NOKIA

SYSTEM TRAINING

UMTS Radio Path and Transmission

Training Document

Contents

1 Module objectives

The aim of this module is to give the participant the introductory knowledge needed for explaining the structure of the UMTS radio and transmission path. The topics to be covered in this module include understanding the key concepts of the radio path and basic WCDMA terminology. The student should also understand how the UMTS functions and identify how the radio resources are managed.

After completing this module, the participant should be able to:

- Explain the terms carrier, spreading, power, FDD, cell characteristics, channelisation code, and scrambling code
- List and identify the structure of the UMTS air interface. The student should be capable of following a model and explaining what is happening to data at every phase in the Uu interface for the UMTS-FDD implementation
- List and clearly explain the key functions and tasks in Radio Resource Management. These are admission, code, power, handover, and diversity control

without using any references (if not otherwise stated).

2 Review of the radio path

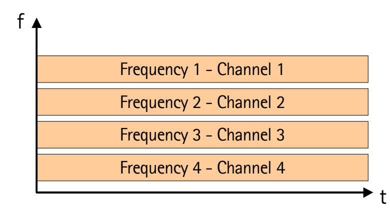
Perhaps the most comprehensively specified part of the UMTS is the Uu radio interface. In the following chapter we will take a closer look at the interface, but first we need to review and examine some basic key aspects of radio path. Therefore, this chapter will review radio path concepts and introduce the WCDMA terminology.

2.1 Radio path basics

Unlike traditional fixed telephone systems, a mobile system does not have a fixed link between the terminal and the network. When we make a call, or when we need to signal information, a temporary connection is made through the air between the terminal and the network. As mobile systems have developed, different methods and solutions have been created to ensure an air connection in the radio spectrum. Different air interface technologies and solutions have evolved, aiming to have as many users as possible sharing the same space whilst ensuring quality, coverage and security.

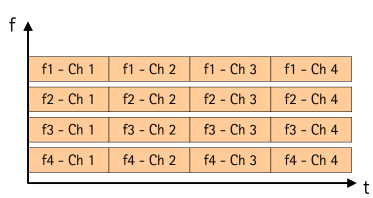
In the first generation of the mobile systems the spectrum was divided into **fixed** channels on different frequencies and of a fixed size (**bandwidth**).
A subscriber was the sole user of the frequency.

If a user wanted to make a call, the system would allocate the mobile a frequency. Once the call is complete, the channel would be released and given to the next user wishing to make a call.



This technique is known as **FDMA** (Frequency Division Multiple Access).

As systems evolved from analogue to digital, the same frequency could be shared by many users.



Each user on a frequency is separated by time. In a system like **GSM**, a user is instructed by the network to use a certain **timeslot** of a frequency.

This technique is know as TDMA (Time Division Multiple Access).

In **CDMA** (Code Division Multiple Access) the users share the same frequency **and** time, but are separated by **codes**.

A common example of explaining this phenomenon is to think of an international gathering, where people from different nationalities are talking to their fellow countrymen.

Although people are from different countries (for example, two people from Iceland), they can understand each other, as they are capable of detecting the language being used.

If the surrounding noise is low, they can share a lot of information with each other without having to repeat anything.

However, as more and more people start talking (in different languages), the noise becomes so loud that the conversation becomes more difficult. Eventually, if the noise becomes very high, it will be impossible to hear each other. Hence, there is no communication.

Technologically speaking, each user in WCDMA (or channel, as this includes signalling) is separated by a **code**. When a mobile terminal is listening to many base stations, it can detect between them, since each cell has its own unique code.

Similarly, when a base station is listening to mobile stations, it can detect different subscribers (**channels**) through a unique code. In WCDMA, the spectrum is split into channels. Each channel carries several users of variable size, separated by a code.

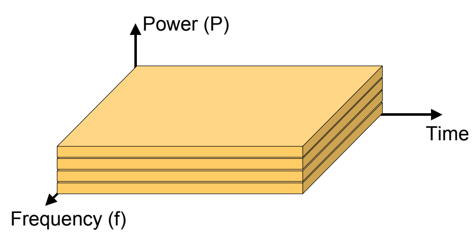


Figure 1. In CDMA, channels occur in the same frequency and time

The number of users able to share the same space is limited by the number of **codes**, and also by the amount of **interference** in the cell (*region of coverage*). Also, the user may have variable bit rates. This means that some users need more space to transfer information quicker than others do.

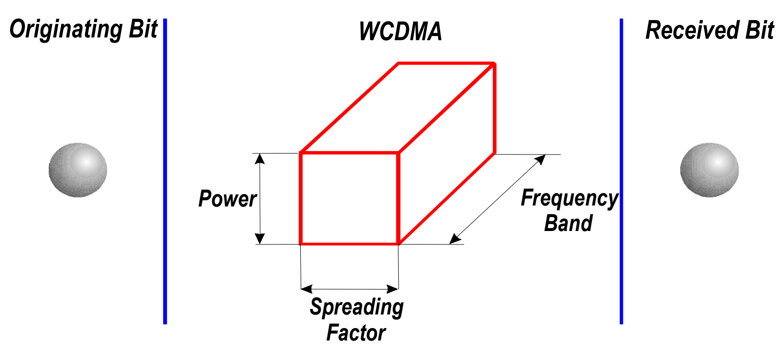
2.2 WCDMA basic theory

The theory behind WCDMA can be made easier by understanding the relationship between the **frequency**, **power** and **spreading** (≈transmission time of one bit/symbol).

Imagine a base station that has a block of information that it needs to send to a mobile. This block of information could contain speech, video, packet data, signalling, etc. For this discussion we can think of it in a simplistic way by imagining this data to be of a fixed volume (not size).

If we take the block of data, we could reduce the amount of the power needed to transmit the information by spreading it along a wide frequency band. Similar to making a cake, once you add the topping, it sits on top of the cake in a pile. By using a knife, the topping is spread to cover the whole surface area of the cake. The bigger the surface of the cake, the better you are able to spread the topping.

In WCDMA, the frequency bandwidth is fixed by specifications (4.4 - 5 MHz). However, the power and the spreading factor are variable. The spreading factor indicates to what degree we are able to spread the data over the fixed frequency band.



The better we are able to spread the data, the lower power we need when to transmit the data. It basically means that we are able to share the frequency between more users. Compare this to a big room with a lot of people. If everybody would whisper, more people would be able to maintain the conversation. If, on the other hand, people would talk loud (with a high power), much less people would be able to keep up the discussion, due to the interference between difference conversations.

