

Distributed Uplink Power Control Algorithm for QoS enhancement

Jongrok Park, Hojae Lee, Seonghyun Kim and Sanghoon Lee
Dep. of Electrical and Electronics Engineering
Yonsei University, Korea
Email: {bulo22, hojae84, sh-kim, slee}@yonsei.ac.kr

Abstract—Distributed uplink power allocation technique as a strategy for maintaining the quality of service (QoS) is described for orthogonal frequency division multiplexing (OFDM) based networks. In proposed algorithm, the power is allocated to subcarriers having large signal-to-interference-plus-noise ratio (SINR) according to the criterion. In order to reduce cochannel interference, we propose the power allocation scheme based on the SINR feed back. The simulation shows that the proposed algorithm is converged while maintaining the required QoS.

Index Terms—power allocation, inter-cell interference, outage probability, OFDM-based cellular networks

I. INTRODUCTION

The remarkable growth of mobile multimedia communications demands higher data service rates over a broad bandwidth with a sufficient robustness to frequency selective fading. Orthogonal frequency division multiplexing (OFDM) is generally regarded to be one of the most suitable candidates for supporting such high data rates due to its high spectral efficiency [1][2]. Multi-carrier code division multiple access (MC-CDMA) and orthogonal frequency division multiple access (OFDMA) techniques have been developed for multiple access. MC-CDMA is capable of exploiting frequency diversity by utilizing frequency-domain spreading [3][4][5]. OFDMA provides each user with a fraction of the available number of subcarriers. In particular, frequency hopping OFDMA (FH-OFDMA) utilizes all of the available bandwidth for each user and has the benefit of an increased frequency diversity as well as an interference averaging effect[6][7].

For OFDM-based cellular networks, the same frequency could be reused in different cells only beyond a sufficiently high reuse distance, similar to CDMA systems. Currently, an frequency reuse factor (FRF) of 1 has been highly considered for greater channel throughput and ease of deployment. The main advantage of an FRF of 1 is the substantial increase in user capacity per unit bandwidth compared to the use of other FRFs. In spite of this advantage, the issue of the interference from other users or cells must be taken into account. In multi-cell environments, the inter cell interference (ICI) is a major factor leading to performance degradation. Mobile stations (MSs) near the cell boundary receive the ICI more intensely than those near to the BS(base station). Therefore, it may not access

multiple users while maintaining a certain level of quality of service (QoS).

To guarantee a desirable QoS regardless of the MS position, a higher FRF can be employed by dividing the entire frequency band into four or seven separate sub-bands as it is done in traditional CDMA systems, which are then assigned to each cell to avoid frequency overlapping. By exploiting such higher FRFs, it is possible to significantly reduce the interference. However, each cell is able to use only one-fourth or one-seventh of the entire bandwidth at the cost of decreasing the ICI. Therefore, a decrease in frequency utilization and channel throughput is inevitable.

In this paper, we propose the algorithm for OFDM based networks. The main goal is to guarantee QoS by using the power control. In the algorithm, each users control the power to decrease the outage probability based on the SINR feedback, and the power is allocated to one of subcarriers according to criterion. The Algorithm is designed for single-cell and multi-cell cases.

II. SYSTEM MODEL

Consider a single cell uplink OFDM system with a single base station receiving signals from the multi-user. The K users use M subcarrier to access the base station. We assume that each user can use maximal power $\bar{P}$. The received SINR for user k at the BS can be written as

$$\Gamma_{k,m} = \frac{P_{k,m}|h_{k,m}|^2}{N_0 + I_{k,m}} \quad (1)$$

where $P_{k,m}$ denotes the power allocated to subcarrier m by user k , $h_{k,m}$ is the channel between the BS and user k on subcarrier m , N_0 is the power spectral density of AWGN, and $I_{k,m} = \sum_{i=1, i \neq k}^K P_{i,m}|h_{i,m}|^2$ is the cochannel interference. Thus, the sum-rate can be written as

$$R = \sum_{k=1}^K \sum_{m=1}^M \log(1 + \Gamma_{k,m}). \quad (2)$$

The sum-rate can be increased by power control and channel allocation. The channel is modeled by [8]

$$h_{k,m} = \sqrt{\rho \frac{1}{d_k^\lambda}} \sqrt{s_{k,i}} \cdot z_{k,m} \quad (3)$$

where d_k is the distance between user k and the BS, ρ is the square of the mean channel gain at $d_k = 1$, λ is the path

