Fast cell site selection with interference avoidance in cellular packet based OFDM systems.

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Abstract: In this paper, we consider fast cell site selection (FCS) in packet based OFDM cellular systems. Mobile station (MS) in multi-coverage regions or soft handover region can have opportunities to select a link better than from the current cell. Conventional FCS schemes track the channel fading variation, achieving a selection diversity gain [1]. However, MSs near the cell boundary suffer from other cell interference (OCI) which is highly time-varying and unpredictable. Therefore, it may be desirable for FCS to reduce the OCI effect near the cell boundary. In this paper, we propose an FCS scheme with interference avoidance for a packet based OFDM system and analyze its performance. Finally, the analytic performance of the proposed scheme is verified by computer simulation

Keywords: fast cell site selection, interference avoidance, selection diversity

Ⅰ. Introduction

Transmission power control (TPC) is the one of key features in CDMA systems. It can reduce the inter cell interference (ICI), improving the system capacity. However, it may involve problems during soft handover in the downlink. The amount of interference can be increased by multiple site transmission during soft handover and the power can be unbalanced in the presence of errors in TPC command reception. To alleviate this problem, a site selection diversity transmit power control (SSDT) scheme was proposed, where the best base station (BS) is dynamically chosen to reduce the interference power [1].

Fast cell site selection (FCS) can be treated as a special case of SSDT [2]. Mobile station (MS) in multi-coverage or soft handover region can have opportunities to select a link better than that from the cell in service. Thus the MS can select the best cell for the transmission at each frame and thus achieve a selection diversity gain. However, it may be desirable to consider some other issues for further improvement.

When the cellular system employs a single frequency network structure, its capacity is limited by other-cell interference (OCI) (i.e, operating in so-called interference-limited environment). As an example, Fig. 1 illustrates the received instantaneous signal-to-interference power ratio (SIR) as a function of the scheduling time (i.e., the time instant normalized with respect to the packet scheduling interval) for users near the cell center (d=300m) and the cell boundary (d=2300m). For fair comparison, the instantaneous SIR is normalized with respect to the average SIR. It can be seen that the instantaneous SIR near the cell boundary has larger variation than that near the cell center. Since the MS near the cell boundary is very close to one or two adjacent BSs and far from other BSs, it may experience fast time-varying interference mainly due to the scheduling results of the adjacent BSs. As a result, The Ms near the cell boundary may not accurately estimate the instantaneous signal-to -interference and noise power ratio (SINR) mainly due to the OCI and measurement delay (i.e., channel state at an instant of channel estimation is not the same as that at an instant of receiving data). Moreover, since the MS near the cell boundary often has a weaker channel gain due to a large path-loss, the OCI from the adjacent BSs can largely affect the MS’ s channel condition. Thus, it is important to adequately control the interference from the adjacent BSs.

In this paper, we consider the use of an interference avoidance (IA) scheme for FCS to provide robust link performance in cell boundary environment in packet based OFDM cellular systems. We assume that the MS can be serviced from one of cells belonging to so-called active set in FCS mode. We call the cell in service primary cell and all the other cells non-primary cells. Most of interferences come from non-primary cells belonging to the active set and they are not easily measurable. The basic operation is identical to conventional FCS schemes in [2,3]. For reliable signal transmission to a target MS near the cell boundary, the proposed scheme does not allocate the resource to the same sub-channels of non-primary cells in the active set.

This paper is organized as follows. In Section II, we propose an FCS scheme with the user of interference avoidance. The proposed scheme is analyzed in Section III. In Section IV, The performance of the proposed scheme is verified by computer simulation. Finally, conclusions are summarized in Section V.

