Fast Cell Site Selection with Interference Avoidance in Packet Based OFDM Cellular Systems

Keon-Wook Lee, Jae-Yun Ko and Yong-Hwan Lee
School of Electrical Engineering and INMC, Seoul National University
Kwanak P. O. Box 34, Seoul 151-600 Korea
e-mail: kwlee@ttl.snu.ac.kr, ylee@snu.ac.kr

Abstract - **In this paper, we consider fast cell site selection (FCS) in the downlink of a packet based orthogonal frequency division multiplexing cellular system. Mobile stations near the cell boundary can have opportunities to encounter a link that can provide better condition than the link in service due to the nature of fading effect. Conventional FCS schemes can track the variation of channel fading, exploiting a site selection diversity gain. However, mobile stations near the cell boundary may suffer from other cell interference (OCI) which is highly time-varying and unpredictable. To mitigate the OCI effect, we propose a new FCS scheme that exploits cell selection diversity while preventing adjacent cells from using the same sub-channels. We also consider the selection of candidate cells. The performance of the proposed FSC scheme is analyzed in terms of the capacity using an upper bound. Finally, analytic results are verified by computer simulation.**

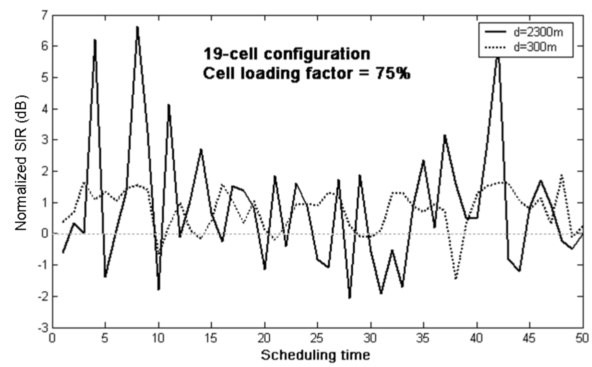

Fig. 1. Instantaneous SIR of users near the cell center and boundary.

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has been widely considered as one of the most promising transmission techniques for high speed packet-based wireless access systems. It can provide high throughput capacity by effectively mitigating the multi-path fading while flexibly allocating the resource in time and frequency domain [1, 2].

When a mobile station (MS) is in a multi-coverage or handover region, it can have opportunities to select a link better than the cell (or sector) in service. It can select the best link for the transmission of next frame and thus can achieve a site selection diversity gain by making the use a fast cell selection (FCS) technique [3]. The FCS can be treated as a special case of site selection diversity transmission (SSDT) in the code division multiple access (CDMA) system [3, 4].

A number of studies have been reported on the FCS technique [5-7]. When the system achieves a link diversity gain through spread spectrum or frequency hopping, it can mitigate the variation of instantaneous channel gain and thus may not noticeably achieve site selection diversity gain. In this case, it may be desirable to select a cell based on the variation of shadowing instead of instantaneous channel fading [5].

In conventional network architecture, the base station (BS) often employs a scheduler that works independently of other BSs. In other words, the scheduling is performed without considering the activity (or scheduling) of adjacent BSs. On the other hands, centralized scheduler architecture installs a scheduler at the top of a cluster comprising several BSs [6]. They can maximize the overall system performance by jointly considering the cell loading and channel quality information reported from all the MSs. To this end, two types of FCS schemes have been considered, called inter and intra BS FCS [7]. The inter BS FCS considers any cell in the network as a candidate for an active set which is defined as a collection of cells in good condition enough to be considered as a communication candidate for the transmission of next frame. Since the active set comprises links controlled by different BSs, the MS determines a serving cell without taking into account the resources available in the target cell. On the other hand, the intra BS FCS sets up an active set comprising cells covered by a common scheduler that controls the FCS operation considering both the channel quality and load balancing. The common scheduler determines a serving cell for each MS that reports the channel quality information of all links in the active set. Note that these conventional schemes only consider the selection diversity gain for performance improvement.

It is well known that the capacity of a cellular system having a single frequency network structure is mainly limited by other cell interference (OCI) rather than thermal noise (i.e., operating in so-called interference-limited environment) [8, 9]. As an example, Fig. 1 illustrates the instantaneous signal-to-interference power ratio (SIR) of user signals near the cell center (d=300 m) and the cell boundary (d=2300 m) as a function of the scheduling time (i.e., the time instant normalized with respect to the packet scheduling interval). For

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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 a variation larger than that near the cell center. Since the MS near the cell boundary is mostly affected by the signals from a few adjacent cells, it may experience fast time-varying interference mainly associated with the scheduling results of these adjacent cells, making it difficult to accurately estimate the instantaneous signal-to-interference and noise power ratio (SINR). The MS near the cell boundary also suffers from the attenuation of channel gain due to the large path-loss, making the reception of signal unreliable in the presence of strong interference from other cells. Thus, it is desirable to effectively reduce the interference from other cells.