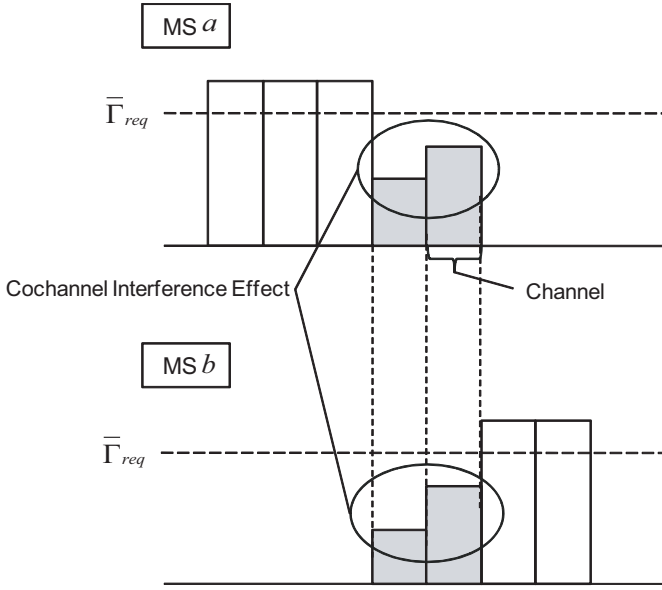


Fig. 1. The interference caused by using same channels

loss exponent, $s_{k,i}$ is the log-normal shadow fading random variable, where $10 \log s_{k,i}$ is a zero-mean unit variance gaussian random variable, and $z_{k,m}$ is the zero-mean unit variance complex gaussian random variable. Therefore, the channel gain is decreased according to the distance.

III. POWER CONTROL ALGORITHM FOR QOS ENHANCEMENT

A. Single-cell Case

In the single cell case, it does not consider the inter cell interference. Therefore, the uplink OFDMA power control for satisfying the request QoS is formulated by:

$$\min_{P_{k,m}} \sum_{k=1}^K \sum_{m \in \mathcal{M}_k} \Pr[\Gamma_{k,m} < \bar{\Gamma}_{req}] \quad (4)$$

$$\text{s.t.} \quad \sum_{m=1}^M P_{k,m} \leq \bar{P}, k = 1, \dots, K \quad (5)$$

$$P_{k,m} \geq 0, k = 1, \dots, K, m = 1, \dots, M \quad (6)$$

where $\mathcal{M}_k$ denotes the set of subcarriers user k allocating the power. The cochannel interference of user k on subcarrier m is decreased when other users do not allocate the power to subcarrier m as Fig. 1. Therefore, we design the distributed power control algorithm that each user allocates the power to different subcarrier. In proposed algorithm, each user allocates equal power to all subcarriers first and receives the SINR feedback only about themselves. The algorithm is constructed as follows.

