IEEK Transactions on Smart Processing and Computing

Client Collaboration for Power and Interference Reduction in Wireless Cellular Communication

Hyungju Nam, Minchae Jung, Kyuho Hwang, and Sooyong Choi

School of Electrical & Electronic Engineering, Yonsei University / Seoul 120-749, Korea
{namhyungju, hosaly, khhwang, csyong}@yonsei.ac.kr

* Corresponding Author: Sooyong Choi

Received August 16, 2012; Revised September 21, 2012; Accepted October 9, 2012; Published October 31, 2012

***Abstract*:** A client collaboration (CC) system is proposed for a user relay system. The proposed scheme focuses on the management of transmit power and leakage interference. In the proposed CC system, edge users transmit signals to the masters considered as user relays. The masters relay the signals of the edge users to the base station using the resource blocks (RBs) that are assigned to the edge users. The leakage interference and power consumption were analyzed in the CC system. In addition, an optimal master location problem was formulated based on the signal-to-leakage-plus-noise ratio (SLNR). Because the optimal master location problem is quite complex, a sub-optimal master location problem was proposed and a closed-form sub-optimal master location was obtained. The edge users generate smaller leakage interference and power consumption in the proposed CC system compared to the system without the CC. The numerical results showed that the edge users generate smaller leakage interference and power consumption in the proposed CC system compared to the system without the CC, and the average throughput increases.

***Keywords*:** Client collaboration, Edge user, User relay, Leakage interference, Master location

1. Introduction

LTE-Advanced (LTE-A) is a strong candidate for the next-generation high-speed and high-capacity mobile communication [1]. Relaying is one of the key features in LTE-A systems [2, 3] because relaying enhances the network capacity and efficiently distributes resources in the cell, or alternatively, extends the cell's coverage area [4, 5]. LTE-A considers only fixed-relays [6]. As the relay equipment is mostly fixed, the relay systems lack mobility. Compared to the base station (BS), even though the relay has a low infra-price, the relay covers limited areas with many installation and maintenance costs. In addition, the relay is not cost efficient when it is used for a small number of users. Although fixed relays support several cases defined in the LTE-A, the user relays cannot be considered sufficiently as part of the standards [7].

This paper proposes a client collaboration (CC) system to overcome the limitations of the conventional fixed relay systems. An edge user transmits the signals to a master instead of transmitting them to the BS. The master relays the signal for the edge user to the BS using the resource blocks (RB), which are assigned to the edge user in the CC system. The proposed CC system is compared with the conventional cellular system based on the leakage interference and power consumption. In addition, an optimal master location problem that maximizes signal-to-leakage-plus-noise (SLNR) was formulated [8, 9]. As the optimal master location problem is quite complex, this study proposes a sub-optimal master location problem and shows that the sub-optimal master location problem is convex. Therefore, the closed-form sub-optimal master location can be obtained using a convex optimization technique. The numerical results show that the sub-optimal master location is similar to the optimal master location. The strong leakage interference and large transmit power consumption from the edge users can be reduced using the proposed CC system. Compared to fixed relay systems, the average throughput also increases.

This paper is organized as follows. Section 2 presents the system model of the conventional cellular networks. The leakage interference and power consumption are also analyzed. Section 3 introduces the proposed CC strategy for edge users and compares the proposed CC system with the conventional cellular systems. In addition, a sub-

This work was supported in part by the Seoul R&BD Program (WR080951)

optimal master location for minimal leakage interference is proposed. The numerical results are presented in Section 4. Section 5 reports the conclusions.

2. Conventional Cellular System

Fig. 1 shows the 1-tier cellular system considered. The number of other cells is K, i.e., $K = 6$ and M users are distributed uniformly in each cell. The assumption was that the channel state information (CSI) is known precisely at the BS. On the other hand, the users know only the received CSI for more practical consideration. The BS communicates with M users using the orthogonal frequency division multiple access (OFDMA) system. The BS and each user are equipped with a single antenna.

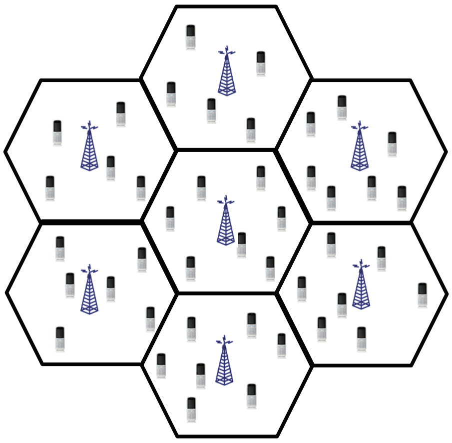

Fig. 1. 1-tier cellular system.

