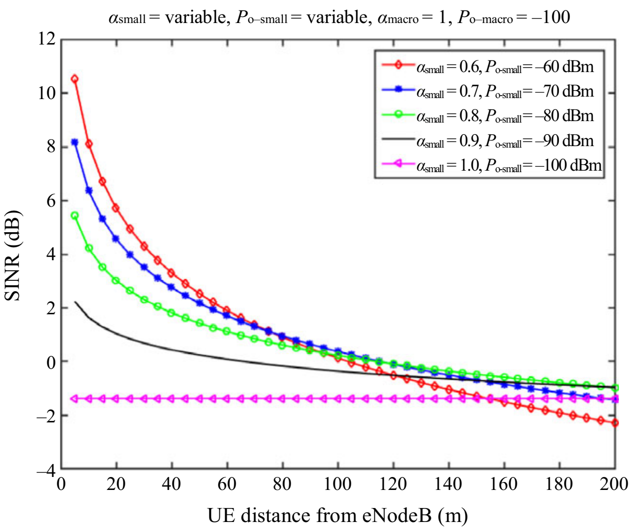

Fig. 11. SIR versus the distance as a function of α_{small} and $P_{o\text{-}small}$ in the HetNet for $\alpha_{macro} = 1.0$.

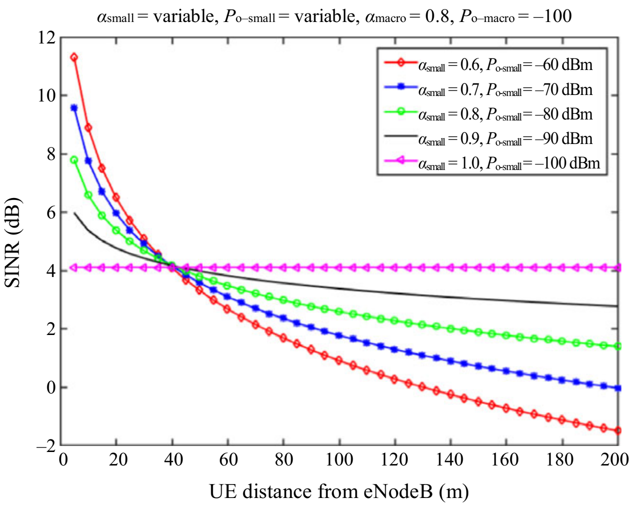

Fig. 12. SIR versus the distance as a function of α_{small} and $P_{o\text{-}small}$ in the HetNet for $\alpha_{macro} = 0.8$.

around –1 dB at the cell edge, even though it is improved when the UE is located very close to the eNodeB. This means that $\alpha_{macro} = 1$ results in high interference, and a lower α_{macro} value may be preferable. Using (16), the received SIR in the HetNet is presented in Fig. 12 when $\alpha_{macro} = 0.8$ and $P_{o\text{-}macro} = -100$ dBm. Note that the received SIR appears to be similar to that in Fig. 9. Comparing Figs. 11 and 12, the SIR for $\alpha_{small} = 1$ is significantly improved, and the crossing point moves close to the eNodeB. This indicates that from the optimum operating point of view of the OL/TPC, a lower α_{macro} and higher α_{small} combination would be generally preferred when both $P_{o\text{-}small}$ and $P_{o\text{-}macro}$ are –100 dBm. Additionally, it is shown that a lower α_{small} and higher $P_{o\text{-}small}$ provide an SIR improvement when the UE is close to the eNodeB, even though the service quality for cell edge users becomes lower.

IV. Conclusion

In this paper, OL/TPC in the LTE uplink for both homogenous small-cell and HetNet environments were analyzed in terms of the UE transmit power, eNodeB received power, interference, and received SIR. The numerical results showed that a different combination of OL/TPC parameters, such as a lower $P_{o\text{-}small}$ and higher α_{small}, was able to optimize the homogeneous small-cell network performance. More specifically, the combination of $\alpha_{small} = 1$ and $P_{o\text{-}small} = -100$ dBm was proposed as an appropriate choice for the homogenous small-cell network. Meanwhile, for the HetNet deployment, $\alpha_{macro} = 0.8$ and $P_{o\text{-}macro} = -100$ dBm in the macrocell were suitable when the small-cell parameters were the same since the FPC was influential in the macrocell environment. Additionally, it was shown that from a network operation point of view for the OL/TPC, a lower α_{macro} and higher α_{small} combination would generally be preferred when both $P_{o\text{-}small}$ and $P_{o\text{-}macro}$ were –100 dBm. Further study will determine an OL/TPC algorithm and investigate its system performance.

Acknowledgements

This work was supported by a grant from the Institute for Information & Communications Technology Promotion (IITP) of the Ministry of Science, ICT and Future Planning (MSIP), Rep. of Korea (R0101-15-224, Development of 5G Mobile Communication Technologies for Hyper-connected Smart Services).

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https://doi.org/10.4218/etrij.2017-0191