Step 1) Each user allocates equal power to all subcarriers:

$$n = 1 \quad (7)$$

$$P_{k,m}^n = \frac{\bar{P}}{M} \quad (8)$$

Step 2) Receive the SINR feedback:

$$\Gamma_{k,m}^n = \frac{P_{k,m}^n |h_{k,m}|^2}{N_0 + I_{k,m}^n} \quad (9)$$

Step 3) The user allocates all power to the subcarrier having maximal SINR when maximal value of SINR is larger than α . On the other hand, if maximal value of SINR is less than β , the user allocates all power to the subcarrier having minimal SINR:

$$\text{if } \max_{m \in \mathcal{M}_k} \Gamma_{k,m}^{n-1} > \alpha \quad n \leftarrow n + 1 \quad (10)$$

$$P_{k,m}^n = \begin{cases} \bar{P} & m = \arg \max_{m \in \mathcal{M}_k} \Gamma_{k,m}^{n-1} \\ 0 & \text{else} \end{cases} \quad (11)$$

$$\text{if } \max_{m \in \mathcal{M}_k} \Gamma_{k,m}^{n-1} < \beta$$

$$P_{k,m}^n = \begin{cases} \bar{P} & m = \arg \min_{m \in \mathcal{M}_k} \Gamma_{k,m}^{n-1} \\ 0 & \text{else} \end{cases} \quad (12)$$

If $\beta \leq \max_{m \in \mathcal{M}_k} \Gamma_{k,m}^{n-1} \leq \alpha$, $P_{k,m}^n = P_{k,m}^{n-1}$

Step 4) Renew α and β :

$$\alpha \leftarrow \alpha - \Delta \quad (13)$$

$$\beta \leftarrow \beta + \Delta \quad (14)$$

$$n \leftarrow n + 1 \quad (15)$$

go to Step 2.

In step 1, the user allocates equal power to all subcarriers and, in step 2, each user receives SINR feedback of each subcarrier. The user has large probability that subcarrier m has large channel gain when the SINR of subcarrier m has maximal value. On the other hand, if the SINR of subcarrier m has minimal value, the user has little probability that subcarrier m has large channel gain. Thus, in Step 3, we allocate the power based on this concept. If each user receives the SINR feedback of each subcarrier, the power is allocated according to maximal value of the SINR. Each user allocates all power to the subcarrier having maximal SINR when maximal value of the SINR is larger than β . We can assume that the user has large channel gain at specific subcarrier having above-average maximal SINR. On the other hand, if maximal value of the SINR is less than β , each user allocates all power to the subcarrier having minimal SINR. We can assume that the user, whose maximal SINR value is lower than β , has low channel gain about all subcarriers and, thus, this user allocates the power in order to reduce cochannel interference of other users. This procedure is repeated until $n = N$ where N is maximal number of iteration.

B. Multi-cell Case

In the multi-cell case, we must consider the inter-cell interference. We assume that the inter-cell interference is received from adjacent six cells as Fig 2. Therefore, the received SINR for user k can be written as

$$\hat{\Gamma}_{k,m} = \frac{P_{k,m}|h_{k,m}|^2}{N_0 + I_{k,m} + I_{k,m}^{inter}} \quad (16)$$

where $I_{k,m}^{inter} = \sum_{b=1}^6 \sum_{i=1}^{U_b} \hat{P}_{i,m}^b |\hat{h}_{i,m}^b|^2$ is the inter-cell interference, where U_b is the number of users using same subcarrier on cell b . Because of path loss effect, the outage probability of edge users is larger than that of inner users. Therefore, we design the algorithm considering the path loss effect. If the user is located at the cell boundary, this user allocate the power to particular subcarrier later than inner users. The algorithm is constructed as follows.

Step 1) Each user allocates equal power to all subcarriers:

$$n = 1 \quad (17)$$

$$P_{k,m}^n = \frac{\bar{P}}{M} \quad (18)$$

Step 2) Receives SINR feedback:

$$\hat{\Gamma}_{k,m}^n = \frac{P_{k,m}^n |h_{k,m}|^2}{N_0 + I_{k,m}^n + I_{k,m}^{inter}} \quad (19)$$

Step 3) Each user allocates all power to the subcarrier having maximal SINR value when the summation of the SINR value is larger than γ :

$$n \leftarrow n + 1 \quad (20)$$

$$if \sum_{m=1}^M \Gamma_{k,m}^{n-1} > \gamma \quad (21)$$

$$P_{k,m}^n = \begin{cases} \bar{P} & m = \arg \max_{m \in \mathcal{M}_k} \Gamma_{k,m}^{n-1} \\ 0 & else \end{cases} \quad (22)$$

If $\sum_{m=1}^M \Gamma_{k,m}^{n-1} \leq \gamma$, $P_{k,m}^n = P_{k,m}^{n-1}$

Step 4) γ is renewed:

$$\gamma \leftarrow \gamma - \Delta \quad (23)$$

go to step 2.

