Service based Handover Scheme Considering Link Asymmetry in OFDMA/TDD Systems

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Abstract—**This paper works on a link asymmetric characteristic between a downlink and uplink in orthogonal frequency division multiple access (OFDMA)/ time division duplexing (TDD) systems and proposes the service based handover scheme which considers the link asymmetry in OFDMA/TDD system. To investigate the downlink and uplink asymmetry, we introduce numerical downlink and uplink signal to interference and noise ratio (SINR) models. The causes of the uplink and downlink asymmetry are mainly due to coverage of neighbor cells and a usage ratio of uplink and downlink traffic. As the coverage of neighbor cells increases, an uplink SINR becomes lower than a downlink SINR. And, as uplink or downlink traffic of mobile stations (MSs) increases, an uplink or downlink SINR decreases, respectively. To cope with the link asymmetry and guarantee a service quality, the proposed handover scheme exploits the weighted sum of downlink and uplink SINR as criteria for initiating and deciding a handover. In addition weighting values are adjusted according to the service. The simulation results show that the proposed scheme outperforms previous studies in terms of the handover outage, the number of a pingpong handover.**

I. INTRODUCTION

Many wireless communication standards including 3GPP LTE-advanced, and IEEE 802.16m have adopted orthogonal frequency division multiple access (OFDMA) and time division duplexing (TDD). These systems are appealing for their potential to provide high data rate services [1], [2]. In TDD systems, a same frequency band is allocated to downlink and uplink channels. For this reason, TDD is widely known for having, when a frame size is smaller than a channel coherence time, channel symmetry between a downlink and an uplink, called reciprocity [3].

Accordingly, many physical and medium access control (MAC) layer technologies of OFDM systems, e.g., link adaptation, scheduling, or handover, actively exploit the channel symmetric feature of TDD [4], [5]. However, practical downlink and uplink qualities can be asymmetric due to the different interference and the different traffic characteristics. The growth of data communications leads to installations of femto-cell BSs and hotspot-zones. Such installations still cause the changing of the cell-deploying and the inter-cell interference, though intercell interference coordination is applied [6]. And the proliferation of smartphones like iPhone has brought about a variety of services in the mobile communications. As a result, the usage pattern of the uplink and downlink traffic can be varied. It means that the user could not use a desired service well due to the poor uplink link quality by link management schemes based on the link symmetry approach. Therefore, to design effective access technology, a study of link asymmetric behavior should be required.

Unfortunately, many previous studies on wireless link modeling does not consider the link asymmetry in OFDMA/TDD system. The study in [7] derives the link model of the OFDM system. However, the difference between uplink and downlink is not mentioned. In [8], Moon and et al.propose a downlink model considering geometric information and the inter-cell interference. But the main interest of [8] is to model a downlink channel of code division multiple access (CDMA) systems, and neither the channel symmetry nor the correlation between downlink and uplink are mentioned. The link model in [9] is considered a downlink and uplink signal-to-noise-interference ratio (SINR) in an OFDMA system. Nonetheless, this study considers only the carrier frequency offset effect on an SINR model and it also fail to mention the link asymmetry of the OFDMA systems. In [10]–[12], these papers exploit the link asymmetry characteristic of OFDMA/TDD system. However the model of links had not been derived, and these studies has not flexible to support the asymmetric traffic service and the channel varying.

For these reasons, we study the link asymmetry of OFDMA/TDD systems. In previous work, we derived the mathematical models of a downlink and an uplink taking into consideration traffic loads and inter-cell interferences in an OFDMA/TDD system [13]. In this paper, based on the proposed link models, we propose the novel handover scheme using the link asymmetry.

The rest of this paper is organized as follows. Section II describes the downlink and uplink link models which exploit geometric information and inter-cell interference. Section III explain the link asymmetry cases. Section IV proposes the novel handover scheme and explains simulation results. And Section V offers our conclusions.

