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Mobility Management in UMTS

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Contents

1. Introduction

Mobile networks and communication have become more and more important in the last years. There exist several technologies to provide continuously access with mobile devices to the different types of wireless networks even while moving. This work will focus on handover types in different networks while packet switched/data connections between the network and the mobile device are active and data is transmitted. Some of these technologies are already in use for many years and some are quite new ones.

This work focuses on the different handover types in the third generation mobile system Universal Mobile Telecommunication System (UMTS) for packet switched services. A description of handover technologies in the older second generation system Global System for Mobile Communication (GSM) and wireless LAN (WLAN) is also given.

In chapter two some aspects of mobility are discussed on a very general base. Chapter three gives an introduction of UMTS. There the hierarchical structure of the UMTS network and the radio technique used for the transmission of signals between the mobile device and the network itself is described. Chapter four deals with the architecture of an UMTS network. The different parts and connections between them are described. In chapter five some problems of the radio transmission technique the UMTS network uses are discussed. This problems are somehow related to handover. In that chapter also radio resource control and the different handover types are described in detail. At the end of chapter five advantages and disadvantages of the technique used in UMTS networks for handover are discussed. To compare the handover techniques used in UMTS with other handover mechanism chapter six describes handovers in GSM and two different methods for handovers in WLANs.

2. Aspects of Mobility

2.1 End-user aspects of Mobility

Mobile communication has become more important in the last years. There are several definitions and aspects of mobility. Viewing at the end-user the following different kinds of mobility can be defined [1,2]:

- Static mobility:
  This is an extreme case of mobility, there is no movement at all. Examples for this case are normal PCs (e.g. connected to the internet via cable) and wired telephones in public switched telephone networks.
- Nomadic mobility:
  In this case it is possible to get access at every point but not while moving from point to point. For example notebooks that move from one point (e.g. a room) to another and get connected at each point via cable to a network apply to this case.
- Continuous mobility:
  Connecting and access to the network is possible at every time while moving or not. An example here is GSM. From a technical point of view this case can be divided into three different kinds of communication:
  - Cellular communication:
    The network has a cellular structure with a fixed infrastructure like GSM networks.

- Hot Spot communication:
  In this case the network consists of different access points/hot spots that cover an area around them. If a devices moves away from an access point to another the connection to the old access point is released and a new connection to the other access point is established. The network does not have a fixed cellular structure. For example WLAN and Bluetooth belong to this type of network.
- Pervasive communication:
  This describes mobile ad-hoc networks. The networks have no infrastructure. Every participant connects itself to the participants around him. Because of the movement of all participants connections often break down and new ones are established to other neighbors. Because of often changing links routing is a big problem in such networks.

2.2 Mobility Scenarios

There exist several different scenarios of mobility [1,2]:

- Service mobility:
  A personalized service can be used by many people at the same time, also in different networks and regions. This can be for example nearly worldwide access to a database at the same time by many people that is possible via GSM networks (via the wireless application protocol (WAP)), WLANs and a fixed network connection (for example with an ethernet cable).
- Network mobility:
  The network itself is mobile. This is the case in mobile ad-hoc networks.
- Personal mobility:
  Personal mobility can be divided into two aspects:
  - Personal communication:
    Services and ubiquitous reachability are provided for every user at every terminal/device a user may use. Examples are SIM cards in GSM or personal 0700-telephone numbers. An incoming call to this number for example can be directed to a mobile phone or a plain telephone.
  - Personalising operating environment:
    A user has the same setting in every device he uses. GSM SIM cards provide a little bit of this because the telephone book and some SMS are available in each device. They are stored in the SIM card. Public switched telephone networks do not offer personalising operating environments.
- Device mobility:
  In this case the device moves. For example mobile phones fit into this scenario. Device mobility affects many layers. That means in every layer compared to wired connections new problems occur that have to be solved. In some layers support for new special applications and services can be provided. Some of this new problems and services are described in the following points. They are listed by the layer that should solve the problem or provide the service:
  - Physical layer:
    The quality of a radio link varies with direction, place, distance etc. Hence this layer has to deal with the reuse of resources and avoiding interferences.

- Data link layer:
  Problems that have to be solved by this layer are for example bandwidth, reliability and security.
- Network layer:
  In wireless networks the movement of a mobile device has to be tracked and the connection to a mobile device must be kept while it moves. To do this also routing has to be changed within the network if a mobile device changes the point of attachment to the network. This problems should be solved in this layer.
- Transport layer:
  End to end connections can mix wired and wireless links. Congestions control is very difficult because of the different characteristics of those links. For example packet loss is mainly caused by high error rates in wired networks. In wireless networks transmission errors have to be solved in the data link layer. Packet loss can occur for example if a queue that saves packets for a mobile device in the fixed network gets an overflow during a handover situation because the new connection to the mobile device is not established fast enough. In this two cases the cause for the loss of packets is different in the wired and wireless network. In the transport layer this different problems that lead to the same result (packet loss) have to be solved in different ways for both cases.
- Middleware and application layer:
  To support some new special applications this layer has to provide service discovery schemes, quality of service and environment auto configuration. Applications must be device aware for the different possible devices. Connection aware applications must adapt to different conditions of network quality. This problems should be solved in the application layer or the middleware itself.

2.3 Functions for different aspects and scenarios

There are several technologies that are needed to provide mobile communication for the different aspects and scenarios [2]:

- Registration:
  Informs the networks which device a user currently uses and that it is ready to receive requests. Usually it is combined with authentication. This is needed for personal and device mobility. It may be needed for service and network mobility in static, nomadic and continuous mobility.
- Paging:
  In power saving mode the cellular networks only know an area where the device is located. This area can contain many cells. Paging is needed to find the current cell where the device is located. Paging is only relevant for device mobility in continuous mobility.
- Location Update:
  Informs the network of new positions and is triggered by movement or by a timer. This is needed for personal and device mobility in continuous mobility.
- Handover:
  Keeps the link while moving from one access point to another. This is only needed for device mobility in continuous mobility while connections are active.
- Rerouting:
  Routes need to be redefined after handovers or new locations to optimize the traffic path. This is only needed for device mobility in continuous mobility and in nomadic mobility to reestablish sessions.

This work focuses further on handover in UMTS. This technique is compared with handover in GSM and handoffs in WLAN. But first UMTS is introduced and the different levels and parts of the system are described.

3. Introduction to UMTS

The third generation mobile communication system UMTS (Universal Mobile Telecommunications System) is successor of GSM (Global System for Mobile Communications). UMTS networks can be divided in two parts. One part that is responsible for the circuit switched services (CS-domain) and one part that manages packet switched services (PS-domain, see chapter 4). The CS-domain manages voice calls and on the other hand the PS-domain is responsible for data connections like connections from a mobile device (called user equipment (UE) in UMTS) to the internet. This work focuses mainly on the PS-domain.

3.1 Hierarchical cell structure

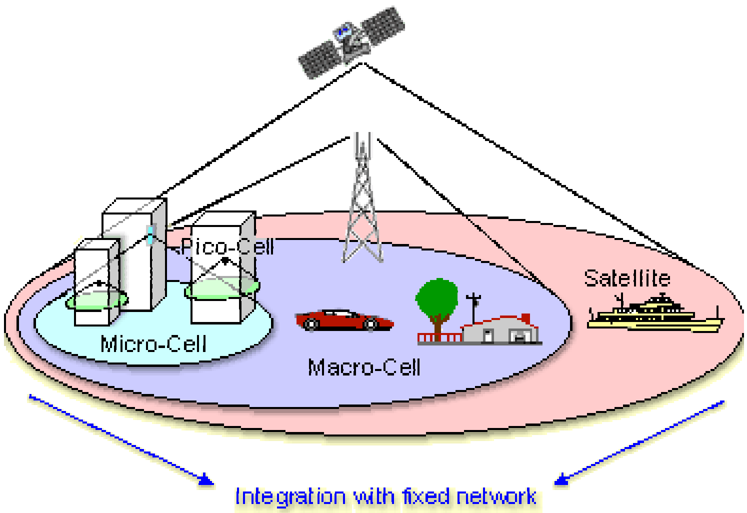

Figure 1 [3]

UMTS is designed to provide global access and world-wide roaming. To support this the URAN (UMTS Radio Access Network) will be build in different hierarchical levels [3]. Higher levels cover larger geographical areas. Lower levels cover only little areas but they can handle a higher density of devices that want to access the network in this little areas. They also provide faster wireless links to the network than larger levels. The whole system is connected and integrated with PTSN (Public Telephone Switched Network) and PDN (Public Data Network) like internet etc. The following levels are planned:

- Satellite system:
  This covers the whole planet. Even on seas and in uninhabited regions access to the network is possible via satellites.
- UTRAN (UMTS Terrestrial Radio Access Network):
  The UTRAN infrastructure is terrestrial and consists also of different levels and cells:
  - Macro layer:
    This cells cover large areas with regions where only few devices access the network.
  - Micro layer:
    In regions with a high density of devices that want access to the network, like bigger cities, micro cells are used. They cover only quite little areas to provide enough capacity for all devices in this area.
  - Pico layer:
    A pico cell is normally located in bigger buildings to provide fast and good

access to the network. For example hot spots are made out of pico cells in buildings.

3.2 W-CDMA

In UTRAN W-CDMA (Wideband-Code Division Multiple Access) is used to transmit wireless data between the sender and the receiver (UE - user equipment and Node B here). GSM uses a combination of FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access).

