Random Access Channel (RACH) Procedure

RACH is a common transport channel in the uplink and is always mapped one-to-one onto physical channels (PRACHs). In one cell, several RACHs/PRACHs may be configured. If more than one PRACH is configured in a cell, the UE performs PRACH selection randomly.

The parameters for RACH access procedure includes: access slots, preamble scrambling code, preamble signatures, spreading factor for data part, available signatures and sub-channels for each Access Service Class (ASC) and power control information. The Physical channel information for PRACH is broadcasted in SIB5/6 and the fast changing cell parameters such as uplink interference levels used for open loop power control and dynamic persistence value are broadcasted in SIB7.

RACH access procedure follows slotted-ALOHA approach with fast acquisition indication combined with power ramping in steps.

Maximum of 16 different PRACHs can be offered in a cell, in FDD, the various PRACHs are distinguished either by employing different preamble scrambling codes or by using common scrambling code with different signatures and sub-channels. With in a single PRACH, a partitioning of the resources between the maximum 8 ASC is possible, thereby providing a means of access prioritization between ASCs by allocating more resources to high priority classes than to low priority classes.ASC 0 is assigned highest priority and ASC 7 is assigned lowest priority.ASC 0 shall be used to make emergency calls which has got more priority. The available 15 access slots are split between 12 RACH sub-channels.

The RACH transmission consists of two parts, namely preamble transmission and message part transmission. The preamble part is 4096 chips, transmitted with spreading factor 256 and uses one of 16 access signatures and fits into one access slot.

ASC is defined by an identifier i that defines a certain partition of the PRACH resources and is associated with persistence value P(i). The persistence value for P(0) is always set to one and is associated with ASC 0.The persistence values for others are calculated from signaling. These persistence values controls the RACH transmissions.

INITIATING THE RACH PROCEDURE

To start a RACH procedure, the UE selects a random number, between 0 and 1 and if r<= P(i), the physical layer PRACH procedure is initiated else it is deferred by 10 ms and then the procedure is started again. Once the UE PRACH procedure is initiated, then the real transmission takes place.

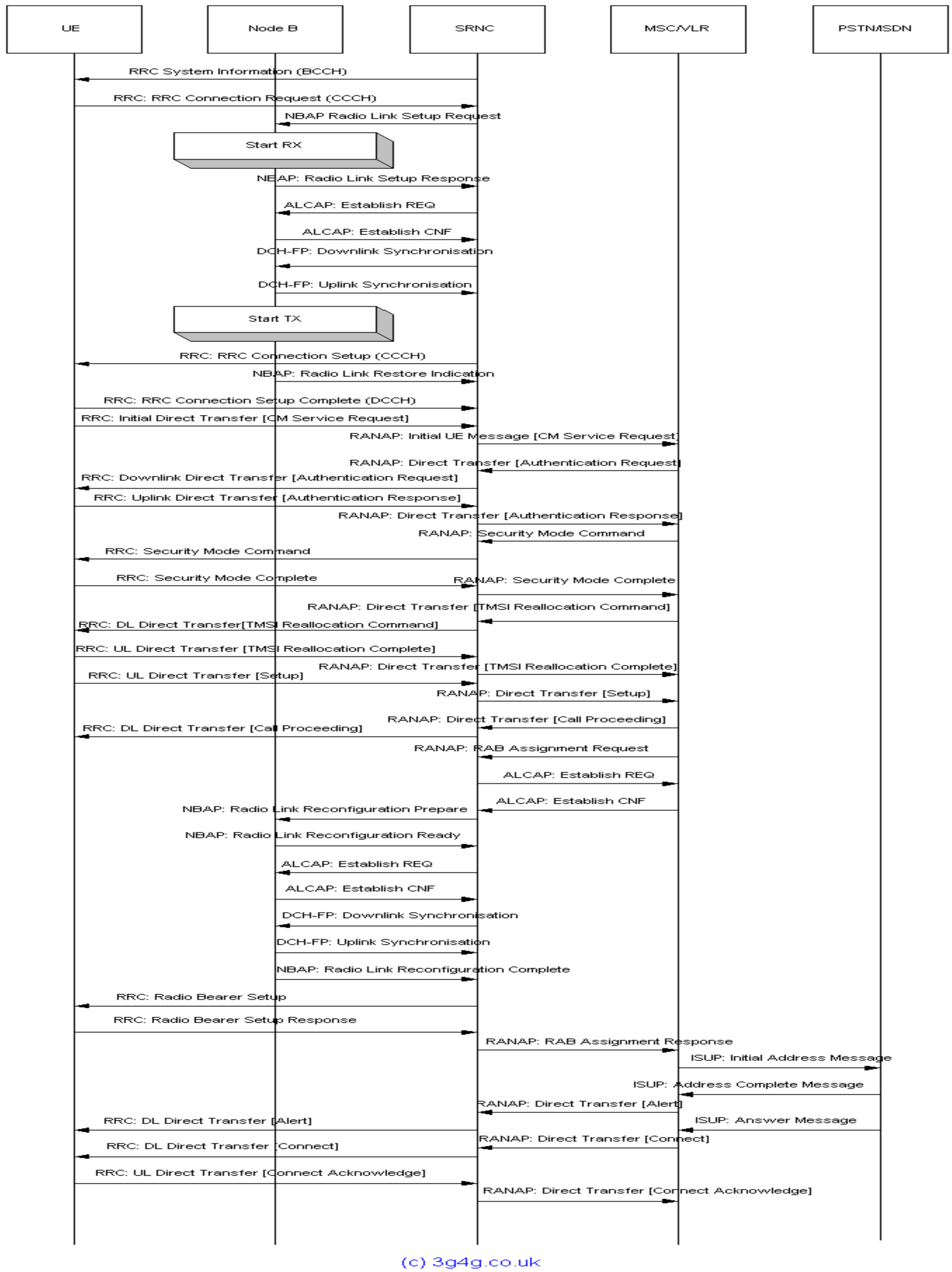
PREAMBLE AND DATA PART TRANSMISSION

As described above, the preamble part transmission starts first. The UE picks one access signature of those available for the given ASC and an initial preamble power level based on the received primary CPICH power level and transmits by picking randomly one slot out of the next set of access slots belonging to one of the PRACH sub-channels associated with the relevant ASC.

The UE then waits for the appropriate access indicator sent by the network on the downlink Acquisition Indicator Channel (AICH) access slot which is paired with the uplink access slot on which the preamble was sent. There are 3 possible scenarios possible.

1. If the Acquisition Indication (AI) received is a positive acknowledgement, then UE sends the data after a predefined amount of with a power level which is calculated from the level used to send the last preamble.
2. IF the AI received is a negative acknowledgement, the UE stops with the transmission and hands back control to the MAC layer. After a back-off period, the UE will regain access according to the MAC procedure based on persistence probabilities.
3. If no acknowledgement is received, then it is considered that network did not receive the preamble. If the maximum number of preambles that can be sent during a physical layer PRACH procedure is not exceeded, the terminal sends another preamble by increasing the power in steps. The ability of the UE to increase its output power, in terms of steps to a specific value is called as open loop power control. RACH follows open loop power control

3G/UMTS Complete Mobile Originated Circuit Switched Call Setup



1. System Information (BCCH)

The UE reads the System Information that is broadcast on BCCH. The information is not read continuously. It is only read if the information changes

2. RRC: RRC Connection Request (CCCH)

The Mobile user decides to initiate a voice call. The first message the UE will send on CCCH is RRC Connection Request. This will contain among other things, Initial UE Identity and Establishment Cause

3. NBAP: Radio Link Setup Request

The SRNC sends this message to Node B. It will pass the Cell Id, TFS, TFCS, frequency, UL Scrambling code, etc to Node B.

4. NBAP: Radio Link Setup Response

Node B allocates the resources and starts PHY Reception. While transmitting the response it includes the Transport layer addressing information that includes the Binding Identity of the AAL2 for Iub data transport bearer

5. ALCAP: Establish REQ

The AAL2 binding identity (Iub Data Transport Bearer Id) is passed to ALCAP protocol in Node B. The Iub Data Transport bearer is now bounce to DCH.

6. ALCAP: Establish CNF

Establish confirm from ALCAP in Node B

7: DCH-FP: Downlink Synchronization

The Node B and SRNC establishes synchronization for the Iub Data Transport bearer by means of exchange of the appropriate DCH Frame Protocol frames.

8: DCH-FP: Uplink Synchronization

Once the UL synchronization is achieved, Node B starts DL transmission.

9: RRC: RRC Connection Setup (CCCH)

RRC Connection Setup message is sent on CCCH with the parameters required to establish DCH. Also the state indicator will be set to DCH for the voice (or CS) call.

10: NBAP: Radio Link Restore Indication

Once the UE establishes Radio Link, Node B will send RL Restore indication to the SRNC.

11: RRC: RRC Connection Setup Complete (DCCH)

RRC Connection Setup complete will be sent on DCCH. Integrity and Ciphering related parameters and UE capability information will be sent back to SRNC

12: RRC: Initial Direct Transfer [CM Service Request]

First NAS message is now sent by the UE. It indicates that a UE originated Voice call is required. The UE identity (TMSI) will also be passed in this message

13: RANAP: Initial UE Message [CM Service Request]

The NAS message will be forwarded to appropriate CN Domain (CS Domain in this case). Along with the CM service request, it will also include LAI and SAI.

14: RANAP: Direct Transfer [Authentication Request]

MSC/VLR needs to perform authentication to make sure that the UE is genuine. For this reason it will challenge the UE with a Authentication token and RAND (random number)

15: RRC: Downlink Direct Transfer [Authentication Request]

SRNC transfers the NAS message to the UE

16: RRC: Uplink Direct Transfer [Authentication Response]

UE computes the response (RES) and sends it back in the NAS message

17: RANAP: Direct Transfer [Authentication Response]

SRNC relays the response to the MSC/VLR. The MSC/VLR will compare the response RES with the expected response XRES. If they are the same then the procedure will continue.

18: RANAP: Security Mode Command

MSC/VLR sends the Security Mode Command to start Ciphering and Integrity Protection. Ciphering is optional while Integrity Protection is mandatory. The Algorithms, etc are known to the MSC/VLR and the UE and only the ones that are common between them are used.

19: RRC: Security Mode Command

RRC Forwards the Security Mode command received from MSC/VLR to the UE.

20: RRC: Security Mode Complete

The UE configures the Ciphering and Integrity Protection and responds back to the network. The response message is Integrity Protected for further safety. Ciphering is started at Ciphering activation time. Since this is a Circuit switched call, the Ciphering will be started in MAC. In case of AM and UM bearers it is started in RLC.

21: RANAP: Security Mode Complete

The network forwards the Security Mode Complete message to MSC/VLR.

22: RANAP: Direct Transfer [TMSI Reallocation Command]

The network may decide to re-allocate the TMSI to the UE. It sends a DT message which includes the NAS TMSI Reallocation Command.

23: RRC: DL Direct Transfer [TMSI Reallocation Command]

The RNC relays the DT message to the UE.

24: RRC: UL Direct Transfer [TMSI Reallocation Complete]

The UE takes the new TMSI and responds with the Complete message

25: RANAP: Direct Transfer [TMSI Reallocation Complete]

The RNC relays the message to the CN domain

26: RRC: UL Direct Transfer [Setup]

The UE now sends the 'Setup' message in UL Direct Transfer message. This will include all the required parameters for setting up the voice call. It will include the number that UE wishes to be contacted and the bearer capability

27: RANAP: Direct Transfer [Setup]

The network relays the message to the MSC/VLR

28: RANAP: Direct Transfer [Call Proceeding]

The MSC/VLR sends Call Proceeding to the UE indicating that it is now starting with the RAB establishment procedure.

29: RRC: DL Direct Transfer [Call Proceeding]

The network relays it to the UE.

30: RANAP: RAB Assignment Request

The CN initiates establishment of the Radio Access Bearer using the RAB Assignment Request message. This message includes the QoS of the call being established, the Transport Address, Iu Transport association, etc.

31: ALCAP: Establish REQ

SRNC initiates the set-up of Iu Data Transport bearer using ALCAP protocol. The request contains the AAL2 Binding Identity to Bind the Iu Data Transport Bearer to the RAB. (Note that this is not done in case of PS RAB)

32: ALCAP: Establish CNF

The CN responds with the ALCAP Establish CNF

33: NBAP: Radio Link Reconfiguration Prepare

SRNC requests Node B to prepare establishment of DCH to carry the RAB. It passes the TFS, TFCS and Power Control Information in the message.

34: NBAP: Radio Link Reconfiguration Ready

Node B allocates the resources and responds with the Ready message. It sends back the AAL2 address and the AAL2 binding Id for the Iub data transport bearer.

35: ALCAP: Establish REQ

SRNC initiates setup of Iub Data Transport Bearer using ALCAP protocol. The request contains the AAL2 Binding Identity to bind the Iub Data Transport Bearer to DCH.

36: ALCAP: Establish CNF

The Node B responds with the Establish Confirm.

37: DCH-FP: Downlink Synchronization

The Node B and SRNC establish synchronism for the Iub Data Transport Bearer by means of exchange of the appropriate DCH frame protocol frames. SRNC sends the DL Synchronization frames.

38: DCH-FP: Uplink Synchronization

The Node B responds with the UE Synchronization frames.

39: NBAP: Radio Link Reconfiguration Complete

Finally the SRNC instructs the Node B of the CFN at which the new configuration will come into effect.

40: RRC: Radio Bearer Setup

SRNC sends the RB Setup message to add the new DCH's. The message will be received using the old configuration.

41: RRC: Radio Bearer Setup Response

After the activation time the UE will respond with complete message using the new configuration.

42: RANAP: RAB Assignment Response

The SRNC responds with the response to the MSC/VLR.

43: ISUP: Initial Address Message

MSC/VLR sends the Initial Address Message to the PSTN. The message tells the PSTN to reserve an idle trunk circuit from originating switch to the destination switch.

44: ISUP: Address Complete Message

The ACM message is sent to indicate that the remote end of the trunk circuit has been reserved.

45: RANAP: Direct Transfer [Alert]

The Alert message is sent to the SRNC. This message contains the ACM received from the PSTN.

46: RRC: Direct Transfer [Alert]

The Alert message is forwarded to the UE. The Alert message will initiate the ringing tone on the handset.

47: ISUP: Answer Message

When the person that is being called picks up his phone, an Answer message is sent to the MSC/VLR.

48: RANAP: Direct Transfer [Connect]

The MSC/VLR sends the Connect message to the SRNC via Direct Transfer message. The Connect message indicates that the End User has answered the call.

49: RRC: DL Direct Transfer [Connect]

The SRNC forwards the Connect message to the UE.

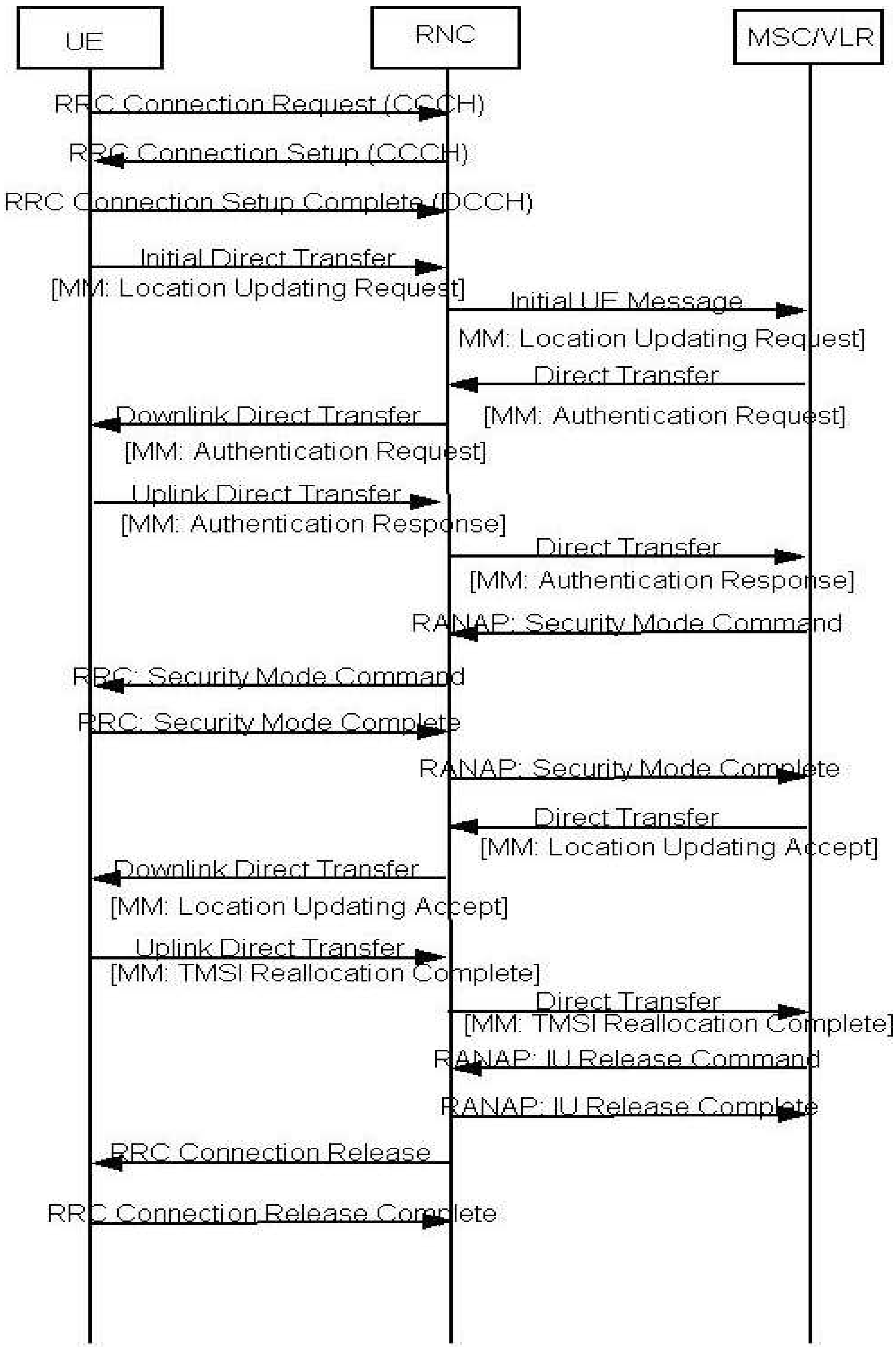
50: RRC: UL Direct Transfer [Connect Acknowledge]

The UE confirms the reception of the Connect message using the Connect Acknowledge and sending it via Direct Transfer

51: RANAP: Direct Transfer [Connect Acknowledge]

The Network forwards the Connect Acknowledge to the MSC/VLR. The call has now been successfully established.

Message Sequence for UE Registration on Circuit Switched and Packet Switched Domain



UE REGISTRATION ON CS DOMAIN

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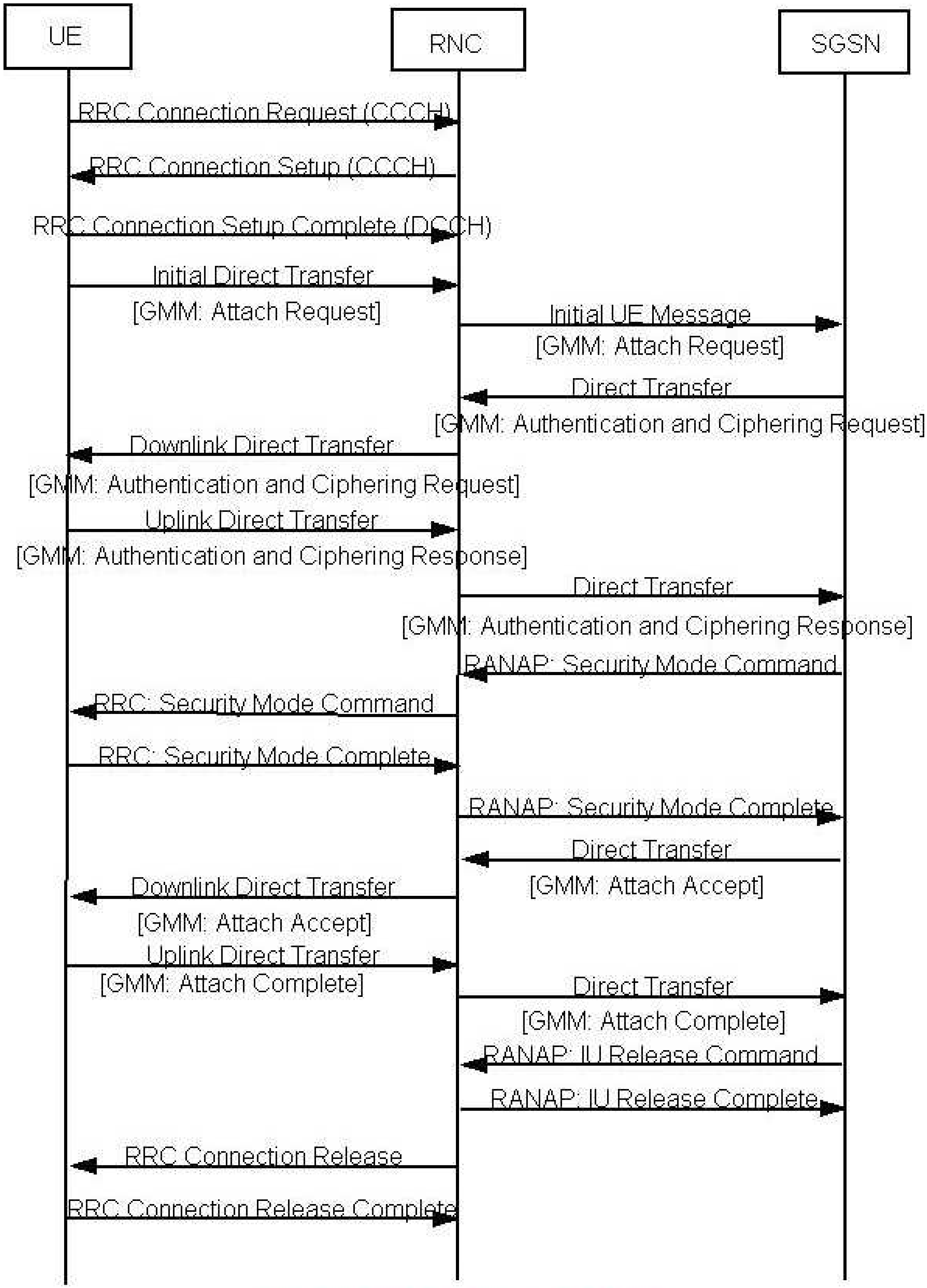

UE REGISTRATION ON PS DOMAIN

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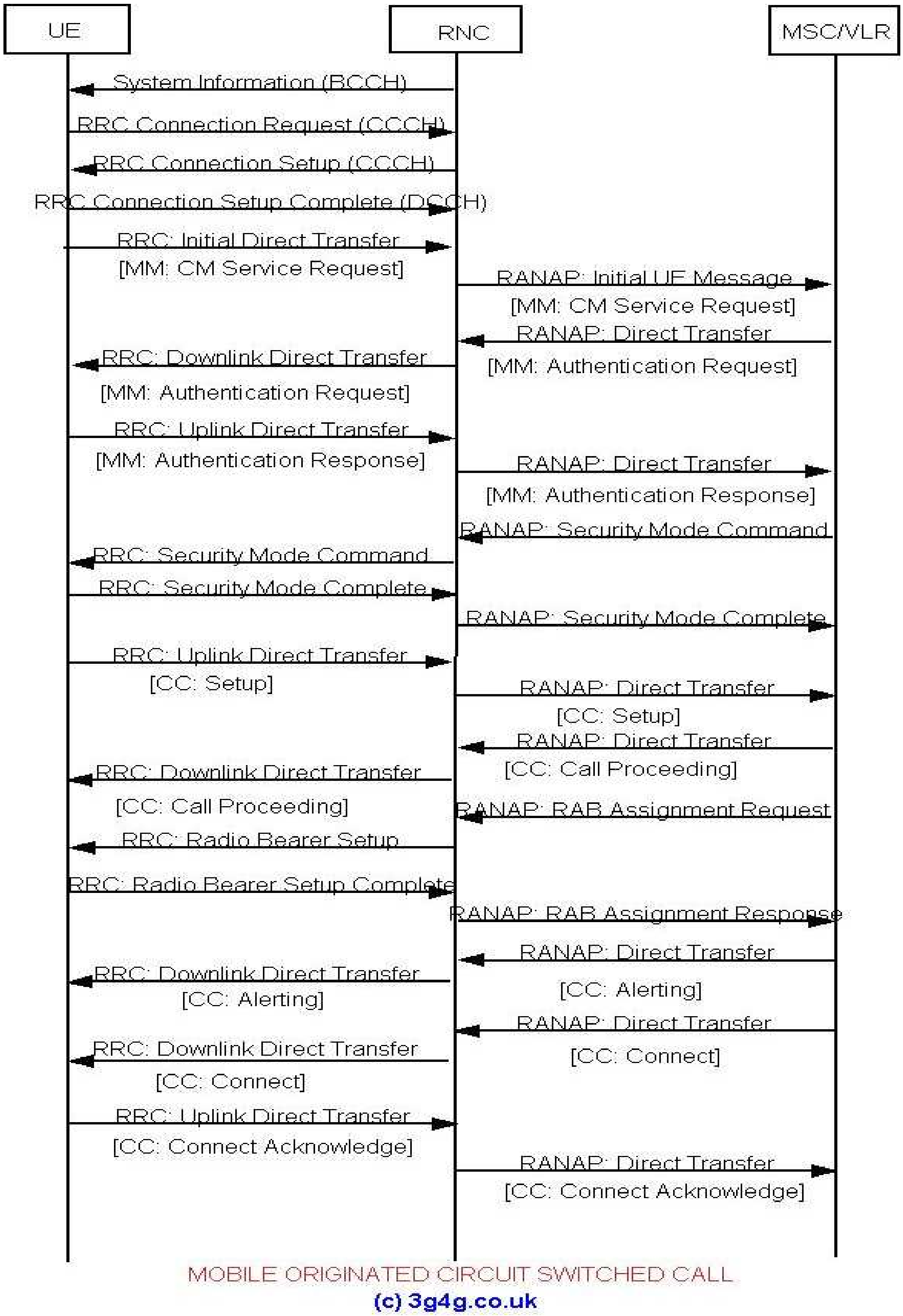
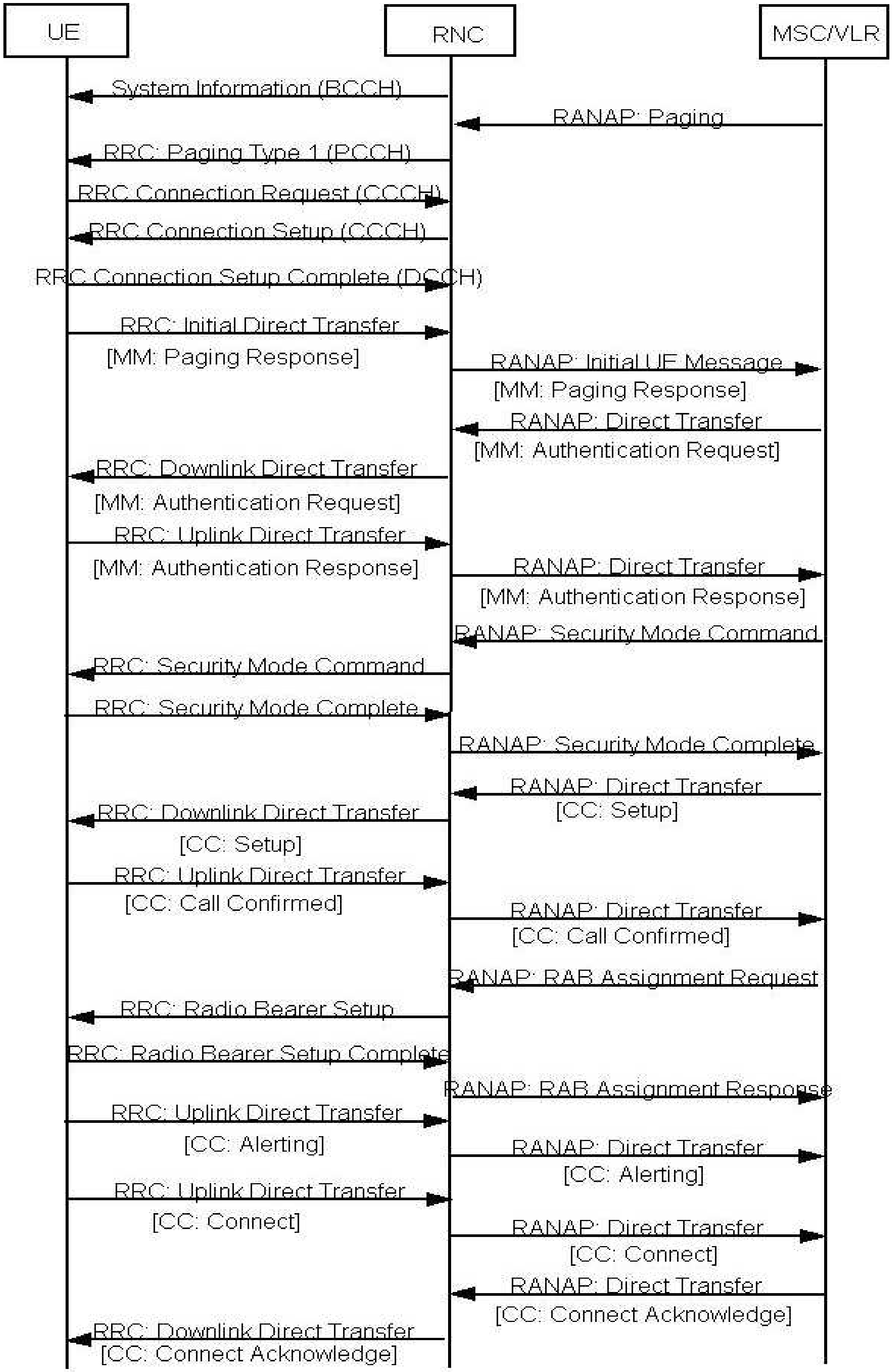
Message sequence for Mobile Originated and Mobile Terminated Circuit Switched Call





