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1. Introduction

The RACH channel is used for initial access to the network as well as to transmit small to medium amount of control information and data packets. In [1], preliminary results for RACH preamble design were presented. This contribution proposes two options of RACH channel design for E-UTRA.

2. RACH Design Principle

The RACH design requirements include fast acquisition of preamble, ability to transmit short to medium packets using the message part, estimation of timing advance, elimination of interference and minimum impact on other data/control channels. Usually, RACH signaling includes two parts of transmission between UE and Node-B. The first part is the transmission of RACH preamble used for fast acquisition and estimation of timing advance.,. The second part is the RACH message transmission, which includes transmission of RACH data packets and associated control information. It may be noted that the timing advance is not discussed in this contribution.

On the RACH preamble design, several options, namely TDM, FDM and CDM are available for multiplexing between the RACH preamble and scheduled-data channels. Figure 1 illustrates time division multiplexing (TDM) and frequency division multiplexing (FDM) of RACH and scheduled data channels. Other TDM/FDM combinations are possible such as frequency-hopped preamble design. Both TDM and FDM approaches will require slots or sub-carriers to be reserved specifically for RACH access. This RACH overhead may affect the system capacity, especially when the channels are not fully utilized.

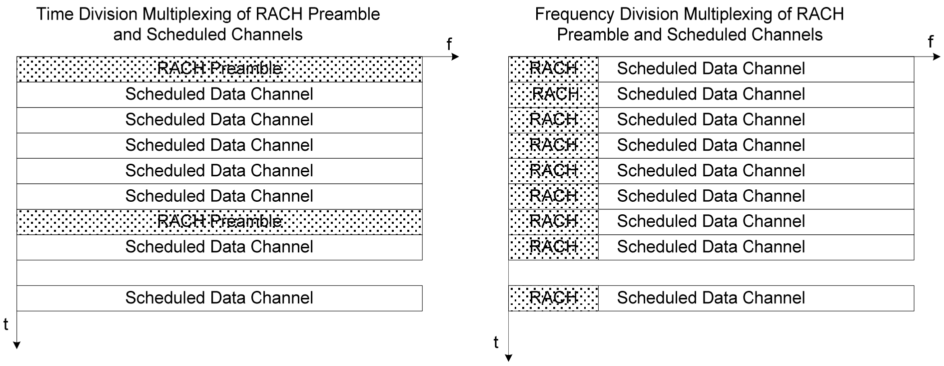

Figure 1 TDM and FDM of RACH and Scheduled Channels

Another RACH preamble design is to multiplex the preamble and scheduled data channel in CDMA fashion, as illustrated in Figure 2. In this approach, there is no resource (time or frequency) reservation necessary for RACH preamble transmission. When an UE needs a RACH access, the preamble is transmitted with a long spreading sequence (signature sequence) on top of scheduled data channels. There is no RACH preamble overhead in this design. However, interference caused by the preamble exists and care should be taken to minimize this effect.

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In this paper, both the TDM/FDM and CDM approaches are discussed as candidate RACH methods for EUTRA. Preliminary details of the above two methods are presented along with some simulation results.

