Random access in cellular systems

GSM
WCDMA
IEEE 802.16e

Random access channels

- ALOHA is commonly used in a random access channels RACH in cellular radio systems.
- Use of RACH
  - Carry control information from the User Equipment (UE) to set up an initial connection. For example, to
    - *Register* the UE after power-on to the network (Internal Mobile Phone Subscriber Identity (IMSI) attach)
    - Resign the UE (IMSI detach)
    - Perform *location update*
    - Answer paging
    - Request outgoing call
  - Send small amount of packet data to network for 1 to 2 frames (Short Messaging Service)

Random access in GSM

- There are different configurations of RACH channel in GSM depending how many time slots are allocated to the physical random access channel.
- One of the configurations is to assign one access slot per TDMA frame consisting 8 slots.
- The random access protocol is based on slotted ALOHA with limit on the maximum number of transmission attempts (0,1,2,…,7)
- The time interval between consecutive transmission can be set between 3 to 50 slots. The time interval should be longer than the coherence time of the channel to obtain time diversity.

Random access in GSM

- Retransmissions are good when the traffic load is small, but in case of congested system, they will increase the load further and cause lower throughput and higher blocking.
- Long interval between retransmissions give time diversity gains

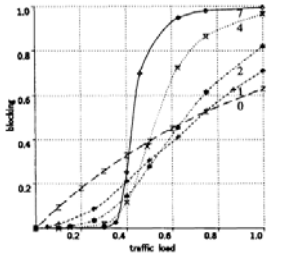

Fig. 1 : Blocking vs. traffic load for different values of the maximum number of retransmissions (0, 1, 2, 4, 7). The interval width for retransmission was chosen to be 14.

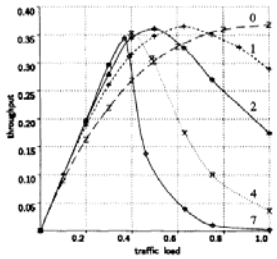

Fig. 2 : Throughput vs. traffic load for different values of the maximum number of retransmissions (0, 1, 2, 4, 7). The interval width for retransmission was chosen to be 14.

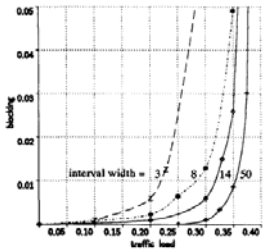

Fig. 3 : Blocking vs. traffic load for a maximum number of retransmissions of 7 and for different values (3, 8, 14, 50) of the interval width for retransmissions .

Luders, C.; Haferbeck, R., "The performance of the GSM random access procedure," *Vehicular Technology Conference, 1994 IEEE 44th* , vol., no., pp.1165-1169 vol.2, 8-10 Jun 1994

Random access in WCDMA uplink

- Random Access Channel (RACH)
  - Signaling: Initial access of UE to the network, location update, connection establishment requests,...
  - Packet access: 10 to 20 ms long packets with spreading factor of 256: up to 16 kbit/s
  - Slotted ALOHA principle with power ramping
- Before transmission, the User Equipment will perform cell search procedure in order to
  - find the chip and frame boundaries (synchronization),
  - indentify the primary scrambling code of the cell and
  - decodes Broadcast channel (BCH) to find out the available RACH sub-channels and the scrambling codes, signatures, persistence probability P_i and maximum number of transmission attempts M_{max}.
- The protocol supports quality of service differentiation by using different persistence probabilities for each Access Service Class (ASC) [0…7]

Random access in WCDMA uplink

- Before sending an actual packet, a preamble is sent.
- A preamble is a short signal which consists of 4096 chips. It is a sequence of 256 repetitions of Hadamard codes of length 16. Hence, there exist 16 different preamble signatures (one for each code).
- Also a scrambling code related to the cell identity is applied to the preamble.
- Before any attempt, the UE selects randomly a signature and sends the related preamble.
- The downlink power is measured and the initial RACH power level is set with a proper margin due to open loop inaccuracy

Random access in WCDMA uplink

- Recursion for generating the codes

$$H_k = \begin{bmatrix} H_{k-1} & H_{k-1} \\ H_{k-1} & -H_{k-1} \end{bmatrix}, \quad H_0 = 1$$