MOBILE TERMINATED CIRCUIT SWITCHED CALL

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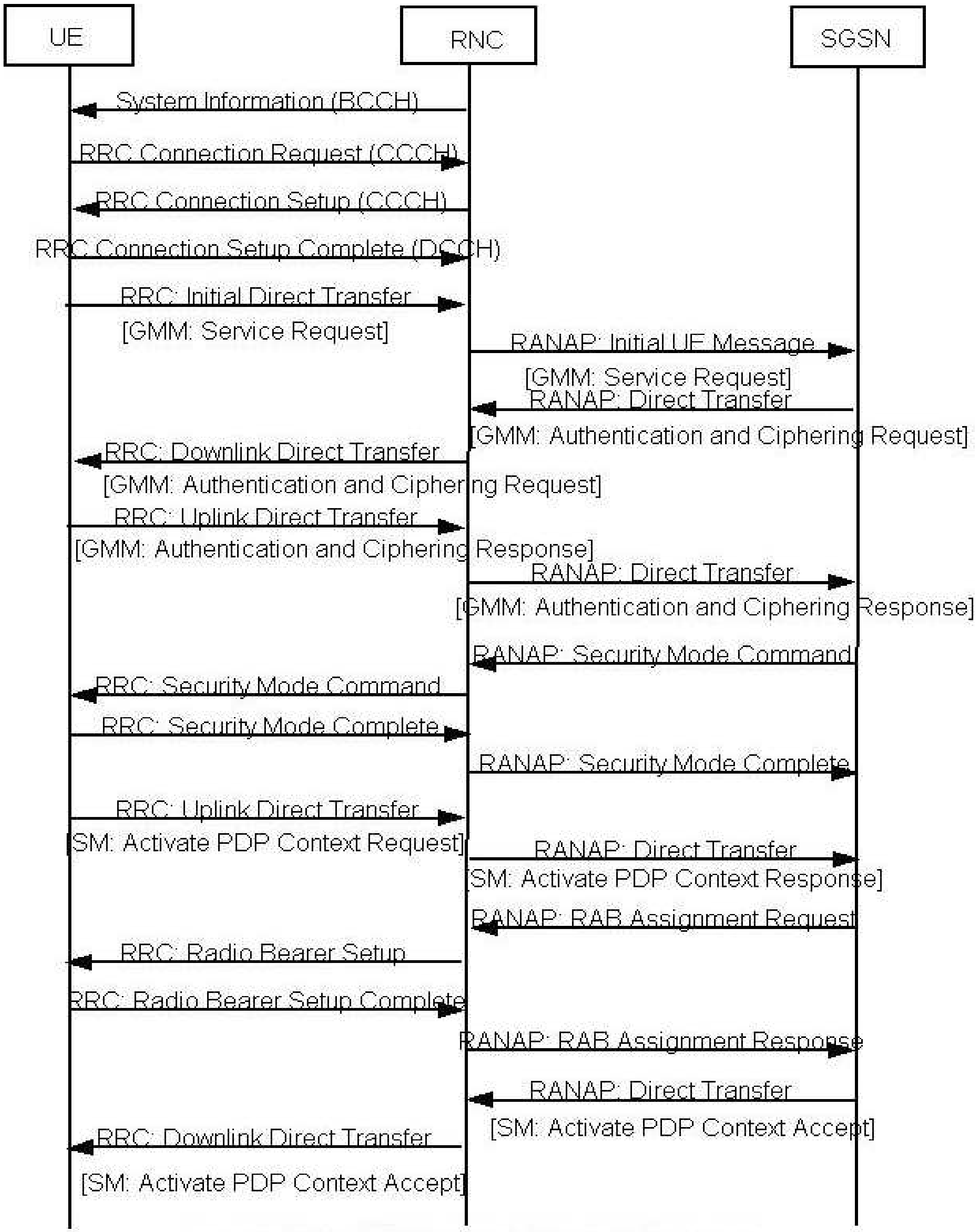
Message sequence for Mobile Originated and Mobile Terminated Packet Switched Call



MOBILE ORIGINATED PACKET SWITCHED CALL

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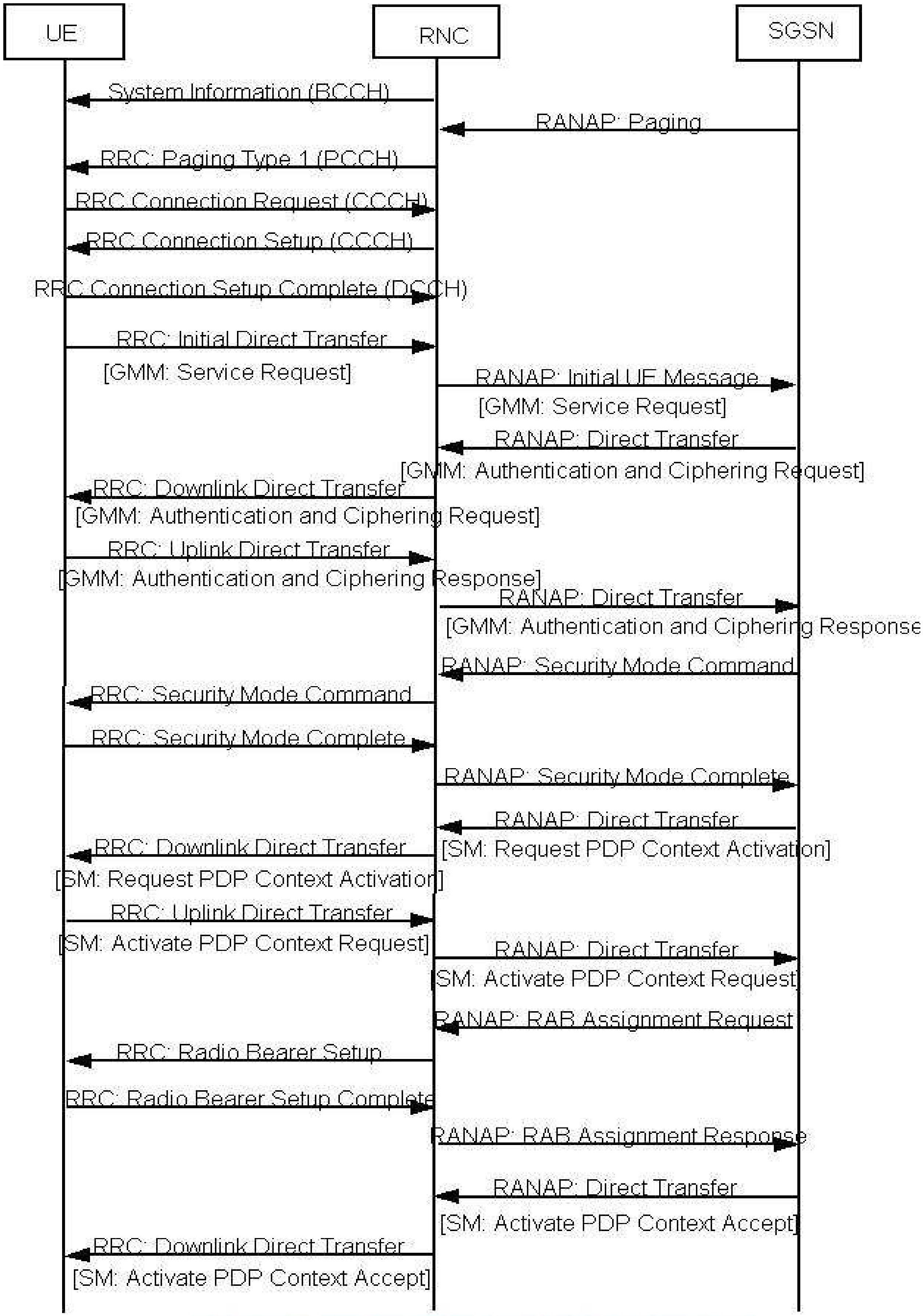

MOBILE TERMINATED PACKET SWITCHED CALL

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A look at Inter-Frequency Measurements

Introduction:

According to 3GPP specifications, a UE is required to support many different kinds of measurements. The most commonly used are intra-frequency measurements, inter-frequency measurements and traffic volume measurements. In this article we will look at Inter-Frequency measurements. If every aspect of that is considered then we would need to write a big fat book. We will look at the need and how and why these measurements are performed. Also it would be important to mention here that all the measurement types are independent of each other.

Why are Inter-Frequency Measurements needed?

Inter-Frequency measurements are not a must for a mobile handset to support. If and only if the UE is able to support more than one frequency than this measurements will be used. Some of the reasons why we need these measurements are as follows:

- There could be presence of Hotspots. Say there could be one cell in a large area. But that area has a race course. During the racing season it is full of people using their mobile phones. Thus this one cell might not be able to handle all these calls. For this particular race course, during the racing season there might be a small cell (technically known as micro cell while the cell that covers the big area is known as macro cell). The users would be handed over to these micro cells during the season so other user's calls won't be much affected.
- If a lot of people are camped on a same frequency and they move to the same area then the traffic on this particular frequency will increase. To evenly balance the traffic between different frequencies some of the users would be forced to do Inter-Frequency measurements and hence perform Inter-Frequency handover.
- The user might move to an area where the current frequency coverage is about to end. At this particular point the network would ask the UE to perform the Inter-Frequency measurement and move to the new frequency as soon as possible to avoid the loss of call.

How are Inter-Frequency Measurements performed?

```
 RNC                                          UE
-----                                        ----
  |                                            |
  |       Measurement Control Message          |
  | -------------------------------------->   |
  |                                            |
  |                                            |
  |          Measurement Report                |
  | <--------------------------------------    |
  |                                            |
```

The network decides that inter frequency measurements need to be performed and sends the MEASUREMENT CONTROL MESSAGE with Measurement type set to Inter-Frequency measurements. Generally it will set an Event as well along with the measurements. The following are list of Events that can trigger Measurement Report.

- *Event 2a:* Change of Best Frequency
- *Event 2b:* The estimated quality of the currently used frequency is below a certain threshold and the estimated quality of a non-used frequency is above a certain threshold
- *Event 2c:* The estimated quality of a non-used frequency is above a certain threshold
- *Event 2d:* The estimated quality of the currently used frequency is below a certain threshold
- *Event 2e:* The estimated quality of a non-used frequency is below a certain threshold
- *Event 2f:* The estimated quality of the currently used frequency is above a certain threshold

The most commonly used events from the above list are events 2b and 2d. In case when UE enters 'End of Coverage' area, network will send MCM with event Id set to event 2b and 2d. Event 2d performs the same function as event 2b for the current frequency but the threshold set in case of 2d is much lower. When event 2b is triggered a hand over to new frequency is performed without any problems. In case if event 2b is not triggered while event 2d is triggered that means that the other frequency is not strong enough but the current frequency has deteriorated very much and the only option is to handover to new frequency. In this case the results will not definitely be success.

Hierarchical Cell Structures (HCS):

No discussion about inter-frequency measurements would be complete without discussing HCS. In UMTS, Node B's will be capable of supporting multiple frequencies, though this is not mandatory (and the cost of these Node B's would be more). Thus the cells with different frequencies would be arranged in a hierarchical structures as shown in the figures below.

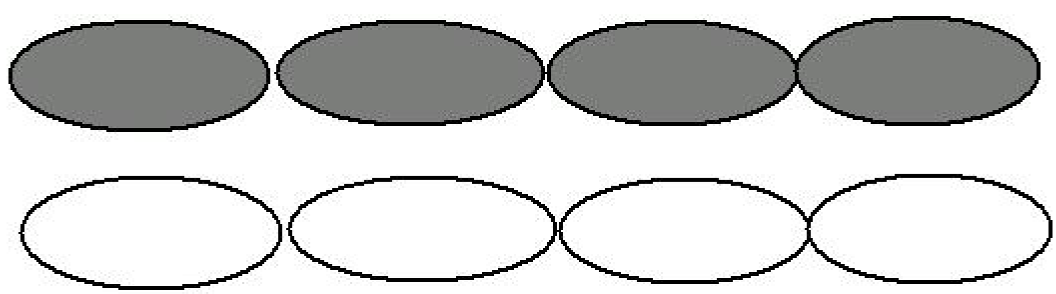


Fig 1: An example of 2 Macro Layer cells

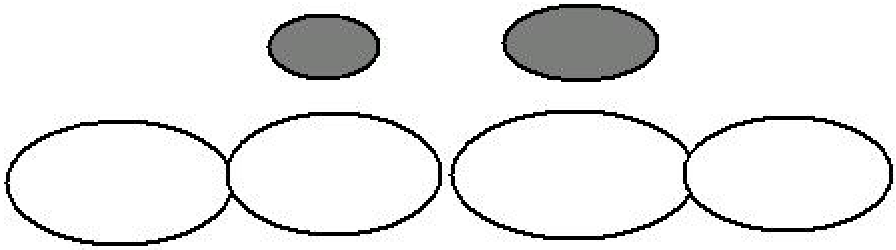


Fig 2: An example of a Macro Layer and a Micro Layer

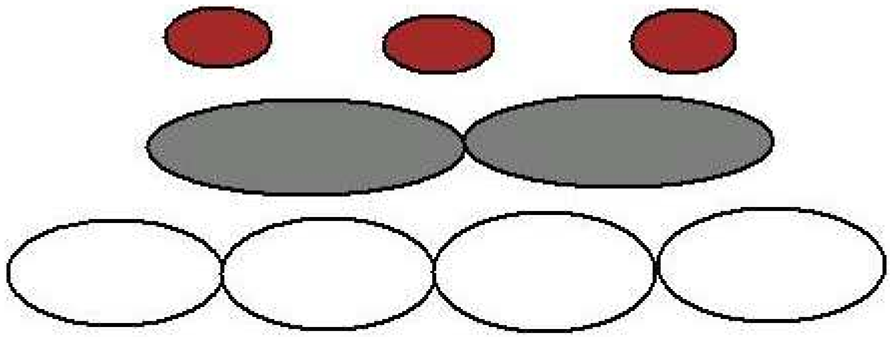


Fig 3: An example of 2 Macro Layer and 1 Micro Layer cells

Figure 1 shows a scenario when there are two identical layers of Macro cells. The network can decide depending on the load which frequency the UE should camp on. Figure 2 shows a Macro and Micro layer. The Micro cells would be available in hot spots where there is extremely high traffic compared to other areas. Figure 3 shows a combination of the first two cases.

A look at PDP Context in UMTS networks

Packet Data Protocol (PDP)

A Packet Data Protocol (PDP) context offers a packet data connection over which the UE and the network can exchange IP packets. Usage of these packet data connections is restricted to specific services. These services can be accessed via so-called access points.

Packet Data Protocol Context is one of the most important concepts for the UMTS Packet Data Architecture.

The PDP Context has a record of parameters, which consists of all the required information for establishing an end-to-end connection:

- PDP Type
- PDP address type
- QoS profile request (QoS parameters requested by user)
- QoS profile negotiated (QoS parameters negotiated by network)
- Authentication type (PAP or CHAP)
- DNS type (Dynamic DNS or Static DNS)

The PDP Context is mainly designed for two purposes for the terminal.

- Firstly PDP Context is designed to allocate a Packet Data Protocol (PDP) address, either IP version 4 or IP version 6 type of address, to the mobile terminal.
- Secondly it is used to make a logical connection with QoS profiles, the set of QoS attributes negotiated for and utilized by one PDP context, through the UMTS network.

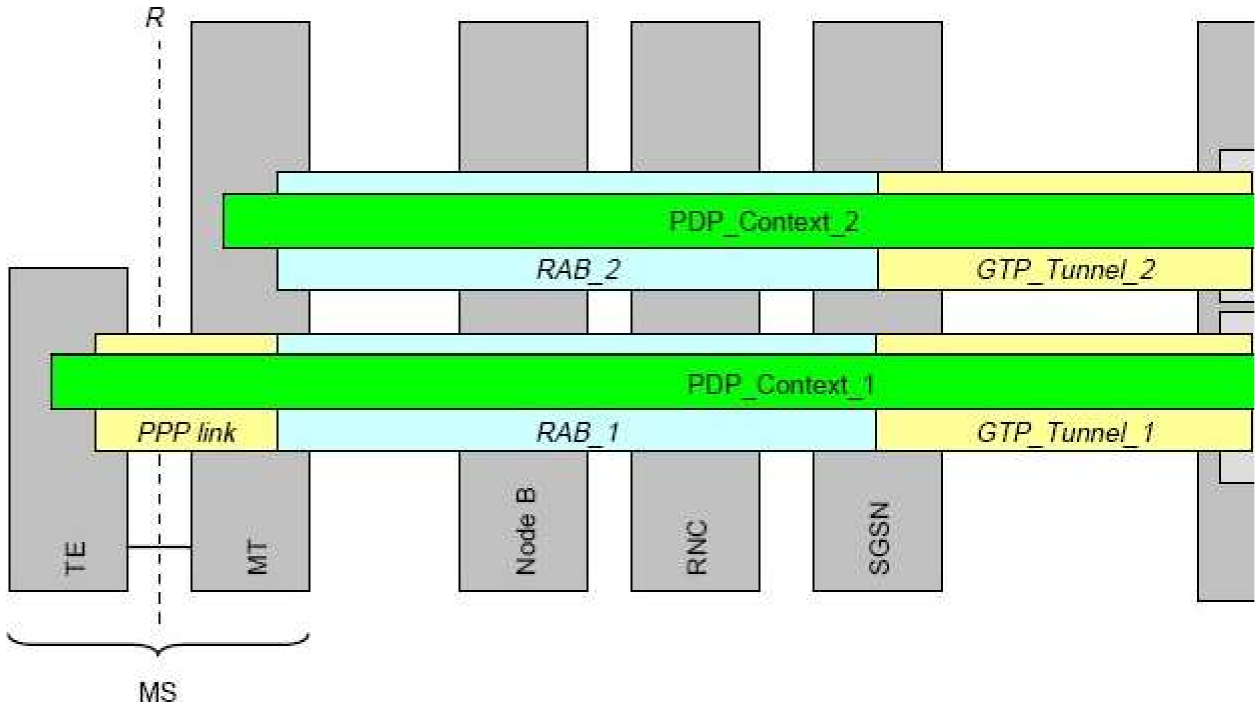
Multiple PDP Context

As mobile phones develop, there will be a need to serve parallel applications running on them with simultaneous PS calls. These PS calls can differ in their QoS (Quality of Service) parameters, and/or in the target network (PDN – Packet Data Network) to which they provide connection.

Multiple PDP Contexts means that one mobile terminal can have multiple PDP contexts. Each of the Multiple PDP Contexts can at the same time have different QoS profiles. The primary PDP Context is a normal PDP Context with default QoS profile attributes and it is always activated first. For the multiple primary PDP Contexts, each context has different PDP Address and different APN

Multiple PDP contexts will have special significance when IMS is introduced and all the services will be PS (IP) based. In an IMS based network the MS can (and will) activate separate PDP contexts for SIP based signaling and for all the sessions of different, eventually parallel services (e.g. parallel VoIP call and PS data call, etc.). A different QoS – which matches the application - will be used for each connection.

The data flow (user plane) of a particular PDP context can terminate either in the Mobile Terminal (MT) itself or in the connected Terminal Equipment (TE) as shown in Figure below. The application for which the connection is provided is running either on the MT or on the TE respectively. An example for the first possibility is a video telephony client running on the mobile, for the second possibility a web browser running on the connected notebook.



In IMS based systems it is expected that several embedded applications will run on the MT, requiring multiple PDP contexts. For the TE (e.g. connected PC) one additional PDP context may be also active.

Multiple PDP contexts have two sub-categories:

1. multiple primary PDP contexts: they provide connections to different PDNs
2. secondary PDP contexts: they provide connections to the same PDN but with different QoS

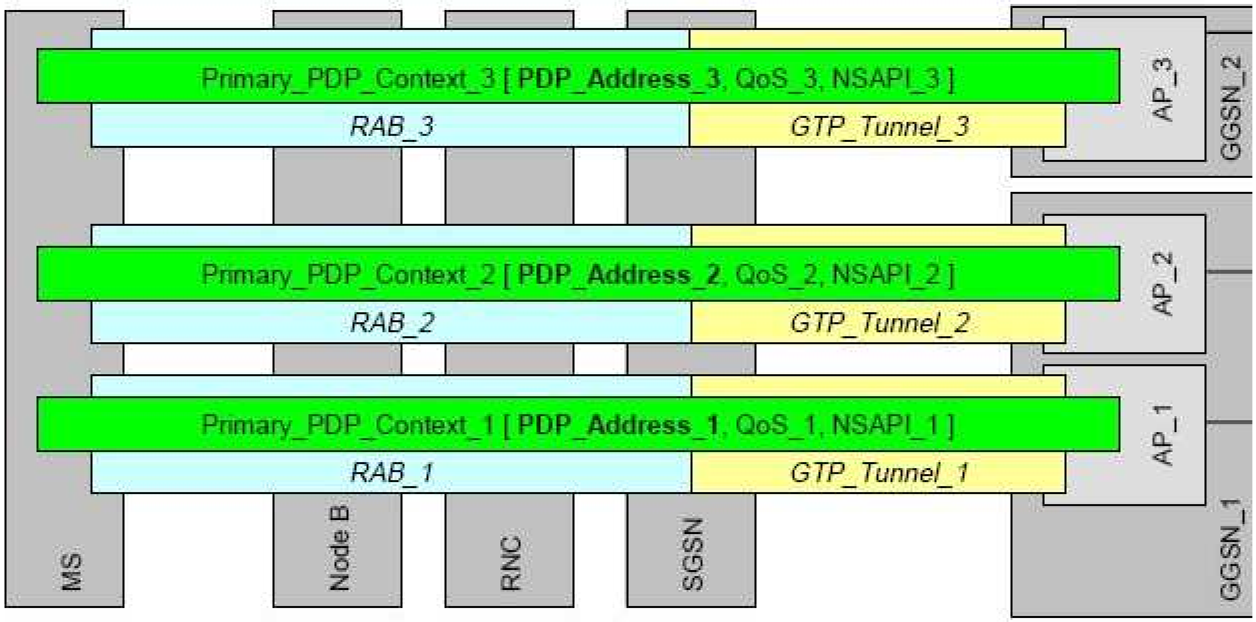
Multiple Primary PDP Contexts

Multiple primary PDP contexts are two or more PDP contexts independent from one another, each of them using one unique PDP address. They give the possibility to have simultaneous connections to different PDNs – e.g. to the internet for one application, while to a private network for another one.

Beside the unique PDP address, each PDP context has its own QoS and NSAPI (Network Layer Service Access Point Identifier, see later) assigned. Each PDP context has a separate RAB (Radio Access Bearer) and GTP tunnel to transfer user plane data.

The PDP contexts typically terminate in different access points on the network side (although it is allowed that they terminate in the same access point). The terminating access points can be located in the same or in different GGSNs.

The example in Figure below shows the user plane path for three primary PDP contexts providing connections to three different PDNs:



Primary PDP contexts can be activated or deactivated independently from one another. QoS of any of the active PDP contexts can be modified with the PDP context modification procedure initiated by the MS or by the network. (See Below for details)

Secondary PDP Contexts

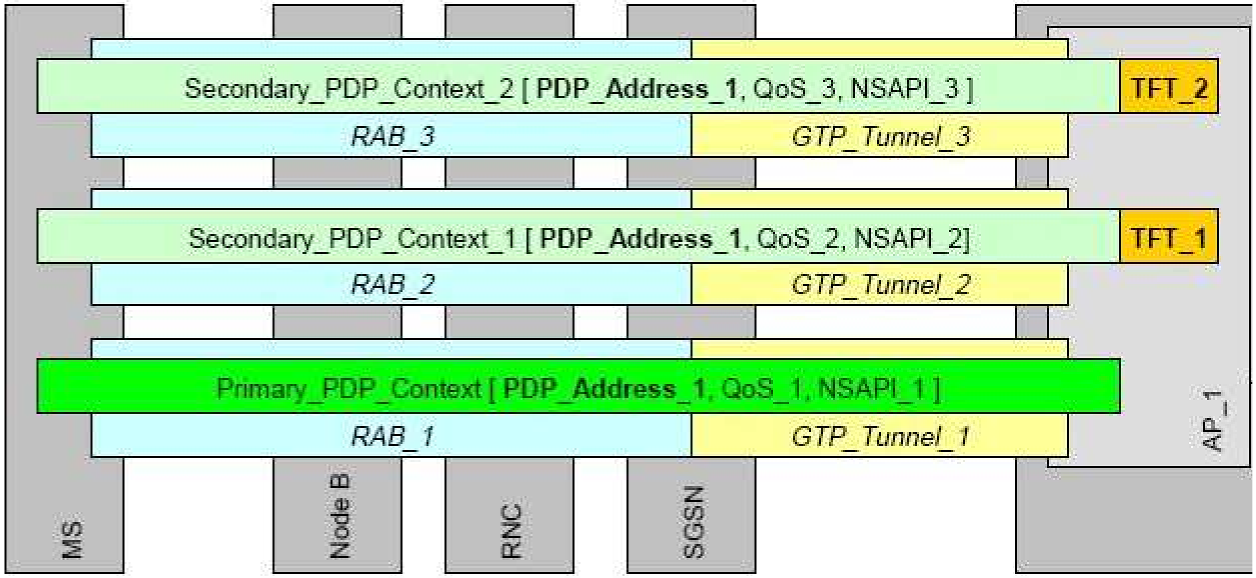
A secondary PDP context is always associated with a primary PDP context. PDP address (IP address) and access point (AP) is re-used from the primary context. Hence the primary and the associated secondary PDP context provide connection to the same PDN with different guaranteed QoS.

One primary PDP context might have multiple secondary contexts assigned. Each PDP context (i.e. the primary and all secondary) has its own RAB and GTP tunnel to transfer user plane data. Also, each context is identified by a unique NSAPI (Network Layer Service Access Point Identifier).

The primary PDP context has to be active prior to activating an associated secondary PDP context. Any secondary PDP context can be deactivated while keeping the associated primary context (and eventual other secondary PDP contexts) active. If a primary PDP context is deactivated, this will also deactivate all the assigned secondary PDP contexts. QoS of any active primary or secondary PDP context can be modified with the PDP context modification procedure initiated by the MS or by the network. (See below for details)

As the PDP address (IP address) is common for the primary and for (all) the associated secondary PDP contexts, the TFT (Traffic Flow Template) is introduced to route downlink user plane data into the correct GTP tunnel and hence into the correct RAB for each context.

The example in Figure below shows the user plane for a primary and two associated secondary PDP contexts:



Combination of multiple primary PDP contexts and secondary PDP contexts is also possible. For example, two primaries with one secondary context for each will result in four active PDP contexts in total. The maximum number of supported PDP contexts is terminal dependent.

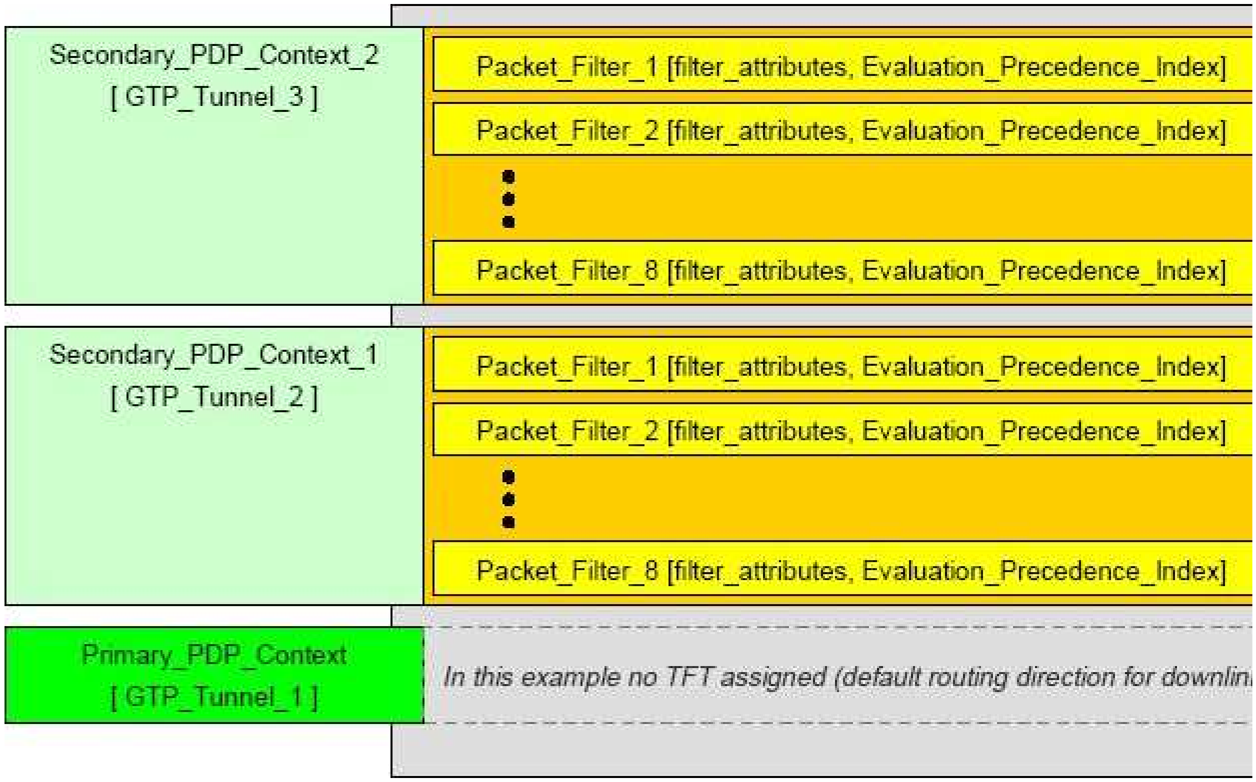
Traffic Flow Template (TFT)

The Traffic Flow Template (TFT) is used by GGSN to discriminate between different user payloads. The TFT incorporates from one to eight packet filters; a unique packet filter identifier identifies each filter. Filtering can be based on one or more of the following filter attributes:

- Source address (with subnet mask)
- IPv4 protocol number
- Destination port range
- Source port range
- IPSec Security Parameter Index (SPI)
- Type of Service (TOS) (IPv4)

The TFT is provided by the MS in the Activate Secondary PDP Context Request message, it is stored by the GGSN, and is examined when routing downlink user plane data. The TFT can be modified or deleted with the MS initiated PDP context modification procedure. A TFT may be also assigned to a primary PDP context by means of the MS initiated PDP context modification procedure.

A TFT is built up from Packet Filters (minimum 1, maximum 8 of them) to provide flexibility in filtering. The relationship between PDP contexts, TFTs and Packet Filters is illustrated in Figure below:



PDP context procedures

Primary PDP context activation

This procedure is used to establish a logical connection with the Quality of Service (QoS) functionality through the network from the UE to the GGSN. PDP context activation is initiated by the UE and changes the session management state to active, creates the PDP context, receives the IP address and reserves radio resources. After a PDP context activation the UE is able to send IP packets over the air interface. The UE can have up to 11 PDP contexts active concurrently.

Secondary PDP context activation

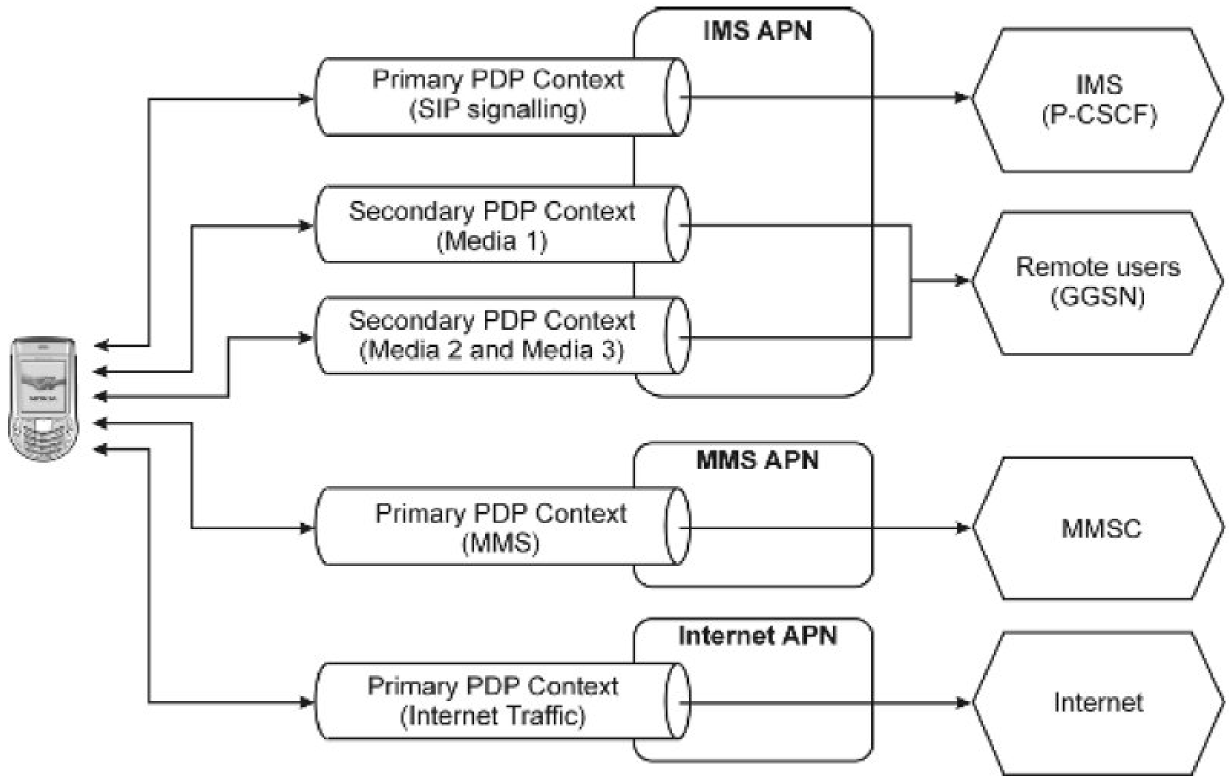
A secondary PDP context activation allows the subscriber to establish a second PDP context with the same IP address as the primary PDP context. The two contexts may have different QoS profiles, which makes the feature useful for applications that have different QoS requirements (e.g., IP multimedia). The access point name, though, will be the same for the primary and secondary PDP contexts.

