Use of Periodic Pilot Tones for Identifying Base Stations of FH-OFDMA Systems

Young-Ho Jung and Yong H. Lee

***Abstract*— A base station (BS) identification scheme for frequency-hopping (FH) orthogonal frequency division multiple access (OFDMA) is proposed. This scheme is based on the use of periodically inserted pilot tones carrying binary information. The identification process consists of two steps. First, locations of pilot tones are detected and second, the binary sequences associated with the pilots are identified. Modified maximum likelihood (ML) rules for the two steps are derived. Computer simulation results demonstrate that the proposed scheme can outperform the existing method that utilizes the slope of a pilot tone hopping sequences, yet it is considerably simpler to implement.**

***Index Terms*— Cell search, OFDMA, frequency hopping, generalized likelihood ratio test.**

I. Introduction

A FH-OFDMA based system, which was considered in IEEE 802.20 standardization [1], [2] is based on the use of a Latin square hopping sequence [3]. Such a sequence generates a hopping pattern with a unique slope, and BSs are identified from the slope of the pilot tone hopping sequence [1], [2]. The identification scheme is well suited to the Latin square hopping-based FH-OFDMA system, but cannot be employed for FH-OFDMA systems with other types of hopping sequences [4]. Furthermore, its implementation can be difficult, because determining the slope of the hopping pattern tends to need heavy computation.

The BS identification scheme proposed in this paper suggests the use of periodically inserted pilot tones carrying binary information. While each user hops from one subcarrier to another, the pilot tones are fixed in the frequency domain. This fact simplifies the detection of pilot locations, yet the probability of hitting between the pilot and user data remains almost the same, as compared with the existing system in which both pilot and user data hop. After detecting the locations of pilot tones, the binary sequence transmitted over the pilot is identified under the assumption that the channel is quasi-static within *two* successive OFDM symbol periods. Computational complexity comparison and simulation results indicate that the proposed approach, consisting of pilot location detection followed by pilot sequence identification, is simpler to implement and can perform better than the scheme in [1].

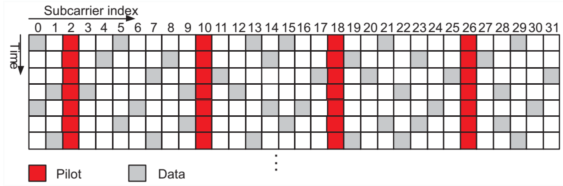

Fig. 1. An example of pilot and data transmission according to the proposed method when $N = 32$, $N_p = 4$, $M = 8$, $m = 2$ and 6 data samples are transmitted over each OFDM symbol.

II. System Model

According to the proposed method, MN_{seq} different BSs can be identified, where M is the period of pilot location, and N_{seq} is the number of available pilot sequences. In the proposed method, pilot tones are located periodically. Let N, N_p and N_d denote the numbers of total subcarriers, pilots and data samples, respectively. The index of the j-th pilot subcarrier, $j \in \{1, 2, \cdots, N_p\}$, in an OFDM symbol can be expressed as $(j-1)M + m$ where $m \in \{0, 1, \cdots, M-1\}$ is the pilot location candidate index. The proposed method first determines the pilot location by estimating m, and then identifies the pilot sequence – details will be presented in the following section. The locations of data subcarriers vary according to a FH pattern. In general, to mitigate intercell interference, only a portion of the total subcarriers are used for pilot and data transmission and the rest remain unused (Fig. 1).

After frequency offset compensation, the frequency domain received signal at the n-th subcarrier of the i-th OFDM symbol is expressed as

$$Y(i,n) = \rho_n(i) H(i,n) d_n(i) + w(i,n), \quad (1)$$

where $d_n(i)$ denotes either a pilot or an information sample transmitted through the n-th subcarrier of the i-th OFDM symbol time, $H(i,n)$ denotes the corresponding frequency domain channel, $w(i,n)$ is additive white Gaussian noise (AWGN), and $\rho_n(i)$ is an indicator variable defined as

$$\rho_n(i) = \begin{cases} 1, & \text{if a pilot or an information sample is transmitted,} \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

$\{Y(i,n) | n = 0, \cdots, N-1\}$ can be expressed by a vector $\mathbf{Y}(i) = [Y(i,0),\ Y(i,1), \cdots,\ Y(i,N-1)]$. Given the n-th subcarrier which is not occupied by a pilot, the probability that this subcarrier carries an information symbol can be written as $\alpha \triangleq \frac{N_d}{N-N_p}$. Therefore, the probability mass function (pmf)

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of $\rho_n(i)$ is given by

$$P(\rho_n(i)=1)=\begin{cases}1, & \text{if } n \text{ is a pilot subcarrier,}\\ \alpha, & \text{otherwise,}\end{cases} \quad (3)$$

and $P(\rho_n(i)=0)=1-P(\rho_n(i)=1)$.

