Performance Analysis on a Preamble-Based Cell Search in Synchronous OFDM Cellular Systems

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***Abstract*— Recently, a novel preamble structure, including a synchronization field (S-field) and a cell searching field (C-field), has been proposed [2]. In this paper, the overall cell search performance is analyzed in terms of the mean acquisition time. It is shown that robust cell search capability can be obtained even in bad cellular environments.**

I. Introduction

For cellular systems, it is one of the most important requirements to provide robust synchronization and cell search capability. However, the synchronization techniques used in conventional OFDM-based systems cannot be directly applied to the cellular system since they cannot discriminate signals from different cells unless their carrier frequencies are different. Recently, synchronization and cell search techniques have been proposed for asynchronous OFDM-code division multiplexing (CDM) cellular systems having channel structure similar to the WCDMA [1]. However, asynchronous cellular systems generally suffer from longer cell search time, especially for the neighbor-cell search. For synchronous cellular systems, a preamble structure with the corresponding synchronization and cell search algorithm was proposed in [2]. In this paper, the overall cell search performance is analyzed in terms of the mean acquisition time (MAT).

II. State Transition Diagram for Cell Search

In Fig. 1, the state diagram for cell search considered in this paper is shown. Here, G_p and G_{ot} represent groups of N_h consecutive symbols. Also, we assume that the starting point of the frame detection is the first state of the group that is θ groups away from the G_p group, where θ is a particular value among $0, 1, \cdots, N_f/N_h - 1$ with equal probability. We also assume that the frame detection, fine timing estimation, and cell identification processes are performed in a fully pipelined structure. Then, we obtain the followings.

$$\begin{aligned}
H_a(z,\kappa) &= P_1^{N_h}(\kappa) z^{N_h},\\
H_b(z,\kappa) &= z^{N_p} \sum_{k=0}^{N_h-1} (1-P_1(\kappa)) z^{N_c+1} P_1^k(\kappa) z^k, \qquad (1)\\
H_c(z,\kappa) &= P_2(\kappa) P_1^{N_h-1}(\kappa) z^{N_h},\\
H_d(z,\kappa) &= (1-P_1(\kappa)) z^{N_p+N_c+1} \sum_{k=0}^{N_h-2} (P_1(\kappa) z)^k\\
&\quad + P_1^{N_h-1}(\kappa)(1-P_2(\kappa)-P_3(\kappa)) z^{N_p+N_c+N_h},\\
H_s(z,\kappa) &= P_3(\kappa) P_1^{N_h-1}(\kappa) z^{N_c+N_h},
\end{aligned}$$

where N_p is the number of symbols for false alarm penalty (time). Here, $P_1(\kappa)$, $P_2(\kappa)$, and $P_3(\kappa)$ represent the probability that either false frame detection does not occur or false frame detection occurs with the failure of cell identification, that either frame detection fails or frame detection is successful with the failure of cell identification, and that both frame detection and cell identification are successful, respectively. Then, we have

$$\begin{aligned}
P_1(\kappa) &= 1 - P_{fa,frame}(\kappa) + P_{fa,frame}(\kappa) P_{df,FDE}(\kappa)\\
&= 1 - P_{fa,frame}(\kappa) P_{fa,FDE}(\kappa)\\
P_2(\kappa) &= P_{df,frame}(\kappa) + (1 - P_{df,frame}(\kappa)) P_{df,FDC}(\kappa),\\
P_3(\kappa) &= (1 - P_{df,frame}(\kappa)) P_{s,FDC}(\kappa),
\end{aligned} \qquad (2)$$

where κ is the squared sum of all multipath gains. Here, $P_{fa,frame}(\kappa)$ is the false alarm probability of frame detection. Also, $P_{df,frame}(\kappa)$ is the detection failure probability of frame detection. In addition, $P_{fa,FDE}(\kappa)$, $P_{df,FDE}(\kappa)$, $P_{df,FDC}(\kappa)$, and $P_{s,FDC}(\kappa)$ denote the false alarm probability of the cell identification when frame detection error occurs, the detection failure probability of the cell identification when the frame detection error occurs, the detection failure probability of the cell identification when the frame detection is correct, and the detection probability of the cell identification, respectively.

III. Mean Acquisition Time Analysis

The channel gain of each path in a fading channel is assumed to be constant during N_h symbols and independent from one N_h-symbol block to another. Here, we can set $N_h \propto \frac{1}{f_d T_s}$, where f_d is the maximum Doppler frequency. Then, we can obtain $H_a(z) = E\{H_a(z,\kappa)\}$, $H_b(z) = E\{H_b(z,\kappa)\}$, $H_c(z) = E\{H_c(z,\kappa)\}$, $H_d(z) = E\{H_d(z,\kappa)\}$, and $H_s(z) = E\{H_s(z,\kappa)\}$ by using numerical integration. Then, the transfer function is given by

$$H(z) = \frac{H_s(z) H_e^{\theta}(z)}{1 - H_e^{N_f/N_h-1}(z) H_f(z)}, \qquad (3)$$

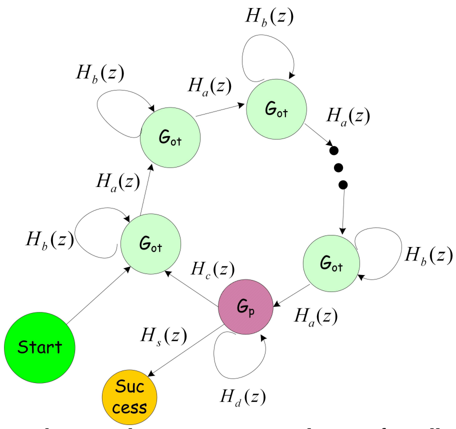

Fig. 1. The equivalent state transition diagram for cell search.