In Step 2, the edge user has large probability that the SINR feedback of each subcarrier is less than inner users. In step 3, if the summation of the SINR value is larger than γ , the user allocates the power to the subcarrier having maximal SINR. The value of γ is decreased according to the number of iteration. Therefore, edge users can allocate the power to the subcarrier having large channel gain with high probability when the number of iteration is large.

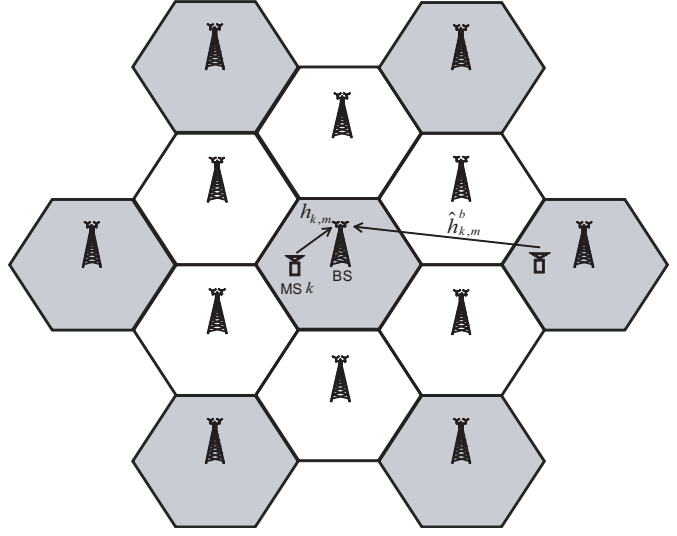


Fig. 2. The inter-cell interference

C. Algorithm For Request Capacity

In the multi-cell case, if we consider request capacity, the uplink power control for satisfying request capacity is formulated by:

$$\min_{P_{k,m}} \sum_{k=1}^K \Pr \left[\sum_{m \in \mathcal{M}_k} \log(1 + \hat{\Gamma}_{k,m}) < C_{req} \right] \quad (24)$$

$$s.t. \sum_{m=1}^M P_{k,m} \leq \bar{P}, k = 1, \dots, K \quad (25)$$

$$P_{k,m} \geq 0, k = 1, \dots, K, m = 1, \dots, M \quad (26)$$

The SINR value of edge users is low because of the path loss effect. Thus, edge users need to use more subcarriers than inner users. In proposed algorithm for request capacity, if the summation of the SINR value is less than particular value, the user selects some subcarriers to allocate the power. The algorithm is constructed as follows.

Step 1) Each users allocate equal power to all subcarriers:

$$n = 1 \quad (27)$$

$$P_{k,m}^n = \frac{\bar{P}}{M} \quad (28)$$

Step 2) Receive SINR feedback:

$$\hat{\Gamma}_{k,m}^n = \frac{P_{k,m}^n |h_{k,m}|^2}{N_0 + I_{k,m}^n + I_{k,m}^{inter}} \quad (29)$$

Step 3) Each users allocates the power to some subcarriers having large SINR value when the summation of the SINR