PDP context modification

The UE, the SGSN or the GGSN initiate this procedure for updating the corresponding PDP context. Additionally, the radio access network is able to request a PDP context modification from the SGSN (e.g., when coverage to the UE has been lost). The procedures modify parameters that were negotiated during an activation procedure for one or several PDP contexts.

PDP context deactivation

This procedure is used to delete a particular logical connection between the UE and the GGSN. The initiative to deactivate a PDP context can come from the UE, the SGSN, the Home Location Register (HLR) or the GGSN.



Access points

Access points can be understood as IP routers that provide the connection between the UE and the selected service. Examples of such services are:

- Multimedia Messaging Service (MMS);
- Wireless Application Protocol (WAP);
- direct Internet access;
- IP Multimedia Subsystem (IMS).

Depending on the operator of the network, more than one of these services might be provided by the same access point. The UE needs to be aware of an Access Point Name (APN) – the address of a GGSN – which gives access to the service-providing entity (e.g., an MMSC, the Internet or the P-CSCF). One GGSN may provide different services that can be accessed by different APNs.

When establishing a primary PDP context with an APN the UE receives an IP address or – in the case of IPv6 – an IPv6 prefix that it has to use when communicating over that PDP context. This means that when a UE has established several connections to different APNs the UE will have different IP addresses for each of the provided services.

Handover principle and concepts

Introduction

By definition, handover means transfer of user connection from one radio channel to other. This definition was formed before the advent of UMTS. When UMTS came this definition was no longer valid. In order not to confuse the jargon, the definition was kept as it is and new definitions were added. These new definitions called the soft and softer handover will be discussed later in this tutorial.

As most of us would be aware, the main purpose of handover is to maintain an ongoing call. This is necessary as the user might be moving (maybe with high speed) and it would be annoying if the call keeps dropping when the user changes to another cell/area. Also it is possible that the number of users in an area changes while the call for a user is ongoing and for the call to continue the network needs to change the frequency of an ongoing call. Finally the user might enter an area where the UMTS network coverage ends and the user might be handed over to a GSM/GPRS network.

It is very difficult to explain everything about handover in a tutorial like this but we will try our best. Interested users can refer to the documents specified in the references section. Also one thing that should be noted is that all these procedures come into effect only when the call is ongoing (RRC Connection is established).

SRNS Relocation, even though not strictly classified as handover will be explained in this tutorial.

Types of Handover(s)

Before we start discussing the handovers in detail we would like to list all of them for convenience of the reader

1. Softer Handover
2. Soft Handover
3. Intra-frequency hard handover
4. Inter-frequency hard handover
5. SRNS Relocation
6. Combined Hard handover and SRNS Relocation
7. Inter-RAT hard handover

Softer Handover

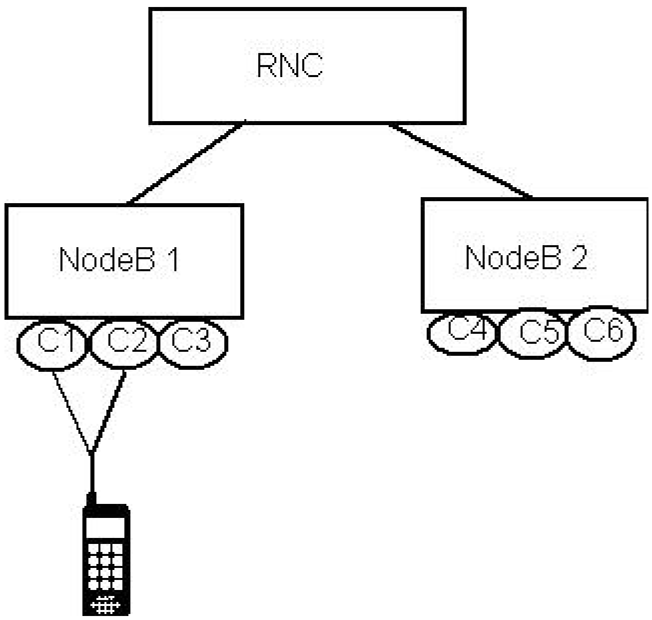


Fig 1: Softer Handover

Strictly speaking softer handover is not really a handover. In this case the UE combines more than one radio link to improve the reception quality. On the other hand the Node B combines the data from more than one cell to obtain good quality data from the UE. [1] Specifies the maximum number of Radio Links that a UE can simultaneously support as 8. In practice this would be limited to 4 as it is very difficult to make the receiver with 8 fingers.

Generally speaking when RRC connection is established, it would always be established on one cell. The network initiates Intra-Frequency measurements to check if there are any other cells the UE can connect simultaneously to improve the quality of the data being transferred between the RNC and the UE. If a suitable cell is found then Active Set Update procedure is initiated. Using this Active Set Update message, the network adds or deletes more than one radio link to the UE. The only requirement is that from the start till the end of this Active Set Update procedure, one Radio Link should remain common.

Soft Handover

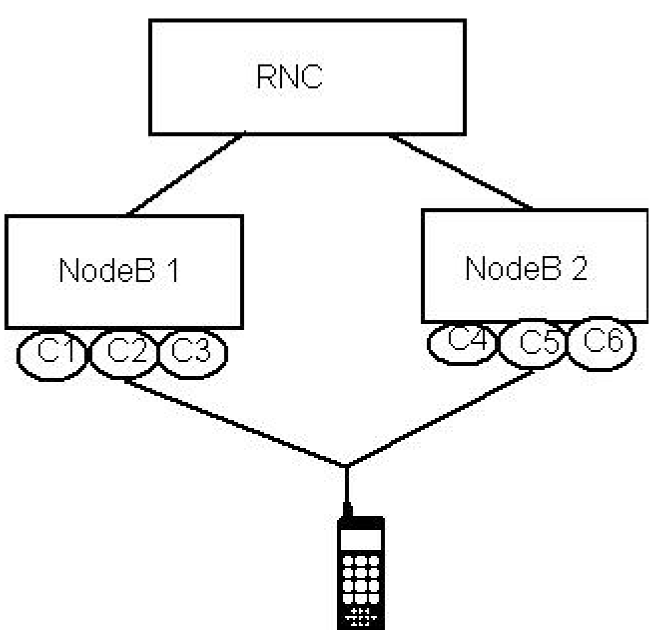


Fig 2: Soft Handover

Soft Handover is the same as softer handover but in this case the cells belong to more than one node B. In this case the combining is done in the RNC. It is possible to simultaneously have soft and softer handovers.

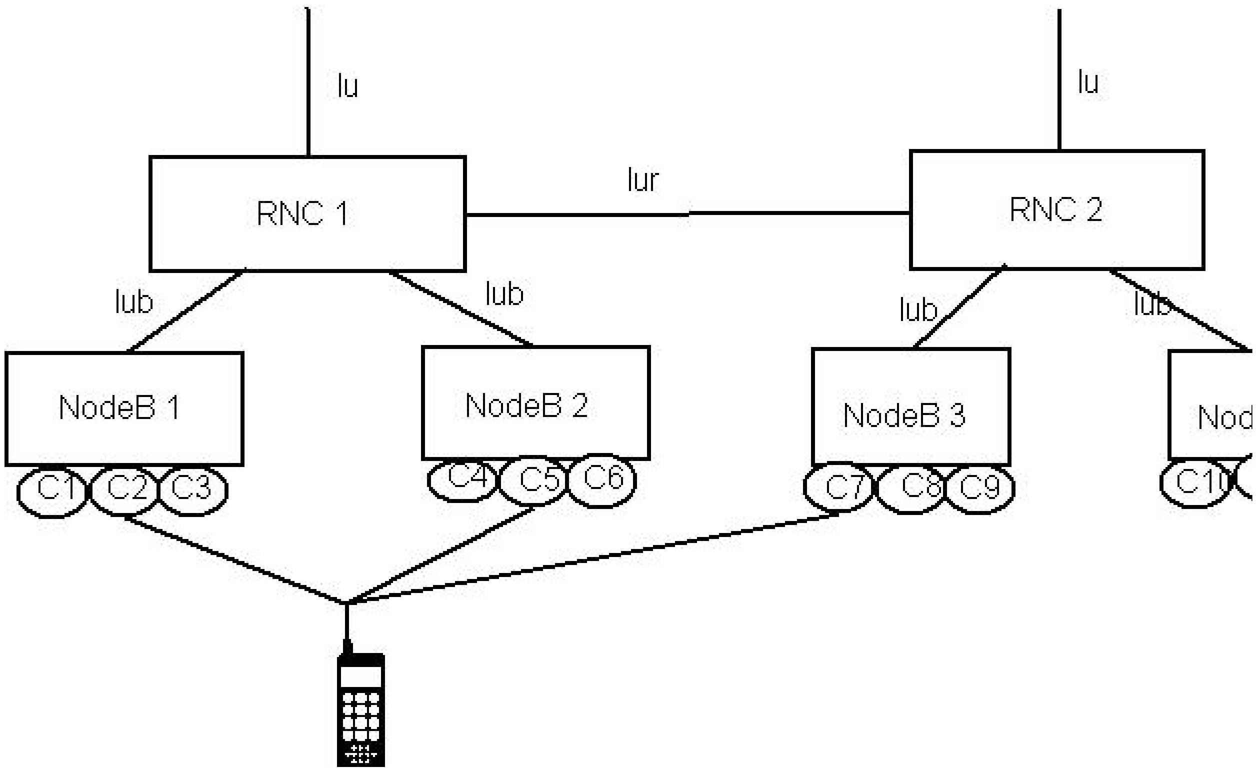


Fig 3: Soft Handover with Iur connection

A more complicated soft handover would include a cell that belongs to a Node B in different RNC. In this case an Iur connection is established with the drift RNC (RNC 2) and the data would be transferred to the Serving RNC (RNC 1) via Iur connection.

In a typical UMTS system, the UE is in soft/softer handover around 50% of the time. One of the very important requirements for the soft/softer handover is that the frames from different cells should be within 50ms of each other or this would not work.

The last thing one needs to remember is that the soft/softer handover is initiated from the RNC and the core network is not involved in this procedure.

Hard Handover

Hard handover occurs when the radio links for UE change and there are no radio links that are common before the procedure is initiated and after the procedure is completed. There are two types of hard handover. First is Intra-frequency hard handover and the second is Inter-frequency hard handover.

Intra-frequency hard handover will not occur for the FDD system. It would happen in TDD system. In this case the code spreading/scrambling code for UE will change but the frequency remains the same.

Inter-frequency hard handover generally occurs when hierarchical cells are present. In this case the frequency at which the UE is working changes. This happens when the current cell is congested, etc. Have a look at the Inter-Frequency Measurement primer for more information.

Hard handover procedure can be initiated by the network or by the UE. Generally it would be initiated by the network using one of the Radio Bearer Control messages. In case of UE initiated, it would happen if the UE performs a Cell Update procedure and that Cell Update reaches the RNC on a different frequency. The Core Network is not involved in this procedure.

SRNS Relocation

SRNS Relocation procedure is not strictly speaking a handover procedure but it can be used in combination with the handover procedure. A simple SRNS Relocation can be explained with the help of figures present in [9].

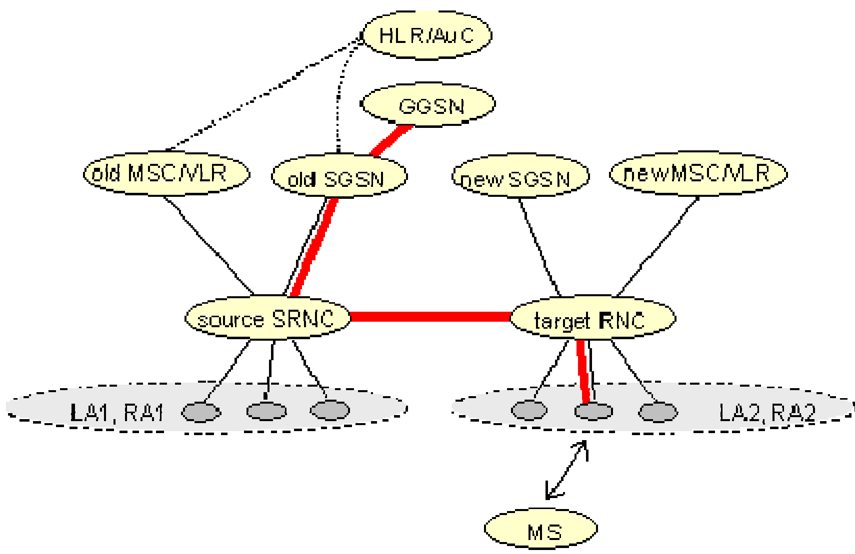


Fig 4: Data flow before SRNS Relocation procedure ([9], Fig 37)

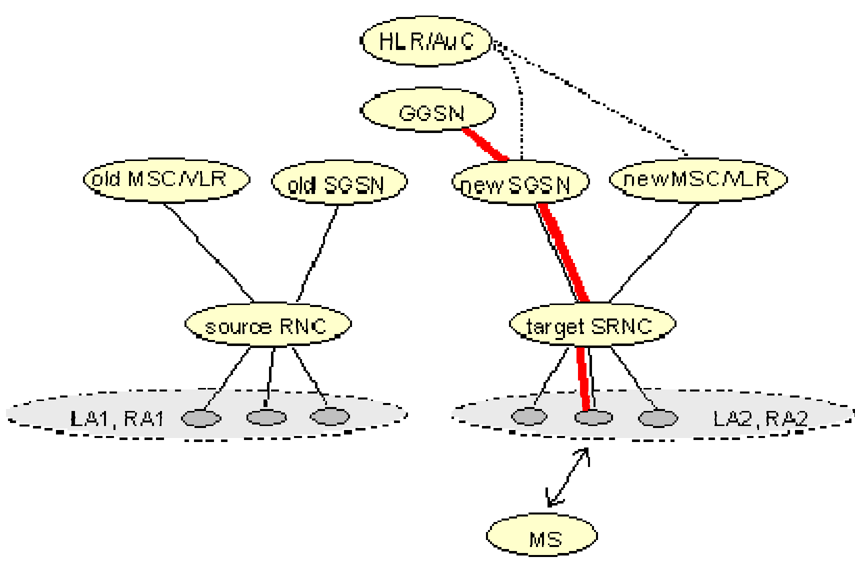


Fig 5: Data flow after SRNS Relocation procedure ([9], Fig 38)

The UE is active on a cell that belongs to a different RNC (than the one on which call was initiated) and a different MSC/SGSN. This arrangement causes unnecessary signaling between two RNC's. Hence the relocation procedure is initiated.

In this, the CN negotiated the relocation procedure between the two RNS's. Once the procedure is completed the connection towards the old domain is released as shown in Fig. 5.

The relocation procedures will generally be used for UE in Packet Switched mode. This procedure is time consuming and is not really suitable for real time services.

Combined Hard handover and SRNS Relocation

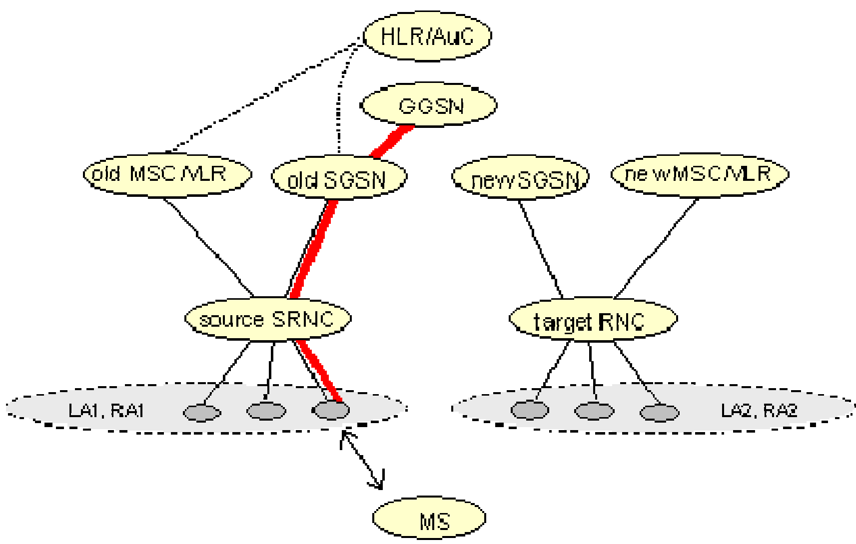


Fig 6: Before Combined hard handover and SRNS Relocation Procedure([9], Fig. 40)

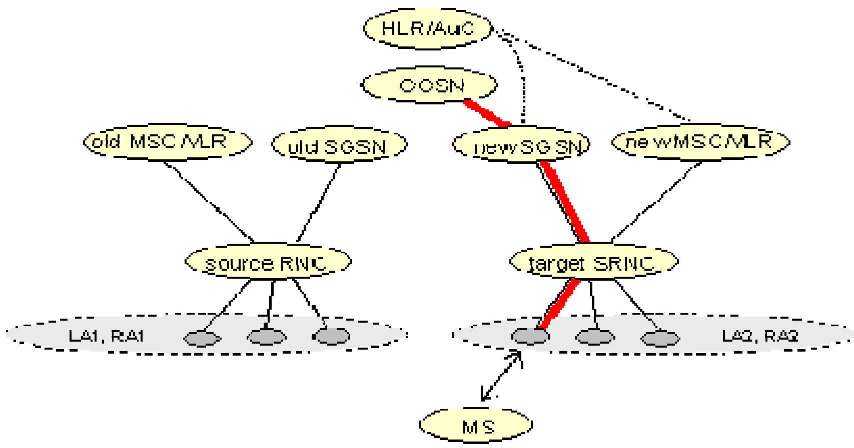


Fig 7: After Combined hard handover and SRNS Relocation Procedure([9], Fig. 41)

The combined procedure is a combination of hard handover and SRNS Relocation. Fig. 6 and 7 explain the procedure.

Inter-RAT hard handover

When UE reaches end of coverage area for UMTS services, it can handover to a 2G service like GSM (if the UE supports multiple RAT). Inter-RAT handover procedure can be initiated in variety of ways. RNS might send a *Handover From UTRAN* command explicitly telling the UE to move to a different RAT or the UE might select a cell that belongs to a different RAT or the Network may ask UE to perform *Cell Change Order from UTRAN*.

Inter-RAT hard handover using *Handover from UTRAN* command can be performed when there are no RAB's or when there is at least one CS domain RAB. The state of the UE is CELL_DCH.

Inter-RAT hard handover using *Cell change order from UTRAN* can be performed when UE is either in CELL_DCH or CELL_FACH state. The only requirement is that there should be at least a PS signaling connection and no CS signaling connection.

Tutorial: Medium Access Control (MAC) in 3G/UMTS Protocol Stack

Introduction

MAC is a Layer 2 protocol and it resides between Physical Layer (L1) and RLC. The internal configuration of MAC is done by the RRC layer (L3). The interface between PHY and MAC are the transport channels where as the interface between RLC and MAC are the logical channels. MAC provides services to both User plane as well as Control plane. MAC takes care of circuit switched as well as packet switch traffic and signaling traffic as well.

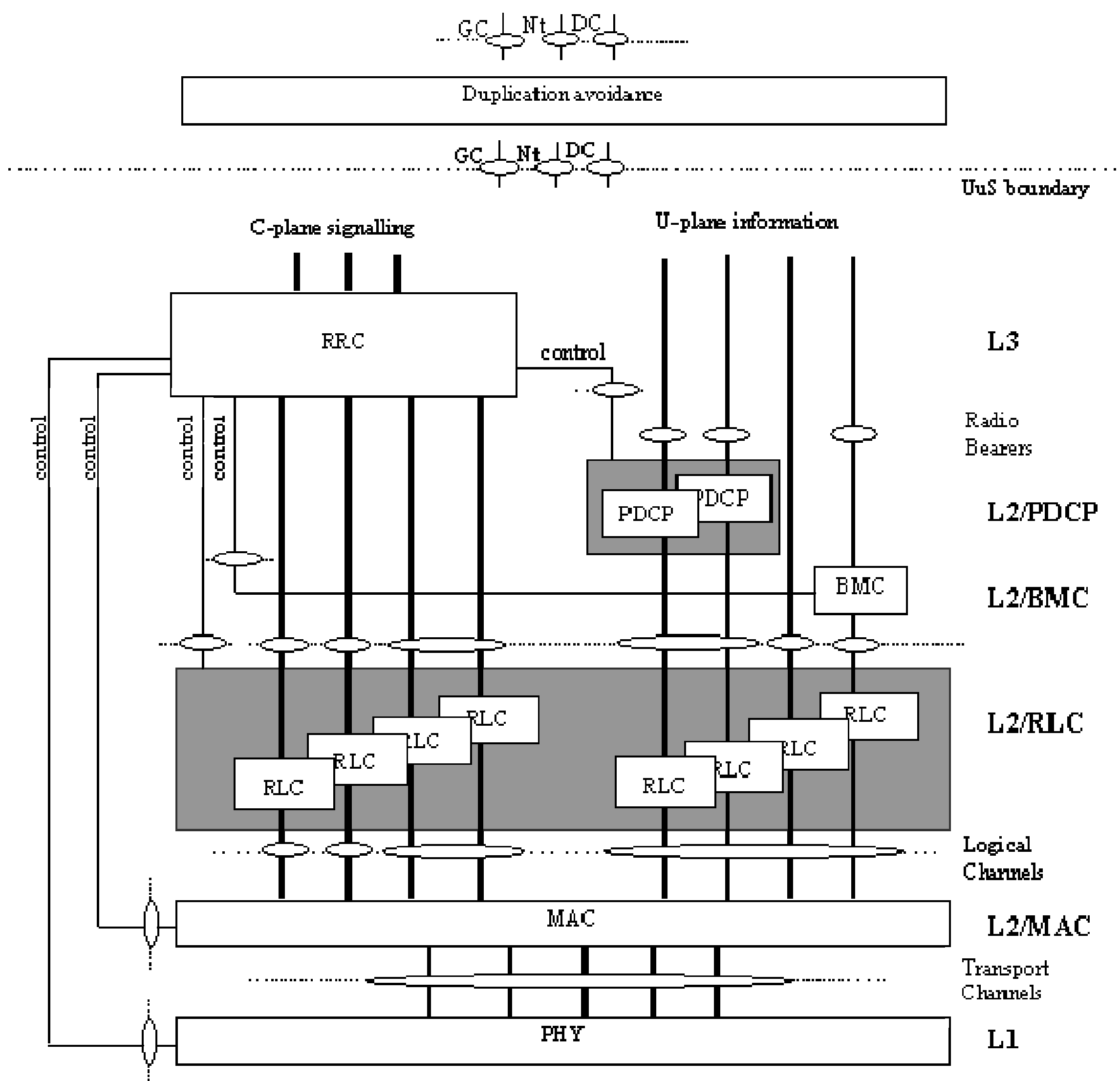


Fig 1: Radio Interface Protocol Architecture (Taken from 25.301, figure 2)

One important thing to remember is that the MAC is not symmetrical protocol. It is different in

UL and DL.

MAC Services

MAC sub layer provides following services to the upper layers:

- Data Transfer: This service provides unacknowledged transfer of MAC SDU's between peer MAC entities.
- Reallocation of radio resources and MAC parameters: On request by RRC, MAC can change the identity of the UE, change the transport format set, change the transport channel type, etc.
- Reporting of Measurements: Traffic volume measurements are performed in MAC and reported to RRC

MAC Functions

MAC Functions include:

- Mapping between logical channels and transport channels
- Selection of appropriate Transport Format for each Transport channel depending on instantaneous source rate. Given the Transport Format Combination Set assigned by RRC, MAC selects the appropriate transport format within an assigned transport format set for each active transport channel depending on source rate. The control of transport formats ensures efficient use of transport channels.
- Priority handling between data flows of one UE. When selecting between the Transport Format Combinations in the given Transport Format Combination Set, priorities of the data flows to be mapped onto the corresponding Transport Channels can be taken into account.
- Priority handling between UEs by means of dynamic scheduling. In order to utilize the spectrum resources efficiently for burst transfer, a dynamic scheduling function may be applied. MAC realizes priority handling on common and shared transport channels.
- Identification of UEs on common transport channels. When a particular UE is addressed on a common downlink channel, or when a UE is using the RACH, there is a need for inband identification of the UE. Since the MAC layer handles the access to, and multiplexing onto, the transport channels, the identification functionality is naturally also placed in MAC.
- Multiplexing/demultiplexing of upper layer PDUs into/from transport blocks delivered to/from the physical layer on common transport channels. MAC should support service multiplexing for common transport channels, since the physical layer does not support multiplexing of these channels.
- Multiplexing/demultiplexing of upper layer PDUs into/from transport block sets delivered to/from the physical layer on dedicated transport channels. The MAC allows service multiplexing for dedicated transport channels. This function can be utilized when several upper layer services (e.g. RLC instances) can be mapped efficiently on the same transport channel. In this case the identification of multiplexing is contained in the MAC protocol control information.
- Traffic volume measurement. Measurement of traffic volume on logical channels and reporting to RRC. Based on the reported traffic volume information, RRC performs transport channel switching decisions.
- Transport Channel type switching. Execution of the switching between common and dedicated transport channels based on a switching decision derived by RRC.

- Ciphering. This function prevents unauthorized acquisition of data. Ciphering is performed in the MAC layer for transparent RLC mode.
- Access Service Class selection for RACH and CPCH transmission. The RACH resources (i.e. access slots and preamble signatures for FDD, timeslot and channelization code for TDD) and CPCH resources (i.e. access slots and preamble signatures for FDD only) may be divided between different Access Service Classes in order to provide different priorities of RACH and CPCH usage. In addition it is possible for more than one ASC or for all ASCs to be assigned to the same access slot/signature space. Each access service class will also have a set of back-off parameters associated with it, some or all of which may be broadcast by the network. The MAC function applies the appropriate back-off and indicates to the PHY layer the RACH and CPCH partition associated to a given MAC PDU transfer.

Channel Structure

Before discussing anything further, we should look at the channel structures for Layer 1, MAC and RLC. The Transport Channels are interface between MAC and Layer 1, while Logical Channels are interface between MAC and RLC.

Transport channels can be further subdivided into Common Transport Channels (where there is need for inband identification of the UEs when particular UEs are addressed); and dedicated transport channels (where the UEs are identified by the physical channel, i.e. code and frequency for FDD and code, time slot and frequency for TDD).

Common transport channel types are:

- Random Access Channel (RACH): A contention based uplink channel used for transmission of relatively small amounts of data, e.g. for initial access or non-real-time dedicated control or traffic data.
- Common Packet Channel (CPCH): A contention based channel used for transmission of burst data traffic. This channel only exists in FDD mode and only in the uplink direction. The common packet channel is shared by the UEs in a cell and therefore, it is a common resource. The CPCH is fast power controlled.
- Forward Access Channel (FACH): Common downlink channel without closed-loop power control used for transmission of relatively small amount of data.
- Downlink Shared Channel (DSCH): A downlink channel shared by several UEs carrying dedicated control or traffic data.
- Uplink Shared Channel (USCH): An uplink channel shared by several UEs carrying dedicated control or traffic data, used in TDD mode only.
- Broadcast Channel (BCH): A downlink channel used for broadcast of system information into an entire cell.
- Paging Channel (PCH): A downlink channel used for broadcast of control information into an entire cell allowing efficient UE sleep mode procedures. Currently identified information types are paging and notification. Another use could be UTRAN notification of change of BCCH information.
- High Speed Downlink Shared Channel (HS-DSCH): A downlink channel shared between UEs by allocation of individual codes, from a common pool of codes assigned for the channel.

Dedicated transport channel types are:

- Dedicated Channel (DCH): A channel dedicated to one UE used in uplink or downlink.

A general classification of logical channels is into two groups; Control Channels (for the transfer of control plane information) and Traffic Channels (for the transfer of user plane information).

Control Channels:

- Broadcast Control Channel (BCCH): A downlink channel for broadcasting system control information.
- Paging Control Channel (PCCH): A downlink channel that transfers paging information. This channel is used when the network does not know the location cell of the UE, or, the UE is in the cell connected state (utilizing UE sleep mode procedures).
- Common Control Channel (CCCH): Bi-directional channel for transmitting control information between network and UEs. This channel is commonly used by the UEs having no RRC connection with the network and by the UEs using common transport channels when accessing a new cell after cell reselection.
- Dedicated Control Channel (DCCH): A point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. This channel is established through RRC connection setup procedure.
- Shared Channel Control Channel (SHCCH): Bi-directional channel that transmits control information for uplink and downlink shared channels between network and UEs. This channel is for TDD only.

Traffic Channels:

- Dedicated Traffic Channel (DTCH): A Dedicated Traffic Channel (DTCH) is a point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.
- Common Traffic Channel (CTCH): A point-to-multipoint unidirectional channel for transfer of dedicated user information for all or a group of specified UEs.

The mapping of Logical channels to transport channels is shown in the diagram below.