TABLE I
NOTATIONS FOR SYSTEM MODEL

Notation	Description
d	Distance between the BS in the center cell and the BS in the neighbor cell
b	Index of the BS in the center cell
m	Index of the MS in the center cell
n	Index of the MS in the neighbor cell
z	Index of the BS in the neighbor cell
r_h	Distance between the center and the vertex of a hexagonal cell
r_e	Radius of an equivalent circle to a hexagonal cell
γ	cell Propagation loss factor (= -4)
ε	minimum distance between a BS and an MS
$P^{(t)}_{\max,BS}$	maximum transmission power of a BS
$P^{(t)}_{\max,MS}$	maximum transmission power of an MS
ζ	Shadow fading from BS b to MS m
θ	Main lobe width of sectored cells
δ	Average number of active MSs in a cell
α	Downlink resource allocation ratio per MS
β	Uplink resource allocation ratio per MS
ρ	Signal to interference and noise ratio
ϕ	Threshold for handover procedure

II. DOWNLINK AND UPLINK SINR MODEL

In this section, we represent the link SINR models to explain the link asymmetry by referring our previous work [13].

For modeling the downlink and the uplink channel, we use notations in Table I.

A. Assumption

This paper considers TDD based OFDMA systems where a downlink and an uplink are multiplexed in a time division manner. The frequency-reuse factor is assumed to be one and consequently every adjacent cell can cause inter-cell interferences to the center cell. All BSs are assumed to be timely synchronized and use same frame structure of TDD mode, but BSs are not coordinated for the resource allocation. Therefore no BS recognizes traffic of its neighbor cells. In addition, MSs are assumed to be uniformly distributed in a cell. Every BS and MS transmit packets with the maximum power in any location. To simplify the analysis of the link modeling, we consider only path loss and shadowing. Fast fading is not considered because it is changed too fast in the time-scale. Therefore ,commonly, handover schemes do not consider it. Under these assumptions, we derive a downlink and an uplink model between BS b and MS m located in the center cell.

B. Downlink SINR model

From [13], the expectation of the received signal power at the desired MS m from the serving BS b is derived as

$$\begin{aligned} E[P^{(r)}_{b\to m}] &= P^{(t)}_{\max,\,BS} \cdot \bar{\alpha} \cdot E[r^{\gamma}_{b\to m}] \cdot E[10^{-\zeta_{b\to m}/10}] \\ &= P^{(t)}_{\max,\,BS} \cdot \bar{\alpha} \cdot \int_{\varepsilon}^{r_e} \frac{2r^{\gamma+1}}{{r_e}^2} dr \\ &\quad \cdot \exp\left\{ \left(\frac{\ln 10}{10} \sigma_{\zeta_{b->m}} \right)^2 /2 \right\}. \end{aligned} \tag{1}$$

In OFDMA systems, users can share tones in a frequency manner, and the transmitting power distributed over tones. Subsets of tones are assigned to each user based on the resource allocation algorithms. Therefore the downlink resource allocation ratio, $\bar{\alpha}$, is different for each user, and this affects the received power of a downlink. The expectation of the received interference power from neighboring BSs at the desired MS m is written as

$$\begin{aligned} E[I^{(r)}_{m}] &= \frac{\theta}{360^{\circ}} \cdot \sum_{z\neq b} \left\{ \sum_{n\in z} \left(P^{(t)}_{\max,BS} \cdot E\left[\alpha_n\right] \right) \right. \\ &\quad \left. \cdot E\left[r^{\gamma}_{z\to m}\right] \cdot E\left[10^{-\zeta_{z\to m}/10}\right] \right\} \\ &\simeq \frac{P^{(t)}_{\max,BS} \cdot 6 \cdot \overline{\delta} \cdot \overline{\alpha}^2 \cdot \theta}{360^{o}} \\ &\quad \cdot \int_{d-r_e}^{d+r_e} \frac{r^{\gamma}}{\pi \cdot r_e^2} \cdot \frac{\sqrt{4d^2 r_e^2 - \left(d^2 + r_e^2 - r^2\right)^2}}{d} dr \\ &\quad \cdot \exp\left\{ \left(\frac{\ln 10}{10} \sigma_{\zeta_{z->m}} \right)^2 /2 \right\}. \end{aligned} \tag{2}$$

The MS n uses a same carrier frequency as the MS m use. Thus the first $\bar{\alpha}$ of $\bar{\alpha}^2$ denotes the received interference power portion of the maximum transmitting power of BS. The other $\bar{\alpha}$ denotes the probability of receiving interference from neighboring cells. The probability of receiving interference increases proportionally with the increasing of $\bar{\alpha}$. Indeed increasing of $\bar{\alpha}$ also increases the probability that an user uses the same resource with other users in neighbor cells.