If we return to the figure, we can think of the block above to be variable; it remains the same volume, only the sizes of the edges change. If the block is low-bit-rate data, it is spread better. Based upon the user's service requirements, the network will decide on the right levels to use. In other words, the power and spreading factor will be different for a video call (high bit rate, only small delays allowed) than for Internet access (lower data rate, less stringent on the delay).

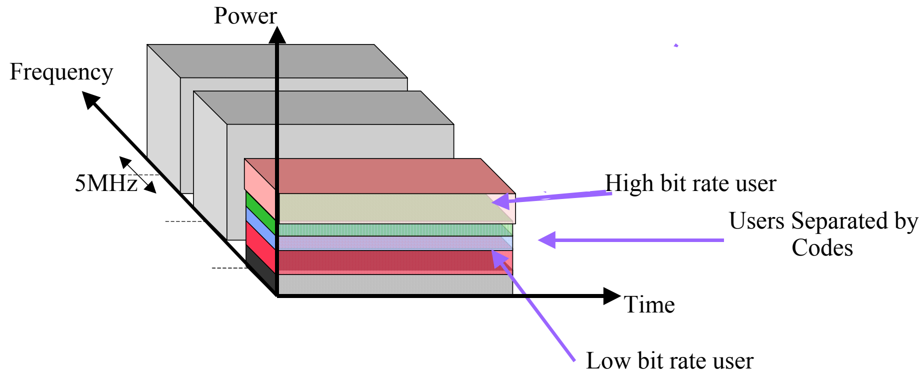


Figure 2. Variable 'slices' allocated to users

In the figure above, a simplified illustration of the air interface resource is presented. Each user has a different need, depending on which service she/he uses. As an example, a normal speech call requires less network resources than, for instance, a video conference.

In addition to this, the figure illustrates how we try to minimise the interference between different types of communication by applying different codes. One could say that the users speak different languages. This is done in order to disturb other users as little as possible. More specific information about these different (W)CDMA concepts will be provided later in this module.

3 WCDMA systems and frequency allocations

The first part of any new system development is the allocation of the spectrum. For UMTS, this allocation was proposed already in 1992. The following figure shows the spectrum allocation in the world's largest markets. With the exception of the USA, the 2 GHz band is reserved for 3G.

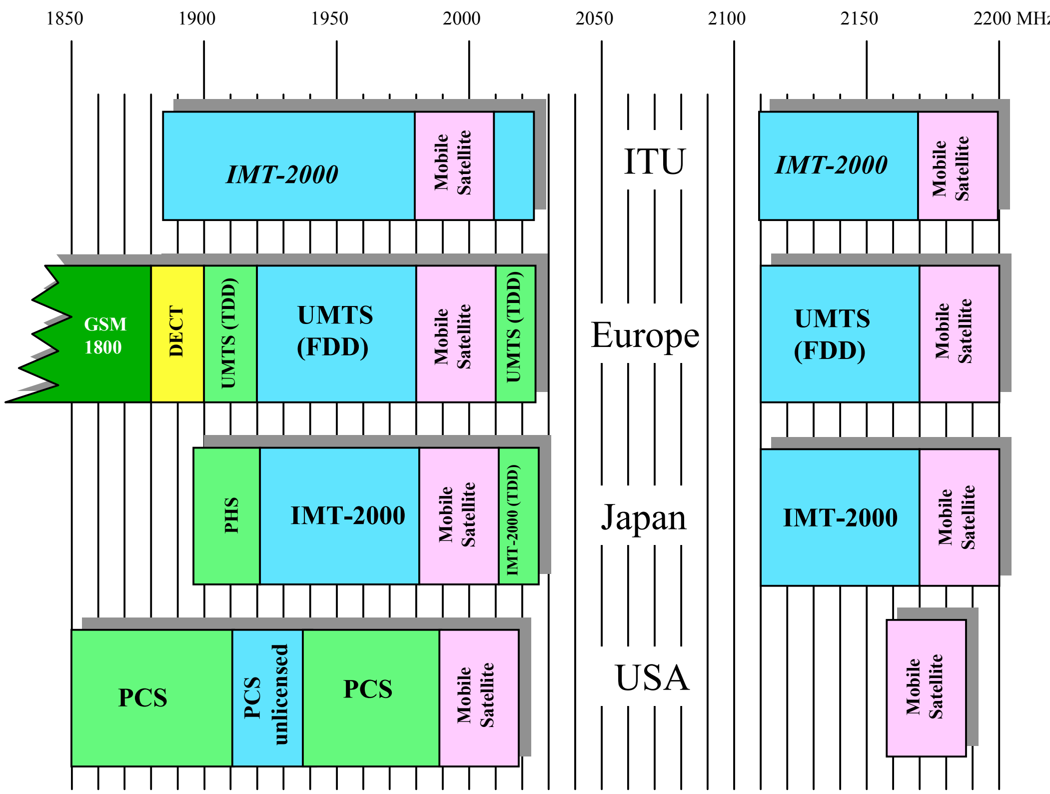
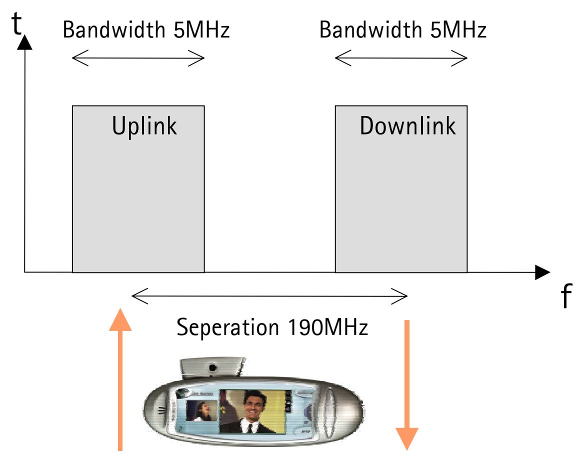


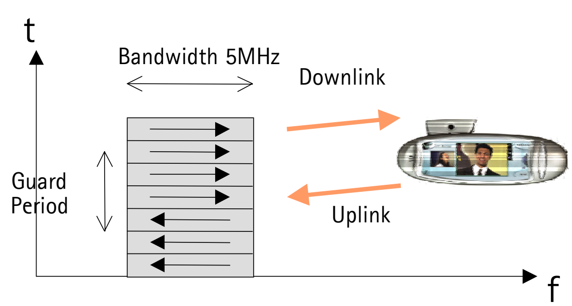
Figure 3. Allocation of spectrum in some of the worlds largest markets

Within the allocated bands, there are two bands reserved for 3G. In the UMTS specifications, they are called UMTS-FDD and UMTS-TDD. These allocations are based on the two different WCDMA structures.