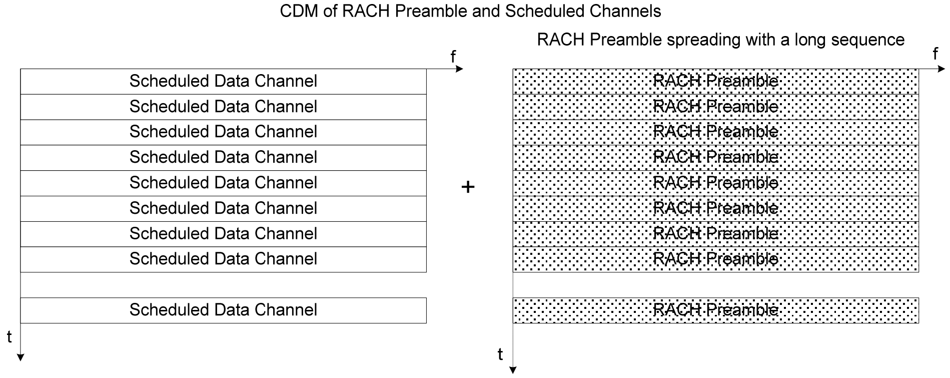

Figure 2 CDM of Scheduled Channels and RACH Preamble

3. RACH Preamble Design using TDM/FDM

In this scheme a dedicated or special symbol is used for RACH. The RACH symbol can be reserved every x frames (e.g. $x = 1 \ldots 10$.) as shown in Figure 3. The scheme can use either localized or distributed mode. In the localized mode the subcarriers are divided into N_{RB} resource blocks with each resource blocks using 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 also consists 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 summarized in Table 1-(a) provides a large number of RACH opportunities. In this example, for 5MHz bandwidth, all 300 subcarriers are divided into 20 resource blocks with N_{RB} =20. A RACH signature sequence occupies 15 subcarriers corresponding to 225kHz bandwidth, thus the length of signature sequence is 15. For the scalable bandwidth structure, the length of signature sequence is fixed to 15. The number of RACH opportunities will be 160 for 5MHz, and it is variable according to different bandwidth deployment. Another design example is summarized in Table 1-(b) with a longer (75) signature sequence and a larger minimum resource block (1.125MHz).

Dividing the RACH opportunities into resource blocks provides the opportunity to take advantage of channel frequency selective characteristics to further improve the performance. The UE chooses the best available resource blocks for RACH preamble transmission based on information of the current frequency selective nature of the channel.

The signature sequence are obtained from different "classes" of generalized chirp like (GCL) or Chu-sequences which are complex valued and have unit amplitude. The GCL/Chu sequence has low cross correlation at all time lags which improves the detection performance.

The number of RACH groups for different bandwidths is summarized in Table-1. The total RACH overhead is dependent on the reserved RACH access rate. For example, if the RACH access is reserved every 1ms, the RACH overhead is 1/14=7.1%.

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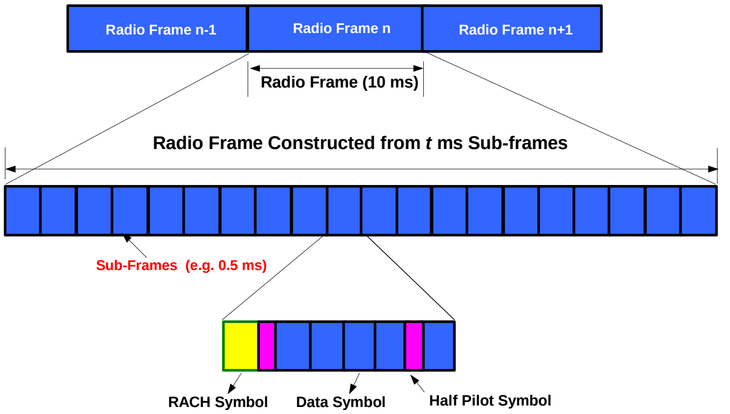

Figure 3. TDM/FDM RACH Structure

Table 1. Examples of RACH Parameters for the TDM/FDM Structure

(a)

RACH Parameters in Localized mode	**Bandwidth (MHz)**					
	1.25	2.5	5.0	10.0	15.0	20.0
min. RB BW (kHz)	225	225	225	225	225	225
# RB (N_{RB})	5	10	20	40	60	80
# of Occupied Subcarriers	15	15	15	15	15	15
# of Sequences (N_S)	8	8	8	8	8	8
# of Cyclic shifted(N_{SH})	1	1	1	1	1	1
# RACH opportunities	40	80	160	320	480	640

(b)

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

3.1. Sequence Design for TDM RACH Preamble

General chirp-like (GCL) [5] or its special case, Chu-sequence [6] can be selected as the signature sequence used in each resource block. 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.

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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. To truncate this optimal sequence we can obtain a signature sequence with arbitrary length. However, this approach may have other problems for E-UTRA uplink and more studies are needed.

3.2. Performance of the RACH preamble

The RACH preamble detection is similar to the detection algorithm of the CDM-based RACH outlined in Appendix A. The basic idea is to detect the received power based on correlation of the received sequence to all the possible sequences. The correlation can be carried out either in time or frequency domain. Once the detected power is greater than a pre-defined power threshold, a RACH preamble is detected. Naturally, the choice of threshold determines detection performance. Figure 4 and Figure 5 illustrate detection performance of the TDM/FDM RACH preamble under AWGN and TU propagation channels, respectively. The following definitions were used in the performance evaluation:

- False alarm refers to a scenario where a particular code was detected when nothing or a different code was transmitted.
- Detection error refers to when a particular code was transmitted but not detected.

