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1. Introduction

This paper summarizes preamble design of random access channel for E-UTRA, including preamble design for non-synchronized random access with code multiplexing approach, and synchronized preamble design with TDM/FDM approach. Detailed design examples are provided together with detection and timing estimation algorithms.

2. Preamble Design for Non-synchronized Random Access with Code Multiplexing

The preamble of non-synchronized random access can be transmitted with a long spreading factor, overlapped with the scheduled data channel. We call this approach as code division multiplexing (CDM) design for preamble. The preamble is separated from the scheduled channel with a long spreading code. The large spreading gain ensures low interference and good detection performance for preamble detection.

The basic structure of the preamble for non-synchronized random access is illustrated in the Figure 1. The length of the preamble is 1ms over two 0.5ms sub-frames. Each 0.5ms sub-frame consists of several DFT-S-OFDM symbols with extended cyclic prefix (CP). The length of the extended CP should be not less than the maximum round-trip delay. In this case, the numerology of long CP frame structure specified for downlink transmission scheme in TR 25.814 is applied. The number of DFT-S-OFDM symbols per 0.5ms sub-frame is 6, and the extended CP duration is 16.67us, for all scalable bandwidth deployments.

The random access channel sequence(s) g_n to generate the transmitted random access preamble waveforms should have the following properties:

1. Good detection probability while maintaining low false alarm rate e.g. by maximizing post-decoder $E_s/(N_t+N_e)$ for a occupied random access channel preamble where N_e is the residual interference due to other random access channel transmissions in a given random access channel and N_t is thermal noise.
    a. cross correlation of the sequences that occupy the same frequency and same cyclic shift value impacts achievable $E_s/(N_t+N_e)$ and false alarm rate
2. Number of random access channel preamble waveforms should be defined to handle the maximum expected multiple access scenarios (traffic load) while guaranteeing low collision probability.
    a. Subsets of preambles could be defined such that performance is improved at lighter loads (e.g., first use cyclic shifts of a single CAZAC/GCL sequence before using additional sequences)
3. Enable accurate timing estimation (e.g. good autocorrelation properties and sufficient occupied BW).
4. Low power de-rating (low CM/PAPR).

A good choice of the signature sequence is the GCL sequence, including Frank-Zadoff-Chu sequence. GCL sequence has optimal periodic autocorrelation performance and very good periodic cross-correlation property when designed properly. Besides, a Walsh orthogonal sequence can be used together with the GCL sequence to fit into the preamble frame structure.

As an example, with 5MHz bandwidth, there are 300 usable sub-carriers per symbol. A GCL sequence with length $M=300$ will occupy one symbol. The GCL sequence can be further spread with a Walsh sequence into several symbols. One example is to select the Walsh sequence with length $W=4$. The total spreading factor will be $WM=1200$, which corresponds to a spreading gain of 30.8dB. Figure 1 illustrates an example of the random access preamble with the Walsh sequence $\{+1, -1, +1, -1\}$. The parameters for this design are summarized in Table 1. Given one GCL sequence, there are 16 possible random access opportunities. When the bandwidth is large, more GCL sequences with good correlation properties can be used to increase the random access opportunities.

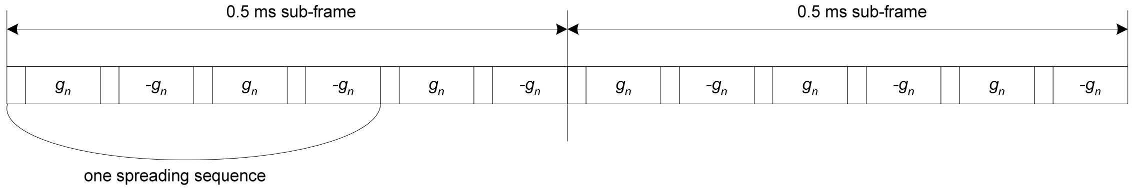

Figure 1 Preamble Design with Code Multiplexing

Table 1 Example CDM Design Parameters for Non-Synchronized Random Access

RACH Parameters of CDM Design	**Bandwidth (MHz)**					
	1.25 MHz	2.5 MHz	5.0 MHz	10.0 MHz	15.0 MHz	20.0 MHz
Chip Length/Sym (M)	75	150	300	600	900	1200
Length of Walsh Code (N_W)	4	4	4	4	4	4
# of Cyclic shifted (N_{SH})	4	4	4	4	4	4
# of Sequences (N_S)	1	2	4	8	12	16
# RACH opportunities	16	32	64	128	192	256