III. Proposed Base Station Identification Method

A. Pilot Position Identification

To minimize the intercell interference among pilot subcarriers, pilot location parameter m is assigned to each BS so that neighboring BSs have different m values (reusing m with the reuse factor M is possible).

Supposed that the set of N_s OFDM symbols $\mathbf{S_Y}=[\mathbf{Y}(1),\ \mathbf{Y}(2),\cdots,\mathbf{Y}(N_s)]$ is received, in which $\{\mathbf{Y}(i)\}$ are independent of each other. Determining m by observing $\mathbf{S_Y}$ is an M hypothesis testing problem that can be solved under the following assumptions.

(A.1) $N_d < N - N_p$.

(A.2) $\rho_n(i)=\begin{cases}1, & \text{if } n \text{ is a pilot subcarrier index,}\\ \alpha, & \text{otherwise.}\end{cases}$

(A.1) is true if there is at least one subcarrier which is not used for transmission in each OFDM symbol. This assumption guarantees that $\alpha < 1$. (A.2) relaxes the integer constraint in the original definition of $\rho_n(i)$ in (2). It can be justified due to the fact that the expected value of $\rho_n(i)$ is equal to α when n is not a pilot subcarrier.

The conditional joint probability density function (pdf) of OFDM symbols in $\mathbf{S_Y}$ assuming m, $\{H(i,n)\}$, $\{\rho_n(i)\}$ and $\{d_n(i)\}$ is given by

$$f(\mathbf{S_Y}|m,H(i,n),\rho_n(i),d_n(i))=\frac{1}{(2\pi\sigma^2)^{NN_s}}e^{L_m(\mathbf{S_Y})}, \quad (4)$$

where

$$L_m(\mathbf{S_Y})=-\sum_{i=1}^{N_s}\sum_{n=0}^{N-1}|Y(i,n)-\rho_n(i)H(i,n)d_n(i)|^2. \quad (5)$$

To evaluate the right-hand-side (RHS) of (5), the knowledge of $H(i,n)$ and $d_n(i)$ is necessary (once m is given, $\rho_n(i)$ becomes known – this is due to (A.2)). The channel information $H(i,n)$ may be estimated by

$$\hat{H}(i,n)=d_n^*(i)Y(i,n)/|d_n(i)|^2, \quad (6)$$

which is the ML estimate that maximizes $f(\mathbf{S_Y}|m,\rho_n(i),d_n(i))$. If $H(i,n)$ in (5) is replaced by $\hat{H}(i,n)$, then (5) becomes

$$L_m(\mathbf{S_Y})=-\sum_{i=1}^{N_s}\sum_{n=0}^{N-1}|Y(i,n)-\rho_n(i)Y(i,n)|^2 \quad (7)$$

$$=-(1-\alpha)^2\sum_{i=1}^{N_s}\sum_{n=0}^{N-1}|Y(i,n)|^2 \quad (8)$$

$$+(1-\alpha)^2\sum_{i=1}^{N_s}\sum_{v=1}^{N_p}|Y(i,(v-1)M+m)|^2. \quad (9)$$

In (7) it is interesting to note that evaluating the squared error no longer needs the knowledge of $d_n(i)$. Because (8) is independent of m, we get the following detection rule:

$$\hat{m}=\arg\max_{m\in\{0,\cdots,M-1\}}\sum_{i=1}^{N_s}\sum_{v=1}^{N_p}|Y(i,(v-1)M+m)|^2. \quad (10)$$

In this rule, the pilot position is identified by comparing the accumulated signal energy of the subcarriers located at candidate pilot positions. The rule in (10) is based on the maximization of $f(\mathbf{S_Y}|m,\hat{H}(i,n),\rho_n(i),d_n(i))$. This type of hypothesis testing is called the generalized likelihood ratio test (GLRT) [5].

