Network Access Mechanisms in GPRS

- The initial access is performed according to the slotted ALOHA mechanism.
- The initial access is used to convey the reason for accessing the network and to determine the distance between the mobile station and the network.
- The initial access is done on the PRACH if a PCCCH is provided in a cell or on the RACH if only the CCCH is available.
- On the CCCH, the regular CHAN_REQ-message is used to convey the reason for access.
Network Access on PRACH:

- On the PRACH, the PACK-CHAN_REQ-message is used which may contain 8 or 11 information bits.
- Independent of the number of information bits, each PACK_CHAN_REQ needs to fit in the shortened access burst which may carry 36 information bits.

Channel coding for access burst:

- Access burst is used by mobile stations for transmission to the base station when no TA information is available.
- To avoid a base station mistaking the electromagnetic noise in the environment as a valid access burst, 41 bit long synchronization sequence is included.
- BSIC (Base Station Identity Code) is appended to the payload.
Two network access methods:

- **One-Phase Packet Access:**
  - Requested and selected by the mobile station
  - The initial access message is responded to by a suitable resource allocation in uplink direction
  - Even if the mobile station requests One-Phase Access, the network may still enforce Two-Phase Access by allocating only a single block to the requesting mobile station to further specify its request.

- **Two-Phase Packet Access:**
  - Selected by the mobile station by asking for a single block allocation (on RACH) or by explicitly requesting Two-Phase Packet Access (on PRACH)
  - Two-Phase packet access is mandatory in case of unacknowledged RLC/MAC transmission mode

One-Phase Access and Contention Resolution:

- The initial access message cannot uniquely identify the sending mobile station
- Ambiguities cannot be avoided
- Different mobile stations may consider the same resource allocation to be destined to itself and start using it
- Contention resolution is required
Contention resolution procedure at One-Phase Access:

- The (PACK)-CHAN_REQ indicates One-Phase Access
- The network will assign sufficient resources
- The mobile station shall include its identification (TLLI: temporary logical link identity) in the first uplink blocks that are sent
- The network shall reply ASAP with a PACK_UL_ACK that includes the TLLI of the addressed mobile station
- If there is a second mobile station using the same uplink resources, it needs to stop its transmission.

Two-Phase Access:

1. (PACK)-CHAN_REQ
2. PACK_UL_ASS [Dedicated UL Resources]
3. PDTCH [RLC/MAC Data Block] + TLLI
4. PDTCH [RLC/MAC Data Block] + TLLI
5. PACK/MAC-RLC PACK_UL_ACK [TLLI, Resource Allocation]
6. PDTCH [RLC/MAC Data Block]
Operation of Two-Phase Access:

- Mobile station sends CHAN_REQ on RACH or PACK_CHAN_REQ on PRACH. PACH_CHAN_REQ allows for distinction between multiple access reasons while CHAN_REQ can only distinguish between One-Phase Access and single block packet access. Both messages cannot identify the mobile station unambiguously. They only contain 2-5 bit long temporary “Random Reference” for immediate identification.
- Network implicitly convey Two_Phase Access decision by assigning only a single uplink radio block to the mobile station.
- The mobile station uses the indicated uplink radio block to transmit a PACH-RES_REQ to the PCU that contains the TLLI plus more detailed information about what resources are required. Including TLLI is part of the contention resolution here.
- The PCU will respond to the PCK_RES_REQ message with a PACK_UL_ASS message that allocates resources to the mobile station. TLLI is also included to finish contention resolution.
- The mobile station starts to transmit on the allocated resources. TLLI need not be included here.

How to distinguish ongoing packet data transactions?

- Problems:
  - Packet data transactions are unidirectional
  - Each packet data transaction may involve more than one timeslot
  - Multiple mobile stations are using the same physical resource which is a given timeslot, being assigned as PDCH
  - Distinction is required for uplink and downlink direction
Introducing the temporary block flow (TBF):

- The TBF is similar to a channel in circuit-switched transactions
- The TBF or rather its identifier, the Temporary Flow Identity (TFI), uniquely identifies an ongoing packet data transfer in uplink or downlink direction
- The TFI is part of each block being sent in uplink and downlink direction
- The TFI is unformatted and has a length of 5 bits

Uplink and downlink TBFs are independent

- TBFs are assigned dynamically by the network (PCU)
- There may be identically numbered TBFs in uplink and downlink direction
- Each TFI is unique for the PDCHs that are allocated to a transaction (and per direction)
- The lifetime of a TBF is limited to the lifetime of the related packet data transaction