Preamble Sequence Design

General chirp-like (GCL) [5] or its special case, Chu-sequence [6] can be selected as the signature sequence. The Chu-sequence is defined [6] as

$$g_n = \begin{cases} e^{-j\frac{2\pi}{M}\frac{1}{2}pn^2} & \text{when } M \text{ is even} \\ e^{-j\frac{2\pi}{M}\frac{1}{2}pn(n+1)} & \text{when } M \text{ is odd} \end{cases}, \quad n = 0,1,\ldots,M-1$$

where p is relatively prime to M. For a fixed p, the Chu-sequence is orthogonal to its time-shift. For different p, Chu-sequences are not orthogonal. Note that all GCL sequences (including the Chu-sequence) have optimal autocorrelation properties.

There is an extra benefit of selecting GCL sequence with a prime number length [4]. From [5], GCL sequence with a prime number length will yield “optimal” cross-correlation performance. However, the optimal sequence can be truncated to obtain a signature sequence with arbitrary length. This approach may yield some increase in PAPR/CM. Careful selection of sequence may make this side effect marginal, particularly for a large M.

Different GCL sequences can be used to increase random access opportunities and to mitigate inter-cell interference for random access channel. Note that for Chu-sequence, different p can yield different group of signature sequences. For $M = 300$, $p = \{1,7,11,13,17,19,23,29,31,37,\ldots\}$. Given a fixed p, the corresponding Chu-sequence is orthogonal when it is shifted circularly. However, the sequences are not orthogonal for different p and behave as random sequences. Thus, by assigning different p to different sector/cell, inter-cell interference can be mitigated. For M=300, one can select at least 20 sequences as listed in Table 2.

Table 2 *p* Values of Chu-Signature Sequences for Sectors/Cells

Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
p	1	7	11	13	17	19	23	29	31	37	41	43	47	53	59	61	67	71	73	79

Preamble Detection and Timing Estimation

When an UE randomly selects a preamble with a GCL sequence g_n and a Walsh sequence w_n, the preamble is a repetition of the sequence with length WM, where W is the length of the Walsh sequence. For one DFT-S-OFDM symbol, the transmit sequence is $x_n=w(i)g_n$, where i is the index of DFT-S-OFDM symbol and $i=0, \ldots, W-1$.

At the receiver, the received signal i-th symbol can be represented as

$$y_n^{(i)} = x_{n-d}^{(i)} \otimes h_n + z_n^{(i)} ,$$

where $\otimes$ indicates circular convolution, h_n is channel impulse response, and d is the delay between the transmit x_n and node-B perceived uplink timing. Note that the delay d should be less than the extended CP length, which is 16.68us in this example. It is assumed that the channel does not change or changes very slowly over W number of symbols. Combining with Walsh code

$$y_n = \frac{1}{\sqrt{W}} \sum_{i=0}^{W-1} w(i) y_n^{(i)} = \sqrt{W} g_{n-d} \otimes h_n + \frac{1}{\sqrt{W}} \sum_{i=0}^{W-1} w(i) z_n^{(i)} .$$

The periodic correlation of sequence g_n and y_n is

$$c_m = \frac{1}{\sqrt{M}} \sum_{n=0}^{M-1} y_n g_{(n-m) \bmod M}^{*}$$

The correlation can be performed either in time or frequency domain. Through some manipulations, we obtain

$$c_m = \sqrt{WM}\, h_{m-d} + z_m^{'} ,$$

where z_m' is the equivalent channel noise.

When the channel information is not available to the receiver at the Node-B, energy of c_m is used for preamble detection and timing estimation.