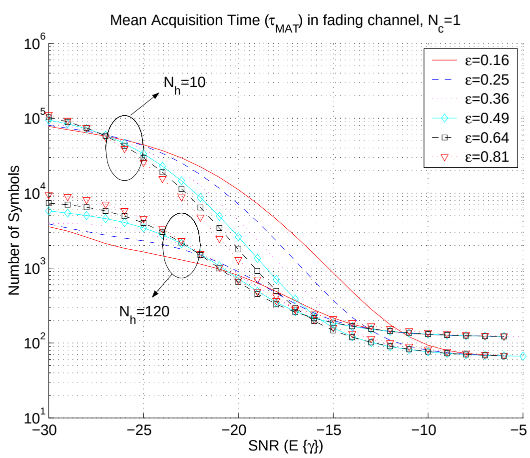

Fig. 2. Mean acquisition time in the ITU-R Vehicular A fading channel.

where N_f denotes the number of OFDM symbols in a frame. Also, in this case, we have $E\{\theta\} = \frac{N_h}{N_f}\sum_{k=0}^{N_f/N_h-1} k = \frac{N_f/N_h-1}{2}$. Finally, we obtain

$$\tau_{MA} = \frac{2H_s'(1) + (N_f/N_h - 1)H_s(1)H_e'(1)}{2(1 - H_f(1))} + \frac{H_s(1)\left((N_f/N_h - 1)H_e'(1)H_f(1) + H_f'(1)\right)}{(1 - H_f(1))^2}. \tag{4}$$

IV. Simulation Results

In the following simulations, we used the following parameters: $N_{FFT} = 2048$, $N_{CP} = 452$, $P = 8$, $\bar{Q} = 8$, $N_f = 120$ symbols, and $N_p = 1200$ symbols. Here, N_{CP} denotes the number of samples in the cyclic prefix. In Fig. 2, the MAT in the Vehic. A fading channel is shown for various values of N_h and ϵ when $N_c = 1$. When SNR is low, the MAT increases as N_h decreases since the false alarm is more likely to occur. However, as SNR increases, the MATs decreases down to 67 symbols and 122 symbols when $N_h = 10$ and $N_h = 120$, respectively, at the average SNR of $-5dB$. From Fig. 2, one can see that a good choice for $\sqrt{\epsilon}$ lies between 0.7 and 0.8. In Fig. 3, the cumulative distribution function (CDF) of the MAT in a two-tier multi-cell environment (19 hexagonal cells), numerically obtained using the result in Fig. 2, is shown. Here, the normalized distance, R, denotes the distance between the nearest base station and the mobile station divided by the cell radius. Also, the path-loss decay factor, log-normal shadowing standard deviation, shadowing correlation between cells, and the signal to background noise ratio at the cell boundary without shadowing variation are set at 4.0, 8dB, 0.5, and 3dB, respectively. It is shown that cell search time is less than 2 frames almost surely even at cell boundary.

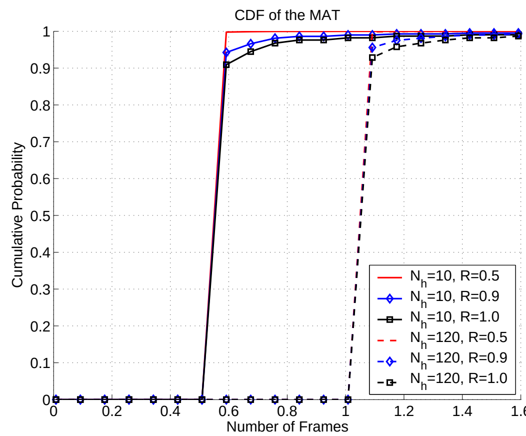

Fig. 3. CDF of the mean acquisition time in multi-cell environments.

V. Concluding Remark

In this paper, the overall performance of the preamble-based synchronization and cell search technique for OFDM cellular systems was analyzed. The mean acquisition time was evaluated from the simulation results in frequency selective fading channels. From the results, it was shown that the MAT increased as the mobile speed got slower in a fading channel. However, at the average SNR of $-5dB$, the MAT was just slightly higher than the frame length. As the mobile speed increased, the MAT decreased except for the case of a very low average SNR (say, less than $-10dB$). Also, from the CDF of the MAT, it was seen that at most two frames are required for successful cell search almost surely in multi-cell environments. Therefore, we can conclude that the preamble-based cell search algorithm provide very robust cell search capability even in bad cellular environments.

References

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