In this paper, we consider the improvement of FCS in a packet based OFDM cellular system by reducing the OCI. For ease of description, define primary cell by a cell in the active set, which is in the best condition for the service of target MS, and non-primary cells by cells in the active set excluding the primary cell. The cells in the active set are candidates for the serving cell, but they are also the major source of interference. Thus, it may be desirable to control the non-primary cells not to generate interference signal. We consider the reduction of OCI by prohibiting the non-primary cells from using the same sub-channels as the primary cell uses for the service of MSs near the cell boundary. Unless the cells in the active set are fully loaded, the proposed scheme can provide site selection diversity as well as the OCI mitigation without additional resources. Moreover, utilizing good flexibility of resource sharing of packet-based OFDM systems in the time and frequency domain, the proposed scheme can easily handle the OCI problem.

The rest of the paper is organized as follows. Section II describes the proposed FCS with the use of interference avoidance. The performance of the proposed scheme is analyzed and verified by computer simulation in Section III. Finally, conclusions are summarized in Section V.

II. PROPOSED FCS SCHEME

Consider the downlink of a packet-based frequency division duplex (FDD) OFDM cellular system with the use of a universal frequency reuse factor. We assume that all the BSs are synchronized to each other and have the same transmit power. The use of an FDD scheme enables the MS to rapidly report the FCS signaling to the BS through a dedicated channel in the uplink. Thus, the proposed FCS scheme can track the channel variation and can accurately determine the primary cell.

In the proposed FCS scheme, the MS first determines the active set. Fig. 2 illustrates the procedure for the update of the active set, where Ω denotes a set of cells in the active set and $C(\Omega)$ denotes achievable capacity by the proposed scheme with the use of Ω.

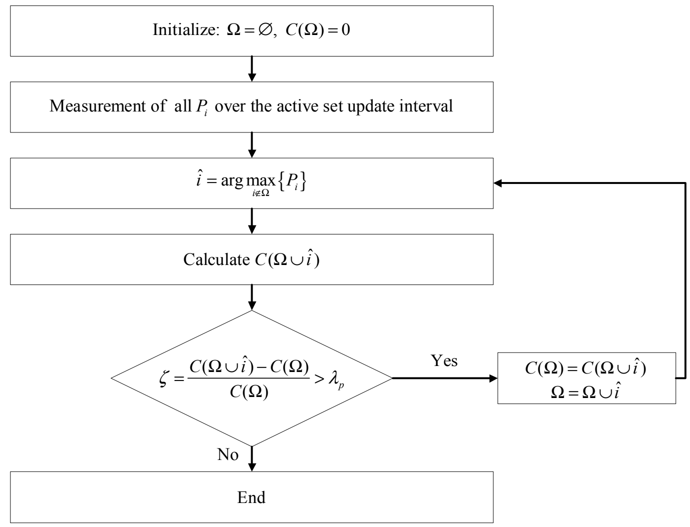

Fig. 2. Update of the active set in the proposed scheme.

1. First, initialize the parameters: $\Omega = \varnothing, C(\Omega) = 0$, where $\varnothing$ denotes an empty set.
2. The MS measures $\{P_i\}$ from all the cells in synchronization with itself, where P_i denotes the average signal power from cell i.
3. Choose a cell $\hat{i}$ providing the maximum average signal power, except the cells in Ω.
4. Calculate the achievable capacity $C(\Omega \cup \hat{i})$ of the proposed scheme when cell $\hat{i}$ is additionally added to the active set. The capacity $C(\Omega \cup \hat{i})$ can be calculated using (9) and (10) in Section III.
5. Define a performance enhancement indicator by $\zeta \triangleq \left(C(\Omega \cup \hat{i}) - C(\Omega)\right)/C(\Omega)$, which represent the amount of performance enhancement with the use of an additional cell $\hat{i}$. If ζ is larger than a pre-determined threshold λ_p, cell $\hat{i}$ is added to the active set and go to step 3. Otherwise, stop the update of the active set.

Then, the MS requests an admission for the proposed FCS to the cells in the active set. If a cell cannot afford to support the admission request due to the loading issue, it will be eliminated from the active set. The active set needs to be updated at a certain time interval rather than at every frame time, requiring a marginal increase of the computational complexity and signaling burden.