In FDMA the frequency is divided. Every pair of communicators uses a part of the spectrum to transmit and receive the whole time they communicate with each other. In TDMA a part of the time (a time slot) is assigned to each pair of communicators. In this time they can use the whole or a big part of the spectrum to transmit and receive data or speech. After that time other pairs use this spectrum until the first pair can use again the spectrum for a time again. The first pair gets again a so called time slot [4].

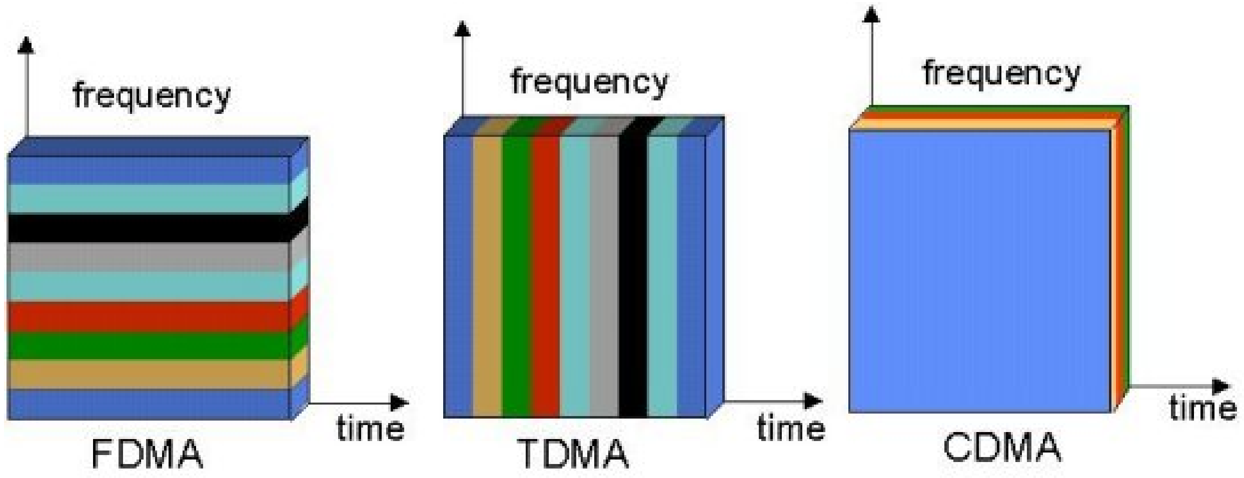

Figure 2 [4]

In CDMA all communication pairs use the entire spectrum and can send and receive all the time parallel. Different codes (channelization- and scrambling code [5,14]) for every pair of communicators are used to identify the different connections. The scrambling code distinguishes UE and Node Bs. The channelization code is used to create different channels [5].

The main idea is that if the codes used are all orthogonal the sender can multiply the data it wants to send with its code and send this information. Because the codes are orthogonal then the data sent by one specific sender can be extracted by multiplying the whole data received with the code of the specific sender again [5,6].

Hence the sender multiplies the data with his code before sending it. The receiver also knows this code. The codes used by the different pairs of communicators are all almost orthogonal. They are only almost orthogonal because there are not enough complete orthogonal codes available for every pair of communicators. The receiver multiplies the received data again with the code of the sender. After this calculation the data sent by other communicators can be filtered out as a kind of background noise by the receiver. This can be done because the codes are almost orthogonal [5,6]. Using this procedure the receiver extracts the data sent by the corresponding sender out of the data sent by all communicators.

Unlike CDMA-2000 used in the USA in UMTS a much wider spectrum of 5MHz is used. CDMA-2000 uses a spectrum of 1,25MHz. That is why it is called Wideband-CDMA (W-CDMA) [5].

4. UMTS Architecture

The UMTS network can be divided into tree parts [7]:

- User Equipment (UE):
  The UE connects to the UTRAN via wireless radio link to one or more cells. Unlike in GSM it is possible to have a link to many cells at the same time.

- UMTS Terrestrial Radio Access Network (UTRAN):
  The UTRAN consists of Node Bs (BTS in GSM) that are connected to Radio Network Controllers (RNCs – BSC in GSM). The RNCs are connected to each other and to the core networks via ATM.

- Core Network (CN):
  The core network is connected to other networks like PTSN (Public Telephone Switched Network), Internet, other mobile networks etc. It is responsible for routing, authentication, location tracking, etc. The core networks is divided into two domains, the circuit switched (CS) and the packet switched (PS) domain (see 4.3). This work will further focus on the PS-domain.

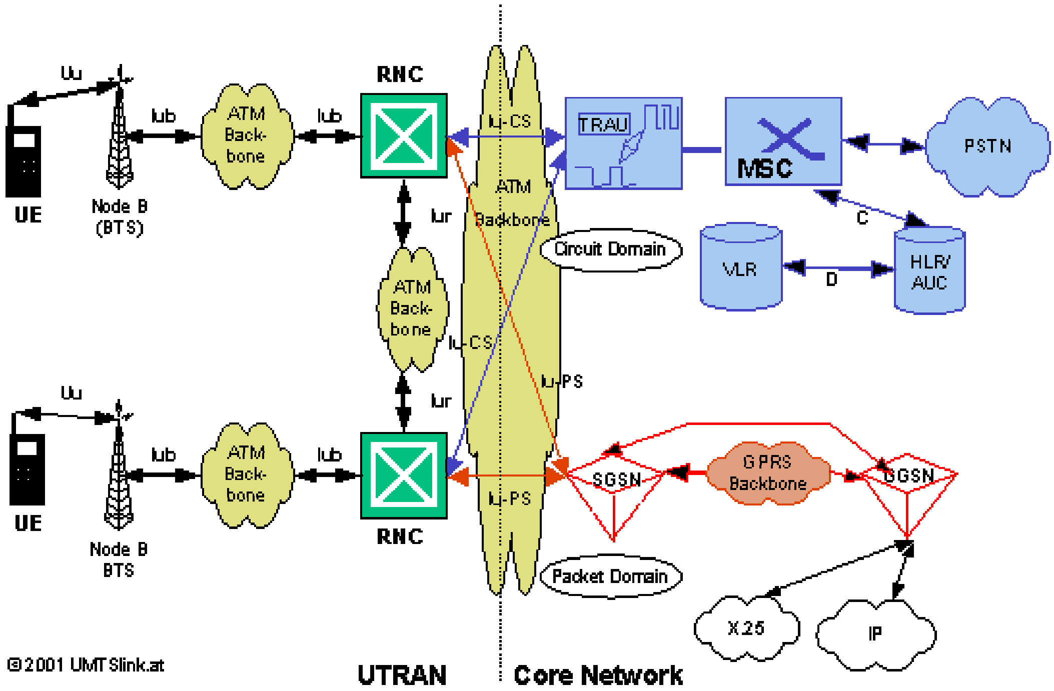

Figure 3 [7]

4.1 User Equipment (UE)

UE is a synonym for device here. For example an UE may be a mobile phone, a personal digital assistant (PDA) or a notebook. UE connects via the radio interface Uu (see figure 3) based on the W-CDMA technology to the UTRAN. A device can be connected to more than one cell simultaneously, more about this topic follows in chapter 4. The UE consists of two parts [8]:

- Mobile Equipment:
  That is the hardware device itself. The device alone can not use any UMTS services.

- USIM-Card:
  All necessary data for authentication and getting access to the UMTS network to use services is stored on an USIM-Card (UMTS Subscriber Identity Module-Card). This

card is equivalent to the SIM-Card in GSM. The USIM-Card is issued by the common carrier and is unlike GSM SIM-Cards able to save some MB of personal data. GSM SIM-Cards only have between 8kB and 32kB of memory.

4.2 UMTS Terrestrial Radio Access Network (UTRAN)

Among other things the UTRAN is responsible for the radio resource management. This includes the responsibility for power control, support for the different handover types and also controlling and managing handovers.

The UTRAN consists of Node Bs and RNCs. Most of the Node Bs manage three cells. A group of Node Bs are connected with the Iub interface to one RNC via an ATM network. The RNC, a Node B is connected to, is called Controlling RNC (CRNC) (of this Node B). One RNC with all connected Node Bs is called Radio Network Subsystem (RNS).

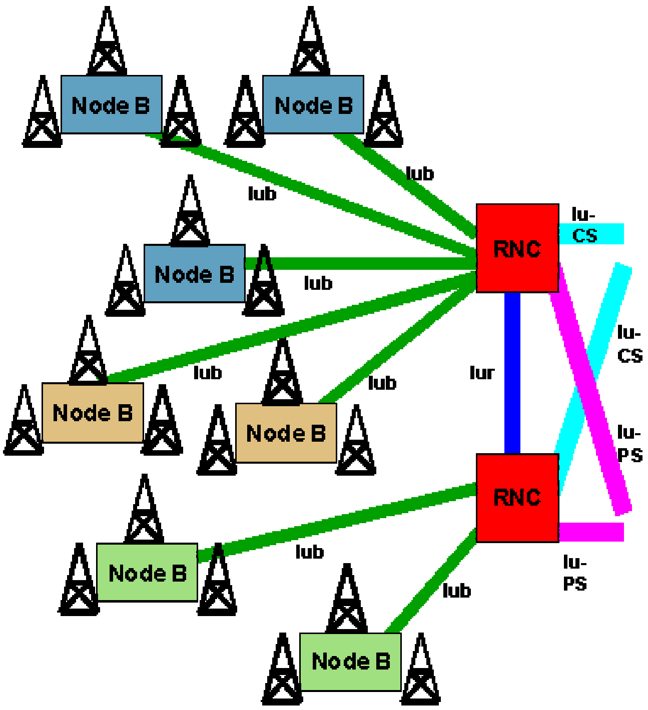

Figure 4 [18]

A Node B operates at physical and network layer and passes the data to the CRNC. It also measures the quality and power of the radio links to the UEs and reports it to the CRNC. The CRNC can react on basis of this information, for example to reduce or increase the power of the radio signal at the Node B and/or UE. The RNC also assigns a W-CDMA code for the radio link between UE and Node B so that the data from the specific UE can be extracted from the whole data sent by all UEs and Node Bs around (see 3.2). It is also responsible for handovers between different RNS, radio resource control, etc.[10] To provide a soft handover (see chapter 4) the RNCs are connected to each other with the Iur interface via an ATM network. They are also connected to the CN via the Iu-CS interface for circuit switched services and via the Iu-PS interface for packet switched services [9,10].