The uplink signal of the m^{th} user can be expressed as

$$y_m = \sqrt{c\left(d_{m,\text{BS}}\right)^{-\alpha} P_m} h_{m,\text{BS}} + \sum_{i=1}^{K} \sqrt{c\left(d_{m_{\text{other}\_i},\text{BS}}\right)^{-\alpha} P_{m_{\text{other}\_i}}} h_{m_{\text{other}\_i},\text{BS}} + n \tag{1}$$

where c and α are path-loss constant and path-loss exponent, respectively, $d_{m,\text{BS}}$ is the distance of between the m^{th} user and the BS in the serving cell, and $d_{m_{\text{other}\_i},\text{BS}}$ is the distance between the m^{th} user in the i^{th} other cell and the BS in the serving cell. P_m and $P_{m_{\text{other},i}}$ are the uplink transmit signal power of the m^{th} user in the serving cell and the other cell, respectively. In addition, h_{xy} is a channel coefficient of the $x-y$ link. All channel coefficients follow a zero-mean independent complex Gaussian distribution with variance of 1. n is the additive white Gaussian noise (AWGN) with a one-sided power spectral density (PSD) of σ_n^2. In (1), the free space path-loss model [10], $P_a = c\left(d_a\right)^{-\alpha} P_0$, is used, where P_0 and P_a refer to the initial transmit power and signal power measured at d_a away from the transmitter, respectively. In (1), the first term represents the desired signal, and the second term represents the interference signal from the other cells. Because this study considered an OFDMA system, the interference from the intra-cell can be ignored by the scheduling.

The average received powers at the BS were assumed to be controlled to the same power level, $\overline{P}_t$ [11]. As the mean power of each channel for the user-BS link is 1, the received power at the BS from the m^{th} user can be expressed as

$$\overline{P}_t = W_{\text{RB},m} N_p \times k, \tag{2}$$

where $W_{\text{RB},m}$ is the number of acquired resource blocks for the m^{th} user, N_p is the noise PSD and k is the constant for the target signal-to-noise-ratio (SNR). Therefore, the transmit power for the m^{th} user is represented as

$$P_m = \frac{1}{c}\left(d_{m,\text{BS}}\right)^{\alpha} \overline{P}_t. \tag{3}$$

2.1 Leakage interference and Power consumption

When only the path-loss effect is considered in the 1-tier cellular system, the leakage interference signal from the m^{th} user to the i^{th} other BS can be expressed as

$$I_m = c\left(d_{m,\text{BS}_{\text{other},i}}\right)^{-\alpha} h_{m,\text{BS}_{\text{other},i}} P_m, \tag{4}$$

where $d_{m,\text{BS}_{\text{other},i}}$ and $h_{m,\text{BS}_{\text{other},i}}$ are the distance and channel coefficient from the m^{th} user in the serving cell to the i^{th} other BS, respectively. Therefore, the leakage interference from every user in the serving cell can be expressed as

$$I_{all} = \sum_{i=1}^{K}\left(\sum_{m=1}^{M} \sqrt{c\left(d_{m,\text{BS}_{\text{other},i}}\right)^{-\alpha} P_m} h_{m,\text{BS}_{\text{other},i}}\right) + n. \tag{5}$$

The effect of the channel coefficient can be ignored because it was assumed that $h_{m,\text{BS}_{\text{other},i}}$ has an average power of 1. In addition, the effect of the noise can be ignored as an interference dominant model was considered. Therefore, from (2), (5) can be rewritten simply as

$$I_{\text{all}} = \sum_{i=1}^{K}\sum_{m=1}^{M}\left(\frac{d_{m,\text{BS}}}{d_{m,\text{BS}_{\text{other},i}}}\right)^{\alpha} \overline{P}_t. \tag{6}$$

The sum of the transmit power can be represented as

$$P_{\text{all}} = \sum_{m=1}^{M} P_m. \tag{7}$$

By substituting (3) into (7), the sum of transmit powers can be rewritten as

$$P_{\text{all}} = \sum_{m=1}^{M} \frac{1}{c}\left(d_{m,\text{BS}}\right)^{\alpha} \overline{P}_t. \tag{8}$$

When the path-loss and shadowing effects in the 1-tier cellular system are considered, the leakage interference from the m^{th} user in the serving cell to the i^{th} other BS can be expressed as

$$I_m = c\left(d_{m,\mathrm{BS}_{\mathrm{other},i}}\right)^{-\alpha} L_m P_m, \tag{9}$$

where L_m is the shadowing effect with a zero-mean independent lognormal random variable with a variance of σ^2 [12, 13]. Similar to (5), the leakage interference from all users in the serving cell to the other BSs can be expressed as

$$I_{\mathrm{all}} = \sum_{i=1}^{K}\left(\sum_{m=1}^{M}\sqrt{c\left(d_{m,\mathrm{BS}_{\mathrm{other},i}}\right)^{-\alpha} L_{i,m}P_m}\right). \tag{10}$$

