Escola Politècnica Superior de Castelldefels
UNIVERSITAT POLITÈCNICA DE CATALUNYA

# TREBALL DE FI DE CARRERA

**TÍTOL DEL TFC: The new enhancement of UMTS: HSDPA and HSUPA**

**TITULACIÓ: Enginyeria Tècnica de Telecomunicació, especialitat Sistemes de Telecomunicació**

**AUTOR: Marc Esquius Serra**

**DIRECTOR: Ari Rantala**

**DATA: 11 de desembre de 2007**

# FINAL THESIS

**Author:** Marc Esquius Serra

**Supervisor:** Senior lecturer Ari Rantala

**Name of the thesis:** The new enhancement of UMTS: HSDPA and HSUPA

**Date:** 11-12-2007

**Number of pages:** 77

**Degree programme:** Telecommunication Engineering

**Specialization:** Telecommunication Systems

# ABSTRACT

During the last two decades, the world of the mobile communications grew a lot, as a consequence of the increasing necessity of people to communicate. Now, the mobile communications still need to improve for satisfies the user demands.

The new enhancement of UMTS in concrete HSDPA and HSUPA is one of these improvements that the society needs. HSDPA and HSUPA which together are called HSPA, give to the users higher data rates in downlink and uplink. The higher data rates permit to the operators give more different types of services and at the same time with better quality. As a result, people can do several new applications with their mobile terminals like applications that before a computer and internet connection were required, now it is possible to do directly with the mobile terminal.

This thesis consists in study these new technologies denominated HSDPA and HSUPA and thus know better the last tendencies in the mobile communications. Also it has a roughly idea about the future tendencies.

# TREBALL DE FI DE CARRERA

**Autor:** Marc Esquius Serra

**Director:** Ari Rantala

**Nom del treball de fi de carrera:** The new enhancement of UMTS: HSDPA and HSUPA

**Data:** 11-12-2007

**Número de pàgines:** 77

**Titulació:** Enginyeria Tècnica de Telecomunicació especialitat en Sistemes de Telecomunicació

# RESUM

Durant les dues dècades passades, el món de les comunicacions mòbils ha crescut molt i com a conseqüència hi ha hagut un increment de la necessitat de comunicar-se entre les persones. Actualment, les comunicacions mòbils necessiten un millorament tant en taxes de transmissió com utilitats per satisfer les demandes dels usuaris.

El nou millorament de UMTS, en concret HSDPA (High-Speed Downlink Packet Access) i HSUPA (High-Speed Uplink Packet Access) , es una de les millores que la societat necessita. HSDPA i HSUPA conjuntament s'anomena HSPA (High-Speed Packet Access). HSPA dóna als usuaris altes taxes de transmissió d'informació tan en el enllaç de baixada com en el de pujada. Aquestes altes taxes de transmissió permeten als operadors oferir millors i més serveis als clients. Gràcies al nou millorament, la gent pot fer ús de més aplicacions i amb millors condicions que abans i tot això amb el mateix dispositiu mòbil. Entre les noves aplicacions hi ha internet a altes velocitats, videoconferències, descàrregues en temps real...

Aquest treball de fi de carrera consisteix en fer un estudi d'aquestes noves tecnologies anomenades HSDPA and HSUPA i així conèixer millor les últimes tendències en les comunicacions mòbils.

# PREFACE

Actually, there are three different implemented generation of mobile radio systems. The first generation (1G) is referred to semi-analogue mobile networks established in the middle of 1980's, for example networks as Nordic Mobile Telephone (NMT) system and the American Mobile Phone System (AMPS). These networks only offer a basic voice services and they are incompatible with each other. People considered, at that time, a kind of curiosity these mobile communications but in short term, the need of mobile communications in increase takes to improve this communications towards global solutions. This global solution is Second Generation (2G), which goal of 2G it was proportionate mobile communications with compatibility with all the different network communication, but at least it obtained semi-global solutions for example the same solution for all Europe.

The first public Second Generation or also Global System for Mobile Communications (GSM) call was made on 1 July 1991 in a city park in Helsinki, Finland. GSM was so attractive because it offered a "nice packet" to be bought which included voice service and also data service and a lot of new applications. Due this fact, GSM was and is a successful mobile system communications so a truly global system. One results of this successful system is the percentages of cellular phones, in many countries is more than 70% of the people has a mobile phone and in the Nordic countries is approaching 90%. In addition of that, the total amount of GSM mobile terminals, nowadays, is higher than the fixed phones and this difference every day is increased.

In the way to obtain a really global mobile system communications, a decade later of GSM, appear the Third Generation (3G) mobile radio system or also called Universal Mobile Telecommunication System (UMTS). In addition of that, it is important to know that between GSM and UMTS appeared two standards called GPRS and EDGE which started to use the packet transmission system, this fact, helps UMTS to develop. UMTS is completely compatible with GSM and for that both technologies will live together at least a lot of years. The goal of UMTS is satisfy the new necessities of end users, offering the possibility to obtain new services like videoconference, video stream, music, internet connection… and also be competitive versus new technologies like Wimax or Wi-Fi.

Nowadays, UMTS is fighting for open a space inside of mobile communications market and try to a major part of GSM users change to a UMTS. For get this objective, all the time the companies are working for improve the services, and in this way, is the topic of this project. High-Speed Downlink or Uplink Packet Access (HSDPA and HSUPA) both considered as 3.5 Generation and 3.75 Generation respectively, these protocols are working for obtain a higher rates of data transmission which can be compared with rates of Wimax or Wi-Fi.

In HSDPA and HSUPA project, first this is an overview of UMTS and then we focused in make a study about these two protocols which in the future all of us will use.

# ACKNOWLEDGEMENTS

First acknowledgements are for Tampere Polytechnic for give me the opportunity to come to Tampere for do my final thesis as an Erasmus student. I would like to thank my supervisor Mr Ari Rantala for his guidance during the all thesis process. Also special thanks to my family for make it possible and give me support every time.

Marc Esquius Serra
Tampere, 11 of December of 2007

# INDEX

# PART 1:

# UNIVERSAL MOBILE TELECOMMUNICATIONS SYSTEM (UMTS)

# 1. Introduction UMTS

UMTS is developed by 3GPP (3 Generation Partnership Project), it is an agreement of collaboration between different countries. It was founded in December of 1998 and the associations which takes part in this agreement are: ETSI (Europe), ARIB/TTC (Japan), CCSA (China), ATIS (USA) and TTA (South Korea). This group has 4 UMTS standardizations areas in April 2007, Radio Access Network, Core Network & Terminals, Services and System Aspects and GERAN (Figure .1).

3GPP use in addition of the number of mobile generation system a release number describing the specification collection. The first version of UMTS network takes de official name “3GPP System Release 99”.

UMTS use an advanced access technology, WCDMA (Wideband Code Division Multiple Access) and it works in the frequency band around 2GHz. WCDMA increase the transmission rates using CDMA for access technology instead TDMA, this change contributes to improve other aspects like more flexibility in number of users and services due to CDMA proprieties.

In summary, UMTS offers the following aspects:

- Easy use, more services and low costs: UMTS proportionate easy and more services for satisfy the costumer necessities, at the same time, offering a high quality in function of people willing to pay. In addition, there will be a huge amount of different UMTS user terminals for adapt all kind of costumers. All of that, in a low price for assure a massive market.
- Fast access: The main advantage of UMTS versus GSM is that in UMTS is able to get transmission rates of 144 kbps on fast movement vehicles or rural area, 384kbps in urban outdoor and in the best conditions it is possible to obtain rates upper than 2Mbps. All the information will travel through Internet Protocol (IP) but know it still uses other kind of protocols. These rates are increased due HSDPA and HSUPA until rates around 14 Mbps.

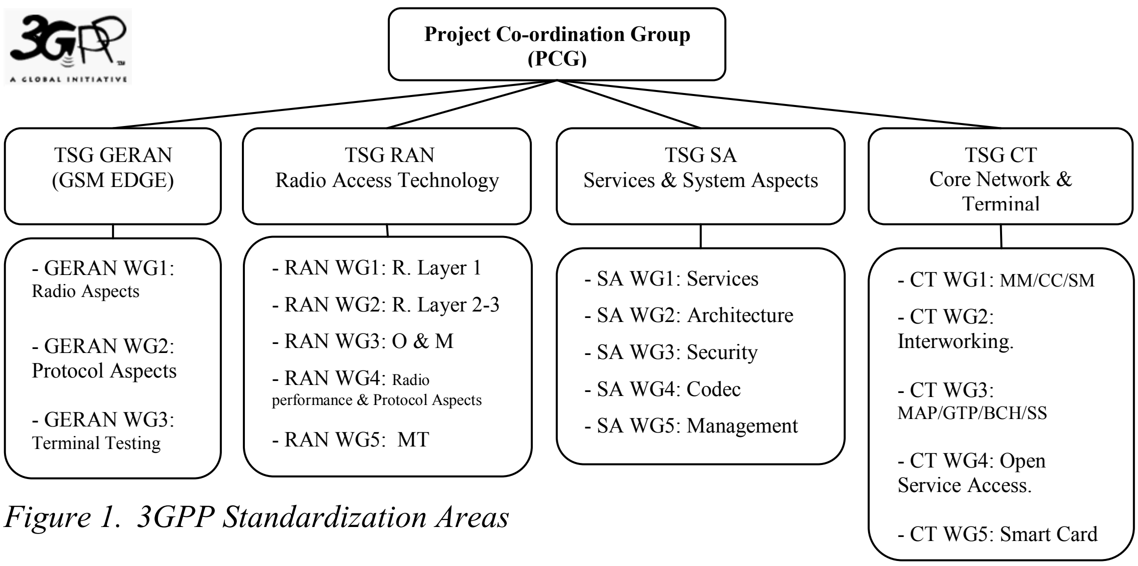


*Figure 1. 3GPP Standardization Areas*

## 1.1 WCDMA in third generation systems and other Radio Access Technologies

UMTS has different radio access technologies and methods due that, it is a mixture of selected technologies and the trend is make a kind of standardization for be able to use the best access technology at each time for to enjoy adequate coverage and services may have to adequate spectrum and platform for their functions.

Currently, the 3GPP recognize three main access technologies:

- WCDMA and its variants, like FDD the most meaningful as far as UMTS concerned. In addition, WCDMA is to be enhanced with High Speed Download Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA).
- Second Generation radio access technology.
- Complementary accesses. Here are all the complementary networks joined with UMTS network. The most important is WLAN and in the future it will play an important role.

### 1.1.1. WCDMA

The main radio technology employed in UMTS is WCDMA whose variants FDD (Frequency Division Duplex) and Time Division Duplex (TDD) were selected by the European Telecommunication Institute (ETSI) in 1998.

WCDMA is a wideband Direct-Sequence Code Division Multiple Access (DS-CDMA) system and it works doing a spreading over a wide bandwidth of the user information bits. The spreading consist in multiply the user information with a quasi-random bits (called chips) derived from CDMA spreading codes. WCDMA uses different codes or spreading factor in function of the user necessities and in this way WCDMA is able to adapt the information to a high transmission rates, upper than 2 Mbps. This basic process makes WCDMA more robust, flexible and resistant to interference, and strong against jamming and adversary interception.

Before explain more aspects of WCDMA, we explain in brief description how it works Spreading and Despreading. User data is assumed to be a BPSK-modulated bit sequence of rate R, and with values of +/- 1. The spreading operation it can be explained with the following example is the multiplication of each user data bit with a sequence of 8 code bits, called chips. The resulting spread data is at a rate of 8 X R and has de same random appearance as the spreading code. In this example we can say that we are using a spreading factor of 8, and this spread data can be transmitted towards the radio interface.

The despreading operation consist in multiply the received signal with the same code that we make the spreading in bit duration by bit duration, that means, we need a correct synchronization between the signal and the codes. These CDMA codes must be orthogonal because we want to obtain maximum level of our signal and minimum level of the interference signal, in other words the autocorrelation with different codes must be 0 and this is the ideal situation. OVSF-Code (Orthogonal Variable Spreading Factor Code) is used for create orthogonal codes. Actually, it does not possible to use orthogonal codes because there are too less and too many users but it is possible to use codes that seems almost orthogonal, these codes are called Gold codes, M codes, Kasami…

The increasing of the signalling rate by factor of 8, in our example, corresponds to a widening in a factor of 8 the occupied spectrum of the spread user data signal which can be due spreading action.

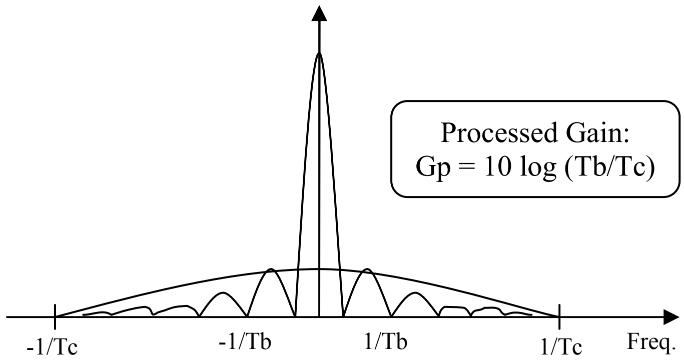


*Figure 2. Spectrum after multiply despreading code*

This fact, permit have all the signals occupying all the bandwidth and during all the time without any distinction between information signal and interference signal. The increase happened in the despreading; the data signal is increased in order of the processing gain which depends of the duration of the bit and duration of the chip. In the figure 2 shows schematically the spectrum after despreading of the one user information. This information can be read by the receiver if the relation between power density of signal and interference is upper than sensitive of receiver, this relation is expressed by Eb/No (Eb is the energy of bit and No power density of interference and noise) or C/I (carrier to interference). For example C/I for GSM system is around 9-12 dB.

The chip rate of 3.84 Mcps leads to a carrier bandwidth of approximately 5 MHz. DS-CDMA systems with a bandwidth of about 1 MHz, such as IS-95, are usually referred to as narrowband CDMA systems. WCDMA with the wide bandwidth can support high user data rates and some other benefits like increased multipath diversity. The network operator can deploy multiple 5 MHz carriers to increase capacity.
In the following table 1 shows the main WCDMA parameters:

| | |
|---|---|
| **Multiple access method** | DS-CDMA. |
| **Duplexing method** | FDD / TDD. |
| **Base station synchronisation** | Asynchronous operation. |
| **Chip rate** | 3.84 Mcps. |
| **Frame length** | 10 ms. |
| **Service multiplexing** | Multiple services with different QoS requirements multiplexed on one connection. |
| **Multirate concept** | Variable spreading factor and multicode |
| **Detection** | Coherent using pilot symbols or common pilot. |
| **Multiuser detection, smart antennas** | Supported by the standard, optional in the implementation. |

*Table 1. Main CDMA parameters*

After have an idea about how WCDMA treat the information stream, is necessary to allocate with a brief description where WCDMA takes part. WCDMA appear when the transmitter has the information of the user, this information needs to be changed by

WCDMA due to it has to travel in a radio interface. Next step is, this information has to be modulated for can be sent it throw the radio path. The information is transmitted as symbols as a consequence of the modulation, depending of the modulation one symbol can be one or more bits. In case of DS-CDMA-FDD, one symbol transmitted in an uplink direction represents one bit and 1 symbol transmitted in the downlink direction represents two bits. In the reception appear the opposite steps, first demodulation of the signal and after that despreading of the signal in the same way to it was explain above.

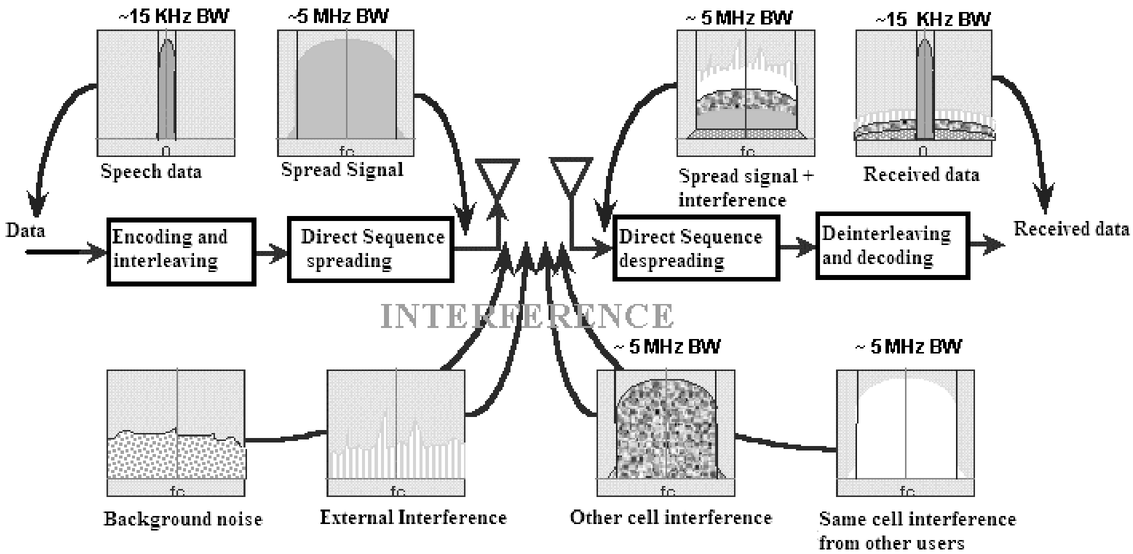


*Figure 3. WCDMA scheme*

Continuing with the benefits, WCDMA has the maximum spectral efficiency because the frequency reuse is 1 between different cells, it means that every cell can use all the available frequencies. WCDMA cells does not have a fixed capacity, in function of the users the cells can breath, it means that if the cell is crowded the radio of the cell decrease and if it is free increase, all of that for keep a good Eb/No in all the communications.

All this benefits require the use of tight *Power Control* and soft handover to avoid one user's signal blocking the others. Power control is perhaps one of the most important aspects in WCDMA, in particular uplink. Without it, a single overpowered mobile could block a whole cell. The main problem which solve the power control is so-called near-far, this problem consist when for example one mobile next to the mobile station is transmitting with the same power than other who is 10 km far away, the first one makes shadow to the second one and the communication is impossible. In a brief description, power control consist in take information about the radio link from the mobile station and user terminal, with these information the network calculate the correct power that requires the communication and this power value is transmitted to the users. The frequency that the network can command the users to modify the power is 1.5 kHz and this is faster than all the changes which the path loss can suffer. Power value depends of the distance between station and user, charge of the network and other specific information. In addition of that, the correct value is the power which if you use more power of this value the quality of the communication does not increase.

Soft Handovers the user terminal is moving around the border of radio coverage of two cells, consist in a overview, in change the base station seamless for the user because the old base station is too far away for transmit correctly the information and the user needs to connect with a close one. First step is the mobile terminal and network realize that receive too low power and the network give the order to change the base station, then the user terminal connect to the closest base station but it is already connected with the last one, it spent some time connected with two base station and finally mobile terminal disconnect from the old base station. In addition, WCDMA uses more types of handover, these types are Inter-Frequency hard handover when the network change between two frequency carriers or Inter-System hard handover when the communication jump between two different technologies like WCDMA FDD to WCDMA TDD or GSM.

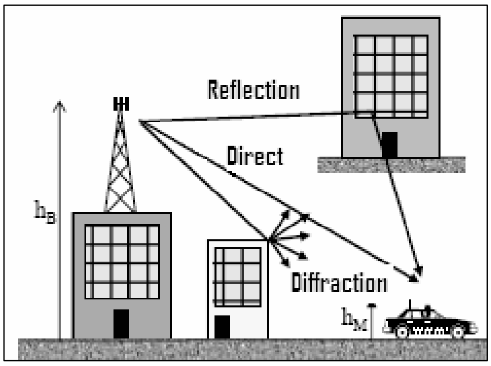

*Figure 4. Multipath reception Scheme.*

Finally of WCDMA introduction, we have to mention that all the signals travel in a radio link affected by multiple reflections, diffractions and attenuation of the signal energy. These effects are caused by obstacles such as buildings, hills, walls… and for that, this problem is called multipath propagation. WCDMA fights against this problem using a special receptor so-called Rake Reception, this receptor catch the most energy reflections, and combine them coherently all the reflection which delay must be at least 26 μs the difference between the direct rays. The resulting signal is more powerful and in conclusion it is better for data treatment.

### 1.1.2. Second Generation radio access technologies

TDMA is the radio access technology of the 2nd Generation Systems, GSM and EDGE (Enhanced Data Rate for GSM Evolution) use the same.

In overview, TDMA (Time Division Multiple Access) is an access method which allows several users to share the same frequency channel by dividing the signal into different timeslots. The users transmit in rapid succession, one after the other and each one using their own timeslot. TDMA frame structure showing a data stream divided into frames and those frames divided into timeslots.

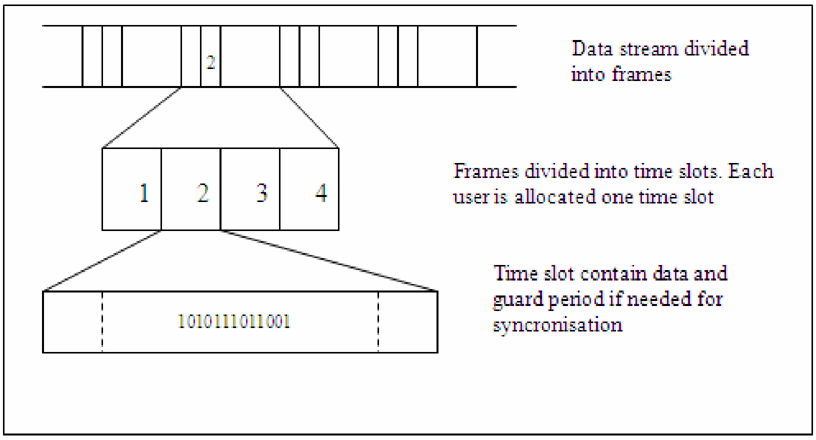

*Figure 5. TDMA scheme*

The uplink and downlink must be separated, this separation consist in use two different frequencies band one for the uplink and the other for the downlink.

Main characteristics of TDMA:

- Share single carrier frequency with multiple users.
- Slots can be assigned on demand in dynamic TDMA.
- Non-continuous transmission makes handoff simpler.
- Less demanding power control than CDMA.
- Higher synchronization overhead than CDMA.
- Advanced equalization is necessary for high data rates.
- Cell breathing is more complicated than CDMA.
- Complexity in frequency / slot allocation.

In one side the advantage of TDMA is that the radio part of the mobile only needs to listen and broadcast for their own timeslot, for this, the rest of the time the mobile has not to listen the network. This fact, permit a safe inter frequency handovers which is difficult to do in CDMA. For the other side, a disadvantage of TDMA systems is that they create interference at a frequency which is directly connected to the timeslot length. This is the annoying sound which can sometimes be heard if a GSM phone is left next to a radio or speakers. Another disadvantage is the higher demanding of timing setting because the mobile terminal is not fixed anywhere and this cause a constantly adjust of their timings. The consequence of this problem is that TDMA systems have hard limits on cell sizes in terms of range.