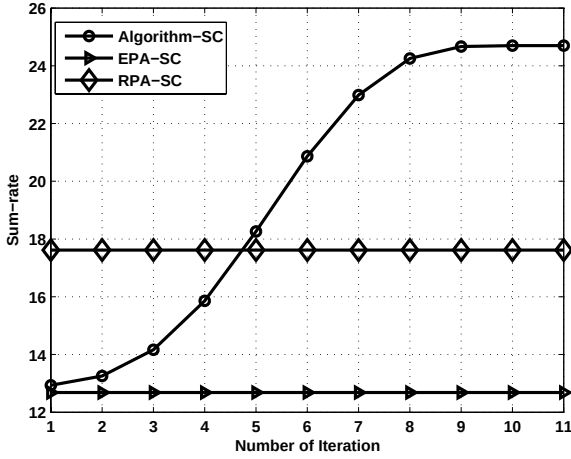


Fig. 3. The sum-rate of Algorithm-SC, EPA-SC, and RPA-SC with $\lambda = 4$, $\bar{\Gamma}_{req} = 0\text{dB}$, $\gamma = 0.4$, $\delta = 0.01$, $\bar{P} = 1$, $K = 10$, and $M = 10$.

value is larger than γ :

$$n \leftarrow n + 1 \quad (30)$$

$$\text{if } \sum_{m=1}^M \Gamma_{k,m}^{n-1} > \gamma \quad (31)$$

$$P_{k,m}^n = \begin{cases} \frac{\bar{P}}{A_k} & \Gamma_{k,m}^{n-1} > \delta \\ 0 & \text{else} \end{cases} \quad (32)$$

If $\sum_{m=1}^M \Gamma_{k,m}^{n-1} \leq \gamma$, $P_{k,m}^n = P_{k,m}^{n-1}$

Step 4) γ and δ are renewed:

$$\gamma \leftarrow \gamma - \Delta_\gamma \quad (33)$$

$$\delta \leftarrow \delta - \Delta_\delta \quad (34)$$

go to step 2.

In Step 3, if the summation of the SINR value is larger than γ , the user allocate the power to some subcarriers having large SINR value, where A_k is the number of subcarriers user k allocating the power. The value of γ is decreased according to the number of the iteration. Thus, edge users use more subcarriers than inner users with reducing cochannel interference.

IV. SIMULATION RESULTS

In this section, we show simulation results of the outage probability and sum-rate for the proposed algorithm. In Fig.3, we show the average sum-rate as a function of the number of iterations with $\lambda = 4$, $\bar{\Gamma}_{req} = 0\text{dB}$, $\gamma = 0.4$, $\delta = 0.01$, $\bar{P} = 1$, $K = 10$, and $M = 10$. The sum-rate is increased according to the number of iteration.

In Fig. 4, the average outage probability of proposed algorithm as a function of the number of iteration with $\lambda = 4$, $\bar{\Gamma}_{req} = 0\text{dB}$, $\gamma = 0.4$, $\delta = 0.01$, $\bar{P} = 1$, $K = 10$, and $M = 10$ is obtained. If the number of iteration is

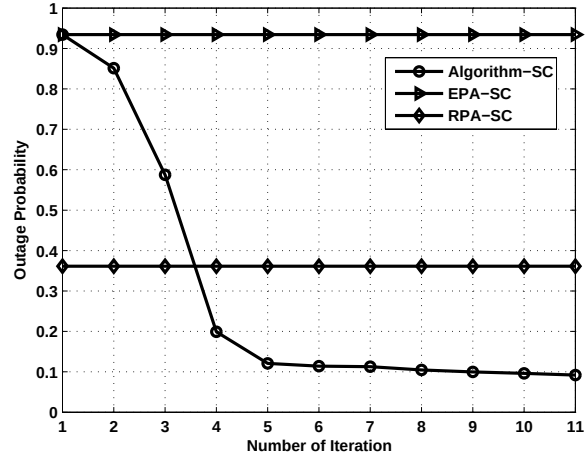


Fig. 4. The outage probability of Algorithm-SC, EPA-SC, and RPA-SC with $\lambda = 4$, $\bar{\Gamma}_{req} = 0\text{dB}$, $\gamma = 0.4$, $\delta = 0.01$, $\bar{P} = 1$, $K = 10$, and $M = 10$.

