Nomor 3GPP Newsletter – December 2007

Overview LTE RACH

Authors: Sujuan Feng, Eiko Seidel

Introduction

This month's newsletter introduces the Random Access Channel procedure as specified for 3GPP Long Term Evolution.
The Random Access Channel (RACH) is defined by 3GPP as an uplink, contention based, common transport channel. It is typically used for random access transmissions and the transport of control information such as to register the terminal to the network after power-up, to perform an location update after moving from one location area to another, or to initiate a call by setting up a connection from the User Equipment (UE) to the Node-B. In current UMTS standard, RACH can also be used to send small amount of data on the uplink, which is quite different from the approach taken by 3GPP. Due to the orthogonal uplink in LTE a specific resource must be reserved to avoid interference to other users in the cell. In LTE no other information in addition to information provided by the preamble ID can be send. This keeps that non-orthogonal resource at a minimum.

Random Access Procedure Triggers

There are five events that will trigger random access procedure.

- Initial access from RRC_IDLE;
- Initial access after radio link failure;
- Handover requiring random access procedure;
- DL data arrival during RRC_CONNECTED when UL synchronisation status is "non-synchronised";
- UL data arrival during RRC_CONNECTED when UL synchronisation status is "non-synchronised" or there are no PUCCH resources for SR available available.

Random Access Procedure

According to 36.300 CR0006R1 (R2-075498), submitted to RP-38 meeting, there are two kinds of random access procedure: contention based and non-contention based random access procedure. Contention based random access procedure can be triggered by all the four events above. Non-contention based random access procedure is only used by Handover and DL data arrival cases. The procedures of these two kinds are shown as follows:

Nomor 3GPP Newsletter – December 2007
Overview LTE RACH
Authors: Sujuan Feng, Eiko Seidel

Contention based random access procedure:

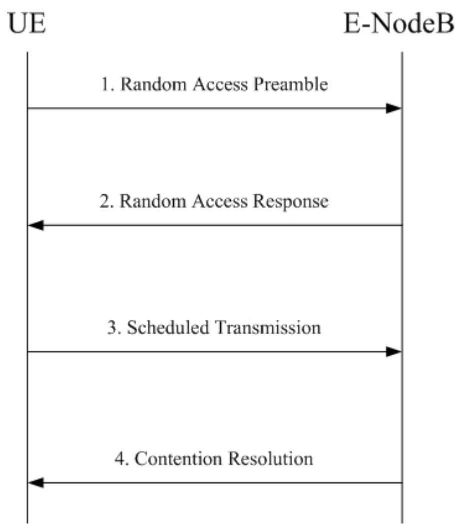

Figure 1: Contention based random access procedure

The procedure as illustrated in figure 1 is characterized by the following steps:

1. Random Access Preamble on RACH
   - 6 bit to carry: 5 bit preamble ID and 1 bit to indicate the information on the size of message 3 or requested resource block (FFS)
2. Random Access Response generated by MAC on DL-SCH
   - Within a flexible window of message 1
   - No HARQ
   - Addressed to RA-RNTI on L1/L2 control channel
   - Containing at least Preamble ID, Timing Alignment, Initial Uplink Grant and Temporary C_RNTI
3. Scheduled Transmission on UL-SCH
   - Use HARQ
   - Size of the transport blocks depends on the UL grant conveyed in step 2 and is at least [72] bits.
   - For initial access:
     - Containing at least NAS UE ID identifier but no NAS message;

    - Conveys the RRC Connection Request generated by the RRC layer and transmitted via CCCH;
    - RLC TM: no segmentation (if RLC is involved);
- After radio link failure:
    - Conveys the RRC Connection Re-establishment Request generated by the RRC layer and transmitted via CCCH;
    - RLC TM: no segmentation (if RLC is involved);
    - Does not contain any NAS message.
- After handover, in the target cell:
    - Conveys the ciphered and integrity protected RRC Handover Confirm generated by the RRC layer and transmitted via DCCH;
    - Conveys the C-RNTI of the UE (which was allocated via the Handover Command);
    - Includes an uplink Buffer Status Report when required.
- For other events:
    - Conveys at least the C-RNTI of the UE.