In **FDD** (Frequency Division Duplex), two separate bands are allocated. One is for **uplink** (from the UE to the BTS), and the second is for **downlink** (to the UE from the BTS). Each band is specified to be 5 MHz, and separated by 190 MHz. In FDD, the users share the same space in both directions. The first terminals and networks will support FDD.



In **TDD** (Time Division Duplex), there is one band that is divided into **timeslots**. The bandwidth is the same at 5 MHz; users are allocated to timeslots. Terminals should work between FDD and TDD bands. TDD will be implemented at a later stage.



4 The UMTS air interface

The structure of the air interface is quite complex. This chapter starts with an overview of the air interface, the "big picture". It is based on the UMTS-FDD (Frequency Division Duplex) implementation. After the overview, we will break up this model and explain the main parts more in detail.

The specifications dictate how the information is transferred on the physical interface, including issues like how the data is coded, transmitted, and received on the air interface. These specifications must be supported by the Node B, the Radio Network Controller (RNC), and the User Equipment (UE). The aim is to divide the responsibilities of the RNC and the Node B as much as possible, which may then enable an open Iub interface (Node B-RNC).

4.1 Overview of the UMTS air interface (Uu)

1 The terminal is a platform with different applications (such as video, voice, and Internet access) running on top of it. We can class this as **data**. The network must also exchange **signalling** messages with the terminals in order to control the activities of the terminal (for instance, location and connection management).

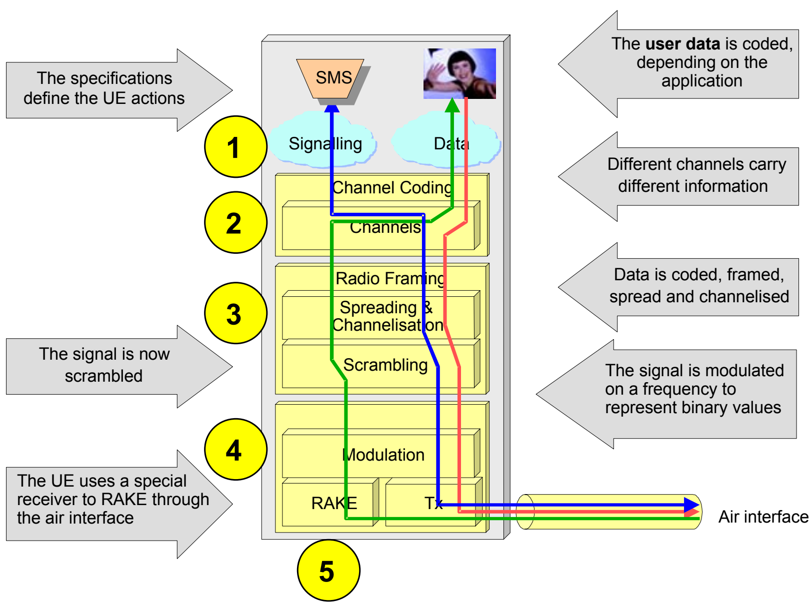


Figure 4. Preparing the data and signalling for the air interface

2

The signalling and data are fed through the network on **logical channels**. There are different channels used for different purposes. The content of the logical channels is mapped into **physical channels** with the help of **transport channels**. In the air interface, different physical channels are used to carry different kind of information. Also, channel coding is made to support error correction. *The roles and functions of the physical transport and logical channels are explained in Chapter 4.5.*

3

As part of the coding process in WCDMA, the data is spread along the spectrum, and combined with a **channelisation code** (used to determine different physical channels), and a unique **scrambling code**. *Channelisation codes, scrambling codes, and other related WCDMA terminology are discussed in Chapter 4.3.*

4

The last step before transmitting the data over the air interface and signalling is the modulation, thus the digital to analogue conversion of the coded data. *Modulation is briefly described in Chapter 4.2.*

5

The receiving signal is reconstructed by the terminal and base station by collecting the circulating radio waves, reapplying the codes, and removing the error-correction coding. The receiver used in WCDMA is called the **RAKE** receiver (RAKE = collect). *More about the RAKE receiver in Chapter 4.4.*

Wrap-up of steps when transmitting data or signalling from a User Equipment:

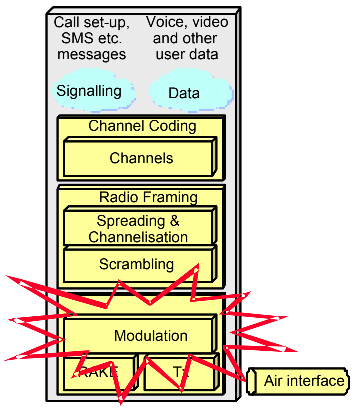
- The data is in a format that can be used by an application.
- The data is fed from a **logical channel**, via a **transport channel** onto a **physical channel**.
- The data in the physical channel is spread along the spectrum with a channelisation code, and combined with a scrambling code.
- Finally, the data is modulated onto the air interface.

Wrap-up of steps when receiving data in the Base Transceiver Station:

- First, de-modulation is done (analogue to digital conversion). Also, the RAKE receiver contributes to a reception with less bit errors by enabling the summing up of signals that have taken different paths in the air interface (micro diversity).
- By using the same scrambling and channelisation codes as on the transmitting side, the receiving part is able to reconstruct the physical channel information.
- The channel coding is removed, and the data is forwarded towards the correct destination network (packet or circuit switched core network) on the appropriate logical channel.

The following chapters will further explain the terminology and concepts. This journey will start with the different types of logical, physical and transport channels.

4.2 Modulation



We start the discussion bottom up. The user data bit and signalling information were manipulated, e.g. redundancy was added, and interleaving was applied. The resulting bits can finally be transmitted. Now, it is time to modulate the data – we map it on an analogue radio wave.

Per definition, the modulation process thus transforms the binary data into an analogue signal at a certain frequency (which corresponds with the carrier bandwidth). There are several different types of modulation methods. In GSM, Gaussian Minimum Shift Keying (GMSK) is used. In EDGE (Enhanced Data Rates for Global Evolution) both GMSK and 8 Phase Shift Keying (8-PSK) can be used. In UMTS, the choice was Quadrature Phase Shift Keying (QPSK). What they all have in common is that they have predefined shapes for bit changes. But what is the difference between them? If seen only from a general point of view, the explanation is very simple: GMSK shifts one bit at the time, QPSK two bits at the time, and 8-PSK three bits at a time. The next figure shows the basic idea with QPSK modulation, which is thus used in WCDMA.

