Cell Scanning Algorithm Using Multiple Frames for IEEE 802.16e OFDMA Systems

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***Abstract*—In this paper, we consider a cell scanning algorithm for IEEE 802.16e OFDMA (Orthogonal Frequency Division Multiplexing Access) downlink systems in a multi-cell environment. A number of researches for cell search algorithm has been studied when there exist a home cell and neighboring cells using a different cell segment index. A cell scanning algorithm is proposed to detect low powered preamble signals which has same segment index as the homecell. From simulation results, it is shown that the number of cells that we can find and the amount of power difference that we can recognize with the proposed cell scanning algorithm. Moreover, we have shown that as the number of used frame increases, the detection performance increases compared to the conventional method.**

I. Introduction

Recently, demands for portable multi-media and mobile internet service are exponentially increasing and many researches are actively performed in order to satisfy these demands. One of systems which can satisfy these demands is IEEE 802.16e systems based on OFDMA and TDD mode [1]. Thus, IEEE 802.16e has attracted much attention and has been deployed in WiBro (Wireless Broadband Internet).

The cell scanning algorithm is to detect not only preamble signals of the home cell and neighboring cells in the first tier but also non-neighboring cells which may not be adjacent to the home cell. Thus, the cell scanning algorithm can be considered as an advanced version of a cell search algorithm, and is required for the cell planning and the system management.

There are several conventional cell search algorithms for IEEE 802.16e OFDMA systems [2]-[4]. In [2], an exhaustive search algorithm was proposed. However, this method suffers from prohibitive computational complexity. In order to resolve this problem, [3] proposed an adaptive length correlation method and reduces the time of the cell search. In [4], a cell identification algorithm based on differential cross-correlation was proposed to mitigate impairment of the frequency selective fading channel.

In this paper, a novel cell scanning algorithm is proposed, in which as many cells including non-neighboring cells as possible. Although the detection of low power preamble signals interfered by a high power preamble signal is not an easy task, the proposed algorithm improves the performance by employing a detection and cancelation scheme.

II. System model

IEEE 802.16e OFDMA is operating in a single carrier frequency band and the frequency reuse factor is approximately 1. The TDD frame is composed of DL (downlink) and UL (uplink) subframes with length $5ms$ and is composed of 42 OFDM symbols, where a preamble is located at the first symbol of every downlink frame.

The cell specific segment index is allocated to each cell as a protocol in the IEEE 802.16e system [1]. A relation between the cell index i and the segment index s can be expressed as

$$s = \begin{cases} 0, & i \in I_0\{0\ldots 31, 96, 99, 102, 105, 108, 111\} \\ 1, & i \in I_1\{32\ldots 63, 97, 100, 103, 106, 109, 112\} \\ 2, & i \in I_2\{64\ldots 95, 98, 101, 104, 107, 110, 113\}. \end{cases}$$

Subcarriers of the preamble are allocated according to the cell specific segment. Thus, preamble signals using the same segment interfere each other, which causes severe degradation.

In this paper, 1024-FFT sized OFDMA system is considered. From [1], the set of the preamble subcarriers is given as

$$P^s = \{86 + s + 3q | q \in \{0, \ldots, 283\}\}, \tag{1}$$

where 86 denotes the number of left guard band subcarriers. All of the preamble have 86 guard band subcarriers on the left side and the right side of the spectrum. In addition, DC carrier is not modulated at all and the appropriate PN is discarded. Therefore, the number of used subcarriers is 851.