### 1.1.3. WLAN radio access technology

WLAN uses as a radio access technology CSMA/CA (Carrier Sense Multiple Access with Collision Detection) and TDMA. TDMA is explained above and now we will give an idea about how it works CSMA/CA.

CSMA/CA is the technique used in Ethernet networks for improver their features. The idea is that all the devices which have some information for transmit first of all they have to use the mode “listen before transmit”, this signifies that the devices have to know if the radio link is used by other communications or not.

"Carrier Sense" describes the fact that a transmitter listens for a carrier wave before trying to send. That is, it tries to detect the presence of an encoded signal from another station before attempting to transmit. If a carrier is sensed, the node waits for the transmission in progress to finish before initiating its own transmission. "Multiple Access" describes the fact that multiple nodes send and receive on the medium. Transmissions by one node are generally received by all other nodes using the medium. “Collision Detection” describes the fact that concurrent transmissions by multiple nodes results in frame collisions. The multiple transmissions interfere with each other so that all are distorted and the receiver can not distinguish the overlapping signals. It is impossible to prevent collisions in CSMA networks, but for this there are different ways to address them and one of them is CSMA/CA.

In pure CSMA, only the carrier sense is used to avoid collisions. If two nodes try to send a frame at nearly the same time, it is undetectable so both begin transmitting. The transmitters do not detect collisions, so transmit the entire frame (thus wasting the bandwidth used). Receivers cannot distinguish between collisions and other sources of frame errors, so collision recovery relies on the ability of the communicating nodes to detect frame errors and invoke an error recovery procedure. For example, the receiver may not send a required ACK, causing transmitters to time out and retry.

In Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), each node listens the channel to see if it is free for transmission. If the channel is actually free, the node begins the transmission with the first data frame. However, collisions are still possible.

## 1.2 Spectrum allocations for Third Generation systems

Assignation of the frequencies for Third Generation Systems started in 1992 when the World Administrative Radio Conference (WARC) of the ITU (International Telecommunication Union) identified the frequencies around 2 GHz it could be used for mobile systems. The first idea was to use the same frequencies in all parts of the world but it was impossible.

The spectrum allocation is different between some geographical situations. In the initials in Europe and most of Asia the IMT-2000 (or WARC-92) bands of 2 x 60 MHz (1920-1980 MHz plus 2110-2170 MHz), channel spacing is 5 MHz and raster is 200 kHz, will be able for WCDMA FDD. The TDD spectrum in Europe varies: it is expected that 25 MHz will be available for licensed TDD use in the 1900-1920 MHz and 2170-2200 MHz bands. In addition, remember that FDD systems use different frequency bands between uplink and downlink, separated by the duplex distance, while TDD systems utilize the same frequency for both.

In Japan, Korea and the rest of Asia, the WARC-92 band is available for IMT-2000. Japan has developed a second generation system called PDC and part of the IMT-2000 TDD spectrum is used by PHP, the cordless telephone system and for Korea side has developed IS-95.
In America use PCS (Personal Communication Systems) in two channels of 60 MHz each one, the uplink band is 1850-1910 MHz and the downlink band is 1930-1990 MHz. The next figure 6 shows the summary of 2 GHz band in different allocations.

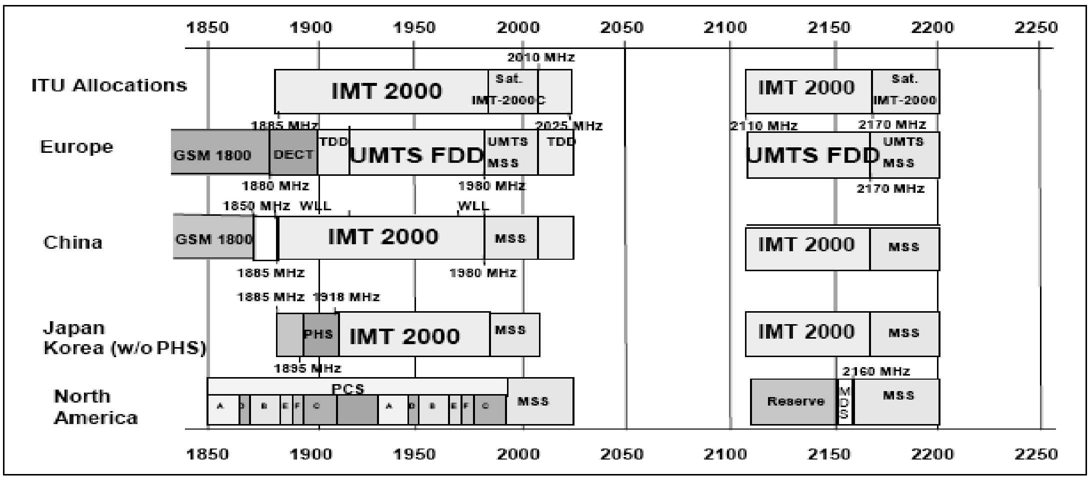


*Figure 6. 2 GHz bans spectrum allocation in Europe, China, Japan, Korea and North America (MSS = mobile satellite spectrum)*

More frequencies have been identified in WRC-2000, now the identified bands are 1710-1885 and 2500-2690 MHz for IMT-2000. Band 806-960 MHz will use for a mobile service on a primary basis. In a summary table of new frequencies allocations is the next figure 7.

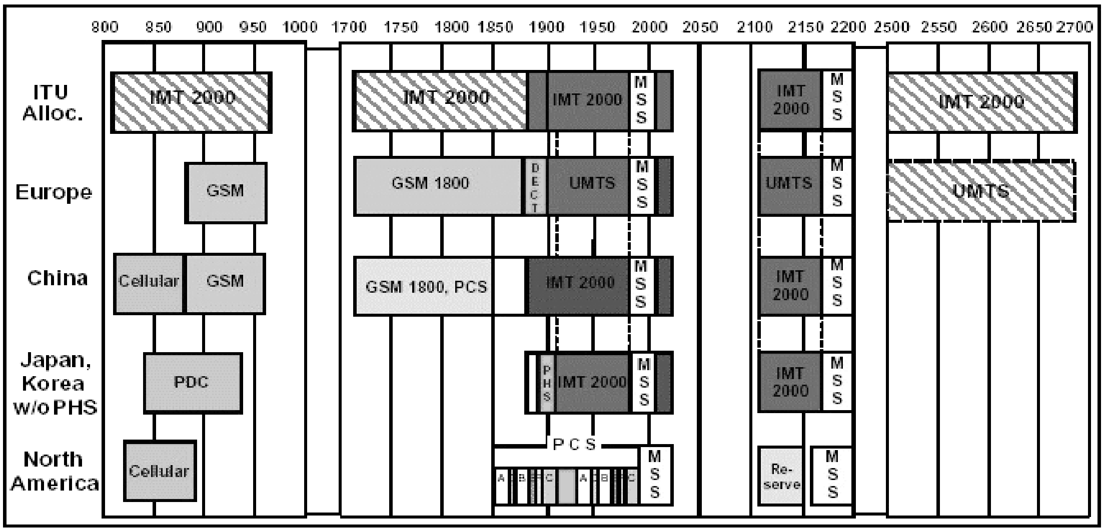


*Figure 7. New frequency allocations for 3G systems*

Actually, 3G systems use these frequencies allocations, and have resulted in many successful UMTS/IMT-2000 deployments to benefit the costumers. Nowadays ITU is working for find new allocations for IMT in WRC-07, these allocations will be available / licensed in 10 years approximately and in this way we can imagine which will be the frequency distribution in the future. The future frequency band will be 3.4-4.2 GHz, this band offer the best potential for fulfil all the capacity demands. This band can also accommodate IMT-Advanced Systems with large carrier bandwidth upper to 100 MHz.

## 1.3 Brief comparison between WCDMA-GSM and releases

In this section we want to emphasise which differences and improvements offer WCDMA versus GSM. The main goal for change from 2G to 3G was for three reasons: technical evolution, network evolution and services evolution.

Starting in the frequency allocation, GSM Europe occupied in the uplink the frequency band of 890-915 MHz, and the downlink frequency band is 935-960 MHz. The bandwidth is 25 MHz and is subdivided into 124 carrier frequency channels, each spaced 200 kHz. Time division multiplexing is used to allow eight full-rate or sixteen half-rate speech channels per radio frequency channel. There are eight radio time slots grouped in TDMA frame. Half rate channels use alternate frames in the same timeslot. The channel data rate is 270 kbps and the frame duration is 4,615 ms.

In the other side, UMTS Europe is allocated in frequency band of 1920-1980 MHz for uplink and 2110-2170 MHz for downlink, bandwidth of 60 MHz for each band (uplink and downlink) and channel spacing is 5 MHz. The channel data rate is between 144 kbps in the worst situation and upper than 2 Mbps, actually it will arrive with HSDPA and HSUPA data rates around 14 Mbps, is like multiply per 5 the actual data rate. The duration of the frame is 10 ms.

The big difference between UMTS and GSM is the air interface, this reflects the new requirements of the third generation systems. GSM utilize FDMA (Frequency Division Multiple Access) y TDMA (Time Division Multiple Access) this technology is not spectral efficient because the frequency reuse factor is more than 1 and it does mean that two neighbour cells can not use the same frequency channels. In contrast, UMTS use WCDMA and this radio access technology has a frequency reuse equal 1, all the cells can use all the radio channels available. Another difference is in the frequency which the network is able to give the orders of power control, handovers… in GSM is around 2 Hz and in UMTS is 1500 Hz, this difference helps to UMTS network to manage better the entire radio link.

| | WCDMA | GSM |
|---|---|---|
| **Frequency band** | 1920-1980 MHz uplink / 2110-2170 MHz downlink | 890-915 MHz uplink and 935-960 MHz downlink |
| **Bandwidth** | 60 MHz | 25 MHz |
| **Carrier spacing** | 5 MHz | 200 kHz |
| **Duration frame** | 10 ms | 4,615 ms |
| **Frequency reuse factor** | 1 | 1-18 |
| **Power control frequency** | 1500 Hz | 2 Hz or lower |
| **Quality control** | Radio resource management algorithms | Network planning (frequency planning) |
| **Frequency diversity** | 5 MHz bandwidth gives multipath diversity with Rake receiver | Frequency hopping |
| **Packet data** | Load-based packet scheduling | Time slot based scheduling with GPRS |
| **Downlink transmit diversity** | Supported for improving downlink capacity | Not supported by the standard, but can be applied |

*Figure 8. Brief comparison between WCDMA and GSM.*

The main difference between the networks is UMTS use the packet domain with IP protocol instead of circuit switching, but UMTS network has inside GSM network too. UMTS network is able to interconnect other networks like Wi-Fi. The next figure 9 represents GSM network, in addition of that we have to explain before UMTS apparition, there were GPRS which started to use packet transmission and then EDGE which started to improve the data rates.

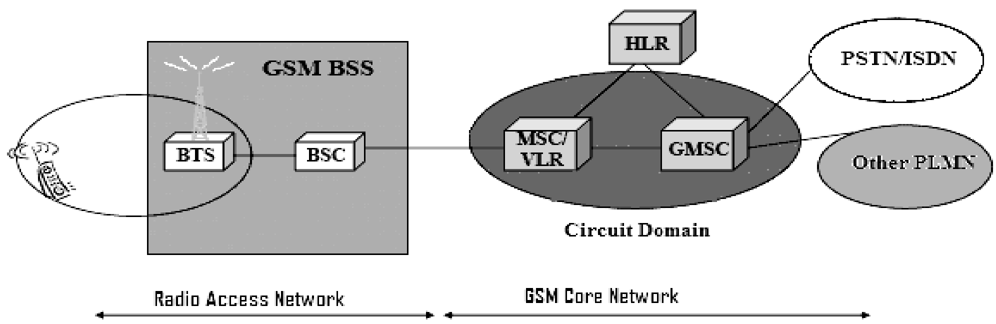


*Figure 9. GSM network*

Below the figure 10 shows the basic UMTS network with release 99'. Is easy to realize that UMTS network has the GSM network inside.

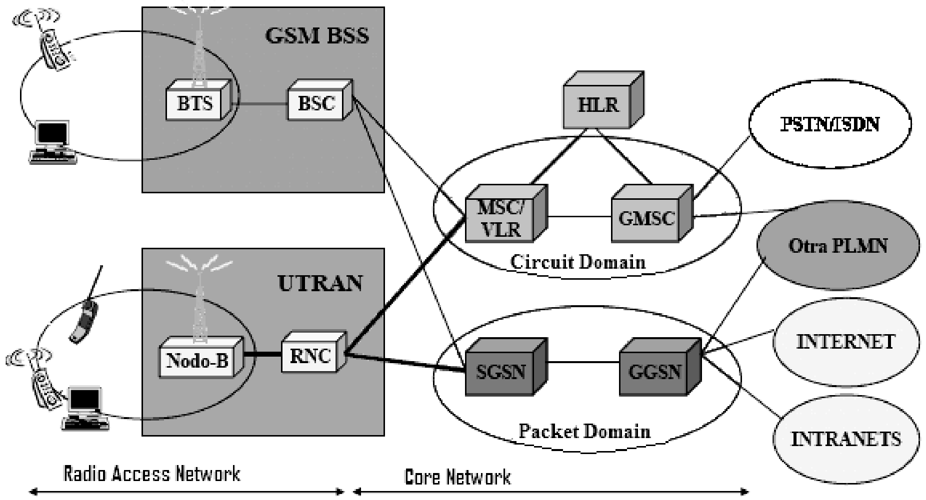


*Figure 10. UMTS network (Release 99') (Public Land Mobile Network (PLMN))*

All the new standardization and improvements of UMTS networks are distributed in releases numerations. The last figure represents the first release of UMTS (Release 99'). In summary, for our project only is interesting to know the last two releases, release 4 and release 5 and an overview of the future releases.

Release 4 consists in:

- Voice is carried on IP protocol.
- Functions of control and connectivity for voice are separated.
- MSC's are divided in Media Gateways (MG) for connectivity and Media Gateways Control (MGC) for signalising.
- MG offer connection with circuit switching under the orders of MGC.
- Communication between MG and MGC is used the MEGACO protocol which permit the division of the transport and control layers.
- Session Initiation Protocol (SIP) is the protocol which manages the application layer for the calls and the multimedia data in internet.

Release 5 consists in:

- All under IP protocol with support in real time of VoIP and multimedia services.
- IP Multimedia Subsystem (IMS) is for the managing of multimedia services and uses the SIP signalising.
- In Release 5 there are some advanced services which need the identification of the user by assignation of public IP address (IPv6 is required in IMS).
- Functional parts of IMS.
    - HSS (Home Subscriber Server): Subscription of the users with IP multimedia control.
    - CSCF (Call State Control Function): Session control.
    - MRF (Multimedia Resource Function): Manage call functions and connexions.
- Interoperate with other networks 2G, permit this connection these components MG, MGC and SGW.

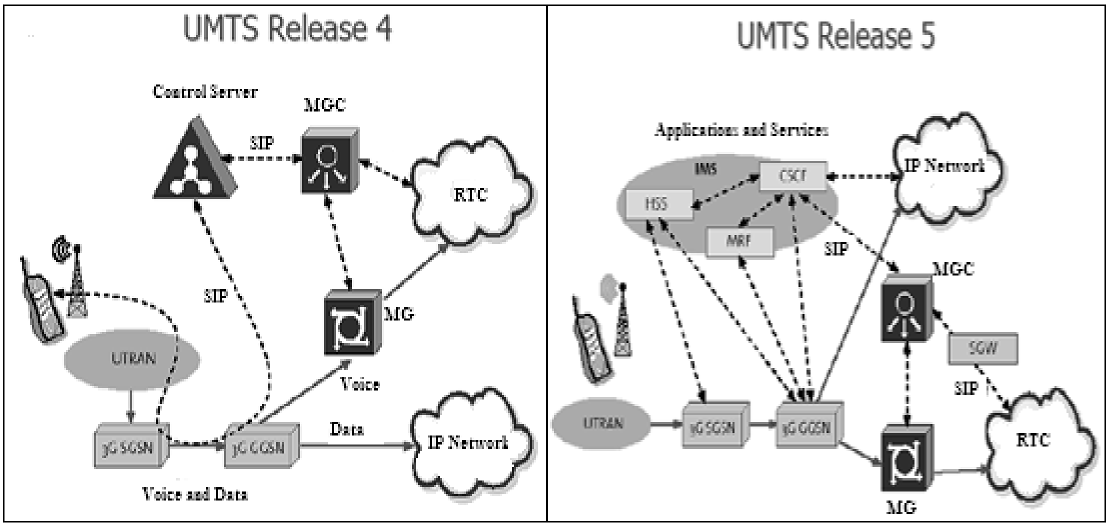


*Figure 11. UMTS network in the release 4 and release 5.*

Actually, release 5 does not unfolded yet in the massive market but in a near future it will be the last trend in mobile phone services. The latest release approved by 3GPP is the release 6. Release 6 is, in a brief description, the complete development of IMS (IP Multimedia Subsystem) and includes the new services as Push Services (Network sent information to the users without any approval, news, weather forecast…), Multimedia Broadcast and Multicast Service (MBMS) these service permit network the broadcasting of multimedia contents to a high number of user without collapse the network. Release 6 offer opportunity to interworking with WLAN (UMTS-WLAN), with interoperability is described with 6 scenarios, and 3 o them are in R6 and the others in R7. Other services are Generic User Profile (GUP) which saves the user data in different places for the future consults, Digital Rights Management is ordered to protect the intellectual property and Priority Service gives priority and quality in function of the users. Finally, in R6 it is possible to share the network between different companies, configure your level of privacy.

As a resume, all the latest Releases in the following table.

| Version | Released | Info |
|---|---|---|
| **Release 99** | 2000 Q1 | Specified the first UMTS 3G networks, incorporating a CDMA air interface. |
| **Release 4** | 2001 Q2 | Originally called the Release 2000 – added features including an all IP Core Network. |
| **Release 5** | 2002 Q1 | Introduced IMS and HSDPA |
| **Release 6** | 2004 Q4 | Integrated operation with WLAN networks and adds HSUPA, MBMS and enhancements to IMS. |
| **Release 7** | In progress (expected mid-2007) | QoS and improvements to real-time applications like VoIP. Focus on HSPA+ (High Speed Access Evolution), SIM high speed protocol, contactless services like mobile payments. |
| **Release 8** | In progress (expected mid-2009) | E-UTRA, All-IP Network (SAE). It is the beginning of fourth generation network. |

*Table 2. Brief summarise of all the last releases.*

## 1.4 Overview Network Distribution and services

The aim of this section is start to enter in matter, giving a main view of the network structure and a summary of the services which can offer UMTS. We will develop the release 4 for explain the UMTS network because the release 5 appear IMS which cause a difficulty increase in the network analysis but also we will see something about it. The main aim of behind 3G network is to prepare the infrastructure able to carry the existing services and the future services. Separation of access technology, transport technology, service technology (connection management) and user applications are very demanding requirements.

The entire network architecture can be divided into subsystems based on the nature of traffic, protocols architectures and physical elements. A part from the nature of the traffic, UMTS network is divided in two big domains; Packet-Switching (PS) and Circuit-Switching (CS).

UMTS network consist of three parts; Core Network (CN), UMTS Terrestrial Radio Access Network (UTRAN) and User Equipment (UE). The basics of these three parts are:

- The *Core Network* is divided in circuit switched and packet switched domains. Some of the circuit switched elements are Mobile services Switching Centre (MSC), Visitor locator register (VLR) and Gateway GPRS. Packet switched elements are Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). Some network elements are, like EIR, HLR, VLR and AUC are shared by both domains. The main function of the core network is to provide switching, routing and transit for user traffic. Core network also contains the data bases and network management functions. The basic Core Network architecture for UMTS is based on GSM network with GPRS. In section 2 in UMTS system architecture we will see in more detail all of this network elements.

- The subsystem controlling wideband radio access has different parts and names, depending of the type of technology used. When we refer to UMTS with WCDMA radio access, the name is UTRAN or UTRA. The other type is GSM and this subnetwork is so-called GERAN. The specification between GERAN and UTRAN is done in 3GPP R4 and R5. The UTRAN provides the air interface access method for User Equipment. Base Station is referred as Node-B and control equipment for Node-B's is called Radio Network Controller (RNC). For one side the functions of Node-B are; Air interface Transmission / Reception, modulation and demodulation, CDMA physical channel coding, micro diversity, error handing and closed loop power control. For other side the functions of the RNS are; Radio Resource Control, Admission Control, Channel Allocation, Power Control Settings, Handover Control, Macro Diversity, Ciphering, Segmentation /Reassembly, Broadcast Signalling and Open Loop Power Control. In the following sections we will describe in detail which are those functions, how are working in the main UMTS communications and when the network has to use those functions.

- *User Equipment* consists in two parts: the Mobile Equipment (ME) is the radio terminal used for radio communications and the UMTS Subscriber Identity Module

(USIM) is a smartcard that holds the subscriber identity, performs authentication algorithm, and stores authentication and encryption keys and some subscription information that is needed at the terminal.

In the following network scheme, we can build in our mind the basic structure of UMTS and since this base all the other components are just added in some of these layers.

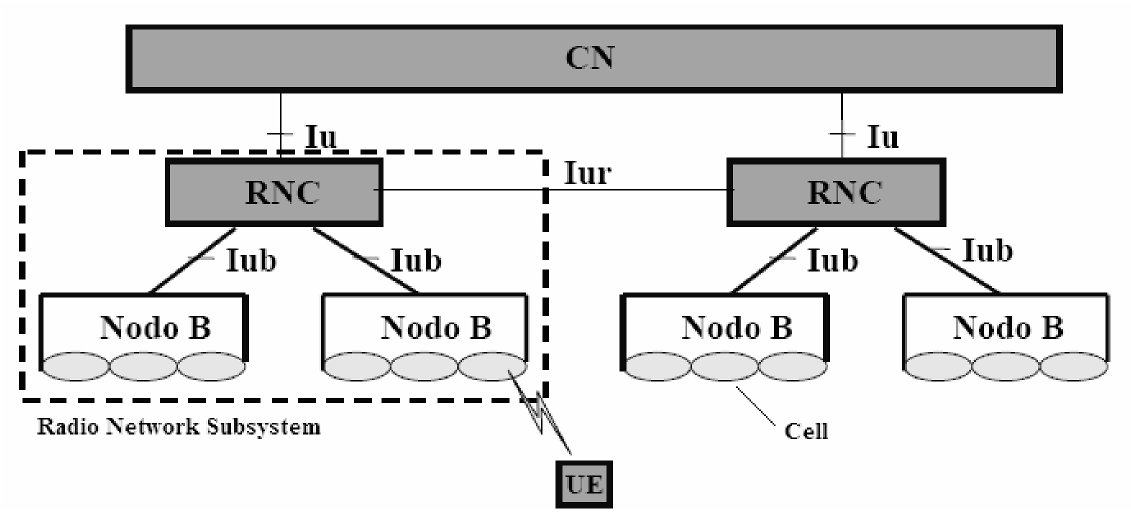


*Figure 12. Overview network distribution.*

**Overview of Services:**

The most important services, in a brief summary, are described in this section. In the beginning, all the services used the circuit switched for the transmission of information; with circuit switching it was able to carry services like voice, SMS, WAP and E-mail. Then appeared packet switching and all the services like SMS, WAP, E-mail, Web, MMS and Streaming uses this mode but voice and video services were still using circuit switching. Finally, in UMTS release 5-6 all the services are in packet switching and the following table describes the 4 main types of services.

| Types of services | Basic features | Application example |
|---|---|---|
| **Conversational** | -Assure a limit level of delay and the difference of time between packets.<br>-Low delay and noisy. | Voice |
| **Streaming** | -Assure the variation of time between packets. | Video and audio |
| **Interactive** | -Ask and answer model.<br>-Assure data contents. | Web navigator |
| **Background** | -Interaction is not necessary.<br>-Assure data contents. | E-mail |

*Table 3. Services Distribution.*

# 2. UMTS System architecture

This chapter is one of the most important in this project for understand how the UMTS networks is distributed and how HSDPA can be filled in. The UMTS utilize the same well-known architecture of 2nd generation systems but with some modifications. The UMTS system consist of a number of logical network elements that each one has a defined work. These network elements can be grouped based on similar functionality, or based on which sub-network they belong to.