Packet Transactions Uplink and Downlink on one ARFCN where all TS's are PDCHs

Note that there may even be identically numbered TBFs in one direction and on one TRX but on different sets of PDCH's!!
The trouble with the resource allocation:

- A packet-switched mobile network does not deploy dedicated resources but rather resources on demand. One PDCH or PDTCH is shared among many users.
- The downlink direction is not critical as the network may identify the addressed mobile in each downlink block.
- The uplink direction is very critical as the transmissions from several mobile stations would probably collide.
- Slotted ALOHA are only for the initial access.
- Uplink transmissions need to be scheduled and controlled by the network.

Three uplink resource allocation methods in GPRS:

- Fixed allocation of uplink resources
  - Mandatory feature for the network and the mobile station.
- Dynamic allocation of uplink resources
  - Mandatory feature for the network and the mobile station.
- Extended dynamic allocation of uplink resources
  - Optional feature for the network and most mobile stations.
Fixed allocation of uplink resources (1)

- The network conveys a bitmap to the mobile station that identifies all blocks within several consecutive 52-multiframes where the mobile station may transmit.
- There may be more than one bitmap depending on the number of timeslots that are in use.
- In addition to the allocation bitmap the mobile station needs to know when to start the transmission (starting time).
- While involved in a fixed allocation, the mobile station may request additional resources, if required.

Fixed allocation of uplink resources (2)

- In this example, bitmap is: 101110111111011
Dynamic allocation of uplink resources (1)

- The dynamic resource allocation method is based on the use of the uplink state flag (USF)
- The USF is part of the MAC-header of each downlink data or control block that is sent
- The USF of downlink block \( k \) identifies the user of uplink block \( (k+1) \)

Dynamic allocation of uplink resources (2)
More details of the Uplink State Flag (USF) (1)

- The USF has a fixed length of 3 bits
  - 8 different values possible
- Seven or six mobile stations can be distinguished
  - Depending on whether PCCCH is part of the PDCH. Another USF-value is reserved to identify fixed allocations
- A mobile station, involved in a mutlislot assignment has probably different USFs assigned, one for each timeslot
- USF-Granularity
  - Depending on its value, a mobile station may use not only the next uplink block but also the next four blocks: 0, only next uplink block; 1, next 4 uplink blocks

More details of the Uplink State Flag (USF) (2)

- The USF is also used to allocate radio blocks for PRACHs
  - The fixed value ‘111’\textsubscript{bin} is reserved to denote PRACH
- Almost all active mobile stations have to decode all downlink data blocks to find their USF
  - This imposes serious constraints on power control
- Mobile stations that intend to transmit on PRACH need to listen to the USF on that PDCH
- Mobile stations being involved in a fixed allocation are not required to decode the USFs
The extended dynamic allocation of uplink resources (1)

- Optional allocation method for the network and the mobile station
- Also using the USF for uplink transmission scheduling
- Only applicable in case of multislot assignments
- Relieves the multislot mobile station from listening to all downlink blocks on all assigned timeslots

The extended dynamic allocation of uplink resources (2)

- Combine several timeslots as a group (here, TS 0, 2, 3, 5, 7)
- The mobile station will listen to the USF values of all radio blocks on the respective downlink channels. If the mobile station detects its USF-value in downlink block k/timeslot N, it will
  - Stop listening to the USFs on all higher numbered timeslots
  - Start transmitting on uplink block k+1 on timeslot N and all higher numbered timeslots of the allocation
Summary for network access and resource allocation

Downlink resource allocation

- Downlink transmission scheduling is easy as it is automatically controlled by the network.
- Downlink reception deserves some attention as a mobile station cannot determine in advance when packets will be sent by the network.
- A mobile station needs to receive and decode all downlink data blocks on all assigned timeslots, corresponding to a downlink TBF.
- A mobile station will identify its downlink data packets by checking the TFI, which is part of each downlink block.
Operation of the bi-directional PACCH (packet associated control channel)

- Contrary to PDTCHs, the related PACCH is bi-directional
- Resources for issuing an RLC/MAC control message on PACCH need to be provided in a dynamic manner and on demand by the network (PCU)
- PACCH operation is different for uplink and downlink directions