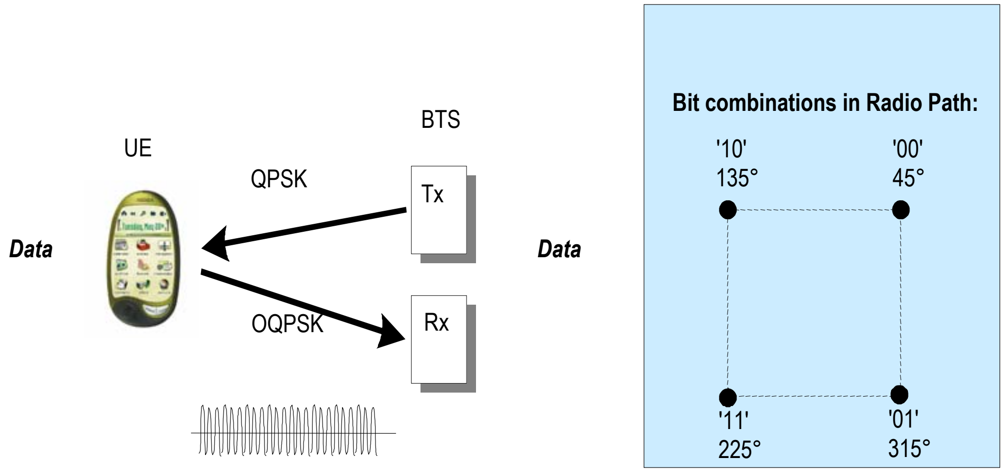
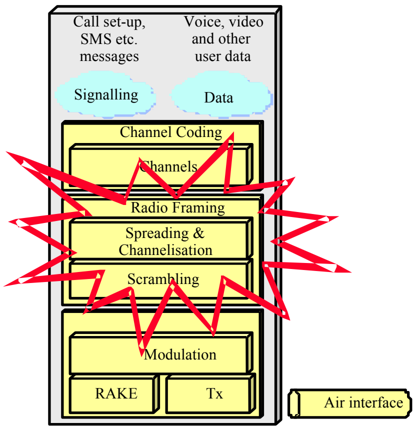


Figure 5. Modulation with QPSK

The chips are hence **modulated** into a signal, which is to be transmitted on the air interface. As the phase of the signal changes angle, this result in a 00, 10, 00, 01 signal. The name QPSK means that there are four possible phase shifts. The receiver is able to reconstruct the signal by monitoring the changes in phase. Downlink QPSK is used. Uplink, a smooth and somewhat dirty QPSK solution is applied: Offset QPSK (OQPSK). If a signal changes in QPSK, the transmitter changes directly to one of the four possible phases. When OQPSK is applied, the change from on phase to the next is done with intermediate steps. This reduces the requirements in the transmitter equipment, which makes it lighter and less expensive. And this is required for the MS.

The Release 5 feature **High Speed Downlink Packet Access (HSDPA)** is a packet-based data service in W-CDMA downlink with higher data transmission rates. In good conditions up to 8-10 Mbps in downlink is possible. Data users close to the Node-B can be assigned higher order modulation with higher code rates for example **16 Quadrature Amplitude Modulation** (QAM).

4.3 Basic WCDMA terminology



This section mainly deals with the **channelisation codes** and **scrambling codes**, and explains how these are used in WCDMA.

There are several related issues that need further attention, such as **chip, symbol,** and **spreading factor**.

First of all, however, we will define our physical resource for air interface transmission, the **WCDMA carrier**, and also some of the main transmission features that have been chosen for the first release of UMTS, namely the **frame structure** of **WCDMA-FDD** and how the information is to be spread by using **DSS** (Direct Sequencing Spreading).

4.3.1 The WCDMA carrier

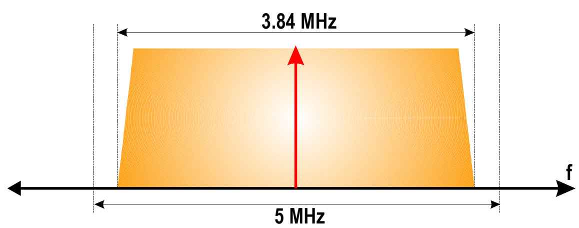


Figure 6. One WCDMA carrier (in one direction)

There are several bandwidths defined for the WCDMA: 5, 10 and 20 MHz. Nowadays the 5 MHz is the most interesting bandwidth. The 10 and 20 MHz alternatives will provide more capacity, but the occupancies occurring in the desired frequency band set some limits: there may be problems to implement the whole frequency band in several countries. The effective bandwidth for WCDMA is 3.84 MHz, and with guard bands the required bandwidth is 5 MHz. The guard bands are needed to reduce the interference between different 5 MHz WCDMA carriers.

4.3.2 Frame structure (UMTS-FDD, Frequency Division Duplex)

The DS-WCDMA-FDD also requires a certain timing structure, but it is not used as in GSM. The basic DS-WCDMA-FDD frame is presented below.

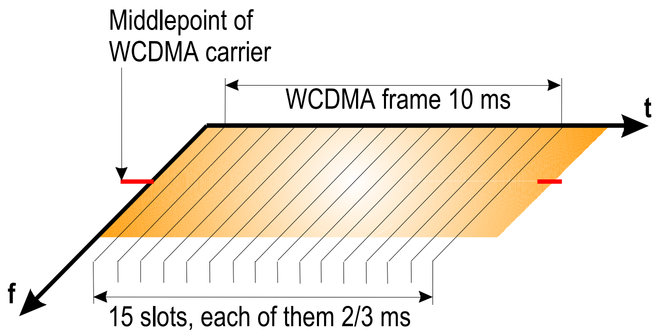


Figure 7. DS-WCDMA-FDD frame

One basic frame is divided into 15 slots (each length is 2/3 ms). Thus, the frame length is 10 milliseconds. This division has nothing to do with the channelisation; the timing structure is mainly required for the synchronisation signal arrangements.

The inter-operability between GSM and WCDMA is seen as one of the major points to be arranged; especially the inter-system handover. For this purpose, the 3GPP Specifications define that every WCDMA frame is numbered by the system (SFN, System Frame Number). This is how the 'frame structure' is known in WCDMA, and there is no need for further, higher-level frame structures like in GSM.

4.3.3 CDMA sequencing – a way to spread information

Sequencing as a term refers to how the information to be transferred over the radio path with CDMA technology is spread over the defined frequency band. There are two basic alternatives: Frequency Hopping (FH) and Direct Sequencing (DS).