Actually, the network elements are distributed in three groups, Radio Access Network called UTRAN, Core Network and UMTS terminal. Radio Access Network has inside all the needed elements which support all the radio related functionalities. Core Network is responsible for switching and routing calls and data connections to external networks. Finally the UMTS Terminal or User Equipment (UE) that the interface between user and the radio interface is defined. There is the possibility of having several entities of the same type and that fact, allows the division of the UMTS system into sub-networks. Such a sub-network is so-called PLMN (Public Land Mobile Network) and typically each PLMN is operated by one operator, in addition of that it is possible to connect with other PLMN as well as other types of networks, such as ISDN, PSTN, the internet, etc…

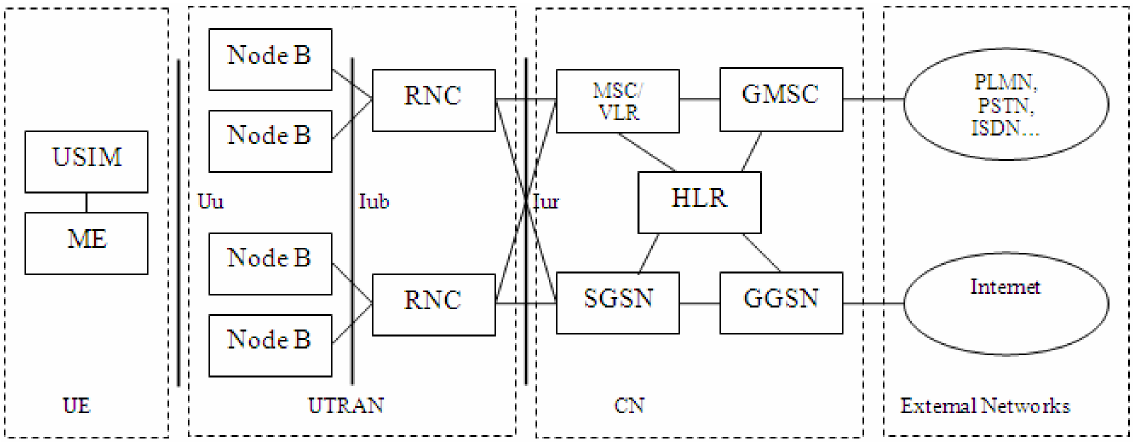


*Figure 13. Network elements in a PLMN*

In addition of UTRAN, there is the GSM network called GERAN. GERAN permits the connection of all the 2nd Generation devices to the UMTS network and makes compatibles both generations. In this project GERAN is out of our goal, for this we will develop UTRAN as a radio access network.

## 2.1 UMTS Radio Access Network

UMTS Terrestrial Access Network (UTRAN) forms the main Radio Access Network (RAN). The main task of the UTRAN is to create and maintain Radio Access Bearers (RABs) for communication between UE (User equipment) and CN (Core Network). With these RABs the CN has an idea about the communication path to the UE so CN is able to take care of the radio communication aspects.

UTRAN is located between two open interfaces: Uu and Iu. The main goal of UTRAN is to provide a bearer service over these interfaces and assure the quality requirements in end-to-end communications; in this way the UTRAN controls the Uu interface and the bearer service in the Iu interface is done in cooperation with the CN.

The layered structure is to divide in small parts the physical radio access because this, as everybody know, is a very changing transmission medium. This division permits us to modify some parts of the architecture and always keep the main structure. UTRA is implemented using WCDMA-FDD. UTRAN uses a Physical Bearer Service (PBS) to know the terrestrial physical basis in the end-to-end service. This is implemented, in functions of 3GPP points of view, by Asynchronous Transfer Mode (ATM) over physical transmission media. In this project we will not explain in what consists PBS and ATM because is not our goal.
Basically, UTRAN consists of Radio Network Subsystem (RNSs) and each RNS contains different number of Bases Stations which in UMTS are called Node Bs. We will use since now Base Station instead Node B. Every RNS needs a RNC (Radio Network Controller) for manage all the BSs. RNSs are separated each other by Iur interface which has been specified as an open interface.

Before continuing, we must to identify the interfaces between the logical networks elements so we are able to understand at each time, which kind of interface the signal goes. The following interfaces are the most important:

- *Cu interface:* Electrical interface between the USIM smartcard and the ME.
- *Uu interface:* WCDMA radio interface. The Uu is interface which the UE accesses the fixed part of the system, in other words, the interface between the UE and UTRAN network.
- *Iu interface*: This connects UTRAN to the CN. The open Iu interface gives UMTS operators the possibility of acquiring UTRAN and CN from different manufacturers.
- *Iur interface*: The open Iur interface allows soft handover between RNCs from different manufactures.
- *Iub interface*: Connects a Node B and an RNC. UMTS is a first commercial mobile telephony system where the Controller-Base Station interface is standardised as a fully open interface. This is for motivate competition between manufacturers. It is likely that new manufacturers concentrating in Base Stations can enter into the market.

UTRAN architecture follows the next scheme in the Figure 14:

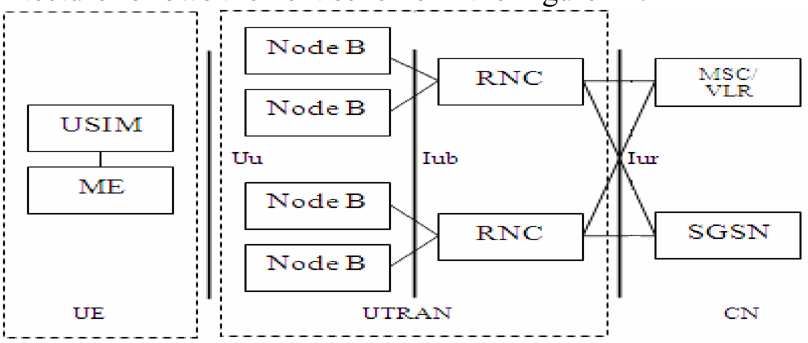


*Figure 14. UTRAN Architecture*

### 2.1.1. Base Station (BS, Node B)

The Base Station is located between the Uu and Iub interfaces. Its main tasks are to convert the data flow between Iub and Uu interfaces using the protocols stacks specified for these interfaces. BS, in Uu interface, implements WCDMA each access physical channels and transfer information from transport channels to the physical channels using the WCDMA procedures explained in section 1.1 in summarize, BS has functions to perform radio signal receiving and transmitting, signal filtering and amplifying, signal modulation and demodulation, and interfacing to the RAN. Also BS takes parts in Operation and Maintenance (O&M) through radio measurements which are send to the RNC for procedure the control functions.

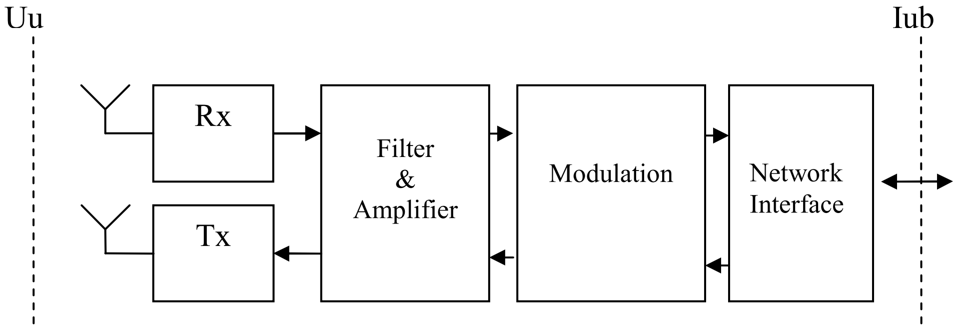


*Figure 15. Basic Structure of BS*

The internal structure basically consists of the components are showed in Figure 15 and the logical structure is generic within UTRAN. BS can be divided into several logical entities. In the side of Uu interface the carrier information consists in physical channels and transport channels and in the other side, Ibu, a BS is a collection of two entities: common transport and a number of Traffic Termination Points (TTPs). In Common Transport appears the channels that are common to all UE in the cell, as well as, the initiation channels. Common transport also has an entity which is used to Operation and Maintenance (O&M) purposes. In UMTS networks, BS is the logical O&M that is subject to network management operations. In every cell must be almost one BS but it is possible more and every cell has a scrambling code and ID cell, these information is used by the UE for recognize in which cell it are. The other entity, TTP consists of a number of BS communication contexts. A BS communication context consists in all the dedicated resources required when the UE is in dedicated mode, due that, at least it has to have one Dedicated Channel (DCH).

The modulation method interfering in system capacity and performance, for that is good to know which modulation uses the BSs but without high level of detail. WCDMA uses Quadrature Phase Shift Keying (QPSK) and also sometimes if it is possible due the receiver is near to the BS, BSs use Quadrature Amplitude Modulation (16QAM). In association with High Speed Download Packet Access (HSDPA) and with specifications of release 5 it is also possible to use a QAM coupled with Adaptive Modulation and Coding (AMC) and Hybrid Automatic Repeat Request (HARQ). This change is due that the main goal of HSDPA is to get much higher rates and QPSK was not efficiently achievable.

In the side of the receiver signal, WCDMA utilizes multipath propagation and for this the RAKE receiver. In addition, using a diversity technique is a prerequisite for providing a soft-handover feature in a cellular system. In WCDMA, polarisation diversity is the most utilized for both uplink and downlink transmission.

### 2.1.2. Radio Network Controller (RNC)

The RNC is the switching and controlling element of the UTRAN which is located between the Iub and Iu interfaces. The RNC controls the two entities of BS: Common Transport and Collection of BS (Node B) communication contexts. This logical role is called *Controlling RNC* (CRNC). *Serving RNC (SRNC)* consist in hold an Iu bearer for some UE, due RNC is a switching point between the Iu and RB (service provided by the RLC for transfer the user data between the UE and RNC). Another logical role is *Drifting RNC* (DRNC) which has the role to allocate the UE and this information is required by SRNC. SNRC and DRNC roles can change the location, hence, these roles follow the UE through soft-handovers using the first RAB (Radio Access Bearer), this action is called “SRNS relocation”.

The main functionalities of RNC can be classified into two parts: UTRAN RRM and control functions. RRM is a collection of algorithms used to guarantee the stability of the radio path and QoS and it has the responsibility of the management of UTRAN. UTRAN control functions are these functions associated to set-up, maintenance and release of RBs and also support functions for RRM algorithms.

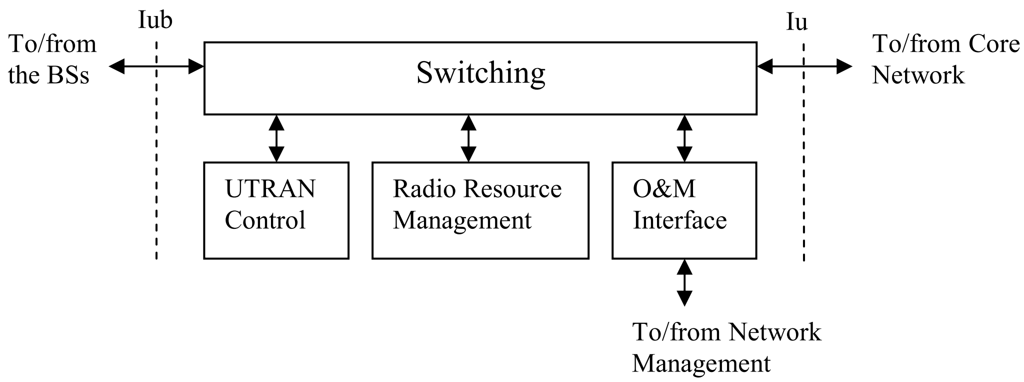


*Figure 16. Basic logical Structure of the RNC*

*Radio Resource Management (RRM)*

RRM is located in the UE, the BS and the RNC. RRM makes use of various algorithms for stabilise the radio path and this algorithms must deliver information over the radio path, all of these using Radio Resource Control (RRC) protocol. RRM has to manage the following tasks: Handover control, Power control, Admission control (AC) and Packet Scheduling (PS) and Code Management.
Now brief information about the tasks is explained:

- *Handover* is the function which the RNC has to do when a UE moves from the coverage of one cell to another or a cause of traffic, a new connection with the new cell has to be set up and the old connection switches off. RNC knows when has to do a handover, when the power signal is lower than a predetermined level but it is not an easy action because appear a lot of different issues but we can not explain all here.

- *Power Control* is the function for the management of the transmitted power in the transmissions (UE or BS) for avoid exceeds of power which distorted other signals, there is more information before about it.

- *Admission Control (AC) and Packet Scheduler (PS):* The basic idea in this task is that all the users creates interference and the network has an interference limit which limit is directly proportional with total users in the network are. The main task of *AC* is to estimate if a new call can have access to the system without sacrificing the bearer requirements of existing calls, in other words, predict the load of the cell if the new call is admitted. *Packet Scheduler* is basically the process to distribute the packets, first PS has to receive the data flow from the radio channels related to one or more links and all of them have a specific priority. Then PS reoriented the packets in function of their priority and finally all the scheduled and prioritised packets of the flows are released to the appropriate links.

- *Code Management:* RNC has to manage channelisation codes and scrambling codes for assure the stability when RNC is controlling the radio resource, without this problem BS can manage theses codes and actually the code generation is done at BS. Scrambling codes are used for recognize the different cells and beneath every scrambling code the RNC has a set of channelisation codes. This set is the same under every scrambling code. When the UE find the correct scrambling code, UE is connected to this cell. When UE and cell are connected theses channels must be separated and the sent information now is transmitted using one spreading code.

*UTRAN Control Functions*

For control and manage RABs, it might perform other functions in addition of RRM algorithms:

- *System information broadcasting:* RNC utilizes point-multipoint system information broadcast. This information is used to maintain the radio connections (UE-UTRAN) offering different data system like radio measurements criteria, paging, radio path information… to operations of network management.

- *Random access and signalling bearer set-up:* Is the signalling connexion between UE and CN. UE and CN transfer higher layer information between the entities for get information of each other can establish a connection.

- *RAB management:* Is happens after signalling connection, RNC creates the impression that there is a fixed bearer between the CN and the UE for transmit the information.

- *UTRAN Security functions:* The RNC has functions of integrity-checking and ciphering mechanisms. Integrity-checking is used to protect signalising connection and ciphering mechanisms for protect the user data transferred.

- *UTRAN-level Mobility Management (MM):* Functions related with keep the UE in touch with UTRAN radio cells, taking into account the user's mobility within UTRAN and the type of traffic or RABs it is using.

- *Database-handling:* Database where the cell information for RNC is stored. There are information about cell ID, Power Control, Handover-related and Environmental.

- *UE positioning:* Consist in know where the UE is located.

## 2.2 UMTS Core Network

Core Network (CN) is the basic platform for all the services in UMTS. The first UMTS releases, the communications services are divided in circuit-switched or packet switched, but since release 5 also introduce a new subsystem called the IP Multimedia Subsystem (IMS). IMS starts to use all communications under IP protocol. UMTS goes in the way to produce a universal core which is able to handle a wide set of different radio accesses. The main radio accesses were described in 1.1 section, in summarize this radio accesses are WCDMA/HSDPA, GSM/EDGE and WLAN as a most important complementary access.

Core Network is one of the UMTS aspects that suffered the most important changes. Now we will give a brief description about the main characteristics of 3GPP R5. CN can be divided in four entities:

- Circuit Switched (CS) domain.
- Packet Switched (PS) domain.
- IP Multimedia Subsystem (IMS).
- BroadCast (BC) domain.

In the Figure 17 shows the CN structure on the different domains.
Now, as a first idea of the CN elements structure we describe a first allocation and then we will describe in more detail.

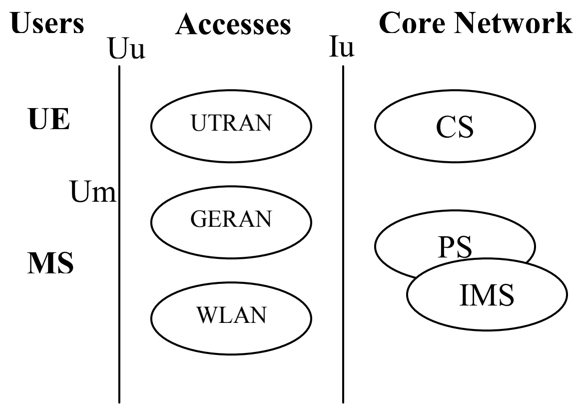


*Figure 17. CN Structure on the different domains*

The first idea is about UMTS R4 because is much more easy to explain due IMS is not included and after that we will describe IMS briefly.
In the CS domain, UMTS network has CS Media Gateway (CS-MGW) and the Gateway Mobile Services Switching Centre (GMSC), both elements can be combined into one physical entity, called "GMSC". Continuing with CS domain there are two more elements, one is CS-MGW and the other is MSC Server.
In the PS domain, there are two important elements: GGSN and SGSN. Finally, the common more important elements are HSS (Home Subscriber Server) and EIR (Equipment Identity Register). The following Figure 18 shows the allocation of the network elements and then we will explain all these components and their functionalities.

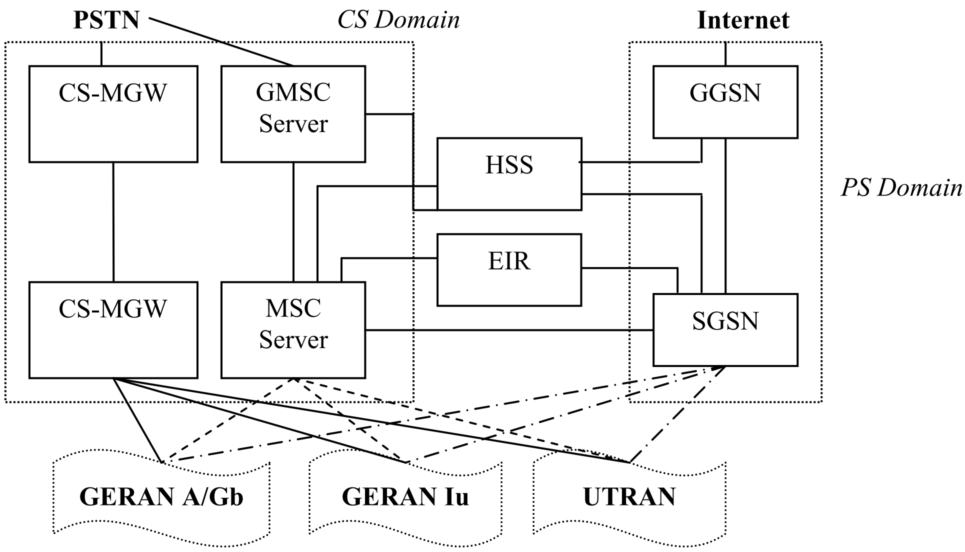


*Figure 18. Core Network structure*

### 2.2.1. CS Domain

The CS Domain is necessary because the network must support CS services for backward compatibilities an also in 3GPP R5 exists the CS domain. In 3GPP R4 there is a possibility that the operator has the ability to fine-tune CS domain control and traffic delivery capacity.

The goal of CS-MGW and MSC Server division is to separate the control and the user interface within the CS domain. This fact introduces facilities since a single MSC server could control many CS-MGW. Other advantage is able to do a geographical optimisation in the user plane. The operators are freely to put the CS_MGW where they want and this fact introduces the geographical optimisation due the users can take the shortest possible way. In the MSC Server there are call control functionalities and the VLR. The plane connectivity and related items are located into an entity called Media Gateway (MGW) but several times we will find this entity with CS (Circuit Switching) in the beginning. GMSC Server has functionalities of switching the information and takes care of the control functionalities like MSC.

### 2.2.2. PS Domain

PS domain has two main network elements: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). SGSN contains the location registration function which keeps the data needed for originating and terminating packet data transfer. These data is subscription information about IMSI (International Mobile Subscriber Identity), several temporary identities and location information like PDP (Packet Data Protocol) addresses, subscribed QoS and so on.

PDP context is the tool for data transfer within PS domain. In order to transfer data, the SGSN must know with which GGSN the active PDP context of a certain end-user exists and for that, SGSN store all the GGSN addresses and the active PDP contexts. In addition, we must know that one PDP context is able to go through several GGSNs.

GGSN store some subscriber information as well, this data are IMSI number, PDP addresses, location information and data about SGSN that the user has registered.

For the whole packet management, these two entities are not enough and for that there are additional elements and functionalities for addressing, security and charging.
For security reasons operators use dynamic addresses allocations for end-users. Actually the typical way to allocate theses addresses is in Dynamic Host Configuration Protocol (DHCP) functionality/server and use IPv4 or IPv6. Also for maintain the security within the network GGSN has a FireWall (FW).

PS domain is getting every time more like an Intranet, for this is required a Domain Name Server (DNS). DNS is responsible to addressing the data from the network elements due DNS provides the address of PS domain elements.

When the user has a dynamic allocated address and the connection has been established between the SGSN and GGSN then the user need Service Access. Service Access is provided by APN (Access Point Names) and usually is for a specific service. For example, one APN for internet access, another APN for WAP services… The same GGSN may contain several different APN.
The PS domain contains two different functionalities in function to roaming or to make an interconnection between others PS networks. This functionality is called Border Gateway (BG). GPRS Roaming Exchange (GRE) is for roaming purposes. Other entity in PS domain is Charging Gateway (CGW), this collects charging information for to be send to billing centre to be post-processed.

The PS domain is able to maintain several connections; first connection is towards different networks in IuPS interface, these networks are UTRAN and GERAN, and in this way GERAN is called GERAN Iu mode. Other possibility is connect GERAN using the A or Gb interface and this is called GERAN a/Gb mode. In order to possible connections, PS domain is connected to CN common functionalities like HSS and EIR. Finally, comment that PS domain is the network platform for multimedia services and it is controlled by IMS in the 3GPP R5.