By summing the log-normal random variables, the received interference at the single other BS can be expressed as follows [13]:

$$e^{Z_I} = \sum_{m=1}^{M} I_m. \tag{11}$$

where e^{Z_I} is the weighted sum of a group of lognormal random variables. Three approaches to the approximation can be used [12], Wilkinson's approach, Schwartz-Yeh approach, and cumulant matching approach. Wilkinson's method was used in this study in light of the conclusion of the comparative study in [12] and [13]. In Wilkinson's method, e^{Z_I} is assumed to be another lognormal random variable. In other words, Z_I is Gaussian with a mean of m_{Z_I} and variance of $\sigma_{Z_I}^2$, which are obtained by equating the first two moments of (11) as follows:

$$\mu_{1I} = E\left(e^{Z_I}\right) = E\left(\sum_{m=1}^{M} e^{Z_m}\right) = e^{\sigma^2/2}\sum_{m=1}^{M} P_m d_m^{-\alpha} \tag{12}$$

$$\begin{aligned}\mu_{2I} &= E\left[e^{2Z_I}\right] \\ &= e\left(\sum_{m=1}^{M} e^{2Z_m}\right) \\ &= e^{2\sigma^2}\sum_{m=1}^{M}\left(P_m d_m^{-\alpha}\right)^2 + 2e^{\sigma^2}\sum_{i=1}^{M}\sum_{s=m+1}^{M}\left(\left(P_m d_m^{-\alpha}\right)\left(P_s d_s^{-\alpha}\right)\right),\end{aligned} \tag{13}$$

where $d_m^{-\alpha}$ and $d_s^{-\alpha}$ are the path-loss effects. After obtaining μ_{1I} and μ_{2I}, m_{Z_I} and $\sigma_{Z_I}^2$ can be derived as

$$m_{z_I} = 2\ln\mu_{1I} - \frac{1}{2}\ln\mu_{2I}, \tag{14}$$

$$\sigma_{Z_I}^2 = \ln\mu_{2I} - 2\ln\mu_{1I}. \tag{15}$$

In the 1-tier cellular system, the entire leakage interference can be expressed as

$$I_{\mathrm{all}} = \sum_{i=1}^{K} e_i^{Z_I} = \sum_{i=1}^{K}\sum_{m=1}^{M} I_m^i. \tag{16}$$

The sum of the transmit powers is the same as the path-loss model, (7) and (8). The users only rely on the path-loss effect because the users cannot know the shadowing effect.

3. Proposed Client Collaboration System

In OFDMA cellular systems, to obtain the target received SNR at BS, the edge users consume considerable transmit powers. Therefore, the edge users generate large leakage interference to the other cells and reduce the average throughput.

To overcome this problem, this paper proposes a client collaboration scheme in wireless cellular networks. The intra-cell interference can be ignored because an OFDMA system is used. Therefore, this paper focuses only on the leakage-interference to the other-cells and the power consumption in the serving cell.

Fig. 2 presents the proposed client collaboration system. The masters are defined as the user relays. The edge users transmit the signals to the masters instead of transmitting them to the BS. The master relays the signals for the edge users to the BS using the resource blocks (RBs) that are assigned to the edge users. At least one edge user who selects the same master builds up a cluster. The edge users are defined as the slaves in the cluster. In the proposed CC system, the edge users produce smaller interference and consume smaller transmit power because the edge users transmit the signals to the masters in the proposed CC system.

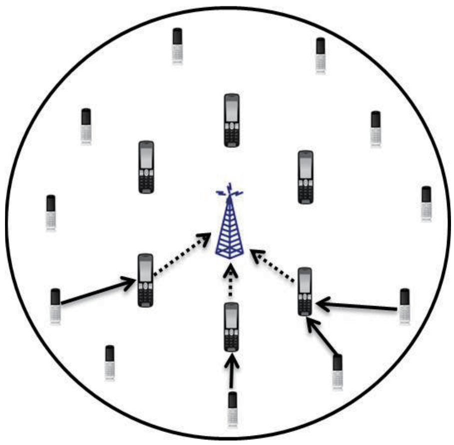

Fig. 2. Proposed client collaboration system.

3.1 Leakage interference and Power consumption

This section analyzes the leakage interference and power consumption in the proposed CC system compared to the conventional cellular system.

3.1.1 Path-loss Model

Similar to the target power level [11], $\bar{P}_t$, it was assumed that the average received powers at the masters are controlled to the same power level, $\bar{P}_s$. $\bar{P}_s$ can be expressed as

$$\bar{P}_s = W_{\mathrm{RB},s} N_p \times k, \tag{17}$$

where $W_{\mathrm{RB},s}$ is the number of acquired resource blocks for the s th slave. Therefore, the transmit power of the s th slave can be represented as

$$P_s = \frac{1}{c}\left(d_{s,\mathrm{Master}_s}\right)^{\alpha} \bar{P}_s, \tag{18}$$

where d_{s,Master_s} is the distance from the s th slave to the master serving the s th slave.