Using (1) and (2), the downlink SINR at the desired MS m is presented as

$$\rho^{(r)}_{b\to m} = E[P^{(r)}_{b\to m}]/E[I^{(r)}_{m}]. \tag{3}$$

C. Uplink SINR model

The expectation of the received signal power at the serving BS b from the desired MS m is expressed as

$$\begin{aligned} E[P^{(r)}_{m\to b}] &= P^{(t)}_{\max,\,MS_{serving}} \cdot \overline{\beta} \cdot E[r^{\gamma}_{m\to b}] \\ &\quad \cdot E[10^{-\zeta_{m\to b}/10}] \\ &= P^{(t)}_{\max,\,MS_{serving}} \cdot \overline{\beta} \cdot \int_{\varepsilon}^{r_e} \frac{2r^{\gamma+1}}{{r_e}^2} dr \\ &\quad \cdot \exp\left\{ \left(\frac{\ln 10}{10} \sigma_{\zeta_{m->b}} \right)^2 /2 \right\}. \end{aligned} \tag{4}$$

And the expectation of the received interference power from MSs in neighbor cells at the serving BS b is derived as

$$E[I_b^{(r)}] = \begin{cases} \frac{\theta}{360^\circ} \cdot \sum_n P^{(t)}_{\max, MS_{neighbor}} \\ \cdot E[\beta_n] \cdot E[r^{\gamma}_{n\to b}] \cdot E[10^{-\zeta_{n\to b}/10}] \\ \simeq \frac{P^{(t)}_{\max, MS_{neighbor}} \cdot 6 \cdot \bar{\delta} \cdot \bar{\beta}^2 \cdot \theta}{360^o} \\ \cdot \int_{d/2}^{d+r_e} \frac{2r^{\gamma+1}}{(r_e+d)^2-(d/2)^2} dr \\ \cdot \exp\left\{\left(\frac{\ln 10}{10}\sigma_{\zeta_{n->b}}\right)^2/2\right\}, \quad (d \leq 2r_e), \\ \frac{\theta}{360^\circ} \cdot \sum_n P^{(t)}_{\max, MS_{neighbor}} \\ \cdot E[\beta_n] \cdot E[r^{\gamma}_{n\to b}] \cdot E[10^{-\zeta_{n\to b}/10}] \\ \simeq \frac{P^{(t)}_{\max, MS_{neighbor}} \cdot 6 \cdot \bar{\delta} \cdot \bar{\beta}^2 \cdot \theta}{360^o} \cdot \int_{r_e}^{d+r_e} \frac{2r^{\gamma+1}}{(r_e+d)^2-r_e^2} dr \\ \cdot \exp\left\{\left(\frac{\ln 10}{10}\sigma_{\zeta_{n->b}}\right)^2/2\right\}, \quad (d > 2r_e). \end{cases} \tag{5}$$

We fix the value of r_e and vary only the cell radius of adjacent cells. Then, when d is larger than $2r_e$, adjacent cells can overlap. MSs in the overlapping area are assumed to be served by the nearest BS. $\bar{\beta}$ affects the received signal and interference power as $\bar{\alpha}$.

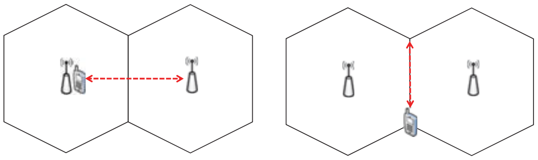
From (4) and (5), the uplink SINR of the desired MS at the serving BS b, $\Gamma^{(r)}_{m\to b}$, is presented as