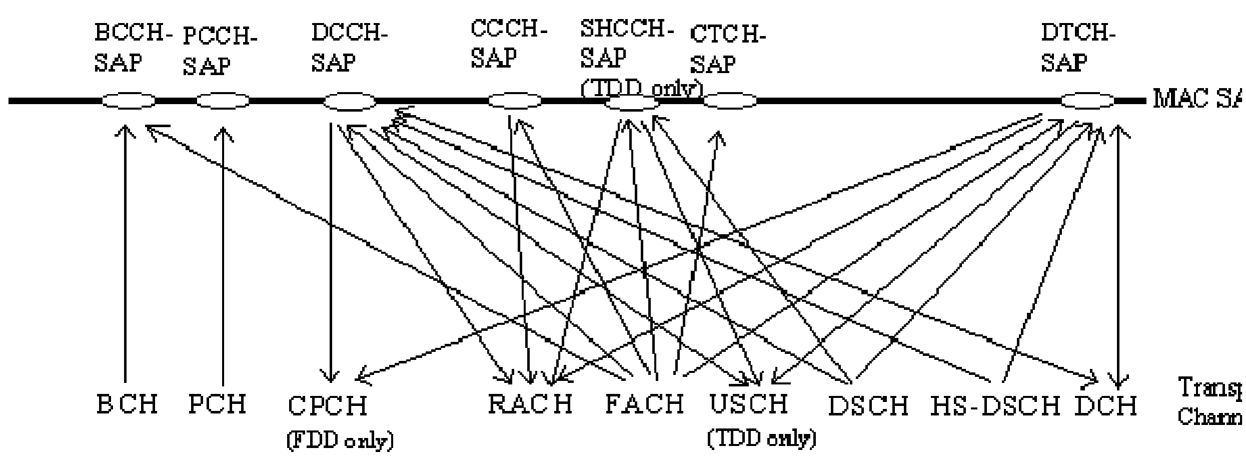


Fig. 2: Logical channels mapped onto transport channels, seen from the UE side (Taken from 25.301, figure 4)

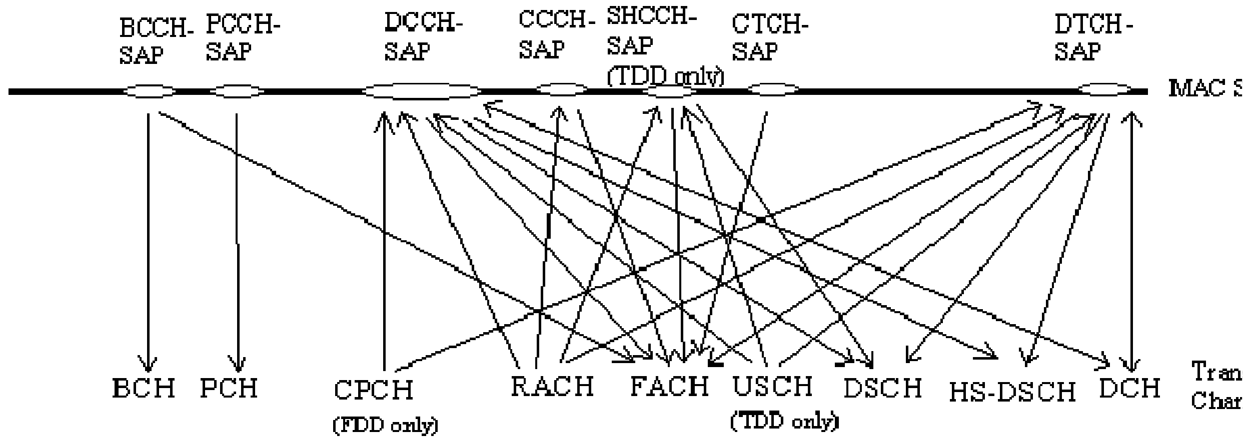


Fig. 3: Logical channels mapped onto transport channels, seen from the UTRAN side (Taken from 25.301, figure 5)

MAC Entities

As mentioned earlier, the MAC protocol is not symmetrical in UL and DL. The MAC entities might be present in the UL and/or DL. The functional entities are as follows:

- MAC-b: Mac-b represents the control entity for the broadcast channel (BCH). There is one (current cell) or multiple (current cell plus neighboring cells) MAC-b entities in each UE and one MAC-b in the UTRAN for each cell. The MAC Control SAP is used to transfer Control information to MAC-b.
- MAC-c/sh: MAC-c/sh handles the paging channel (PCH), the forward access channel (FACH), the random access channel (RACH), common packet channel (UL CPCH) that exists in FDD mode, the downlink shared channel (DSCH) and the uplink shared channel that exists in TDD mode. There is one MAC-c/sh entity in each UE and one in UTRAN for each cell.
- MAC-d: MAC-d handles the dedicated transport channel (DCH). There is one MAC-d entity in the UE and one MAC-d entity in the UTRAN for each UE that has one or more dedicated logical channels to or from the UTRAN.
- MAC-hs: MAC-hs handles the high speed downlink shared channel (HS-DSCH). There is one MAC-hs entity in the UTRAN for each cell that supports HS-DSCH transmission.

Discussion of Functions of MAC

1. Ciphering of Transparent Mode Radio Bearers

In case of TM RBs, RLC acts like a pipe that transfers the data to the MAC layer without adding any headers. Thus in this case Ciphering has to be performed in the MAC layer. In all other cases (AM and UM RBs), Ciphering is performed in the RLC layer. The part of MAC PDU that is ciphered is the MAC SDU as shown in the fig below.

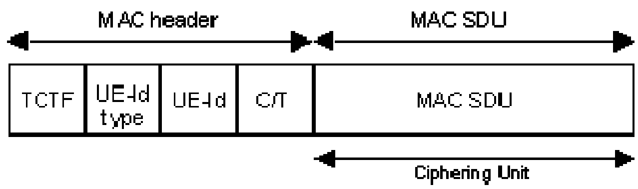


Fig. 4: Ciphered part of MAC PDU
(Taken from 25.321, figure 11.5.1)

2. Traffic Volume Measurement for Dynamic RB Control

Dynamic radio bearer control is performed by RRC, based on the traffic volume measurements reported by MAC. Traffic volume information is measured in MAC layer and the results are reported from MAC layer to RRC layer. This concept can be explained with the help of the diagram below.

```
UE-RRC                            UE-RLC                              UE-MAC
UTRAN
-------                  --------                 ----------                -
------
   |                                |                                      |
|
   |                       Measurement Control Message (Traffic Volume Meas.)
|
   |<--------------------------------------------------------------------------
--|
   |                                |                                      |
|
   |       CMAC-Measure-REQ     |                                          |
|
   |------------------------------------------------->|
|
   |                                    |   MAC-Data-REQ                   |
|
   |                                            |-------------------------->|
|
   |                                    |   MAC-Data-REQ                   |
|
   |                                            |-------------------------->|
|
   |                        CMAC-Measure-IND                               |
|
   |<-------------------------------------------------|
|
   |                                |                                      |
|
   |        Measurement   Report   (Traffic   Volume   Meas.)              |
|
   |---------------------------------------------------------------------------
->|
   |                                |                                      |
|
   |                                |                                      |
|
```

At least every TTI, the MAC layer shall receive from each RLC entity the value of its Buffer Occupancy (BO), expressed in bytes. RRC can configure MAC to keep track of statistics (i.e.

raw BO, average of BO and variance of BO) on the BO values of all Radio Bearers mapped onto a given transport channel. When the average or variance is requested, an averaging interval duration will also be provided.

Every time the BO values are reported to MAC, the UE shall verify whether an event was triggered or if a periodic report is required. If reporting is required (multiple reports may be triggered in a single TTI), the MAC shall deliver to RRC the reporting quantities required for the corresponding RBs. In the case of average and variance of BO, the averaging should be performed for the interval with the configured duration ending at the time when the event was triggered.

3. Access Service Class Selection for RACH Transmission

The physical RACH resources (i.e. access slots and preamble signatures for FDD) may be divided between different Access Service Classes in order to provide different priorities of RACH usage. It is possible for more than one ASC or for all ASCs to be assigned to the same access slot/signature space.

Access Service Classes are numbered in the range 0 £ 7 £ NumASC £ 7 (i.e. the maximum number of ASCs is 8). An ASC is defined by an identifier that defines a certain partition of the PRACH resources and an associated persistence value Pi. A set of ASC parameters consists of NumASC+1 such parameters (i, Pi), i = 0… NumASC. The PRACH partitions and the persistence values Pi are derived by the RRC protocol from system information. The set of ASC parameters is provided to MAC with the CMAC-Config-REQ primitive. The ASC enumeration is such that it corresponds to the order of priority (ASC 0 = highest priority, ASC 7 = lowest priority). ASC 0 shall be used in case of Emergency Call or for reasons with equivalent priority.

At radio bearer setup/reconfiguration each involved logical channel is assigned a MAC Logical channel Priority (MLP) in the range 1… 8. When the MAC sub layer is configured for RACH transmission in the UE, these MLP levels shall be employed for ASC selection on MAC.

The following ASC selection scheme shall be applied, where NumASC is the highest available ASC number and Min MLP the highest logical channel priority assigned to one logical channel:

- in case all TBs in the TB set have the same MLP, select ASC = min(NumASC, MLP);
- in case TBs in a TB set have different priority, determine the highest priority level MinMLP and select ASC = min(NumASC, MinMLP).

When an RRC CONNECTION REQUEST message is sent RRC determines ASC by means of the access class. The ASC to be used in these circumstances is signaled to MAC by means of the CMAC-CONFIG-REQ message.

If MAC has knowledge of a U-RNTI then the ASC is determined in the MAC entity. If no U-RNTI has been indicated to MAC then MAC will use the ASC indicated in the CMAC-CONFIG-REQ primitive.

4. Transport format combination selection in UE

RRC can control the scheduling of uplink data by giving each logical channel a priority between 1 and 8, where 1 is the highest priority and 8 the lowest. TFC selection in the UE shall be done in accordance with the priorities indicated by RRC. Logical channels have absolute priority, i.e.

the UE shall maximize the transmission of higher priority data. Hence higher priority data flows will be given higher bit rate combinations while lower priority data flows will have to use low bit rate combinations. Note that zero bit rate is a special case of low bit rate combination.

MAC has to derive the priority parameters from two sources:

- The buffer occupancy parameter received from RLC
- MAC logical channel priority received from RRC

A given TFC can be in any of the following states:

- Supported state;
- Excess-power state;
- Blocked state.

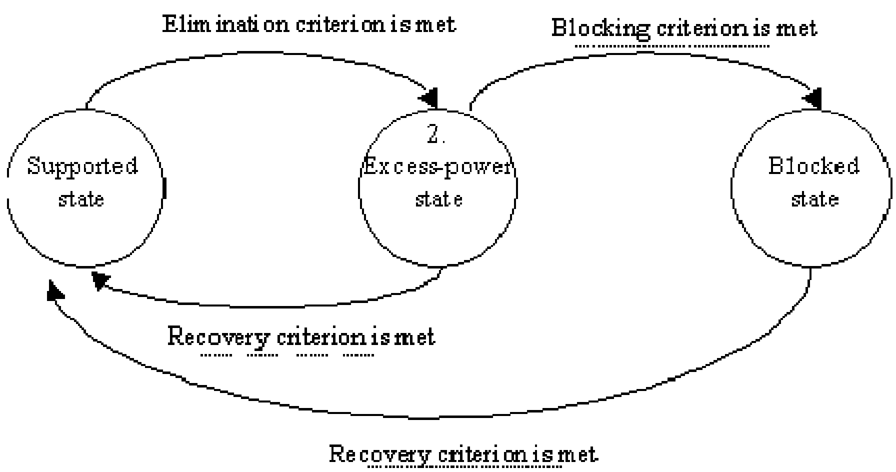


Fig. 5. State transitions for the state of a given TFC (Taken from [1], fig. 11.4.1)

UEs in CELL_FACH state may estimate the channel path loss and set to excess power state all the TFCs requiring more power than the Maximum UE transmitter power. All other TFCs shall be set to Supported state.

Every time the set of supported TFCs changes, the available bitrates shall be indicated to upper layers for each logical channel in order to facilitate the adaptation of codec data rates when codec's supporting variable-rate operation are used. The details of the computation of the available bitrates and the interaction with the application layer are not further specified.

At Radio Bearer Setup (or Reconfiguration), each logical channel is assigned MAC logical channel priority (MLP) in rage 1-8 by RRC. MAC has to then select a TFC that can transmit as much as and as high priority data as possible. In a noisy cell, a high priority TFC can be blocked if its use would cause the UE to transmit more power than the UEs current maximum transmitter power.

Introduction to 3G/UMTS MAC

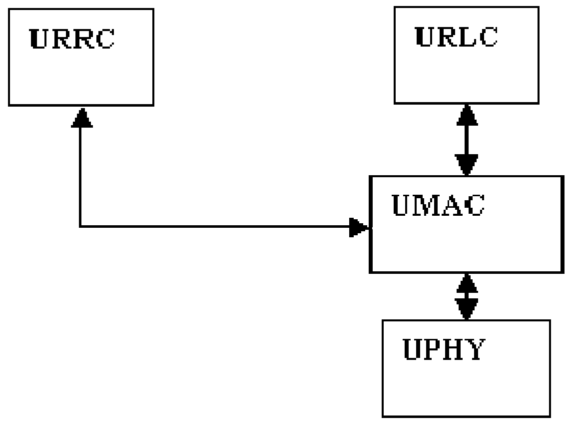
UMAC Basics

Functional Overview

The functions of MAC can be summarized as follows:

- mapping between logical channels and transport channels;
- selection of appropriate Transport Format for each Transport Channel depending on instantaneous source rate;
- priority handling between data flows of one UE;
- priority handling between UEs by means of dynamic scheduling;
- identification of UEs on common transport channels;
  U-MAC provides the UE identification along with dedicated logical channel data that is to be sent on common transport channels. In reverse it monitors dedicated logical channel data being received on common transport channels so that data directed at particular UE identification can be recognized and processed. Common logical channel data does not have to have UE identification added or recognized because either the data is purely common to all UEs or the UE identification is held within a higher layer message held in the data.
- multiplexing/demultiplexing of upper layer PDUs into/from transport blocks delivered to/from the physical layer on common transport channels;
- multiplexing/demultiplexing of upper layer PDUs into/from transport block sets delivered to/from the physical layer on dedicated transport channels;
- traffic volume measurement;
  Every now and then UMAC request URLC the amount of data to be sent. UMAC informs about this to URRC telling about the traffic waiting to be sent on that particular radio bearer. Based on this URRC configures UMAC allowing to act accordingly so that it can send the right amount of data to UPHY. This provision of data transfer service of UMAC can be likened to providing a pipe whose width U-MAC can adjust within a certain range. If there is a requirement for a width of pipe outside of this range then U-MAC informs U-RRC (U-RRC configures U-MAC to monitor the amount of data waiting to be sent by U-RLC via a variety of methods). If too much data is waiting, U-RRC can provide different options to enable more data to be sent. In reverse, if little data is waiting then U-RRC can provide different options that limit the amount of data able to be sent (therefore limiting the amount of radio resources being used). U-MAC is therefore providing control on an inner loop (or micro level) whereas U-RRC is providing control on an outer loop (or macro level).
- Transport Channel type switching;
- ciphering for transparent mode RLC;
  As URLC doesn't add any header to the data in TM mode the ciphering is done in UMAC. For UM and AM mode ciphering is done in URLC.
- Access Service Class selection for RACH and CPCH transmission;
- control of HS-DSCH transmission and reception including support of HARQ;
- HS-DSCH Provided Bit Rate measurement.

If one has to look at the UMAC in terms of design perspective it will look as follows



Thus according to the above figure there are three interfaces/SAP to U-MAC. They are:

- **URRC SAP Interface**: This interface provided the primitives between URRC and UMAC. The primitives are configuration primitives by whom the U-RRC layer can configure the U-MAC layer, both at start up and during operation of the layer.
- **U-PHY SAP interface**: This interface provided the primitives which are service primitives. Through these primitives' data and control information is passed between the U-PHY and U-MAC layers.
- **URLC SAP interface**: The primitives between URLC and UMAC are service primitives by which data and control information is passed between the U-MAC and U-RLC layers.

Channel structure

The MAC operates on the channels defined below; the transport channels are described between MAC and Layer 1, the logical channels are described between MAC and RLC.

Transport channels

Common transport channel types are:

- Random Access Channel(s) (RACH);
- Forward Access Channel(s) (FACH);
- Downlink Shared Channel(s) (DSCH);
- High Speed Downlink Shared Channel(s) (HS-DSCH);
- Common Packet Channel(s) (CPCH) for UL FDD operation only;
- Uplink Shared Channel(s) (USCH), for TDD operation only;
- Broadcast Channel (BCH);
- Paging Channel (PCH).

Dedicated transport channel types are:

- Dedicated Channel (DCH).

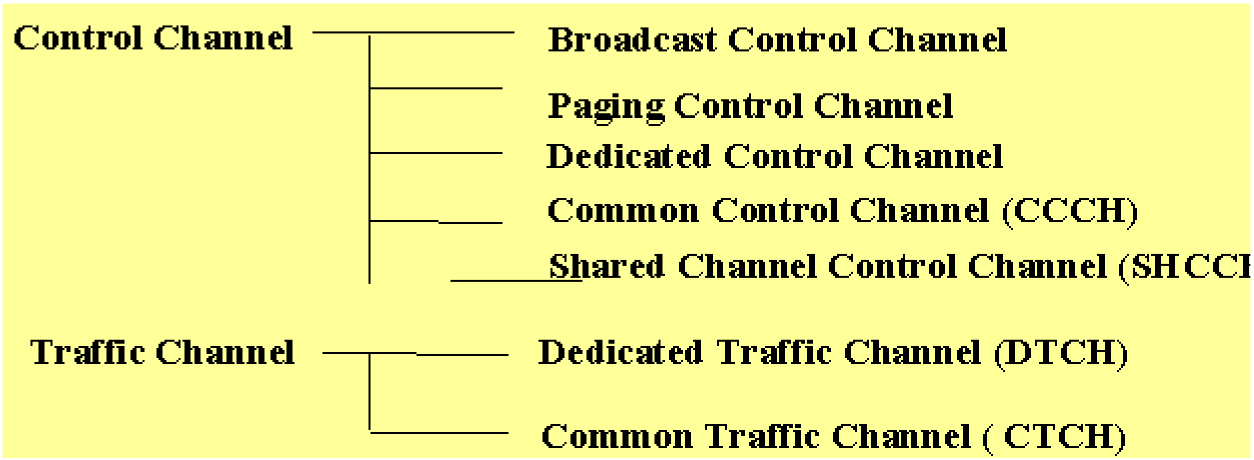
Logical Channels

The MAC layer provides data transfer services on logical channels. A set of logical channel types is defined for different kinds of data transfer services as offered by MAC.

Each logical channel type is defined by what type of information is transferred.

Logical channel structure

The configuration of logical channel types is depicted in figure below.



Data Processing in UL and DL

U-MAC is part of the U-Plane of the UMTS protocol stack and so its performance influences the overall system performance. Processing of data, in particular in the UL, is time critical in that completion of the processing of UL data must be within a finite time and leave enough time for U-PHY to carry out its processing before transmitting the data over the air interface. Processing of data in the DL is less time critical and can be done on an 'as soon as possible' basis

To process the data in UL which is very time critical there is always some background processing in UMAC while it is preparing to send the data in UL. The background tasks and UL processing are initiated by a trigger called TTI. It's an event timer set to trigger U-MAC at each frame boundary (i.e. at 10ms intervals) so that there is 10ms left before data transmission on the air interface is to take place. UL data transfer is then initiated (i.e. TF and TFC selection) which results in UMAC_Status_IND primitive being sent to U-RLC.

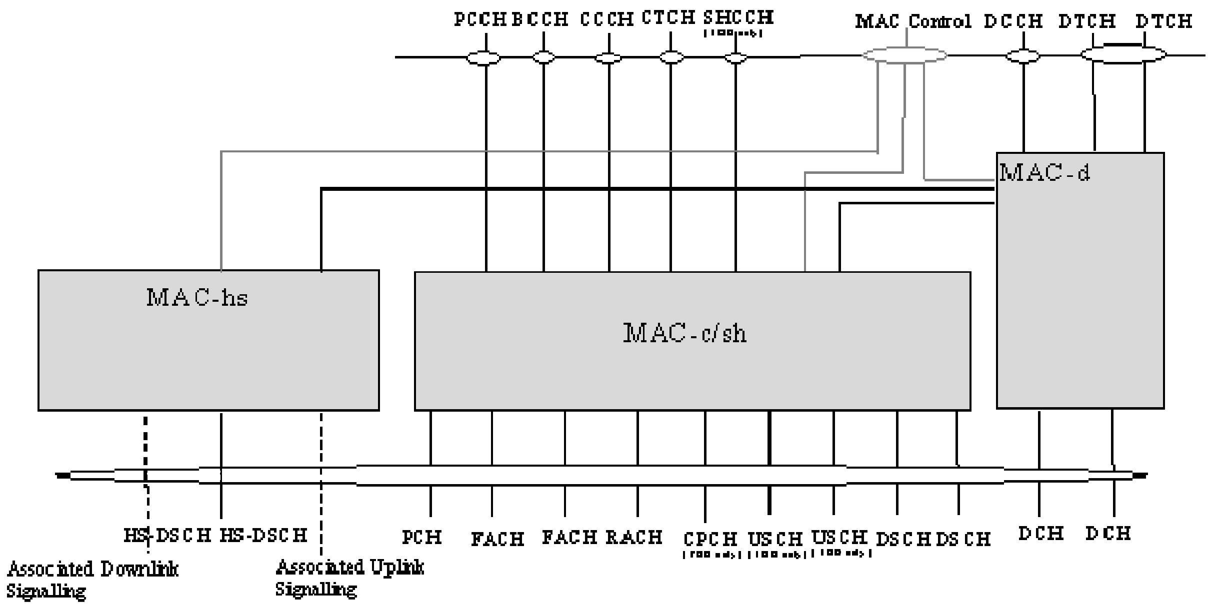
Finally, traffic volume measurement takes place (therefore taking in to account the latest buffer occupancies in U-RLC). When the required data is received back from U-RLC it is processed and passed to U-PHY.

In the DL Data is received from U-PHY asynchronously with the data grouped by its TTI, i.e. each primitive contains data for a single TTI. UMAC after identifying that the data is meant for this UE, will transfer the PDUs to URLC.

U-MAC's primary task is to carry data between U-PHY and U-RLC in both the UL and the DL. This task is of the highest priority. In the background, two other sets of tasks are also happening. Firstly, configuration primitives received from U-RRC are received asynchronously. Secondly, every frame (10ms), other tasks are initiated that need attention, i.e. traffic volume measurement, RACH access, activation of delayed configurations etc.

MAC Overview

The basic UMAC architecture of UMAC is shown blow



As shown in the above figure UMAC consist of three different UMV entities which can be considered as different modules when implementing UMAC for UE.

In terms of design perspective the following section gives and idea what are the modules UMAC can have while implementing. Please note that this is just an idea of having certain modules in UMAC. Engineers can design and can implement modules different to what explained below.

URRC SAP

This sub-component or module is responsible for handling all primitives received from, and sent to, U-RRC. So basically this can be implemented as file which will contain definition for all the data structures related to the primitives received from URRC. URRC SAP's header file contains the 'C' structures, that represent the configuration primitives, and is shared with U-RRC. The members of the structure will be the parameters of the primitives. The file will also contain the function definition and prototype for handling message to and from URRC.

All the primitives received through URRC SAP should contain primitive identifier. This will enable the developer to call the corresponding function to take the actions based on the received primitive.

On the transmitting side, the URRC SAP creates the final primitive and adds the primitive header before sending it to U-RRC.

U-PHY SAP

This sub-component or module is responsible for handling all primitives received from, and sent to, U-PHY.

Primitives are received encapsulated by a primitive header within which is an identifier of the primitive

On the transmitting side, the U-PHY SAP creates the final primitive and adds the primitive header before sending the primitive to U-PHY.

U-PHY SAP's header file contains the 'C' structures, that represent the primitives and is shared with U-PHY.

U-RLC SAP

The 'U-RLC SAP' sub-component is responsible for handling all primitives received from, and sent to, U-RLC.

If we consider a better design then I would recommend that this SAP should be only used in the DL. In DL the primitives are received with primitive identifier embedded into it. The correct function in the correct U-MAC sub-component (MAC-c/sh, MAC-d, MAC-b) is called passing the primitive itself. For data transmission primitives this needs the Radio Bearer number to be acquired from within the primitive to enable the appropriate mapping for the Radio Bearer to be identified from the configuration provided by the 'Database'. The primitive may then contain several instances, for example the data for several Radio Bearers. In this case the sub-component splits the primitive intelligently to handle the passing of the data to different sub-components (if required).

On the transmitting side, the U-RLC SAP creates the final primitive and adds the primitive header before sending the primitive to U-RLC. U-RLC SAP's header file contains the 'C' structures, that represent the primitives, and is shared with U-RLC.

In case of UL I will recommend that instead of passing the primitives in each TTI it's better to have the function calls. This is because it is felt that the performance of the protocol stack can be significantly improved by violating the principle of everything being handled by the U-RLC SAP. When U-MAC needs to get the data or PDUs from URLC in each TTI or if it needs to know the buffer occupancies in U-RLC, direct function calls are made so that the latest values are obtained. By using function calls, the other possible solution of extra primitives passing between the layers, and the extra delays that incurs at a critical time due to the overhead of the Protocol Stack Framework, is avoided. In a similar way, in the case of U-RLC TM Radio Bearers, U-MAC uses a function call to request the more detailed (than the pure buffer occupancies) information required about what is waiting in the U-RLC buffer.

Create UMAC

This sub-component (can be given any other name) is responsible for initializing the U-MAC software ready for use by calling the initialization procedures within each of the other sub-components. In other way this is the initialization of the UMAC task. Please note that this is just the initialization of the UMAC data structure or it's just a software initialization. Following this U-MAC still needs to be configured by U-RRC, via the URRC SAP, before any data transfer can occur. This initialization should occur when power is first applied to the processor or when the CUMAC_Initialization_REQ primitive is received.

The initialization process can be viewed as initializing the data structure, allocating the necessary memory for the static buffers or primitives and so on. In this process most of the variables used in UMAC are initialized to their default values as suggested in the 3GPP specs.

Kill UMAC

This sub-component is responsible for halting the U-MAC software so that it uses the minimum of system resources.

MAC-b (mac_b)

The 'MAC-b' sub-component is responsible for handling of the broadcast information received in the DL on the BCH transport channel. It is initiated by the receipt of the UPHY_Data_IND primitive that has a data indication, within the primitive, with the Transport Channel Type set to BCH. There can be several instances of MAC-b (due to the possibility of there being several broadcast channels being monitored at one time). Due to the simplicity of the 'MAC-b' sub-component there is no requirement for instance context data. The 'Database' provides the configuration information to map the data to the correct BCCH so that the data can be passed to U-RLC with the UMAC_Data_IND primitive.

MAC-c/sh (mac_csh)

The 'MAC-c/sh' sub-component is responsible for processing of information on the common and shared transport channels in both the UL and the DL.

In terms of implementation and design it is initiated by one of two events.

1. In UL common/shared transport channel data is received by U-MAC from U-RLC (via the UMAC_Data_REQ primitive, that has a data request within the primitive with the Radio Bearer ID set to a value whose logical channel maps on to a common/shared transport channel.
2. In DL common/shared transport channel data is received by U-MAC from U-PHY (via the UPHY_Data_IND primitive that has a data indication within the primitive with the Transport Channel Type set to DSCH, PCH or FACH). Data with an invalid CRC is discarded.

NOTE: The RLC provides RLC-PDUs to the MAC, which fit into the available transport blocks on the transport channels.

When data is received from U-RLC in the UL, via the UMAC_Data_REQ primitive, the TCTF and UE ID (CRNTI is always added in UL but only for dedicated logical channel data) header fields are added and then the data is passed to the 'U-PHY SAP' sub-component for transmission to U-PHY.

In the DL (if multiple transport channels are received then this procedure is carried out for each transport channel), the TCTF field is stripped off the data. If the logical channel indicated by the TCTF field is for a common/shared logical channel then the data is passed up to U-RLC with the UMAC_Data_IND primitive. If the logical channel indicated by the TCTF field is for a dedicated logical channel then the UE ID field is stripped off the data. The UE ID is compared against the UE ID provided by the 'Database'. This can either be a U-RNTI, a C-RNTI or a DSCH-RNTI, the UE ID Type field gives the type (U-MAC has all three values, if available at the UE, configured in the 'Database'). If the two UE IDs do not match then the data is discarded. If the two UE IDs match then the data is de-multiplexed, if necessary, and then passed up to U-RLC, also with the UMAC_Data_IND primitive.

Thus the following functionality is covered by UMAC -c/sh:

- TCTF MUX:
  - this function represents the handling (insertion for uplink channels and detection and deletion for downlink channels) of the TCTF field in the MAC header, and the respective mapping between logical and transport channels.
    The TCTF field indicates the common logical channel type, or if a dedicated logical channel is used;
- add/read UE Id:
  - the UE Id is added for CPCH and RACH transmissions
  - the UE Id, when present, identifies data to this UE.
- UL: TF selection:
  - in the uplink, the possibility of transport format selection exists. In case of CPCH transmission, a TF is selected based on TF availability determined from status information on the CSICH;
- ASC selection:
  - For RACH, MAC indicates the ASC associated with the PDU to the physical layer. For CPCH, MAC may indicate the ASC associated with the PDU to the Physical Layer. This is to ensure that RACH and CPCH messages associated with a given Access Service Class (ASC) are sent on the appropriate signature(s) and time slot(s). MAC also applies the appropriate back-off parameter(s) associated with the given ASC. When sending an RRC CONNECTION REQUEST message, RRC will determine the ASC; in all other cases MAC selects the ASC;
- scheduling /priority handling
  - this functionality is used to transmit the information received from MAC-d on RACH and CPCH based on logical channel priorities. This function is related to TF selection.
- TFC selection
  - transport format and transport format combination selection according to the transport format combination set (or transport format combination subset) configured by RRC is performed,

There is one MAC-c/sh entity in each UE.

MAC-d (mac_d)

The 'MAC-d' sub-component is responsible for processing of information on dedicated transport channels in both the UL and the DL.

The following functionality is covered by MAC-d:

- Transport Channel type switching
  - Transport Channel type switching is performed by this entity, based on decision taken by RRC. This is related to a change of radio resources. If requested by RRC, MAC shall switch the mapping of one designated logical channel between common and dedicated transport channels.
- C/T MUX:
  - The C/T MUX is used when multiplexing of several dedicated logical channels onto one transport channel (other than HS-DSCH) or one MAC-d flow (HS-DSCH) is used. An unambiguous identification of the logical channel is included.
- Ciphering:
  - Ciphering for transparent mode data to be ciphered is performed in MAC-d. Details about ciphering can be found in [10].
- Deciphering:
  - Deciphering for ciphered transparent mode data is performed in MAC-d. Details about ciphering can be found in [10].

- UL TFC selection:
    - Transport format and transport format combination selection according to the transport format combination set (or transport format combination subset) configured by RRC is performed.

The MAC-d entity is responsible for mapping dedicated logical channels for the uplink either onto dedicated transport channels or to transfer data to MAC-c/sh to be transmitted via common channels.

One dedicated logical channel can be mapped simultaneously onto DCH and DSCH. One dedicated logical channel can be simultaneously mapped onto DCH and HS-DSCH. The MAC-d entity has a connection to the MAC-c/sh entity. This connection is used to transfer data to the MAC-c/sh to transmit data on transport channels that are handled by MAC-c/sh (uplink) or to receive data from transport channels that are handled by MAC-c/sh (downlink).

The MAC-d entity has a connection to the MAC-hs entity. This connection is used to receive data from the HS-DSCH transport channel which is handled by MAC-hs (downlink).

There is one MAC-d entity in the UE.

In terms of implementation and design perspective it is initiated by one of two events...

1. Dedicated transport channel data is received by U-MAC from U-RLC (via the UMAC_Data_REQ primitive, that has a data request within the primitive with the Radio Bearer ID set to a value whose logical channel maps on to a dedicated transport channel.
2. Dedicated transport channel data is received by U-MAC from U-PHY (via the UPHY_Data_IND primitive that has a data indication within the primitive with the Transport Channel Type set to DCH). Data with an invalid CRC is discarded.

When data is received from U-RLC in the UL, via the UMAC_Data_REQ primitive, the mapping information is acquired from the 'Database'. The data is multiplexed with other logical channels on a block by block basis (with the C/T field added). The data is ciphered if required (again the 'Database' is queried to see if ciphering is configured for this particular Radio Bearer) and then the data is passed to U-PHY with the UPHY_DCH_Data_REQ primitive. Note that the UMAC_Data_REQ primitive received from U-RLC will have contained all of the dedicated logical channel data, therefore this procedure will be executed for each logical channel and the UPHY_DCH_Data_REQ primitive will include all the data to be sent on the single CCTrCh.

In the DL, for data received directly from U-PHY with the UPHY_Data_IND primitive the mapping and configuration is queried from the 'Database' for the transport channel the data is received on (if multiple transport channels are received in the UPHY_Data_IND primitive then this procedure is carried out for each transport channel). The data is de-multiplexed on a block by block basis (by stripping off and using the C/T field), deciphered if required before being passed to U-RLC with the UMAC_Data_IND primitive (with the correct Radio Bearer set within the primitive).

MAC-d has another final task, which is to handle loopback testing. When this mode is in operation U-MAC will echo the TBs received back to U-PHY with the addition of the CRC information of the received blocks appended. U-RRC should have provided the appropriate TFs to allow this to happen.

Database

This module can be considered as a heart of the UMAC layer. The best way to implement this is to define a structure whose members are equivalent to the configuration parameters given my URRC once the UMAC task is initialised. The 'Database' sub-component processes and holds the information provided by U-RRC through the URRC SAP plus other information regarding the status of the U-MAC layer at a particular point in time (previous successful transmission of data on a logical channel etc.). It provides an intelligent interface to access information, for example to provide the TTI for each UL transport channel as well as straightforward access to the configuration information. It also provides the ability to handle configuration information that is not to be used until a specified time in the future and handle the switching of information (plus, for the special case of a TFCSS configuration, reverting back to the unmodified TFCS after the configured time). The following information is contained within the database:

- Radio Bearer configurations.
- Transport Format Sets.
- Transport Format Combination Set.
- Transport Format Combination Subset.
- Traffic Volume Measurement Configurations.
- Random Access Channel transmission control elements.
- Ciphering details.
- HFN details.
- CODEC details.
- Test loop status.
- Success of transmission of logical channel data in the last Transmission Time Interval.