When the path-loss effect was considered, the leakage interference from the s th slave to the i th other BS can be expressed as

$$\begin{aligned} I_s &= c\left(d_{s,\mathrm{BS}_{\mathrm{other},i}}\right)^{-\alpha} P_s \\ &= \left(\frac{d_{s,\mathrm{Master}_s}}{d_{s,\mathrm{BS}_{\mathrm{other},i}}}\right) \bar{P}_s, \end{aligned} \tag{19}$$

where $d_{s,\mathrm{BS}_{\mathrm{other},i}}$ is the distance from the s th slave to the i th other BSs. If the number of slave users is S, the leakage interference from all users in the serving cell to the other BSs can be expressed as

$$I_{\mathrm{all,CC}} = \sum_{i=1}^{K}\sum_{m=1}^{M-S}\left(\left(\frac{d_{m,\mathrm{BS}}}{d_{m,\mathrm{BS}_{\mathrm{other},i}}}\right)^{\alpha}\bar{P}_t\right) + \sum_{i=1}^{K}\sum_{s=1}^{S}\left(\left(\frac{d_{s,\mathrm{Master}_s}}{d_{s,\mathrm{BS}_{\mathrm{other},i}}}\right)^{\alpha}\bar{P}_s\right), \tag{20}$$

where the first term is the interference from the cellular users without clustering and the masters, and the second term is the interference from the slaves with clustering. The interference difference between the conventional cellular system and the system with the CC can be obtained using the following equation:

$$\begin{aligned} I_{\mathrm{diff}} &= I_{\mathrm{all}} - I_{\mathrm{all,CC}}, \\ &= \sum_{i=1}^{K}\sum_{s=1}^{S}\left(\left(\frac{d_{s,\mathrm{BS}}}{d_{s,\mathrm{BS}_{\mathrm{other},i}}}\right)^{\alpha}\bar{P}_t - \left(\frac{d_{s,\mathrm{Master}_s}}{d_{s,\mathrm{BS}_{\mathrm{other},i}}}\right)^{\alpha}\bar{P}_s\right), \end{aligned} \tag{21}$$

where $d_{s,\mathrm{BS}}$ is the distance from the s th slave to the serving BS. The users without clustering do not change the interference due to the use of the same transmit power compared to the conventional cellular systems. Therefore, the slaves in the cluster lead to a decrease in interference. Because the slaves generate large interference in the conventional cellular system, the quantity of interference reduction is quite large in the CC system.

In the proposed CC system, the sum power can be expressed as follows:

$$\begin{aligned} P_{\mathrm{all,CC}} &= \sum_{m=1}^{M-S} P_m + \sum_{s=1}^{S} P_s \\ &= \sum_{m=1}^{M-S}\frac{1}{c}\left(d_{s,\mathrm{BS}}\right)^{\alpha}\bar{P}_t + \sum_{s=1}^{S}\frac{1}{c}\left(d_{s,\mathrm{Master}_s}\right)^{\alpha}\bar{P}_s. \end{aligned} \tag{22}$$

Similar to (21), the first term is the sum of the powers for the cellular users without clustering and the masters, and the second term is the sum of powers for the slaves with clustering. The difference in sum of powers between the conventional cellular system and the system with the CC can be obtained using the following equation:

$$\begin{aligned} P_{\mathrm{diff}} &= P_{\mathrm{all}} - P_{\mathrm{all,CC}} \\ &= \sum_{m=1}^{M} P_m - \left(\sum_{m=1}^{M-S} P_m + \sum_{s=1}^{S} P_s\right) \\ &= \sum_{s=1}^{S}\left(\frac{1}{c}\left(d_{s,\mathrm{BS}}\right)^{\alpha}\bar{P}_t - \frac{1}{c}\left(d_{s,\mathrm{Master}_s}\right)^{\alpha}\bar{P}_s\right). \end{aligned} \tag{23}$$

3.1.2 Path-loss and Shadowing Model

Compared to (18), the transmit power of the s th slave can be expressed as

$$c\left(d_{s,\mathrm{Master}_s}\right)^{-\alpha} L_s P_s = \bar{P}_s, \tag{24}$$

$$P_s = \frac{1}{c}\left(d_{s,\mathrm{Master}_s}\right)^{\alpha} L_s^{-1}\bar{P}_s, \tag{25}$$

where L_s is the shadowing effect with a zero-mean independent lognormal random variable with a variance of σ^2 [12, 13].

The leakage interference from the s th slave to the i th other BS can be expressed as

$$I_s = c\left(d_{s,\mathrm{BS}_{\mathrm{other},i}}\right)^{-\alpha} L_{i,s} P_s. \tag{26}$$

The interference from all users in the serving cell to the other BSs can be expressed as

$$\begin{aligned} I_{all} &= \sum_{i=1}^{K}\left(\sum_{m=1}^{M-S} I_{i,m} + \sum_{s=1}^{S} I_{i,s}\right) \\ &= \sum_{i=1}^{K}\sum_{m=1}^{M-S}\left(\frac{d_{m,\mathrm{BS}}}{d_{m,\mathrm{BS}_{\mathrm{other},i}}}\right)^{\alpha}\bar{P}_t + \sum_{i=1}^{K}\sum_{s=1}^{S}\left(\frac{d_{s,\mathrm{Master}_s}}{d_{m,\mathrm{BS}_{\mathrm{other},i}}}\right)^{\alpha}\bar{P}_s \\ &= e^{Z_{I,\mathrm{nonCC}}} + e^{Z_S}, \end{aligned} \tag{27}$$

where $e^{Z_{I,\mathrm{nonCC}}}$ and e^{Z_s} are the sums of the lognormal random variables using Wilkinson's approach. By examining the path-loss model, the interference difference relies only on the slaves.