The transmitter converts the signal in the frequency domain $c_{i,k}$, a symbol of the k-th subcarrier from the ith cell, into the signal in the time domain $c(i,d)$ by IDFT (Inverse Discrete Fourier Transform). The last N_g samples of each OFDM symbol are inserted at the start of the same OFDM symbol as CP(Cyclic Prefix) to deal with delay spread of the channel. The d-th sample of the i-th cell signal in the time domain is defined as

$$c(i,d) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} c_{i,k} e^{j2\pi kd/N}, \qquad -N_g \leq d < N, \tag{2}$$

where N denotes a total subcarrier number and $j^2 = -1$. The impulse response of channel in the time domain is given as

$$h(i,d) = \sum_{l=0}^{L-1} h_{i,l}(d)\, \delta(d - \tau_l), \tag{3}$$

where h_l denotes a channel coefficient of the l-th multi-path, τ_l denotes time delay of the l-th multi-path and L denotes the number of multi-path fading channel taps. The received signal of the d-th sample in time domain is obtained as

$$y(d) = \sum_{s=0}^{2} \sum_{i \in I_s} \sqrt{P_{s,i}} h(i,d) * c(i,d) + n(d), \tag{4}$$

where I_s denotes a set of cells in the s-th segment, $P_{s,i}$ denotes a power of the transmitted preamble signal from the i-th cell in the s-th segment, $n(d)$ denotes independent identically distributed (i.i.d) complex white Gaussian noise components with mean zero and σ^2 variance and $*$ denotes the convolution operation. In the frequency domain, the received signal of the k-th subcarrier Y_k is obtained by DFT (Discrete Fourier Transform) after removing the CP as

$$Y_k = \sum_{s=0}^{2} \sum_{i \in I_s} \sqrt{P_{s,i}} H_{i,k} c_{i,k} + N_k, \tag{5}$$

where N_k denotes noise components in the frequency domain and $H_{i,k}$ denotes the complex channel coefficient in the frequency domain.

III. Proposed cell scanning algorithm

Fig. 1 shows the overall process of the proposed cell scanning algorithm. First of all, the exact timing of the received signal is estimated by successive combination of Schmidl's, Park's, and Van de beek's methods [5]-[7]. This part composed of the initial and fine timing synchronization. After achieving the exact timing, the estimation and compensation of frequency offset are performed with Van de beek's method in [7]. Once the timing synchronization and frequency synchronization parts are successively carried out, channel compensation is performed in order to mitigate the channel impairments. Here, all of the residual processes are iteratively operated for the cell scanning algorithm from channel compensation part until the cell can not be detected any more. A differential vector obtained from channel compensation is used for cell identification in which the cell indices are obtained. To maintain a predetermined target false alarm probability, a threshold shall be determined in this part. After estimating the cell index, channel estimation with Van de beek's method in [8] and SNR estimation are carried out. The received SNR can be obtained in SNR estimation part with the estimated cell index and channel. Finally, a cancelation method is proposed to remove previously estimated preamble signals.

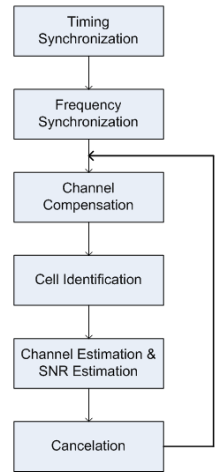

Fig. 1. Total flow chart of the proposed cell scanning algorithm.

A. Timing Synchronization

We assume that all of received preamble signals that we wish to detect in multi-path fading channel arrive in the CP duration. Hence, the proposed cell scanning algorithm can be operated with an estimated representable timing, which also allows preamble signals to be detected.

The three timing synchronization methods, Schmidl's, Park's and Van de beek's methods, are used to find the exact timing of the received signal [5]-[7]. First of all, we sample the received signal in the time domain at a regular interval and compute the initial timing synchronization metric [5]. If the value of the initial timing metric is larger than a specific threshold, we use the fine timing synchronization methods [6][7]. As a result, we can remove the plateau which makes the uncertainty of estimation from Schmidl's method and the uncertainty of estimation from Van de beek's method by appropriately using these three timing synchronization methods. Moreover, we also reduce the computational complexity from Park's timing synchronization method.

The conventional timing synchronization methods for OFDM systems use repetitive patterns or a guardband (CP: Cyclic prefix). However, the repetitive parts of the preamble used for IEEE 802.16e OFDMA systems are not exactly same in the time domain. But we know the preamble in the time domain has three pseudo repetitive subsymbols because each preamble uses one out of every three subcarriers. Thus, we can apply Schmidl's synchronization method, in which the correlation length is approximately $N/3$.