When configurations are received by U-MAC from U-RRC they are not handled immediately but stored in a queue until immediately after the event timer trigger is received (via the 'Data Handler'). At the same time configurations that have been delayed further, due to possessing an activation time, are activated if the correct CFN has now arrived . The UMAC design should ensure that configurations do not change during processing of data (e.g. between the request of data from U-RLC with UMAC_Status_IND and the receipt of data with UMAC_Data_REQ).

As a good design please try to develop the habit that as much as possible of the configuration information stored by the 'Database' is stored as pointers to the primitive structures that have been received from U-RRC. The memory of the primitive structure is released when the configuration is no longer required. The pointers should be stored in static variables. When other sub-components request some information from the 'Database' then they receive the pointer to the primitive structure. This means that the sub-components of U-MAC also need to be able to share the CUMAC SAP's header file. However there are a couple of special exceptions that can be considered. Firstly, TFCS configurations and TFCSS configurations are handled by using the information provided to modify the already stored TFCS configuration primitive. Secondly, again with TFCS and TFCSS configurations, the information provided is decoded from the CTFC to the TFIs and stored like this therefore avoiding the need to decode the CTFCs every time Transport Format Combination Selection takes place.

Finally, the Database module should be intelligent enough to handle the arrival of different primitives at the same time.

Data Handler

This sub-component receives a frame tick via an event timer trigger configured to initiate U-MAC once every frame at the frame boundary. From this it informs other sub-components that need to be actioned to do something at this time. These are:

- The 'Database' sub-component. New configurations or configurations that are awaiting a CFN that matches their activation time are handled.
- The 'Control of RACH transmissions' sub-component. RACH accesses that previously failed need to be re-attempted (if the RACH access procedure allows it). If a new transmission is allowed then Transport Format Selection takes place and a request made for data from U-RLC with the UMAC_Status_IND primitive.
- The 'Transport Format Combination Selection' sub-component. Transport Format Combination Selection takes place and a request made for data from U-RLC with the UMAC_Status_IND primitive.
- The 'Traffic Volume Measurement' sub-component. The traffic volume for each UL transport channel needs to be checked every frame and measurements reported to U-RRC if necessary.

Transport Format Combination Selection

The 'Transport Format Combination Selection' module provides a Transport Format Combination Selection service for DCH transport channels to be mapped to a single CCTrCh. Some preparation of data for the Transport Format Combination Selection routine, which does not depend on information that changes every frame, is done as soon as configuration primitives are handled after receipt from U-RRC.

TFC selection is processor intensive, therefore limiting the amount of work done when we want to move data through the stack is desirable. Firstly, TFC selection is done on the transport channels whereas U-RRC configures U-MAC with Radio Bearers (which map one to one on to logical channels). The transport channel information (which logical channels are mapped to each transport channel) is therefore prepared at configuration time. Secondly, an array of TF information is prepared at configuration time to save the TFC selection from searching through each transport channel's TFS.

Transport Format Combination Selection needs to acquire the logical channel to transport channel mappings from the 'Database' sub-component, the TTIs of the transport channels and the buffer occupancies of the logical channels from U-RLC (via direct function calls) to make the selection. The logical channel priorities stored by the 'Database' in the Radio Bearer configurations are also taken in to account. There is also the facility for TFCs in the TFCS to be flagged as not being available if the estimated U-PHY power usage of a TFC is greater than the maximum UE transmit power. This is handled internally within the 'Database' so should not be visible to 'Transport Format Combination Selection'.

When the event timer trigger is received (via the 'Data Handler') then logical channel to DCH transport channel mappings are read from the 'Database', Transport Format Combination Selection is done and the required data is requested from U-RLC via the UMAC_Status_IND primitive or a function call. Note that in both cases, U-MAC calculates how much header information will be need to be added to the U-RLC data, during transmission, and subtracts this value from the TB sizes in the selected TFs. This new value is the one used in the UMAC_Status_IND primitives sent to U-RLC.

In the case of two or more DCH transport channels, with different TTIs, being multiplexed to a single CCTrCh (for example, if we have two DCH transport channels, one with a TTI of 10ms and another with a TTI of 20ms) every 20ms data for both transport channels will be transferred to U-PHY. However in the 'in-between frame', i.e. every other 10ms, data for only the transport channel with the TTI of 10ms will be transferred to U-PHY. This raise the big question which is what happens in the TFC selection when data is being transferred for only one of the two transport channels? The solution for this is to remember the TF selected (as part of the TFC) for the 20ms TTI transport channel in the last frame and ensure the use of the same TF in this frame. The other option from U-MAC's point of view would be to select a zero TF, i.e. one that does not contain any data format (zero size, no coding). The theory is that U-PHY will still need the 20ms TTI transport channel properly identified in the TFCI for encoding purposes (as the 20ms TTI transport channel data is physically transmitted over 20ms). Ditto for decoding purposes in the UTRAN's U-PHY. If, in another case, no transport channels' TTI coincides with the current frame then the Transport Format Combination selected for the last frame where there was data to send is to be used by U-PHY, however U-MAC will not bother informing U-PHY of this as it can be assumed. No data needs to be requested from U-RLC (although the UMAC_Status_IND primitive is still sent to U-RLC so that it knows the success or not of the last transmission on each RB).

Control of RACH transmissions

The 'Control of RACH transmissions' sub-component controls the timing of sending data to U-PHY plus selection of the Access Service Class of RACH transport channel information being passed to U-PHY.

When the event timer trigger (via the 'Scheduler') is received the sub-component determines whether there is old data waiting to be re-sent or new data is required. If new data is required then logical channel to RACH transport channel mappings are read from the 'Database' and Transport Format Selection is done. The required data is then requested from U-RLC via the UMAC_Status_IND primitive. Note that, like the 'Transport Format Combination Selection' sub-component, U-MAC calculates how much header information will be need to be added to the U-RLC data, during transmission, and takes this in to account in the UMAC_Status_IND primitive sent to U-RLC. If old data is to be re-sent then the 'Control of RACH transmissions' procedure is executed to determine whether it should send the data to U-PHY immediately or wait longer.

When U-MAC wants to transmit data on the RACH transport channel it needs to request access by sending the UPHY_RACH_Data_REQ primitive to U-PHY containing the data. If U-PHY receives a positive AICH signal then it transmits the RACH data to the UTRAN. U-PHY will then confirm whether the data was sent or, if not, the reason why not with the UPHY_RACH_Access_CNF primitive. This keeps the functionality of U-MAC working to a minimum granularity of a frame. In the case of an unsuccessful RACH transmission then a retry may occur in the next frame (initiated by the 'Scheduler' sub-component), dependant on the Control of RACH transmissions procedure. An identifier is attached to the UPHY_RACH_Data_REQ primitive so that U-PHY is aware that the data is being retried so that it may increase the preamble power.

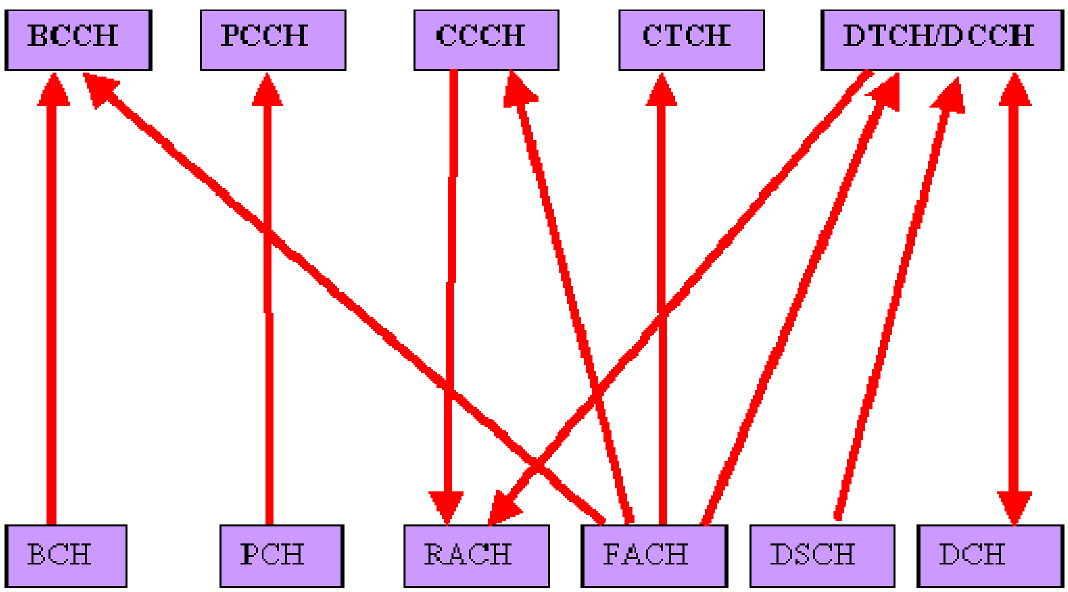
Traffic Volume Measurements

The 'Traffic Volume Measurement' sub-component monitors the amount of information queued to be transmitted by U-MAC in the UL, providing reports to U-RRC as requested in the configuration of U-MAC by U-RRC.

It is initiated by the 'Scheduler' sub-component every 10ms at which time the 'Traffic Volume Measurement' sub-component, from the configuration held by the 'Database', finds out the buffer occupancies of all logical channels, mapped to the required transport channels to be monitored, via direct function calls to U-RLC. It then does the appropriate calculations and reports, if necessary, the traffic volume on all Radio Bearers to U-RRC with the CUMAC_Measurement_IND primitive (either the straightforward buffer occupancy, the buffer occupancy average over time or the buffer occupancy variance over time). The calculations also involve keeping track of the running averages and variances for each logical channel. The two triggers that initiate U-MAC to send a measurement report to U-RRC are measurements that occur at a defined period and / or measurements that go above or below specified configured values. When new measurements are configured then functions in the 'Traffic Volume Measurements' sub-component are called to initialize local variables and also to determine logical channel to transport channel mappings so that they do not have to be worked out when the measurements are to be calculated.

Data Flow through UMAC

The figure below shows the mapping of logical channels to transport channels.



In the case of dedicated channels (DCH, DTCH and DCCH) and FACH there can be multiple instances of each. It is also important to note that U-MAC does not distinguish between DTCH and DCCH - as far as U-MAC is concerned they are processed in the same manner.

When data enters U-MAC, either at the U-PHY SAP or the U-RLC SAP the SAP sub-component looks up routing information, in the Database, to decide which internal U-MAC sub-component needs to process the data.

Uplink Data Flow through UMAC

Uplink Initiation

As soon as UMAC receives the trigger via the 'Data Handler' it triggers procedures in both the 'Control of RACH transmissions' and 'Transport Format Combination Selection' sub-components. These results in a single UMAC_Status_IND primitive being sent to U-RLC. The request can include information about multiple logical channels.

The 'Control of RACH transmissions' sub-component determines which logical channels are mapped to the RACH transport channel. If any logical channels are mapped it then acquires the buffer occupancy for each of those logical channels from U-RLC (via direct function calls) and does a Transport Format selection from the configured RACH TFS. Both CCCH and DTCH/DCCH may be mapped to RACH, so the UMAC_Status_IND primitive is sent to U-RLC (via U-RLC SAP) requesting the appropriate amount of data for both.

The 'MAC-d' sub-component determines which logical channels are mapped to the DCHs, acquires the buffer occupancy for each of those logical channels from U-RLC (again via direct function calls to U-RLC) and does a Transport Format Combination selection from the configured DCH TFCS. The UMAC_Status_IND primitive is then sent (again via U-RLC SAP) requesting the appropriate amount of data for the DTCH/DCCHs.

Note that the two sub-components should send a request to U-RLC SAP even if no actual data is required, so that U-RLC SAP knows this and can send the UMAC_Status_IND primitive to U-RLC at the right time. Also included in the UMAC_Status_IND primitive is a boolean that provides details to U-RLC about whether the last transmission on each particular logical channel was successful or not. This is only regarding the data being passed to U-PHY and so is really only of use for RACH transport channel data. After a transmission, in the case of there being no data actually to send in the next frame from the logical channel then the primitive is sent anyway but requesting zero data.

The Buffer Occupancy request for UM and AM Radio Bearers returns the number of bytes waiting in U-RLC for that Radio Bearer. For TM Radio Bearers the size of the next SDU plus the number of SDUs of that size is returned. This is due to the different way that TM works in relation to UM and AM, by not allowing segmentation in U-RLC. U-MAC is provided with the U-RLC mode by U-RRC, in the Radio Bearer configuration.

Although U-RRC provides a logical channel priority to U-MAC for CCCH it is actually fixed to one (specified in the U-RRC 3GPP specification) so in practice CCCH data will take priority over DTCH/DCCH data (one being the highest logical channel priority possible).

Uplink Data, Common logical channel to common Tr channel

In this the CCCH (logical channel) data that is to be sent on the RACH transport channel. The data received from URLC will immediately be processed by MAC-c/sh and passed on to U-PHY.

Uplink, dedicated logical mapped to common Tr channel

In this case DTCH/DCCH data has to be sent on the RACH transport channel. In this scenario there can be several DTCH/DCCHs may be multiplexed. The incoming data from URLC is multiplexed by MAC-c/sh, then the appropriate headers are added and the data is passed on to U-PHY.

Uplink, common logical channel mapped to dedicated or common logical channel mapped to common Tr channel

In this scenario the requirement will be that both CCCH logical channel data and DTCH/DCCH logical channel data is to be sent on the RACH transport. It thus combines the previous two cases.

Uplink, dedicated logical channel mapped to dedicated Tr channel

The DTCH/DCCH logical channel data is to be sent on DCH transport channels. The incoming data is immediately processed by MAC-d and passed on to U-PHY. As all the logical channels were requested in a single UMAC_Status_IND primitive then all the data for the logical channels is received in a single UMAC_Data_REQ primitive. The transport channel data is transferred to U-PHY as a single UPHY_Data_REQ primitive (i.e. all of the data for a single CCTrCh is sent together).

Downlink data flow

In the DL it is much more straightforward as data is received from U-PHY with the UPHY_Data_IND primitive asynchronously. Each UPHY_Data_IND primitive contains data for a single TTI. The data is processed as soon as possible and passed to U-RLC with a single UMAC_Data_IND primitive. If U-PHY sends several transport channels in a single primitive then each will be processed sequentially within the single STF. The U-PHY SAP will separate transport channel data that is to be sent to different U-MAC sub-components (i.e. 'MAC-b', 'MAC-c/sh' and 'MAC-d') and transfer only the data appropriate to that sub-component. After processing U-MAC will collate the data in U-RLC SAP - i.e. the primitive will include the data for all of the logical channels being sent due to the data with a particular TTI in an incoming UPHY_Data_IND. The different scenarios which can happen DL in terms of mapping of logical channel to transport channel are as follows:

- Downlink, BCH to BCCH
- Downlink, FACH to BCCH
- Downlink, FACH to BCCH
- Downlink, PCH to PCCH
- Downlink, FACH to CCCH
- Downlink, DSCH/FACH to DTCH/DCC
- Downlink, dedicated to dedicated

Identification of Logical Channel Type from Radio Bearer ID

No U-RRC messages defined in the U-RRC 3GPP specification contain the Logical Channel Type. This means that when UE U-RRC receives the Radio Bearer configuration from UTRAN U-RRC it has no information about the Logical Channel Type used for each Radio Bearer (whereas there is a Transport Channel Type so that information is known). Therefore how can U-MAC be given the information to map a Logical Channel Type to a Transport Channel Type? The answer is that in the UE the Logical Channel Type can be inferred from the Radio Bearer ID. For Radio Bearers 0 through 4 the Logical Channel Type is specified in the U-RRC 3GPP specification section 6.3. For Radio Bearers 5 through 31 the Logical Channel Type is always DCCH or DTCH (which U-MAC does not distinguish between). In the DL Radio Bearer IDs are not specified in the 3GPP specifications for some of the common logical channels. However, for our implementation negative values have been assigned. The table below illustrates the above facts.

Radio Bearer	Logical Channel inferred
RB 0	CCCH
RB 1	DCCH
RB 2	DCCH
RB 3	DCCH

RB 4	DCCH
RB 5..32	DTCH or DCCH

Elements for layer-to-layer communication

The interaction between the MAC layer and other layers are described in terms of primitives where the primitives represent the logical exchange of information and control between the MAC layer and other layers. The primitives shall not specify or constrain implementations. The MAC is connected to layer 1, RLC and RRC. The following sub clauses describe the primitives between these layers.

Primitives between MAC and RLC The primitives between MAC layer and RLC layer are shown in table below.

Generic Name	Parameter			
	Requeté	Indication	Résponse	Confirm
MAC-DATA	Data, BO, UE-ID type indicator, RLC Entity Info	Data, No_TB, TD (note), Error indication		
MAC-STATUS		No_PDU, PDU_Size, TX status, Status_Report_REQ	BO, RLC Entity Info	
NOTE: TDD only.				

MAC-DATA-Req/Ind:

- MAC-DATA-Req primitive is used to request that an upper layer PDU be sent using the procedures for the information transfer service;
- MAC-DATA-Ind primitive indicates the arrival of upper layer PDUs received within one transmission time interval by means of the information transfer service.

MAC-STATUS-Ind/Resp:

- MAC-STATUS-Ind primitive indicates to RLC for each logical channel the rate at which it may transfer data to MAC. Parameters are the number of PDUs that can be transferred in each transmission time interval and the PDU size; it is possible that MAC would use this primitive to indicate that it expects the current buffer occupancy of the addressed logical channel in order to provide for optimized TFC selection on transport channels with long transmission time interval. At the UE, MAC-STATUS-Ind primitive is also used to indicate from MAC to RLC that MAC has requested data transmission by PHY (i.e. PHY-DATA-REQ has been submitted, see Fig. 11.2.2.1), or that transmission of an RLC PDU on RACH or CPCH has failed due to exceeded preamble ramping cycle counter.
- MAC-STATUS-Resp primitive enables RLC to acknowledge a MAC-STATUS-Ind. It is possible that RLC would use this primitive to indicate that it has nothing to send or that it is in a suspended state or to indicate the current buffer occupancy to MAC.

Parameters in primitives between MAC and RLC

a) Data: It contains the RLC layer messages (RLC-PDU) to be transmitted, or the RLC layer messages that have been received by the MAC sub-layer.

b) Number of transmitted transport blocks (No_TB) : indicates the number of transport blocks transmitted by the peer entity within the transmission time interval, based on the TFI value.

c) Buffer Occupancy (BO): the parameter Buffer Occupancy (BO) indicates for each logical channel the amount of data in number of bytes that is available for transmission and retransmission in RLC layer. When MAC is connected to an AM RLC entity, control PDUs to be transmitted and RLC PDUs outside the RLC Tx window shall also be included in the BO. RLC PDUs that have been transmitted but not negatively acknowledged by the peer entity shall not be included in the BO.

d) RX Timing Deviation (TD), TDD only: it contains the RX Timing Deviation as measured by the physical layer for the physical resources carrying the data of the Message Unit. This parameter is optional and only for Indication. It is needed for the transfer of the RX Timing Deviation measurement of RACH transmissions carrying CCCH data to RRC.

e) Number of PDU (No_PDU): specifies the number of PDUs that the RLC is permitted to transfer to MAC within a transmission time interval.

f) PDU Size (PDU_Size): specifies the size of PDU that can be transferred to MAC within a transmission time interval.

g) UE-ID Type Indicator: indicates the UE-ID type to be included in MAC for a DCCH and DTCH when they are mapped onto a common transport channel (i.e. FACH, RACH, DSCH in FDD or CPCH). On the UE side UE-ID Type Indicator shall always be set to C-RNTI.

h) TX status: when set to value "transmission unsuccessful" this parameter indicates to RLC that transmission of an RLC PDU failed in the previous Transmission Time Interval, when set to value "transmission successful" this parameter indicates to RLC that the requested RLC PDU(s) has been submitted for transmission by the physical layer.

i) RLC Entity Info: indicates to MAC the configuration parameters that are critical to TFC selection depending on its mode and the amount of data that could be transmitted at the next TTI. This primitive is meant to insure that MAC can perform TFC selection (see sub clause 11.4).

j) Error indication: When a MAC SDU is delivered to upper layer, an error indication is given for the SDU to upper layer if an error indication for the SDU has been received from lower layer.

k) Status_Report_REQ: indicates to all AM RLC entities mapped on HS-DSCH to generate a status report when the MAC-hs resets.

Primitives between MAC and RRC

The primitives between MAC and RRC are shown in table below.

Generic Name	Parameter			
	Request	Indication	Response	Confirm
CMAC-CONFIG	UE information elements,			

	RB information elements, TrCH information elements, RACH transmission control elements, Ciphering elements, CPCH transmission control elements			
CMAC-MEASUREMENT	Measurement information elements	Measurement result		
CMAC-STATUS		Status info		

CMAC-CONFIG-Req:

- CMAC-CONFIG-Req is used to request for setup, release and configuration of a logical channel, e.g. RNTI allocation, switching the connection between logical channels and transport channels, TFCS update or scheduling priority of logical channel.

CMAC-MEASUREMENT-Req/Ind:

- CMAC-MEASUREMENT-Req is used by RRC to request MAC to perform measurements, e.g. traffic volume measurements;
- CMAC-MEASUREMENT-Ind is used to notify RRC of the measurement result.

CMAC-STATUS-Ind:

- CMAC-STATUS-Ind primitive notifies RRC of status information.

Parameters in primitives between MAC and RRC

a) UE information elements: S-RNTI, SRNC identity, C-RNTI, Activation time

b) RB information elements: RB multiplexing info (Transport channel identity, Logical channel identity, MAC logical channel priority)

c) TrCH information elements: Transport Format Combination Set, MAC-hs reset indicator, Re-ordering release timer (T1)

d) Measurement information elements: Reporting Quantity identifiers Time interval to take an average or a variance (applicable when Average or Variance is Reporting Quantity)

e)Measurement result: Reporting Quantity

f) Status info: when set to value ""transmission unsuccessful"" this parameter indicates to RRC that transmission of a TM RLC PDU failed (due to e.g. Maximum number of preamble ramping cycles reached for RACH in FDD), when set to value "transmission successful" this parameter indicates to RRC that the requested TM RLC PDU(s) has been submitted for transmission by the physical layer.

g) RACH transmission control elements: Set of ASC parameters (identifier for PRACH partitions, persistence values), Maximum number of preamble ramping cycles (FDD) or synchronization attempts (1.28 Mcps TDD), Minimum and maximum number of time units between two preamble ramping cycles, NBO1min and NBO1max (FDD only), ASC for RRC CONNECTION REQUEST message

h) Ciphering elements: Ciphering mode, Ciphering key, Ciphering sequence number

i) CPCH transmission control elements: CPCH persistency value, P for each Transport Format, Maximum number of preamble ramping cycles N_access_fails, NF_max (Maximum number of frames for CPCH transmission for each Transport Format), N_EOT (Number of EOT for release of CPCH transmission), Backoff control timer parameters, Transport Format Set, Initial Priority Delays, Channel Assignment Active indication

Elements for peer-to-peer communication

Protocol data units

General

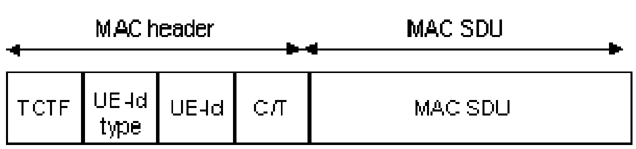
A MAC PDU is a bit string, with a length not necessarily a multiple of 8 bits. Generally the bit string is to be read from left to right and then in the reading order of the lines.

Depending on the provided service, MAC SDUs are bit strings with any non-null length, or bit strings with an integer number of octets in length. An SDU is included into a MAC PDU from first bit onward.

In the UE for the uplink, all MAC PDUs delivered to the physical layer within one TTI are defined as Transport Block Set (TBS). It consists of one or several Transport Blocks, each containing one MAC PDU. The Transport Blocks, shall be transmitted in the order as delivered from RLC. When multiplexing of RLC PDUs from different logical channels is performed on MAC, the order of all Transport Blocks originating from the same logical channel shall be the same as the order of the sequence delivered from RLC. The order of the different logical channels in a TBS is set by the MAC protocol.

MAC PDU (non-HS-DSCH)

A MAC PDU consists of an optional MAC header and a MAC Service Data Unit (MAC SDU) see figure below.



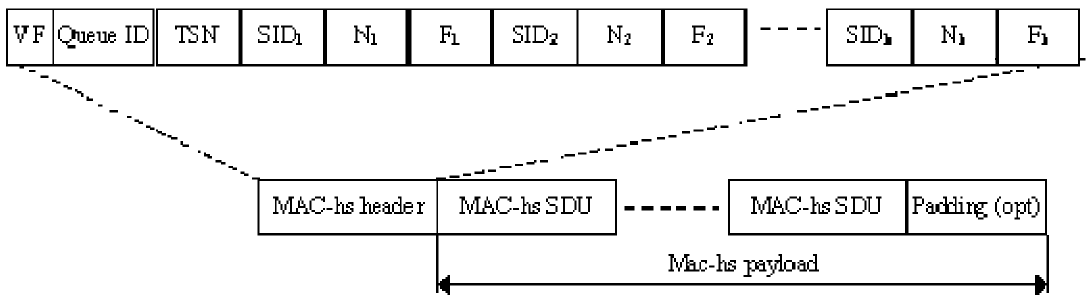
Both the MAC header and the MAC SDU are of variable size. The content and the size of the MAC header depends on the type of the logical channel, and in some cases none of the parameters in the MAC header are needed. The size of the MAC-SDU depends on the size of the RLC-PDU, which is defined during the setup procedure.

MAC-d PDU (HS-DSCH)

For HS-DSCH the MAC-d PDU format equals the MAC PDU format for the non HS-DSCH case.

MAC PDU (HS-DSCH)

In case of HS-DSCH a MAC PDU consists of one MAC-hs header and one or more MAC-hs SDUs where each MAC-hs SDU equals a MAC-d PDU. A maximum of one MAC-hs PDU can be transmitted in a TTI per UE. The MAC-hs header is of variable size. The MAC-hs SDUs in one TTI belongs to the same reordering queue.



Formats and parameters NOTE: MAC header field encodings as specified in this clause with designation "Reserved" are forbidden to be used by a sender in this version of the protocol.

MAC PDU: Parameters of the MAC PDU header (non HS-DSCH) and MAC-d PDU header (HS-DSCH)

The following fields are defined for the MAC header for transport channels other than HS-DSCH and for the MAC-d PDU header for HS-DSCH:

- Target Channel Type Field: The TCTF field is a flag that provides identification of the logical channel class on FACH and RACH transport channels, i.e. whether it carries BCCH, CCCH, CTCH, SHCCH or dedicated logical channel information. The size and coding of TCTF for FDD and TDD are shown in tables 1, 2, 3, 4 and 5. Note that the size of the TCTF field of FACH for FDD is either 2 or 8 bits depending of the value of the 2 most significant bits and for TDD is either 3 or 5 bits depending on the value of the 3 most significant bits. The TCTF of the RACH for TDD is either 2 or 4 bits depending on the value of the 2 most significant bits.

Table 1: Coding of the Target Channel Type Field on FACH for TDD

TCTF	Designation
000	BCCH
001	CCCH
010	CTCH
01100	DCCH or DTCH over FACH
01101-01111	Reserved (PDUs with this coding will be discarded by this version of the protocol)
100	SHCCH

101-111	Reserved (PDUs with this coding will be discarded by this version of the protocol)

Table 2: Coding of the Target Channel Type Field on FACH for FDD

TCTF	Designation
00	BCCH
01000000	CCCH
01000001- 01111111	Reserved (PDUs with this coding will be discarded by this version of the protocol)
10000000	CTCH
10000001- 10111111	Reserved (PDUs with this coding will be discarded by this version of the protocol)
11	DCCH or DTCH over FACH

Table 3: Coding of the Target Channel Type Field on USCH or DSCH (TDD only)

TCTF	Designation
0	SHCCH
1	DCCH or DTCH over USCH or DSCH

Table 4: Coding of the Target Channel Type Field on RACH for FDD

TCTF	Designation
00	CCCH
01	DCCH or DTCH over RACH
10-11	Reserved (PDUs with this coding will be discarded by this version of the protocol)

Table 5: Coding of the Target Channel Type Field on RACH for TDD

TCTF	Designation
00	CCCH
0100	DCCH or DTCH Over RACH
0101- 0111	Reserved (PDUs with this coding will be discarded by this version of the protocol)
10	SHCCH
11	Reserved (PDUs with this coding will be discarded by this version of the protocol)

- C/T field: The C/T field provides identification of the logical channel instance when multiple logical channels are carried on the same transport channel (other than HS-DSCH) or same MAC-d flow (HS-DSCH). The C/T field is used also to provide identification of the logical channel type on dedicated transport channels and on FACH and RACH when used for user data transmission. The size of the C/T field is fixed to 4 bits for both common transport channels and dedicated transport channels. Table below shows the 4-bit C/T field.

Table : Structure of the C/T field

C/T field	Designation
0000	Logical channel 1
0001	Logical channel 2
...	...
1110	Logical channel 15
1111	Reserved (PDUs with this coding will be discarded by this version of the protocol)

- UE-Id: The UE-Id field provides an identifier of the UE on common transport channels. The following types of UE-Id used on MAC are defined:
    - UTRAN Radio Network Temporary Identity (U-RNTI) may be used in the MAC header of DCCH using RLC UM (SRB1), when mapped onto common transport channels in downlink direction; the U-RNTI is never used in uplink direction;
    - Cell Radio Network Temporary Identity (C-RNTI) is used on DTCH and DCCH in uplink, and may be used on DCCH in downlink and is used on DTCH in downlink when mapped onto common transport channels, except when mapped onto DSCH transport channel;
    - In FDD, DSCH Radio Network Temporary Identity (DSCH-RNTI) is used on DTCH and DCCH in downlink when mapped onto DSCH transport channel;- the UE id to be used by MAC is configured through the MAC control SAP. The lengths of the UE-id field of the MAC header are given in table below.

Table : Lengths of UE Id field

UE Id type	Length of UE Id field
U-RNTI	32 bits
C-RNTI	16 bits
DSCH-	16 bits

RNTI	

- UE-Id Type: The UE-Id Type field is needed to ensure correct decoding of the UE-Id field in MAC Headers.

Table : UE-Id Type field definition

UE-Id Type field 2 bits	UE-Id Type
00	U-RNTI
01	C-RNTI or DSCH-RNTI
10	Reserved (PDUs with this coding will be discarded by this version of the protocol)
11	Reserved (PDUs with this coding will be discarded by this version of the protocol)

MAC header for DTCH and DCCH (not mapped on HS-DSCH)

a) DTCH or DCCH mapped to DCH, no multiplexing of dedicated channels on MAC: no MAC header is required.