Because the user cannot know the shadow effect, the transmit power only relies on the path-loss effect. Therefore, the sum of the powers is the same as that for the path-loss model.

3.2 Sub-optimal master location

This section proposes a sub-optimal master location that can be obtained by maximizing the SLNR, which is defined as

$$SLNR = \frac{\text{received signal}}{\text{leakage interference} + \text{noise}}. \tag{28}$$

The effect of noise was assumed to be very low compared to the interference. Therefore, this study considered the interference limited system.

With the path-loss model, the optimization problem can be formulated as follows:

$$\begin{aligned} \max \quad & \frac{\bar{P}_t}{\sum_{i=1}^{K}\left(P_s\left(d_{s,\mathrm{BS}_{\mathrm{other},i}}\right)^{-\alpha}+P_m\left(d_{m,\mathrm{BS}_{\mathrm{other},i}}\right)^{-\alpha}\right)} \\ \text{s.t.} \quad & 0 \le P_s, P_m \le P_{\max}. \end{aligned} \tag{29}$$

The received signal is constant because of the target power level. Therefore, the interference must be minimized to maximize the SLNR. Therefore, the following optimization problem given is

$$\begin{aligned} \min \quad & \sum_{i=1}^{K}\left(P_s\left(d_{s,\mathrm{BS}_{\mathrm{other},i}}\right)^{-\alpha}+P_m\left(d_{m,\mathrm{BS}_{\mathrm{other},i}}\right)^{-\alpha}\right) \\ \text{s.t.} \quad & 0 \le P_s, P_m \le P_{\max}, \end{aligned} \tag{30}$$

where $P_{\max}$ is the maximum transmit power constraint. Using the rectangular coordinate system, (30) can be transformed to

$$\begin{aligned} \min_{m_1,m_2} \sum_{i=1}^{K} & \begin{pmatrix} P_s\left(\sqrt{\left(s_1-\mathrm{BS}_{x_1}^i\right)^2+\left(s_2-\mathrm{BS}_{x_2}^i\right)^2}\right)^{-\alpha} \\ +P_m\left(\sqrt{\left(m_1-\mathrm{BS}_{x_2}^i\right)^2+\left(m_2-\mathrm{BS}_{x_2}^i\right)^2}\right)^{-\alpha} \end{pmatrix} \\ \text{s.t.} \quad & -r \le s_1, s_2, m_1, m_2 \le r, \\ & 0 \le P_s, P_m \le P_{\max}, \end{aligned} \tag{31}$$

where r is the cell radius. In addition, $\mathrm{BS}_{x_1}^i$, $\mathrm{BS}_{x_2}^i$, s_1, s_2, m_1 and m_2 are the two-dimensional coordinates number of the i th other BS, slave and master location, respectively. (31) can be solved through an exhaustive search. On the other hand, the computational complexity is quite high. As the leakage interference is dominated by P_s and P_m, (31) can be simplified for a sub-optimal master location as follows:

$$\begin{aligned} \min \quad & P_m + P_s \\ \text{s.t.} \quad & 0 \le P_m, P_s \le P_t, \end{aligned} \tag{32}$$

The following can be obtained by substituting (3) and (18) into (32):

$$\begin{aligned} \min_{m_1,m_2} \quad & \bar{P}_t\left(\sqrt{\left(m_1^2+m_2^2\right)}\right)^{\alpha}+\bar{P}_s\left(\sqrt{\left(m_1-s_1\right)^2+\left(m_2-s_2\right)^2}\right)^{\alpha} \\ \text{s.t.} \quad & -r \le s_1, s_2, m_1, m_2 \le r. \end{aligned} \tag{33}$$

For simple analysis, it was assumed that the path-loss exponent is 2 and the BS is located at the origin. In addition, the objective function in (33) can be represented as

$$\begin{aligned} & \bar{P}_t\left(\sqrt{\left(m_1^2+m_2^2\right)}\right)^{\alpha}+\bar{P}_s\left(\sqrt{\left(m_1-s_1\right)^2+\left(m_2-s_2\right)^2}\right)^{\alpha} \\ & =\left(\bar{P}_t\left(m_1^2+m_2^2\right)\right)+\bar{P}_s\left(\left(m_1-s_1\right)^2+\left(m_2-s_2\right)^2\right) \\ & =\begin{pmatrix} \left(\bar{P}_t+\bar{P}_s\right)m_1^2+\left(\bar{P}_t+\bar{P}_s\right)m_2^2-2\bar{P}_s m_1 s_1 \\ -2\bar{P}_s m_2 s_2+\bar{P}_s s_1^2+\bar{P}_s s_2^2 \end{pmatrix}. \end{aligned} \tag{34}$$