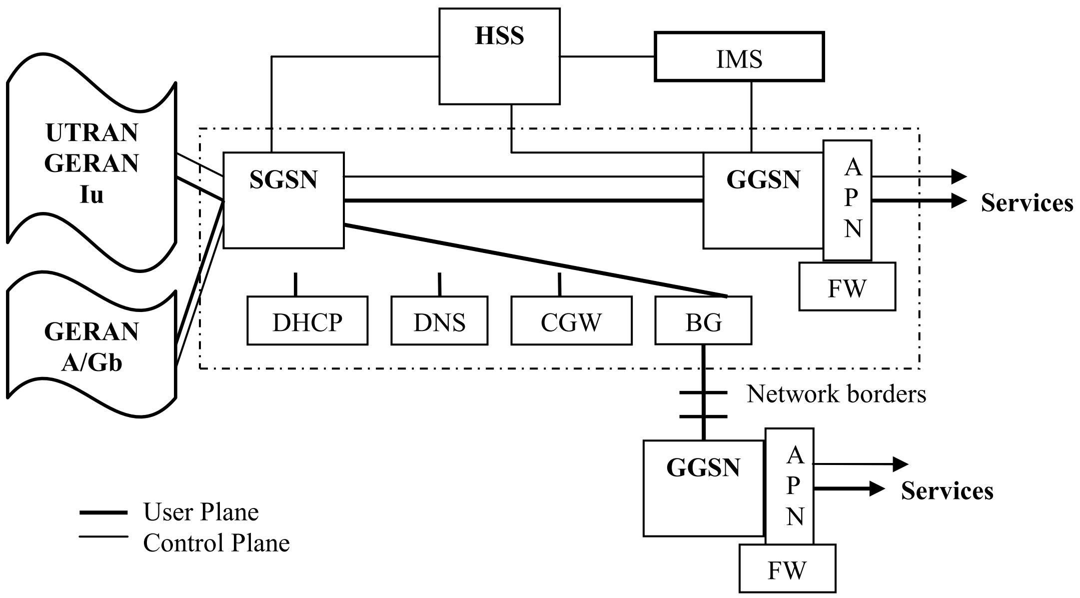


*Figure 19. PS Domain Structure.*

### 2.2.3. Common Core Network Entities

There are some network elements that are common in both domains (PS and CS domain). These common functionalities are mainly collected in an entity called HSS (Home Subscriber Server). HSS is the integration of HLR (Home Location Register) and AuC (Authentication Centre) in one. HLR and AuC are components in the GSM network but in UMTS they are together but they keep the same functionalities. The following functionalities develop HSS:

- Mobility Management (MM): Supports user mobility through CS domain, PS domain and IMS. The basic job is store addresses.
- User security information generation, user security support and access authorization. These are the functionalities of AuC.
- Service-provisioning support: HSS provides access to the service profile data that are used within all the different domains. The HSS communicates with Session Initiation Protocol (SIP), Application Server (AP) and the Open Service Architecture / Service Capability Server (OSA/SCS) to support application services in the IM CN subsystem and so on.
- Call / Session establishment support: HSS support call and establishment procedures in CS domain, PS domain and IMS.
- Identification handling: HSS provides the identifiers of the users in the system; IMSI and MSISDNs for the CS domain; IMSI, MSISDNs and IP addresses for the PS domain; private identities and public identities for the IMS CN subsystem.
- Service authorization support: HSS provides the basic authorization for call/session establishment and service invocation.

EIR (Equipment Identity Register) is the other entity that is in common for all the domains. EIR stores the information about the use's devices. EIR has three different lists: white list is all the equipment that is in correct state, black list are all the stolen equipment information and the grey list are all the suspect mobile phones. Actually, only is in use the black and grey list.

### 2.2.4. Brief description about the role of the CN

The main role of the CN it can be divided in three parts: Communication Management, Mobility Management and Charging, Billing and Accounting.

- *Communication Management (CM):* CM have two main tasks, one is connection management and the other session management. Connection management takes care of the connection in CS domain and related issues. Session management takes care of the PS end of the network.
- *Mobility Management (MM):* MM has to cover the UE locations together with their identities and addresses. One important function of MM is that it takes care about Roaming issues.
- *Charging, Billing and Accounting:* Charging is the collection of procedures generating charging data. The charging data is pos-processed in Billing procedures and Billing produces a bill for the end user. Finally, Accounting is the action of charging data collection over a predefined time period and this action don't have

any implication with end users. All this actions are in the CN but in an independent frame.

### 2.2.5. Brief description about IP Multimedia Subsystem (IMS)

The aims of this section is to give an idea about IMS elements due in the beginning of the chapter of UMTS Core Network we said that in UMTS, in concrete 3GPP R5, has IMS within the Core Network. IMS use IP to connect terminals and SIP (Session Initiation Protocol) as a most important protocol. In addition of that, we must say that IMS is designed to be access-independent so that IMS services can be provided over any IP connectivity network and IMS architecture is based on a layered. The main entities can be classified in six main categories:

- *Session management and routing family (CSCFs)*: There are three types of Call Session Control Functions (CSCF): Proxy-CSCF, Serving-CSCF and Interrogating-CSCF. Proxy-CSCF is the first contact point for users within the IMS and its tasks are SIP compression, IP security association, interaction with the Policy Decision Function (PDF) and emergency session detection. Serving-CSCF is responsible for handling the registration process, making routing decisions, maintaining session states and storing the service profile. Finally Interrogating-CSCF is the contact point within an operator’s network for all connection destined for a subscriber or that network operator.

- *Databases (HSS, SLF):* Home Subscriber Server (HSS) and Subscription Local Function (SLF) are the two IMS databases. HSS has almost the same functionalities like in the backward releases. SLF is used as a resolution mechanism that enables the I-CSCF, the S-CSCF and the AS to find the address of the HSS that holds the user data.

- *Inter-Working functions (BGCF, MGCF, IMS-MGW, SGW):* These functions provides the exchanging signalling and media between the IMS and CS CN.

- *Services (AS, MRFC, MRFP):* AS has functions like process incoming SIP sessions received from the IMS, originate SIP requests and capability to send accounting information to the charging functions.

- *Support functions (THIG, SEG, PDF):* Capabilities in control QoS, the source-destination of IMS media traffic, authorise and control the usage of the bearer traffic.

- *Charging:* IMS supports online and offline charging capabilities. It has almost the same functionalities explained before in UMTS R4, information about charging user for then be sent it to billing.

We have to repeat that all this IMS functionalities are completely integrated in UMTS subsystem and helps to approximate to the future with all mobile communications under IP protocol and packet switching.

## 2.3 The UMTS Terminal

Is the most visible part of the UMTS network because is the user device and in this chapter we will provide a short insight into the UMTS terminal architecture and those functionalities. The UMTS terminal is officially called User Equipment (UE).

### 2.3.1. Terminal architecture

UE is responsible for all the communication functions that are needed at the other side of the radio interface. The main function of UE is related to the interaction between terminal and network. Some of the most important functions of UE are described below.

- Device is able to integrate circuit card for insertion of the Universal Integrated Circuit Card (UICC) containing Universal Subscriber Identity Module (USIM) and also can be possible IMS Identity Module (ISIM) application.
- Service provider and network registration and deregistration.
- Location update.
- Originating and receiving connexion oriented and connectionless services.
- IMEI, equipment identification.
- Basic identification of terminal capabilities.
- UE must be able to support emergency calls without USIM.
- Support for the execution of authentication and encryption algorithms.
- UE should facilitate the future evolutions like Application Programming Interface (API) capability, some new protocols, and optional insertion of several UICC cards and so on.

Actually, mobile device is divided in different modules that can be implemented independently. UE consists of Mobile Equipment (ME) and the UICC.
UICC is the user-dependent part of the UE and it contains at least one or more USIMs and the appropriate software. USIM is a logical concept that is physically implemented within UICC and also in UICC is possible to include ISIM applications for IMS services. The user's operator has to provide the information contents of USIMs and then USIM to the service profiles. ISIM is just for subscriber and network authentication within the IMS services.

The ME is the user-independent part of the UE and is implemented by different modules. Terminal Equipment (TE) is the equipment that provides end-user applications functions, such as call control, IP… and it also knows the possible telecommunication services in function of user applications. Mobile Termination (MT) is the part of ME that terminates radio transmission to and from the network and adapts TE capabilities. MT is able to change its location within network or move to a coverage area. MT is divided into two different parts. First part is Network Termination (NT) is the dependent part of the MT. NT uses non-access stratum protocol for Mobility Management and Communication Management. Second part is Radio Termination (RT) is related to the RAN only. It develops common functions to all services using the same RT-specific radio access technology. The scheme of the UE is showed in the Figure 20 below.

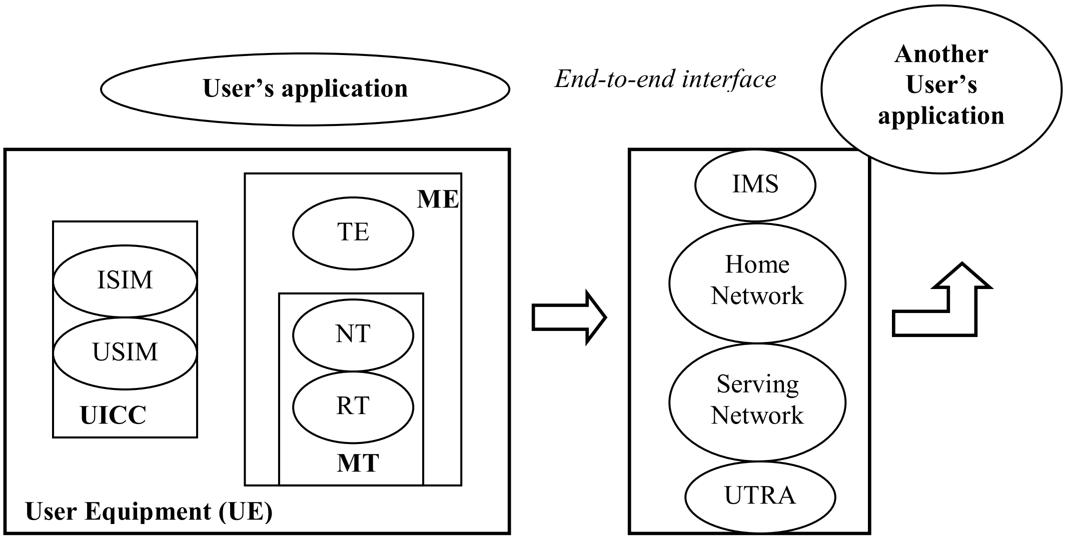


*Figure 20. User Equipment architecture.*

# 3. Main Characterization Physical Layer

The Physical Layer of the UTRA protocol stack provides transport services for the Medium Access Control (MAC) layer above it (Figure 21). The services of the physical layer are so-called transport channels. The physical layer shows the transport channels to the physical channels. One feature is that information of different transport channels can be transmitted simultaneously over one physical channel. The different transport formats are determined by the Radio Resource Control (RRC) layer.

The physical layer has the following main tasks: error protection and detection, measurement of transmission channel characteristics, reporting of measurement results to RRC layer, duplication and merging of data stream for soft handovers, mapping transport channels to physical channels, spreading and modulation as well as synchronisation and power control.
In the new evolutions of UMTS appear some changes in the physical layer but the biggest change is that in Release 5 is the addition of high speed downlink packet access (HSDPA) feature. Here in this chapter we can not make an exhaustive description because is a huge topic for this we just give a first insight about physical layer.

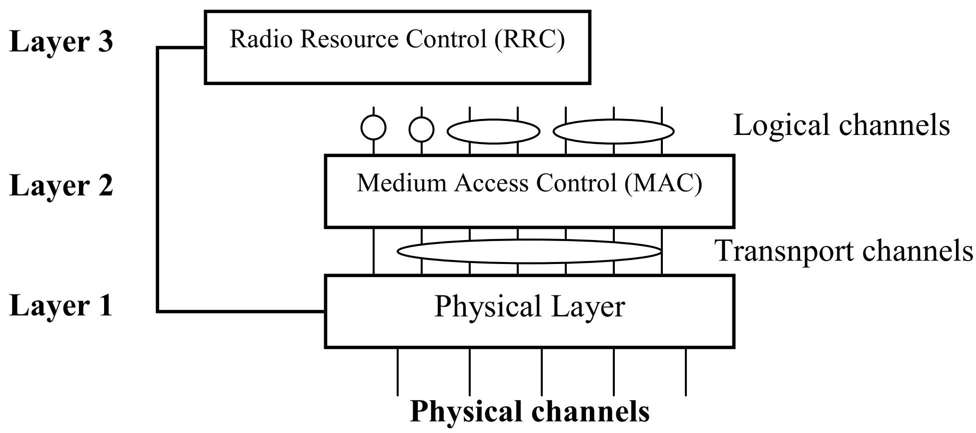


*Figure 21. UTRA Protocol stacks.*

## 3.1 Overview of Transport channels and their mapping to the physical channels

All the information generated in UTRAN need to be sent through air interface and the transport channels carries this information. These transport channels are distributed in the physical layer to different physical channels. The physical layer is able to carry variable bit rate transport channels to offer bandwidth on demand service and also multiplex several services in one connexion.

Traffic channels have a complementary element, Transport Format Indicator (TFI) which indicates the type of the data that is expected to receive from the higher layers.

The combination of different TFI information from different transport channels to a Transport Format Combination Indicator (TFCI). TFCI transmit this information to the physical control channel and in this way this informs to receiver which physical channels are available.

Two types of transport channels exist: dedicated channels and common channels. The main difference between them is that a common channel is a resource divided between all or a group of users in a cell and dedicated channels resource, identified by a concrete code on a concrete frequency that is used for a single user.

### 3.1.1. Dedicated Transport Channel (DCH)

The dedicated transport channels carries all the information intended for the user coming from upper layers and also includes information for the actual service as well as control information. All the information that DCH carries is not visible to the physical layer so the higher layers control the information. In summarise, the DCH carries the service data and control data, such as handover commands or measurements reports from the terminal. The DCH has some important features such as fast power control, fast data rate change, modifying the antenna features it is able to transmit to a certain parts of the cell and DCH supports soft handover.

### 3.1.2. Common Transport Channel

There are 6 different common transport channels and now we will describe them briefly.

- *Broadcast Channel (BCH):* Is used to transmit information specific to the UMTS network or specific cell. Is the broadcast information that every user within the coverage area need to know about the available random access codes and access slots in the cell and without the correct decodification of this information the user can not connect into the network.
- *Forward Access Channel (FACH):* Is a downlink transport channel which carries control information to terminals. FACH is able to carry packet data and is typical that in the same network there are more than one FACH, those is because every different FACH have different bit rates for adapt to different users.
- *Paging Channel (PCH):* Is a downlink transport channel which carries the necessary information when the network wants to initiate a communication with one terminal.
- *Random Access Channel (RACH):* Is an uplink transport channel for carry control information from the user such as a request for establishing a communication…
- *Uplink Common Packet Channel (CPCH):* Is an extension to the RACH that also carry packet-based user data in the uplink direction. The reciprocal information in the downlink is carried on the FACH channel. CPCH has fast power control, a physical layer-based collision detection mechanism and a CPCH status monitoring procedure.
- *Downlink Shared Channel (DSCH):* Is used to carry dedicated user data and control information and the same channel can be shared with several users.

- *Required Transport Channels:* The common transport channels required in a connection are RACH, FACH and PH, while the use of DSCH and CPCH is optional.

### 3.1.3. Mapping of Transport Channels

All the transport channels need physical channels for to be transmitted through the air. The transport channels are distributed in the following physical channels as we can see in the table below:

| Transport Channels | Physical Channels |
|---|---|
| BCH | Primary Common Control Physical Channel (PCCPCH) |
| FACH | Secondary Common Control Physical Channel (SCCPCH) |
| PCH | Secondary Common Control Physical Channel (SCCPCH) |
| RACH | Physical Random Access Channel (PRACH) |
| DCH | Dedicated Physical Data Channel (DPDCH)<br>Dedicated Physical Control Channel (DPCCH) |
| DSCH | Physical Downlink Shared Channel (PDSCH) |
| CPCH | Physical Common Packet Channel (PSPCH) |

*Table 4. Distribution transport channels to physical channels*

There are more physical channels that only carry information about physical layer procedures.

# 4. Fundamental knowledge about Protocols Stack in the Radio Interface

The ISO (International Organization for Standardization) divided the functions of protocols into categories, called layers, and made a model in order to facilitate the understanding of complex digital protocol, this model is called OSI (Open System Interconnection). All the layers, starting for the lower layer, provide services to their layers above. The OSI protocol stack is divided into seven layers and every layer is located in the receiver and in the transmitter due they can only communicate between the same layers. The Radio Interface Protocols have the function to set up, reconfigure and release the Radio Bearer services.

The protocol stack at the Uu-interface between the UE and the UTRAN comprise only layers 1-3. All higher functions are managed directly between UE and CN based on the communication paths provided by these layers.

The brief explanation about the different layers is showed below:

1. *Physical layer:* Responsible of the direct communication between the transmitter and receiver through the physical medium (air).
2. *Data link:* Usually is divided into two sublayers: the Medium Access Control (MAC) which is responsible for coordinating access to a common medium and the other is the Logical Link Control (LLC) which handles error correction.
3. *Network:* Is responsible for transmitting messages over several stations.
4. *Transport:* Guarantees a secure end-to-end connection.
5. *Session:* Responsible for opening and terminating communication.
6. *Presentation:* Transform the information being transmitted so that the remote station can understand the presentation.
7. *Application:* It represents the interface of the user.

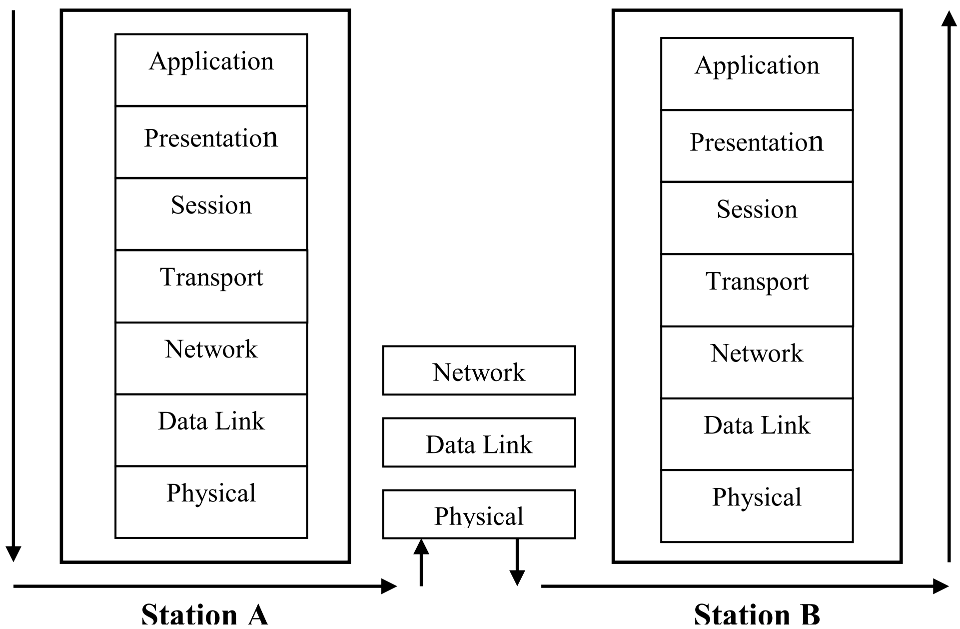


*Figure 22. The ISO/OSI reference model*

## 4.1 The UTRA protocol stack

The physical layer provides transport channels at the interface to the MAC (Layer 2). MAC layer converts the information transferred over logical channels. Above the MAC layer there is the Radio Link Control (RLC) which is responsible for error protection and error-free data transmission and offers services to higher layers via service access points (SAPs). In the user plane the two sublayers Packet Data Convergence Protocol (PDCP) and Broadcast and Multicast Control (BMC) can stack on the RLC sublayer. PDCP is responsible to adapt the packet data protocols like TCP/IP, in concrete for example header compression and exists only for the PS domain services. BMC is responsible for point-to-multipoint connections. In the layer 3, there is RRC (Radio Resource Control), which offers services to higher layers with non access stratum via access point. The RRC transports high layer signalling like mobility management, call control, session management and so on.

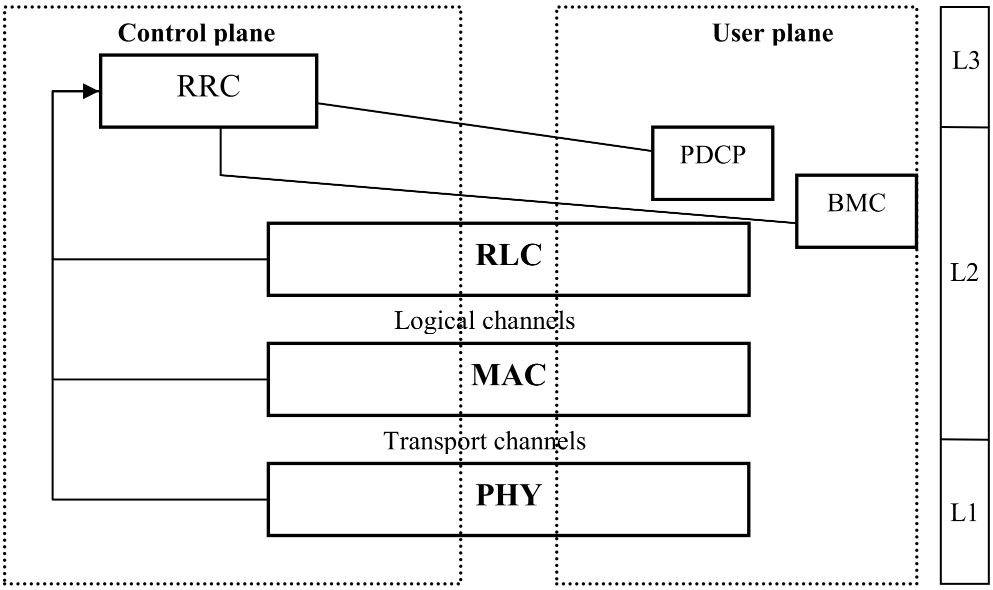


*Figure 23. UTRA FDD Radio Interface architecture.*

## 4.2 Medium Access Control Protocol

First of all, MAC needs a provisioning of logical channels. In the MAC layer the logical channels are mapped to the transport channels and also it is able to select an appropriate transport format (TF) for each transport channel in function of the instantaneous source rate of the logical channels. The MAC layer also develops functions related with priority handling / scheduling and monitoring of the traffic volume. The MAC is able to do a selection of the different messages that have transmitted with common channels into the appropriate receiving stations. The address used for do the selection is called Radio Network Temporary Identifier (RNTI). In addition of the MAC functions, it is responsible to switching between the common and dedicated transport channels, ciphering if the bearer is using transparent RLC mode.

For do all this functionalities MAC divide its architecture in three parts: MAC-b, MAC-c/sh and MAC-d. MAC-b handles the broadcast channels. MAC c/sh handles the common channels and shared channels. MAC-d is responsible for handling the dedicated channels.