PACCH operation for downlink TBF’s

- While involved in a downlink TBF, the mobile station needs to decode all data and control blocks on all assigned timeslots
  - Control messages on PACCH that are destined to a specific mobile station are tagged either by:
    - Including the downlink TFI in the RLC header of the RLC/MAC control message
    - Including the mobile station’s identity (TLLI) or the downlink TFI within the message content
  - At certain times, the mobile station needs to issue control messages on PACCH
    - Note that a downlink TBF does not provide uplink resources to the mobile station. Accordingly, the network needs to allocate a single uplink block to a given mobile station dynamically.
PACCH operation in downlink direction

- Network polls the mobile station
  - RRBP (relative reserved block period) allocates a single uplink radio block for the addressed mobile station
- The mobile station will reply in the specified radio block with a signal message

PACCH operation for uplink TBF’s

- While involved in an uplink TBF, the mobile station may use the allocated resources also to transmit RLC/MAC control messages
  - The distinction between RLC/MAC data and control blocks is done via the RLC/MAC header
- The network may transmit RLC/MAC control messages to the mobile station on all assigned timeslots at any time
  - The mobile station needs to receive and decode all downlink blocks on all assigned timeslots. Only in case of extended dynamic resource allocation will the network limit the transmission of RLC/MAC control blocks on PACCH to the lowest numbered timeslot
  - The distinction of RLC/MAC control messages for different mobile stations is done according to the procedure for downlink TBF PACCH operation
Resource release in GPRS

- GPRS requires that an active packet transmission (TBF) be terminated without signaling
- This requirement applies for both directions, uplink and downlink
- The release procedures for uplink and downlink TBFs are different

The release of uplink resources (1)

- The release of the uplink resource is initiated by the mobile station
- Uplink resource release is based on the countdown procedure
- The countdown procedure is mandatory for all resource allocation methods: fixed, dynamic, and extended dynamic
- TBF release is confirmed by the network
  - On expiry of the countdown procedure, the network will issue a PACK_UL_ACK with the Final ACK bit set to 1. This applies to both RLC operation modes, acknowledged and unacknowledged. Retransmissions can only be invoked in acknowledged RLC operation mode
The release of uplink resources (2)

This message will also assign another uplink radio block for the final control message from the mobile station.

The countdown procedure (1)

- Every RLC/MAC uplink data block contains the 4 bit long parameter Countdown Value (CV).
- CV indicates how many RLC/MAC data blocks remain in the mobile station to be transmitted to the network.
- When the countdown procedure has not started yet, the value of CV defaults to ’15’$_{dec}$.
- The countdown procedure may be started at ’15’$_{dec}$ or at a smaller value.
  - This depends on another parameter, BS.CV.MAX.
The countdown procedure (2)

- Once the countdown procedure has started, the mobile station cannot invoke additional resources for that TBF
  - This limitation does not apply in case of possibly necessary retransmissions. In that case, the network needs to assign additional resources
- The countdown procedure is somewhat different for single and multiple timeslot assignments
- The countdown procedure is based on the following formula

\[
\text{Countdown procedure starts } \Leftrightarrow \frac{(\text{total No of blocks} - 1) - \text{BSN}}{\text{Number of timeslots}} = 15 \text{ or } BS_{CV\_MAX}
\]

The division is non-integer and its result needs to be rounded up
This formula also applies in case of only one timeslot

BSN (Block Sequence Number):
- BSN numbers and identifies each RLC/MAC data block
- BSN is used in both RLC operation modes, acknowledged and unacknowledged
- BSN is part of each RLC header in uplink and downlink data blocks
The countdown procedure in a one-timeslot configuration

- 20 data blocks (numbered 0 to 19) to be sent. BS_CV_MAX=3
- When data block with BSN=16 is sent (3 blocks left), countdown procedure starts
- Data block with BSN=19 carries CV=0
- That block triggers the network to respond with a control message carrying Final_Ack=1

![Diagram of countdown procedure in a one-timeslot configuration]

The countdown procedure in a four-timeslot configuration

- 20 data blocks to send. BS_CV_MAX=2
- With BSN=11, the mobile station initiates the countdown procedure
- Note that the following 4 blocks carry the same CV-value
- Only the very last block with BSN=19 is sent with CV=0
- This block triggers the network to reply with a PACK_UL_ACK-message with FINAL_ACK=1 which means all blocks have been properly received.

![Diagram of countdown procedure in a four-timeslot configuration]

TBF Information:
Number of RLC Blocks = 20 (not all are presented here)
BS_CV_MAX = 2
The release of downlink resources (1)

- For downlink TBF release, the network will set the Final Block Indicator (FBI) bit to 1, indicating that this block is the last to be sent.