The first differential and hessian matrix of the objective function can be, respectively, expressed as

$$D=\left[2\left(\bar{P}_t+\bar{P}_s\right)m_1-2\bar{P}_s s_1 \quad , \quad 2\left(\bar{P}_t+\bar{P}_s\right)m_2-2\bar{P}_s s_2\right] \tag{35}$$

$$H=\begin{bmatrix} 2\left(\bar{P}_t+\bar{P}_s\right) & 0 \\ 0 & 2\left(\bar{P}_t+\bar{P}_s\right) \end{bmatrix}. \tag{36}$$

Because P_t and P_s are positive semi-definite, the hessian matrix is positive semi-definite. In addition, the constraints are convex. Therefore, (33) is a convex optimization problem.

Using the first-order necessary condition (FONC) [14], the global optimal solution can be found using the following:

$$m_1=\frac{\bar{P}_s s_1}{\bar{P}_t+\bar{P}_s},\ m_2=\frac{\bar{P}_s s_2}{\bar{P}_t+\bar{P}_s} \tag{37}$$

4. Numerical Results

This section evaluates the performance of the proposed CC scheme in Section 3 and compares the proposed CC scheme with the conventional cellular system. The 1-tier cellular systems shown in Fig. 1 was used to compare the proposed CC system with the conventional cellular system in terms of the leakage interference, power consumption and average throughput performance. The simulation parameters are summarized in Table 1 based on LTE-A [15]. Round-robin scheduling was used for resource allocation. The number of active users was assumed to be 30 per cell. In the proposed CC system, the signal of the slave goes through 2 links, i.e., slave-master link and master-BS link. Therefore, the throughput of the slave is determined by the smaller of the two links.

Table 1. Simulation Parameters.

Parameters	Values
Cell structure	Hexagonal, 1-tier, 750m radius
Number of user per cell	500
Number of active user per cell	30
Number of RB in 1-time slot	50
Number of frame	100
Path loss exponent	4
Path loss constant	1
Noise PSD	-174dBm/Hz
Shadowing STD	8dB
Target power level at BS	$\overline{P}_t = 3\text{dB}$
Target power level at master	$\overline{P}_s = 10\text{dB}$
User max Tx power	23dBm

Fig. 3 shows the optimal master location through an exhaustive search and the sub-optimal master location by the proposed method. The sub-optimal master location is similar to the optimal master location. The master is not always available at precisely the desired sub-optimal location. In this situation, the slave needs to select the master closest to the desired sub-optimal location.

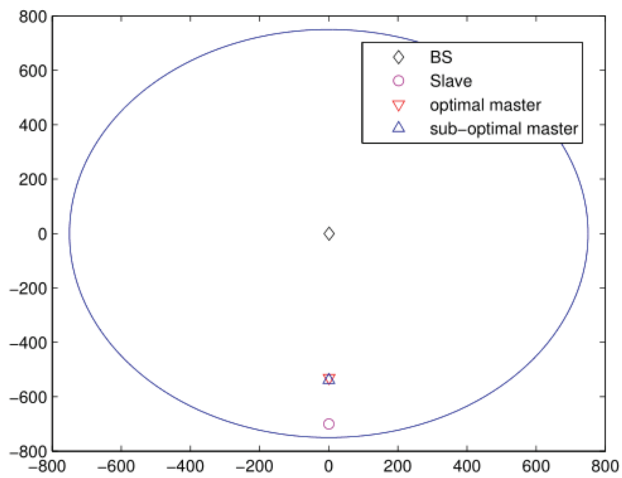

Fig. 3. Comparison of proposed sub-optimal master location with an optimal master location.

Figs. 4 and 5 show the leakage interference from all users in the path-loss model, and the path-loss and shadowing model respectively. The edge ratio means the number of slave users. We assume that the standard deviation for the shadowing effect was assumed to be 8dB. The result of the path-loss and shadowing model was similar to that of the path-loss model. The proposed CC systems reduced the leakage interference. In Fig. 5, the theoretical result corresponds to the numerical results. The sum power showed the same result. In (21) and (23), the interference and power consumption differences increased when the number of slaves increases. The simulation results showed that the interference and power reduction increase further as the number of slave users increases.

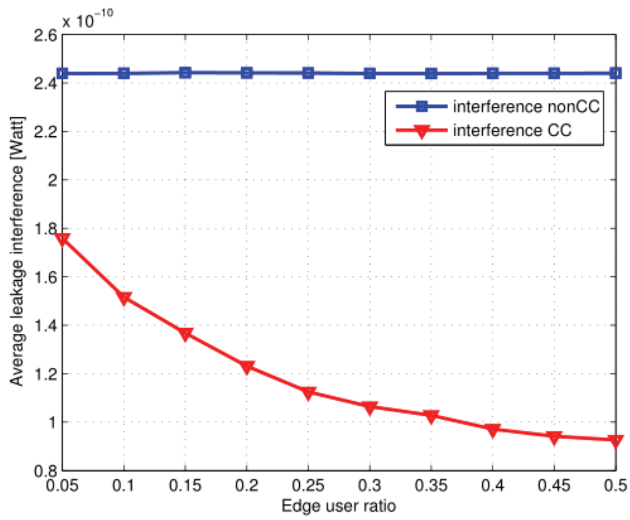

Fig. 4. Leakage interference in the path-loss model.