$$\rho^{(r)}_{m\to b} \quad = \quad E[P^{(r)}_{m\to b}]/E[I_b^{(r)}]. \tag{6}$$

III. LINK ASYMMETRIC CASES

In this section, we introduce link asymmetric cases based on represented link models First, the link asymmetry can be caused by d. The changing of link models can be found according to the variation of d when α and β are the same. In (1), the downlink signal model has the integral region r_e, and (2) which is the downlink interference model also has the integral region $2r_e$ (a difference between $d + r_e$ and $d - r_e$). On the other hand, integral regions of (5) which are uplink interference models are varied in proportion to d. In the downlink, as d increases, the transmission power of neighbor BSs increases by the power control mechanism. And it occurs increasing of downlink interferences. Only one factor affects the downlink SINR. In the uplink case, however, two factors affect the uplink SINR. One is the transmission power of MSs in neighbor cells, and the other is the region which generates interference. They increase and broaden respectively as d increases. And these factors cause the increasing of the uplink interference. Therefore the uplink SINR decreases, according to increasing of d, more than the downlink SINR. Consequently, the link asymmetry can be caused by the difference of the downlink and uplink model.

Secondary parameters of the link asymmetry are α and β which are downlink and uplink resource allocation ratio per MS respectively. The uplink and the downlink SINR model are in inverse proportion to α and β, respectively. α and β can have asymmetry according to the service characteristics. In (1) and (4), The downlink and uplink signal power are proportional to $\bar{\alpha}$ and $\bar{\beta}$, respectively. This occurs because the MS is allocated more subcarriers to receive more data in downlink and the MS also use more carriers to transmit more data in uplink. In (2) and (5), however, the downlink and the uplink interference model are proportional to $\bar{\alpha}^2$ and $\bar{\beta}^2$ respectively. Because the MS in neighbor cells also uses more subcarriers to communicate with the BS in neighbor cells, and the probability that the desired MS uses same frequency with other MSs in neighbor cells increases. When α becomes larger than β, the downlink interference power increases more than the uplink interference power. Then the downlink SINR becomes less than the uplink SINR. In the other case, the uplink SINR becomes lower than the downlink SINR.


(a) Trajectory 1

(b) Trajectory 2

Fig. 1. Simulation Trajectories

IV. PROPOSED HANDOVER SCHEME

We have proposed the handover scheme based on above results of the link asymmetry in [10]. The proposed handover scheme uses both downlink and uplink quality to initiate and decide a handover. It showed that the proposed handover scheme reduces the handover outage probability and handover delay. However we find that it is not effective when the mobility pattern is changed. Thus, in this paper, we proposed the advanced handover scheme. It exploits the downlink and uplink quality adaptively according to the trend of channel variation or the asymmetric traffic service. The proposed scheme use same message exchange as described in [10], and it initiates the handover procedure using the follow criteria;

$$\lambda(\rho_{D,T} - \rho_{D,S}) + (1-\lambda)(\rho_{U,T} - \rho_{U,S}) \ > \phi_1, \tag{7}$$

where $\rho_{D,T}$, $\rho_{D,S}$, $\rho_{U,T}$ and $\rho_{U,S}$ denote a downlink SINR and uplink SINR of handover target cell and serving cell, respectively. And ϕ_1 is a handover initiation threshold. λ is a weighting factor. By adjusting λ, the handover entity can choose the criteria signal.

Then the handover is executed by following condition;

$$\begin{aligned} \lambda(\rho_{D,T} - \rho_{D,S}) + (1-\lambda)(\rho_{U,T} - \rho_{U,S}) \ > \phi_2 \\ \& \, \rho_{D,T} \ \geq \phi_3 \, \& \, \rho_{U,T} \ \geq \phi_4, \end{aligned} \tag{8}$$

where ϕ_2 is a hysteresis to decide handover, and ϕ_3 and ϕ_4 are a minimum required SINR threshold to maintain connection for a downlink and uplink. The newly proposed scheme exploits the link asymmetry more effectively by not only considering both uplink and downlink and but also adjusting link weighting of the criteria. λ can be varied by the mobility pattern and service asymmetric traffic.