- The FBI bit is part of the RLC header in each downlink data block.

- Within the same block, the network will allocate a single uplink block to the mobile station to confirm proper reception or to require retransmission (acknowledged mode only).

- In unacknowledged RLC mode, the mobile station will confirm the TBF release by issuing a `PACK_CTRL_ACK`.

The release of downlink resources (2)
**Acknowledged and unacknowledged operation mode**

- The radio link control protocol (RLC) on the air interface provides two operation modes:
  - Acknowledged Operation Mode: offers means for error recognition and correction
  - Unacknowledged Operation Mode: offers no means for error recognition and correction. Error recognition and correction need to be taken care of by higher layer protocols
- Acknowledged RLC Operation Mode is based on ARQ mechanism

**Automatic Repeat Request (ARQ) (1)**

- Erroneous data blocks can selectively be requested for retransmission
- Each frame is unambiguously numbered within a sliding receive/transmit window
- The respective acknowledgement messages contain a bitmap to distinguish properly received data blocks from erroneous data blocks (PACK_UL_ACK and PACK_DL_ACK)
Quality of Service (QoS)

- In GPRS, each subscription is related to a QoS profile
- Before packet data transmission can be performed, network (GGSN) and mobile station need to negotiate a QoS profile
- Two options:
  - The network operator may define a default QoS profile that is applicable to all subscribers (Best Effort)
  - The network operator may define several QoS profiles that can be subscribed to
The QoS profile

- The QoS profile is built from the following parameters:
  - Service precedence/priority
    - Does a subscriber enjoy transmission precedence?
  - Delay class
    - How much time will it take for a data packet to be routed through the GPRS network?
  - Throughput
    - Mean throughput and peak throughput need to be distinguished
  - Reliability class
    - How much error control and correction are provided by GPRS?

Service precedence /priority

Under normal network conditions, all users shall be served. However, in case of network congestion, those users with a higher priority level will enjoy a privileged handling of their transactions compared to lower priorities.

- Thus, a user with a low priority level may encounter higher delays or even data losses in case of network overload.
- Three precedence levels defined, with ‘1’ being the highest priority and ‘3’ the lowest

<table>
<thead>
<tr>
<th>Precedence</th>
<th>Precedence Name</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High priority</td>
<td>Service commitments shall be maintained ahead of precedence classes 2 and 3</td>
</tr>
<tr>
<td>2</td>
<td>Normal priority</td>
<td>Service commitments shall be maintained ahead of precedence class 3</td>
</tr>
<tr>
<td>3</td>
<td>Low priority</td>
<td>Service commitments shall be maintained after precedence classes 1 and 2</td>
</tr>
</tbody>
</table>
Delay class (1)

- The delay class relates to the maximum delay times that a data packet may encounter while transported through the GPRS network.
- This delay does not consider delay times that are caused outside the PLMN.
- Four delay classes need to be distinguished with ‘1’ offering the lowest delay times and ‘3’ bearing the highest risk for delays.
- Delay class ‘4’ is ‘best effort’ which means that all transactions are handled according to the “first-in-first-out” principle.

Delay class (2)

<table>
<thead>
<tr>
<th>Delay Class</th>
<th>SDU size: 128 octets</th>
<th>SDU size: 1024 octets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Transfer Delay (sec)</td>
<td>95 percentile Delay (sec)</td>
</tr>
<tr>
<td>1. (Predictive)</td>
<td>&lt; 0.5</td>
<td>&lt; 1.5</td>
</tr>
<tr>
<td>2. (Predictive)</td>
<td>&lt; 5</td>
<td>&lt; 25</td>
</tr>
<tr>
<td>3. (Predictive)</td>
<td>&lt; 50</td>
<td>&lt; 250</td>
</tr>
<tr>
<td>4. Best Effort</td>
<td>Unspecified</td>
<td></td>
</tr>
</tbody>
</table>

SDU: service data unit
Mean throughput rate (1)

- The mean throughput rate is measured in units of octets per hour
- 19 different mean throughput rates have been defined, ranging from 0.22bit/s up to 111kbit/s
- As in the delay class parameter, there is an extra mean throughput rate called ‘best effort’

Mean throughput rate (2)