Once the active set is determined, the MS selects the primary cell in the active set at every frame time for the reception. As in [7], we also consider two cases; intra BS FCS and inter BS FCS with interference avoidance (IA). Since the cells in the active set are controlled by different BSs in the inter BS FCS with IA, each BS does not know the scheduling results of other BSs. As a result, BSs belonging to the non-primary cells do not have information on the sub-channels used by the primary cell. Thus, in the inter BS FCS with IA, it may be desirable for the IA scheduling to reserve common sub-channels in all cells in the active set. Such sub-channels can be determined by negotiation among the BSs in the active set during the update of active set. The MS selects the primary cell by only measuring the channel quality (e.g., instantaneous SINR) of the predetermined sub-channels of cells in the active set. Then, the MS requests a service to the primary cell through an uplink dedicated channel. Cells which do not receive a request from the MS become non-primary cells automatically. On the other hand, a common scheduler in the intra BS FCS with IA receives the channel quality information of all the cells in the active set from the MSs. Then, it controls the FCS with IA operation by making the use of both the channel quality and loading status.

III. PERFORMANCE ANALYSIS

We consider the performance of the proposed FCS scheme with an active set comprising n cells among total N cells in the cellular network. We assume that the channel characteristics are unchanged over an OFDM sub-channel. In Rayleigh fading environment, the instantaneous SINR $\gamma_{i,k,n}(t)$ of the received signal of MS k from cell i in the active set can be represented as

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

where $h_{i,k}(t)$ and $P_{i,k}$ respectively denote the channel gain and the average signal power from cell i to MS k, and N_0 denotes the power of zero mean additive white Gaussian noise (AWGN). Note that the first term in the denominator in (1) represents the total amount of interference power to MS k.

Since the non-primary cells do not use the sub-channels assigned for MS k by the primary cell, $\gamma_{i,k,n}(t)$ can be represented as

$$\gamma_{i,k,n}(t) = \frac{\left|h_{i,k}(t)\right|^2 \cdot P_{i,k}}{\sum_{j=1, j\notin active\_set}^{N} \left|h_{j,k}(t)\right|^2 \cdot P_{j,k} + N_0} = \frac{\left|h_{i,k}(t)\right|^2 \cdot P_{i,k}}{I_{k,n}(t) + N_0} \tag{2}$$

where $I_{k,n}(t)$ denotes the total amount of interference power excluding the interference from the non-primary cells. Note that $I_{k,n}(t)$ is independent of the choice of the primary cell for a given active set. Since the major interference is removed by the proposed scheme, the time variation of $I_{k,n}(t)$ is assumed to be negligible and the denominator term $I_{k,n}(t)+N_0$ can be approximated as its average power $I'_{k,n}$. Thus, (2) can further be approximated as

$$\gamma_{i,k,n}(t) \simeq \frac{\left|h_{i,k}(t)\right|^2 \cdot P_{i,k}}{I'_{k,n}} = \left|h_{i,k}(t)\right|^2 \cdot \bar{\gamma}_{i,k,n} \tag{3}$$

where $\bar{\gamma}_{i,k,n}$ represents the average SINR of MS k in service by cell i among n cells in the active set.

The inter BS FCS with IA simply selects a cell providing the maximum instantaneous SINR as the primary cell. On the other hand, the intra BS FCS with IA selects the primary cell considering the loading status and the instantaneous SINR of all cells in the active set. For ease of analysis, we assume that the loading status is good for the scheduling with IA. Thus, both proposed FCS schemes can select the primary cell based on the instantaneous SINR. The instantaneous SINR $\Gamma_{n,k}$ of MS k serviced by the proposed FCS scheme can be represented as

$$\Gamma_{n,k} = \max_{i\in\{1,\cdots,n\}} \{\left|h_{i,k}(t)\right|^2 \cdot \bar{\gamma}_{i,k,n}\}. \tag{4}$$

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

$$\begin{aligned} f_{\gamma_{i,k,n}}(z) &= \frac{1}{\bar{\gamma}_{i,k,n}} \cdot e^{\frac{-z}{\bar{\gamma}_{i,k,n}}} \\ F_{\gamma_{i,k,n}}(z) &= 1 - e^{\frac{-z}{\bar{\gamma}_{i,k,n}}} = 1 - \bar{\gamma}_{i,k,n} \cdot f_{\gamma_{i,k,n}}(z). \end{aligned} \tag{5}$$