$H_4 =$

$$\begin{bmatrix}
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\
1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\
1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\
1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\
1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\
1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\
1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\
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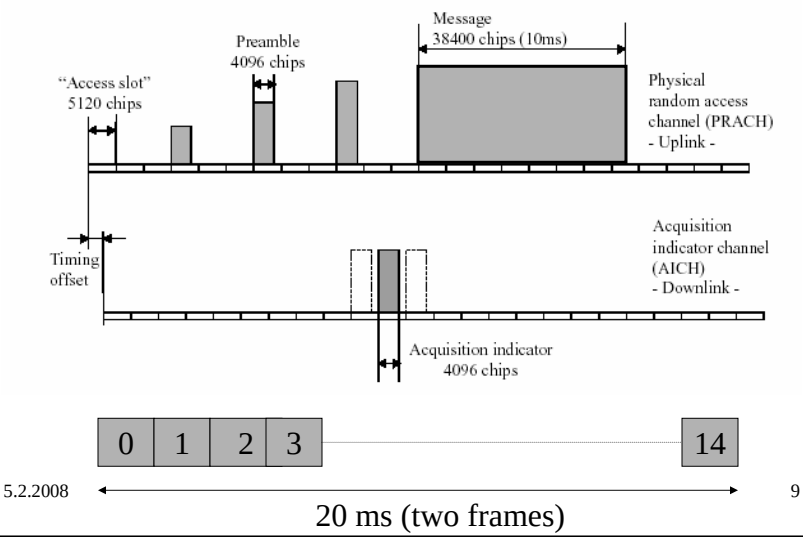
1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 \\
1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 \\
1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\
1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1
\end{bmatrix}$$

Random access in WCDMA uplink

- UE transmits 1 ms long preamble with the selected signature
- Node-B replies by repeating the preamble using Acquisition Indication Channel (AICH)
- UE decodes AICH message to see whether the node-B has detected the preamble.
  - If AICH is not detected, the preamble is resend with 1dB higher transmit power.
  - If AICH is detected, a 10 or 20 ms long message part is transmitted with the same power as the last preamble

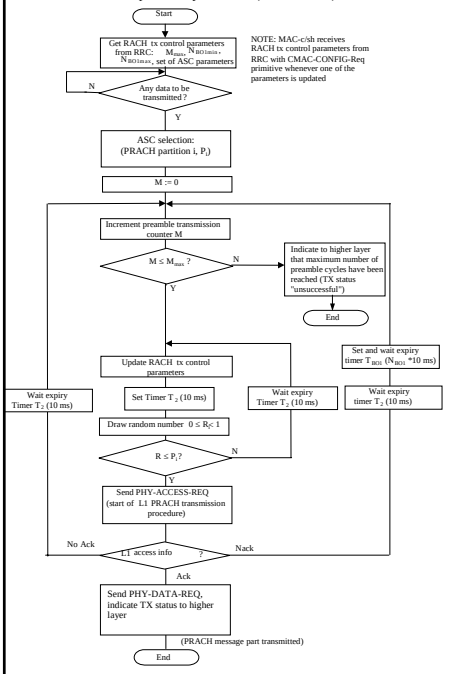
Random access in WCDMA uplink



Random access in WCDMA uplink

- If the base station detects successfully the preamble, it can send back an AI. This indicator contains a replica of the preamble so that the UE can be aware of its target.
- The AI can take 2 values (positive acknowledgment ACK or negative acknowledgment NACK) depending on whether the message transmission is allowed or not.
- If two or more UEs selected the same signature and there were power capture, then ACK is ambiguous.
- The throughput of the Release 99 RACH has been reported to be approx 40% of the slotted ALOHA throughput (Huusko, et. Al. 2003).

3GPP TS 25.321 MAC protocol specification(Release 1999)



Huusko, J.; Peramaki, T.; Jarvensivu, P.; Jurvansuu, M., "WCDMA RACH channel medium access control performance," *Personal, Indoor and Mobile Radio Communications, 2003. PIMRC 2003. 14th IEEE Proceedings on* , vol.3, no., pp. 2636-2639 vol.3, 7-10 Sept. 2003

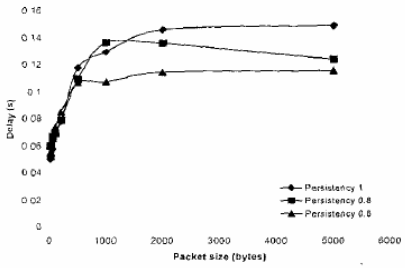


Figure 4. Channel access delay (10 UEs).

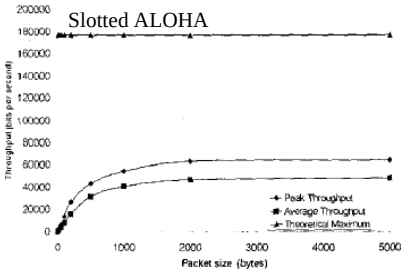


Figure 5. RACH channel throughput (10 UEs).

Slotted ALOHA

Access procedures – WiMAX example

Ranging in IEEE 802.16e

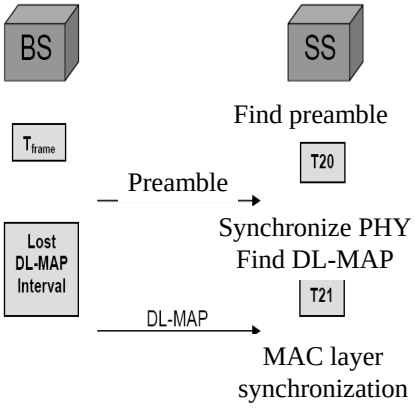
- Within 802.16e, ranging procedure is defined in order to synchroneze the subscriber station (SS) [i.e. user equipment] with the base station (BS)
- The process aims to align the SSs transmissions with the BS receive frame (timing) and acquire power adjustments.
- The different ranging procedure are
  - new SS registers to the network
  - SS making handovers to the BS
  - SS that have been inactive stay synchronized with the BS by periodically sending ranging requests