In [5], an auto-correlation for a correlation length, $N/3$, is given as

$$P_{Schmidl}(d) = \sum_{l=0}^{N/3-1} y(d+l)\, y^*(d+l+N/3). \tag{6}$$

The Schmidl's timing synchronization method estimates timing by using the auto-correlation obtained from (6), which is normalized by a total energy of the 2-nd subsymbol. The Schmidl's timing synchronization metric is defined as

$$M_{Schmidl}(d) = \frac{|P_{Schmidl}(d)|^2}{\sum_{l=N/3}^{2N/3-1} |y(d+l)|^2}. \tag{7}$$

And then, the estimated timing obtained by the Schmidl's method in the initial timing synchronization is given as

$$\tilde{d} = \arg\max_{d} \{ M_{Schmidl}(d) > \gamma_{\text{timing}} \}, \tag{8}$$

where γ_{timing} denotes a threshold for the timing synchronization. Here, we define a window D for the fine timing synchronization as

$$D = \left\{ d | \tilde{d} - \frac{\delta}{2} \leq d < \tilde{d} + \frac{\delta}{2} \right\}, \tag{9}$$

where δ denotes a size of window D.

Moreover, the preamble has another property. Since it only uses real numbers, it has the conjugate symmetry character. The exact timing is obtained with this property.

In [6], an auto-correlation for a correlation length, $N/2$, is given as

$$P_{Park}(d) = \sum_{l=0}^{N/2-1} y(d-l+N/2)\, y(d+l+N/2). \tag{10}$$

As in the Schmidl's timing synchronization metric (7), the Park's timing synchronization method estimates timing by using the auto-correlation obtained from (10), which is normalized by a total energy of the 2-nd subsymbol. The Park's timing synchronization metric is defined as

$$M_{Park}(d) = \frac{|P_{Park}(d)|^2}{\sum\limits_{l=0}^{N/2-1} |y(d+l+N/2)|^2}. \tag{11}$$

However, the Park's method can not estimate the exact timing in the multi-path fading channel. Thus, the Van de beek's method [7] is simultaneously used for fine timing synchronization with Park's method.

In [7], a metric of Van de beek's method is defined as

$$M_{Beek}(d) = \sum_{l=0}^{N_g-1} y(d+l)\, y^*(d+l+N). \tag{12}$$

Finally, the estimated timing obtained by Park's and Van de beek's methods in the fine timing synchronization is given as

$$\hat{d} = \arg\max_{d \in D} \left\{ M_{Park}(d) \cdot M_{Beek}(d) \right\}. \tag{13}$$

B. Frequency Synchronization

After obtaining the exact timing, we estimate and compensate a frequency offset by using the frequency synchronization method proposed by Van De Beek [7].

The Van De Beeks frequency synchronization method can estimate a factional frequency offset of received sysmbol. The estimated factional frequency offset of received sysmbol is given as

$$\hat{\varepsilon}_f = \frac{1}{2\pi} \arg \left\{ \sum_{l=0}^{N_g-1} y^*(d+l)\, y(d+l+N) \right\}, \tag{14}$$

which should be between -0.5 and 0.5.

C. Channel Compensation

After achieving timing and frequency synchronization, cross-correlations of the DFT output vector of the received preamble signal with all possible frequency domain preamble patterns are computed in the frequency domain for cell identification. Since channel estimation is not carried out in the initial cell identification process, there is some degradation in the performance over multi-path fading channels. To alleviate the channel impairments, we estimate a cell index by using a differentia-based cell identification method in the frequency domain. Let Y_k^s be the received signal of the s-th segment in the frequency domain as $Y_k^s = \sum\limits_{i \in I_s} \sqrt{P_{s,i}} H_{i,k} c_{i,k} + N_k$. Then a differential vector is expressed as

$$R_k = Y_{2k}^s Y_{2k+1}^{s\,*}. \tag{15}$$

To avoid a correlation between noises, non-overlapping subcarriers are chosen. Let $D_{j,k}$ be a known normalized cell specific preamble pattern of the j-th cell in the frequency domain. Then a differential vector is expressed as