4.3 Core Network (CN)

The core network is divided into two parts [10,11,19]. One for circuit switched services (CS-domain) and one for packet switched services (PS-domain). The CS-domain contains the following parts:

- Mobile Switching Center (MSC):
  The MSC is a switching node that routes data of CS-services within and out of the own network via the Gateway Mobile Switching Center (GMSC). A MSC manages many RNCs that are connected via the Iu-CS interface. The MSC is also connected to different databases for example to the Home Location Register (HLR) and manages the mobility for the CS-services. Depending on the size of the network there is normally more than one MSC in an UMTS network.

- Gateway Mobile Switching Center (GMSC):
  The GMSC is connected to the MSC and interconnects the own UMTS network to other CS-switched networks like PTSN (Public Telephone Switched Network) or ISDN (Integrated Services Digital Network). In an UMTS network can be more than one GMSC.
- Visitor Location Register (VLR):
  One VLR is normally assigned to every MSC. The VLR saves temporarily security, authentication and identification data of all participants that are currently managed by the MSC. Some of the data are copied from the Home Location Register (HLR, see below).
- Transcoder Rate Adapter Unit (TRAU):
  The TRAU is a gateway between the RNC and the MSC that is responsible for the conversion of the format (Adaptive Multi Rate (AMR) to Pulse Code Modulation 30 (PCM30) and vice versa) of speech data. This is necessary because UTRAN and CN use different formats [19]. In an UMTS network can be more than one TRAU.

The PS-domain consists of the following parts:

- Serving GPRS Support Node (SGSN):
  The SGSN in the PS-domain is similar to the MSC in the CS-domain. It routes data of PS-services in the own UMTS networks and outside via the Gateway GPRS Support Node (GGSN). It also manages many RNCs that are connected via the Iu-PS interface and is connected to databases like the Home Location Register (HLR, see below). The SGSN also is responsible for authentication and mobility management. Depending on the size there is normally more than one SGSN in an UMTS network.

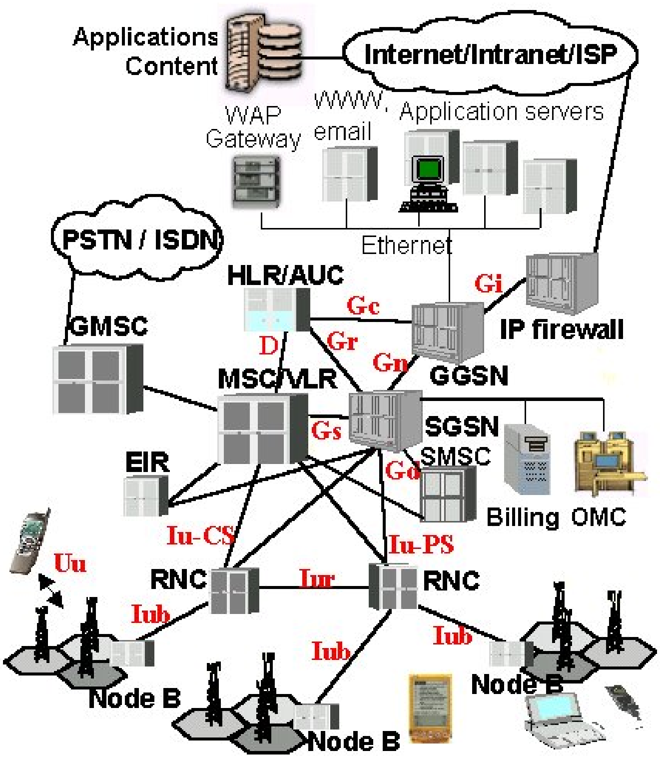

Figure 5 [37]

- Gateway GPRS Support Node (GGSN):
  The GGSN again is very similar to the GMSC in the CS-domain. It interconnects the UMTS network with other PS networks like the Internet or X.25 networks and is connected to the SGSN. In an UMTS network can be more than one GGSN.

There are also some elements that are used by both domains. One important component of them is the following:

- Home Location Register (HLR)/Authentication Center (AuC):
  The HLR/AuC is a database that saves data of participants that rarely change like security and encryption information, phone number, services that a user is allowed to access by contract etc. [12,13,19]

5. Handover in UMTS

As described in chapter 3.2, in UMTS, unlike in GSM, all UEs use the same frequency all the time. To every pair of communicators a code is assigned so that the data of those can be extracted of the whole data sent by all UEs. Normally a soft handover is done. During a handover phase an UE connects to several cells. If it is necessary a connection to a cell is released after one or more connections to other cells have already been established. A handover phase can take a long time. It can even take the whole time the connection is active depending on the position of the UE. There are several cases of handovers in UMTS. The cases describe the different possible positions of an UE and the cell organization and responsible nodes (Node Bs, RNCs etc.) within the UTRAN near this positions. The following cases apart from the hard handover occur frequently in UMTS networks [15,16,17,18,20,23]. Apart from the hard handover type this work will further focus on them:

- Softer handover (intra Node B/intra RNS):
  This handover type is done if the UE moves from one cell to another cell that both belong to the same Node B.
- Soft handover (inter Node B/intra RNS):
  A softer handover is done if the UE moves from a cell in one Node B to a cell in another Node B and both Node Bs belong to the same RNS. That means they are connected to and managed by the same RNC.
- Soft handover (inter Node B/inter RNS/intra SGSN):
  If the UE moves from a cell in one Node B to a cell in another Node B that belong to different RNS the handover is called soft handover (intra RNC).
- Soft handover (inter Node B/inter RNS/inter SGSN):
  In this case the UE moves from a cell in one Node B to a cell in another Node B that belongs to a different RNS. The Node Bs are connected to different RNCs and those two RNCs are also connected to different SGSNs. In this case the UE even has to be relocated to the new SGSN.
- Hard handover:
  A so called hard handover (or inter-frequency handover) is only needed if for some other reason the frequency has to be changed or the Iur interface does not exist between two RNCs in case of a soft handover (inter Node B/inter RNS). A reason to change the frequency could be for example a change of the UMTS cell level (see 3.1) from a macro cell to a satellite or another change of the radio access technology (inter RAT handover) for example from UMTS to a WLAN or GSM network. A hard handover occurs quite rarely and differs a lot from the handover types above. The hard handover type is only mentioned here for the sake of completeness.

5.1 Macro Diversity

As already mentioned in chapter 3.2 the codes used in W-CDMA by the different pairs of communicators are only almost orthogonal [14] because there are not enough complete orthogonal codes available for all pairs of communicators. Thus codes that are less orthogonal are used for communicators that are located in different cells to keep the codes used within one cell or even the neighbor cells as much orthogonal as possible.

If an UE is located in an overlapping part of two cells A and B and it is quite far away from the Node B of cell A, it is connected to, the UE and Node B have to send at high transmission power level. This situation is shown in figure 6. Then the radio signals of the UE (and Node B

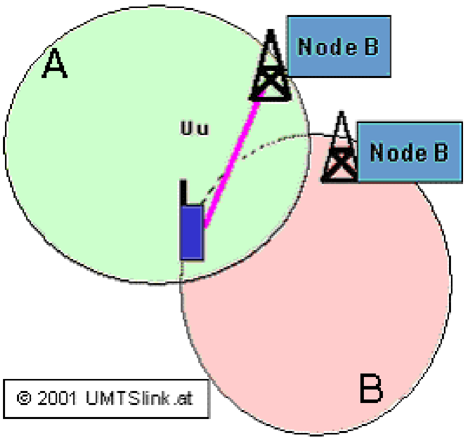

Figure 6 [18]

of cell A) reach far into cell B. In cell B UEs with less orthogonal codes to the code used by the UE (that is connected to cell A) are located. These UEs within cell B and the Node B of cell B can not filter out the data sent by the UE located at the border of cell A because the codes used are quite similar (only almost orthogonal [14,16]) and the signal out of cell A has too much power. To compensate this UEs and the Node B in cell B increase their power transmission level. This again disturbs the UEs and Node B in cell A that increase the transmission power level once again. This is called interference. Increasing the power transmission level is done until the UEs can not increase the transmission power level anymore. The UEs have a limit of the transmission power level for example of 125mW for mobile phones (class 4) [16]. The Node Bs have a power level limit too. If there are too many UEs in such overlapping regions the Node Bs reduce the size of their cells [21].