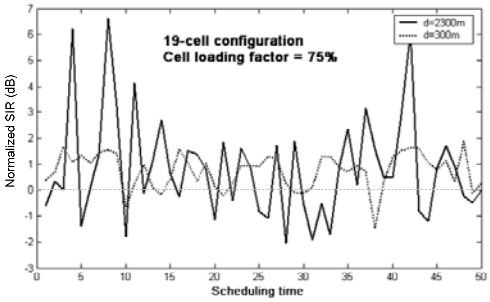


Fig. 1. Instantaneous SIR of the cell center and boundary

Ⅱ. Proposed FCS scheme

Consider a packet-based OFDM cellular downlink system with a universal frequency reuse factor. We assume that all the BSs are synchronized, use the same transmit power and do not perform power control. The use of universal frequency reuse can provide benefits of site selection diversity. We also assume that the considered system uses a frequency division duplex (FDD) scheme for the uplink and downlink. Thus, the FCS signaling can rapidly be reported through an uplink dedicated channel.

As in the conventional FCS schemes, we consider two cases; intra BS FCS and inter BS FCS [3]. In the proposed inter BS FCS, all cells within an active set are controlled by independent schedulers and the MS can select any cell within the active set as a primary cell. In this case, the MS selects the primary cell by measuring the channel quality (e.g., instantaneous received SINR) of cells within the active set. Then, it requests the selected primary cell to service the FCS mode with interference avoidance through an uplink dedicated control channel. BS of primary cell exchanges the information with other BSs for the synchronization of scheduling and IA operation.

In the proposed intra BS FCS, the active set only includes cells (more specifically, sector) controlled by the common scheduler. MS sends the channel state information of all cells within the active set. Then, the common scheduler controls the FCS operation can consider the MS' s channel quality, the load balancing and IA operation.

Ⅲ. Performance analysis

In this section, we analyze the performance of the proposed scheme using an upper-bound method. We assume that there are n cells within an active set in a two-tier (i.e., 19 cells) hexagonal cellular network. In Rayleigh fading channel, the received SINR through one of OFDM sub-channels of MS k linked to serving BS i can be represented as

$$\gamma_{i,k}(t) = \frac{\left|h_{i,k}(t)\right|^2 \cdot P_{i,k}}{\sum_{j=1,\, j\neq i}^{19} \left|h_{j,k}(t)\right|^2 \cdot P_{j,k} \cdot b_j + N_0} \qquad (1)$$

where $h_{i,k}(t)$ and $P_{i,k}$ respectively denote the channel gain and the average signal power from BS i to MS k, b_j is a scheduling indicator having a value of 1 when BS j allocates the resource at the same sub-channel and a value of 0, otherwise. $\sum_{j=1,j\neq i}^{19}\left|h_{j,k}(t)\right|^2 \cdot P_{j,k} \cdot b_j$ represents the total interference power to MS k and N_0 denotes the variance of zero mean additive white Gaussian noise (AWGN).

For interference avoidance among n cells belonging to the active set, non-primary cells within the active set does not uses same sub-channels assigned by the primary cell. Assuming perfect interference avoidance from non-primary cells within the active set, instantaneous received SINR can be represented as

$$\gamma_{i,k}(t) = \frac{\left|h_{i,k}(t)\right|^2 \cdot P_{i,k}}{\sum_{j=1,\, j\notin \text{active set}}^{19} \left|h_{j,k}(t)\right|^2 \cdot P_{j,k} \cdot b_j + N_0} = \frac{\left|h_{i,k}(t)\right|^2 \cdot P_{i,k}}{I_{i,k} + N_0} \qquad (2)$$

where $I_{i,k}$ denotes the total interference power with IA. Since most of interferences come from cells belonging to the active set, the effect of fast fading on $I_{i,k}$ is negligible. Thus, $I_{i,k}$ can be approximated by the average received interference power and $I_{i,k}$ is indifferent from the selection of primary cell in the active set. Then, (2) can further be approximated to

$$\gamma_{i,k}(t) \simeq \frac{\left|h_{i,k}(t)\right|^2 \cdot P_{i,k}}{\sum_{j=1,\, j\notin \text{active set}}^{19} P_{j,k} \cdot b_j + N_0} = \left|h_{i,k}(t)\right|^2 \cdot \overline{\gamma}_{i,k} \qquad (3)$$

where $\overline{\gamma}_{i,k}$ is the average received SINR by the proposed scheme when BS i serves MS k as the primary cell. The corresponding channel capacity C_{IA} can be expressed as

$$C_{\text{IA}} = E\left\{\log_2\left(1+\gamma_{i,k}(t)\right)\right\} \qquad (4)$$