The detection algorithm consists of three steps. The average power of correlation sequence is first computed.

$$\bar{P} = \frac{1}{WM} \sum_{m=0}^{M-1} |c_m|^2 .$$

Next, the following is computed

$$\gamma_d = \frac{1}{\bar{P}} \max_m |c_m|^2, \quad \text{and } \hat{d} = \arg\max_m |c_m|^2 ,$$

where γ_d is the maximum power and $\hat{d}$ is the estimated timing delay of the channel path with maximum power. The final step is to check whether the maximum power is greater than a pre-defined power threshold γ_{TH} . Thus,

$$\begin{cases} \gamma_d \geq \gamma_{TH} & \text{random access request with delay } \hat{d} \text{ is present} \\ \gamma_d < \gamma_{TH} & \text{random access is absent} \end{cases} .$$

Performance

The detection and false alarm performance of the CDM scheme over a TU 3km/hr channel is illustrated in Figure 2. When the SNR is -18dB, the detection error rate is 1% with a falsm alarm rate of 0.1%. This indicates that the effective SNR for the preamble detection at the Node-B can be as low as -18dB for effective detection.

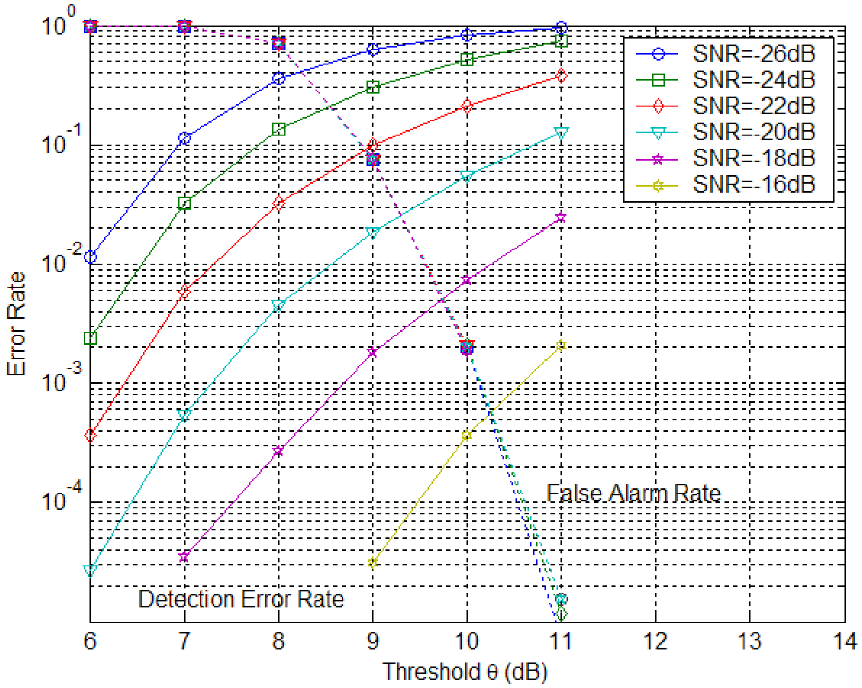

Figure 2. Detection Error and False Alarm Performance over TU-3km/h Channel

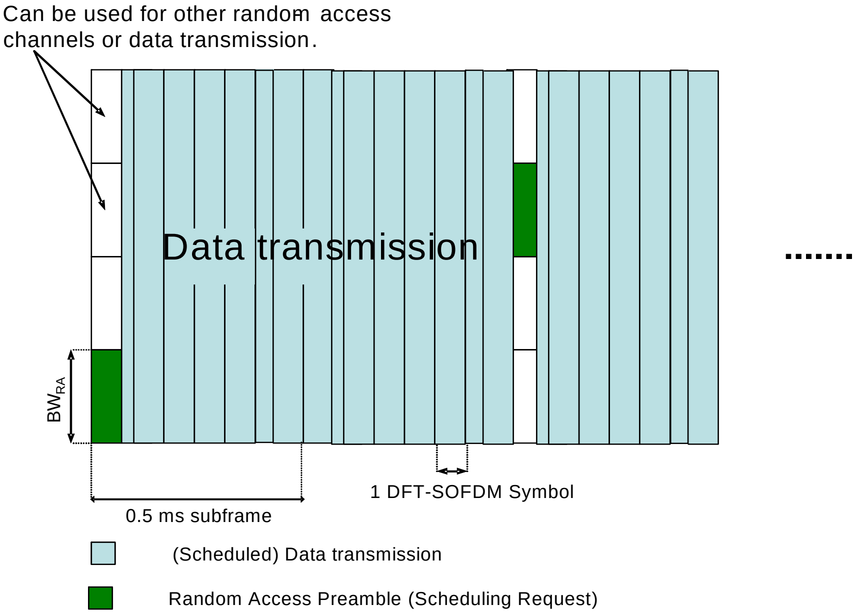

Figure 3 Synchronized Random Access Design

3. Preamble Design for Synchronized Random Access