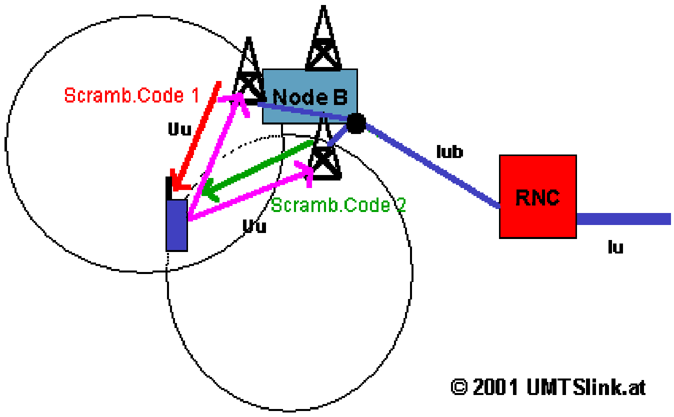

Figure 7 [16]

To solve this problem an UE is able to connect to more than one cell, even if these belong different Node Bs or RNS, at the same time. In this case the UE is able to correct (some of the) transmission errors by comparing the data received from the different cells. Both cells send the same data just coded with a different scrambling code to the UE. The UTRAN is able to correct (some of the) transmission errors by comparing the data received by the different cells from the UE (see figure 7). Thus the transmission power level of the UE and Node Bs can be reduced to a lower level because some transmission error can be corrected in that way.

This solution is called macro diversity or micro diversity if the involved cells belong to the same Node B. Keeping more than one active connection to different cells is possible because all cells use the same frequency (see 3.2). In GSM this would be much more complicated because the cells use different frequencies.

This technique is used for soft handover in UMTS because in a soft handover situation radio links to cells the UE moves towards are added and (later) radio links to cells the UE moves away from are removed. An UE can be in a handover situation with many radio links for quite a long time or even for the whole time a radio link is active and data is transmitted.

5.2 Mobility Management and Radio Resource Control

Figure 8 shows the control plane of UMTS mobility management between UE - UTRAN and UTRAN - CN.

On top of the Radio Link Control (RLC) there is the Radio Resource Control (RRC). It is responsible for a reliable connection between the UE and the UTRAN and especially manages radio resources. It is also involved in handovers.

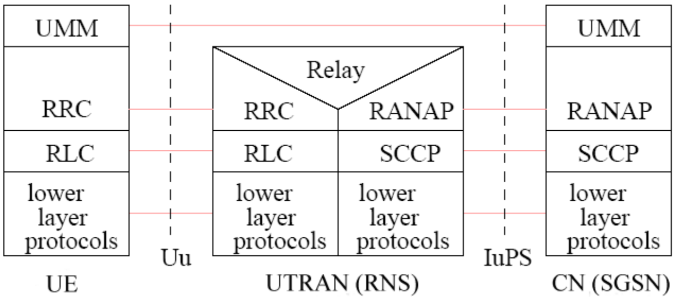

Figure 8 [22]

The Signal Connection Control Part (SCCP) and on top of that the Radio Access Network Application Part (RANAP) manage the connection between the UTRAN und the CN. The RANAP also supports mobility management signaling transfer between the CN and the UE. Those signals are not interpreted by the UTRAN. It also manages the relocation of RNCs (see 5.6), radio access bearer (RAB) etc.

On top of this layers UMTS Mobility Management (UMM) provides mobility management functions.

In a UMTS network a SGSN manages one or more RNCs and a RNC manages many Node Bs. To track the location of an UE some geographical groups are defined within the UTRAN (see figure 9):

- Location Area (LA):
  A LA covers the area of one or even more RNS. A LA can only cover the area of more than one RNSs if the corresponding RNCs are managed by the same SGSN.
- Routing Area (RA):
  A RA is a subset of a LA. It only covers one RNS or even only a subset of a RNS.
- UTRAN RA (URA):
  An URA is a subset of an RA. It only covers some Node Bs of one RNS.

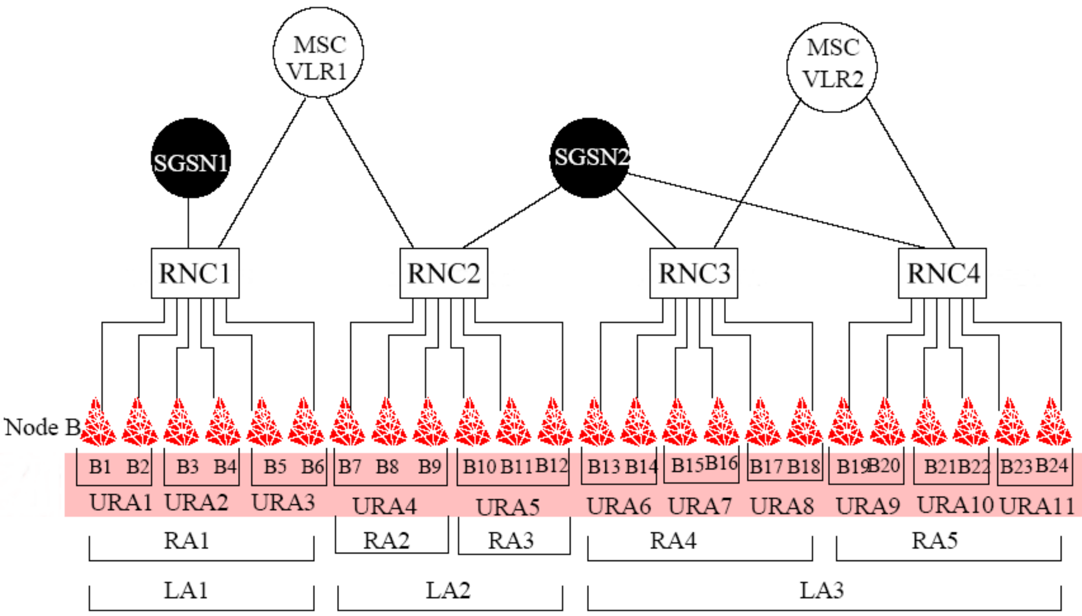

Figure 9 [22]

LAs are used in the CS-domain only. Routing areas (RA) are used in the PS-domain this work focuses on. The RA an UE is located in is tracked by the CN (that means by the SGSN). In case of an active RRC connection the current URA an UE is located in is tracked by the UTRAN. If the UE is also cell connected the UTRAN even tracks the cell the UE is located in.

An UE is cell connected if an active RRC connections exists and Packet Data Units (PDA) is transmitted so that the inactivity timer does not expire. If for some time no PDA is transmitted the inactivity timer expires and the UE looses the cell connection. It is tracked again at URA level only by the UTRAN. Table 1 shows the different areas and by what nodes of the UMTS network they are tracked [22].

	UTRAN cell connected	UTRAN URA connected	CN (SGSN)
Cell	Yes	No	No
URA	Yes	Yes	No
RA	No	No	Yes

Table 1

5.3 Softer Handover (intra Node B/intra RNS)

This handover type is done if the UE moves from one cell to another cell that both belong to the same Node B. Figure 7 shows this situation.

A so called rake receiver in the UE processes the two signals the UE receives from the different antennas that are both connected to the same Node B. It uses a mathematical and stochastic method called maximum ratio combining to minimize the probability of transmission errors. The Node B also combines the two signals received from the UE by two antennas with a rake receiver. It also uses maximum ratio combining to reduce the probability of errors. With this technique micro diversity is entirely provided by a single Node B.

About 5-15% of all UTMS connections are expected to be in softer handover situations [25].

Figure 10 shows a radio link addition in an intra Node B/intra RNS handover situation:

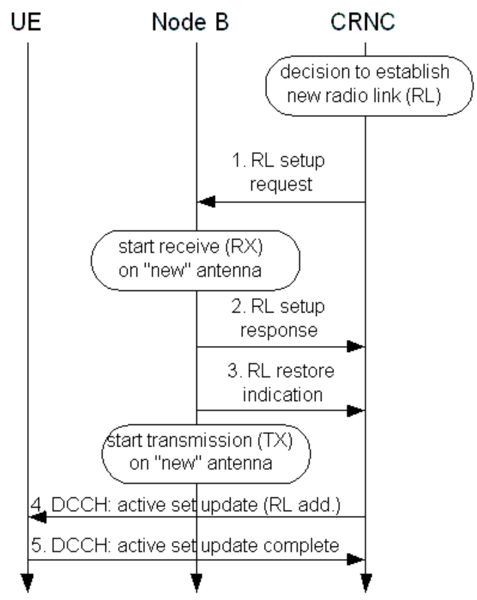

Figure 10 [25]

1. When the CRNC decides, based on measured data from the UE, to establish another radio link it sends the message “radio link setup request” to the Node B. The Node B immediately starts receiving uplink data from the UE on the “new” antenna.
2. After allocation of the requested resources the Node B sends the message “radio link setup response” to the CRNC.
3. After getting uplink synchronization via the Uu interface of the “new” antenna to the UE the Node B notifies the CRNC with the message “radio link restore indication”. The Node B starts sending downlink data to the UE on the “new” antenna.
4. The CRNC sends the message “active set update (RL addition)” via the Dedicated Control Channel (DCCH) with the appropriate connection information to the UE.
5. The UE updates the active set and confirms this by sending the message “active set update complete” via the DCCH. The new radio link is now added and used to receive and transmit radio signals.