In the proposed inter BS FCS scheme, MS k chooses a cell yielding the largest received SINR as the primary cell and then sends the primary cell index $\hat{i}_k$ and the SINR for AMC to the BS through a dedicated control channel. Then, BS of primary cell sends the scheduling result to the MS k through a broadcasting channel. That is, MS k selects cell $\hat{i}_k$ by

$$\hat{i}_k = \arg\max_{i\in\{1,\cdots,n\}} [\gamma_{i,k}(t)] = \arg\max_{i\in\{1,\cdots,n\}} \{\left|h_{i,k}(t)\right|^2 \cdot \overline{\gamma}_{i,k}\} \qquad (5)$$

In the proposed intra BS FCS, MS k reports the

SINR from all cells within the active set. For ease of analysis, we assume that the scheduler does not consider load balancing. Then, the scheduler selects a cell for MS k using (5). Thus, both the FCS schemes select a cell yielding the maximum instantaneous received SINR as the primary cell. The instantaneous SINR $\Gamma_{n,k}$ of MS k with proposed scheme can be described as

$$\Gamma_{n,k} = \max_{i \in \{1,\cdots,n\}} \{|h_{i,k}(t)|^2 \cdot \bar{\gamma}_{i,k}\} \quad (6)$$

The gain $h(t)$ in Rayleigh fading channel can be described as an independent zero-mean complex Gaussian random variable with unit variance. The instantaneous received SINR $\gamma_{i,k} = |h_{i,k}(t)|^2 \cdot \bar{\gamma}_{i,k}$ can be represented as an exponential random variable with mean $\bar{\gamma}_{i,k}$. The probability density function (pdf) and cumulative density function (cdf) of $\gamma_{i,k}$ are given by

$$f_{\gamma_{i,k}}(z) = \frac{1}{\bar{\gamma}_{i,k}} \cdot e^{\frac{-z}{\bar{\gamma}_{i,k}}}, \quad F_{\gamma_i}(z) = 1 - e^{\frac{-z}{\bar{\gamma}_{i,k}}} = 1 - \bar{\gamma}_{i,k} \cdot f_{\gamma_{i,k}}(z) \quad (7)$$

Thus, the cdf $F_{\Gamma_{n,k}}(z)$ and pdf $f_{\Gamma_{n,k}}(z)$ of $\Gamma_{n,k}$ can be represented as

$$\begin{aligned} F_{\Gamma_{n,k}}(z) &= \Pr\{\Gamma_{n,k} \le z\} = \Pr\{\gamma_{1,k} \le z\} \cdot \Pr\{\gamma_{2,k} \le z\} \cdots \Pr\{\gamma_{n,k} \le z\} \\ &= F_{\gamma_{1,k}}(z) \cdot F_{\gamma_{2,k}}(z) \cdots F_{\gamma_{n,k}}(z) \end{aligned} \quad (8)$$