## 4.3 The Radio Link Control Protocol

The RLC provides segmentation and retransmission services for user and control data. The RRC configures each RLC to operate in one of three modes: transparent mode (Tr), unacknowledged (UM) or acknowledged mode (AM). This service in the control plane is called Signalling Radio Bearer (SRB) and in the user plane is called Radio Bearer (RB) only if the PDCP and BMC protocols are not used by that service, otherwise the RB service is provided by the PDCP or BMC.

The main RLC functions are; Segmentation and reassembly of variable length higher layer PDUs into/from smaller RLC Payload Units (PU), Concatenation of ELC SDU, Padding is used for fill the spaces, Transfer of user data controlled by QoS settings, Error correction, duplicate detection, flow control, Sequence number check for guarantees the integrity of reassembled PDUs, Protocol error detection and recovery, Ciphering for acknowledged and unacknowledged RLC modes and finally suspend/ resume function for data transfer due is needed during the security mode control procedure.

All these functions are divided in the different parts within RLC architecture. In concrete RLC has three parts: transparent, unacknowledged and acknowledged. These parts are connected with the MAC layer and all the information of the three parts is concentrated in RLC Control. In addition, transparent and acknowledged parts are using unidirectional paths and unacknowledged uses bidirectional paths.

## 4.4 Packet Data Convergence Protocol and Broadcast/Multicast Control Protocol

PDCP and BMC exist only in the user plane and PDCP only for services from PS domain. PDCP has compression methods for improve the spectral efficiency, this compression is necessary due the normal header it can be between 40 to 60 bytes and after compression this header only takes 20 bytes or less.

The BMC is used to adapt broadcast and multicast services, originating from the broadcast domain on the radio interface. In the Release ’99 only SMS Cell Broadcast uses this service. The main BMC function are storage of cell broadcast messages, traffic volume monitoring, scheduling of BMC messages, transmission of BMC messages to UE and delivery of cell broadcast messages to the upper layer.

## 4.5 Radio Resource Control Protocol

The Radio Resource Control (RRC) takes care of the major part of the control signalling between UE and UTRAN. RRC messages carry all the parameters required to set up, modify and release Layer 2 and Layer 1 protocols entities. In addition of that, RRC carry the information required in the higher layers. In the message's payload, RRC is able to carry information about user mobility like measuring signals, handovers, cell updates and so on.

RRC architecture is divided in four entities:

- *Dedicated Control Function Entity (DCFE):* Is responsible to carry all functions and signalling specific to one UE. SNRC has one DCFE entity for each UE having an RRC connection with this RNC. Normally, DCFE uses acknowledged mode.
- *Paging and Notification control Function Entity (PNFE):* Is responsible of paging of inactive mode UE's. There is at least one PNFE in the RNC.
- *The Broadcast Control Entity (BCFE):* Is responsible the system information broadcasting and also in RNC must be at least one BCFE.
- *Routing Function Entity (RFE):* This function is allocated outside of RRC. Its tasks is the routing of higher layer messages to different MM/CM entities in the UE side or different core network domains in the UTRA side.

# PART 2:

# High-Speed Downlink Packet Access and High-Speed Uplink Packet Access (HSDPA and HSUPA)

# 5. What are HSDPA and HSUPA?

This part of the project is the most important due that is our final goal, characterization of the High-Speed Downlink & Uplink Packet Access (HSDPA and HSUPA), actually when we refer to both technologies we will call HSPA (High-Speed Packet Access). The beginning of data enhancement within UTRAN and its air interface had been initiated in release 4, the DSCH (Downlink Shared Channel) had already been developed and it makes the way easy for further enhancements towards a higher bit-rate network. The finally specification was in June 2004 for HSDPA and for HSUPA was in December 2005 and the first commercial network for HSDPA were launched in 2005 and in 2007 is launched the first commercial network for HSUPA. The technologies of HSDPA and HSUPA consist in the optimization of UMTS/WCDMA, and they are included within 3GPP specifications. HSDPA is included into Release 5 and HSUPA as an evolution of HSDPA is included into Release 6. If we want to allocate these two technologies in generation's parameters, we can say that HSDPA is known as 3.5G and HSUPA as 3.75G or 3.5 plus due is the evolution of the first, as we mentioned before. These technologies have been designed to improve the performance of mobile-phone communications through an increase of downlink first and then uplink data rates by means of fast physical layer retransmission and transmission combining and fast link adaptation controlled by Base Station (Node B) as well.

The High-Speed Downlink Packet Access lacks two basic features of other WCDMA channels, variable spreading factor and fast power control although HSUPA has still been used them. Instead of that in Release 5 and in order to achieve higher data throughput, reduce delay and high peak rates, HSDPA employs such techniques as Adaptative Modulation and Coding (AMC), and Hybrid Automatic Repeat Request (HARQ) combined with a cell change procedure and fast-scheduling (Figure 24 shows the main technologies). HSUPA has been used Fast HARQ and fast-scheduling. All these techniques mentioned before could be considered as backbone of HSPA. A part of these techniques, HSPA is able to use advanced antennas and receiver techniques as a Multiple Input Multiple Output antenna processing (MIMO) but this only in release 6. There are two other technologies that right now have been discarded but maybe in the future in Long Term Evolution could be in use. These two technologies are: Fast Cell Selection (FCS) and Standalone Downlink Shared Channel (Standalone DSCH).

The primary benefits of HSPA are perceived by the user due that roughly improvements factor of ten in the speed of service delivery, improvements of a factor of five in capacity items and important improvement in service latency. HSDPA is able to get data rates around 14 Mbits/s in downlink and HSUPA, although with similar technology, it is able to get data rates around 7 Mbits/s, which is caused mainly for the power limitations.

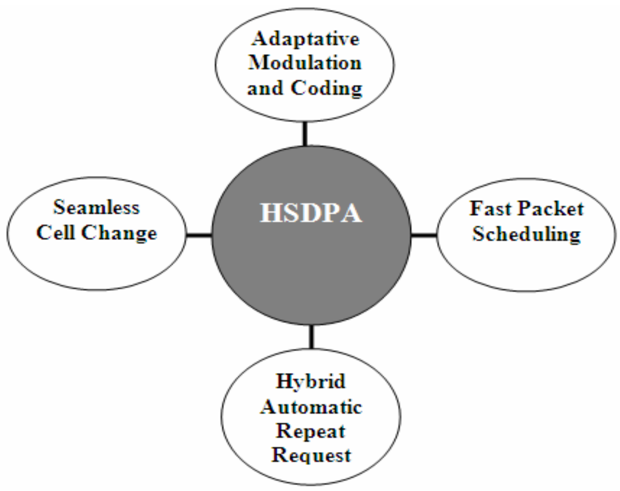


*Figure 24. The main function entities*

These benefits depend on a lot of different factors for obtain the achievable data rates, these factors are: modulation used for the resource, cell coverage, UE mobility, UE distance from the BS and the number of simultaneous users. In addition of these factors which their influence is negatively, the improvement is still huge if we compare with the UTRAN release 4 data capability. Also, the improved cell capacity is other of the HSPA enhancements. In fact, all these features contribute directly to obtain a spectrum efficiency which helps to fit well all the service offerings. In concrete, the main services are streaming, interactive and background services rather than real time services.

Actually, HSDPA and HSUPA will open a big market related in multimedia services for the communication companies and also a big improvement in all the old services such as business applications (e-mail, internet…), and all the rest applications such as games online and so on. The figure 25 shows HSPA evolution towards an enhancement of the peak data rates every year.

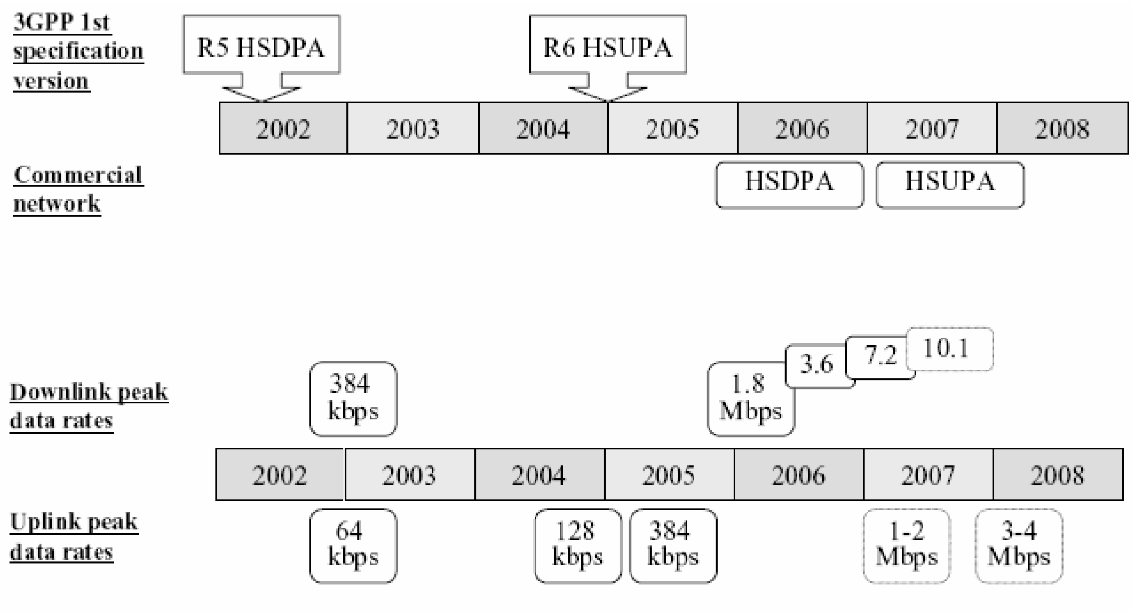


*Figure 25. Evolution of HSPA.*

# 6. Allocation of HSPA within UMTS, Impacts and Benefits

The aims of this chapter are make a first evaluation of HSDPA and HSUPA through its allocation within UMTS network. The main changes in the UMTS architecture are in the access network due is there where is possible to obtain the new enhancements, in Core Network there is no change required, a part of the memory requirements of HSPA. Originally, in the release 4 of UMTS, data traffic could be using the common channels (CCH's), the DCH and DSCH. The data rate of DCH could vary in function of SF (Spreading Factor). The HSPA principally employs a time-multiplexing approach to transfer data packets on a single shared channel while they are using a multicode with a fixed SF. This fact seems easy to implement, however, is needed a set of procedures to make it practical over the air interface. These procedures are such as efficiently schedule, correct modulations, correct encode and final transmission over the air interface. In addition, the radio link should be adapted correctly.

The large delays of the existing Radio Network Controller (RNC) based on Automatic Repeat Request cause a huge amount of memory on the terminal side so an architectural changes are needed to arrive at feasible memory requirements. A part of that, it is useful to change the allocation of the link adaptation and put it closer to the air interface. In HSDPA is used, as a transport channel, High-speed Downlink Shared Channel (HS-DSCH), it is defined for FDD and TDD modes. In the other side, HSUPA is used an uplink Enhanced Dedicated Channel (E-DCH).

| Feature | DSCH | HS-DSCH | E-DCH |
|---|---|---|---|
| Variable Spreading Factor | Yes | No | Yes |
| Fast Power Control | Yes | No | Yes |
| Adaptative Modulation and coding (AMC) | No | Yes | No |
| BTS based scheduling | No | Yes | Yes |
| Soft Handover | Yes | No | Yes |
| Fast L1 HARQ | No | Yes | Yes |
| TTI length (ms) | 80, 40, 20, 10 | 2 | 10, 2 |

*Table 5. Comparison of DSCH versus HS-DSCH.*

First insight of the general functionality of HSDPA starts on the BS or Node B. The BS estimates the channel quality of each active HSDPA user in function of power control, ACK/NACK ratio, and some specific information that the user transmit to BS. After that, is time to scheduling and link adaptation, the velocity of this will depend on the active scheduling algorithm and the user prioritization scheme. The link adaptation function and AMC select the correct code and modulation combination for all the users of the cell. For keep a good spectral efficiency and a large dynamic range of HSDPA link adaptation, the user should utilize up to 15 multicodes in parallel. These features permit to avoid using a variable SF.

In HSUPA is almost the same than HSDPA, it also uses a packet scheduler but it operates on a request-grant. Request-grant consists on the UE's need a permission to send data and the schedule decides when and how many UE's are allow transmitting.

## 6.1 Impacts

In Release '99 transport channels always are transmitted directly between UE and RNC. With the HSDPA retransmission procedure for the packet data, the L1 ACK/NACK is transmitted between BS and UE and it let only the packet arrive to RNC. The Figure 26 shows schematically this impact on the efficiency in retransmissions.

HSPA do not require any modification inside of Core Network, it just needs to solve the memory requirements for HSPA and this is just changes in the memory devices. In the Access Network, in concrete the BS, is required more complexity due in HSPA it has to do more procedures than before. Also RNC has some changes in its structure.

HSUPA is quite similar to HSDPA retransmission but it uses fast HARQ instead HARQ. The difference is that the UE and BS take care about the packet and the retransmissions and when finally the packet is received well, BS transmits the packet to the RNC.

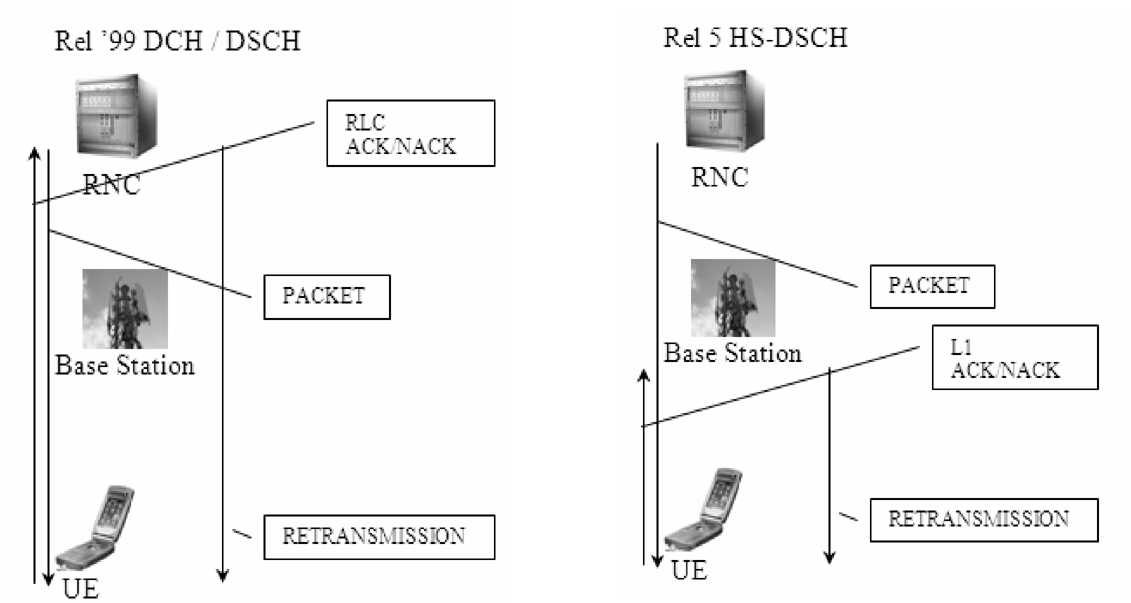


*Figure 26. Rel. '99 and Rel.5 HSDPA retransmission control in the network*

Some other impacts can be appreciated in the changes of bit rates between the different elements of the network. It is possible to see these changes on the bit rates in the following figure 27 where there is the comparison between UMTS and HSDPA. The elements have to be prepared for do the correct data processing with the new data rates.

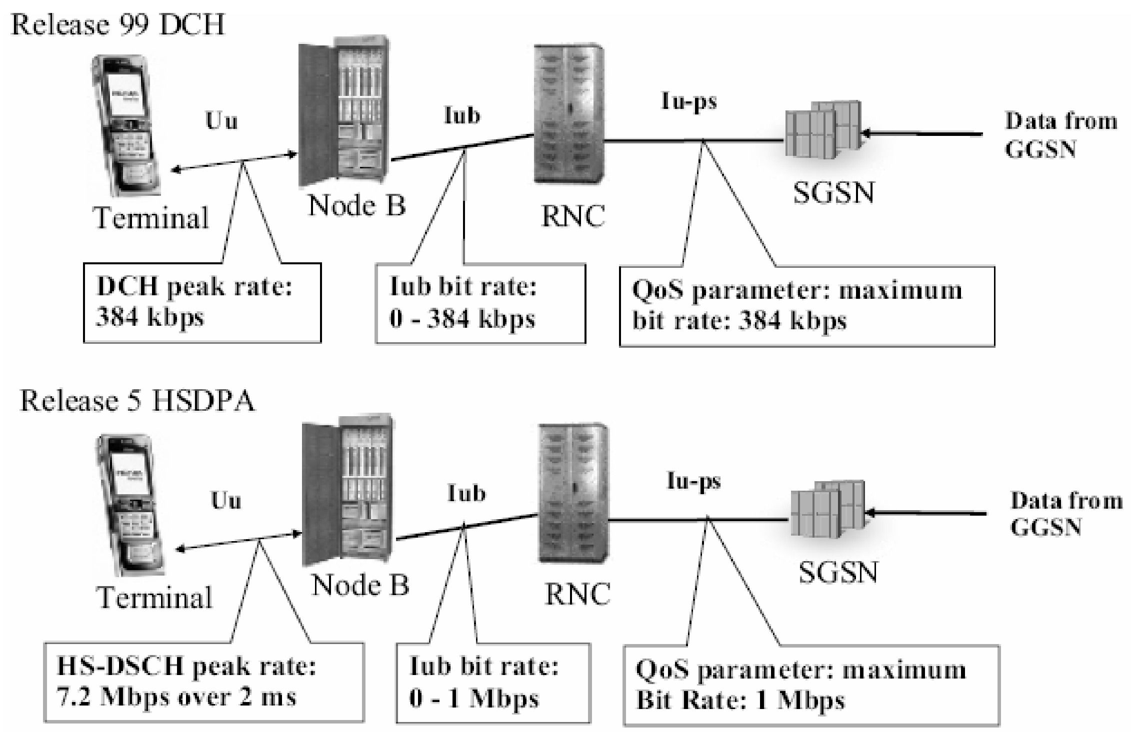


*Figure 27. Impacts in the data rates between different network elements.*

The impacts in the global network are less than if we compare with building a new standalone data network and for that the cost of upgrading from the WCDMA to HSPA is very low.

## 6.2 Benefits

The key benefits of HSPA can be categorized in 3 ways:

- *Improved speed for end user applications:* As we mentioned before data rates achievable of 14.4 Mbit/s downlink and 7.2 Mbit/s uplink. In Release 6 and with the use of MIMO antennas, the throughput could increase.

- *Improved interactivity for end user applications:* One of the major improvements of HSPA technology is the improvement of the network latency or round trip delay for data applications. In the beginning the round trip delay of as low as 60 ms, it means that a huge amount of services can be delivered over HSDPA. That fact give a great improvement in interactivity for example voice, video and also multi-user games. This is the first step towards a new era of mobile multimedia.

- *Improved network capacity for the operator:* With more spectral efficiency, HSPA is able to carry a bigger number of users at the same time. In concrete, with HSDPA the capacity is increased by a factor of 5 if the UMTS carries a bandwidth of 5 MHz. This fact offer the operator a much improved cost structure for offering data services with a reduced cost per bit.

With aims of illustrates the benefits in the case of HSDPA, the figure 28 shows the data throughputs, capacity and delays improvements. We can see that HSDPA is much faster than the other technologies and this permit us to save a lot of time. In the particular example of the file of 3 Mbytes, the measurement that the people of UMTS Forum did, gives the conclusion that UMTS HSDPA saving 81% of the time.

This advantage versus the other technologies gives to HSPA an important place in the future of the mobile communications and also it makes possible the apparition of new services and applications which we will explain more in the next sections.

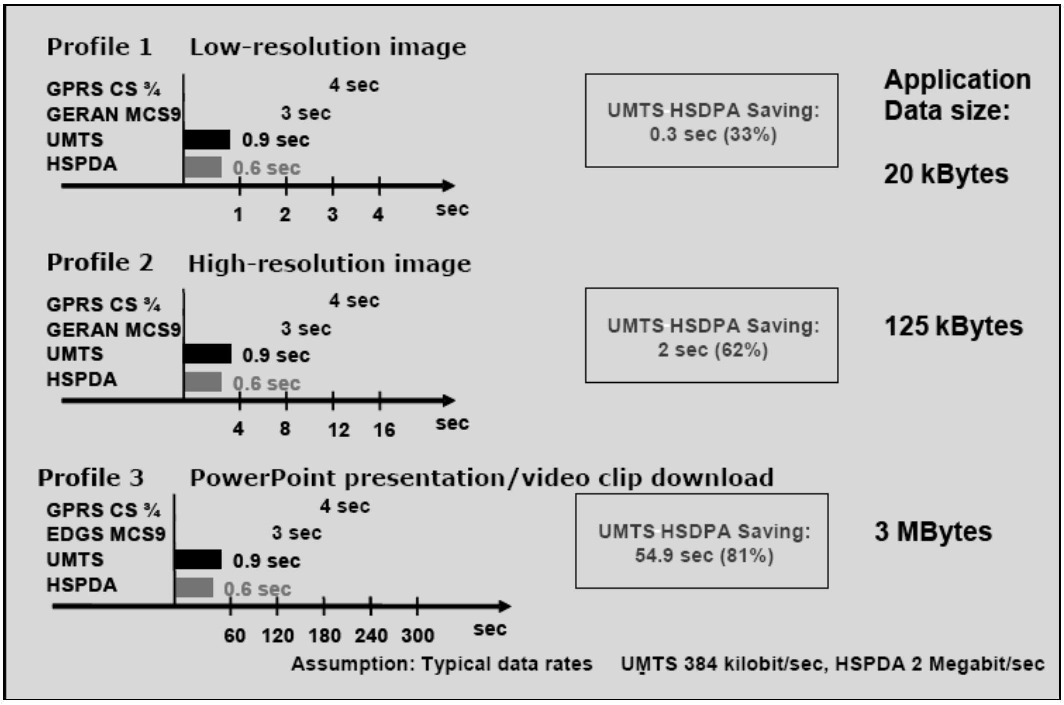


*Figure 28. Measurements have been taken by the people of UMTS Forum.*

# 7. The main techniques of HSDPA and HSUPA

## 7.1 Adaptative Modulation and Coding (AMC)

Adaptative Modulation and Coding is one of the main techniques utilized in HSDPA. The principal goal of AMC is to compensate the radio channel instability by fine-tuning the transmission parameters. AMC uses different procedures and instruments, such as power control, adaptive antenna, dynamic code, channel allocation and so on, to carry out radio link adaptation. All theses procedures follow the same objective and for that they are complementing each other. In HSDPA the application of power control introduces an increase in the complexity and its remarkable gain it is not enough, for that, HSDPA excludes power control.

The main feature is to fine-tune the modulation and coding parameters of the physical layer to compensate the channel variations. This is mainly done by making use of the radio channel measurements extracted by the mobile terminal and, for HSDPA, is using the Channel Quality Indicator (CQI) and retransmission procedures. When HSDPA has that and also traffic information like QoS and the state of radio and physical resources, now is ready to make use of AMC. AMC enables the network through the selection of the best modulation and coding methods.