$$P_k = D_{j,2k} D_{j,2k+1}. \tag{16}$$

D. Differential Cross-correlation

We can define a cell identification metric using differential vectors which were shown previously. The cell identification metric is defined as

$$\begin{aligned} \eta_j &= \frac{\left\{ \sum\limits_{k=0}^{K/2-1} \mathrm{Re}(R_k)\, P_{j,k} \right\}^2}{\left(\sum\limits_{k=0}^{K/2-1} \{\mathrm{Re}(R_k)\}^2 \right) \left(\sum\limits_{k=0}^{K/2-1} |P_{j,k}|^2 \right)} \\ &= \frac{\left\{ \dfrac{2}{K} \sum\limits_{k=0}^{K/2-1} \mathrm{Re}(R_k)\, P_{j,k} \right\}^2}{\dfrac{2}{K} \sum\limits_{k=0}^{K/2-1} \{\mathrm{Re}(R_k)\}^2}, \end{aligned} \tag{17}$$

where j denotes a candidate for the cell index. In order to take the simple form, the numerator and the denominator were multiplied by $2/K$.

The estimated cell index is obtained by finding j which has a maximum value of the cell identification metric. In addition, the cell identification metric is compared with a threshold to maintain the false alarm probability. Cell indices which are larger than the threshold become the candidates of the transmitted preamble signal. The estimated cell index is given by

$$\hat{j} = \arg\max_{j} \{\eta_j > \gamma\}, \tag{18}$$

where γ denotes a threshold. Since we normalize the cell identification metric by an average power of the received signal, effects of the frequency selective fading, intra-cell interferences and the noise are can be mitigated.

E. Channel Estimation and SNR Estimation

The channel estimation is performed with the estimated cell index. The Modified LS method in [8] for the channel estimation is used to get the transmitted preamble sequence with the estimated cell index. Thus, we can also obtain channel coefficients, interference signals and noise with estimated preamble sequence as follows

$$\begin{aligned} Y_k^s/c_{\hat{j},k} &= \sqrt{P_{s,\hat{j}}} H_{\hat{j},k} c_{\hat{j},k}/c_{\hat{j},k} + \sum_{i \neq \hat{j}} \sqrt{P_{s,i}} H_{i,k} c_{i,k}/c_{\hat{j},k} + N_k/c_{\hat{j},k} \\ &= \sqrt{P_{s,\hat{j}}} H_{\hat{j},k} + I_k + N_k. \end{aligned} \tag{19}$$

Let $Z_k = \sqrt{P_{s,\hat{j}}} H_{\hat{j},k} + I_k + N_k, k = 1, \cdots, K-1$. Then elements of a vector $\mathbf{Z}$ are allocated as the estimated preamble sequence pattern with Z_k. $\mathbf{Z}$ is given as

$$\mathbf{Z} = \left[0 \ \cdots \ 0 \ Z_0 \ 0 \ 0 \ Z_1 \ 0 \ \cdots \ 0 \ Z_{K-2} \ 0 \ 0 \ Z_{K-1} \ 0 \ \cdots \ 0\right]. \tag{20}$$

Let $\mathbf{D}$ be an IDFT matrix, which is given as

$$\mathbf{D} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & e^{j2\pi \cdot 1 \cdot 1/N} & \cdots & e^{j2\pi \cdot (N-1) \cdot 1/N} \\ \vdots & \vdots & & \vdots \\ 1 & e^{j2\pi \cdot 1 \cdot (N-1)/N} & \cdots & e^{j2(N-1)(N-1)/N} \end{bmatrix}. \tag{21}$$