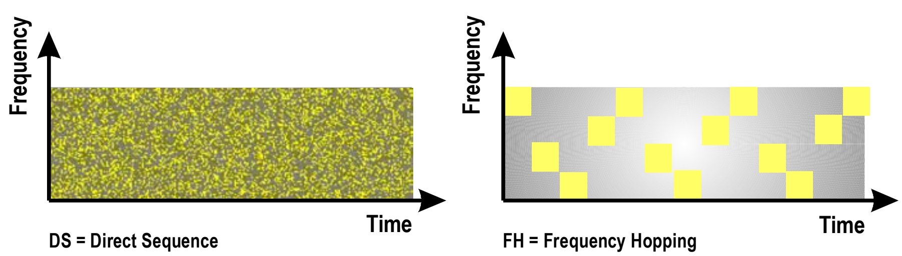


Figure 8. CDMA sequencing principles

In case of DS, the information to be transferred is spread all over the defined frequency band as a function of time, and it looks pretty much like background noise. In case of FH sequencing, the information to be transferred is located in different parts of the frequency band as a function of time according to a certain hopping sequence. The 3G-wideband radio access will use the **Direct Sequencing** variant.

4.3.4 Codes - What and why?

A code is a specific sequence of bits applied to data to scramble the information. When the receiving end is monitoring the air interface, it should be possible to retrieve the original data by applying the code. The same code must therefore be applied both at the transmitting and the receiving end.

The WCDMA system uses several codes. In theory, one type of a code should be enough. But, in practise, the radio path physical characteristics provide that the WCDMA system should use different codes (with certain features) for different purposes. There are basically two kinds of codes available: **channelisation codes** and **scrambling codes**. The following table shows the usage of these codes.

Table 1. Properties of channelisation and scrambling codes

	Channelisation code	**Scrambling code**
Usage	**Uplink:** Separation of physical data and control channels from the same terminal **Downlink**: Separation of downlink dedicated user channels	**Uplink:** Separation of terminals **Downlink:** Separation of sectors (cell)
Length	Variable (depends on the user allocation)	Fixed
Number of codes	Depends on the spreading factor (SF)	**Uplink:** Several millions **Downlink:** 512

For example, in a radio network each cell is separated by a code. This is roughly comparable to the frequency division method used in GSM. In UMTS, a different code (known as a primary scrambling code) differentiates between different cells.

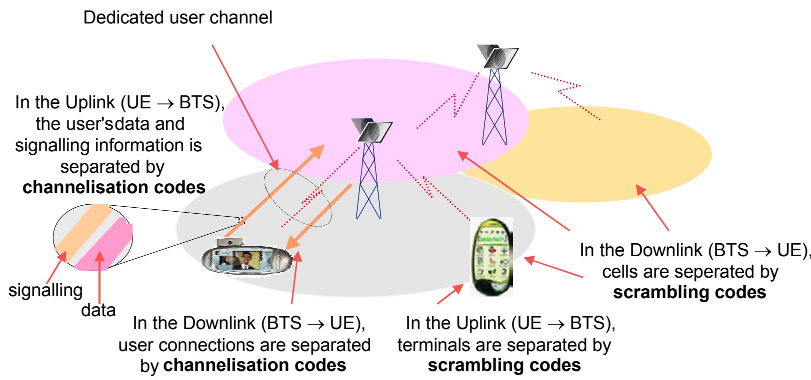


Figure 9. The difference between scrambling and channelisation codes

However, as a cell will contain physical channels, a second code known as the channelisation code is applied. Hence, the terminals can make a difference to the channel that they are listening to.

Several calls can take place at the same time, in the same cell, on the same carrier frequency band. The individual connections are separated at the receiver's side by the used code. A **physical channel** in the UMTS FDD-mode is uniquely identified by the used frequency band and code.

Summary of code usage in the uplink and downlink direction:

In the **downlink** direction, we need to be able to make a difference between different cells. Therefore the scrambling code is used for this purpose. Since we also must make a difference between different users within the cell, the channelisation code is used for this purpose. It also means that we will only use one dedicated physical channel in the downlink direction, and both signalling information (such as power control commands) and application data must be mapped onto this physical channel.

In the **uplink** direction, we do not need to separate between cells. It means that we can utilise the scrambling code for separating between the different users. Following the same logic as earlier, it means that we can use the channelisation code to separate between different channels.

4.3.5 Chip and symbol – Two kinds of bits

In the following, two important concepts of WCDMA will be explained, namely *chip* and *symbol*. It is important to be familiar with the meaning of these terms, as it helps to understand the whole structure of the air interface.

The basic idea behind WCDMA is that the signal to be transferred over the radio path is formed by multiplying the original, baseband digital signal with another signal, which has much greater bit rate. Because both of the signals consist of information units, one must make a clear distinction between the information units in question:

- A **symbol** is an information unit, transmitted via the radio interface. Downlink each symbol represents two bits. In other words, downlink, a symbol is a tuple (x1,y2); x1 and y2 each represent one bit. The next symbol (x2,y2) delivers two new bit values.
  Uplink, also symbols are transmitted. This can be also represented in tuples. But at the first position, there can be a different data rate than in the second position, i.e. (x1,y) is possible for the first symbol, and (x2,y) for the second.
  The **symbol rate** (expressed as kilo symbols per second, ks/s) indicates the number of symbols transferred over the radio path. Downlink, if the symbol rate is 480 kilo symbol per second, the bit rate is 960 kilo bit per second. Uplink, if the symbol rate is 480 kilo symbol per second, the data rate is 480 kilo bit per second (first position in the tuple) plus 15 kilo bit per second (second position in the tuple, which has a fixed data rate).
- One bit of the code signal used for signal multiplying is called a **chip**.

The code signal bit rate, which is hereafter referred to as the **chip rate**, is fixed in WCDMA, being 3.84 million chips per second (Mcps/s). With this chip rate the size of one chip in time is 1 / 3 840 000 seconds.

One way to better understand the meaning of the terms *symbol* and *chip* is to study the simplified example in the figure below. Let us assume that we want to send some baseband data from a Node B to a user. This data has already been subject to channel coding and rate matching.

