Base station identification for FH-OFDMA systems

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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, location of pilot tones are detected and second, the binary sequence 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.**

I. INTRODUCTION

A FH-OFDMA based system which is being 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], [5]. 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 to transmit the information of the hopping patterns. While each user hops from one subcarrier to another, the pilot tone is fixed in the frequency domain. This fact simplifies the detection of pilot locations, yet the probability of hitting between the pilot or data of an adjacent cell 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 *two* quasi-static within *two* successive OFDM symbol period. Computational complexity comparison and simulation results indicate that the proposed approach to BS identification, consisting of pilot location detection followed by pilot sequence identification, is simpler to implement and can perform better than the scheme in [1].

II. SYSTEM MODEL

In the proposed method, pilot tones are located periodically. Let N, N_p and N_d denote the number of total subcarriers, that of pilots and that of data, respectively, in an OFDM symbol. The index of the j-th pilot subcarrier, $j \in \{1, 2, \cdots, N_p\}$, can be expressed as $(j-1)M + m$ where M is the period of pilot location and $m \in \{0, 1, \cdots, M-1\}$. Fig.1 illustrates the pilot locations when $N = 32$, $N_p = 4$ and $M = 8$. Note that there are eight groups of pilot locations depending on the choice of m. 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. 2). For example, the FH-OFDMA system in [2] only exploits about 30% of the subcarriers for transmission.

Assuming perfect frequency synchronization, the frequency domain received signal at the n-th subcarrier of the i-th OFDM symbol is expressed as

$$Y(i,n) = \rho_n(i)H(i,n)d_n(i) + w(i,n), \qquad n \in \{0, \cdots, N-1\}, \tag{1}$$

where $d_i(n)$ denotes either a pilot or a data sample transmitted through the n-th subcarrier at the i-th OFDM symbol time, $H(i,n)$ denotes the corresponding frequency domain channel, $w(i,n)$ is AWGN, and $\rho_n(i)$ is an indicator variable defined as

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

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

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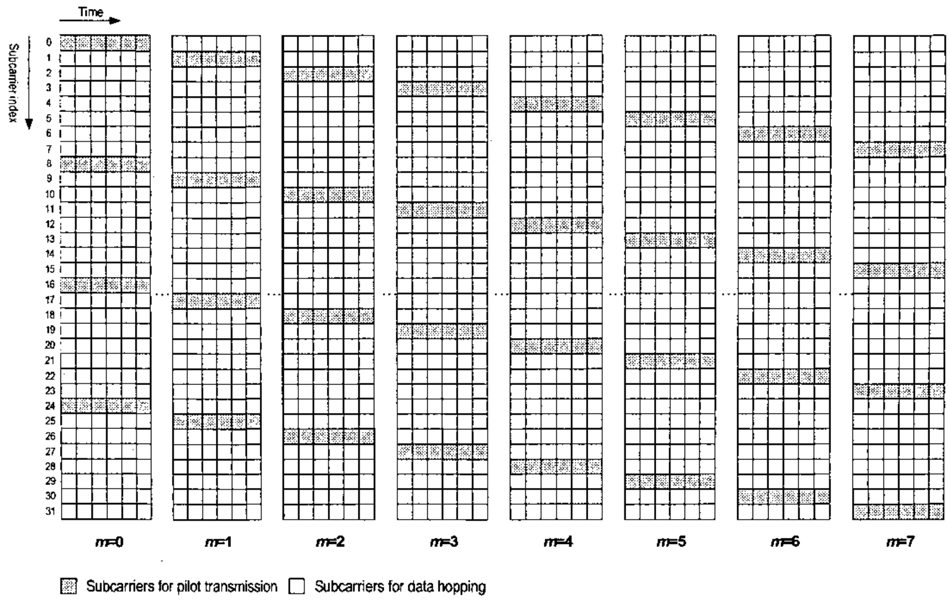

Fig. 1. Pilot locations when $N = 32$, N_p=4 and M=8.

function (pmf) of $\rho_n(i)$ is given by

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

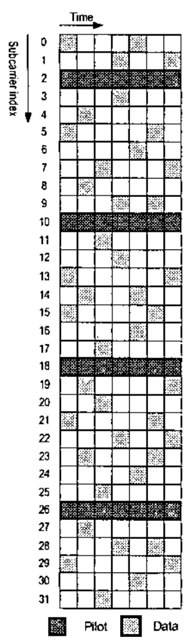

Fig. 2. An example of pilot and data transmission according to the proposed method when $N = 32$, $N_p = 4$, $M = 8$, $m = 2$ and 6 data samples are transmitted over each OFDM symbol.