The modulations have been used in HSDPA, in concrete the modulations which allow Release 5 and in specifically the HS-DSCH, are 16-Quadrature Amplitude Modulation (16QAM) or Quadrature Phase Shift Keying (QPSK) modulation. In the figure 29 there is the symbols allocation of each one. QPSK has already been specified in Release 4 but 16QAM is a new modulation specification of Release 5 for HSDPA. AMC has been using R=1/2 turbo code for QPSK and R=1/2, R=3/4 turbo codes for 16QAM.

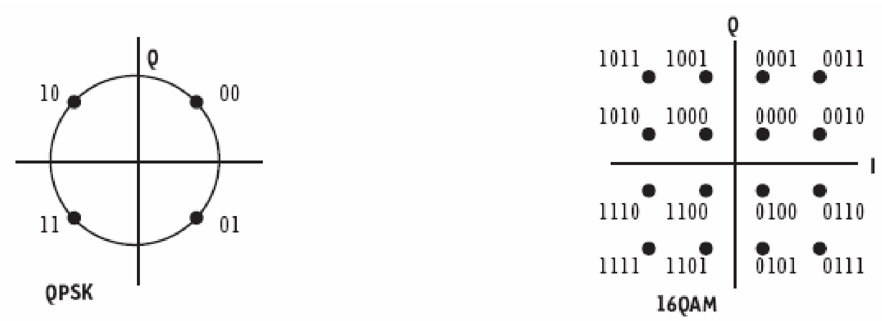


*Figure 29. Symbols allocation of the two modulations used in HSPA.*

With aims to explain the differences between two modulations, now we start by explaining the features of 16QAM. Higher order modulation methods, like our 16QAM, provide higher spectral efficiency in terms of data throughput compared with modulations with less order and they can be used to improve peak data rates due they are using more bits per symbol. In addition, it is also possible to combine the modulation selection with the channel-encoding process, usually this channel-encoded is referred to Transport Format and Resource Combination (TFRC) within of UMTS specifications. For the other side, the utilization of high order modulations cause some limitations like the total interference level that the system is able to accept, and for that is only possible to use them when the total interference level is under a threshold defined before. In other words, the system will require a huge SNR for handle the communication with a controlled error rate. If we do not care about this interference in reception will be a huge percentage of error in the selection of the correct symbol. The figure 30 shows the main idea of AMC, in function of the distance which is related with SNR, the system varies its modulation.

QPSK is a low order modulation due it just has 4 symbols, which feature gives to QPSK more flexibility in terms of level of interference and in conclusion it is able to accept a higher interference level than 16QAM. The combination with these two modulations gives to the system this spectral efficiency due it use each one at the correct time in function of the radio features. Also in the figure 30 is possible to see when is useful to use QPSK modulation, when the requirements of SNR stat to be difficult to obtain.

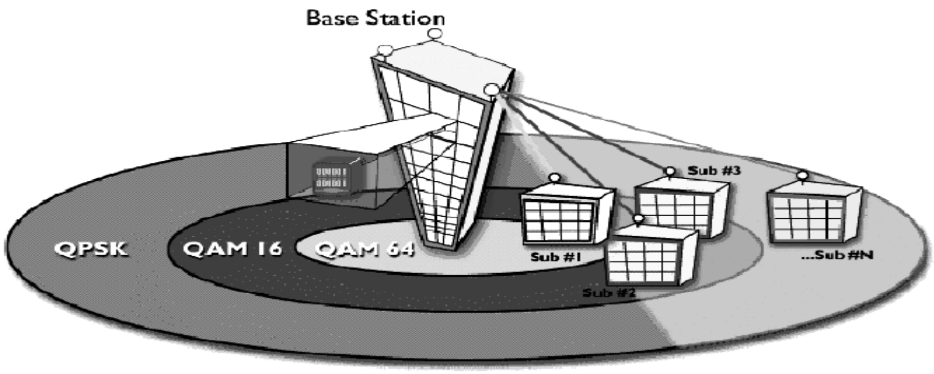


*Figure 30. Overview when the system uses the different modulations in function of distance, in our first appreciation HSDPA only uses 16QAM and QPSK but is also possible to add 64 QAM but its requirements of SNR increase.*

The AMC performance is vulnerable to the radio channel and delay measurements extracted by the terminal: the measurement cycle or radio channel measurement may not follow the usual channel variation due to fast-channel fading, and for that they are not error free. This error cause wrong decisions in reception, as well as a wrong packet scheduling, transmit power settings as well as modulation and coding selecting. These problems cause a waste of capacity when the transmitter is transmitting with too much potency and a huge percentage of error when is with poor level of potency. For solve that, HSDPA has been equipped with advanced CQI estimation procedures that use CPICH received pilot power information, channel timing, adaptive reporting cycle and higher layer interacting to obtain errorless in AMC operation. Also, other technique used in HSDPA, is HARQ that gives some link-layer information into the process.

## 7.2 Hybrid Automatic Repeat Request (HARQ)

As a consequence of the radio channel instability, in concrete the radio measurements may not in isolation form AMC operation, complementary mechanisms are needed. HARQ is a variation of ARQ error control method used in the physical layer. In standard ARQ error-detection information bits are added to data to be transmitted, such as a cyclic redundancy check (CRC). In our case, HARQ, a part of error detection bits it also has a Reed-Solomon code or Turbo code which that feature HARQ performs better than ordinary ARQ in poor signal conditions. First at all, we will explain HARQ in HSDPA and then we are explaining Fast HARQ that is used in HSUPA.

### 7.2.1. HARQ in Downlink

In HSDPA, HARQ allows the receiving Network Element (NE) to detect errors and when necessary to request retransmissions. The retransmissions are one of the most common facts in data transmissions, which assure errorless reception of data packets. One difference between the old ACK is that HACK is able to combine the explicit information from both the original transmission and the corresponding retransmission with the link adaptation process. Figure 31 shows schematically this packet combination. This fact permits to reduce the number of required retransmissions and also errorless link adaptation with independence of the radio channel variations. Figure 26 shows the variation in the retransmission scheme respect to older versions.

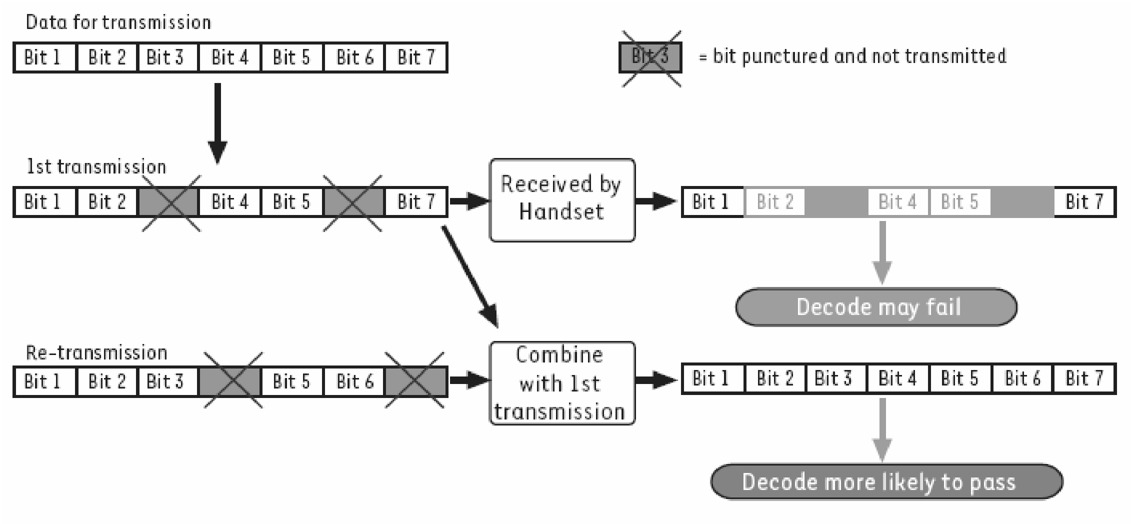


*Figure 31. Packets combination with HARQ.*

The HARQ can be classified in a number of different variants in function to which strategy and protocol were used. These variants are: Rate Compatible Puncture Turbo Codes, Incremental Redundancy and Chase Combining, are some examples. Some of them use additional redundant information for transmitting if the decoding fails in an early phase of the process, the others treat each retransmission independently.

The most critical fact is the retransmission delay and overhead signaling, in particular for mobile network applications. One of the simpler types of retransmission procedure is called Stop & Wait (SAW) which was selected for HSDPA. In SAW, the transmitter operates on the current data packet until successful reception of the data packet by the UE has been assured. SAW uses a smart mechanism and message to confirm successful transmission of data packet, and in this way to avoid the next retransmissions. To avoid the total delay due to waiting time, it employs N channel HARQ with SAW to make all the retransmission process parallel and, hence, save the wasted time and resource.

The HARQ protocol is based on an asynchronous downlink and a synchronous uplink scheme, the combined scheme used in HSDPA depends on the Incremental Redundancy method.

The HARQ functionality is allocated in physical layer inside HS-DSCH coding chain and it can be split into different elements. The HARQ functionality consists of a two-stage rate matching functionality which allows tuning the redundancy version of different retransmission when using non-identical retransmissions. The buffer should be considered as a virtual buffer only. HARQ can be operated in two different ways, with identical or with non-identical retransmissions. The following figure 32 shows the blocks that HARQ functionality could be divided.

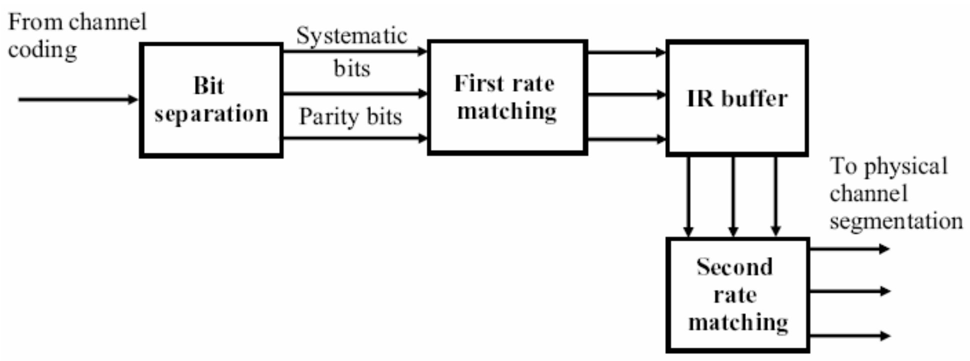


*Figure 32. HARQ functionality*

### 7.2.2. Fast HARQ in Uplink

In HSUPA there are some differences between HSDPA which we are explaining below. The first principle of Fast HARQ is to allow the BS to ask for the UE to retransmit the uplink packet if it was not received correctly. The BS has the capability to combine the multiple transmissions of a single packet through different methods. An N-channel SAW HARQ protocol, similar to the one used in HSDPA, has been used. For understand this procedure in schematically manner, the figure 33 shows the comparison between uplink retransmissions in Release '99 and in HSUPA.

With Fast HARQ, the block (as a data packet block) error rate (BLER) target of the first transmission could be significantly higher, as the delay experienced from the retransmission of an erroneously received packet is dramatically reduced when compared to RLC (Radio Link Control) level retransmission. A high level of BLER target reduces the UE transmission power required for a given data rate. In this way, it is possible to increase the capacity of one cell but like always it is not possible to increase the BLER too much due to it has consequences. The consequence is that the system will need a large number of retransmissions and then the delays could be appreciate by the UE, even if the peak delay values are not seen very often due to the avoidance of RLC retransmission. Also the following problem with the utilization of high BLER is that the effective throughput for a fixed data rate is reduced.

When the system has too many retransmissions through physical layer makes the RLC level retransmission probability close to zero, which benefits especially delay and delay variance sensitive services and the slow RLC retransmission could be eliminated. Delays are not reduced in the same proportion than the system can reduce BLER due the firsts retransmissions would be sent anyway but it can be appreciate a delay reduce. To get goods settings in HARQ parameters, it is a difficult work because for example in one side it could be penalized the system level and the other, it obtains gain in the link level. For avoid this problem it is useful to select the appropriate settings for each type of service. HSUPA HARQ the retransmission is completely synchronous.

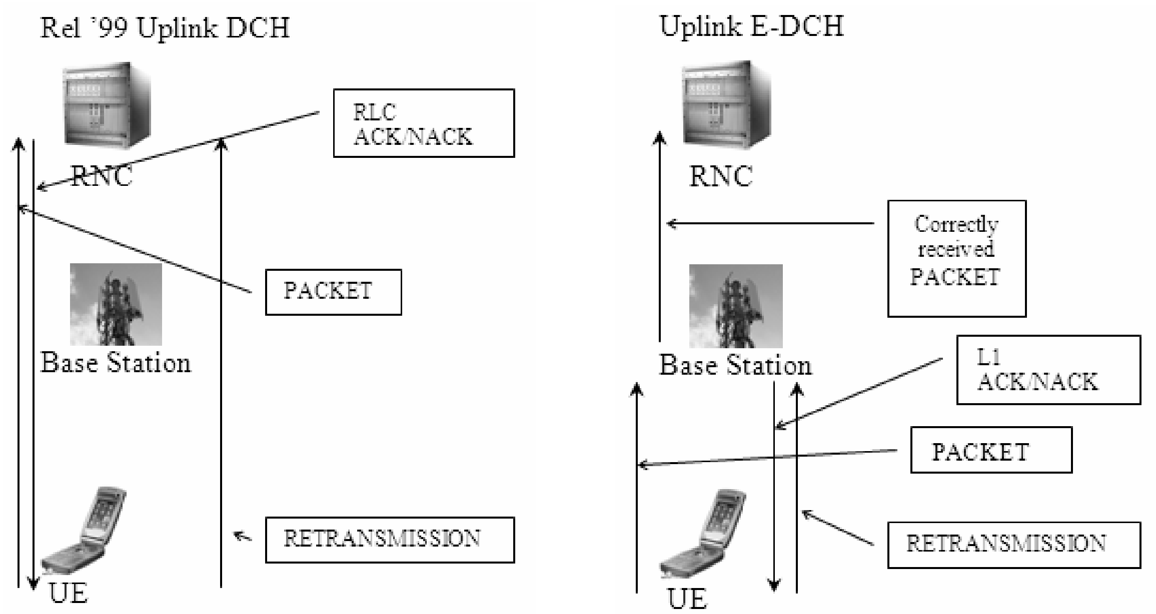


*Figure 33. Rel. '99 Uplink DCH and Uplink E-DCH retransmission control.*

## 7.3 Fast Scheduling

The Fast Scheduling is other of the new techniques that HSPA has been used. The efficient operation of HSPA with its techniques such as AMC and HARQ implies that the packet-scheduling cycle has to be fast enough to track short-term variations in a UE fading signal. The Fast Scheduling in HSDPA is very important due to the absence of fast-power control and Variable Spreading Factor (VSF) mechanisms, as we know yet, these mechanisms have been replaced by AMC, HARQ and fast-retransmissions procedures. This is the main reason to reallocate the Packet Scheduler from the RNC in Release 4 to a BS in HSDPA. Thanks to this fact, the delays in the scheduling process is decreased and at the same time the radio measurements give a better description of the radio channel condition, for obtain a better scheduling decisions.

A part of the reallocation, Fast Scheduling also uses fixed code allocation strategy and the reduction in the Transmission Time Interval (TTI) from 10 or 20 ms in Release 4 to a fixed slot of 2 ms in HSDPA.

In HSUPA, the Fast Scheduling also has been changed from the RNC to BS in order to be able to make scheduling decisions with minimum latency as close to the radio interface as possible. HSUPA scheduling do the same thing for the uplink and moves the scheduling to the Node B, but the similarities between HSDPA and HSUPA scheduling end here. With HSDPA all the cell power con be directed to a single user for a short period of time, and in this way can reach very high peak data rates for that particular UE, but all the others with 0 data rate. And then the BS changes the power cell distribution and other users start to transmit and this fact is repeated every time in function of the numbers of users. This fact it is completely different to HSUPA. So, in the uplink the cell's transmission power resources cannot be given to a single UE at one time and others in some other times, every user can use just its power and that is all. This fact needs to have a good uplink scheduling, so the dedicated channel was seen as the only feasible one with HSUPA, completely opposite with HSDPA that it uses shared channels. One feature of the fast scheduler is that it needs to know in anytime the total sources available in each user to make a correct scheduling.

The HSUPA scheduler decides how many users are able to transmit at the same time, it just interpret that each user want to transmit as maximum as possible, then the scheduler allow more users to start their transmissions but when the scheduler realizes that the old transmissions are slower than before it means that there are too many users transmitting at the same time. The network overload is undesired problem with WCDMA because it occur a huge increase of total interference due to all the users.

## 7.4 Seamless Cell Change

Seamless Cell Change permits the UE to connect to the best cell available to serve it on the downlink, providing to seamless connectivity in HS-PDSCH (High Speed Physical Downlink Shared Channel) mode. This action reduces of undesirable interference, particularly in the case of soft handover. Cell change is a part of mobility procedures for HS-PDSCH which also assures UE mobility in association with high-speed data connection. To obtain this, serving HS-DSCH (High Speed Downlink Shared Channel) cell has to transfer from one of the radio links belonging to the source HS-DSCH to a radio link belonging to the target HS-DSCH. Serving HS-DSCH it could be explained through the next example which the cell with BS performs transmissions and receptions of the serving HS-DSCH radio link for a given UE. This action needs specific treatment because HS-PDSCH allocation to a given UE only belongs to the serving HS-DSCH radio link assigned to the UE. With the same idea of handovers in UTRAN, the serving cell change should be decided by UE or the network. In Release 5 only allows deciding to do handovers the network which is handled by Radio Resource Control (RRC) signaling.

The serving HS-DSCH should be configured based on different considerations, including physical channel configuration, UE-UTRAN synchronization and serving BS position in the network hierarchy. There are two different procedures; one is HS-DSCH BS relocation and the other HS-DSCH cell change. The first procedure, HS-DSCH BS relocation needs as a pre-request the second procedure, HS-DSCH cell change, but not in the opposite way. Other characteristic is when there is HS-DSCH relocation, the HARQ old ends and a new HARQ is processed in the new relocation. At the end, these two procedures are UE seamless in high-speed data mode due it uses a fast relocation of the serving radio link.

# 8. Characterization of HSPA Physical Layer Structure

This chapter consist in describe the physical layer structure of HSPA, which is the part that more changes are introduced. Layer 2 will be affected as well because new high speed MAC entity will be required but the impact to other layers will be minimum. First at all, we are explaining that for HSDPA and then we are continuing with the differences in HSUPA.

## 8.1 HSDPA Physical Layer Structure

The HSDPA is operated similar to DSCH together with DCH in Release ‘99, but HSDPA carries the services with tighter delay constrains, such as AMR speech. To develop these features, three new channels are introduced in the physical layer specifications:

- *High-speed Downlink Shared Channel (HS-DSCH):* Carries the user data in the downlink direction, with a roughly peak rate of 14.4 MBits/s through 16 QAM modulation.

- *High-speed Shared Control Channel (HS-SCCH):* Carries the physical layer control information to enable decoding of the data on HS-DSCH and to perform the possible physical layer combining of the data sent on HS-DSCH in the case of retransmission of an erroneous packet.

- *Uplink High-speed Dedicated Physical Control Channel (HS-DPCCH):* Carries the necessary control information in the uplink and downlink quality feedback information.

The deep description of each news channels is below.

### 8.1.1. High-speed Downlink Shared Channel (HS-DSCH)

The HS-DSCH as we mentioned before is the physical channel to carry all the user information. In HS-DSCH, the Transmission Time Interval (TTI) or interleaving period has been defined to be 2 ms with 3 slots, to achieve a short round trip delay for the operation between the UE and BS for retransmissions. If HS-DSCH has information to transmit, it transmits each 2 ms continually without breaks. The TTI of 2 ms is shorter than the last Releases, for example in Release ’99 supports 10, 20, 40 or 80 ms TTI sizes. The instantaneous peak rate is increased due to short TTI and in addition, a higher order modulation 16 QAM and a lower encoding redundancy. In the code domain, the SF is always fixed at 16 but also is used multicode transmission as well as code multiplexing of different users. The maximum number of codes that can be used is 15, but depending on the terminal capabilities it could be received 5, 10 or 15 codes. The total number of channelisations codes with SF of 16 is also 16 but with the same scrambling code. In fact it is no possible to have 16 channelisations because it needs to have a code space available for common channels (HS-SCCH and DCH) and finally the total channelisations are 15.

The modulations have been used in HS-DSCH are 16 QAM and QPSK (in Rel. ’99). It also was studied the possibility to use 8 PSK and 64 QAM but at the end these modulations were discarded for performance and complexity reasons. One of the advantages that 16 QAM offers is the double peak data rate than the QPSK modulation and it allows around 14 Mbits/s peak data rate with 15 codes of SF 16. All these improvements give to the system a complexity increase, for example when the system is trying to decide one symbol in the constellation of 16 QAM, now it needs to know the phase and also the amplitude, instead the only phase in Release ’99. One disadvantage of the use high order modulations is that they are more vulnerable than the low order modulations due to the symbols are closer between them and it causes more provability to have mistakes in the reception decisions. More information about modulations was explained in section 3.1.

The HS-DSCH channel coding chain has some simplifications when compared to Rel. ’99. There is only one transport channel active on the HS-DSCH and for that the blocks related to the channel multiplexing can be left out. The interleaving only spans over a single 2 ms period and there is no separated intra-frame or inter-frame interleaving. The only code scheme used is turbo coding. The HS-DSCH channel coding chain is illustrated in the figure 34. The major difference is the addition of HARQ functionality which is presented in section 7.2.