4. Contention Resolution on DL-SCH

- Early contention resolution shall be used i.e. eNB does not wait for NAS reply before resolving contention
- Not synchronised with message 3;
- HARQ is supported;
- Addressed to:
    - The Temporary C-RNTI on L1/L2 control channel for initial access and after radio link failure
    - The C-RNTI for UE in RRC_CONNECTED;
- HARQ feedback is transmitted only by the UE which detects its own UE identity, as provided in message 3, echoed in the RRC Contention Resolution message.

Nomor 3GPP Newsletter – December 2007
Overview LTE RACH
Authors: Sujuan Feng, Eiko Seidel

Non-contention based random access procedure:

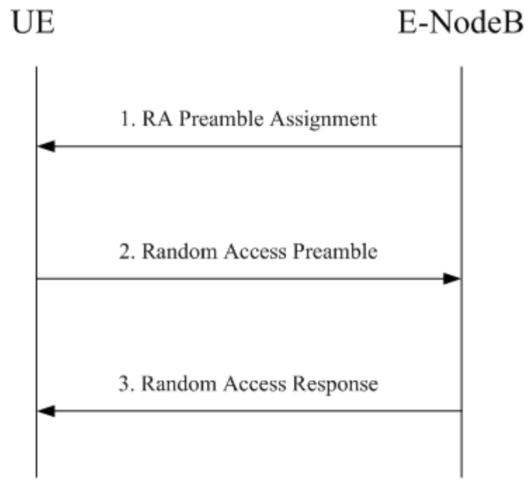

Figure 2: Non-contention based random access procedure

The procedure as illustrated in figure 2 is characterized by the following steps:

1. RA Preamble Assignment on DL dedicated signaling:
    - HO command generated by target eNB and sent via source eNB for handover;
    - MAC signalling (L1/L2 control channel or MAC control PDU is FFS) in case of DL data arrival.
2. Random Access Preamble on RACH
    - Use the preamble received from message 1
3. Random Access Response
    - Within a flexible window of message 1
    - No HARQ
    - Addressed to RA-RNTI on L1/L2 control channel;
    - Containing at least Timing Alignment, Initial Uplink Grant for handover case and Timing Alignment for DL data arrival case, RA-preamble identifier

Nomor 3GPP Newsletter – December 2007

Overview LTE RACH

Authors: Sujuan Feng, Eiko Seidel

Preamble Transmission Procedure by Layer 1

Before the preamble transmission procedure, Layer 1 should receive following information from higher layers:

- Random access channel parameters (PRACH configuration, frequency position, and preamble format)
- Parameters for determining the root sequences and their cyclic shifts in the preamble sequence set for the cell (index to root sequence table, cyclic shift (Ncs), and set type (normal or high-speed set))

The procedure is as follows:

- Layer 1 receives preamble transmission request from higher layers
- A preamble index, preamble transmission power (PREAMBLE_TRANSMISSION_POWER), associated RA-RNTI, and PRACH resource are indicated by higher layers as part of the request.
- A preamble is selected from the preamble sequence set using the preamble index.
- The preamble is transmitted with transmission power PREAMBLE_TRANSMISSION_POWER on the indicated PRACH resource.
- If no associated PDCCH with RA-RNTI is detected then the physical random access procedure is exited.
- If an associated PDCCH with RA-RNTI is detected then the corresponding DL-SCH transport block is passed to the higher layers and the physical random access procedure is exited

Compared with UMTS preamble transmission:

- Fixed transmission power is used instead of Open Loop Power Control
- Physical random access procedure is exited if no response is received

Nomor 3GPP Newsletter – December 2007

Overview LTE RACH

Authors: Sujuan Feng, Eiko Seidel

Random Access Channel

According to 36.211 CR0002 (R1-075112), submitted to RAN_38 meeting, the physical Random Access Channel has following features.