Since $\gamma_{1,k,n}(t),\cdots,\gamma_{n,k,n}(t)$ are independent each other, the cdf and pdf of $\Gamma_{n,k}$ can be represented respectively as

$$\begin{aligned} F_{\Gamma_{n,k}}(z) &= \Pr\{\Gamma_{n,k} \le z\} \\ &= F_{\gamma_{1,k,n}}(z) \cdot F_{\gamma_{2,k,n}}(z) \cdots F_{\gamma_{n,k,n}}(z) \end{aligned} \tag{6}$$

$$\begin{aligned} f_{\Gamma_{n,k}}(z) &= \frac{dF_{\Gamma_{n,k}}(z)}{dz} \\ &= \left[\prod_{i=1}^{n} F_{\gamma_{i,k,n}}(z)\right] \cdot \sum_{i=1}^{n} \left(\frac{f_{\gamma_{i,k,n}}(z)}{F_{\gamma_{i,k,n}}(z)}\right) \\ &= \sum_{i=1}^{n} \left[\frac{1}{\bar{\gamma}_{i,k,n}} e^{-\frac{z}{\bar{\gamma}_{i,k,n}}} \cdot \prod_{\substack{j=1 \\ j\neq i}}^{n} \left(1 - e^{-\frac{z}{\bar{\gamma}_{j,k,n}}}\right)\right] \\ &= \sum_{i=1}^{n} \left[(-1)^{i+1} \cdot \sum_{j=1}^{{}_nC_i} i \cdot \frac{1}{H_{n,k}^{(i)}(j)} \cdot e^{-i \cdot \frac{1}{H_{n,k}^{(i)}(j)} \cdot z}\right] \end{aligned} \tag{7}$$

where ${}_nC_i = n!/\left((n-i)!i!\right)$ and $H_{n,k}^{(i)}(j)$ denotes the j-th element of set $H_{n,k}^{(i)}$ which comprises all the possible ${}_nC_i$ elements, each of which is the harmonic mean of i number of SINR values selected among n average SINR values

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$\{\overline{\gamma}_{1,k,n}, \overline{\gamma}_{2,k,n}, \cdots, \overline{\gamma}_{n,k,n}\}$ (i.e., the cardinality of the set $H_{n,k}^{(i)}$ is ${}_nC_i$). For example, $H_{n,k}^{(1)} = \{\overline{\gamma}_{1,k,n}, \overline{\gamma}_{2,k,n}, \cdots, \overline{\gamma}_{n,k,n}\}$ and $H_{n,k}^{(n)} = \left\{n / \left(\sum_{i=1}^{n} 1/\overline{\gamma}_{i,k,n}\right)\right\}$.

Thus, the channel capacity $C_p(n)$ of the proposed scheme with n selection diversity is given by

$$C_p(n) = E\left\{\log_2(1+\Gamma_{n,k})\right\}. \tag{8}$$

Using Jensen's inequality, it can be shown that

$$C_p(n) \le \log_2\left(1+E\left\{\Gamma_{n,k}\right\}\right) \tag{9}$$

where

$$E\left\{\Gamma_{n,k}\right\} = \sum_{i=1}^{n}\left[(-1)^{i+1}\cdot\sum_{j=1}^{{}_nC_i}\frac{H_{n,k}^{(i)}(j)}{i}\right]. \tag{10}$$

Thus, the proposed scheme can provide a capacity gain, mainly from the selection diversity gain and IA.

IV. Performance Evaluation

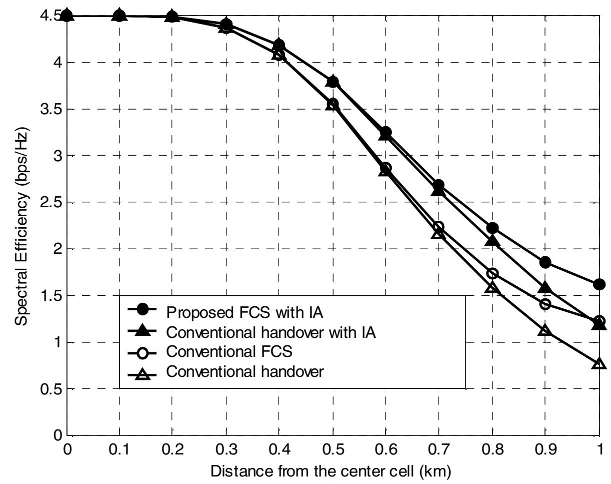
To verify the validation of the proposed scheme, we evaluate the performance of four cell selection schemes, conventional handover with/without IA and FCS with/without IA. The conventional handover schemes select the primary cell yielding the highest average SINR rather than the instantaneous SINR. The simulation environment is summarized in Table I.