In Figure 11 the message flow diagram of a radio link removal is shown in an intra Node B/intra RNS situation:

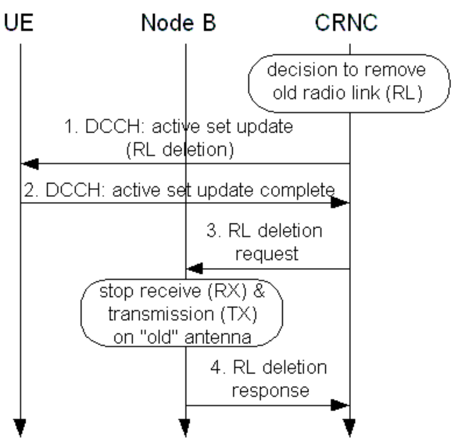

Figure 11 [25]

1. When the CRNC decides, based on the measured data from the UE [25], to remove one of the radio links from the radio set it sends the message “active set update (RL deletion)” to the UE via the DCCH. Thereby the update type and cell IP parameters are also transmitted.
2. After deactivating the link the UE sends the message “active set update complete” to the CRNC via the DCCH.
3. Then the CRNC sends the message “radio link deletion request” to the Node B and deallocates the resources of the old radio link.
4. After stopping the transmission and reception and deallocating the resources the Node B informs the CRNC by sending the message “radio link deletion response”. The radio link is removed.

5.4 Soft Handover (inter Node B/intra RNS)

A soft handover (inter Node B/intra RNS) is done if the UE moves from a cell in one Node B to a cell in another Node B and both Node Bs are managed by the same RNC. That means they belong to the same RNS. The data to the CN are transmitted via the Iu-PS interface of the RNC. The UE receives the radio signal from two different Node Bs coded with two different scrambling codes. It uses a rake receiver to combine the signals using maximum ratio combining.

The RNC gets the signal from the UE from two different Node Bs. Because a RNC manages many Node Bs (for example 200 [16]) it does not have a rake receiver to combine the signals and reduce the probability of transmission errors (see 5.5 and 5.7). The RNC uses selection combining to filter the transmission errors. Every packet of one of the links (UE – Node B) has a quality field in the packet header. The RNC checks this information in every packet it receives from one of the Node Bs and forwards the packet with the best quality to the CN via the Iu-PS interface.

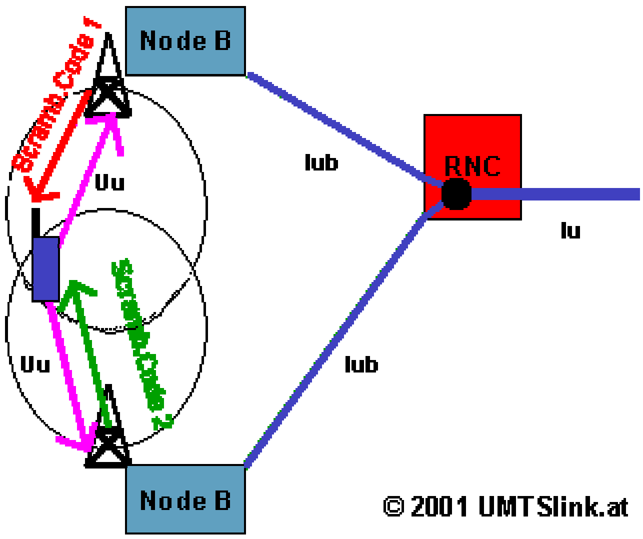

Figure 12 [16]

Figure 13 shows the message flow diagram of a radio link addition in case of an inter Node B/intra RNS handover:

1. When the CRNC decides, based on the measured data from the UE, to establish another radio link it sends the message “radio link setup request” to the Node B (new). The Node B (new) immediately starts receiving uplink data from the UE.

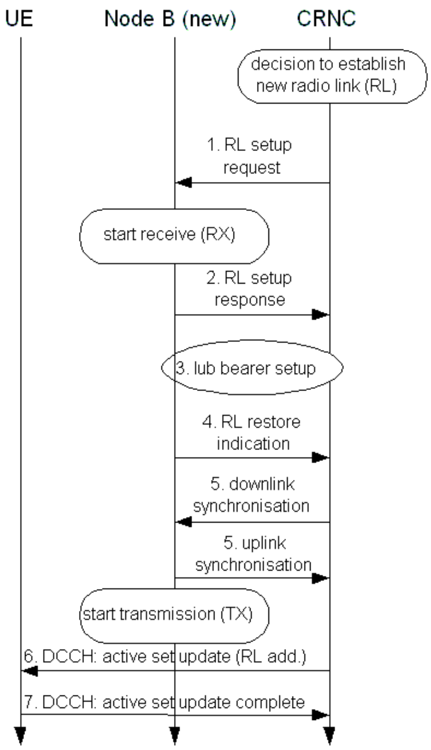

Figure 13 [25]

2. After allocation of the requested resources the Node B (new) sends the message “radio link setup response” to the CRNC including the description of the just established transport layer connection.
3. At this point the CRNC sets up the Iub data transport bearer. This includes the ATM binding identity to bind the Iub data transport bearer to the Dedicated Channel (DCH).
4. After getting uplink synchronization on the Uu interface the Node B (new) notifies the CRNC with the message “radio link restore indication”.
5. The Node B synchronies the already existing data transport bearers with the new by exchanging the messages “downlink synchronization” and “uplink synchronization” with the CRNC. The Node B (new) starts sending downlink data to the UE.
6. The CRNC send the message “active set update (RL addition)” via the Dedicated Control Channel (DCCH) with the appropriate connection information to the UE.
7. The UE updates the active set and confirms this by sending the message “active set update complete” via the DCCH. The new radio link is now added and used to receive and transmit radio signals.

The following figure 14 illustrates the messages exchanged when a radio link is deleted:

1. When the CRNC decides, based on the measured data from the UE [25], to remove one of the radio links from the radio set it sends the message “active set update (RL deletion)” to the UE on the DCCH. Thereby the update type and cell parameters are also transmitted.
2. After deactivating the link the UE sends the message “active set update complete” to the CRNC.
3. Then the CRNC sends the message “radio link deletion request” to the Node B (removed) and deallocates the resources of the old radio link.
4. After stopping the transmission and reception and deallocating the resources the Node B (removed) informs the CRNC by sending a “radio link deletion response” message.

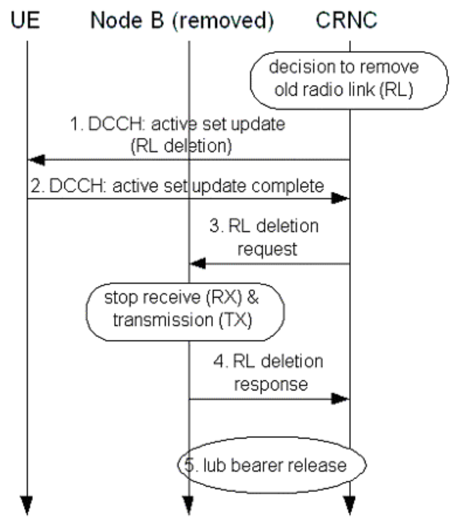

Figure 14 [25]

5. After receiving this information the CRNC initiates the release of the Iub data transport bearer. The radio link is removed.

5.5 Soft Handover (inter Node B/inter RNS/intra SGSN)

If the UE moves from one Node B to another Node B that belongs to different RNS the handover is called soft handover (inter Node B/inter RNS/intra SGSN).

In this case the RNC that passes the data to the SGSN is called serving RNC (SRNC). The other RNC is called drift RNC (DRNC). The DRNC routes the received data transparently to the SRNC. The SRNC uses selection combining to forward the packets with the best quality to the CN via the Iu-PS interface. Selection combining is used instead of maximum ratio combining because RNCs are not able to do the quite difficult calculations for that method.

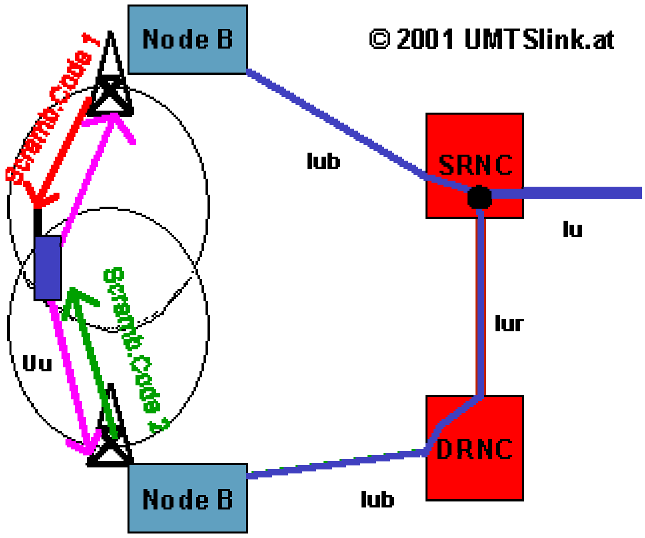

Figure 15 [16]

Only the SRNC has a connection to the CN. When the UE moves too far away from the SRNC a SRNC relocation is executed. The DRNC becomes SRNC and vice versa [17,25].