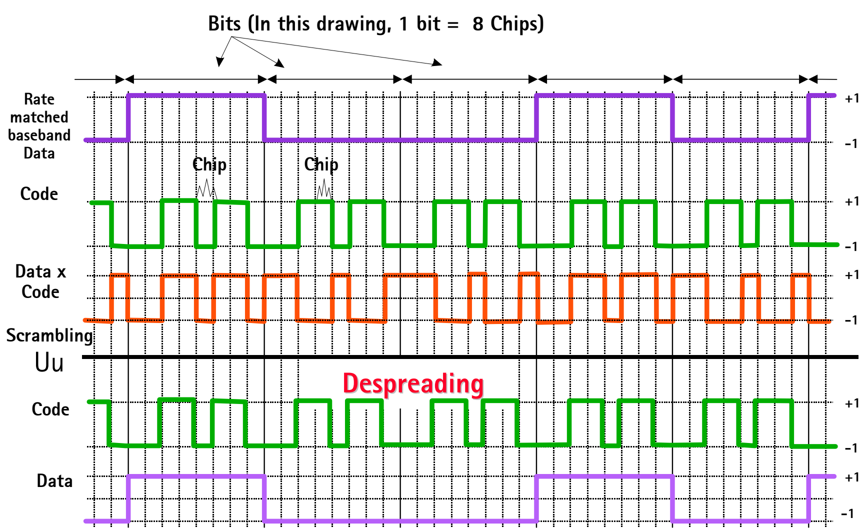


Figure 10. Chip and symbol in Binary Phase Shift Keying

The rate matched baseband data (symbols) in have the **values -1 or 1**. The –1 is actually a zero (0) bit (symbol). This conversion has to be made, since we will multiply the symbol with the code chips. (Multiplying with (0) zero would be useless.)

One baseband bit (=symbol) will in this example be multiplied with eight code chips, and this **code** has a **chip rate** of 3.84 Mega chips per second. This is referred to as **spreading**, and the **spreading factor** (SF) in this example is thus 8. By knowing these values, we are able to calculate the **symbol rate**: 3.84 Mcps / 8 = 480 Kilo symbols per second. Downlink, QPSK is applied. 480 kilo symbol per second are consequently 980 kilo bit per second.

When the data is spread, it is at the same time combined with a **channelisation code**. In simple terms, the baseband data is spread by 'chipping' the data. For example, if we use a factor of 8 to spread 010, the result would be 000000001111111100000000 (without the channelisation code). The collection of these chips (etc. 11111111) is therefore the same as the **symbol**. This is a signal processing function.

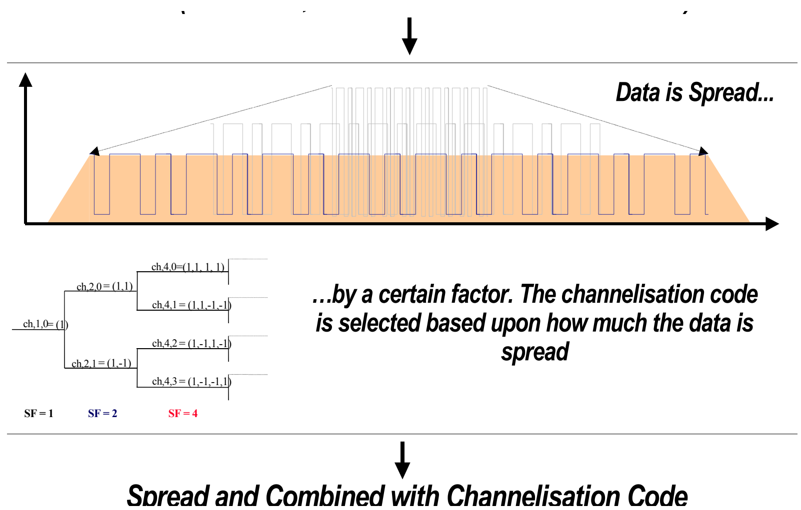


Figure 11 Spreading of data

Please remember that in the uplink, the channelisation codes are used to separate different dedicated channels from one user. In the downlink, their role is to separate the users.

What is not shown in the previous figure is the second code type, the **scrambling code**. The scrambling code is applied to the data after the channelisation code, and it does not change the actual **chip rate**, it remains 3.84 Mega chips per second. As mentioned earlier, the role of the scrambling code is to separate users in the uplink.

In the downlink direction, it is used to separate the different cells. The figure below illustrates the consecutive process of applying the channelisation code and scrambling codes to the data.

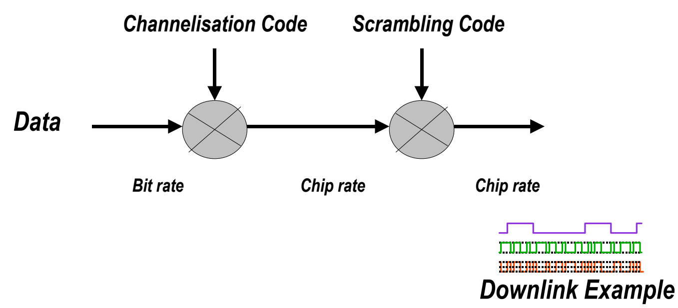


Figure 12. Both channelisation code and scrambling codes are applied to the data – Scrambling code does not affect the chip rate

Once the signal arrives in the User Equipment (UE), we can **spread** it by applying the same scrambling and channelisation codes as when the spreading took place.

Further information about spreading factor, channelisation codes and scrambling codes will be given in the following three chapters.

4.3.6 Spreading factor

In the previous section, as well as in the earlier parts of (W)CDMA theory, the term *spreading factor* (SF) has been mentioned a few times. Let us now make two mathematically based conclusions:

- Spreading factor is a multiplier describing the number of chips used in the WCDMA radio path per one symbol. Spreading factor K can be expressed mathematically as follows:

$$K = 2^k, \text{ where } k = 0, 1, 2 \ldots 8$$

For instance, if k = 6, the spreading factor K gets the value 64, indicating that one symbol uses 64 chips in the WCDMA radio path.

- Another name for spreading factor is **processing gain** (G_p), and it can be expressed as a function of used bandwidths:

$$G_p = \frac{B_{Uu}}{B_{Bearer}} = \frac{System\,Chip\,Rate}{Bearer\,Symbols\,Rate} = Spreading\,Factor$$

In the formula, B_{Uu} stands for the bandwidth of the Uu interface and B_{Bearer} is the bandwidth of the rate matched baseband data. In other words, the B_{Bearer} contains already excessive information, such as channel coding.

4.3.7 Further examination of scrambling and channelisation codes

As mentioned before, there are two types of codes: channelisation and scrambling codes (also known as gold codes). In WCDMA, there are **512 primary codes**. There could be more, but the specification body decided to limit the number to 512 to reduce the amount of scanning the terminals to be in the process.

The scrambling codes are divided into 512 code sets, each of them containing a primary scrambling code and 15 secondary scrambling codes.