B. Pilot Sequence Identification

To simplify notation, let $\{Y_v(i)|v=1,2,\cdots,N_p\}$ denote the received signal at the pilot locations of the i-th OFDM symbol where $Y_v(i)=Y(i,(v-1)M+\hat{m})$. Suppose that the pilot sequence corresponding to $\{Y_v(i)\}$ is the l-th pilot sequence, which is an N_p-dimensional vector denoted as $[d_{l1}(i),d_{l2}(i),\cdots,d_{lN_p}(i)]^T$ where $d_{lv}(i)\in\{-1,1\}$ (Fig. 2). Assuming $\hat{m}=m$, the ML rule maximizing (4) for determining l is expressed as

$$\hat{l}=\arg\min_{l'\in\{0,\cdots,N_{seq}-1\}}\sum_{i=1}^{N_s}\sum_{v=1}^{N_p}|Y_v(i)-H_v(i)d_{l'v}(i)|^2, \quad (11)$$

where $H_v(i)=H(i,(v-1)M+\hat{m})$ and N_{seq} is the number of candidate sequences. In contrast to (5), which accumulates the squared errors for all subcarriers, (10) only accumulates those at pilot locations for which $\rho_n(i)=1$. Since $H_v(i)$ is unknown, we may consider the GLRT in which $\hat{H}_v(i)=d_{l'v}(i)Y(i,n)/|d_{l'v}(i)|^2$ is used for $H_v(i)$ in (11). However, in this case, the squared error $|Y_v(i)-\hat{H}_v(i)d_{l'v}(i)|^2$ becomes zero for all l'. Therefore, an alternative estimate for $H_v(i)$ is needed. An ML estimate which is suitable for our purpose can be derived by observing $\{Y_v(i-1),Y_v(i)\}$ under the assumption that $H_v(i)=H_v(i-1)$. The resulting ML estimate is given by

$$\hat{H}_{l'v}(i)=\frac{\{d_{l'v}(i-1)Y_v(i-1)+d_{l'v}(i)Y_v(i)\}}{|d_{l'v}(i-1)|^2+|d_{l'v}(i)|^2}. \quad (12)$$

Replacing $H_v(i)$ in (11) with (12), we get the following detection rule:

$$\hat{l}=\arg\max_{l'}\sum_{i=2}^{N_s}\sum_{v=1}^{N_p}Y_v(i)Y_v^*(i-1)d_{l'v}(i)d_{l'v}(i-1), \quad (13)$$

where $l'\in\{0,\cdots,N_{seq}-1\}$. This rule evaluates the correlation between differentially encoded received signals and differentially encoded pilot sequences. To simplify the detection procedure, we may transmit an all one sequence at odd times and transmit $\mathbf{d}_{l'}=[d_{l'1},\ \cdots,\ d_{l'P}]^T$ at even times. Then $d_{l'v}(i)d_{l'v}(i-1)=d_{l'v}$ and the rule in (13) is simplified as

$$\hat{l}=\arg\max_{l'\in\{0,\cdots,N_{seq}-1\}}\Lambda_{l'}. \quad (14)$$

where $\Lambda_{l'}=\sum_{i=2}^{N_s}\sum_{v=1}^{N_p}Y_v(i)Y_v^*(i-1)d_{l'v}$.

From now, the conditions to maximize the correct identification probability for the pilot sequence will be discussed

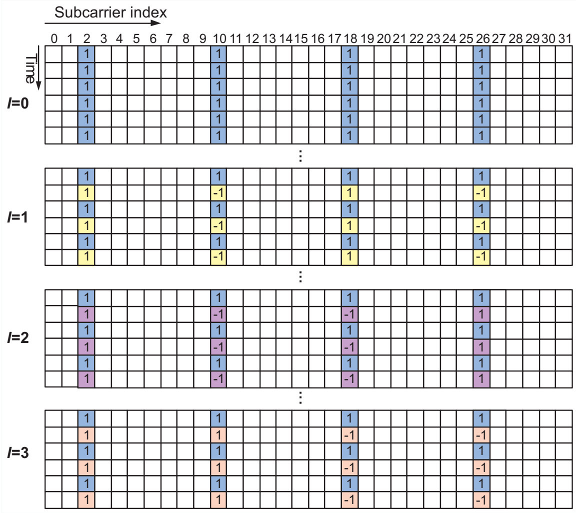

Fig. 2. An example illustrating the pilot sequences when $m = 3$ and $N_{seq} = 4$. Here the pilot sequence at odd times are all one sequences and those at even times are Hadamard sequences.