Figure 16 illustrates the steps for an inter Node B/inter RNS radio link addition [25]:

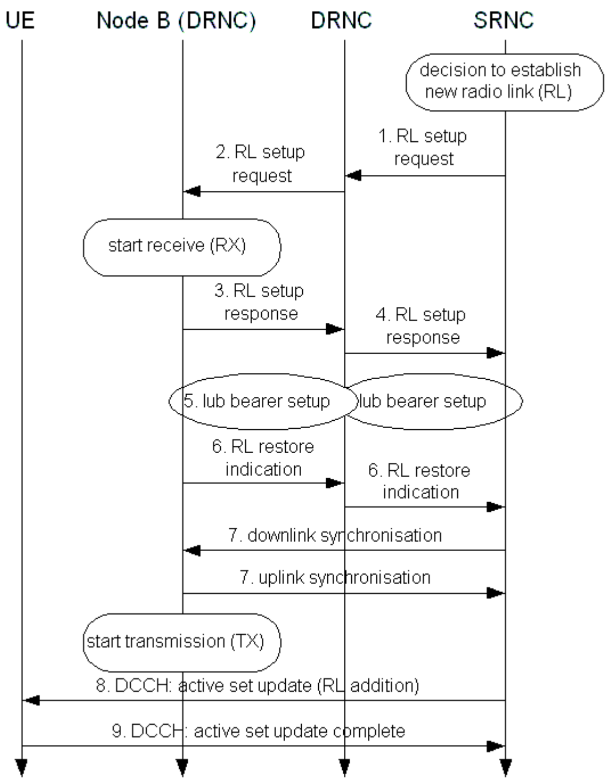

Figure 16 [25]

1. When the SRNC decides, based on the measured data from the UE, to establish another radio link it sends the message "radio link setup request" to the DRNC to request radio resources. If this is the first connection to the UE via this DRNC an Iur connection between SRNC and DRNC is established. Radio bearer and physical channel parameters are signaled to the DRNC.
2. If radio resources are available the DRNC sends the message "radio link setup request" to the Node B (DRNC) with the corresponding parameters. The Node B (DRNC) immediately starts receiving uplink data from the UE.
3. After allocation of the requested resources the Node B (DRNC) sends the message "radio link setup response" to the DRNC together with information about the Asynchronous Transfer Mode (ATM) data transport bearers.
4. The DRNC send the message "radio link setup response" to the SRNC including the description of the just established transport layer connection.

5. At this point the SRNC sets up the Iur and Iub data transport bearer. This includes the ATM binding identity to bind the Iub data transport bearer to the Dedicated Channel (DCH). This is done for every Iur and Iub data transport bearer that must be set up.
6. After getting uplink synchronization on the Uu interface the Node B (DRNC) notifies the DRNC with the message "radio link restore indication". Then the DRNC send the message "radio link restore indication" to the SRNC.
7. The Node B (DRNC) synchronies the already existing data transport bearers with the new by exchanging the messages "downlink synchronization" and "uplink synchronization" with the SRNC. The Node B (DRNC) starts sending downlink data to the UE.
8. The SRNC send the message "active set update (RL addition)" via the Dedicated Control Channel (DCCH) with the appropriate connection information to the UE.
9. The UE updates the active set and confirms this sending the message "active set update complete" to the SRNC via the DCCH. The new radio link is now added and used to receive and transmit radio signals.

In figure 19 a SRNC relocation message flow diagram for the inter Node B/inter RNS/inter SGSN case is shown. In the case in this chapter (Node B/inter RNS/intra SGSN) the steps are the same expect step 2 – 4, 9 and 11. They are left out in the case in this chapter because both RNCs are managed by the same SGSN (SGSN1 = SGSN2 in figure 19).

The following Figure 17 describes the removal of a radio link [25]:

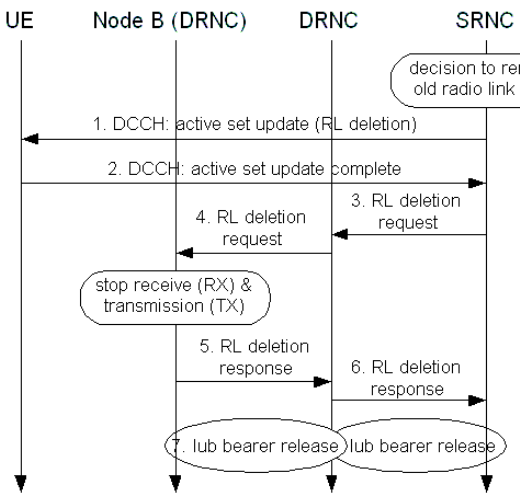

Figure 17 [25]

1. When the SRNC decides on base of the measured data of the UE [25] to remove one of the radio links from the radio set it sends the message "active set update (RL deletion)" to the the UE via the DCCH. Thereby the update type and cell parameters are also transmitted.
2. After deactivating the link the UE sends the message "active set update complete" to the SRNC via the DCCH.
3. The SRNC requests the DRNC to deallocate the resources of the old radio link by sending the message "radio link deletion request".
4. Then the DRNC sends also the message "radio link deletion request" to the Node B (DRNC).
5. After stopping the transmission and reception and deallocating the resources the Node B (DRNC) informs the DRNC by sending a "radio link deletion response" message.
6. The DRNC also send a "radio link deletion response" message to the SRNC.
7. After receiving this information the SRNC initiates the release of the Iur and Iub data transport bearer. The radio link is removed.

5.6 Soft Handover (inter Node B/inter RNS/inter SGSN)

This case is similar to the an inter Node B/inter RNS/intra SGSN soft handover. The UE moves from a cell in one Node B to a cell in another Node B and the Node Bs are connected to different RNCs. These two RNCs are also connected to different SGSNs. If a SRNC relocation is executed in this case also a SGSN relocation has to be performed.

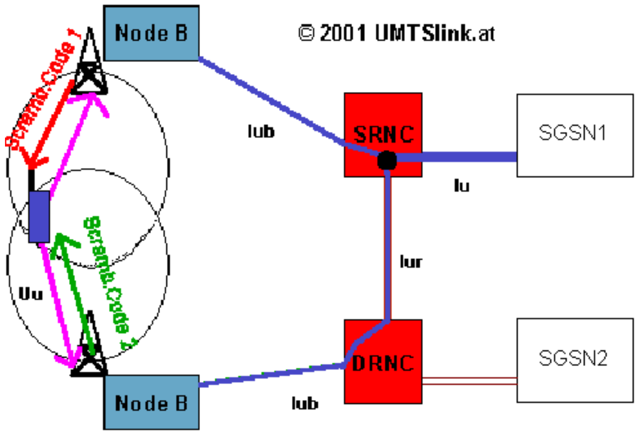

Figure 18 [16]

Figure 19 illustrates a SRNC and SGSN relocation message flow diagram [22,36]:

1. The current SRNC is RNC1. It is connected to SGSN1. RNC1 detects that a relocation to RNC2 is necessary. RNC2 is connected to SGSN2. RNC1 sends an “relocation required” message to SGSN1 to inform it of this decision.
2. In this inter SGSN case step 2 – 4 are executed. They are responsible for the SGSN relocation. With the message “forward relocation request” SGSN1 sends the Mobility Management (MM) and Packet Data Protocol (PDP) context of the UE to SGSN2.
3. To establish the Iu user plane transport bearers between SGSN2 and RNC2 both exchange a ”relocation request” and a “relocation ack” message. By doing this they also exchange the routing information needed to deliver the packets.
4. SGSN2 send the message “forward relocation response” to SGSN1 to indicate that SGSN2 and RNC2 now are ready to receive downstream packets buffered in RNC1. That can be packets that are yet not acknowledged by the UE.
5. The message “relocation command” is sent by SGSN1 to RNC1 to instruct RNC1 to forward the buffered downstream packets to RNC2. Until here the CN is prepared for the new path by allocating resources. Packets are still routed through the old path.
6. RNC1 starts the data-forwarding timer when it receives the message “relocation command”. In step 12 the expiration of this timer is checked. RNC1 sends the message “relocation commit” to RNC2. This message provides information about the packets buffered by RNC1 (for example sequence numbers) that must be tunneled to RNC2. RNC1 stops transmitting packets to the UE and forwards all packets it gets (from the GGSN) to RNC2. RNC2 switches all bearers from RNC1 to the SGSN.
7. Immediately after RNC2 is switched from RNC1 in step 6 successfully RNC2 sends the message “relocation detected” to SGSN2. With this message SGSN2 knows that RNC2 is now SRNC and the CN has to route the packets to RNC2 from now on.
8. RNC2 restarts the RLC connection to the UE. By using the “UTRAN mobility information” and “UTRAN mobility information confirm” messages they exchange information to identify the last upstream packets received by RNC2 and the last downstream packets received by the UE. Other information like RA, LA and other RRC information can also be transmitted by this message. If necessary an RA update procedure is executed. The confirmation message is sent by the UE when it has reconfigured itself. The packet exchange between RNC2 and the UE can start at this point. While the steps 6 – 8 are executed the packet exchange between the UE and the network is stopped for loss-less relocation. The connection to the UTRAN is moved from RNC1 to RNC2.