Fig. 3 depicts the performance of four CS schemes in terms of the spectral efficiency according to the distance from the center cell. Compared to the conventional handover with/without IA, it can be seen that the proposed FCS is quite effective for MSs near the cell boundary. In the cell boundary region, the signals from the cells in the active set have almost the same average signal strength with independent fading channel gain. 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. Moreover, the proposed scheme can provide significant performance improvement by making the use of IA especially in the cell boundary region. The interference from the non-primary cells has a power comparable to that of the desired signal and has highly time-varying characteristics. Thus, by removing the interference signals from the non-primary cells, the target MS can obtain a noticeable performance gain and the use of $n=2$ or 3 is quite sufficient in practice. The proposed scheme exploits the merits of the selection diversity as well as the OCI mitigation. Hence, as shown in the simulation results, the proposed scheme is quite effective to MSs near the cell boundary.

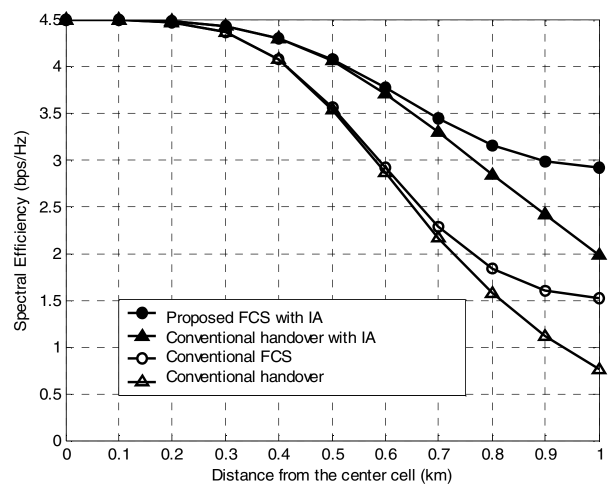
To verify the accuracy of the performance analysis, Fig. 4 depicts the analytic upper bound (9) along with the simulation results. We assume the same simulation condition as in Table I except no restriction on the maximum achievable spectral

TABLE I
SIMULATION PARAMETERS

Cell configuration	19 cells (two-tier)
Cell radius	1 km
Loading factor	0.75 (75% loading)
Path-loss exponent	4
Fading channel	Rayleigh fading
Link adaptation	Ideal (i.e., using the Shannon's capacity curve)
Maximum achievable spectral efficiency	4.5 bps/Hz
Outage stage occur	When the SINR is less than -5 dB



(a) When $n=2$



(b) When $n=3$

Fig. 3. Performance of the proposed FCS scheme.

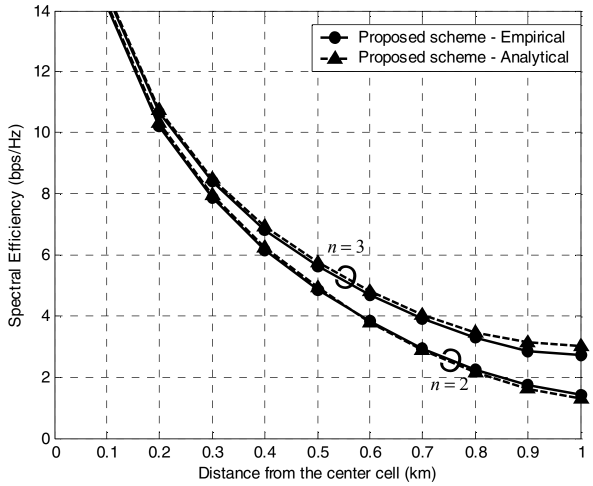


Fig. 4. Verification of the performance analysis.

efficiency. It can be seen that the analytic upper bound agrees well with the simulation results. However, it can be seen that when $n = 2$, the analytic upper bound is slightly less than the simulation results near the cell boundary. This is mainly due to the fact that the use of IA with $n = 2$ may not sufficiently consider the most of significant interference terms near the cell boundary, making it inaccurate to ignore the time-varying effect on $I_{k,n}(t)$. Thus, in such case, approximation in (3) does not hold anymore. Nonetheless, since the difference between the simulation results and analytic upper bound is negligible, the analytic upper bound can be applied to the analysis of performance.

V. CONCLUSION

It is desirable for MSs near the cell boundary to exploit macro-diversity gain (i.e., site selection diversity) and to mitigate the interference from other cells. To this end, we have proposed an FCS scheme with the use of interference avoidance in the downlink of a packet based OFDM cellular system. For ease and efficiency of interference avoidance, we have considered the elimination of major interference sources in the active set rather than the whole ones. The performance of the proposed scheme has been analyzed using an upper bound and verified by computer simulation. The simulation results show that the proposed scheme considerably improves the performance over the conventional ones particularly in the cell boundary region, which is of major concern.

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