For obtaining the channel impulse response, IDFT are performed as

$$\mathbf{z} = \frac{1}{\sqrt{N}} \mathbf{DZ}, \tag{22}$$

where $\mathbf{z} = z(d), 0 \leq d \leq N$. Zero fading is performed except for the sampled signals in CP duration which are larger than a specific threshold as

$$q(d) = \begin{cases} Z(d) & if \, |z(d)| > \gamma_{est} \ and \ d \leq CP \\ 0 & o.w, \end{cases} \tag{23}$$

where γ_{est} denotes a threshold for the channel estimation. Let $\mathbf{q} = q(d), 0 \leq n \leq N$. Then, an estimated channel coefficients are finally obtained with DFT as

$$\hat{\mathbf{H}} = \sqrt{N} \mathbf{D}^H \mathbf{q}. \tag{24}$$

After obtaining channel coefficients, we can estimate SNR with estimated preamble sequence and channel coefficients. First of all, we have to estimate q noise power. The noise power can be easily estimated from left and right guard band. The estimated noise power is expressed as

$$\hat{\sigma}^2 = \frac{1}{G} \sum_{g=0}^{G-1} |N_g|^2, \tag{25}$$

where G denotes the subcarrier number of left and right guard band. The signal power is not easy to estimate due to the signals from other cells. The estimated signal power is given as

$$\begin{aligned} \hat{P}_{s,\hat{j}} \left|\hat{H}_{\hat{j},k}\right|^2 &= \frac{1}{K} \sum_{k=0}^{K-1} Y_k^s \sqrt{\hat{P}_{s,\hat{j}}} \hat{H}_{\hat{j},k}^* c_{\hat{j},k}^* \\ &= \frac{1}{K} \sum_{k=0}^{K-1} \left[\left(\sum_{i \in I_s} \sqrt{P_{s,i}} H_{i,k} c_{i,k} + N_k \right) \sqrt{\hat{P}_{s,\hat{j}}} \hat{H}_{\hat{j},k}^* c_{\hat{j},k}^* \right] \\ &= \frac{1}{K} \sum_{k=0}^{K-1} \sqrt{P_{s,\hat{j}}} H_{\hat{j},k} c_{\hat{j},k} \sqrt{\hat{P}_{s,\hat{j}}} \hat{H}_{\hat{j},k}^* c_{\hat{j},k}^{*} \\ &\quad + \frac{1}{K} \sum_{k=0}^{K-1} \left[\left(\sum_{i \neq \hat{j}} \sqrt{P_{s,i}} H_{i,k} c_{i,k} + N_k \right) \sqrt{\hat{P}_{s,\hat{j}}} \hat{H}_{\hat{j},k}^* c_{\hat{j},k}^* \right] \\ &= P_{s,\hat{j}} \left| H_{\hat{j},k} \right|^2 + e_p, \end{aligned} \tag{26}$$

where e_p denotes estimation error of signal power. Then, the SNR of received signal can be estimated from the estimated noise power and the signal power. The estimated SINR is obtained as

$$\hat{\xi}_b = \frac{\hat{P}_{s,\hat{j}} \left|\hat{H}_{\hat{j},k}\right|^2}{\sum_{i \neq \hat{j}} \hat{P}_{s,i} \left|H_{i,k}\right|^2 + \hat{\sigma}^2}. \tag{27}$$

F. Cancelation

The proposed cancelation method is used for removing previously estimated preamble signals and detecting the signal from neighboring cells. This method is performed with the estimated preamble signal, channel coefficients and SNR.

$$\begin{aligned} Y_k^s - \sqrt{P_{s,\hat{j}}} \hat{H}_{\hat{j},k} c_{\hat{j},k} &= \sqrt{P_{s,\hat{j}}} H_{\hat{j},k} c_{\hat{j},k} - \sqrt{P_{s,\hat{j}}} \hat{H}_{\hat{j},k} c_{\hat{j},k} \\ &\quad + \sum_{i \neq \hat{j}} \sqrt{P_{s,i}} H_{i,k} c_{i,k} + N_k \\ &= \sqrt{P_{s,\hat{j}}} \left(H_{\hat{j},k} - \widehat{H}_{\hat{j},k} \right) c_{\hat{j},k} \\ &\quad + \sum_{i \neq \hat{j}} \sqrt{P_{s,i}} H_{i,k} c_{i,k} + N_k \\ &= \sqrt{P_{s,\hat{j}}} e_{\hat{j},k} c_{\hat{j},k} + I_k + N_k, \end{aligned} \tag{28}$$

where $e_{\hat{j},k}$ denotes a channel estimation error.