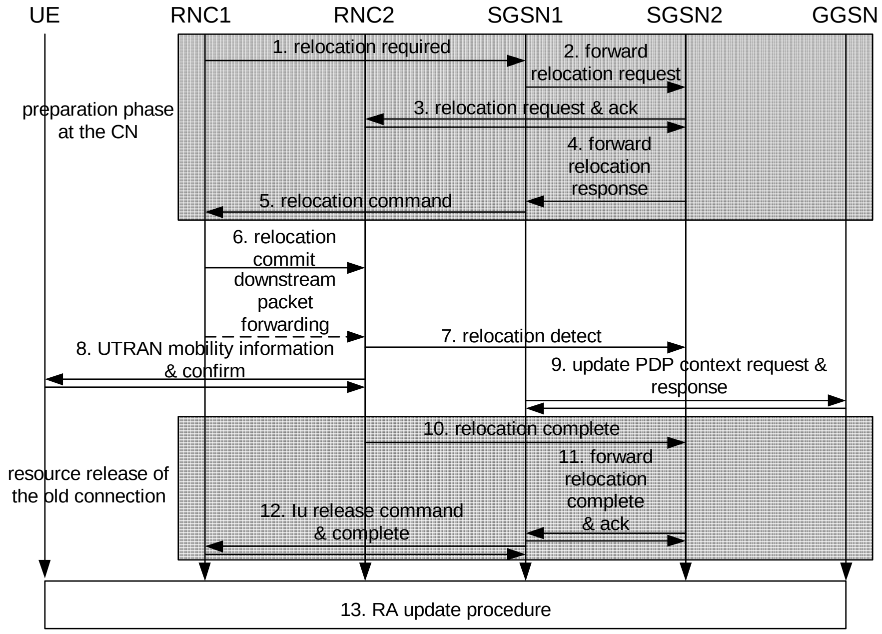

Figure 19 [22]

9. In this inter SGSN case here after the execution of step 7 the user plane is switched from RNC1 to RNC2 by the SGSN2. SGSN2 and the corresponding GGSN exchange the messages “Update PDP Context Request” and “Update PDP Context Response”. They modify the GGSN address, tunnel endpoint identifier (TEID) and Quality of Service (QoS) settings stored in the GGSN PDP context. The GGSN connection is switched from SGSN1 to SGSN2.
10. After executing step 8 RNC2 sends the message “relocation complete” to SGSN2. This initiates the release of the resources of the old Iu connection.
11. Because of the inter SGSN handover situation here SGSN2 demands SGSN1 to release the old Iu connection by sending the message “forward relocation complete”. SGSN2 confirms this by sending the message “forward relocation ack” back.
12. SGSN1 instructs RNC1 to release the Iu connection by sending the message “Iu release command”. When the data-forward timer set in step 6 expired RNC1 releases the old Iu connection and confirms this by sending the message “Iu release complete”.
13. At this point a RA update procedure completes the relocation [22]. This work will not focus on this further.

5.7 Advantages and disadvantages of soft handover/W-CDMA

Some of the advantage of soft handover are already mentioned in the chapters above, especially in chapter 5.1 “Macro Diversity”. But there are also some more advantages of soft handover in W-CDMA networks compared with TDMA/FDMA networks like GSM [16,26]:

- Speech quality:
  The speech quality is very good. The handover is seamless and the frequency is not changed. One or even more connections from the UE to the UTRAN are up all the time. There is no short interruption of the data transfer when a connection to one cell is released. Transmission errors can be detected and corrected very well because the UTRAN receives the radio signal from different locations and can use just the signal of the cell that currently has the best radio link to the UE. In this case especially in buildings, radio signal reflections by walls etc. can better be filtered by the UTRAN. The probability that many radio links at the same time are disturbed is very low.

- Power saving:
Because of the possibility to correct transmission errors easily by comparing the signals received by the different antennas from the UE a higher transmission error rate in each link can be compensated. Hence the transmission power level can be lower than in networks or situations with only one radio link to the network. This saves power. UEs can work longer with same battery power.
- Lower transmission power level:
Because of the effect described above the transmission power level of the UE and the cells is normally lower than it could be with only one radio link only. This reduces possible adverse health effects and reduces the possibility of disturbing other systems.
- No ping-pong effect:
Because an UE can have more than one connection it is not possible that a UE located in the middle of two cells often does a (hard) handover between these two cells.
- Frequency planning and network expansion:
Because in W-CDMA all participants use the same frequency no detailed frequency planning is needed. New cells can be added easily because no new frequency planning is needed when expanding an existing network.

But the technology of soft handover in a W-CDMA network also has disadvantages compared to TDMA/FDMA networks like GSM [16,26]:

- Costs of computation:
Especially in a softer handover (intra Node B/intra RNS) many arithmetic exercise has to be done by the Node B to do the maximum ratio combining. The UE also has to do this work. Even in other soft handover cases the cost of computation by the SRNC to do the selection combining are quite high compared to hard handover. For the latter combining is not needed (see 5.5). This computations cost power and hardware.
- Complex to implement:
The implementation of the different soft handover scenarios in the UTRAN is more difficult than hard handover only. The firmware/software of the UE is also much more complex because it must be able to handle many radio links with different scrambling codes and has to do maximum ratio combining. UE and UTRAN have to adjust permanently the transmission power level to reduce interferences with other participants. For more detailed description of the problems that may occur at high transmission power levels see chapter 5.1 “Macro Diversity”.

6. Mobility in other networks

6.1 Handover in GSM

Unlike UTMS GSM only supports hard handover with a change of the frequency. A MS (mobile subscriber, MS is equivalent to UE in UMTS) is always connected to one BTS (base transceiver station, BTS is similar to Node B in UMTS) only at the same time. Due to this there is a short delay that can be up to 60ms long while a handover is in progress [27].

Like in UMTS there are several cases of handovers depending on the systems involved. These cases are quite similar to those in UMTS. Because in GSM macro diversity is not possible there is one handover type more than in UMTS that is called intracell handover. If the radio channel within the cell the MS uses suddenly is disturbed an intracell handover is done to change the frequency the MS and BTS use to communicate. Figure 21 shows the message flow diagram of an GSM handover [27]. In this case the new BTS belongs to an other BSC (base station controller) than the old one. BSC is similar to RNC in UMTS. MSC is also called MSC in UMTS (see 4.3).

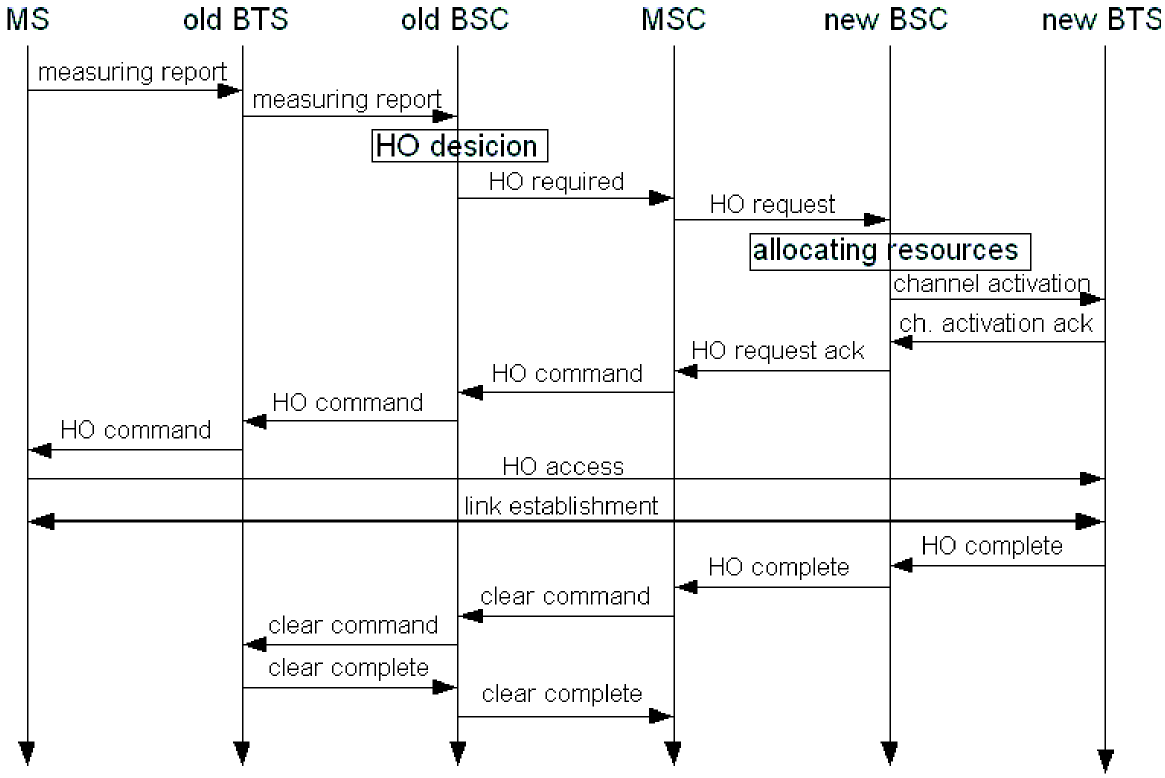

Figure 21 [27]

6.2 Handover in WLAN

A WLAN consists of one or many access points (APs). Each of them covers an area around it. These areas may overlap.

Each APs is connected to a fixed IP based network. A mobile station (MS) that connects to an AP usually gets an IP address of the subnet the AP resists in by Dynamic Host Configuration Protocol (DHCP). The different APs can be located in different subnets. Every AP connects the mobile station to the own subnet wireless.

To support handover of MSs between different APs there exist two different methods in WLANs. The IEEE 802.11f Inter Access Point Protocol (IAPP) defines a layer two handover mechanism that works if all APs belong to the same subnet. It was especially designed for WLANs. In difference to this method Mobile IP is more general approach to solve mobility problems in IP networks and is not specially designed for WLANs only. Both methods are quite new and development especially of further features finally leading to industry wide standards is still in progress:

- IEEE 802.11f Inter Access Point Protocol (IAPP):
  This protocol supports roaming and handover of MSs between different APs that belong to the same IP subnet [28]. The IP address of the MS is always the same regardless of which AP it is connected to. IAPP has been a proprietary standard developed in different ways and implementations [29] by some companies that is now further developed and leads to IEEE 802.11f [28].