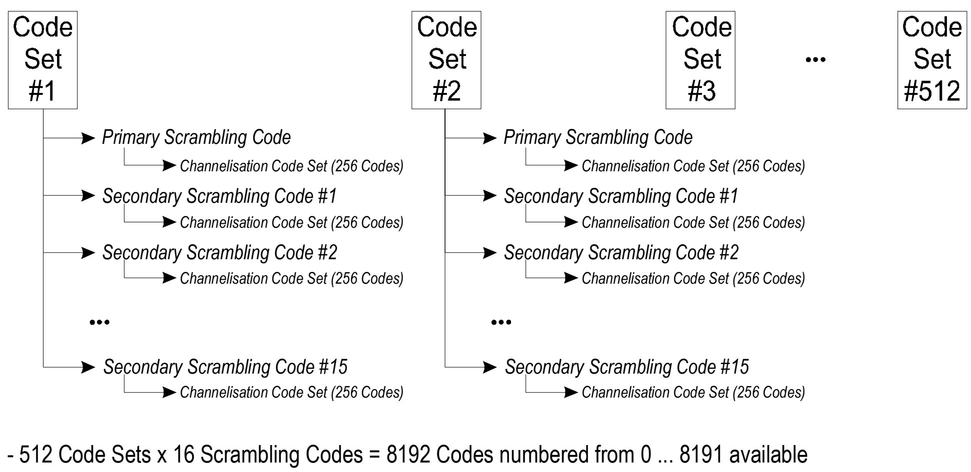


Figure 13. Scrambling code arrangements

Based on the code selection method, there are altogether 8191 scrambling codes available in downlink direction, and millions in the uplink direction. Each primary/secondary code has associated with itself a set of channelisation codes and whilst using the highest spreading factor, it can support 256 channels.

4.3.7.1 Scrambling code

Only one primary scrambling code is allocated for a cell. The Primary CCPCH (carrying the cell information on the logical BCCH channel) is transmitted by using this code. The other downlink physical channels may use either the primary scrambling code or a secondary scrambling code from the set associated with the primary scrambling code of the cell.

In the uplink direction, there are millions of available scrambling codes. All uplink channels may use either short or long scrambling codes. Long codes are used if the base station uses the RAKE receiver. In the downlink direction, long scrambling codes are always used.

4.3.7.2 Channelisation code

Channelisation codes are used for channel separation both in uplink and downlink direction. In the downlink direction, channel separation is the same as the user separation, as we only have one dedicated physical channel, which is shared by the signalling and the application data.

Channelisation codes have different spreading factor values and thus also different symbol rates. There are a total of 256 short codes available under certain conditions. The channelisation code length is one symbol. If, for instance, the spreading factor is 4, then the channelisation code contains 4 chips. One baseband bit of data in the air interface is therefore described with a 4-chip code.

The channelisation codes are orthogonal, that is, they have orthogonal properties. Orthogonal as a term means that the channelisation codes in the 256-member code list are selected so that they interfere with each other as little as possible. This is necessary in order to have a good channel separation. On the other hand, the code used for user and cell separation must have good correlation properties. The scrambling codes do have these characteristics, and this is the basic reason why both scrambling and channelisation codes are used.

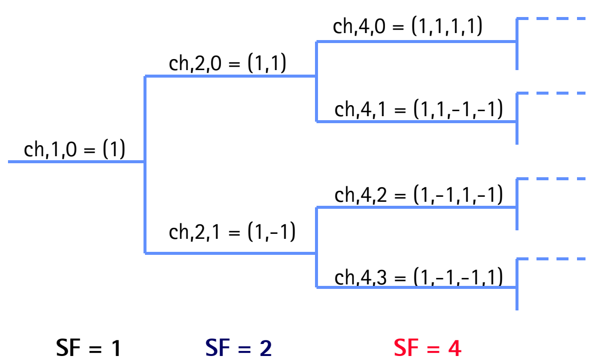
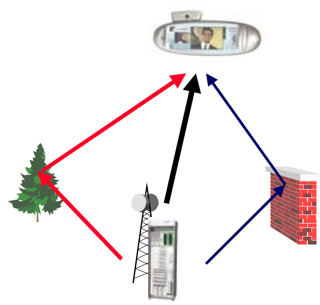


Figure 14. WCDMA code tree

Every WCDMA cell uses one downlink scrambling code, which is locally unique and acts like a **cell ID**. The characteristic of this scrambling code is **pseudo-random**, that is, it is not always orthogonal. Under this scrambling code the cell has a set of channelisation codes, which are orthogonal in nature and used for channel separation purposes

4.4 Receiving signals at the terminal

The environment around us is full of buildings, trees, hills, water, etc. For the mobile communication this presents a problem of multipath signals. A signal from a Node B to a mobile is often not direct, as there are objects standing in the way. When a signal is reflected by these objects, it will arrive at its destination later than the other signals.



In WCDMA, the terminal employs a **RAKE** receiver to handle multipath propagation. The RAKE consists of receiver(s), adjustable-by-system delay functionality, code generator, and gain and phase tuning equipment. One multipath component that the RAKE recognises is called a **finger**. Typically, RAKE is able to handle several fingers. One of these fingers receives the signal from the Uu interface and tries to open it with the code used for this connection.

The second (third & forth) finger receives the same signal from the Uu interface, and the code used for this connection is inserted to the receiver after short, adjustable delay. When the signal is demodulated and regenerated, the outcomes of the fingers can be summed together.

Why is the RAKE receiver capable to detect several multipath, and even read the user data on individual multipaths? The scrambling code is a pseudo-noise sequence, i.e. it has no repeating pattern. Because of this, the RAKE receiver not only determines the multipaths and their run-time difference. Each RAKE finger holds a code generator, which can be synchronised to one incoming multipath. The data carried on the multipath can be retrieved. This happens on every RAKE finger. The individual multipaths may have a very low receive level, and the data (still in form of samples of the electro-magnetical wave) is inaccurate. After adjusting the run-time difference of the multipaths in each RAKE finger, the individually weak multipath results are combined, resulting in a comparatively strong result.

There are two benefits: First of all, the transmission output power can be low in comparison to GSM, because the receiver can retrieve the user data by combining the information carried on several multipaths. This has a direct impact on the radio interface capacity, where the transmission of all active users takes place at the same time.
Secondly, and only in the FDD-mode, a UE can be connected to several cells/Node B simultaneously. Each cell/Node B is hereby sending the same data downlink to

the UE. In other words, several cells are used to create a multipath propagation situation. The RAKE receiver in the UE can generate the different codes, used by different cells on the individual RAKE fingers.