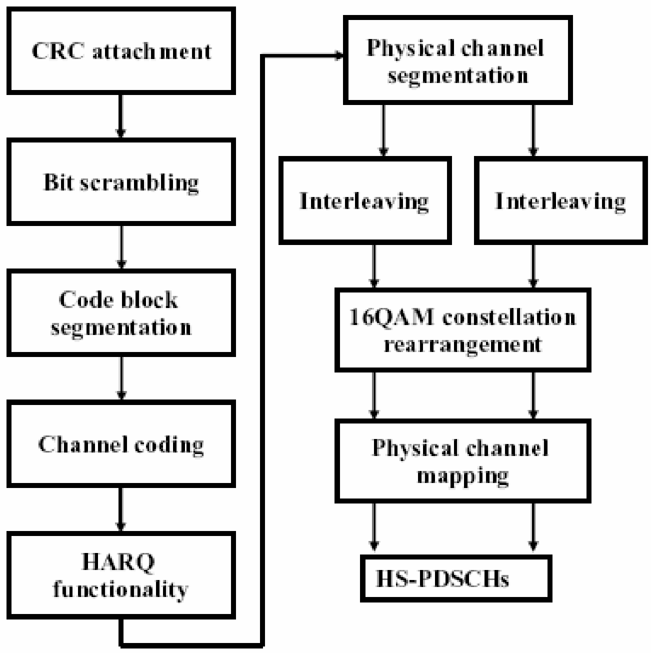


*Figure 34. HS-DSCH channel coding chain.*

In the following table 6 there is a comparison of different channels types, respect to the key physical layer properties.

| Channel | HS-DSCH | DSCH | Downlink DCH | FACH |
|---|---|---|---|---|
| **S. Factor** | Fixed, 16 | Variable (256-4) frame-by-frame | Fixed, (512-4) | Fixed (256-4) |
| **Modulation** | QPSK / 16 QAM | QPSK | QPSK | QPSK |
| **Power Control** | Fixed/slow power setting | Fast, based on the associated DCH | Fast with 1500 kHz | Fixed/slow power setting |
| **HARQ** | Packet comb. at L1 | RLC Level | RLC Level | RLC Level |
| **Interleaving** | 2 ms | 10-80 ms | 10-80 ms | 10-80 ms |
| **Channel coding schemes** | Turbo coding | Turbo and convolutional coding | Turbo and convolutional coding | Turbo and convolutional coding |
| **Transport channel multiplexing** | No | Yes | Yes | Yes |
| **Soft Handover** | For associated DCH | For associated DCH | Yes | No |
| **Inclusion in specification** | Release 5 | Release ‘99 | Release ‘99 | Release ‘99 |

*Table 6. Comparison of different channel types*

### 8.1.2. High-speed Shared Control Channel (HS-SCCH)

The HS-SCCH carries the key information for HS-DSCH modulation. The first insight of HS-SCCH is to give a channel connection between terminal and the network for share control information. The UTRAN needs to allocate a number of HS-SCCHs that correspond to the maximum number of users that will be code-multiplexed. It is needed to transmit HS-DSCH always that HS-DSCH has data, if not it is not required. HS-SCCH has to time slot offset compared with HS-DSCH, this offset is showed in figure 35. There is a lot of HS-SCCH but at the same time, each terminal will only need to consider a maximum of four of them.

Each HS-SCCH block has a 3 slot duration that is divided into two functional parts. The fist part/slot carries the time-critical information that is needed to start the demodulation process. The next part (2 slots) contain less time-critical parameters including CRC (Cyclic Redundancy Check) to check the validity of the HS-SCCH information and HARQ process information. Both parts employ a protection masking to allow the terminal to decide when the control channel is intended to a specific terminal.

The HS-SCCH uses SF 128 that can accommodate 40 bits per slot after channel encoding because there is no pilot or Transmit Power Control bits on HS-SCCH. It uses half rate convolution coding with both parts encoded separately from each other due to the time-critical information is required to be available immediately after the first slot.

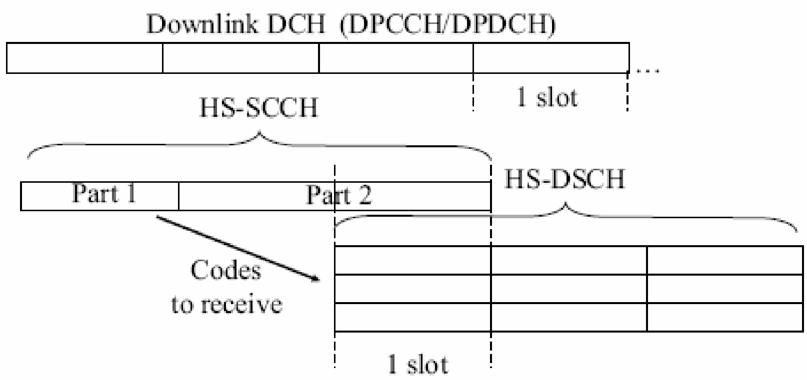


*Figure 35. HS-SCCH and HS-DSCH time difference.*

### 8.1.3. Uplink High-speed Dedicated Physical Control Channel (HS-DPCCH)

The HS-DPCCH has to carry both ACK/NACK information for the physical layer retransmission and the quality feedback information. The BS uses this information in its scheduler to enable the link adaptation and physical layer retransmissions. Originally there was another uplink channel to carry this information but with the enhancements of HSPA it was decided to leave the existing uplink channel and add these new, HS-DPCCH. The HS-DPCCH is divided into two parts:

- *ACK/NACK transmission:* Reflect the results of the CRC check after the packet decoding and combining.

- *Downlink Channel Quality Indicator (CQI):* Indicates which estimated transport block size, modulation type and number of parallel codes could be received correctly with a reasonable BLER in the downlink direction.

The two parts of HS-DPCCH are showed in the following figure 36.

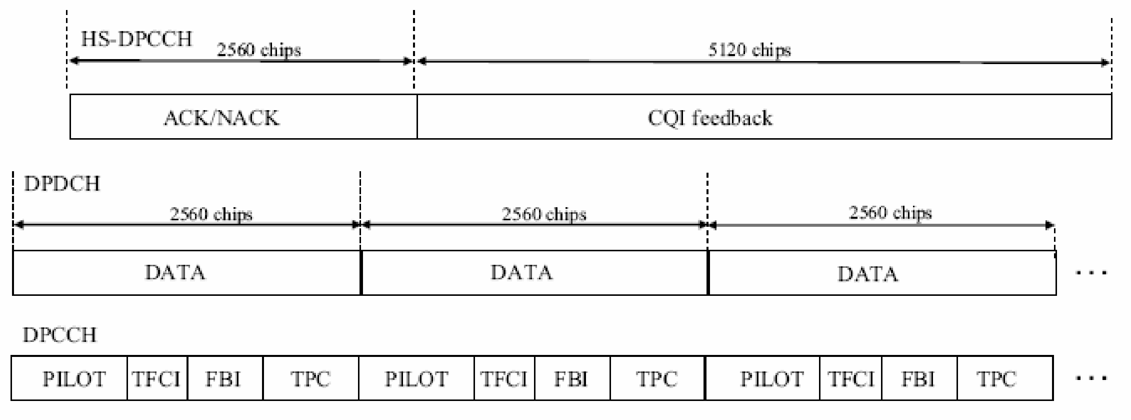


*Figure 36. HS-DSCCH structure.*

The HS-DPCCH uses a fixed spreading factor of 256 and has 2 ms in 3 slot structure. The first slot is used for the HARQ information as figure 36 shows. The rest 2 slots are for CQI use. The HARQ information is always sent when there has been a correctly decoded HS-SCCH received in the downlink.

## 8.2 HSUPA Physical Layer Structure

In HSUPA new signalling channels are needed. The main new transport channel that it has been used is E-DCH; it has the functionality to transforms the transport blocks delivered by the MAC layer to bits transmitted on physical channels. It is required channels for scheduling control such as E-DCH absolute grant channel (E-AGCH) and E-DCH relative grant channel (E-RGCH), as well as retransmission support on the E-DCH HARQ indicator channel (E-HICH). The user data is carried on the enhanced dedicated physical data channel (E-DPDCH) while new control information is on the E-DPCCH.

Unlike HSDPA, HSUPA does not support adaptive modulation because it does no support any higher order modulation schemes because as we mentioned before, in uplink the terminals has problems with the power requirements. When it is used high order modulation then the terminals need more energy per bit to could be transmitted. The E-DCH is supported by HARQ which is provided in the transport channel processing chain.

After transport channels processing, the E-DCH maps to one or multiple parallel new dedicated physical data channels, E-DPDCH, for physical layer transmission. Both physical channels, E-DCH and DCH can coexist in the same UE with the restriction that the maximum DCH data rate is 64 kbps when the E-DCH is configured. In the downlink three new physical channels were introduced to provide HARQ feedback and facilitate uplink scheduling.

In HSUPA there may be up to five different types of dedicated channels transmitted simultaneously in the uplink. The E-DPDCH supports orthogonal variable spreading factors to adjust the number of channel bit to the amount of data actually being transmitted. It uses BPSK modulation and fast power control loop. E-DPDCH supports fast physical layer level HARQ and fast scheduling. HARQ is allocated in the transport channel processing chain and the scheduling is visible in the MAC layer.

The E-DPDCH summarize is represented in table 7.

| **Feature** | **E-DPDCH** |
|---|---|
| **Maximum SF** | 256 |
| **Minimum channel data rate** | 15 kbps |
| **Minimum SF** | 2 |
| **Maximum channel data rate** | 1920 kbps |
| **Fast Power Control** | Yes |
| **Modulation** | BPSK |
| **Soft Handover** | Yes |
| **TTI length (ms)** | 10, 2 |
| **Max. nº. of parallel codes** | 2xSF2 + 2xSF4 |

*Table 7. Features of E-DPDCH.*

There are other physical channels such as E-DPCCH, E-HICH, E-RGCH and E-AGCH.

- The E-DPCCH is an uplink physical channel used for transmitting out-of-band information about E-DPDCH transmission from the mobile to the base station.
- The E-HICH is a downlink physical channel used for transmitting positive and negative acknowledgements for uplink packet transmission.
- The E-RGCH is a downlink physical channel used for transmitting scheduling commands that affect the relative transmission power the UE is allowed to use.
- The E-AGCH is a downlink physical channel used for transmitting the BS scheduler’s decisions.

# 9. New capabilities of the radio network elements within UMTS architecture

This chapter pretends to give a main overview of the most essential HSDPA and HSUPA RRM (Radio Resource Management) functionalities at the BS and RNC. In HSDPA, BS has the functionalities to HS-DSCH link adaptation, packet scheduling and HS-SCCH power control. The new algorithms for RNC in HSDPA include resource allocation, admission control and mobility management. In the figure 37 is possible to see the functionalities distribution of RRM.

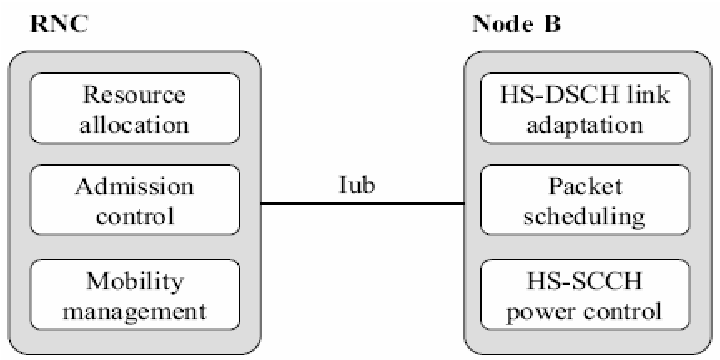


*Figure 37. The main functionalities of RNC and BS or Node B in HSDPA.*

The RRM for HSUPA consists of functions located in the RNC, BS and UE. The RNC is responsible for allocating resources to HSUPA, admission control, handover control and also it controls DCH channels. The Bs shares the resources among the different HSUPA users. Finally, the UE is responsible for selecting the transport block based on the available transmit power and on the available data in the buffer. The resume of all the functionalities is showed in the figure 38.

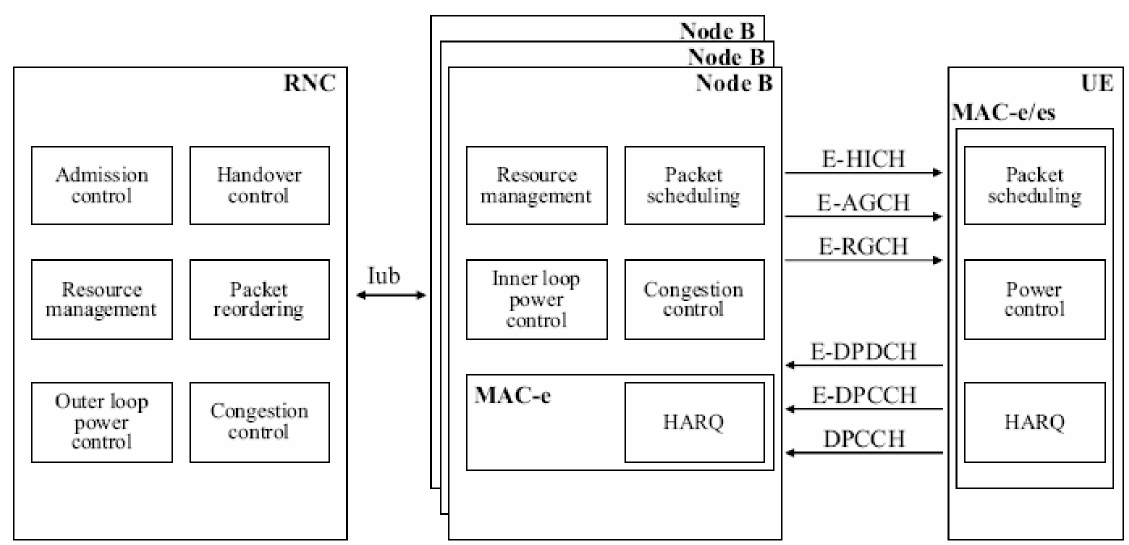


*Figure 38. Overview of the different functionalities of RNC, BS (Node B) and UE.*

## 9.1 Base Station (BS)

The BS functionalities are divided in HSDPA and HSUPA features.

### 9.1.1. BS in HSDPA

The BS has three main functionalities: HS-DSCH link adaptation, packet scheduling HS-SCCH power control. In BS is needed HS-DSCH link adaptation functionality for adjust the bit rate every transmission time interval (TTI), depending on the user reception quality. BS needs a HS-SCCH power control to minimize the power overhead while guaranteeing reliable reception. Finally, packet scheduling in MAC layer to control how often admitted HSDPA users are served on the HS-DSCH, a well design of that it is able to maximize cell capacity.

*HS-DSCH link adaptation*

The HS-DSCH link adaptation algorithm adjusts the transmit bit rate on the HS-DSCH each TTI when a user is scheduled for a transmission. This link adaptation is in function to CQI which is UE measurements that are sent to BS. The CQI indicates the maximum transport block size that can be received correctly with at least 90% probability. The figure 39 shows this idea about link adaptation.

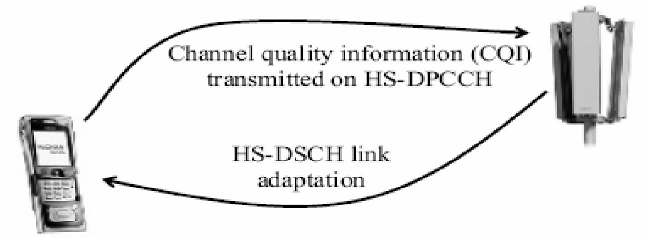


*Figure 39. Main idea of HS-DSCH link adaptation.*

*Packet Scheduling*

The main problem that packet scheduling, in BS, is trying to solve is how to share the available resources between all the users capable to receive data. One of the most common formulations to solve this is one proposed by Kelly. The basic idea is create a formula which is capable to calculate the utility function. The utility function is a measurement of the happiness or satisfaction gained after packet scheduling. The processes in packet scheduling are explained before in section 7.3.

*HS-SCCH power control*

The quality reception of HS-SCCH is important due to transport block on the HS-DSCH can only be decoded if the HS-SCCH has first been correctly received. The correct power level for transmit correctly the HS-SCCH it has to be decided by BS. This correct power level is needed to assure a minimum interference into the network and at the same time, enough power for to be received correctly. The HS-SCCH should be controlled each TTI.

### 9.1.2. BS in HSUPA

The main functionalities of the BS for HSUPA are packet scheduling and HARQ. The HARQ is explained in section 7.2. And the packet scheduling for HSUPA is described below.

*Packet scheduling*

The packet scheduling is divided in two different modes for HSUPA: BS scheduling mode with L1/MAC control signaling in the uplink and downlink, and RNC-controlled non scheduled mode. HSUPA has two main advantages over WCDMA: L1 HARQ and BS packet scheduling. The first gives a benefit in terms of spectral efficiency and the second gain comes from faster packet scheduling which enables operation at higher loads factors and higher cell throughputs. The more detailed information about packet scheduling is in section 7.3.

The BS also has the functionality of congestion control for HSDPA and HSUPA and it consists in take care of the network load and tries to avoid the congestion.

## 9.2 Radio Network Controller (RNC)

The RNC functionalities are divided in HSDPA and HSUPA features.

### 9.2.1. RNC in HSDPA

In RNC, there are three main functionalities: resource allocations, admission control and mobility management. HSDPA resource allocation refers to the functionality that allocates power and channelization to the BS for HSDPA transmission in each cell. HSDPA admission control is needed to select the user's access. Other functionality is the mobility management for HSDPA, the data is transmitted from one cell to the UE at a time, and effective BS buffer management is needed during handovers due to the distributed architecture.

*Resource allocation*

Resource allocation is needed before BS starts to transmit. The RNC needs to allocate channelization codes and power for the transmission of HSDPA data. The signal between RNC and BS is used NBAP (Node B Application Part) protocol specified by 3GPP. The resources are allocated by sending an NBAP from RNC to BS.

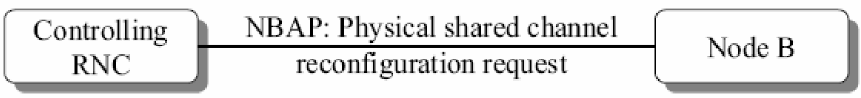


*Figure 40. Signalling for RNC resource allocation.*

*Admission Control*

The admission control within RNC has the functionality to determinate which new users with HSDPA terminals can be accepted to transmit into the cell. The RNC needs some information to decide a correct admission control, theses information are like QoS parameters, check availability of RNC and BS, check priority of the users and so on.

*Mobility Management*

HSDPA do not use soft handover since HS-DSCH and HS-SCCH transmission take place only from a single cell. Mobility management has to take care to cell change when the radio link is getting weak, handovers in intracell and intercell and so on.

### 9.2.2. RNC in HSUPA

In RNC for HSUPA there are four functionalities: resource allocation, QoS parameterization, admission control and mobility management.

*Resource allocation*

The RNC sets the terminal value for the maximum received wideband power for the BS. The received power consists of thermal noise, inter-cell interference, intra-cell interference from DCH connexions and intra-cell interference from E-DCH connections.

*QoS parameterization*

The RNC gives a number of QoS parameters to the BS, which can use the parameters in the packet scheduling. Theses parameters are such as scheduling priority indicator, guaranteed bit rate and the maximum number of transmissions for HARQ.

*Admission control*

The Admission control decides whether or not to admit a new user to HSUPA. It is similar to HSDPA admission control. The RNC decides who is able to begin transmitting in function of number of HSUPA users, uplink interference levels, scheduling priority indicator, guaranteed bit rate and so on.

*Mobility Management*

Mobility Management in the RNC decides in the first place, which cells are in the active set and then which cells is the serving HSUPA cell. The first action is like the handover control in WCDMA and the second decides which cell is in control of the HSDPA user. The serving cell is the same for HSDPA and HSUPA and it should happen at the same time.

# 10. User Terminal capabilities in Downlink and Uplink

The goal of this chapter is give a briefly idea about which capabilities the terminals have in the uplink and downlink. The description consists in give the main features of the terminals for the downlink as well as for the uplink.

## 10.1 HSDPA terminal capabilities

The HSDPA feature is optional for terminals in Rel.5 with a total of 12 different categories of terminal from the physical layer standpoint, and the data rates of these categories are between 0.9 and 14.4 Mbps. The HSDPA features are independent from the backward releases which this means that is possible to have DCH channels together with HS-DSCH channels. But when this fact happens, the DCH data rates are limited by the terminal and its possible data rates are 32, 64, 128 or 384 kbps.

The first ten HSDPA terminal capability categories need to support 16 QAM and the last two support only QPSK modulation. One difference between classes is in the maximum number of parallel codes that must be supported. Another capability of the peak rate over multiple continuous TTIs is the inter-TTI parameter. Categories with values of 1 are the devices that can also sustain the peak rate during 2 ms over multiple TTIs, while the other devices for 2 or 4 ms after each received TTI. Additionally there is a soft buffer capability which uses two principles for determining its value. Terminals with smaller soft buffer value, like category 5 cannot support incremental redundancy at the higher data rates.

| Category | Maximum number of parallel codes HS-DSCH | Minimum inter-TTI interval | Transport channels bits per TTI | ARQ type at maximum data rate | Achievable maximum data rate (Mbps) |
|---|---|---|---|---|---|
| **1** | 5 | 3 | 7 298 | Soft | 1.2 |
| **2** | 5 | 3 | 7 298 | IR | 1.2 |
| **3** | 5 | 2 | 7 298 | Soft | 1.8 |
| **4** | 5 | 2 | 7 298 | IR | 1.8 |
| **5** | 5 | 1 | 7 298 | Soft | 3.6 |
| **6** | 5 | 1 | 7 298 | IR | 3.6 |
| **7** | 10 | 1 | 14 441 | Soft | 7.2 |
| **8** | 10 | 1 | 14 411 | IR | 7.2 |
| **9** | 15 | 1 | 20 251 | Soft | 10.2 |
| **10** | 15 | 1 | 27 952 | IR | 14.4 |
| **11** | 5 | 2 | 3 630 | Soft | 0.9 |
| **12** | 5 | 1 | 3 630 | Soft | 1.8 |

*Table 8. HSDPA terminal capability categories.*

The highest capability is able to provide data rate of 14.4 Mbps. This is possible through a 1/3 rate turbocoding. All the different categories are represented in the table 8.

It is also possible to modify the terminal data rate through to change the code rate. In the following table there is a theoretical data rate that they keep the number of multicodes fixed to 15 and they only change the code rate. As we can see in the table 3.4, the max throughput has a huge variance due to minimum of 1.8 Mbps and a maximum of 10.7 Mbps. Theses data rates can be allocated for a single user or divided between several users. The network can match the allocated power or code resources to the terminal capabilities and the data requirements of the active terminals.

| TFRCs | Modulation | Effective code rate | Max. throughput (Mbps) |
|---|---|---|---|
| 1 | QPSK | ¼ | 1.8 |
| 2 | QPSK | 2/4 | 3.6 |
| 3 | QPSK | ¾ | 5.3 |
| 4 | 16 QAM | 2/4 | 7.2 |
| 5 | 16 QAM | 3/4 | 10.7 |

*Table 9.Theoretical bit rates with 15 multicodes with different TFRCs.*

## 10.2 HSUPA terminal capabilities

The terminals in HSUPA can be explained using the same approach than in HSDPA. The terminal informs the network of one from six possible terminal categories instead of signaling individual capabilities. The main differences between different categories are related to the terminal's multicode capability and to the support of 2 ms TTI. All terminal categories support the 10 ms TTI. All the categories except category 1 can carry out multicode transmission.

In addition, the minimum total terminal RLC/MAC buffer size for combined HSDPA and HSUPA operation. In this way, we want to show which size of buffers is typical to have. The values range varies from 50 kbytes, for HSDPA category 12 and HSUPA category 1, to 400 kbytes for HSDPA category 10 and HSUPA category 6. The maximum uplink DCH when is configured at the same time with HSUPA is 64 kbps for all the UE categories.

| Category | Supported TTIs | Maximum data rate with 10 ms TTI | Maximum data rate with 2 ms TTI |
|---|---|---|---|
| 1 | 10 ms | 0.72 Mbps | N/A |
| 2 | 2 ms and 10 ms | 1.45 Mbps | 1.45 Mbps |
| 3 | 10 ms | 1.45 Mbps | N/A |
| 4 | 2 ms and 10 ms | 2 Mbps | 2.91 Mbps |
| 5 | 10 ms | 2 Mbps | N/A |
| 6 | 2 ms and 10 ms | 2 Mbps | 5.76 Mbps |

*Table 10. HSUPA Terminal capability categories.*

In the following releases this data rate should be improved and it is possible in Release 7 the maximum HSUPA data rate will arrive around 7 Mbps.