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

III. Proposed Base Station Identification Method

Each BS is identified by assigning a pilot sequence and a pilot location which is characterized by m (see again Fig. 1). The total number of BSs that can be identified is given by MN_{seq} where N_{seq} is the number of available pilot sequences ($m \in \{0, 1, \cdots, M-1\}$). At a mobile unit, the pilot location is identified first by estimating m and then pilot sequence identification follows. Details on this two step procedure are described in the following subsections.

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 N_s OFDM symbols $\{\mathbf{Y}(1), \cdots, \mathbf{Y}(N_s)\}$ are received where $\mathbf{Y}(i) = [Y(i,0), \cdots Y(i,N-1)]^T$ and $\{\mathbf{Y}(i)\}$ are independent of each other. Denote the set of the received symbols by $\mathbf{S_Y} = \{\mathbf{Y}(1), \cdots, \mathbf{Y}(N_s)\}$. 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.3) $\rho_n(i)$ and $H(i,n)$ are deterministic.

(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

$$f(\mathbf{S_Y}|m, H(i,n), \rho_n(i), d_n(i)) = \frac{1}{(2\pi\sigma^2)^{NN_s}} \exp\left[L_m(\mathbf{S_Y})\right], \tag{4}$$

where

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

In the GLRT, an m value which maximizes $f(\mathbf{S_Y}|m, \hat{H}(i,n), \rho_n(i), d_n(i))$ is evaluated, where $\hat{H}(i,n)$ is the ML estimate given by

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

Using (6) in (5), $L_m(\mathbf{S_Y})$ is rewritten as

$$\begin{aligned} L_m(\mathbf{S_Y})\Big|_{H(i,n)=\hat{H}(i,n)} &= (1-\alpha)^2 \sum_{i=1}^{N_s}\sum_{n=0}^{N-1} |Y(i,n)|^2 \\ &- (1-\alpha)^2 \sum_{i=1}^{N_s}\sum_{v=1}^{N_p} |Y(i,(v-1)M+m)|^2. \end{aligned} \tag{7}$$

Because the first term of (7) is independent of m, we get the following detection rule:

$$\hat{m} = \arg \max_{m\in\{0,\cdots,M-1\}} \sum_{i=1}^{N_s}\sum_{v=1}^{N_p} |Y(i,(v-1)M+m)|^2. \tag{8}$$

In this rule, pilot position is identified by comparing the accumulated signal energy of the subcarriers corresponding to pilot position candidates.

B. Pilot Sequence Identification

To simplify notations, 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 $Y_v(i) = Y(i,(v-1)M + hatm)$. Suppose that the pilot sequence corresponding to $\{Y_v(i)\}$ is the l-th pilot sequence, $l \in \{0, 1, \cdots, N_{seq}\}$, 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. 3). From the conditional pdf of $\{Y_v(i)\}$, the ML rule for determining l is given by

$$\hat{l} = \arg \max_{l'\in\{0,\cdots,N_{seq}-1\}} \sum_{i=1}^{N_s}\sum_{v=1}^{N_p} |Y_v(i) - H_v(i)d_{l'v}(i)|^2, \tag{9}$$

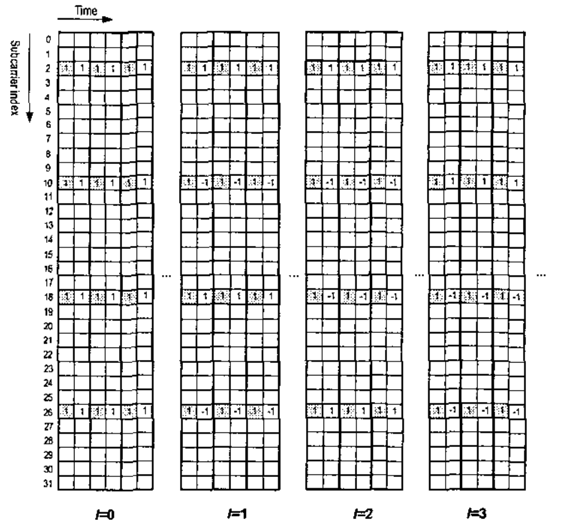

Fig. 3. An example illustrating the pilot sequences when $m = 3$ and $N_{seq} = 4$. Here the pilot sequence at odd times are all one sequences and those at even times are Hadamard sequences. $\{l\}$ denote the indices of Hadamard sequences.