$$\begin{aligned} f_{\Gamma_{n,k}}(z) &= \frac{dF_{\Gamma_{n,k}}(z)}{dz} = \left[\prod_{i=1}^{n} F_{\gamma_{i,k}}(z)\right] \cdot \sum_{i=1}^{n} \left(\frac{f_{\gamma_{i,k}}(z)}{F_{\gamma_{i,k}}(z)} \right) \\ &= \sum_{i=1}^{n} \left[f_{\gamma_{i,k}}(z) \cdot \left(\prod_{\substack{j=1 \\ j \ne i}}^{n} F_{\gamma_{j,k}}(z) \right) \right] \\ &= \sum_{i=1}^{n} \left[\frac{1}{\bar{\gamma}_{i,k}} e^{-\frac{z}{\bar{\gamma}_{i,k}}} \cdot \prod_{\substack{j=1 \\ j \ne i}}^{n} \left(1 - e^{-\frac{z}{\bar{\gamma}_{j,k}}} \right) \right] \\ &= \sum_{i=1}^{n} \left[(-1)^{i+1} \cdot \sum_{j=1}^{{}_nC_i} S_n^i(j) \cdot e^{-S_{n,k}^i(j) \cdot z} \right] \end{aligned} \quad (9)$$

where ${}_nC_i = \frac{n!}{(n-i)!i!}$ and $S_{n,k}^i(j)$ is *j-th* element of a set where each element is defined as summation of i elements which are selected from $\{1/\bar{\gamma}_{1,k}, 1/\bar{\gamma}_{2,k}, \cdots, 1/\bar{\gamma}_{n,k}\}$. For example, $S_{3,k}^2(1) = 1/\bar{\gamma}_{1,k} + 1/\bar{\gamma}_{2,k}$, $S_{3,k}^2(2) = 1/\bar{\gamma}_{1,k} + 1/\bar{\gamma}_{3,k}$, $S_{3,k}^2(3) = 1/\bar{\gamma}_{2,k} + 1/\bar{\gamma}_{3,k}$.

Thus, the channel capacity $C_P(n)$ of the proposed FCS scheme with n selection diversity is

$$C_P(n) = E\{\log_2(1 + \Gamma_{n,k})\} \quad (10)$$

From Jensen' s inequality and (9), (4) and (10) can be shown that

$$C_{IA} \le \log_2(1 + E\{\gamma_{i,k}(t)\}) = \log_2(1 + \bar{\gamma}_{i,k}) \quad (11)$$

$$C_P(n) \le \log_2(1 + E\{\Gamma_{n,k}\}) = \log_2\left(1 + \sum_{i=1}^{n}\left[(-1)^{i+1} \cdot \sum_{j=1}^{{}_nC_i} \frac{1}{S_{n,k}^i(j)}\right]\right) \quad (12)$$

where $E[\Gamma_n]$ is

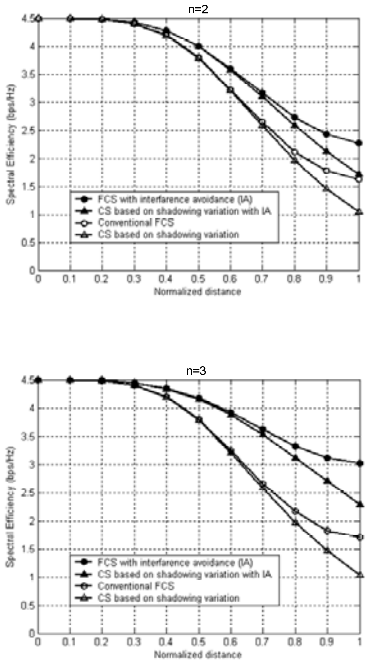
$$E\{\Gamma_{n,k}\} = \sum_{i=1}^{n}\left[(-1)^{i+1} \cdot \sum_{j=1}^{{}_nC_i} \frac{1}{S_{n,k}^i(j)}\right] \quad (13)$$

Thus, the proposed scheme has a capacity gain over the IA only, mainly due to the selection diversity gain by (13).