# 11. Mobility with HSDPA and HSUPA

The mobility is one topic with a huge importance in these technologies. If it is not possible to assure a good mobility performance then all the systems are not useful due to HSPA is a technology for mobile communications which the receiver never is in the same place. Our goal is just give an insight about the main features in mobility skills and we divided the mobility in HSDPA and HSUPA.

## 11.1 Mobility in HSDPA

The mobility in HSDPA users is affected by the fact that transmission of the HS-PDSCH and HS-SCCH to a user belongs to one of the radio links assigned to the UE which is called the serving HS-DSCH cell. UTRAN decide the assignation of the serving HS-DSCH cell in function to HSDPA UE capabilities. Synchronized change of the serving HS-DSCH cell is supported between UTRAN and UE. The connectivity is achieved if the UE moves from one cell to another, in that moment, start and stop of transmission and reception of the HS-PDSCH and the HS-SCCH is done at a certain time dictated by UTRAN, and then the cell change is done. This fact allows full mobility and coverage in HSDPA.

When is compared with the DCH the big difference is the lack of soft handover for the HS-DSCH. The serving HS-DSCH cell may be changed with DCH through soft handover without updating the user's active set for the Release '99 channels. One requirement for the terminal is to be able to cope with up to six cells in the DCH active set. In release 5 new UE measurements are included to inform UTRAN of the best serving HS-DSCH cell.

If the HSDPA is used while the system is operating in soft handover then it is needed to modify measurements to get information about changes in the relative strengths of the cells in the active set. This information does not cause variations for the DCH but it may cause some changes in the serving HS-DSCH cell with HSDPA operation. This information is given to RNC when the cell with the optimum CPICH (Common Pilot Channel) strength in the active set changes. When the terminal realize of that change, it will send (as a part of uplink RRC signaling) a measurement report to the RNC.

In Rel. 5 the serving HS-DSCH cell can only be changed inside the terminal's active set by using a physical channel reconfiguration procedure. When a change of serving HS-DSCH cell happens, the terminal stop to listen the old base station, delete the old messages and start to listen the new one following the instructions of downlink RRC signaling. Also in the BS, all the old packets are deleted inclusive possibly unfinished HARQ processes. Then the network will have to sort out the unsent packets when used RLC is acknowledged mode. In the other mode, unacknowledged mode the packets are not to be transmitted and some of them are lost during the cell operation, but packet loss can be minimizes by the RNC calculating carefully when the handover will take place and not sending packets to the serving HS-DSCH cell. During synchronized serving HS-DSCH cell change, any interruption to packet transmission can be minimized by the terminal or the network because both know when the handover takes place. To minimize possible data loss, is introduced the support of out-of-sequence payload data units (PDUs) in unacknowledged mode RLC in release 6. In the figure 41 is possible to see how the terminal checks the different CPICH levels and in function of these levels it will decide to which BS (Node B) connect.

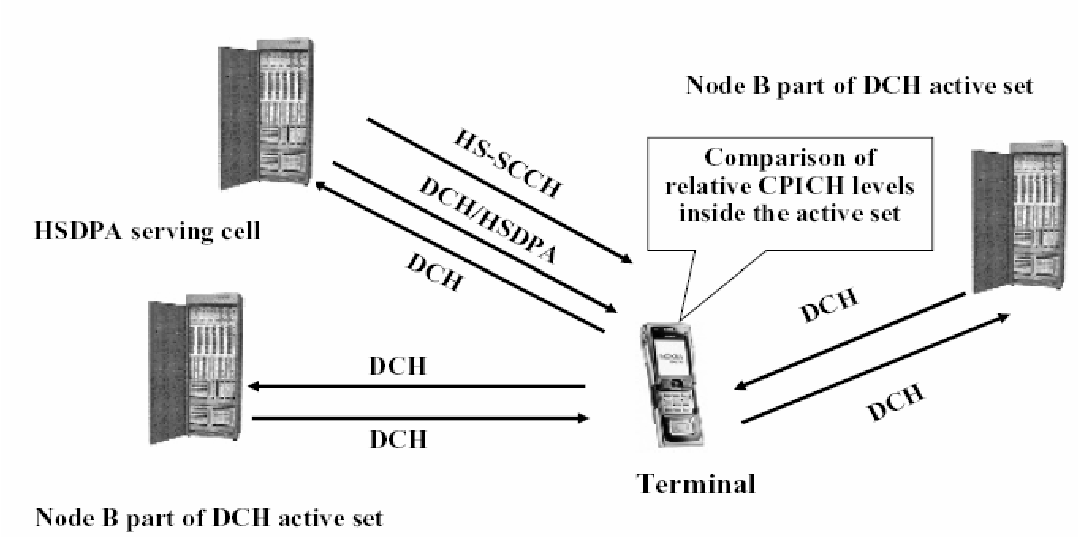


*Figure 41. HSDPA operation with DCH active set of 3.*

## 11.2 Mobility in HSUPA

HSUPA as a difference of HSDPA, it can be operated in soft handover. In HSUPA can be different active sets in use like in backward releases. In HSUPA functionalities such as scheduling or HARQ is not needed to operate with a lot of base stations as in older releases. The terminal has to handle few cells (maximum four) for HSUPA operation. Some different active sets is possible to have when, for example, the active set contains base stations that do not have HSUPA capability, then at least the DPCCH is received by all the base stations in the DCH active set and only the HSUPA stations can do its work (scheduling and HARQ operation).

The total number of additional signaling channels the terminal has to listen to in soft handover must be limited. Also one important aspect is that every cell in the E-DCH active set must be also in the DCH active set but it could be possible that one DCH active cell may contain cells that do not belong to the E-DCH active set.

The change cell uses almost the same criteria as the change in serving HSDPA cell. It follows the same procedures that HSDPA for the UE measurements and the same criteria for chose which cell has the best conditions. The serving E-DCH cell would be the same that serving HSDPA cell. The network should configure the uplink and downlink operation so it will be impossible to use the downlink when the uplink is being used. One important terminal capability is that all the HSUPA devices have to include also HSDPA.

# 12. Brief analysis about HSDPA and HSUPA Performance

This chapter pretends to give an overview of the performance in HSDPA and HSUPA, focused in the end user perspective. The analysis about HSPA technologies could be a very difficult work and it is out of our goal to make a very detailed study. Like in all the last chapters, we divided the analysis of performance in HSDPA and HSUPA.

## 12.1 Performance HSDPA

The HSDPA suffers a change in environment and channel performance by the fast adaptation of modulation, coding and code resource settings. Basically the performance of HSDPA depends on the following factors:

- *Channel conditions:* Time dispersion, cell environment, terminal velocity and cell interference.
- *Terminal performance:* Basic detector performance such as sensitivity and interference suppression capability.
- *Nature and accuracy of radio resource management (RRM):* Power and code resources allocated to the HSDPA channel and accuracy of SIR estimation and packet scheduling algorithms.

After know some of the factors which intervene in the HSDPA performance we have realized that is really complicated to do all the procedures with all the simulations required for arrive a good conclusions about HSDPA performance. We do not have enough time to do it and for that we will explain the main conclusions those are explained in HSDPA/HSUPA for UMTS by Harri Holma and Antti Toskala.

The resume of the HSDPA performance is described below:

- HSDPA link performance is more robust than before due to fast L1 retransmissions, incremental redundancy and link adaptation.
- The field measurements that they have done show median data rates of 1 Mbps with a terminal capability of 1.8 Mbps. Practical data rates will improve when higher bit rate UE categories are available.
- HSDPA reduces network latency compared with Release ’99 DCH. The average RTTs can be clearly below 100 ms with HSDPA.
- HSDPA improve cell throughput by up to 1 Mbps/MHz/sector in three-sector macrocells due to advanced link level techniques, enhanced terminal receivers and multiuser diversity with fast scheduling.
- Fast scheduling helps to improve cell throughput by over 30 % with low mobile speeds.
- HSDPA and WCDMA can coexist on the same carrier. The shared carrier provides an attractive performance, especially when the amount of WCDMA traffic is low and the HSDPA terminal has a limited bit rate of 1.8 Mbps. For a high capacity and high bit rate solution a dedicated HSDPA carrier can be used later.
- HSDPA itself may require additional investments in Iub transport to facilitate the high peak bit rates, but HSDPA also improves the efficiency of Iub compared with

Release ’99. This improvement is because in HSDPA is transmitted only from one cell without soft handover and HSDPA users have a shared Iub resource instead of dedicated resources like in Release 99.
- Finally, HSDPA bit rates and capacity can be further enhanced by more than 100% by advanced terminal receivers.

As a conclusion, it is tested that HSDPA introduces enhancements in comparison to Release ’99.

## 12.2 Performance HSUPA

As we have done with HSDPA, we will explain briefly the main conclusions that other studies arrive. The main HSUPA performances are described below:

- The higher data rates in HSUPA are achieved without higher order modulation which permit efficient mobile power amplifier operation and facilitates good coverage for high data rates.
- High HSUPA bit rates above 1 Mbps are available in a large macro-cell at a 50% probability.
- The advanced techniques improve cell capacity and spectral efficiency in loaded cells. Those techniques are the same as we mentioned before such as fast L1 retransmissions with HARQ and fast Base Station (Node B) scheduling.
- Fast retransmissions allow a higher error rate in HSUPA than in Release ’99 and keeping the same end-to-end delay. If the block error rate is increased from 1% to 10% then the cell capacity gain is 15-20% and with higher block error rate levels even above 50%.
- Fast Scheduling permit to use higher average interference levels in HSUPA than in the Release ’99. Fast scheduling makes the SNR required smaller. The capacity gain from fast scheduling is around 10-20%.
- The total capacity gain from HSUPA is 25-60% and this capacity can be improved using new base station antenna like MIMO.

# 13. Brief comparison between GSM, UMTS and HSPA

Finally, we want to do a comparison about the main features between the three more important technologies, 2G with GSM, 3G with UMTS and 3.75 with HSPA (HSDPA and HSUPA). This comparison will give an insight about the improvements suffered by the mobile networks and at the same time the improvements suffered by mobile terminals.

First at all, we have to allocate these systems in function when they were launched. The first GSM (Global System for Mobile Communication) network was launched in 1991 by Radiolinja in Finland with joint technical infrastructure maintenance from Ericsson. It is the most popular standard for mobile communications and its use is very huge, above 2 billion people use GSM across 212 countries. Then appear UMTS with WCDMA for introduce a new enhancement to the GSM networks. The first UMTS network was launched in 2002. By the end of 2005 there were 100 open WCDMA networks and a total of over 150 operators. The number of WCDMA subscribers globally was over 50 million by February 2006 and actually the number of WCDMA subscribers is around 171 millions by December 2007 (Data provided by Wireless intelligence). Finally, the enhancement of UMTS, HSPA was launched in June 2004 for HSDPA and then in December 2005 for HSUPA. The commercial HSPA network was a little bit later, HSDPA were launched in 2005 and HSUPA is launched in 2007. In December 2007 there are around 11 millions subscribers of HSPA with HSDPA alone or both (Data provided by Wireless intelligence).
Now we have been introduced the chronological launches and we going to explain with more detail the main features of each one and thus we can compare each other and evaluate the enhancement succeeded.

The most important feature for the customer is the maximum data rate that the network is able to offer. In GSM the maximum data rate is 270 kbps, in UMTS the maximum data rate around 2 Mbps and finally in HSPA the maximum data rate is around 14 Mbps for the downlink and around 7 Mbps for the uplink. From GSM to now the mobile systems have been evolved through achievable data rates around 50 times more. We have to say that the handsets available right now they are not able to support the maximum data rate of 14.4 Mbps but they are able to support 10 Mbps like the new model N82 from Nokia.

The spectrum allocation is the same that we explained before in the first chapter of UMTS. As a remind of the spectrum allocation, GSM is allocated in 890-915 MHz uplink and 935-960 MHz downlink, UMTS is allocated 1920-1980 MHz uplink / 2110-2170 MHz downlink and finally HSPA is allocated in the same range of frequencies than UMTS due to is the enhancement of UMTS as now everybody know.

The main features between GSM and UMTS are explained in the UMTS chapter in the comparison section 1.3, for that reason we will focus in compare the UMTS against HSPA but we included a summarize table where is possible to see the main characteristics of each one. The main differences between UMTS and HSPA are in the physical layer. New physical channels and transport channels are introduced in UMTS, but HSPA keeps the old channels as well. The main new physical channels are HS-DSCH, HS-SCCH and HS-DPCCH for HSDPA and for HSUPA the new physical channel is uplink E-DCH. A part those new additional physical channels there are some new transport channels as well. More detailed information about that is in the section 8. It is possible to see those differences in the table 11 where DSCH is the physical channel used in UMTS.

| Feature | UMTS | HSDPA | HSUPA |
|---|---|---|---|
| Variable Spreading Factor | Yes | No | Yes |
| Fast Power Control | Yes | No | Yes |
| Adaptative Modulation and coding (AMC) | No | Yes | No |
| BTS based scheduling | No | Yes | Yes |
| Soft Handover | Yes | No | Yes |
| Fast L1 HARQ | No | Yes | Yes |
| TTI length (ms) | 80, 40, 20, 10 | 2 | 10, 2 |

*Table 11. Comparison about the main procedures in UMTS and HSPA*

HSPA introduce differences in the allocation of the network functions. In HSPA the Base Station (Node B) has more importance than before, it carry more functionalities for avoid exceeds in the delays and make a better approximation of the air channel like path losses and so on. The RNC has a little bit less responsibility due to share some functionality with BS. In the CN there were not changes, just an increment of memory into their devices because with HSPA more redundancy is transmitted. The next table 12 gives some of the most important parameters of each technology.

| | HSPA | UMTS | GSM |
|---|---|---|---|
| **Max. Data Rate** | 14.4 Mbps downlink / 7.2 Mbps uplink | 2 Mbps | 270 kbps |
| **Frequency band** | 1920-1980 MHz uplink / 2110-2170 MHz downlink | 1920-1980 MHz uplink / 2110-2170 MHz downlink | 890-915 MHz uplink and 935-960 MHz downlink |
| **Bandwidth** | 60 MHz | 60 MHz | 25 MHz |
| **Carrier spacing** | 5 MHz | 5 MHz | 200 kHz |
| **Duration frame** | 2 ms | 10 ms | 4,615 ms |
| **Freq. reuse factor** | 1 | 1 | 1-18 |
| **Power control frequency** | HSUPA 1500 Hz, HSDPA do not need power control. | 1500 Hz | 2 Hz or lower |
| **Quality control** | Adaptative modulation and coding, HARQ. | Radio resource management algorithms | Network planning (frequency planning) |
| **Frequency diversity** | 5 MHz bandwidth gives multipath diversity with Rake receiver | 5 MHz bandwidth gives multipath diversity with Rake receiver | Frequency hopping |
| **Packet data** | Fast Scheduling | Load-based packet scheduling | Time slot based scheduling with GPRS |
| **Downlink transmit diversity** | Supported for improving downlink capacity | Supported for improving downlink capacity | Not supported by the standard, but can be applied |

*Table 12. Comparison about the main features in GSM, UMTS and HSPA.*

A part from the AMC instead Power Control and HARQ instead ARQ for control the quality, there is the new method in packet scheduling which permit a best packet routing with better results and with less time which is called Fast Packet Scheduler. A part from that there is a new enhancement in the cell change that permit a better seamless cell change than before.

The differences in the terminals consist in the changes that they need to do in function of the final services which are able to offer. The terminals are offering the same main services like call, videoconferences and so on but with better quality. A part from the main services the HSPA terminals are opening a new world in the mobile communications through the introduction of high quality in online games, streaming, video, mobile-TV… Those new services are different in comparison with UMTS. For obtain that, the HSPA terminals require more capabilities apart of those which UMTS has. First makes sure that the terminal is able to operate with the new physical and transport channels and their protocols and then improve the storage of terminals because otherwise it will be impossible to save all the information that the new services give to the users.

Actually is possible to buy both types of terminals, UMTS terminals and UMTS HSPA terminals. The last ones they are not using the maximum data rate but it is still good because for example Nokia N82 is able to support 10 Mbps in downlink.

# 14. Conclusion

The thesis consisted in explain the new technology HSPA for a mobile communications. A brief summary is included now, just for remind the main aspects of HSPA and in this way obtain a clear structure about the principal enhancements that HSPA offers.

The main aspects can be summarized:

- The HSDPA and HSUPA utilize the same main structure than in UMTS but with some changes in allocation of the functionalities and functionalities. The Node B or BS has more importance due to now it has more functionalities for avoid delay in link adaptation.

- The main changes have been introduced are in the physical layer and transport layer. The above layers have not been changed substantially.

- The HSPA gives roughly improvements factor of ten in the speed of service delivery, improvements of a factor of five in capacity items and important improvement in service latency.

- The HSPA is able to support efficiently real time streaming UMTS QoS classes with guaranteed bit rates.

- The HSPA gives great benefits to the users towards to high bit rate services and also new services much more attractive for the customers such as internet connectivity with good data rates, mobile-TV and several applications in real time.

As a conclusion we would like to explain the main future lines. The WCDMA-based evolution systems will continue in 3GPP with further releases and the idea is going to integrate all the technologies in the same device, that fact will be the 4 Generation Systems. A part from that 3GPP has been started to study something else. 3GPP has started a study on the UMTS Terrestrial Radio Access Network Long-Term Evolution (UTRAN LTE). The main goals of this new technology are more latency reductions, scalable bandwidth, downlink peak rates up 100 Mbps and uplink peak rates up to 50 Mbps and so on. This new technology will do a huge step in the mobile communications.

The enhancements in the world of mobile communications none stop. The future consists in mobility and control as much as possible. In this way, the mobile communications has an important place due to is the tool for obtain that. For example the executives that want to be connect with their offices and control their work, the house's owners that they want to control their houses with cameras and that cameras connected to internet and with the mobile terminal they can watch what is going on there, and so on. The mobile communications in few years will grow faster than before and no one knows where the final step is.

# 15. References

[1] B. Walke, P. Seidenberg and M. P. Althoff. UMTS The Fundamentals. Communication Networks, Aachen University (RWTH), Germany. WILEY, 2001.

[2] Heikki Kaaranen, Ari Ahtiainen, Lauri Laitinen, Siamäk Naghian, Valtteri Niemi. UMTS Networks. Helsinki, Finland. JOHN WILEY & SONS, LTD, 2005.

[3] Harri Holma and Antti Toskala. WCDMA for UMTS. Nokia company, Finland. JOHN WILEY & SONS, LTD, 2004.

[4] Harri Holma and Antti Toskala. HSDPA / HSUPA for UMTS. Nokia Networks, Finland. JOHN WILEY & SONS, LTD, 2006.

[5] UMTS Forum
http://www.umts-forum.org/
Last website check: 09-12-2007

[6] UMTS World
http://www.umtsworld.com/
Last website check: 09-12-2007

[7] Wireless Intelligence
https://www.wirelessintelligence.com/index.aspx
Last website check: 09-12-2007

[8] The European Telecommunications Standards Institute (ETSI)
http://www.etsi.org/WebSite/homepage.aspx
Last website check: 09-12-2007

[9] 3GPP, 3rd Generation Partnership Project
http://www.3gpp.org/
Last website check: 09-12-2007

[10] A New Hybrid Packet Scheduling Algorithm with QoS Provision in HSDPA
http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=4195311
Last website check: 09-12-2007

[11] HSDPA performance and evolution
http://www.ericsson.com/ericsson/corpinfo/publications/review/2006_03/files/6_hsdpa.pdf
Last website check: 09-12-2007

[12] Overflow Control for UMTS High-Speed Downlink Packet Access
http://ieeexplore.ieee.org/Xplore/login.jsp?url=/iel5/7693/28463/01271244.pdf?arnumber=1271244
Last website check: 09-12-2007

[13] A STUDY OF UMTS TERRESTRIAL RADIO ACCESS PERFORMANCE
http://lib.tkk.fi/Diss/2003/isbn9512267187/
Last website check: 09-12-2007

[14] UMTS/IMT=2000 Based on Wideband CDMA
http://www.itu.int/itudoc/itu-t/workshop/rio/s2p1-es.html
Last website check: 09-12-2007

[15] Modeling Frame Synchronization for UMTS High-Speed Downlink Packet Access
http://ieeexplore.ieee.org/Xplore/login.jsp?url=/iel5/25/26755/01193099.pdf?arnumber=1193099
Last website check: 09-12-2007

[16] Optimizing the ARQ Performance in Downlink Packet Data Systems With Scheduling
http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1413216
Last website check: 09-12-2007

[17] El Release 6 de UMTS
http://www.coit.es/publicaciones/bit/bit149/56-58.pdf
Last website check: 09-12-2007

[18] Adaptive Modulation and Coding in 3G Wireless Systems
http://ieeexplore.ieee.org/Xplore/login.jsp?url=/iel5/8066/22307/01040403.pdf
Last website check: 09-12-2007

[20] HSDPA Mobile Broadband Data
http://www.eetchina.com/ARTICLES/2005NOV/PDF/HSDPA_Mobile_Broadband_Data.PDF
Last website check: 09-12-2007

[21] Adaptive Modulation and Coding (AMC)
http://ieeexplore.ieee.org/Xplore/login.jsp?url=/iel5/9179/29123/01313134.pdf
Last website check: 09-12-2007

[22] A Fast Scheduling Algorithm Considering Buffer Occupancy and Channel Condition for High Speed Downlink Packet Access
http://ieeexplore.ieee.org/Xplore/login.jsp?url=/iel5/9004/28571/01286037.pdf
Last website check: 09-12-2007

[23] HSDPA and HSUPA Functional Testing
http://www.tek.com/Measurement/App_Notes/2F_19851/2FW_19851_0.pdf
Last website check: 09-12-2007

[24] Nokia HSDPA Solution
http://www.nokia.com/NOKIA_COM_1/About_Nokia/Research/Demos/HSDPA/HSDPA_A4.pdf
Last website check: 09-12-2007

[25] HSDPA for Improved Downlink Transfer
http://www.umtschips.com/download_library/pdf/hsdpa_downlink_wp_12-04.pdf
Last website check: 09-12-2007

[26] Adaptive Modulation (QPSK, QAM)
http://www.intel.com/netcomms/technologies/wimax/303788.pdf
Last website check: 09-12-2007

[27] HSDPA: An Overview
http://www.widermind.com/UserFiles/File/HSDPA%20Overview(1).pdf
Last website check: 09-12-2007

[28] GSM World
http://www.gsmworld.com/technology/3g/evolution.shtml
Last website check: 09-12-2007

[29] Terminal Mobile
http://www.tecnogadgets.com/

[30] HSPA devices
http://hspa.gsmworld.com/devices/

[31] Dictionary
http://www.wordreference.com/

[32] Dictionary
http://www.google.es/language_tools?hl=es

[33] Subject Information in UPC (EPSC): Mobile Communications, Ramon Ferrus.