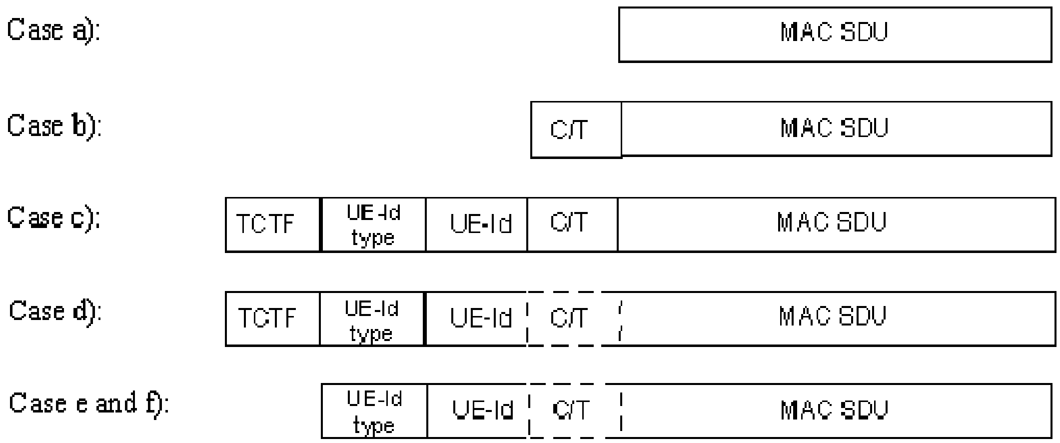
b) DTCH or DCCH mapped to DCH, with multiplexing of dedicated channels on MAC: C/T field is included in MAC header.

c) DTCH or DCCH mapped to RACH/FACH: TCTF field, C/T field, UE-Id type field and UE-Id are included in the MAC header. For FACH, the UE-Id type field used is the C-RNTI or U-RNTI. For RACH, the UE-Id type field used is the C-RNTI.

d) DTCH or DCCH mapped to DSCH or USCH: the TCTF field is included in the MAC header for TDD only. The UE-Id type and UE-Id are included in the MAC header for FDD only. The UE-Id type field used is the DSCH-RNTI. The C/T field is included if multiplexing on MAC is applied.

e) DTCH or DCCH mapped to DSCH or USCH where DTCH or DCCH are the only logical channels: the UE-Id type and UE-Id are included in the MAC header for FDD only. The UE-Id type field used is the DSCH-RNTI. The C/T field is included in the MAC header if multiplexing on MAC is applied.

f) DTCH or DCCH mapped to CPCH: UE-Id type field and UE-Id are included in the MAC header. The C/T field is included in the MAC header if multiplexing on MAC is applied. The UE-Id type field used is the C-RNTI.



MAC PDU formats for DTCH and DCCH

MAC-d Header for DTCH and DCCH (mapped on HS-DSCH)

The MAC-d PDU header for DTCH and DCCH mapped on HS-DSCH is as shown in figure below.

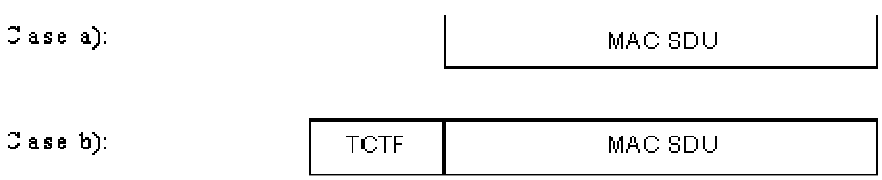
C/T field is included in the MAC-d PDU header if multiplexing on MAC is applied.

MAC-d PDU format for DTCH and DCCH mapped on HS-DSCH

MAC header for BCCH

a) BCCH mapped to BCH: no MAC header is included.

b) BCCH mapped to FACH: the TCTF field is included in MAC header.



MAC PDU formats for BCCH

MAC header for PCCH

There is no MAC header for PCCH.

MAC header for CCCH

CCCH mapped to RACH/FACH: TCTF field is included in MAC header.

TCTF	MAC SDU

MAC PDU formats for CCCH

MAC Header for CTCH

The TCTF field is included as MAC header for CTCH as shown in figure below.

TCTF	MAC SDU

MAC PDU format for CTCH

MAC Header for SHCCH

The MAC header for SHCCH is as shown in figure below.

Case a):	TCTF	MAC SDU
Case b):		MAC SDU

MAC PDU format for SHCCH

a) SHCCH mapped to RACH and USCH/FACH and DSCH: TCTF has to be included.

b) SHCCH mapped to RACH and USCH/FACH and DSCH, where SHCCH is the only channel.

MAC PDU: Parameters of the MAC header (HS-DSCH)

- Version Flag (VF): The VF field is a one bit flag providing extension capabilities of the MAC-hs PDU format. The VF field shall be set to zero and the value one is reserved in this version of the protocol.
- Queue identifier (Queue ID): The Queue ID field provides identification of the reordering queue in the receiver, in order to support independent buffer handling of data belonging to different reordering queues. The length of the Queue ID field is 3 bit.
- Transmission Sequence Number (TSN): The TSN field provides an identifier for the transmission sequence number on the HS-DSCH. The TSN field is used for reordering purposes to support in-sequence delivery to higher layers. The length of the TSN field is 6 bit.
- Size index identifier (SID): The SID fields identifies the size of a set of consecutive MAC-d PDUs. The MAC-d PDU size for a given SID is configured by higher layers and is independent for each Queue ID. The length of the SID field is 3 bit.
- Number of MAC-D PDUs (N): The number of consecutive MAC-d PDUs with equal size is identified with the N field. The length of the N field is 7 bits. In FDD mode, the maximum number of PDUs transmitted in a single TTI shall be assumed to be 70. In 1.28 Mcps TDD mode, the maximum number of PDUs transmitted in a single TTI shall be assumed to be 45. In 3.84 Mcps TDD mode, the maximum number of PDUs transmitted in a single TTI shall be assumed to be 318. If more PDUs than the defined maximum number of PDUs for the corresponding mode are received, the UE behavior is unspecified.

- Flag (F): The F field is a flag indicating if more fields are present in the MAC-hs header or not. If the F field is set to "0" the F field is followed by an additional set of SID, N and F fields. If the F field is set to "1" the F field is followed by a MAC-d PDU. The maximum number of MAC-hs header extensions, i.e. number of fields F set to "0", in a single TTI shall be assumed to be 7. If more extensions than the maximum defined for the corresponding mode are included in a TTI, the UE behavior is unspecified.

MAC header for DTCH and DCCH

a) DTCH or DCCH mapped to HS-DSCH: The Queue ID field and TSN field are always included in the MAC-hs header. One SID field, N field and F field is included for each MAC-d PDU size included in the MAC-hs PDU. Padding is not explicitly indicated but is included in the end of the MAC-hs PDU if the total size of the MAC-hs payload plus the MAC-hs header is smaller than the transport block set size.

Soft Handover (SHO)

Introduction:

Soft Handover is one of the most interesting feature of the WCDMA operation. In this case the UE always has radio link connection. In case of GSM only hard handover was possible where the radio connection is lost before new connection is established. In UMTS hard handover is also possible when we are changing frequencies but generally soft handover will be used when in the same frequency.

Hard handover is possible in the same frequency (Intra-frequency) scenario when RAB is being added and there are not enough codes available on the current cell then the network might ask the UE to move to new cell (scrambling code).

In this tutorial we will not mention Softer handover separately as it is a special case of Soft Handover. For more details please see Handover Tutorial. Softer handover will be referred to as Soft Handover in this document.

Please note that Soft handover procedure could include Radio link that belongs to the same Node

B, different Node B but the same RNC or a Node B that belongs to dirrent RNC (Drift RNC). For more details please see Handover Tutorial.

Also note that the Soft Handover procedures does not involve the Core Network. It just involves the RNC, Node B and the UE. The Soft Handover procedure is only applicable to UEs in FDD mode of operation.

Basic Definitions:

Before we begin there are some terms that need to be discussed. The UE measures the cells on the Intra Frequency in order for the network to decide which cells to add in the Active Set. An Active Set contains all the Cells that the UE is listening to and Transmitting to. The Cells that UE measures belong to one of the three categories:

1. Cells, which belong to the **active set**. User information is sent from all these cells. In FDD, the cells in the active set are involved in soft handover. The UE shall only consider active set cells included in the variable CELL_INFO_LIST for measurement; i.e. active set cells not included in the CELL_INFO_LIST shall not be considered in any event evaluation and measurement reporting.
2. Cells, which are not included in the active set, but are included in the CELL_INFO_LIST belong to the **monitored set**.
3. Cells detected by the UE, which are neither in the CELL_INFO_LIST nor in the active set belong to the **detected set**. Reporting of measurements of the detected set is only applicable to intra-frequency measurements made by UEs in CELL_DCH state.

Entering CELL_DCH:

When RRC Connection is setup, UE generally moves to CELL_DCH. This is based on the network configuration and it is the network that will decide if the UE has to enter CELL_DCH or CELL_FACH. For simplicity we assume that the network puts the UE in CELL_DCH. In CELL_DCH state UE generally starts with one Radio Link that belongs to its Active Set.

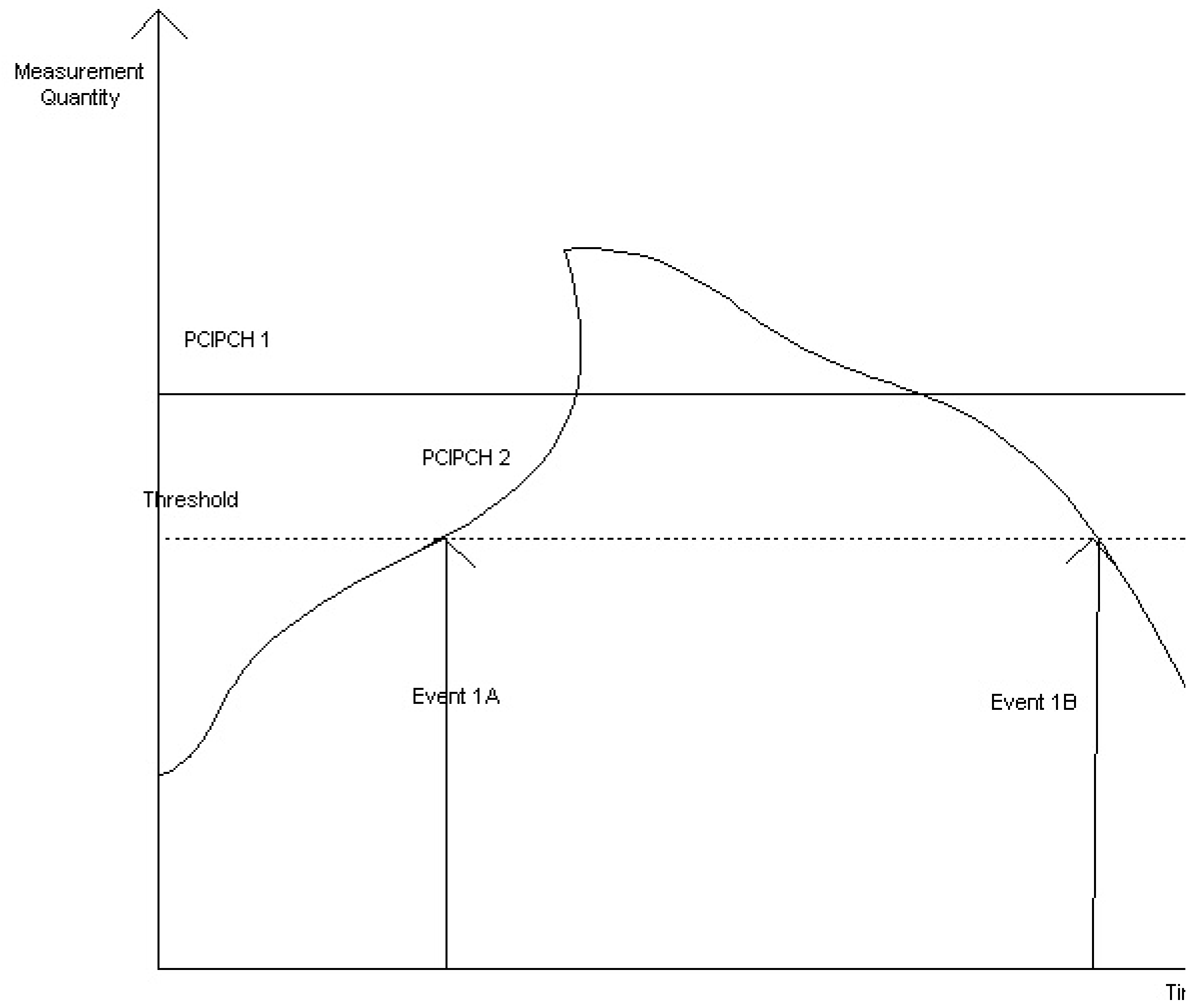
In CELL_DCH state UE will generally start Intra Frequency Measurements. These measurements are either setup via System Information broadcasted on BCH or through a Measurement Control Message (MCM).

The System Information Block Sib11/12 or MCM contains the Cell Info List that the UE has to store to perform measurements. All the cells in the Cell Info List are either in Active Set and if not in Active Set then they are in Monitored Set. The network might ask the UE to report Detected Cells. These are the cells that UE can see but were not sent in the Cell Info List. If asked then the UE reports them whenever Measurement Reports are sent out.

Intra-Frequency Measurements

These Measurements can be either Periodic or Event Based. For SHO, Event Based Measurements are generally used.

The Intra Frequency Measurement Events are from 1A to 1I. For SHO Event 1A, Event 1B and Event 1C are important. Event 1A and Event 1C could be periodic Event Based Measurements. In this case the network might ask that if an Event is trigerred than the UE should keep sending the report N number of times; where N is specified in the Measurement Control message or Sib11/12.

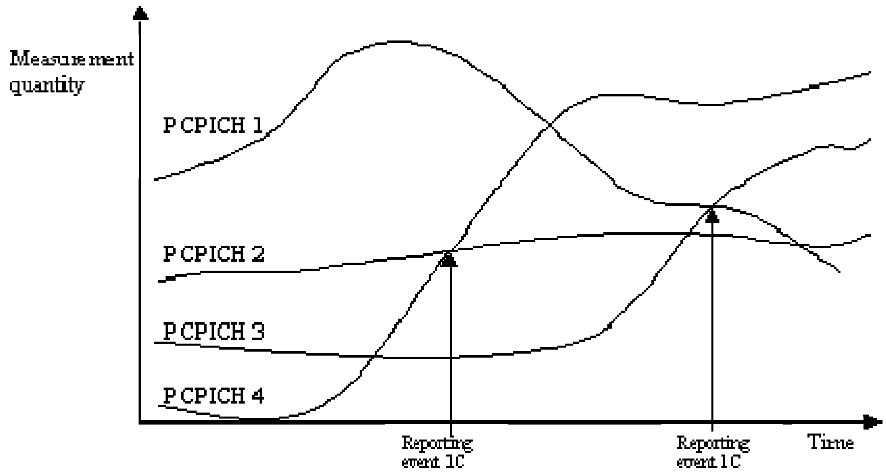


The figure above demonstrates a simple (cannot happen in practice though) scenario when Cell 1 has same power but Cell 2 has its power increasing till a certain point after which it decreases.

Now the Intra Frequency Event 1A notifies to UTRAN that a particular Cell has reached power level above the threshold. Similarly Event 1B notifies to UTRAN that a particular cell has power level below the threshold. For Event 1A (and 1C) UTRAN can request more than one report for a single event that has occurred. This is to make sure that only suitable cells are added to active list.

When Event 1A is sent to the UTRAN, UTRAN will add the new cell in the UE's active cell list and will send an ACTIVE SET UPDATE message that will add the cell to the UE's active set. Similarly when Event 1B is sent then UTRAN will send ACTIVE SET UPDATE message to remove the cell from UE's active set. When Event 1C is sent, UTRAN will send ACTIVE SET UPDATE message that will remove one or more cells and will add one or more cells. The only restriction for 1C is that there should be atleast one radio link that is not affected by the procedure. This radio link will exist before and after ACTIVE SET UPDATE message.

To avoid problems, Event 1B can only occur is there are more than one active radio links. Similarly there is an option available in the Measurement Criteria IE that deactivates Event 1A after certain number of cells are added in the active set. This is to avoid sending 1A and 1C for the same scenario. Similarly Event 1C only becomes applicable if there are more than one active radio links. The network can decide how many radio links are needed in active set for Event 1C triggering to start.



The figure above shows the scenario of triggering of Event 1C. In this case when the first Event 1C is triggered UTRAN sends ACTIVE SET UPDATE to add Cell 4 and delete Cell 2. Similarly when the second Event 1C is triggered Cell 1 is replaced by Cell 3.

Signaling Examples

Lets look at an example where Cell 2 has triggered Event 1A and the network decides to add it in the Active Set

```
  UE                                 Node B                          RNC
------                              ---------                     ----------
   |                                   |                               |
   |    RRC: Measurement Report (Event 1A: Cell 2)                     |
   |-------------------------------------------------------------------->|
   |                                   |  NBAP: RL Setup Request       |
   |                                   |<------------------------------|
   |                                   |                               |
   |                              Start RX                             |
   |                                   |     NBAP: RL Setup Response   |
   |                                   |------------------------------>|
   |                                   |   ALCAP: ERQ                  |
   |                                   |<------------------------------|
   |                                   |              ALCAP: ECF       |
   |                                   |------------------------------>|
   |                                   |         NBAP: RL Restore Ind  |
   |                                   |------------------------------>|
   |                                   |      DCH-FP: Downlink Sync    |
   |                                   |<------------------------------|
   |                                   |       DCH-FP: Uplink Sync     |
   |                                   |------------------------------>|
   |                                 Start TX                          |
   |   RRC: Active Set Update          |                               |
   |<--------------------------------------------------------------------|
   |        (add Cell 2)               |                               |
   |                        RRC: Active Set Update Complete            |
   |-------------------------------------------------------------------->|
   |                                   |                               |
   |                                   |                               |
```

Similarly suppose Cell 2 has now triggered Event 1B and UTRAN decides that Cell 2 has to be removed than the signaling flow will be as follows:

```
  UE                               Node B                             RNC
------                           ---------                        ----------
   |                                  |                                |
   |    RRC: Measurement Report (Event 1B: Cell 2)                     |
   |------------------------------------------------------------------>|
   |   RRC: Active Set Update         |                                |
   |<------------------------------------------------------------------|
   |        (remove Cell 2)           |                                |
   |                          RRC: Active Set Update Complete          |
   |------------------------------------------------------------------>|
   |                                  |                                |
   |                                  | NBAP: RL Deletion Req          |
   |                                  |<-------------------------------|
   |                                  |     NBAP: RL Deletion Resp     |
   |                                  |------------------------------->|
   |                                  |  ALCAP: REL                    |
   |                                  |<-------------------------------|
   |                                  |                   ALCAP: RLC   |
   |                                  |------------------------------->|
   |                                  |                                |
   |                                  |                                |
```

The signaling for Event 1C will be combination of the above.

CAMEL: An Introduction

Introduction

Customized Applications for Mobile network Enhanced Logic also known as CAMEL was developed as a standard for mobile intelligence across different vendor equipments for GSM network. What this means is that the end user should be able to roam between different networks (maybe in different countries) and be reachable at the same number and should receive only one bill from the original service provider (Home Operator).

Before CAMEL, the GSM networks used INAP (Intelligent Network Application Part) for injecting intelligence in GSM networks. The limitations of INAP was that it did not support mobility management. CAMEL solved the mobility management problem and provided with much more functionality. With the evolution of 3G standards, CAMEL has evolved to provide new functionalities that will be discussed later.

CAMEL has been divided into Phases. The last section in this primer lists the functionality of each phases. The latest Phase is Phase 4. If an IPLMN (Interrogating PLMN) or VPLMN (Visiting PLMN) supports CAMEL Phase 4, it shall also provide the functionality of all previous CAMEL phases.

The first commercial implementation of CAMEL (phase 1) was in August 2000 by France Telecom Mobiles (France), Mobistar (Belgium) and Dutchtone (The Netherlands).

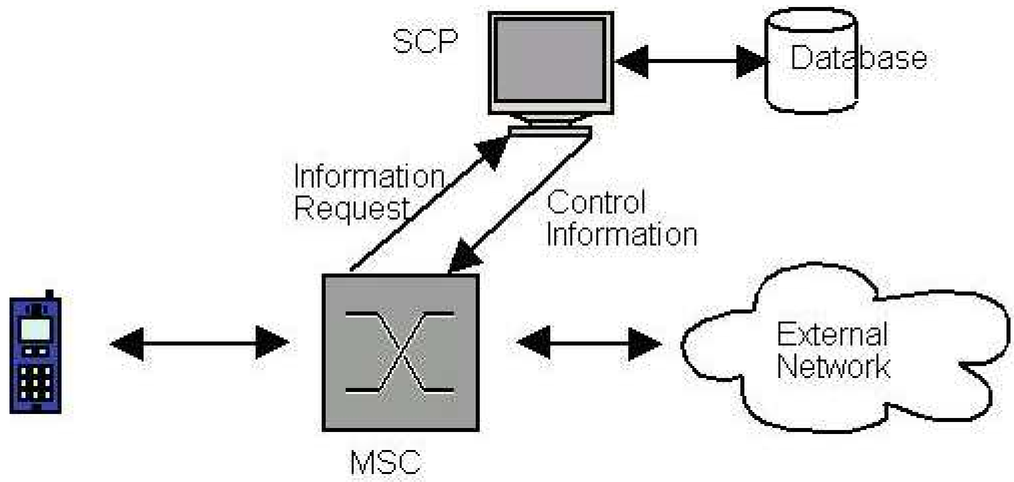
NOTE: CAMEL feature is a network feature and not a supplementary service. It is a tool to help the network operator

Applicability of CAMEL procedures

- The CAMEL feature is applicable to Mobile Originated and Mobile Terminated Call Related Activities. CAMEL procedures are applicable to all circuit switched basic services without distinction (except Emergency calls).
- The CAMEL feature is applicable to Supplementary Services Invocation
- CAMEL procedures are applicable to GPRS sessions and PDP contexts
- CAMEL procedures are applicable to Mobile Originating/Terminating short message service through both circuit switched and packet switched serving network entities
- CAMEL procedures are applicable to IP multimedia services (except Emergency calls) to support legacy services
- CAMEL shall support IPMM sessions which are based on the same charging paradigm as CS/PS calls. This applies most probably to VoIP and Video over IP.
- CAMEL procedures are applicable to IP multimedia sessions addressed by either E.164 numbers or SIP URLs.

Example of CAMEL procedure

Before we proceed further and use more technical terms, it would be wise to understand CAMEL procedure with the help of some examples.



Take a simple scenario of a voice call being made. When a subscriber starts to make a call, this request is received by the network's Mobile Switching Centre (MSC). The MSC then sends a message that 'queries' the SCP's database. Note that the essential element of any CAMEL solution is a Service Control Point (SCP). This unit effectively hosts a database which holds the instructions needed for an intelligent application.

The SCP processes that query, comes up with an appropriate response and then sends a message back to the MSC telling what action it should take with the subscriber's request for a specific service. The call is then connected in the most appropriate manner, a process which is transparent to the customer. A very good example of this process in action is short code dialing over a VPN (Virtual Private Network) where the user calls a colleague's internal extension telephone number but is, in fact, routed to that person's mobile phone which is roaming abroad.

The main addition in CAMEL phase 2 which phase 1 omitted is support for a Specialized Resource Function (SRF) a component most often found in Voice Response Units (VRUs). For example, when an account balance reaches zero for a pre-paid customer under phase 1, the customer will simply be cut off. With phase 2 thanks to support for SRF, the customer will hear automatically generated messages from the Voice Response Unit warning that the balance is dangerously low before a call and even during the call. Naturally this leads to greater customer satisfaction.

Technical Terms

For any further discussions we would need to use some technical terms. They are discussed in this section.

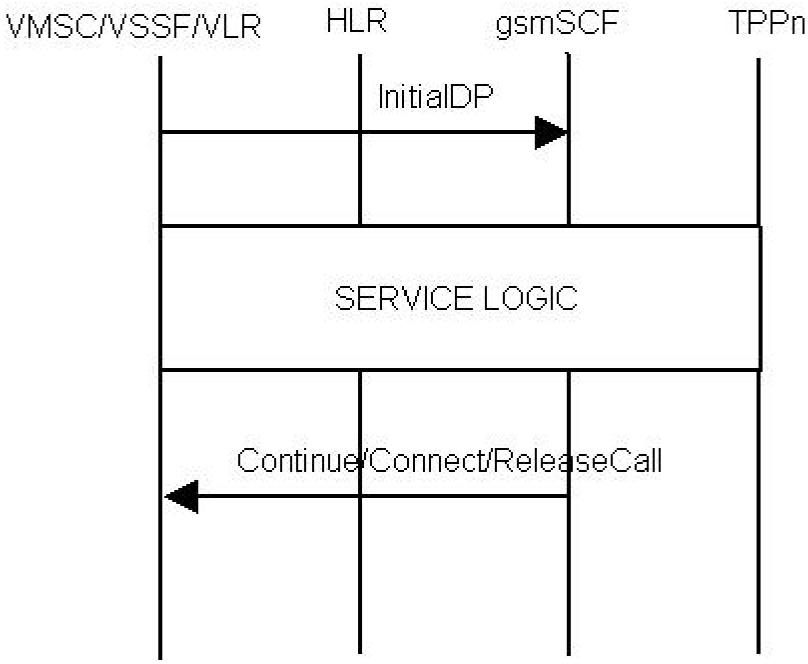
- **Interrogating PLMN (IPLMN)**: The PLMN that interrogates the Home PLMN (HPLMN) for information to handle mobile terminating call.

- **CAMEL Service Environment (CSE)**: A CSE is a logical entity which processes activities related to Operator Specific Services (OSS).
- **CAMEL Subscription Information (CSI)**: Identifies that CAMEL support is required for the subscriber and the identities of the CSEs to be used for that support.
- **Service Control Function (SCF)**: SCF contains the actual independent service logic to apply to the call.
- **Basic Call State Model (BCSM)**: BSCM represents an abstract view of call processing, seen from the perspective of service feature control performed by the SCF. The BCSM consists of two sets of call processing logic, Originating BCSM (O-BCSM) and Terminating BCSM (T-BCSM).
- **Points in Call (PIC)**: PIC are defined by standards to represent those points in which action might be taken. They provide a view of a state or event in which call processing logic may initiate an action, such as suspension of call processing while a database is queried.
- **Detection Points (DP)**: DP represent transitional events that occur between some PICs.
- **Triggers**: A trigger is the term used to define specific call-processing logic associated with a given point in call. Triggers are nothing more than software logic that is loaded in a network element to carry out instructions to initiate an intelligent network process based on analysis of conditions at a detection point.
- **Events**: Unlike a trigger, which depends on some form of input criteria, an event is simply a call occurrence such as no answer, busy signal or call termination.
- **Arming of detection points**: Detection points have two classifications: Trigger Detection Points (TDP) and Event Detection Point (EDP). A detection point is armed if control logic is established to initiate service control based on a trigger or event.
- **GSM Service Control Function (gsmSCF)**: functional entity that contains the CAMEL service logic to implement OSS. It interfaces with the gsmSSF, the gsmSRF, the GMLC and the HLR.
- **GSM Service Switching Function (gsmSSF)**: functional entity that interfaces the MSC or GMSC to the gsmSCF. The concept of the gsmSSF is derived from the IN SSF, but uses different triggering mechanisms because of the nature of the mobile network.
- **GSM Specialized Resource Function (gsmSRF)**: functional entity which provides various specialized resources. It interfaces with the gsmSCF and with the MSC.

Examples of Signaling procedures

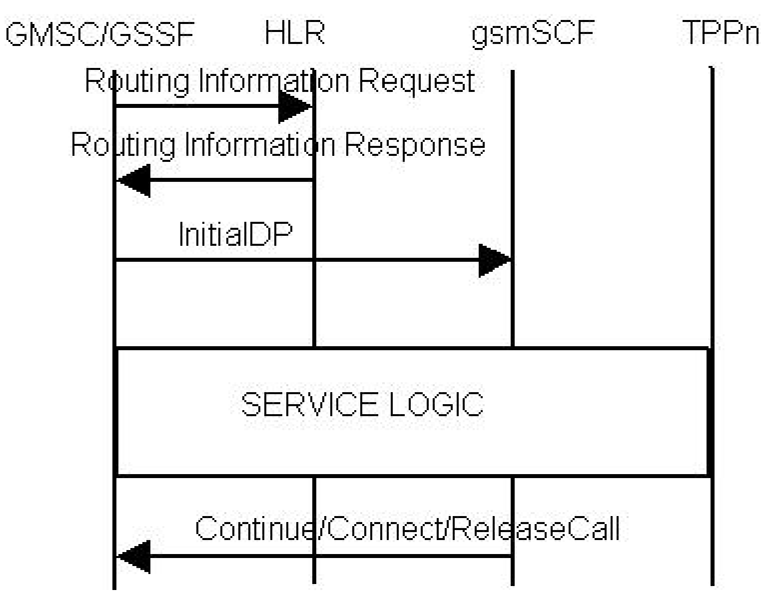
[13] Gives example of Signaling procedures using CAMEL for originating and terminating calls and has been described below.

Mobile Originating Calls:



If an active originating CAMEL Subscription Information (CSI) is found in the VLR during the call set up of a MS, the Visited Service Switching Function (VSSF) sends an Initial Detection Point message to the gsmSCF and the VMSC suspends the call processing. The Initial Detection Point shall always contain the service key, called and calling party number, calling party's category, location number, bearer capability, event type Basic Call State Model (BCSM), location information and the International Mobile Station Identity (IMSI). After the service logic processing CAMEL specific handling is initiated from the gsmSCF, see figure above.

Mobile Terminating Calls:



In the case of mobile terminating call, the Gateway MSC (GMSC) in the interrogating PLMN identifies the HLR of the called party with the help of the MSISDN. Then the GMSC sends a Routing Information-Request to the HLR. The HLR checks the CSI of the called party and sends the information stored in the subscriber record back to the GMSC. Now, the GMSC acts according to CSI. If the terminating CSI is active the trigger criteria of a Detection Point (DP) is fulfilled and the call processing is suspended. An Initial DP message, which shall always contain the service key, called party number, event type BCSM and the IMSI is sent to the CSE and the service logic execution is started. Thereafter CAMEL specific handling is initiated, see figure above.

Contents of each CAMEL Phase

CAMEL phase 1:

1.1 CAMEL phase 1 functionality:

Functionality	*Purpose / supports*	*Restrictions*
Triggering on MO, MT and forwarded calls.	• Call screening • Simple VPN • Call Forwarding • Call Redirection • Call Rerouting • Homing of pre-paid calls to HPLMN	• No IN announcements supported • No charging operations • Limited set of detection points, e.g. the hunting services are not possible. • MT calls trigger in the GMSC only. • Not possible to activate Call Forwarding's with VPN short codes.
Any Time Interrogation	• The CSE may request HLR to provide subscriber status and/or location information at any time.	• The exact location may not be up-to-date unless the mobile has an active call ongoing. • CS only

CAMEL phase 2:

2.1 CAMEL phase 2 functionality:

Functionality	*Purpose / supports*	*Restrictions*
Triggering on MO, MT and forwarded calls.	• Call screening • VPN for calls • Call Forwarding • Call Redirection • Call Rerouting • Follow-on calls • In-band user interaction (DTMF) • Tones and announcements	• MT calls trigger in the GMSC only.