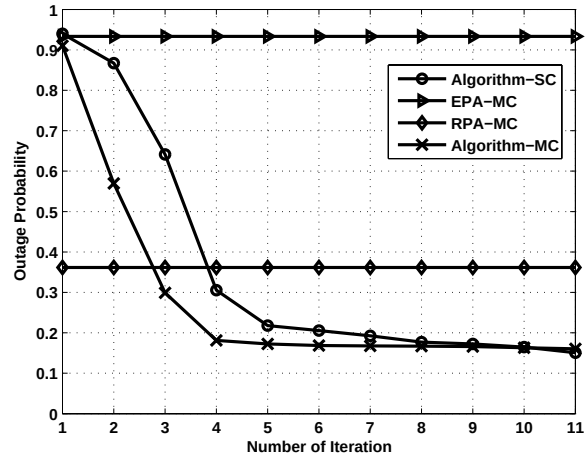


Fig. 5. The outage probability of Algorithm-SC, EPA-MC, RPA-MC and Algorithm-MC with $\gamma = 0.35$, and $\Delta = 0.01$.

large, the outage probability of the Algorithm-SC(algorithm on single-cell case) is decreased due to the reduction of the cochannel interference. The EPA-SC(equal power allocation on single cell case) and the RPA-SC(random power allocation on single-cell case) are compared with the Algorithm-SC, where RPA-SC allocate all power to one subcarrier randomly.

In Fig. 5, we compare the outage probability of various strategies. The simulation results are obtained with $\gamma = 0.35$ and $\Delta = 0.01$. The Algorithm-MC(algorithm on multi-cell case) is converged faster than Algorithm-SC in multi-cell environments.

In Fig. 6, we show the probability that the capacity of subcarriers is larger than request capacity. The simulation results are obtained with $\gamma = 0.35$, $\Delta_\gamma = 0.01$, $\delta = 0.78$,

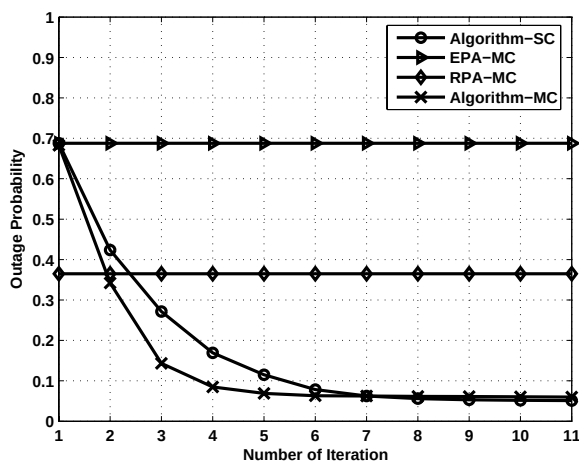


Fig. 6. The outage probability of Algorithm-SC, EPA-MC, RPA-MC and Algorithm-MC with $\Delta_\gamma = 0.01$, $\delta = 0.78$, $\Delta_\delta = 0.03$ and $C_{req} = 1\text{bit}$.

$\Delta_\delta = 0.03$ and $C_{req} = 1\text{bit}$. As Fig. 5, The Algorithm-MC(algorithm on multi-cell case) is also converged faster than Algorithm-SC.

V. CONCLUSION

We have shown that the proposed algorithm reduce the outage probability according to increasing the number of iteration. This is because the power is allocated to reduce the cochannel interference, and the QoS of users are guaranteed. Algorithm is designed to adapt each cases. It have considered the inter-cell interference, the path loss on the multiuser case, and the QoS of the each subcarriers. The power allocation schemes of algorithms have allocated power according to the SINR value of each subcarriers. Thus, only using the SINR feedback, the performance have been improved.

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