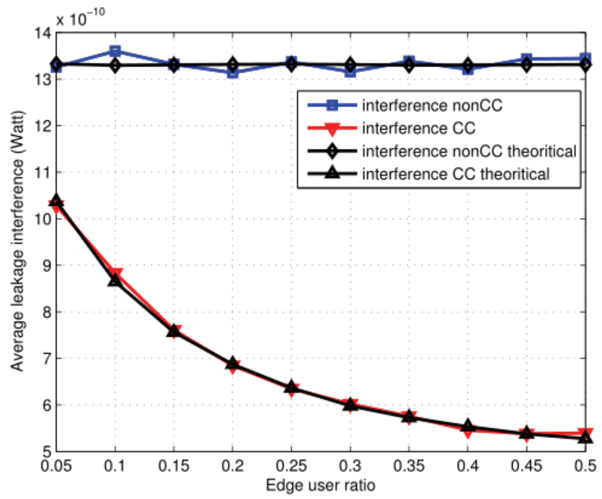

Fig. 5. Leakage interference in the path-loss and shadowing model.

Fig. 6 and Table 2 show the CDFs of the throughput, average throughputs, leakage interference and power consumption of the conventional cellular, fixed relay and CC system. In the fixed relay system, it was assumed that 6 fixed relays are placed evenly in each cell in a hexagonal layout. The number of slaves was 3 with 30 active users in each cell. During 1 sub-frame, the slave transmits the signal to the master at the first time-slot. The master relays the signal to the BS at the second-time slot using the RBs assigned to the slaves. The CC system can reduce the interference. Therefore, the throughput of the inner user is improved. On the other hand, the throughput of the slave is lower than that of the cellular system due to the loss of the time resource. The average throughput improves because the throughput of the inner user improves more than the throughput of the slave loss. Compared to the fixed relay system, the proposed CC system has the throughput gains for all users.

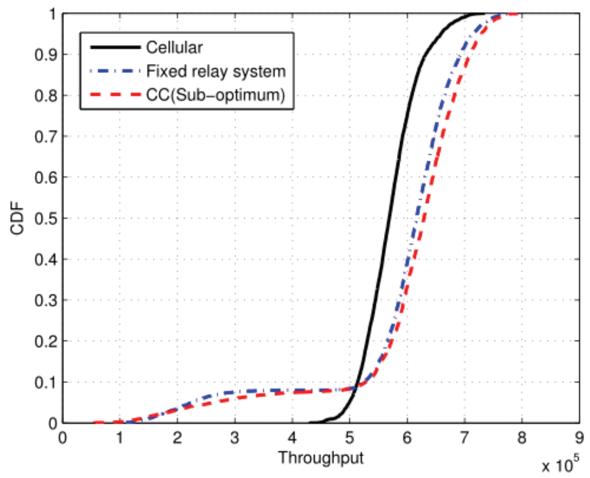

Fig. 6. Throughput CDFs of the conventional cellular, fixed relay and the CC system.

Table 2. Average throughput, Leakage interference and power consumption of the three systems.

System	Average throughput	Leakage interference	Power consumption
Cellular	5.75×10^{5} bps	1.97×10^{-14} Watt	4.19×10^{-3} Watt
Fixed relay	6.02×10^{5} bps	1.66×10^{-14} Watt	3.68×10^{-3} Watt
CC	6.33×10^{5} bps	1.38×10^{-14} Watt	3.20×10^{-3} Watt

5. Conclusion

This paper proposed the CC scheme for edge users in cellular systems and analyzed the sub-optimal master(user relay) location. In addition, the interference reduction and power consumption were analyzed mathematically based on the path-loss model and path-loss with shadowing. Through the CC system, the leakage interference and power consumption were reduced compared to the conventional cellular systems. The numerical result showed that the sub-optimal master location is similar to the optimal master location. Through SLS, the throughput improvement for the inner user was better than the throughput loss for the edge user.