Charging operations	• Pre-paid (MO, MT, CF) • Free-phone • Premium rate • Personal Discount • Location Dependent discount • Reverse Charging	-
CSE provided e-parameters	• MO AoC	-
New detection points (Abandon, Busy, Not Reachable, No Answer, Route Select Failure cases)	• Cleaner termination of relationship. • Better pre-paid service. • Hunting type of services.	-
Triggering criteria	• To reduce CSE & SSP load	-
Any Time Interrogation	• The CSE may request HLR to provide subscriber status and/or location information at any time.	• The exact location may not be up-to-date unless the mobile has an active call ongoing. • No call supervision
USSD communication between MS and CSE	• USSD call-back for pre-paid roaming • Control & enquiry of IN services	
Control of north American carrier information	• Enhances pre-paid • CSE based carrier selection • Selecting correct long distance network for user interaction	
Notification of supplementary service (CCBS, ECT, CD and MPTY) invocation to CSE	• Fraud control	

3 CAMEL phase 3:

3.1 CAMEL phase 3 functionality:

Functionality	Purpose / supports	Restri
Triggering on MO, MT and forwarded calls.	• Call screening • Full VPN • Call Forwarding • Call Redirection • Call Rerouting • Follow-on calls • In-band user interaction (DTMF)	

	• Tones and announcements	
Charging operations	• Pre-paid (MO, MT, CF) • Free-phone • Premium rate • Personal Discount • Location Dependent discount • Reverse Charging	
CSE provided e-parameters		
CAMEL2 new detection points (Abandon, Busy, Not Reachable, No Answer, Route Select Failure cases)	• Cleaner termination of relationship. • Better pre-paid service. • Hunting type of services.	
CAMEL3 new trigger detection points.	• To trigger on demand only, e.g. for hunting services.	
Triggering criteria	• To reduce CSE & SSP load	
Any Time Interrogation. Enhanced with CAMEL3 current location retrieval, and ATI for GMLC.	• The CSE may request HLR to provide subscriber status and/or location information at any time.	•
USSD communication between MS and CSE	• USSD call-back for pre-paid roaming • Control & enquiry of IN services	
Control of north American carrier information	• Enhances pre-paid • CSE based carrier selection • Selecting correct long distance network for user interaction	
Notification of supplementary service (CCBS, ECT, CD and MPTY) invocation to CSE	• Fraud control	
Call Gapping	• To control CSE overload situations within HPLMN	•
MT call triggering in VMSC-B	• To control MT supplementary services (CW, hold, CF, CD, ECT, MPTY) • Pre-paid for MT air-time charge (1st minute free, e.g. in USA)	
Abandon as an EDP-R	• Improves charging	
Enhanced Free Format Charging data (40 octets -> 160 octets)	• Makes the CSE service logic easier	
Reporting of MSRN/FTN to CSE	• Charging control of optimally routed calls	

CSE-HLR interface: ATM/ATSI/NSDC	• Multiple Subscriber Profile phase 2 • CSE can control CF, barring supplementary services. • Off-line subscription control based on VPLMN / time-of-day • Virtual operators	
Subscribed dialed services (D-CSI)	• HPLMN specific service numbers	•
Serving Network Dialed services (N-CSI)	• VPLMN specific service numbers	•
MO SMS control (CS+PS)	• Enhances pre-paid. • Enhances VPN	• •
Inter-working with GPRS	• GPRS pre-paid	•
CS Mobility management notifications	• CSE can monitor location / reachability	
Service Interaction Indicators	• CSE can control inter-working with supplementary services (CW, hold, CF, CD, ECT, MPTY). • Multiple subscriber profile phase 2	

CAMEL phase 4:

4.1 CAMEL phase 4 functionality in Release 5:

Functionality	Purpose / supports	Restrictions
Triggering on MO, MT and forwarded calls.	• Call screening • Full VPN • Call Forwarding • Call Redirection • Call Rerouting • Follow-on calls • In-band user interaction (DTMF) • Tones and announcements	
Charging operations	• Pre-paid (MO, MT, CF) • Free-phone • Premium rate • Personal Discount • Location Dependent discount • Reverse Charging	
CSE provided e-parameters	• MO & MT AoC	
CAMEL2 new detection points (Abandon, Busy, Not	• · Cleaner termination of relationship. • · Better pre-paid service.	

Reachable, No Answer, Route Select Failure cases)	• · Hunting type of services.	
CAMEL3 new trigger detection points.	• · To trigger on demand only, e.g. for hunting services.	
Triggering criteria	• · To reduce CSE & SSP load	
Any Time Interrogation. Enhanced with CAMEL3 current location retrieval, and ATI for GMLC. CAMEL4 enhances this to PS domain.	• The CSE may request HLR to provide subscriber status and/or location information at any time. • ATI for GMLC	
USSD communication between MS and CSE	• USSD call-back for pre-paid roaming • Control & enquiry of IN services	
Control of north American carrier information	• Enhances pre-paid· • CSE based carrier selection • Selecting correct long distance network for user interaction	
Notification of supplementary service (CCBS, ECT, CD and MPTY) invocation to CSE	• · Fraud control	
Call Gapping	• · To control CSE overload situations within HPLMN	For CS calls only. Not for SMS or GPRS.
MT call triggering in VMSC-B	• · To control MT supplementary services (CW, hold, CF, CD, ECT, MPTY) • · Pre-paid for MT air-time charge (1st minute free, e.g. in USA)	
Abandon as an EDP-R	• · Improves charging	
Enhanced Free Format Charging data (40 octets -> 160 octets)	• · Makes the CSE service logic easier	
Reporting of MSRN/FTN to CSE	• · Charging control of optimally routed calls	
CSE-HLR interface: ATM/ATSI/NSDC	• Multiple Subscriber Profile phase 2 • CSE can control CF, barring supplementary services. • Off-line subscription control based on VPLMN / time-of-day • Virtual operators	

Subscribed dialed services (D-CSI)	• · HPLMN specific service numbers	· No call supervision
Serving Network Dialed services (N-CSI)	• · VPLMN specific service numbers	· No call supervision
SMS control (CS+PS)	• · Enhances pre-paid. • · Enhances VPN	· Not content based
Inter-working with GPRS	• · GPRS pre-paid	· Not content based
CS Mobility management notifications	• · CSE can monitor location / reachability	
Service Interaction Indicators	• · CSE can control inter-working with supplementary services (CW, hold, CF, CD, ECT, MPTY). • · Multiple subscriber profile phase 2	
Interactions with Optimal Routing	• · CSE can control usage of OR	
Call Party Handling	• Wake-up calls • Conference calling • Parallel hunting • Click-to dial • IN based CCBS	
Mid call procedure for MO and MT calls	• Control CPH configuration during call. • Automatic call collect	
CAMEL for IMS	• IMS pre-paid • Convergence to CS and GPRS services	
Inclusion of flexible tone injection	• Enhancements of pre-paid warning tones • Various informative tones	
	•	
Provision of location information of called subscriber (Alerting phase)	• The location of B-subscriber at the beginning of the call provided to service logic	
Notification of GPRS mobility management to CSE	• CSE can monitor location / reachability in PS side	
Inclusion of ODB data in the CSE-HLR interface	• Enhancement of MSP ph 2	
Location information during an ongoing call (Handover DP)	• Charging based on current location, for inter-PLMN and/or inter-system handovers	

Transfer of the IMEI (with software version) and MS class mark to the CSE	• allow the gsmSCF to determine information about the capabilities of the ME	
Any Time Interrogation from CSE to MNP-SRF	• Number portability query for prepay calls	
Partial implementation of CAMEL phase 4	• A functional entity (VMSC, GMSC or SGSN) may support the complete CAMEL phase4 functionality or, as a network option, it may support the complete CAMEL phase3 functionality and a partial implementation of CAMEL phase4.	

4.2 CAMEL phase 4 additions in Release 6

Enhancements of Dialed Services	·Full control of Dialed Services	
Full CAMEL4 prepay support for SCUDIF	·The capability to report basic service code changes during ongoing call.	
Change of position procedure armed with criteria	· Technical enhancement to reduce the signaling load	

High Speed Downlink Packet Access (HSDPA): A Tutorial

Introduction:

HSDPA is a major Release 5 feature. Some of the enhancements will be done in Release 6. HSDPA is designed to support data rates up to 10.8 Mbps and at the same time it will co-exist with R99 in the same frequency band of 5MHz. As could be observed this data rate is much higher than the Broadband speeds people generally use in their homes (512Kbps download). HSDPA will be able to satisfy the most demanding Multimedia applications.

The peak rate offered by HSDPA is about 10Mbps in 5MHz channel. One important thing to note is that the more important thing here is not the peak rate but the throughput capacity which increases significantly. This leads to more users being able to use high data rates on a single carrier.

What’s New in HSDPA:

3 Slot TTI (2ms)

CQI: Channel Quality Indication

AMC: Adaptive Modulation and Coding

Constellation Re-Arranging (16 QAM)

H-ARQ: Hybrid Automatic Repeat Request

N-channel SAW: N-Channel Stop and Wait Protocol

New MAC (High Speed) instance

New Stuff for HSDPA:

The implementation of HSDPA will require changes mainly in Physical layer. Layer 2 will be affected as well because new high speed MAC entity will be required. The impact to other layers will be minimum. The following sections will throw some light on some of the new features required for HSDPA.

HSDPA Physical and Transport Channels:

To support HSDPA new Physical channels have been defined:

HS-PDSCH or High Speed Physical Downlink Shared Channel: This is a downlink channel which is both time and code multiplexed. The channelization codes have a fixed spreading factor, SF = 16. Multi-code transmissions are allowed that translates to UE being assigned multiple channelization codes in the same TTI, depending on the UE capability. The same scrambling code sequence is applied to all the channelization codes that form the single HS-DSCH CCTrCH. If there are multiple UE's then they may be assigned channelization codes in the same TTI (multiplexing of multiple UE's in the code domain).
HS-DPCCH or High Speed Dedicated Physical Control Channel: This is an uplink channel

that carries the Acknowledgements of the packet received on HS-PDSCH and also the CQI (Channel Quality Indication). THE CQI estimates have to be transmitted by the UE every 2.0 ms frame. This information is very important as it ensures reliability and impacts power capacity. **HS-SCCH or High Speed Shared Control Channel:** The HS-SCCH is a fixed rate (60 kbps, SF=128) downlink physical channel used to carry downlink signaling related to HS-DSCH transmission. This provides timing and coding information thus allowing the UE to listen to the HS-DSCH at the correct time and using the correct codes to allow successful decoding of UE data.

The main features of the physical channel are as follows:

Fixed Spreading Factor of 16 for HS-DSCH

QPSK and 16 QAM Modulation

Static TTI Length of 3 Time Slots = 2ms

Fixed CRC of 24 bits

Error Correction using 1/3 Turbo Coding

To support HSDPA the following new Transport channels have been defined:
HS-DSCH or High Speed Downlink Shared channel: The High Speed Downlink Shared Channel is a downlink transport channel shared by several UEs. The HS-DSCH is associated with one downlink DPCH, and one or several Shared Control Channels (HS-SCCH). The HS-DSCH is transmitted over the entire cell or over only part of the cell using e.g. beam-forming antennas.

Adaptive Modulation and Coding (AMC):

HSPDA standard ensures that highest possible data rate is achieved for all users regardless of whether they are close to the base station or far off. This is done using ACM. For HS-DSCH, the transport format, including the modulation scheme and code rate, can be selected based on the downlink channel quality. The selection of transport format is done by the MAC-HS located in Node B and is based on channel quality feedback reported by the UE. The spreading factor cannot change but the coding rate can change between 1/4 and 3/4. The higher coding rate reduces the number of errors. Also the standards support multicodes. This means that up to 15 codes can be allocated to a UE.

Hybrid Automatic Repeat Request (HARQ):

In case of ARQ, the receiving system on receipt of data checks the CRC. If the CRC is the same as that received in the message ACK is sent back to the sender. In case if CRC does not match then NACK is sent back and the packet discarded. In case of HARQ, this method of CRC checking is improved based on the following two things.

Chase Combining: In this when an error is detected in CRC, NACK is sent back but the packet is not discarded. It is stored. In case the re-transmitted packet is again erroneous then the previous and current packet is combined in an attempt to recover from errors. Each time the packet is resent, the same scheme is applied. Eventually the error will be either resolved or maximum number of retries is reached. In that case higher layer protocols will deal with the error.

Incremental Redundancy (IR): IR is similar to Chase combining but the redundant information that was not transmitted earlier is also included to improve the chances of reception without errors or with enough errors removed so as to allow combining with the previously stored packet and resolve the errors.

Fast Cell Site Selection (FCSS):

When the UE moves between the cells, it is possible that it would be served by different cells. Hence the UE will construct a list of Active Set (the term Active Set is incorrect and the term that will be used eventually is "Eligible Set") Cells that it can use at any one time. The mobile will indicate on HS-DPCCH as to which one is the best cell for DL transmission. The serving cell then decides the modulation and coding scheme to be used for the mobile and in addition may code multiplex multiple mobiles within that HSDPA frame. To Simplify this procedure, it is further subdivided into Intra-Node B FCS and Inter-Node FCS.

High Speed Uplink Packet Access (HSUPA)

Introduction:

High Speed Uplink Packet Access (HSUPA) is a release 6 feature in 3GPP specifications and is part of HSPA (High Speed Packet Access) family. HSUPA is more often called as the Enhanced Uplink Dedicated Channel (E-DCH) by the technically aware people. The main aim of HSUPA is to increase the uplink data transfer speed in the UMTS environment and it offers data speeds of up to 5.8 Mbps in the uplink. HSUPA achieves its high performance through more efficient uplink scheduling in the base station and faster retransmission control.

Requirements:

HSUPA was designed based on the following requirements

- The Enhanced Uplink feature shall aim at providing significant enhancements in terms of user experience (throughput and delay) and/or capacity. The coverage is an important aspect of the user experience and that it is desirable to allow an operator to provide for consistency of performance across the whole cell area.
- The focus shall be on urban, sub-urban and rural deployment scenarios.
- Full mobility shall be supported, i.e., mobility should be supported for high-speed cases also, but optimization should be for low-speed to medium-speed scenarios.
- The study shall investigate the possibilities to enhance the uplink performance on the dedicated transport channels in general, with priority to streaming, interactive and background services. Relevant QoS mechanisms shall allow the support of streaming, interactive and background PS services.
- It is highly desirable to keep the Enhanced Uplink as simple as possible. New techniques or group of techniques shall therefore provide significant incremental gain for an acceptable complexity. The value added per feature/technique should be considered in the evaluation. It is also desirable to avoid unnecessary options in the specification of the feature.
- The UE and network complexity shall be minimized for a given level of system performance.
- The impact on current releases in terms of both protocol and hardware perspectives shall be taken into account.
- It shall be possible to introduce the Enhanced Uplink feature in a network which has terminals from Release'99, Release 4 and Release 5. The Enhanced Uplink feature shall enable to achieve significant improvements in overall system performance when operated together with HSDPA. Emphasis shall be given on the potential impact the new feature may have on the downlink capacity. Likewise it shall be possible to deploy the Enhanced Uplink feature without any dependency on the deployment of the HSDPA feature. However, a terminal supporting the Enhanced Uplink feature must support HSDPA.

Abbreviations:

It would be important to remember following abbreviations before proceeding:

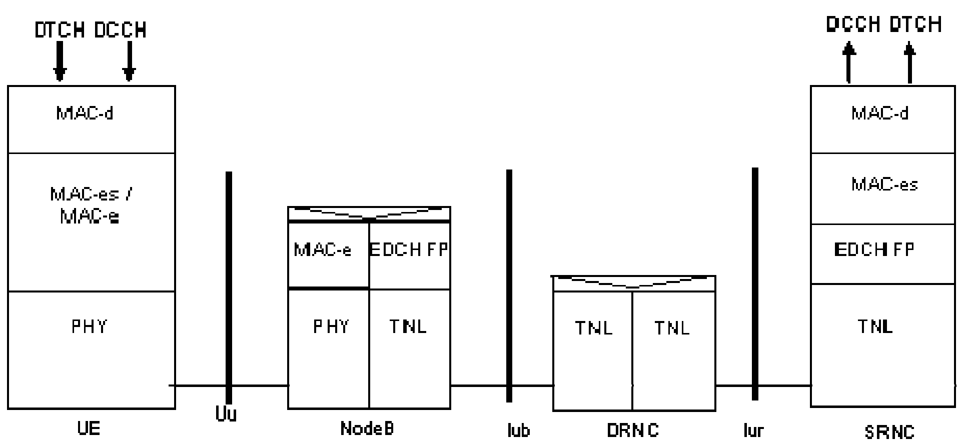
- AG: Absolute Grant
- E-AGCH: E-DCH Absolute Grant Channel
- E-DCH: Enhanced Dedicated Channel
- E-DPCCH: E-DCH Dedicated Physical Control Channel
- E-DPDCH: E-DCH Dedicated Physical Data Channel

- E-HICH: E-DCH Hybrid ARQ Indicator Channel
- E-RGCH: E-DCH Relative Grant Channel
- E-RNTI: E-DCH Radio Network Temporary Identifier
- E-TFC: E-DCH Transport Format Combination
- HARQ: Hybrid Automatic Repeat Request
- HSDPA: High Speed Downlink Packet Access
- RG: Relative Grant
- RLS: Radio Link Set
- RSN: Retransmission Sequence Number
- SG: Serving Grant
- TSN: Transmission Sequence Number

HSUPA General Features

- Maximum transmission rate of 5.76Mbps
- BPSK modulation
- No adaptive modulation
- Multicode transmission
- Spreading Factor either 2 or 4
- 10ms and 2ms TTI but initially only 10ms TTI to be used.
- Hybrid ARQ (HARQ)
- Fast Packet Scheduling in the uplink
- Soft Handover supported

Protocol Architecture of E-DCH



The following modifications to the existing nodes are needed to support enhanced uplink DCH:

UE: A new MAC entity (MAC-es/MAC-e) is added in the UE below MAC-d. MAC- es/MAC-e in the UE handles HARQ retransmissions, scheduling and MAC-e multiplexing, E-DCH TFC selection.

Node B: A new MAC entity (MAC-e) is added in the Node B to handle HARQ retransmissions, scheduling and MAC-e demultiplexing.

S-RNC: A new MAC entity (MAC-es) is added in the SRNC to provide in-sequence delivery (reordering) and to handle combining of data from different Node Bs in case of soft handover.

HSUPA Physical Layer categories

The following E-DCH UE categories are defined in the specifications:

HSUPA category	Maximum number of HSUPA codes transmitted	Minimum spreading factor	Support for 10 and 2 ms HSUPA TTI	Maximum number of bits transmitted within a 10 ms HSUPA TTI	Maximum number of bits transmitted within a 2 ms HSUPA TTI	Maximum Bit rate
Category 1	1	SF4	10 ms TTI only	7296	-	0.73 Mbps
Category 2	2	SF4	10 ms and 2 ms TTI	14592	2919	1.46 Mbps
Category 3	2	SF4	10 ms TTI only	14592	-	1.46 Mbps
Category 4	2	SF2	10 ms and 2 ms TTI	20000	5837	2.92 Mbps
Category 5	2	SF2	10 ms TTI only	20000	-	2.00 Mbps
Category 6	4	SF2	10 ms and 2 ms TTI	20000	11520	5.76 Mbps

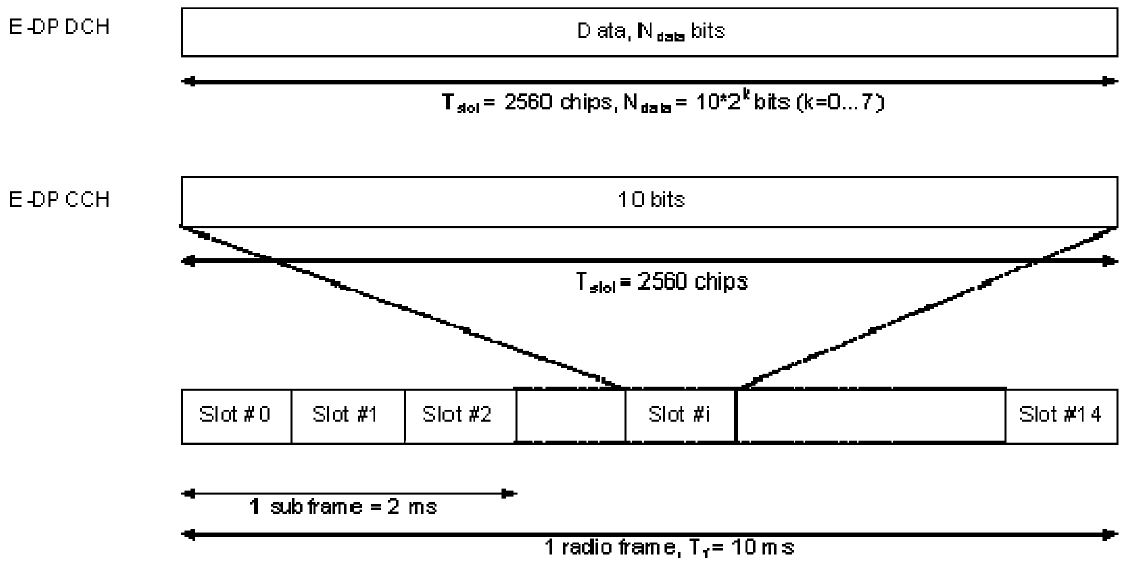
New Channels

Dedicated transport channel

E-DCH - Enhanced Dedicated Channel: The Enhanced Dedicated Channel (E-DCH) is an uplink transport channel.

Uplink Dedicated Physical channels

E-DPCCH and E-DPDCH:



The E-DPDCH is used to carry the E-DCH transport channel. There may be zero, one, or several E-DPDCH on each radio link. The E-DPCCH is a physical channel used to transmit control information associated with the E-DCH. There is at most one E-DPCCH on each radio link.

E-DPDCH and E-DPCCH are always transmitted simultaneously, except for the case that E-DPDCH but not E-DPCCH is DTXed due to power scaling. E-DPCCH shall not be transmitted in a slot unless DPCCH is also transmitted in the same slot.

Figure above shows the E-DPDCH and E-DPCCH (sub)frame structure. Each radio frame is divided in 5 sub frames, each of length 2 ms; the first sub frame starts at the start of each radio frame and the 5th sub frame ends at the end of each radio frame. The E-DPDCH slot formats, corresponding rates and number of bits are specified in Table A. The E-DPCCH slot format is listed in Table B.

Table A: E-DPDCH slot formats

Slot Format #i	Channel Bit Rate (kbps)	SF	Bits/ Frame	Bits/ Sub frame	Bits/Slot (Ndata)
0	15	256	150	30	10
1	30	128	300	60	20
2	60	64	600	120	40
3	120	32	1200	240	80
4	240	16	2400	480	160
5	480	8	4800	960	320
6	960	4	9600	1920	640

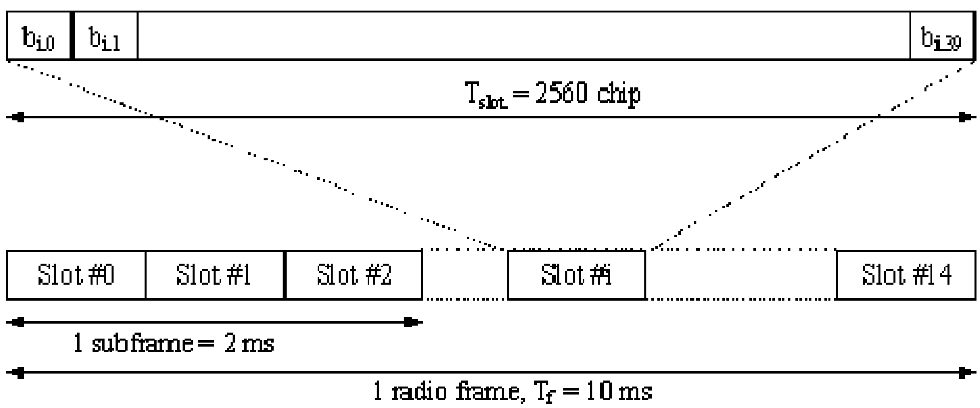
7	1920	2	19200	3840	1280

Table B: E-DPCCH slot formats

Slot Format #i	Channel Bit Rate (kbps)	SF	Bits/ Frame	Bits/ Subframe	Bits/Slot (Ndata)
0	15	256	150	30	10

Downlink Dedicated Physical channels

E-DCH Relative Grant Channel (E-RGCH):

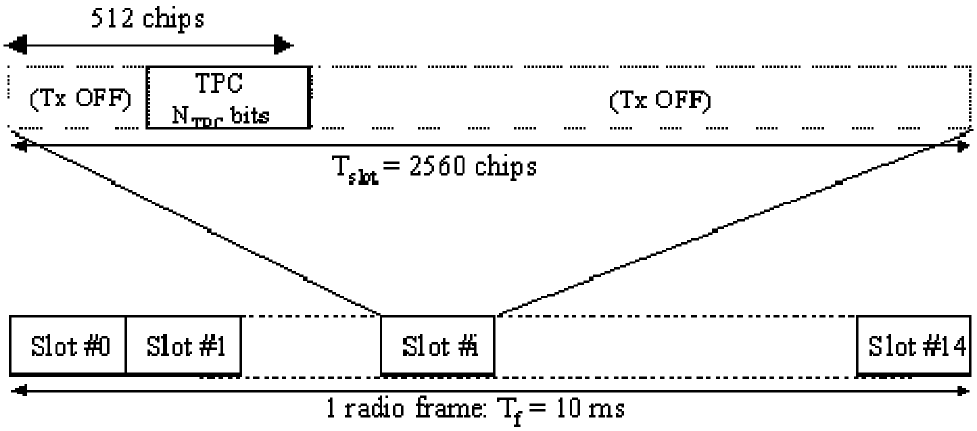


The E-DCH Relative Grant Channel (E-RGCH) is a fixed rate (SF=128) dedicated downlink physical channel carrying the uplink E-DCH relative grants. Figure above illustrates the structure of the E-RGCH. A relative grant is transmitted using 3, 12 or 15 consecutive slots and in each slot a sequence of 40 ternary values is transmitted. The 3 and 12 slot duration shall be used on an E-RGCH transmitted to UEs for which the cell transmitting the E-RGCH is in the E-DCH serving radio link set and for which the E-DCH TTI is respectively 2 and 10 ms. The 15 slot duration shall be used on an E-RGCH transmitted to UEs for which the cell transmitting the E-RGCH is not in the E-DCH serving radio link set.

E-DCH Hybrid ARQ Indicator Channel (E-HICH):

The E-DCH Hybrid ARQ Indicator Channel (E-HICH) is a fixed rate (SF=128) dedicated downlink physical channel carrying the uplink E-DCH hybrid ARQ acknowledgement indicator. Figure above (same as E-RGCH) illustrates the structure of the E-HICH. A hybrid ARQ acknowledgement indicator is transmitted using 3 or 12 consecutive slots and in each slot a sequence of 40 binary values is transmitted. The 3 and 12 slot duration shall be used for UEs which E-DCH TTI is set to respectively 2 ms and 10 ms.

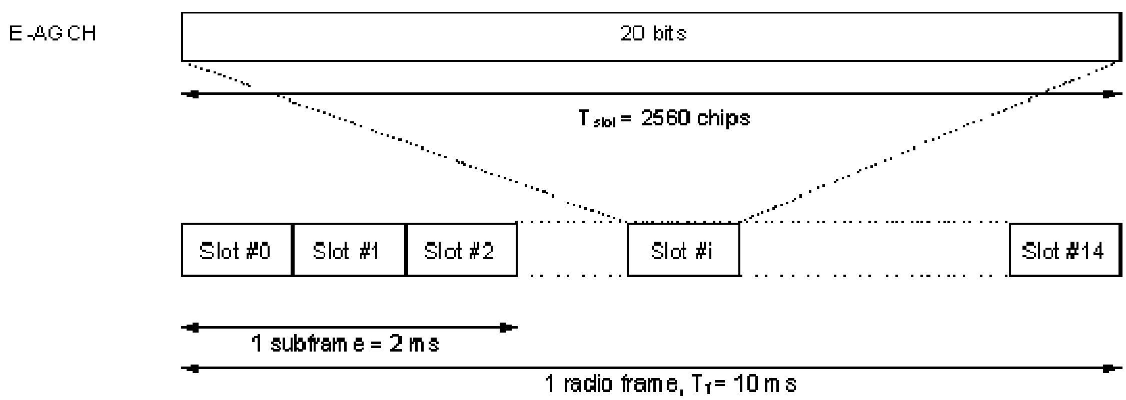
Fractional Dedicated Physical Channel (F-DPCH):



The F-DPCH carries control information generated at layer 1 (TPC commands). It is a special case of downlink DPCCH. Figure above shows the frame structure of the F-DPCH. Each frame of length 10ms is split into 15 slots, each of length Tslot = 2560 chips, corresponding to one power-control period. There are 2 bits/slot.

Common downlink physical channels

E-DCH Absolute Grant Channel (E-AGCH):



The E-DCH Absolute Grant Channel (E-AGCH) is a fixed rate (30 kbps, SF=256) downlink physical channel carrying the uplink E-DCH absolute grant. Figure above illustrates the frame and sub-frame structure of the E-AGCH. An E-DCH absolute grant shall be transmitted over one E-AGCH sub-frame or one E-AGCH frame. The transmission over one E-AGCH sub-frame and over one E-AGCH frame shall be used for UEs for which E-DCH TTI is set to respectively 2 ms and 10 ms.

HARQ protocol

General Principle

The HARQ protocol has the following characteristics:

- Stop and wait HARQ is used;
- The HARQ is based on synchronous downlink ACK/NACKs;
- The HARQ is based on synchronous retransmissions in the uplink:
    - The number of processes depends on the TTI: 8 processes for the 2ms TTI and 4

processes for the 10ms TTI. For both scheduled and non-scheduled transmission for a given UE, it is possible to restrict the transmission to specific processes for the 2ms E-DCH TTI;

  - There will be an upper limit to the number of retransmissions. The UE decides on a maximum number of transmissions for a MAC-e PDU based on the maximum number of transmissions attribute (see subclause 11.1.1), according to the following principles:
    - The UE selects the highest 'maximum number of transmissions' among all the considered HARQ profiles associated to the MAC-d flows in the MAC-e PDU.
  - Pre-emption will not be supported by E-DCH (ongoing re-transmissions will not be pre-empted by higher priority data for a particular process);
  - In case of TTI reconfiguration, the MAC-e HARQ processes are flushed and no special mechanism is defined to lower SDU losses.
- Intra Node B macro-diversity and Inter Node B macro-diversity should be supported for the E-DCH with HARQ;
- Incremental redundancy shall be supported by the specifications with Chase combining as a subcase:
  - The first transmission shall be self decodable;
  - The UTRAN configures the UE to either use the same incremental redundancy version (RV) for all transmissions, or to set the RV according to set of rules based on E-TFC, Retransmission Sequence Number (RSN) and the transmission timing;
  - There shall be no need, from the H-ARQ operation point of view, to reconfigure the Node B from upper layers when moving in or out of soft handover situations.