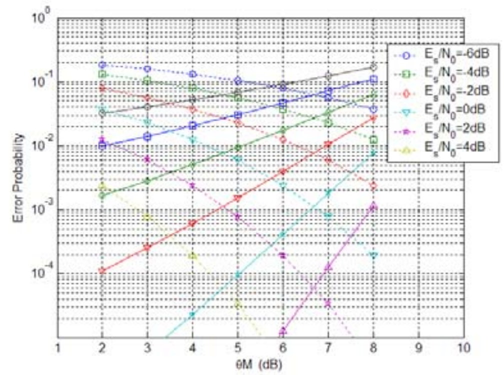

Figure 4 Detection Error and False Alarm Probabilities of TDM-RACH over AWGN Channel.

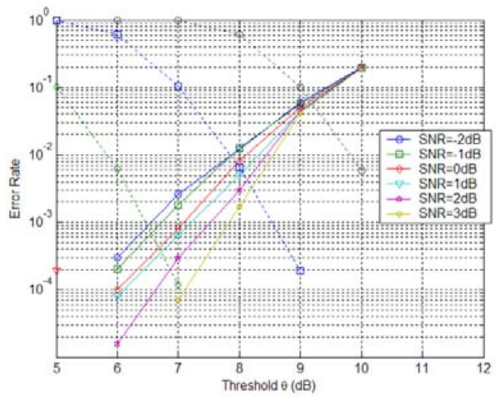

Figure 5 Detection Error Rate and False Alarm Performance of TDM-RACH over TU Channel at 3 km/h.

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3.3. RACH Message part for the TDM/FDM Structure

If the preamble is detected at the Node-B, the Node-B sends an ACK. Upon detection of the ACK at the UE, the UE sends the message part in the next slot using the same RB location which was used to send the preamble. As an alternative, the message can be scheduled as outlined in a later section if the system is lightly loaded. However, more studies need to be performed to optimize the RACH message design.

4. RACH Preamble Design using CDM approach

To minimize uplink interference, the RACH preamble is designed to use time-frequency spreading with long spreading factor. With this approach, no reservation of symbols and sub-carriers are required and uplink interference generated is minimal when the spreading gain is large enough. In addition, simple receiver structure with frequency domain processing can be used to process the preamble.

In our design, the RACH preamble should fit into the current E-UTRA numerology with 1 ms using two 0.5 ms sub-frames. The frequency spreading length M usually equals to 300 for 5MHz bandwidth for a full bandwidth spreading. Furthermore, a Walsh code with length N_W is applied symbol-by-symbol in time domain to yield total spreading gain of MN_W. Then repetition is applied to cover total of 14 symbols in two 0.5 ms sub-frames. For each DFT-S-OFDM symbol, N_S numbers of signature sequence groups are pre-defined so that different groups can be assigned to different neighboring sectors. Each group also consists of several cyclically shifted version of the signature sequences (N_{SH}). The total RACH opportunities are N_W*N_S* N_{SH} . Table 2 presents two RACH design parameters with different combinations of N_W and N_{SH}.

Table 2 RACH Example Parameters of CDM Design

RACH Parameters of CDM Design	Bandwidth (MHz)					
	1.25	2.5	5.0	10.0	15.0	20.0
Chip Length/Sym (M)	75	150	300	600	900	1200
Length of Walsh Code (N_W)	2	2	2	2	2	2
# of Cyclic shifted (N_{SH})	10	10	10	10	10	10
# of Sequences (N_S)	2	4	8	16	24	32
# RACH opportunities	40	80	160	320	480	640

(a)

RACH Parameters of CDM Design	Bandwidth (MHz)					
	1.25	2.5	5.0	10.0	15.0	20.0
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})	6	6	6	6	6	6
# of Sequences (N_S)	2	4	8	16	24	32
# RACH opportunities	48	96	192	384	576	768

(b)

The GCL or Chu-sequence g_n discussed previously can be applied as the signature sequence with length M. A fixed delay is applied to g_n to yield the delayed signature sequence. For the example in Table 2 (a), the delayed sequence is

$$g_{d,n} = g_{(n-30d) \bmod M}, \quad d = 0, \ldots 9$$

where the delay is M/N_{SH} = 30. Note that the number of cyclic shifted sequences is based on the maximum allowed delay, which should be greater than the length of cyclic prefix of the system, and suitable for timing offset estimation. In Table 2 (a), the 30-information chip delay of 5MHz bandwidth equals to 6.67us. In Table 2 (b), the 50-information chip delay is equivalent to 11.11us.

To provide temporal spreading, a Walsh sequence of length N_W is used. For example, when N_W=*2*, the Walsh sequence is

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