Time and frequency structure:

- Random Access Preamble Format
  The physical layer random access preamble, illustrated in Figure 3, consists of a cyclic prefix of length T_{CP}, and a sequence part of length T_{SEQ}.

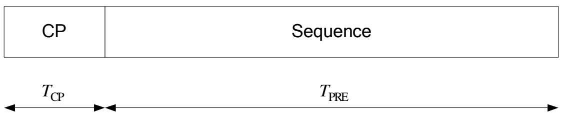

Figure 3: Random Access Preamble Format

CP (Cy [illegible] uard-time and the allocated TTIs for RACH are decided by e-NodeB according to the cell coverage requirement. UE only knows T_{CP} and T_{PRE}.

The configuration in following is applied for FDD. Higher layers control the preamble format.

Burst format	T_{CP}	T_{PRE}
0	$3152 \times T_s$	$24576 \times T_s$
1	$21012 \times T_s$	$24576 \times T_s$
2	$6224 \times T_s$	$2 \times 24576 \times T_s$
3	$21012 \times T_s$	$2 \times 24576 \times T_s$

Table 1: Configuration of Random Access Preamble (FDD)

The burst format is decided by e-NodeB. Format 0 is used for normal cell. Format 1, also known as extended format, is used for large cell. To support low data rate at the cell edge and consider the power balancing, repetition is required for preamble. So Format 2 and 3 are called repeated format. Format 2 is for maximum cell size of 30km and Format 3 is used for maximum cell size of 100km.

- In the frequency domain, the random access burst occupies a bandwidth corresponding to 6 resource blocks for both frame structures.
- The transmission of a random access preamble, if triggered by the MAC layer, is restricted to certain time and frequency resources. These resources are enumerated in increasing order of the subframe number within the radio frame and the resource blocks in the frequency domain such that index 0 correspond to the lowest numbered resource block and subframe within the radio frame.

Nomor 3GPP Newsletter – December 2007

Overview LTE RACH

Authors: Sujuan Feng, Eiko Seidel

- For preamble format 0-3, there is at most one random access resource per subframe.Table 2 lists the subframes in which random access preamble transmission is allowed for a given configuration. The start of the random access preamble shall be aligned with the start of the corresponding uplink subframe at the UE assuming a timing advance of zero.

PRACH configuration	System frame number	Subframe number
0	Even	1
1	Even	4
2	Even	7
3	Any	1
4	Any	4
5	Any	7
6	Any	1, 6
7	Any	2 ,7
8	Any	3, 8
9	Any	1, 4, 7
10	Any	2, 5, 8
11	Any	3, 6, 9
12	Any	0, 2, 4, 6, 8
13	Any	1, 3, 5, 7, 9
14	Any	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
15	Even	9

Table 2: Random access preamble timing for preamble format 0-3

- According to the agreement at WG1#50, frequency hopping is allowed and only one frequency hopping pattern common to all cells.

Preamble sequence generation:

Preambles are generated from one or several root Zadoff-Chu sequences. The u^{th} root Zadoff-Chu sequence is defined by

$$x_u(n) = e^{-j\frac{\pi u n(n+1)}{N_{\text{ZC}}}}, \quad 0 \le n \le N_{\text{ZC}} - 1,$$

where the length N_{ZC} for FDD is 839.

There are 64 preambles available in each cell. The set of 64 preamble sequences in a cell is found by including first, in the order of increasing cyclic shift, all the available cyclic shifts of a root Zadoff-Chu sequence with the logical index RACH_ROOT_SEQUENCE where RACH_ROOT_SEQUENCE is broadcasted as part of the System Information. Additional preamble sequences, in case 64 preambles cannot be generated from a single root Zadoff-Chu sequence, are obtained from the root sequences with the consecutive logical indexes until all the 64 sequences are found. The logical root sequence order is cyclic: the logical index 0 is consecutive to 837.