A TDM/FDM region corresponding to one or several DFT-S-OFDM symbol is reserved for synchronized random access. A random access symbol can be reserved every x frames (e.g. $x = 1 \ldots 10$.) as shown in Figure 3. In the localized mode the sub-carriers are divided into N_{RB} resource blocks with each resource blocks uses a fixed number of contiguous sub-carriers. Next, for each of the N_{RB} resource blocks, a number of signature sequence groups are pre-defined so that every group consists of N_S signature sequence and different groups can be assigned to different neighboring sectors. Each group may also consist of several cyclically shifted version of the signature sequences (N_{SH}). As such, the total number of RACH opportunities per DFT-SOFDM symbol is given by N_{RB}*N_S.* N_{SH} .

There are different design options for E-UTRA based on this structure. One design example is summarized in Table 3. In this example, which corresponds to 5MHz bandwidth, 300 subcarriers are divided into 4 resource blocks with N_{RB} =4. A RACH signature sequence occupies 75 subcarriers corresponding to 1.25MHz bandwidth. The number of RACH opportunities varies with bandwidth (e.g. 64 for 5MHz).

Table 3 Example RACH Parameters for the TDM/FDM Structure

RACH Parameters in Localized mode	Bandwidth (MHz)					
	1.25	2.5	5.0	10.0	15.0	20.0
min. RB BW (kHz)	1125	1125	1125	1125	1125	1125
# RB (N_{RB})	1	2	4	8	12	16
# of Occupied Subcarriers	75	75	75	75	75	75
# of Sequences (N_S)	8	8	8	8	8	8
# of Cyclic shifted(N_{SH})	2	2	2	2	2	2
# RACH opportunities	16	32	64	128	192	256

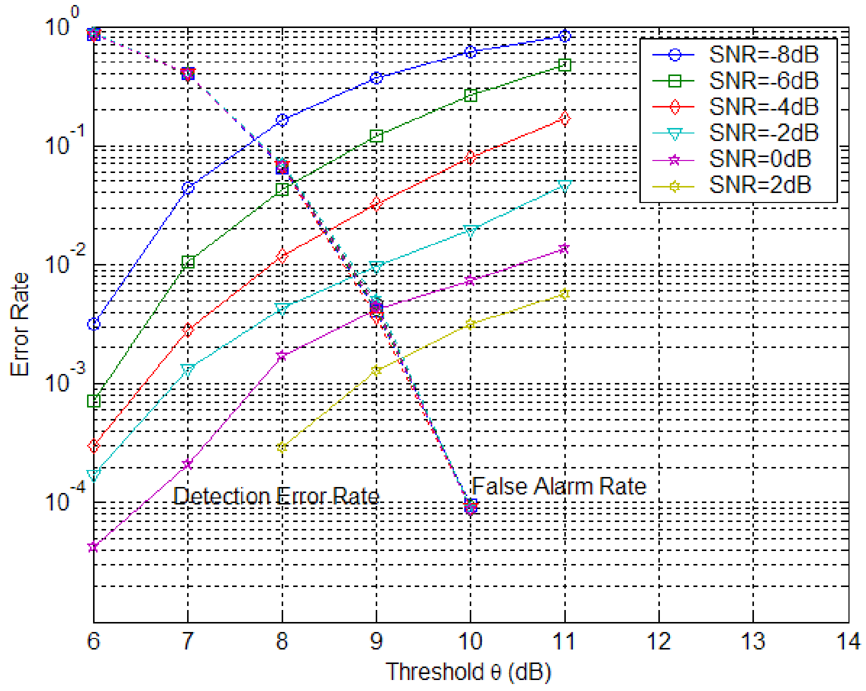

Figure 4 Detection Error Rate and False Alarm Rate for Synchronized Random Access Channel

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