References

[1] A. Ghosh, R. Ratasil, B. Mondal, N. Mangalvedhe, and T. Thomas, "LTE-advanced: Next-generation wireless broadband technology," *IEEE Trans. Wireless Commun*, vol. 17, no. 3, pp. 10-12, Jun. 2010. Article (CrossRef Link)

[2] O. Oyman, J. N. Laneman, and S. Sandhu, "Multihop relaying for broadband wireless mesh networks: from theory to practice," *IEEE Commun. Mag*, vol. 45, no. 11, pp. 116-122, Nov. 2007. Article (CrossRef Link)

[3] Y. Yangn, H. Hu, J. Xu and G. Mao, "Relay technologies for WiMAX and LTE-advanced mobile systems," *IEEE Commun. Mag*, vol. 47, no. 10, pp. 100-105, Oct. 2009. Article (CrossRef Link)

[4] A. Bou Saleh, S. Redana, J. Hamalainen and B. Raaf, "On the Coverage Extension and Capacity Enhancement of Inband Relay Deployments in LTE-Advanced Networks," *Journal of Electrical and Computer Engineering*, vol. 2010, Article ID 894846, 12 pages, 2010. Article (CrossRef Link)

[5] R. Schoenen, W. Zirwas, and B. H. Walke, "Capacity and Coverage Analysis of a 3GPP-LTE Multihop Deployment Scenario," *Communications Workshops, 2008. ICC Workshops '08. IEEE International Conference on*, pp. 31-36, May. 2008. Article (CrossRef Link)

[6] T. Riihonen, R. Wichman, and S. Werner, "Evaluation of OFDM(A) relaying protocols: capacity analysis in infrastructure framework," *IEEE Trans. Veh. Technol.*, vol. 61, no. 1, pp. 360-374, Jan. 2012. Article (CrossRef Link)

[7] R. Balakrishnan, X. Yang, M. Venkatachalam and I. F. Akyildiz, "Mobile relay and group mobility for 4G WiMAX networks," *Wireless Communications and Networking Conference (WCNC), 2011 IEEE*, pp. 1224-1229, Mar. 2011. Article (CrossRef Link)

[8] M. Sadek, A. Tarighat, and A. Sayed, "A leakage-based precoding scheme for downlink multi-user mimo channels," *Wireless Communications, IEEE Transactions*, vol. 6, no. 5, pp. 1711-1721, May. 2007. Article (CrossRef Link)

[9] M. Sadek, S. Aissa, "Leakage based precoding for multi-user MIMO-OFDM systems," *Wireless Communications, IEEE Transactions*, vol. 10, no. 8, pp. 2428-2433, AUG. 2009. Article (CrossRef Link)

[10] Rappaport, *Wireless Communications: Principles and Practice*, Prentice Hall, 2001. Article (CrossRef Link)

[11] J. W. Makr and W. Zhuang, *Wireless Communications and Networking*, Prentice Hall, 2003. Article (CrossRef Link)

[12] A. A. Abu-Dayya and N.C. Beaulieu, "Outage probabilities in the presence of correlated lognormal interferers," *IEEE Trans. Veh. Technol.*, vol. 43, pp. 164-173, Feb. 1994. Article (CrossRef Link)

[13] Ziqiang Xu, A.N. Akansu and S. Tekinay, "Cochannel Interference Computation and Asymptotic Performance Analysis in TDMA/FDMA Systems with Interference Adaptive Dynamic Channel Allocation," *IEEE Trans. Veh. Technol.*, vol. 49, no. 3, May. 2000. Article (CrossRef Link)

[14] E. K. P. Chong and S. H. Zak, *An introduction to optimization 3rd edition*, Wiley, 2008. Article (CrossRef Link)

[15] 3GPP TR 36.814 v0.3.1, Further Advancements for E-UTRA, Physical Layer Aspects. Article (CrossRef Link)

Hyungju Nam received the B.S. and M.S. degrees from the School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea, in 2009 and 2011, respectively. He is currently working toward the Ph.D. degree at the same university. His primary research area is on interference cancellation techniques for wireless communications and hot topics in wireless communication systems such as filter bank multicarrier communications.

Minchae Jung received the B.S. degree from the School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea, in 2008. He is currently working toward the Ph.D. degree at the same university. His primary research area is on interference cancellation techniques for wireless communications and hot topics in wireless communication systems such as cognitive radio networks.

Kyuho Hwang received the B.S. and M.S. degrees from the School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea, in 2006 and 2008, respectively. He is currently working toward the Ph.D. degree at the same university. His primary research area is on cogntive radios, stochastic geometry, personal/body area network and machine learning algorithms.

Sooyong Choi (S'98–M'04) was born in Seoul, Korea, in 1971. He received the B.S.E.E, M.S.E.E. and Ph.D. degrees from Yonsei University, Seoul, Korea, in 1995, 1997, and 2001, respectively. During 2001, he worked as a Post-Doc. Researcher at the IT Research Group, Yonsei University. His work focused on proposing and planning for the 5th generation communication system. From February 2002 to August 2004, he had been a Postdoctoral Fellow at University of California, San Diego. From September 2004 to July 2005, he had been a Researcher and Research Assistant Professor at Oklahoma State University, Stillwater. Since September 2005, he has been an Associate Professor in the School of Electrical and Electronic Engineering, Yonsei University. His primary research area is on adaptive signal processing techniques for digital communication and storage systems, interference cancellation techniques (equalization and detection) and MIMO detection techniques for wireless communication and modem techniques for future wireless communication systems.