  Because IEEE 802.11f still seems to be in development [30] this work further focuses on an IAPP implementation in the ORiNOCO product line [31,32] by “Agere Systems' wireless LAN equipment business” that was bought by Proxim Corporation [31,32].

There are two main parts of this IAPP. The first is the IAPP Announce Protocol, it is used to provide the information about all APs for all other APs:

1. If an AP starts up it sends an announce request message to an IP multicast destination address via defined UDP group addressing. This indicates that the AP is up and demands the other APs to answer.
2. The other APs answer with an announce response carrying among other things the IP address and the BSSID of the AP. The starting AP builds a BSSID-to-IP table with this information.
3. When the new AP has received announce responses from all other APs it sends also an announce response that indicates that the new AP is operational. The other APs add him to their BSSID-to-IP table.
4. After some time every AP reissues an announce response to inform all other APs about any changes in its status.

The second important part is the IAPP Handover Protocol. A handover is always initiated by the MS:

1. When a MS moves away from its current (old) AP it issues a re-association request to the new AP.
2. If the new AP accepts this request it sends a re-association response to the MS and starts the service for this MS although the handover procedure has not finished yet.

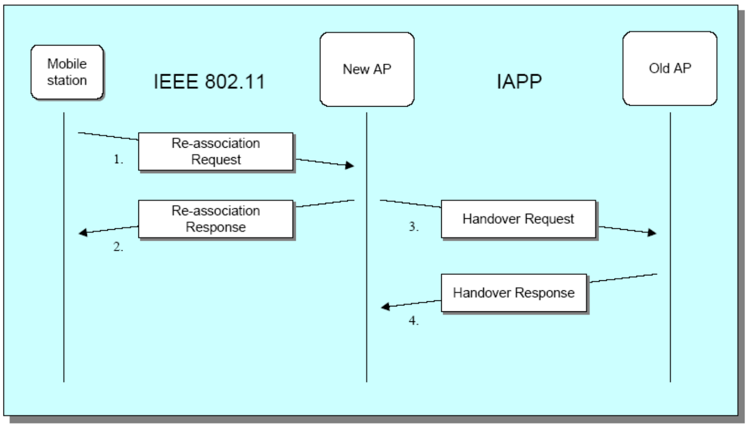

Figure 21 [31]

3. Based on the information the new AP got by the re-association request (for example the BSSID of the old AP) it looks up the IP of the old AP in its BSSID-to-IP table and sends an handover request with a sequence number to the old AP.
4. The old AP sends a handover response also with this sequence number to the new AP. The handover is completed at this point.

- Mobile IP (RFC 2002, 3344 and more for IPv4):
  Mobile IP was the first protocol purposed to maintain the IP connection with a mobile node (MN) even while moving from one subnet to another that allocates a new IP address to the MN [33]. Mobile IP takes care that the MN is always reachable by the same IP address for other devices in the network even while moving from one AP to another. Mobile IP is a general approach to solve mobility management problems in an IP network with different subnets and not specially developed for WLANs. Thus it can be implemented in other techniques too. In Mobile IP the decision to initiate a handover is again made my the MN. Mobile IP itself just detects that the MN has changed the subnet and asks for a new care-of address and reregisters at the HA (see below) [35]. This work describes with Mobile IP for IPv4 [34]. In IPv6 the protocol was developed further with the new capabilities of IPv6.

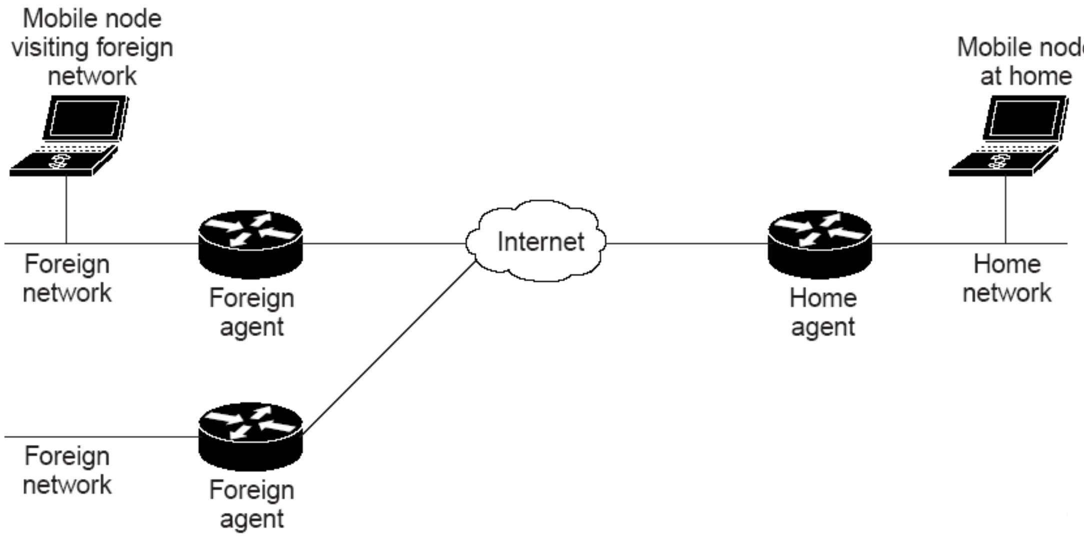

Figure 22 [34]

Mobile IP comprises the following three components:

- Mobile Node (MN):
  This can be for example PDA, notebook or a data-ready mobile phone. The MN can move free within the network and is able to change its point of attachment from one subnet to another while it still can be reached by its home IP address.
- Home Agent (HA):
  The HA is a router located in the home network of the MN. It forwards and tunnels IP packets to the MN if the MN is currently located in a foreign network. To do this the HA knows the IP address of the MN in the foreign network. The MN got this IP address in the foreign for example by DHCP. This IP address is called care-of address.
- Foreign Agent (FA):
  The FA is a router located in the foreign network. It assists the MN by informing its HA of its current care-of address. The FA delivers IP packets to the MN that are tunneled and forwarded to the current care-of address by the HA of the MN. It is also the default router for the MN as long as it is connected to this foreign network. The packets sent by the MN are routed directly to the receiver without a detour via the HA.

The Mobile IP process consists of mainly three parts:

- Agent Discover:
  During this phase all HA and FA advertise their presence by multicasting or broadcasting. On base of this information a MN determines if it is located in a foreign network or in its home network. A MN does not need to wait for this advertisements. It can also request an advertisement of the FA by sending a so called “agent solicitation”. If the MN resides in a foreign network it requests a care-of address. This is a temporary IP address for the MN in this subnet.
- Registration:
  In this phase the MN registers itself with its current care-of address at his HA. The HA uses the mobility binding table to map the home IP address of the MN to its current care-of address.

- Routing:
  Mobile IP routes the traffic in a triangular manner. When an IP device, called corresponding node (CN) sends a packet to the MN the HA receives this packet and redirects and tunnels this packet to the care-of address of the MN. The FA of the MN detunnels the packet and forwards it to the MN. Packets send by the MN are routed directly to the CN by the FA without using the HA.

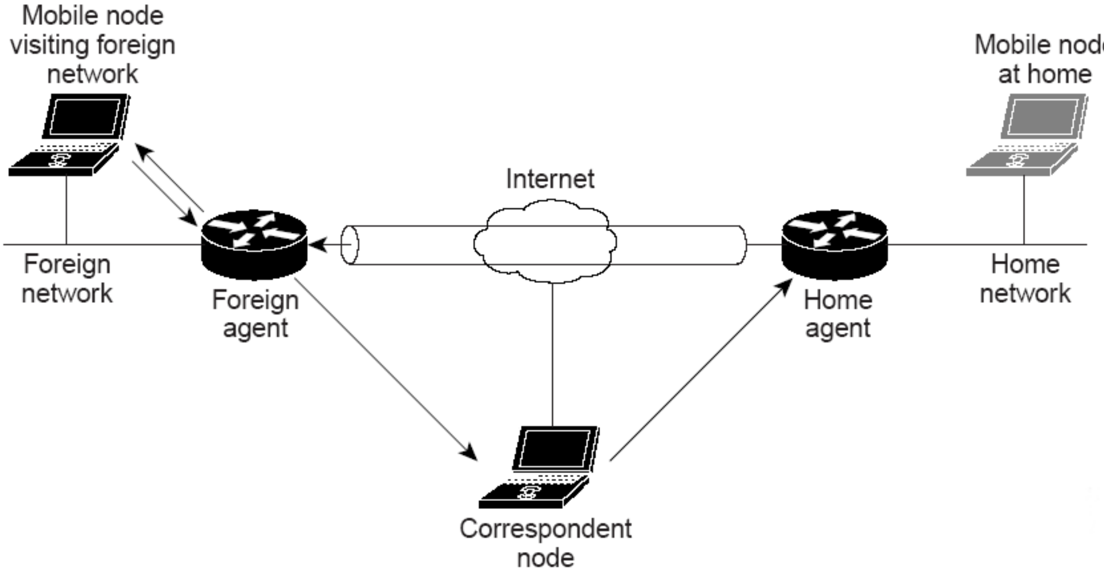

Figure 23 [34]

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