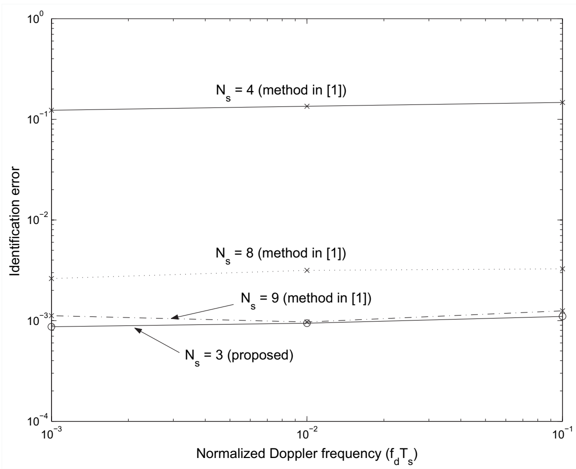

Fig. 3. Comparison of BS identification errors where N_s is the number of OFDM symbols used for the identification.

and based on them, the optimum pilot sequences maximizing identification probability are designed. In (14), $\Lambda_{l'}$ is a random variable whose expectation is given by

$$E[\Lambda_{l'}] = \begin{cases} \sum_{i=2}^{N_s} \sum_{v=1}^{N_p} |H_v(i)|^2 & \text{, if } l' = l \\ \sum_{i=2}^{N_s} \sum_{v=1}^{N_p} |H_v(i)|^2 d_{l'v} d_{lv} & \text{, if } l' \neq l. \end{cases} \quad (15)$$

Since the probability density function of $\Lambda_{l'}$ is symmetric with respect to its expectation, when the Hamming distance between $\mathbf{d}_l$ and $\mathbf{d}_{l'}$ is maximized, the difference between $E[\Lambda_{l'}|l' = l]$ and $E[\Lambda_{l'}|l' \neq l]$ also can be maximized, and the pairwise detection error probability can be minimized. Because detection error mainly comes from the sequence whose Hamming distances compared with $\mathbf{d}_l$ is minimum, when the minimum Hamming distance among $\{\mathbf{d}_l | l = 0, \cdots, N_{seq} - 1\}$ are maximized, detection probability can be maximized. Therefore, (N_p, $\log_2 N_{seq}$) [1] block codes maximizing minimum Hamming distance are optimum pilot sequences maximizing the probability of correct identification.

[1]In a (n, k) block code, n is the length of block code and k is the length of the original information block.

For example, in the case of $N_p = N_{seq}$, minimum distance of Hadamard sequence is $N_p/2$ and it is identical to that of the upper bound of minimum distance [6], [7]. Therefore, in this case the identification error can be minimized by assigning a Hadamard sequence to $\{\mathbf{d}_l\}$, as shown in Fig. 2.

IV. Simulation Results

The performance of the proposed method was compared with the existing method in [1] through computer simulation with the following parameters: $N = 128$, $N_p = 16$, $M = 8$, $N_{seq} = 16$ and the number of hopping sequences N_{hop} was 128 (For the methods in [1], N should be a prime number, and N and N_{seq} are set to 127). 30 independent data streams were transmitted by using randomly selected Latin square hopping sequences, and 12 tap frequency selective Rayleigh fading with exponentially decaying power profile was assumed. Fig. 3 shows the BS identification error versus the normalized Doppler frequency $f_d T_s$ ($f_d T_s \in \{0.001, 0.01, 0.1\}$) when $E_b/N_0 = 3$dB. The proposed method with $N_s = 3$ outperformed the existing method with $N_s \leq 8$. To reach the performance of the former, the existing method needed 9 OFDM symbols ($N_s = 9$). The number of operations (multiplication or addition) for the conventional method in [1] and the proposed method is given by $NN_{hop}(N_p + N_s)$ and $NN_s + 2(N_s - 1)N_p N_{seq}$ respectively. The proposed scheme was considerably simpler to implement. For example, the number of multiplications and additions needed by the proposed method with $N_s = 3$ was 1408, while that needed by the existing method was 306451 when $N_s = 3$ and 403225 when $N_s = 9$. In the aid of two step parameter estimation approach, the number of candidates can be dramatically reduced and even with much less computational complexity, the proposed BS identification method can outperform the conventional method which directly estimate the slope of Latin square sequence.

V. Conclusion

A base station identification method for FH-OFDMA systems was proposed. In the proposed method, by identifying the position of pilots and the pilot sequence, a base station is identified. It was shown though simulation that the proposed method outperformed the existing method utilizing the slope of a pilot tone hopping sequences, yet it was much simpler to implement. Further work in this area will include BS identification for multi-input multi-output FH-OFDMA systems.

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