To evaluate the performance of the proposed scheme, we adjust λ by the mobility pattern. Fig.1 shows two mobility

TABLE II
SIMULATION ENVIRONMENT AND APPLIED PARAMETERS

Simulation Parameters	
Number of BS	7 active BSs, 29 dummy BSs
Cell coverage	1 km
Velocity	60km/h (Uniform dist.)
Path loss exponent	4
Shadowing model	Log-normal dis.(mean: 0, standard deviation: 8dB), Correlation distance: 50m
Thermal Noise Density	-174dBm/Hz
Moving average window size	100 frames
System Parameters	
Bandwidth	10MHz
Frame size	5 msec
Processing time	10 msec
Transmission delay	5 msec
Decision hysteresis	3dB
T3 Timeout	50msec
Synchronization	5msec
RF switching time	5msec

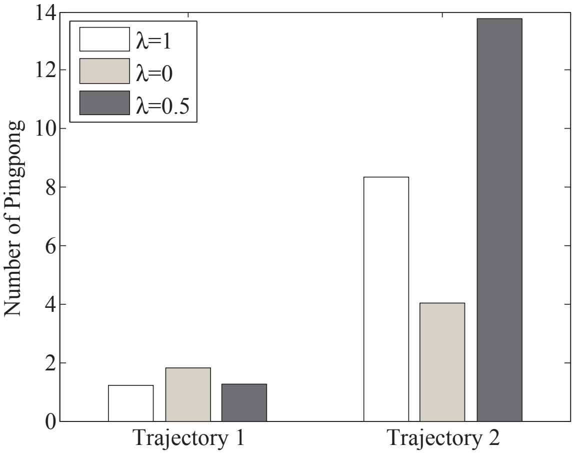


Fig. 2. Number of average handover

trajectories. In trajectory 1, the MS traverses at right angles to the cell boundary. On the other hand, in trajectory 2, the MS traverses along the cell boundary. We built the simulator using OPNET. Table III represents simulation parameters [14]. To mitigate ping-pong effect, we calculate moving average of measured SINR and use the averaged SINR for handover initiation and decision threshold. Fast fading is not considered on the channel. Because fast fading effects are eliminated due to the averaged SINR. The number of measurements of a handover is 100. We set λ as 1, 0, and 0.5. When the λ is 1 and 0, the handover algorithm refers only downlink and uplink signal, respectively. And, when λ is 0.5, the handover algorithm refers both downlink and uplink quality with same weighting.

Fig.2 shows the number of pingpong according to the trajectory. The pingpong is a handover to a neighbor cell that returns to the original cell after a short time. In trajectory 1, the case when λ is 1 has the lowest number of pingpong, and the case when λ is 0 has the highest number of pingpong. Because the MS heads to the target BS directly, the downlink signal from the serving cell decrease and that from the target cell increase steadily. And the downlink interference is also varied steadily, because the downlink interference factor is neighbor BSs and they are located in a fixed spot. In the case of uplink, the serving uplink signal also decrease steadily, however the interference is varied dynamically. The uplink interference factors are geographical position of users in neighbor cells and uplink traffic load. They are keep moving and changing. As a result, the pingpong handover happens more frequently in the uplink rather than in the downlink. And the case when λ is 0.5 shows the larger number of pingpong than the case when λ is 1 but the smaller number of pingpong than the case when λ is 0. In this case, the stability of the downlink SINR compensate for varying of the uplink SINR.

In the trajectory 2, the downlink SINR from the serving BS and the target BS is very similar. And the uplink signal from the serving BS and the target BS are also similar, however uplink interferences are different by a moving of MSs. Thus the pingpong happens many times in downlink than in uplink. The case when λ is 0.5 shows the largest number of the pingpong, by contrast to the case of the trajectory 1. Because the downlink and uplink SINR are varied largely and no stable link exists. This leads that the sum of downlink and uplink SINR is not stable but fluctuating.

Fig.3 and Fig.4 show the handover outage ratio. The handover outage is defined that the downlink or uplink signal level is lower than the outage threshold for sequential 30 frames. Because the service interruption time should be less than 150msec for the seamless conversation [15]. The handover outage ratio is the ratio of the number of handover outage and the number of handover trials. To analyze reasons of the handover outage, we represent outage links separately in Fig.3 and Fig.4. Joint means both a downlink and uplink are outage during the handover. Total handover outage ratio is difference between a sum of the downlink and uplink outage and the joint outage.