where $H_v(i) = H(i,(v-1)M + \hat{m})$ and N_{seq} is the number of candidate sequences. In this case, if $\hat{H}_v(i) = d_{l'v}(i)Y_v(i)/|d_{l'v}|^2$ is used for $H_v(i)$ in (9), then $Y_v(i) - \hat{H}_v(i)d_{l'v}(i) = 0$ regardless of l'. Therefore, an alternative estimate of $H_v(i)$ is needed and we suggest the use of the following estimator:

$$\hat{H}_{l'v}(i) = \frac{\{d_{l'v}(i-1)Y_v(i-1) + d_{l'v}(i)Y_v(i)\}}{|d_{l'v}(i-1)|^2 + |d_{l'v}(i)|^2}. \tag{10}$$

This is an ML estimator when $H_v(i) = H_v(i-1)$, and it is valid when channel is quasi-static. Replacing $H_v(i)$ in (9) with (10), we get the following detection rule:

$$\hat{l} = \arg\max_{l'} \sum_{i=2}^{N_s}\sum_{v=1}^{N_p} Y_v(i)Y_v^*(i-1)\left(d_{l'v}(i)d_{l'v}(i-1)\right), \quad l' \in \{0,\cdots,N_{seq}-1\}. \tag{11}$$

This rule evaluates the correlation between differentially encoded received signals and differentially encoded pilot sequences. Therefore the rule in (11) can detect the transition between $d_{l'v}(i)$ and $d_{l'v}(i-1)$. To simplify the detection procedure, we 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 (11) is simplified as

$$\hat{l} = \arg \max_{l'\in\{0,\cdots,N_{seq}-1\}} \Lambda_{l'}. \tag{12}$$

where

$$\Lambda_{l'} = \sum_{i=2}^{N_s}\sum_{v=1}^{N_p} Y_v(i)Y_v^*(i-1)d_{l'v}. \tag{13}$$

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. 4 shows the BS identification error versus the normalized Doppler frequency $f_d T_s$ ($f_d T_s \in \{0.001, 0.01, 0.1\}$). 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.

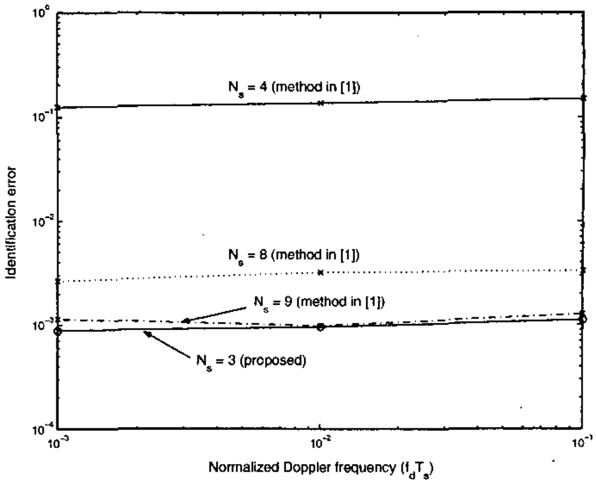

Fig. 4. Comparison of BS identification errors where N_s is the number of OFDM symbols used for the identification.

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, FH-sequence of the corresponding base station was indirectly estimated. 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.

References

[1] European Patent 1148673A2, "Identification of a base station, using latin-square hoppling sequence, in multicarrier spread-spectrum systems", October 2001.

[2] C802.20-03/16, "Initial Contribution on a System Meeting MBWA characteristics, IEEE 802.20 March 2003 session.

[3] G.J. Pottie and A.R. Calderbank, "Channel coding strategies for cellular radio," *IEEE Trans. Veh. Technol.*, vol. 44, pp.763-770, November 1995.

[4] S. Maric and E. Titlebun, "A class of frequency hop codes with nearly ideal characteristics for use in multiple-access spread-sprectrum communications and radar and sonar systems," *IEEE Trans. Commun.*, vol. 40, pp.1442-1447, September 1992.

[5] S. Wicker and V. Bhargava, *Reed-Solomon Codes and Their Applications*, IEEE Press, New York, 1994.

[6] S. M. Kay, *Fundamentals of statistical signal processing: Detection theory*, Prentice-Hall, NJ, 1998.