Access procedure in WiMAX

- The access procedure in IEEE802.16-2004 WiMAX system consists of 10 steps
- Steps 7 – 9 are optional

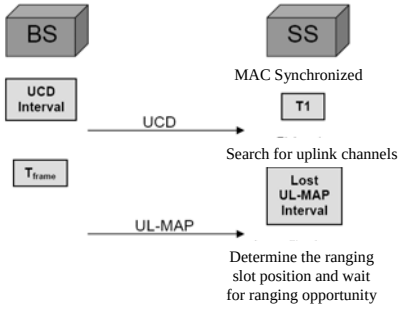
1. Search for downlink channel and synchronize PHY
2. Obtain uplink parameters
3. Ranging and uplink parameter adjustment
4. Negotiate basic parameters
5. MS authorization and key exchange
6. Register with BS
7. Establish IP connectivity
8. Transfer operational parameters
9. Establish connections
10. Normal operation

Synchronization



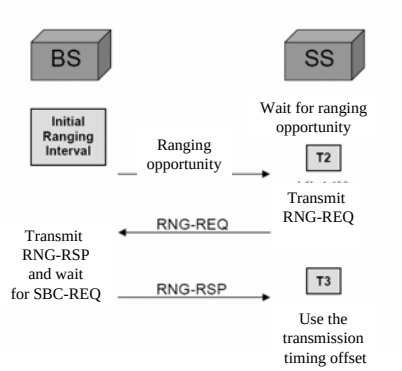
- First the subscriber station SS must synchronize it self to the frame timing used by the base station BS by correlating against the preamble.
- After obtaining PHY layer synchronization, SS will decode the downlink frame in order to find the DL-MAP message.
- DL-MAP determines the timing Downlink Bursts and thus provides MAC layer sync.

Transmission parameters



- After MAC layer synchronization, SS starts to wait for the UCD (Uplink Channel Descriptor) message
- UCD defines the transmission parameters utilized in the uplink direction.
- After obtaining UCD and UL-MAP, SS starts to wait for transmission window reserved for the ranging operation.

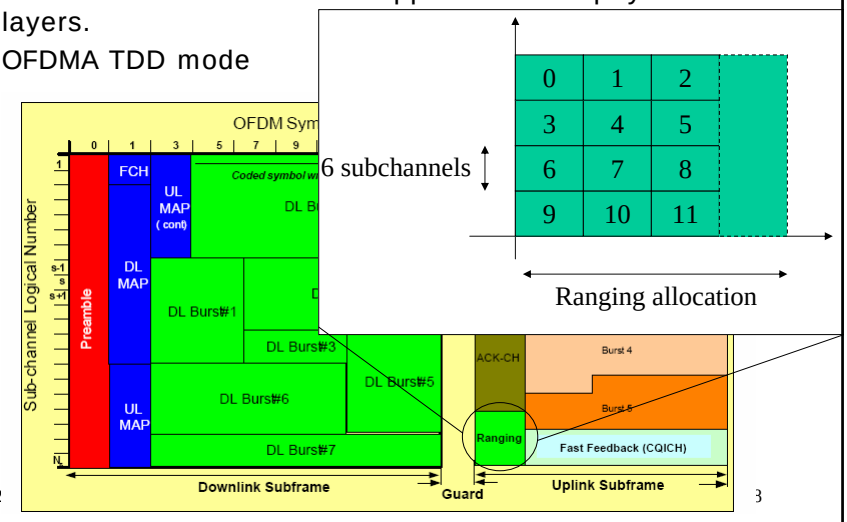
Ranging



- There are 12 ranging slots.
- The ranging slots is identified by
  - Its time interval index
  - The group of subchannels (6 channels per slot)
  - Hadamard codes (similar to WCDMA RACH)
- The subscriber station selects randomly one of the ranging slots and codes and transmits the Ranging Request (RNG-REQ) to the BS

Ranging

- The IEEE 802.16 standard supports several physical layers.
- OFDMA TDD mode



Ranging

- In case of successful detection, the BS broadcasts a ranging response (RNG-REP) that contains
  - The received slot and code based on which SS identifies the reply
  - Time and power correction (offset)
  - Status notification
    - Success: The BS provides bandwidth allocation for the SS
    - Continue: The SS adjusts its timing offset and transmission power based on the response information, selects new ranging code and slot and sends new RNG-REQ.
- If the SS does not receive RNG-REP it will retry ranging with higher transmit power.

Negotiate basic parameters

- After successful ranging, basic transmission parameters are negotiated.
- The SS sends Basic Capability Request (SBC-REQ) message where it announces supported physical layer capabilities (modulation, coding, multiplexing)
- Base station replies by sending SBC-RSP that indicated the parameters that are supported by both BS and SS.
- This procedure is followed by authentication and key-exchange.