From the u^{th} root Zadoff-Chu sequence, random access preambles with zero correlation zones of length $N_{\text{CS}} - 1$ are defined by cyclic shifts according to

$$x_{u,v}(n) = x_u((n + C_v) \bmod N_{ZC})$$

where the cyclic shift is given by

$$C_v = \begin{cases} vN_{CS} & v = 0,1,\ldots,\lfloor N_{ZC}/N_{CS} \rfloor - 1 \quad \text{for unrestricted sets} \\ d_{start}\lfloor v/n_{shift}^{RA} \rfloor + (v \bmod n_{shift}^{RA})N_{CS} & v = 0,1,\ldots,n_{shift}^{RA} n_{group}^{RA} + \bar{n}_{shift}^{RA} - 1 \quad \text{for restricted sets} \end{cases}$$

and N_{CS} is given by Table 3.

The variable d_u is the cyclic shift corresponding to a Doppler shift of magnitude $1/T_{SEQ}$ and is given by

$$d_u = \begin{cases} u^{-1} \bmod N_{ZC} & 0 \le u^{-1} \bmod N_{ZC} < N_{ZC}/2 \\ N_{ZC} - u^{-1} \bmod N_{ZC} & \text{otherwise} \end{cases}$$

The parameters for restricted sets of cyclic shifts depend on d_u. For $N_{CS} \le d_u < N_{ZC}/3$, the parameters are given by

$$\begin{aligned} n_{shift}^{RA} &= \lfloor d_u/N_{CS} \rfloor \\ d_{start} &= 2d_u + n_{shift}^{RA} N_{CS} \\ n_{group}^{RA} &= \lfloor N_{ZC}/d_{start} \rfloor \\ \bar{n}_{shift}^{RA} &= \max\left(\lfloor (N_{ZC} - 2d_u - n_{group}^{RA} d_{start})/N_{CS} \rfloor, 0\right) \end{aligned}$$

For $N_{ZC}/3 \le d_u \le (N_{ZC} - N_{CS})/2$, the parameters are given by

$$\begin{aligned} n_{shift}^{RA} &= \lfloor (N_{ZC} - 2d_u)/N_{CS} \rfloor \\ d_{start} &= N_{ZC} - 2d_u + n_{shift}^{RA} N_{CS} \\ n_{group}^{RA} &= \lfloor d_u/d_{start} \rfloor \\ \bar{n}_{shift}^{RA} &= \min\left(\max\left(\lfloor (d_u - n_{group}^{RA} d_{start})/N_{CS} \rfloor, 0\right), n_{shift}^{RA}\right) \end{aligned}$$

For all other values of d_u, there are no cyclic shifts in the restricted set.

Nomor 3GPP Newsletter – December 2007

Overview LTE RACH

Authors: Sujuan Feng, Eiko Seidel

N_{CS} configuration	N_{CS} value	
	Normal set	High-speed set
0	0	15
1	13	18
2	15	22
3	18	26
4	22	32
5	26	38
6	32	46
7	38	55
8	46	68
9	59	82
10	76	100
11	93	128
12	119	158
13	167	202
14	279	237
15	419	-

Table 3: Cyclic shifts N_{CS} for preamble generation

Table 4: Root Zadoff-Chu sequence order for high-speed configuration

Baseband signal generation:

The time-continuous random access signal $s(t)$ is defined by

$$s(t)=\beta_{\text{PRACH}}\sum_{k=0}^{N_{ZC}-1}\sum_{n=0}^{N_{ZC}-1}x_{u,v}(n)\cdot e^{-j\frac{2\pi nk}{N_{ZC}}}\cdot e^{j2\pi\left(k+\varphi+K\left(k_0+\frac{1}{2}\right)\right)\Delta f_{\text{RA}}\left(t-T_{\text{CP}}\right)}$$