The effect of previously estimated preamble signals can be mitigated by using the proposed cancelation method. Low power preamble signals shadowed by high power preamble signals can be detect from the canceled signal. Remaining low power preamble signals which used the same segment can be also detected by repetitively using channel compensation, cell identification, channel estimation, SNR estimation and cancelation method.

IV. Simulation results

In this paper, we have proposed cell scanning algorithm using multiple frames in a multi-cell environment. The performance of the proposed algorithm is evaluated in this section. The parameters for the simulation is listed in Table I. We assumed that timing synchronization and frequency synchronization are perfect in order to measure the detection performance with multiple frames evaluated the detection performance only.

TABLE I
SIMULATION PARAMETERS

Parameter	Values
Carrier Frequency	2.3Ghz
Channel model	Itu-R, Veh. A
Mobile velocity	10 km/h
FFT size (N)	1024
CP size (CP)	128

We also assumed that the channel is invariant during one OFDM symbol but the variation of channel is fast enough to guarantee the independency between channels .

From Figs. 2 and 3, the amount of power difference that we can recognize and the number of cells that we can find when we use multiple frames are found. Fig. 2 shows the detection failure probability of the cell which are received with 15dB less power than the home cell. Fig. 3 shows the detection failure probability of a cell when there are 5 different cells with same power. As the number of used frames increases, the detection performance also increases while that of the cell scanning algorithm without cancelation does not. From above results, the proposed cancelation method dramatically increases the detection performance in various situations.

We can derived the number of required frames with different target false alarm probability and target detection failure probability. If we set the target false alarm probability and the target detection failure probability as 10^{-2}. Then, 8 frames is needed to detect the cell which has 15dB less received power compared to that of the home cell. We can also detect a cell within 5 cells of equal received power with only 4 frames.

V. CONCLUSION

In this paper, we proposed the novel cell scanning algorithm for IEEE 802.16e OFDMA systems. Low power preamble signals could be detected by the proposed cell scanning algorithm. From simulation results, it was shown that the proposed cancelation method could remove the previously estimated preamble signals very well. Moreover, the number of cells that we can find and the amount of power difference that we can recognize are shown. By using independent multiple frames, it was shown that the detection performance was improved due to the time diversity. From the simulation results, 8 frames was needed to detect the cell which has 15dB less received power compared to that of the home cell when the target false alarm probability and the target detection failure probability set to 10^{-2}. Moreover, we could detect a cell within 5 cells of equal received power with only 4 frames with the same target false alarm probability and the same target detection failure probability.

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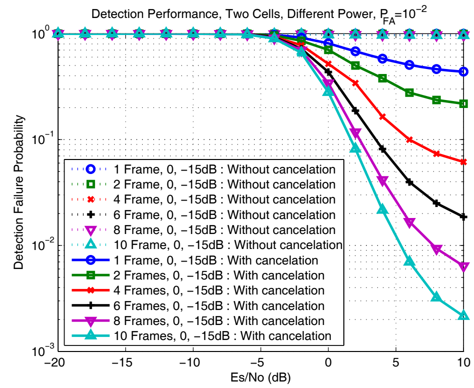

Fig. 2. Detection performance in fading channel, Two cells, Different Power, $P_{FA} = 10^{-2}$.

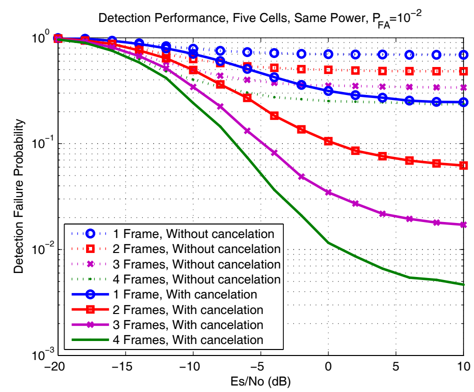

Fig. 3. Detection performance in fading channel, Five cells, Same Power, $P_{FA} = 10^{-2}$.

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