Error handling

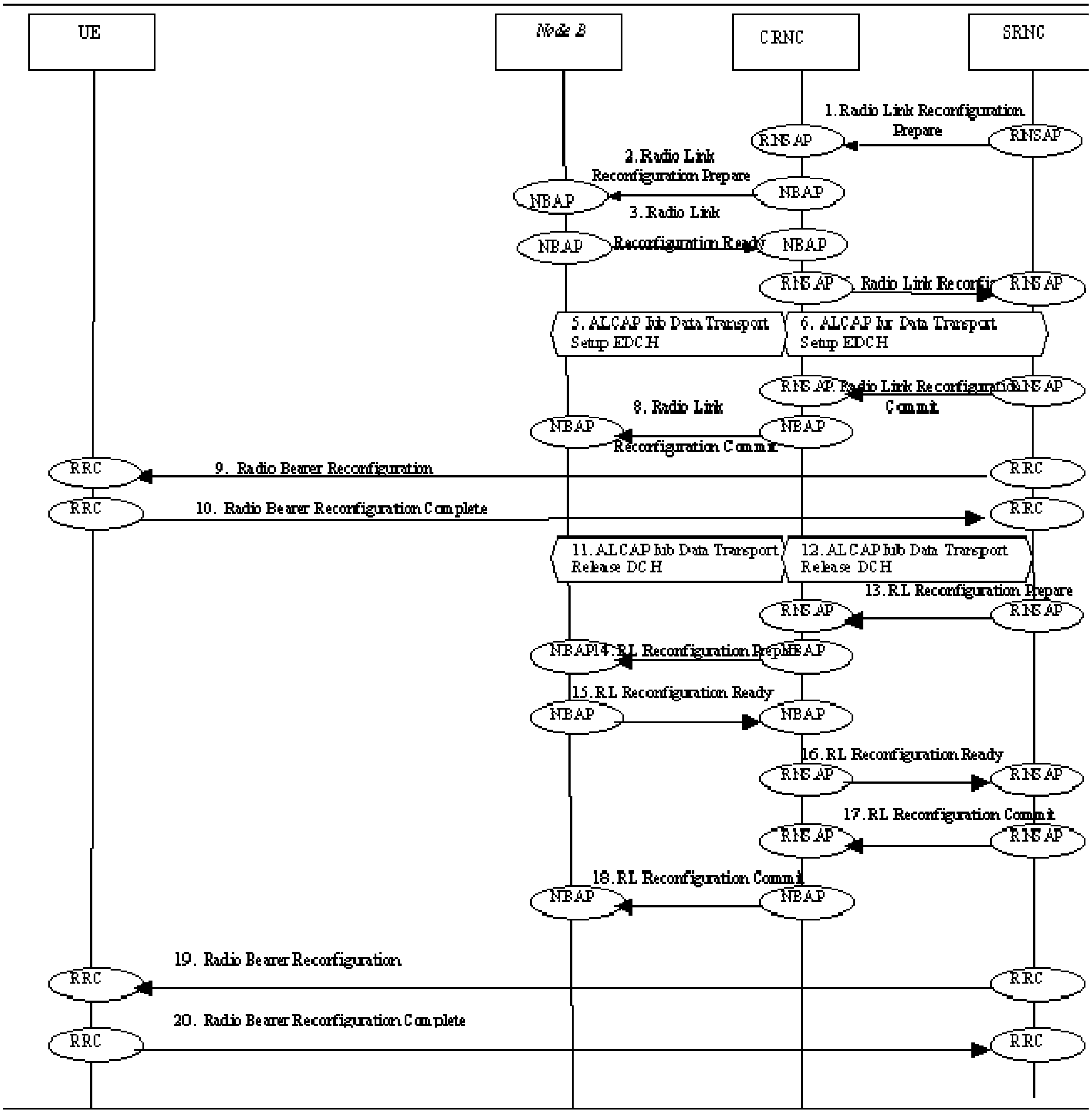
The most frequent error cases to be handled are the following:

- NACK is detected as an ACK: the UE starts afresh with new data in the HARQ process. The previously transmitted data block is discarded in the UE and lost. Retransmission is left up to higher layers;
- ACK is detected as a NACK: if the UE retransmits the data block, the NW will re-send an ACK to the UE. If in this case the transmitter at the UE sends the RSN set to zero, the receiver at the NW will continue to process the data block as in the normal case;
- Error cases have been identified regarding the HARQ operation during soft handover:
  - In case the HARQ control information transmitted on the E-DPCCH could not be detected RSN_max times in a row for one HARQ process, a soft buffer corruption might occur. Each HARQ process uses RSN and the transmission time (CFN, sub-frame) elapsed since storing data in the associated soft buffer in order to flush the soft buffer and to avoid a wrong combining of data blocks.
  - Duplication of data blocks may occur at the RNC during soft handover. The reordering protocol needs to handle the detected duplications of data blocks.

Signaling examples

E-DCH Establishment with TTI Reconfiguration

This scenario shows an example of E-DCH configuration. Also TTI reconfiguration is shown in the same scenario. It is assumed that in this example DCH was established before.



1. The SRNC decides there is a need for a establishing E-DCH for a UE and prepares the RNSAP message Radio Link Reconfiguration Prepare which is transmitted to the CRNC. Parameters: DCHs to Delete IE, E-DPCH Information (TFCS, TTI), Serving E-DCH RL ID, E-DCH FDD Information.
2. The CRNC requests the E-DCH Node B to perform a synchronized radio link reconfiguration using the NBAP message Radio Link Reconfiguration Prepare, for the E-DCH radio link. Parameters: DCHs to Delete IE, Service E-DCH RL ID, E-DCH FDD Information.
3. The E-DCH Node B returns a NBAP message Radio Link Reconfiguration Ready. Parameters: DCH Information Response , E-DCH FDD Information Response.
4. The CRNC returns the RNSAP message Radio Link Reconfiguration Ready to the SRNC. Parameters: DCH Information Response, E-DCH FDD Information Response.
5. The CRNC initiates set-up of a new Iub Data Transport Bearers using ALCAP protocol. This request contains the AAL2 Binding Identity to bind the Iub Data Transport Bearer to the E-DCH.
6. The SRNC initiates set-up of a new Iur Data Transport bearer using ALCAP protocol. This request contains the AAL2 Binding Identity to bind the Iur Data Transport Bearer to the E-DCH.
7. The SRNC proceeds by transmitting the RNSAP message Radio Link Reconfiguration Commit to

the CRNC.
Parameters: SRNC selected activation time in the form of a CFN.

8. The CRNC transmits the NBAP message Radio Link Reconfiguration Commit to the E-DCH Node B including the activation time.
Parameters: CRNC selected activation time in the form of a CFN.
9. The SRNC also transmits a RRC message Radio Bearer Reconfiguration to the UE.
Parameters: activation time, E-DCH Info and E-RNTI.
10. The UE returns a RRC message Radio Bearer Reconfiguration Complete to the SRNC.
11. The CRNC initiates release of the old Iub Data Transport bearer (DCH) using ALCAP protocol.
12. The SRNC initiates release of the old Iur Data Transport bearer (DCH) using ALCAP protocol.
13. The SRNC decides there is a need for a TTI reconfiguration and prepares the RNSAP message Radio Link Reconfiguration Prepare which is transmitted to the CRNC.
Parameters: E-DPCH Information (TTI).
14. The CRNC requests the E-DCH Node B to perform a synchronized radio link reconfiguration using the NBAP message Radio Link Reconfiguration Prepare, for the E-DCH radio link
15. The E-DCH Node B returns a NBAP message Radio Link Reconfiguration Ready.
Parameters: E-DCH FDD Information Response.
16. The CRNC returns the RNSAP message Radio Link Reconfiguration Ready to the SRNC.
Parameters: E-DCH FDD Information Response.
17. The SRNC proceeds by transmitting the RNSAP message Radio Link Reconfiguration Commit to the CRNC.
Parameters: SRNC selected activation time in the form of a CFN.
18. The CRNC transmits the NBAP message Radio Link Reconfiguration Commit to the E-DCH Node B including the activation time.
Parameters: CRNC selected activation time in the form of a CFN.
19. The SRNC also transmits a RRC message Radio Bearer Reconfiguration to the UE.
Parameters: activation time, E-DCH Info and E-RNTI.
20. The UE returns a RRC message Radio Bearer Reconfiguration Complete to the SRNC.

Multimedia Broadcast / Multicast Service

Introduction

Point to multipoint services exist today which allow data from a single source entity to be transmitted to multiple endpoints. These services are expected to be used extensively over wireless networks, hence there is a need for a capability in the PLMN to efficiently support them. The Multimedia Broadcast/Multicast Service (MBMS) will provide this capability for such broadcast/multicast services provided by the home environment and other VASPs.

MBMS is an IP data cast (IPDC) service that can be offered via existing UMTS and GSM networks. It would be possible for the user to interact with this service via an uplink channel. This feature causes this service to be more complicated as it is not as straightforward as a Unicast service like conventional digital television.

MBMS is a UMTS release 6 features and according to [1] it is already very popular with operators and equipment manufacturers. It is expected that Networks would be supporting MBMS by Q4, 2007 while UE's will be supporting MBMS by Q2, 2008. As per [1], 30% of UE's will be supporting MBMS by 2010. Release 6 was finalized in June 2005.

It is important to note that MBMS is not just a technology to preserve capacity or reduce costs - by providing an efficient means to reliably distribute multimedia content over 3G networks but also an opportunity for 3G network operators to deliver new and innovative revenue-generating services to their subscribers.

Difference between Broadcast and Multicast

BROADCAST	**MULTICAST**
Broadcast service is a unidirectional point-to-multipoint service in which data is transmitted from single source to multiple UE's in the associated broadcast area	Multicast service is a unidirectional point-to-multipoint service in which data is transmitted from single source to Multicast group in associated Multicast area.
These are push type services. The end user does not have to subscribe to be part of broadcast group	The end user has to be part of Multicast group to receive them.
No interaction possible	Interaction possible. In this case multicast users have a return channel for the interaction procedure.
They are free	They could be free or paid type.

Broadcast and Multicast before Release 6

To date, the following services (defined in R99 and R4) are available:

1. A cell broadcast service (CBS) [15, 16] allowing for low bit-rate data to be transmitted to

all subscribers in a set of given cells over a shared broadcast channel. This service offers a message-based service

2. An IP-Multicast service [13, 14] allowing for mobile subscribers to receive multicast traffic. This service does not allow for multiple subscribers to share radio or core network resources and as such does not offer any advantages as far as resource utilization within the PLMN and over the radio access network.

General Description of MBMS [2]

3GPP has defined two modes of operation of MBMS

- the broadcast mode
- the multicast mode

MBMS broadcast mode

The broadcast mode is a unidirectional point-to-multipoint transmission of multimedia data (e.g. text, audio, picture, video) from a single source entity to all users in a broadcast service area. The broadcast mode is intended to efficiently use radio/network resources e.g. data is transmitted over a common radio channel. Data is transmitted in the broadcast service area as defined by the network (Home environment). MBMS data transmission should adapt to different RAN capabilities or different radio resource availability, e.g. by reducing the bitrates of the MBMS data.

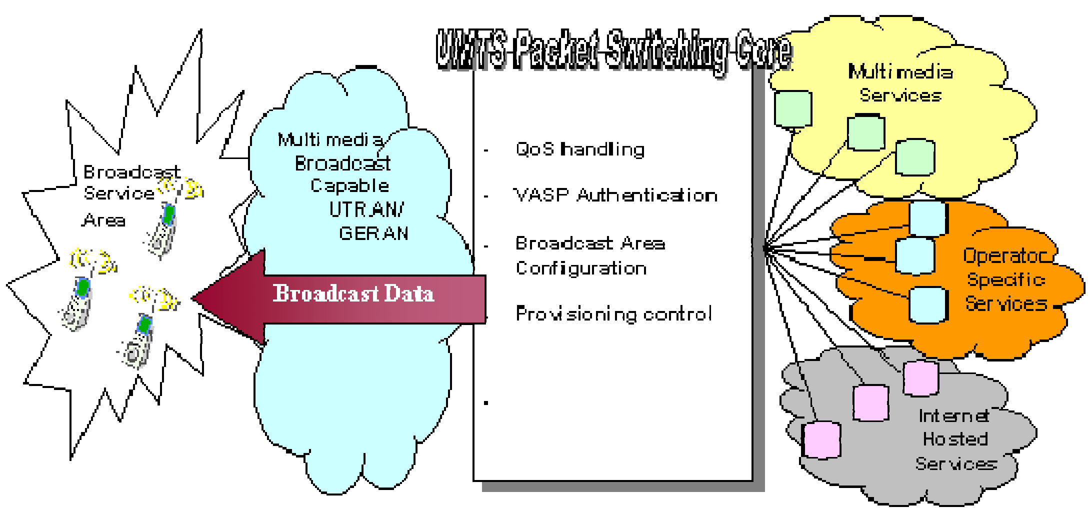


Figure above gives an example of how a network can be configured to broadcast a variety of high bit rate services to users within the associated broadcast service area. A broadcast service received by the UE, involves one or more successive broadcast sessions. A broadcast service might, for example, consist of a single on-going session (e.g. a media stream) or may involve several intermittent sessions over an extended period of time (e.g. messages).

The difference between the CBS of R99 and Broadcast of R6 is that CBS is used for low bit rate services (messaging) while the broadcast mode enables the broadcast of multimedia services (Audio, Video etc).

An example of a service using the broadcast mode could be advertising or a welcome message to the network. As not all users attached to the network may wish to receive these messages then the user shall be able to enable/disable the reception of these broadcast service on his UE. The broadcast mode differs from the multicast mode in that there is no specific requirement to activate or subscribe to the MBMS in broadcast mode.

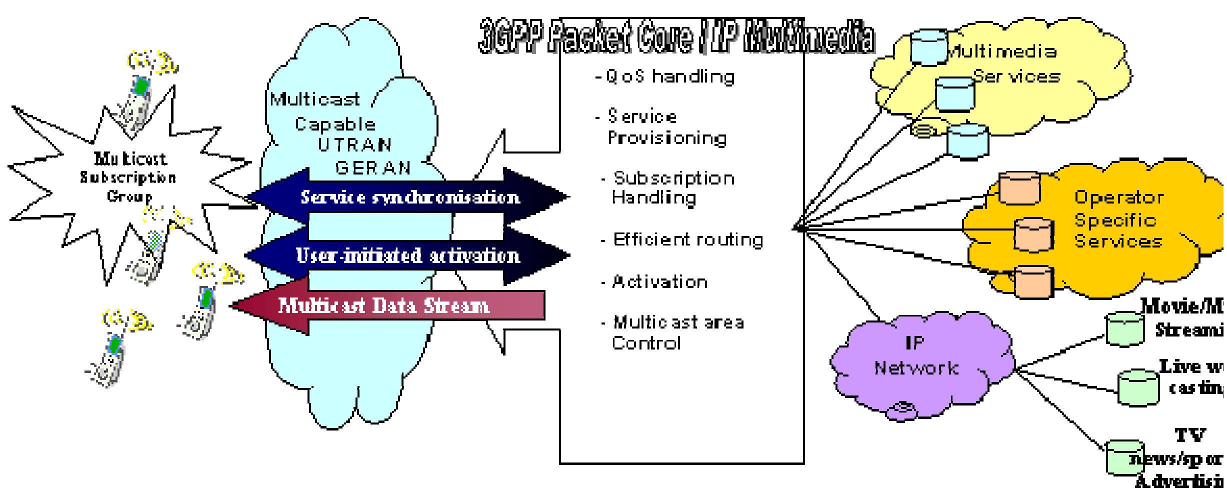
The broadcast mode should allow terminals to minimize their power consumption. It is expected that charging data for the end user will not be generated for this mode. The reception of the traffic in the broadcast mode is not guaranteed. The receiver may be able to recognize data loss.

MBMS multicast mode

The multicast mode allows the unidirectional point-to-multipoint transmission of multimedia data (e.g. text, audio, picture, video) from a single source point to a multicast group in a multicast service area. The multicast mode is intended to efficiently use radio/network resources e.g. data is transmitted over a common radio channel. Data is transmitted in the multicast service area as defined by the network (Home environment). In the multicast mode there is the possibility for the network to selectively transmit to cells within the multicast service area which contain members of a multicast group. MBMS data transmission should adapt to different RAN capabilities or different radio resource availability, e.g. by reducing the bitrates of the MBMS data.

A multicast service received by the UE, involves one or more successive multicast sessions. A multicast service might, for example, consist of a single on-going session (e.g. a multimedia stream) or may involve several intermittent multicast sessions over an extended period of time (e.g. messages). An example of a service using the multicast mode could be a football results service for which a subscription is required.

Unlike the broadcast mode, the multicast mode generally requires a subscription to the multicast subscription group and then the user joining the corresponding multicast group. The subscription and group joining may be made by the PLMN operator, the user or a third party on their behalf (e.g. company). Unlike the broadcast mode, it is expected that charging data for the end user will be generated for this mode.



Reception of multicast services cannot be guaranteed over the access network. For many applications and services guaranteed data reception may be carried out by higher layer services or applications which make use of MBMS. Multicast mode should allow terminals to minimize their power consumption.

The multicast mode defined in this specification should not be confused with IP Multicast (discussed above). There are similarities between these two services and such similarities may be exploited in 3GPP networks given that 3GPP multicast mode has been defined with consideration to maximizing efficiency on the radio interface and of network resources.

Multicast mode shall be inter-operable with IETF IP Multicast. This could allow the best use of IP service platforms to help maximize the availability of applications and content so that current and future services can be delivered in a more resource efficient manner. Figure above shows a general high level overview of multicast mode network.

MBMS RAN Requirements

The following RAN requirements have been identified [7]:

1. MBMS data transfer shall be downlink only.
2. QoS attributes shall be the same for MBMS Multicast and Broadcast modes.
3. During MBMS data transmission it shall be possible to receive paging messages, which also should contain some additional information, such as CLI.
4. Simultaneous reception of MBMS and non-MBMS services shall depend upon UE capabilities.
5. Simultaneous reception of more than one MBMS services shall depend upon UE capabilities.
6. A notification procedure shall be used to indicate the start of MBMS data transmission. This procedure shall contain MBMS RB information.
7. A mechanism to enable the Network to move MBMS subscribers between cells is required.
8. MBMS UE multicast activation (Joining) shall be transparent to UTRAN.
9. A mechanism is required that enables the non-transmission of MBMS multicast mode in a cell which does not contain any MBMS UEs joined to the multicast group.
10. Reception of MBMS shall not be guaranteed at RAN level. MBMS does not support individual retransmissions at the radio link layer, nor does it support retransmissions based on feedback from individual subscribers at the radio level. This does not preclude the periodic repetitions of the MBMS content based on operator or content provider scheduling or retransmissions based on feedback at the application level.
11. MBMS shall not prevent the capability for SRNS/SBSS relocation.
12. A mechanism to provide UTRAN the received QoS per UE is not required as part of MBMS.
13. UE controlled "service based" cell selection/reselection shall not be permitted.
14. Handover and SGSN relocation shall not be affected by an active MBMS session.
15. In the case of UTRAN only, guaranteed 'QoS' linked to a certain initial downlink power setting is not required; however, the purpose and possibility of some reporting mechanism could be identified to measure the delivered QoS.
16. MBMS Multicast mode transmissions should use dedicated resources (p-t-p) or common

resources (p-t-m). The selection of the connection type (p-t-p or p-t-m) is operator dependent, typically based on downlink radio resource environment such as radio resource efficiency. A "threshold" related to the number of users may be utilized, resulting in the need for a mechanism to identify the number of subscribers in a given "area".

17. MBMS solutions to be adopted should minimize the impact on the RAN physical layer and maximize reuse of existing physical layer and other RAN functionality.
18. MBMS charging should be transparent to the RAN.
19. MBMS should allow for low UE power consumption.
20. Header compression should be used.
21. MBMS should not prevent support for SGSN in pool.
22. Data loss during cell change should be minimal.

The following MBMS Notification Requirements have been identified:

1. MBMS notification shall be transmitted within the MBMS service area.
2. MBMS notification shall be sent so it could be received by all UEs with an activated MBMS service, regardless of their RRC state or the lack of an RRC connection.
3. MBMS notification should maximize the reuse of existing channels.
4. MBMS notification should allow terminals to minimize their power consumption, meaning that UEs with an activated MBMS service should not listen permanently, but at regular intervals to MBMS notification.
5. Reception of MBMS notification cannot be guaranteed.
6. UEs may receive MBMS notification and simultaneously monitor other occasions, e.g. UE dedicated paging and CBS messages. The avoidance of collisions cannot be guaranteed. If collisions occur, the UE dedicated Paging has higher priority (UE requirement).

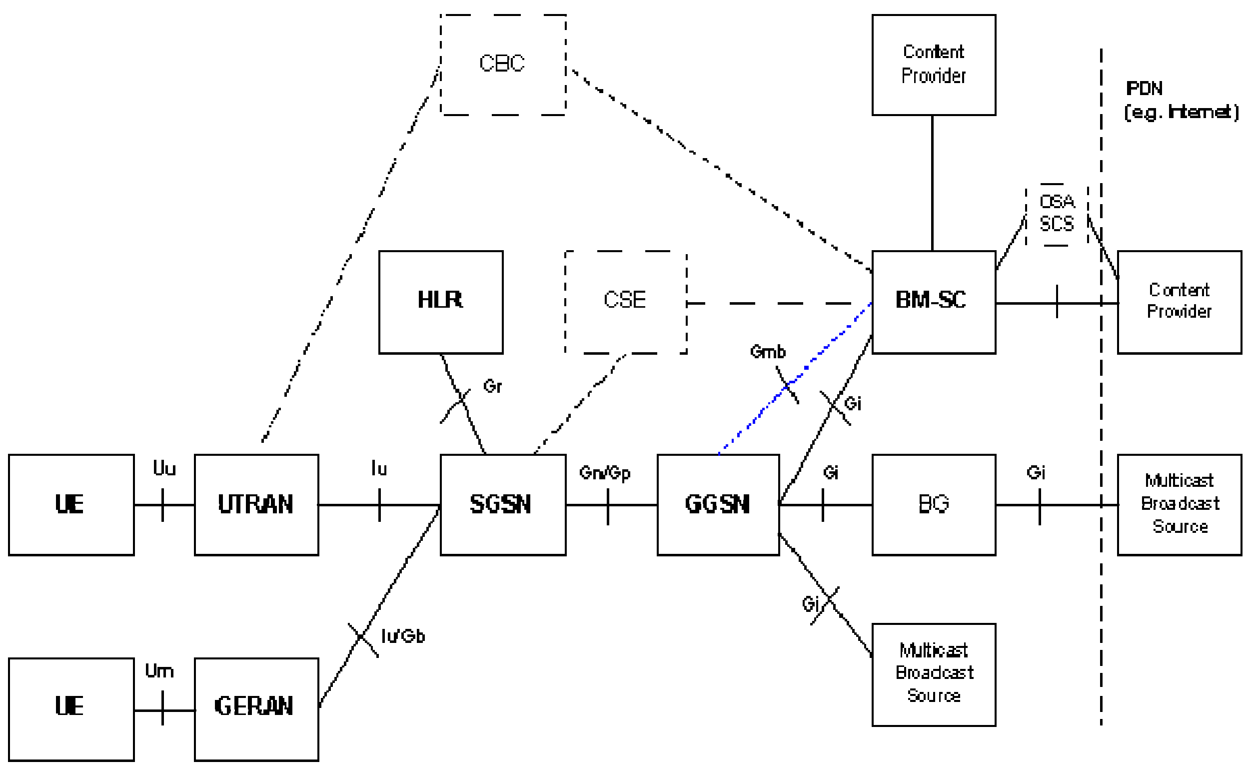
MBMS Architecture

The MBMS architecture is based on the following principles:

1. MBMS architecture shall enable the efficient usage of radio-network and core-network resources, with the main focus on the radio interface efficiency. Specifically, multiple users should be able to share common resources when receiving identical traffic.
2. The MBMS architecture shall support common features for MBMS multicast and broadcast modes, e.g. both modes shall preferably use the same low-layer bearer for data transport over the radio interface.
3. The MBMS architecture does not describe the means by which the BM-SC obtains the service data. The data source may be external or internal to the PLMN e.g. content servers in the fixed IP network, any UE attached to the PLMNMBMS shall support both IP multicast and IP uncast sources.
4. MBMS architecture should re-use, to the extent possible, existing 3GPP network components and protocol elements thus minimizing necessary changes to existing infrastructure and providing a solution based on well-known concepts.
5. MBMS shall be a point-to-multipoint bearer service for IP packets in the PS domain.
6. MBMS shall be interoperable with IETF IP Multicast.
7. MBMS shall support IETF IP Multicast addressing.
8. It shall be possible for UEs to receive MBMS when the terminal is attached.

9. It shall be possible for UEs to receive MBMS data in parallel to other services and signaling (e.g. paging, voice call).
10. MBMS shall support different quality of service levels. The mechanisms for this are for further study, one example is repetitions to all users.
11. MBMS service areas shall be defined per individual service with a per cell granularity.
12. MBMS is not supported in the CS domain.
13. When the UE is already receiving data of an MBMS service, it shall be possible for the UE to be notified about a forthcoming and potentially about an ongoing data transfer from other MBMS services.
14. Charging data shall be provided per subscriber for MBMS multicast mode .
15. The MBMS bearer service concept should contain the decision making process for selection of point-to-point or point-to-multipoint configurations.
16. The architecture should be able to provide home MBMS multicast services to users when roaming outside their home network as subject to inter-operator agreements.
17. MBMS should be designed to minimize power consumption within the mobile station.
18. Applications shall be tolerant to packet loss and duplication caused by e.g. UE mobility or transmission loss.
19. The backwards compatibility of the MBMS service to the R99 IP multicast delivery mechanism shall be considered. Interworking possibilities between MBMS capable network elements and non-MBMS capable network elements (e.g. interworking with R99 IP Multicast service GGSNs) shall be described.
20. The MBMS standard should avoid placing excessive signaling load requirements on the network. In particular, the MBMS standard should permit operators to configure their networks so that when a UE, which is not actually receiving a media stream, changes between GSM and UMTS cells in the same Routing Area, there is no significant signaling traffic load on the network.

MBMS Architecture



MBMS Architecture is as shown above. The dotted lines means functions / reference points that are optional. Gp applies only when SGSN and GGSN are in different PLMN.

SGSN: In the MBMS architecture the SGSN performs user individual service control functions and the SGSN concentrates all individual users of the same MBMS service into a single MBMS service. The SGSN maintains a single connection with the source of the MBMS data.

GGSN: The GGSN terminates the MBMS GTP tunnels from the SGSN and links these tunnels via IP multicast with the MBMS data source.

BM-SC: The BM-SC is an MBMS data source. MBMS data may be scheduled in the BM-SC, e.g. for transmission to the user every hour. It offers interfaces over that content provider can request data delivery to users. The BM-SC may authorize and charge content provider.

MBMS Data Sources: The architecture allows for other MBMS broadcast/multicast data sources. Internal data sources may directly provide their data. Data delivery by external sources is controlled by Border Gateways (BG) which may allow for example data from single addresses and ports to pass into the PLMN for delivery by an MBMS service.

Optional Network Elements:

- The SGSN may use CAMEL to handle pre-paid services, e.g. credit checking for on-line charging.
- The Cell Broadcast Centre (CBC) may be used to announce MBMS services to the users. How this is accomplished is FFS.
- The BM-SC might use OSA-SCS to interact with third parties.

MBMS Channel Structure

There exists two transmission modes to provide the MBMS service:

- Point-to-point transmission (p-t-p/PTP)
- Point-to-multipoint transmission (p-t-m/PTM)

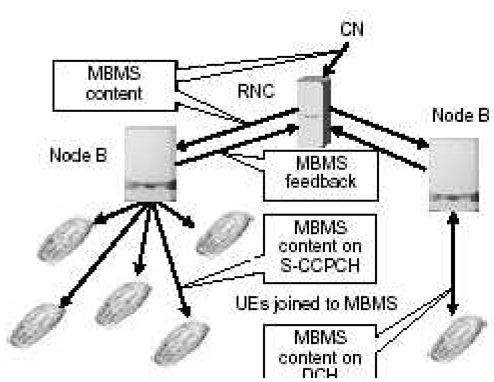


Figure above [17] shows an example scenario where one cell uses p-t-m while an other cell has only one joins UE which is kept in p-t-p state. From the MBMS operation point of view, procedures are obviously simpler if the content is always provided in a point-to-multipoint manner without shifting users back and forth between different states.

Point-to-Point Transmission

Point-to-point transmission is used to transfer MBMS specific control/user plane information as well as dedicated control/user plane information between the network and one UE in RRC Connected Mode. It is used only for the multicast mode of MBMS.

For a UE in CELL_FACH and Cell_DCH, DCCH or DTCH is used, allowing all existing mappings to transport channels.

Point-to-multipoint Transmission

Point-to-multipoint transmission is used to transfer MBMS specific control/user plane information between the network and several UEs in RRC Connected or Idle Mode. It is used for broadcast or multicast mode of MBMS.

Logical Channels

MBMS point-to-multipoint Control Channel (MCCH):

This logical channel is used for a p-t-m downlink transmission of control plane information between network and UEs in RRC Connected or Idle Mode. The control plane information on MCCH is MBMS specific and is sent to UEs in a cell with an activated (joined) MBMS service. MCCH can be sent in S-CCPCH carrying the DCCH of the UEs in CELL_FACH state, or in standalone S-CCPCH, or in same S-CCPCH with MTCH. The MCCH is always mapped to one specific FACH in the S-CCPCH as indicated on the BCCH. If MCCH is the only logical channel mapped in to the FACH, the absence of the TCTF field is explicitly signaled otherwise the TCTF field is used in MAC header to identify MCCH logical channel type. In case of soft combining, the MCCH is mapped to a different S-CCPCH (CCTrCH in TDD) than MTCH. Reception of paging has priority over reception of MCCH for Idle mode and URA/CELL_PCH UEs.

MBMS point-to-multipoint Traffic Channel (MTCH):

This logical channel is used for a p-t-m downlink transmission of user plane information between network and UEs in RRC Connected or Idle Mode. The user plane information on MTCH is MBMS Service specific and is sent to UEs in a cell with an activated MBMS service. The MTCH is always mapped to one specific FACH in the S-CCPCH as indicated on the MCCH. The TCTF field is always used in MAC header to identify MTCH logical channel type.

MBMS point-to-multipoint Scheduling Channel (MSCH):

This logical channel is used for a p-t-m downlink transmission of MBMS service transmission schedule between network and UEs in RRC Connected or Idle Mode. The control plane information on MSCH is MBMS service and S-CCPCH specific and is sent to UEs in a cell receiving MTCH. One MSCH is sent in each S-CCPCH carrying the MTCH. The MSCH is always mapped to one specific FACH in the S-CCPCH as indicated on the MCCH. Due to different error requirements the MSCH is mapped to a different FACH than MTCH. If MSCH is the only logical channel mapped in to the FACH, the absence of the TCTF field is explicitly signaled otherwise the TCTF field is used in MAC header to identify MSCH logical channel type.

Transport Channel

FACH is used as a transport channel for MTCH, MSCH and MCCH.

Physical Channel

SCCPCH is used as a physical channel for FACH carrying MTCH or MCCH or MSCH.

Mapping between channels

Only in downlink, the following connections between logical channels and transport channels exist:

- MCCH can be mapped to FACH
- MTCH can be mapped to FACH
- MSCH can be mapped to FACH

The mappings as seen from the UE and UTRAN sides are shown in Figure a and Figure b below respectively [6]:

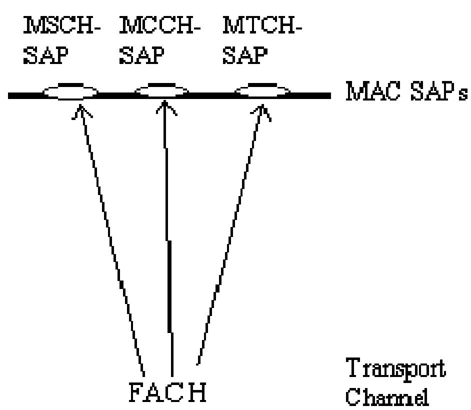


Figure a: Logical channels mapped onto transport channel, seen from the UE side

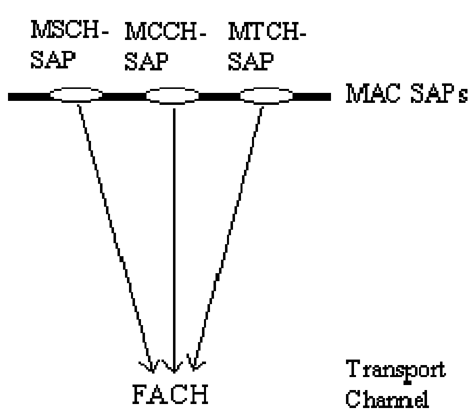


Figure b: Logical channels mapped onto transport channel, seen from the UTRAN side

Data Flows through Layer 2

Data flow for MCCH mapped to FACH:

For MCCH, the RLC mode to be employed is UM-RLC, with required enhancements to support out of sequence SDU delivery. A MAC header is used for logical channel type identification.

Data flow for MTCH mapped to FACH

For MTCH, the RLC mode to be employed is UM-RLC, with required enhancements to support selective combining. Quick repeat may be used in RLC-UM. A MAC header is used for logical channel type identification and MBMS service identification.

Data flow for MSCH mapped to FACH:

For MSCH, the RLC mode to be employed is UM-RLC. A MAC header is used for logical channel type identification.

MBMS Notification Indicator Channel

MBMS notification utilizes a new MBMS specific PICH called the MBMS Notification Indicator Channel (MICH) in each cell.