<table>
<thead>
<tr>
<th>Mean Throughput Class</th>
<th>Mean Throughput in Octets per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Best effort</td>
</tr>
<tr>
<td>2</td>
<td>100 (~0.22bit/s)</td>
</tr>
<tr>
<td>3</td>
<td>200 (~0.44bit/s)</td>
</tr>
<tr>
<td>4</td>
<td>500 (~1.11bit/s)</td>
</tr>
<tr>
<td>5</td>
<td>1 000 (~2.2bit/s)</td>
</tr>
<tr>
<td>6</td>
<td>2 000 (~4.4bit/s)</td>
</tr>
<tr>
<td>7</td>
<td>5 000 (~11.1bit/s)</td>
</tr>
<tr>
<td>8</td>
<td>10 000 (~22bit/s)</td>
</tr>
<tr>
<td>9</td>
<td>20 000 (~44bit/s)</td>
</tr>
<tr>
<td>10</td>
<td>50 000 (~111bit/s)</td>
</tr>
<tr>
<td>11</td>
<td>100 000 (~222bit/s)</td>
</tr>
<tr>
<td>12</td>
<td>200 000 (~444bit/s)</td>
</tr>
<tr>
<td>13</td>
<td>500 000 (~1111bit/s)</td>
</tr>
<tr>
<td>14</td>
<td>1 000 000 (~2222bit/s)</td>
</tr>
<tr>
<td>15</td>
<td>2 000 000 (~4444bit/s)</td>
</tr>
<tr>
<td>16</td>
<td>5 000 000 (~11111bit/s)</td>
</tr>
<tr>
<td>17</td>
<td>10 000 000 (~22222bit/s)</td>
</tr>
<tr>
<td>18</td>
<td>20 000 000 (~44444bit/s)</td>
</tr>
<tr>
<td>19</td>
<td>50 000 000 (~111111bit/s)</td>
</tr>
</tbody>
</table>
Peak Throughput Rate

- The peak throughput rate is measured in units of octets per second.
- 9 different peak throughput rates are defined, offering transfer rates from 8kbit/s to 2.048Mbit/s.

<table>
<thead>
<tr>
<th>Peak Throughput Class</th>
<th>Peak Throughput in Octets per second</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Up to 1000 (8kbit/s)</td>
</tr>
<tr>
<td>2</td>
<td>Up to 2000 (16kbit/s)</td>
</tr>
<tr>
<td>3</td>
<td>Up to 4000 (32kbit/s)</td>
</tr>
<tr>
<td>4</td>
<td>Up to 8000 (64kbit/s)</td>
</tr>
<tr>
<td>5</td>
<td>Up to 16000 (128kbit/s)</td>
</tr>
<tr>
<td>6</td>
<td>Up to 32000 (256kbit/s)</td>
</tr>
<tr>
<td>7</td>
<td>Up to 64000 (512kbit/s)</td>
</tr>
<tr>
<td>8</td>
<td>Up to 128000 (1024kbit/s)</td>
</tr>
<tr>
<td>9</td>
<td>Up to 256000 (2048kbit/s)</td>
</tr>
</tbody>
</table>

Reliability Class

- In this context, reliability relates to the probability of data loss, data corruption or out-of-sequence delivery of data packets.
- Five different reliability classes have been defined, differing in the data protection measures being applied by the underlying GPRS protocols like LLC or RLC/MAC.
- The following table outlines the dependencies between the different reliability classes and the GPRS protocols.

<table>
<thead>
<tr>
<th>Reliability Class</th>
<th>Data Protection Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simple error detection</td>
</tr>
<tr>
<td>2</td>
<td>Advanced error detection</td>
</tr>
<tr>
<td>3</td>
<td>Error correction</td>
</tr>
<tr>
<td>4</td>
<td>Advanced error correction</td>
</tr>
<tr>
<td>5</td>
<td>Highest reliability</td>
</tr>
<tr>
<td>Reliability Class</td>
<td>Traffic type</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Non real-time traffic, error-sensitive applications that cannot cope with data loss</td>
</tr>
<tr>
<td>2</td>
<td>Non real-time traffic, error-sensitive applications that can cope with infrequent data loss</td>
</tr>
<tr>
<td>3</td>
<td>Non real-time traffic, error-sensitive applications that can cope with data loss, GMM/SM, and SMS</td>
</tr>
<tr>
<td>4</td>
<td>Real-time traffic, error-sensitive applications that can cope with data loss</td>
</tr>
<tr>
<td>5</td>
<td>Real-time traffic, error non-sensitive applications that can cope with data loss</td>
</tr>
</tbody>
</table>