where $0\le t<T_{\text{PRE}}+T_{\text{CP}}$, β_{PRACH} is an amplitude scaling factor and $k_0=k_{\text{RA}}N_{\text{sc}}^{\text{RB}}-N_{\text{RB}}^{\text{UL}}N_{\text{sc}}^{\text{RB}}/2$. The location in the frequency domain is controlled by the parameter k_{RA}, expressed as a resource block number configured by higher layers and fulfilling $0\le k_{\text{RA}}\le N_{\text{RB}}^{\text{UL}}-6$. The factor $K=\Delta f/\Delta f_{\text{RA}}$ accounts for the difference in subcarrier spacing between the random access preamble and uplink data transmission. The variable Δf_{RA}, the subcarrier spacing for the random access preamble, and the variable φ, a fixed offset determining the frequency-domain location of the random access preamble within the resource blocks. For FDD, Δf_{RA} = 1250 Hz, φ = 12.

Nomor 3GPP Newsletter – December 2007

Overview LTE RACH

Authors: Sujuan Feng, Eiko Seidel

Configurable parameter of RACH

Physical Random Access Channel Parameter

Parameter	Size [bits]	Configuration	Comment
PRACH time-domain configuration	4 (FDD) TBD (TDD)	Broadcast (SIB)	Provides information about the PRACH time-domain (subframe) configuration.
PRACH frequency-domain configuration	TBD	Broadcast (SIB)	Provides information about the PRACH frequency-domain configuration. Only applicable to TDD carrier.
Preamble-format	2 (FDD) TBD (TDD)	Broadcast (SIB)	For TDD there is also a short preamble, i.e. a total of five preambles formats
Root-sequence-index	10	Broadcast (SIB)	
Zero-correlation-zone length	4	Broadcast (SIB)	Different interpretation depending on *High-speed flag*
High-speed flag	1	Broadcast (SIB)	
PRACH transmit power setting.	TBD	Broadcast (SIB)	Some signaling related to the setting of the PRACH transmit power is needed. Exactly what is to be signaled is TBD.

MAC Random Access Channel Parameter

Parameter Name	Scope	Note
Number of RA preambles	RRC-BCCH, RRC-DCCH	This parameter is used to determine the total number of RA preambles that UE can select from (i.e. for contention based RA). The minimum cannot be zero.
Size of RA preambles group A	RRC-BCCH, RRC-DCCH	This parameter indicates the size of the group A of RA preambles. The group B of RA preambles is constituted by the remaining RA preambles out of the "Number of RA preambles". Note: The chosen encoding (0..63 or 1..64) will impact the way the RA request parameters are designed.
RA power ramping step size	RRC-BCCH, RRC-DCCH	Step size of the RA power ramping
Minimum power	RRC-BCCH, RRC-DCCH	Minimum power used during RA procedure
Maximum power	RRC-BCCH, RRC-DCCH	Maximum power used during RA procedure

Nomor 3GPP Newsletter – December 2007

Overview LTE RACH

Authors: Sujuan Feng, Eiko Seidel

Maximum number of RA transmis-sions	RRC-BCCH, RRC-DCCH	Maximum number of RA transmissions before MAC declare RA failure
RA time-frequency resour-ces	RRC-BCCH, RRC-DCCH	These parameters describe the location of the RA time-frequency resource(s) within the frequency band. There may be more than one RA time-frequency resource available. RRC needs to indicate to MAC the PRACH configuration in use to determine the timing.
RA response win-dow size	RRC-BCCH, RRC-DCCH	This parameter describes the RA response window size in TTIs
RA response win-dow offset	RRC-BCCH, RRC-DCCH	This parameter describes the start of the RA response win-dow in time
Dedicated RA preamble expirati-on	RRC-DCCH	This parameter describes the life time of a dedicated RA preamble.
RA backoff	RRC-BCCH, RRC-DCCH	This parameter describes the value of the backoff that should be applied if an RA fails
MAC contention resolution timer	RRC-BCCH, RRC-DCCH	This parameter describes the maximum amount of time al-lowed for contention resolution.
RA request parame-ter(s)	RRC-BCCH, RRC-DCCH	This/These parameter(s) will be used as input to a MAC function which determines (depending on the size of the message to be transmitted or the requested resource blocks) which group of RA preambles shall be used to choose an RA Preamble.

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