In trajectory 1, the case when λ is 0 shows the lowest outage ratio. This is why the downlink SINR is stable comparing to the uplink SINR explained above. fluctuating of an uplink SINR causes more handover outages, and the case when λ is 0 decrease the number of outages by refereing the uplink SINR, mainly. the case when λ is 0.5 shows a little higher outage probability than the case when λ is 0, However, with considering above pingpong results, we can conclude that 0.5 is the best value for λ in trajectory 1. Because it not only reduces the handover overhead and delay but also serves the reliable connection during a handover.

In trajectory 2, the case when λ is 0 still shows the lowest outage ratio. The downlink outages of each case is almost same because the downlink SINR is almost same at each trial. But the uplink SINR is changed at each trial. Thus the case when λ is 0 prevents some uplink outages but the case when λ is 1

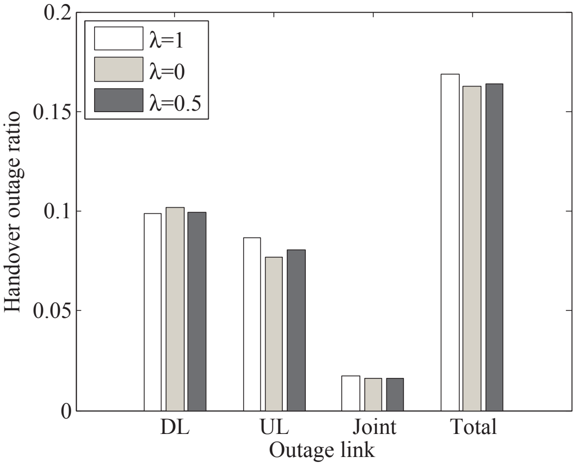


Fig. 3. Handover outage ratio in trajectory 1

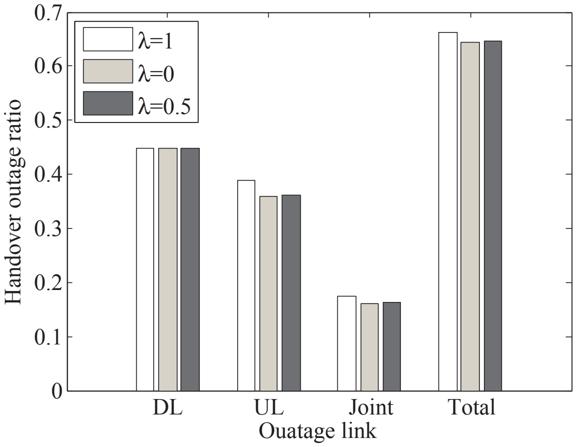


Fig. 4. Handover outage ratio in trajectory 2

cannot. The case when λ is 0.5 also avoid uplink outages but, with considering pingpong results, 0 is the best value for λ in trajectory 2. In this manner, λ can be optimized by behavior of the link SINR and the service asymmetric traffic character or requirement.

According to the simulation results, we can achieve the better performance by considering the asymmetric feature of a downlink and uplink. And we can also support the optimized performance by adjusting the weighting of the downlink and uplink. Thus we expect the proposed handover scheme can be used to improve quality of user experience.

V. CONCLUSION

In this paper, we mathematically derived the wireless link model for OFDMA/TDD systems. By varying parameters that can be changed in practical mobile communication system, we also found cases that cause the link asymmetry. As a result, we show that the neighbor cell size and the ratio of uplink and downlink traffic load can bring about the link asymmetry in an OFDMA/TDD system. Based on the analysis, we proposed the advanced handover scheme. This proposed scheme reduces the handover outage ratio and the number of pingpong during the handover by exploiting both the downlink and uplink SINR for the handover initiation and deciding. Consequently, we need new link quality management schemes adapted for the link asymmetric characteristic to improve the quality of experience.

ACKNOWLEDGMENT

This work was supported by the IT R&D programs of MSIP(Ministry of Science, ICT and Future Planning), Korea [13ZI1130, Research on Advanced Technologies of Access Network for Traffic Capacity Enhancement II].

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