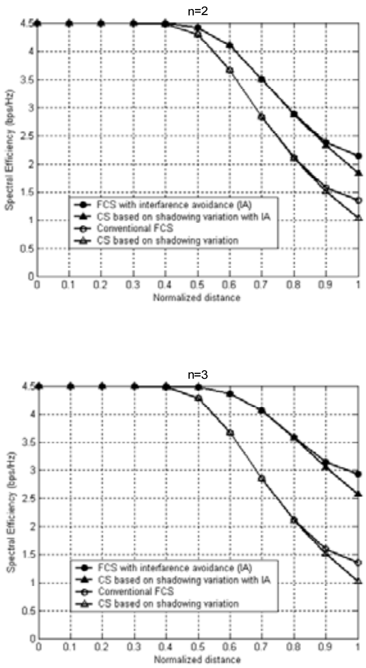
Ⅳ. Simulation results

For evaluation of the proposed scheme, we consider four types of cell selection (CS) scheme, CS based on shadowing variation scheme with / without interference avoidance (IA) and FCS with / without IA. The CS based on shadowing variation scheme tracks the path-loss and shadowing variation rather than the instantaneous gain variation [4]. It can be treated as a hard handover because of its slow selection characteristics. Therefore, we can see the fast fading effect in the site selection diversity by comparing this with FCS scheme. For performance comparison by computer simulation, we assume that the maximum achievable spectral efficiency is 4.5 bps/Hz and an outage state occurs when the SINR is less than -5 dB in hexagonal-shaped 19 cells environment with cell radius 1 Km.

Fig. 2 depicts the throughput performance of four CS schemes for different diversity orders. It can be seen that the use of FCS is quite effective for users in cell boundary area with more cells within the active set. In cell boundary area, the signals from the cells within the active set have almost the same average signal strength. Thus, the site selection diversity gain increases as the MS moves toward the cell boundary and/or the number of cells in the active set increases. However, this gain may not be noticeable in systems achieving large diversity gain (e.g., the use of space-time coding) due to the similar path-loss and fast fading mitigation effect. Consequently, the performance difference due to the FCS gain becomes marginal as the diversity order increases. Fig. 2 also shows that the improvement in the spectral efficiency by IA compared to that by conventional schemes. This is because, with IA, non-primary cells within the active set do not allocate resources in same sub-channel. Since the major interferences come from non-primary cells within the active set, the IA can enhance the performance.



(a) Diversity order = 1



(b) Diversity order = 4

Fig. 2. Comparison of 4 type of cell selection scheme with a normalized distance

Fig. 3 depicts the spectral efficiency of the proposed scheme by computer simulation and capacity upper bound which is derived from Section III as a function of difference of average received SINR. We assume that average received SINR from current cell is -4 dB and average received SINRs from non-primary cells belonging to the active set are same. Fig. 3 also shows that site selection diversity gain is large when difference of average received SINR is small (i.e., cell boundary region). It can also be seen that the analytic bound agrees well with the simulation results.

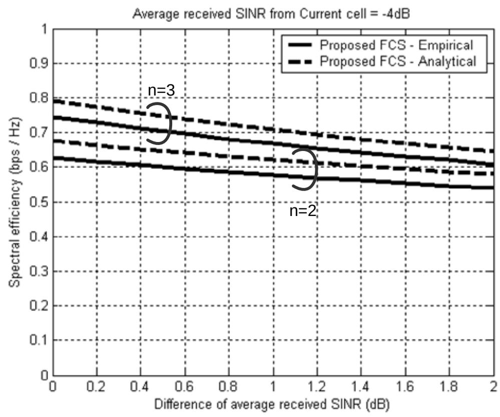


Fig. 3. Analytical upper bound of proposed scheme with a difference of average received SINR

Ⅴ. Conclusions

We proposed FCS with interference avoidance scheme in packet based OFDM systems. At cell boundary region, it is very important that MS exploits macro-diversity gain (i.e., site selection diversity) for being guaranteed better link quality and mitigates other cell interference effect which is highly fluctuated and unpredictable. With the proposed scheme, which is well conformed to above two purposes, it is possible to achieve robust performance at cell boundary region. We analyzed the performance of the proposed scheme by the use of upper bound analysis and verified it by computer simulation. Simulation results demonstrate that proposed scheme shows the performance improvement over conventional FCS

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