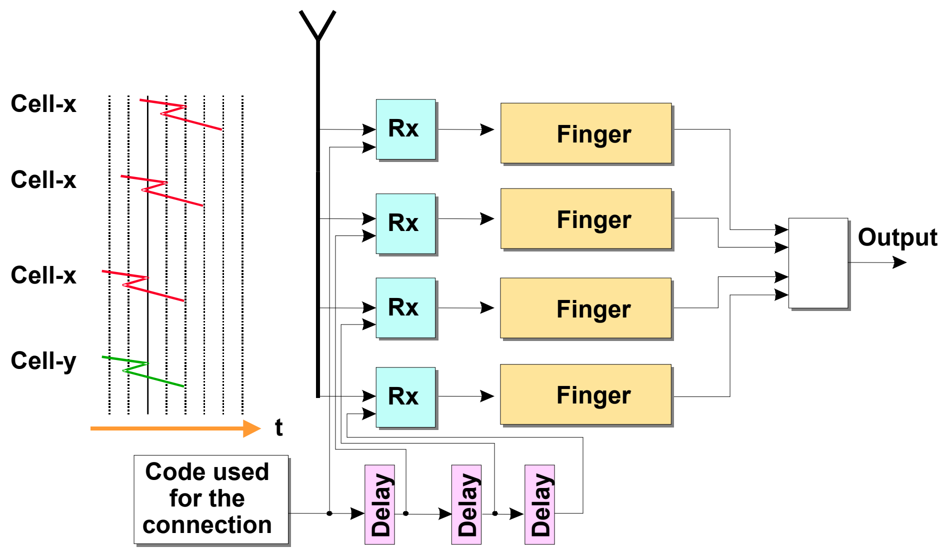
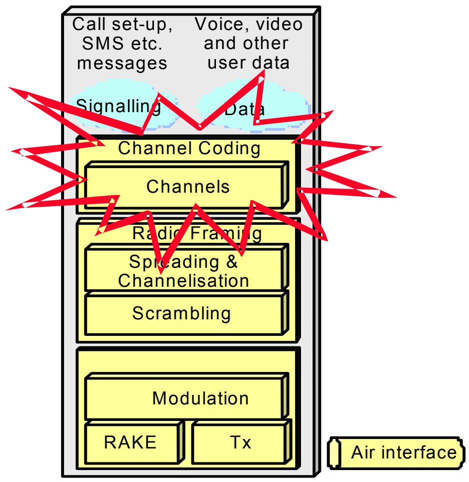


Figure 15. Simplified block diagram of the RAKE receiver

The RAKE receiver (located in the UE) uses typically three fingers for multipath reception. The fourth finger is reserved for “environment observation”. The reason for this behaviour is that in WCDMA, the UE may have active radio connections simultaneously through three cells.

4.5 Channel coding; rate matching; usage of logical, transport and physical channels



The applications used will produce a stream of bits to be transmitted. The resource requirements mainly depend on the type of the application. One of the main benefits with the UMTS air interface is the possibility to allocate resources in according to the need. But, before the application data (or signalling) is transmitted, we need to prepare the data for this journey. The first step in this process is to map the information to the correct logical channel, transport channel, apply the channel coding and match the bit rate and finally map to the correct physical channel.

You can read more about these processes in the following.

4.5.1 Channel coding

If we assume that certain signalling or data information is to be transmitted over the air interface, one of the steps in the process is to apply the channel coding.

Channel coding is done in order to improve transmission quality in the air interface in case of interference, low reception levels, etc. This is possible by adding redundant bits to the signal. This will naturally increase the bit rate.

In UMTS, both 1/2 and 1/3 rate convolutional coding, as well as so-called turbo coding, will be implemented.

1/2 rate coding means that there is roughly one redundant bit for every real bit, while as the 1/3 rate channel coding leads to a three-fold bit rate.

Turbo coding is a quite new channel coding method. It is used mainly for applications that require high bit rates. Turbo coding is a "fast convolutional coding" method with a coding rate of 1/3.

4.5.2 Rate matching

After the error protection, the baseband data rate is matched to the bearer bit rates used in the UMTS radio interface. The data rates are given with the available channelisation codes, resp. with the given spreading factors.

In the figure below, you can see different bit rates that may be applied for user data. The bit rates range between 15 and 960 kilobits per second.

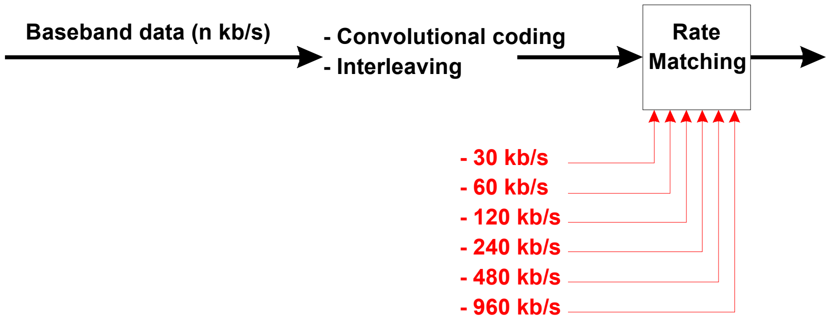


Figure 16. Adaptation of the bit rate for the WCDMA air interface

Please note that these bit rates are not the same as the application or user data rates. To exemplify this, let us imagine a speech call at 12.2 kilobits per second. These bits must undergo channel coding in order to enable error correction. After this channel coding (convolutional coding), the bit rate is around 24 kbit/s. Now we need to rate match this data to the closest allowed bit rate in UMTS, which in this case is 30 kbit/s (as you can see from the figure above). We repeat some of the encoded data bits according to a certain pattern in order to increase the bit rate to the wanted level.

In some cases, we are able to perform so-called **puncturing** in case the bit rate is somewhat higher than certain allowed bit rate. Puncturing means that we remove some of the redundant bits from the channel coding, thus reducing the bit rate down to the wanted level.

4.5.3 UMTS channel structure (UMTS-FDD)

As described previously, data and signalling between the terminal and the network is achieved through a series of channels. In UMTS, the channels exist in three layers. The first layer is known as the **logical channel**, and the application and signalling procedures use these channels to communicate with the network. Different channels are used for different purposes. For example, there are channels for carrying paging information for all idle UEs in the cell, channels dedicated to UEs for signalling, and other channels dedicated to individual UEs for user data transfer. Logical channel were hereby specified for uplink and downlink transmission. In other words, each logical channel transmits a specified content, or is used for a well defined task.

As shown in the figure above, there are also **transport channels** in between the logical channels and the physical channels. These transport channels are needed to describe how logical channel information is organised for transport. It is possible to map several logical channels into one transport channel.

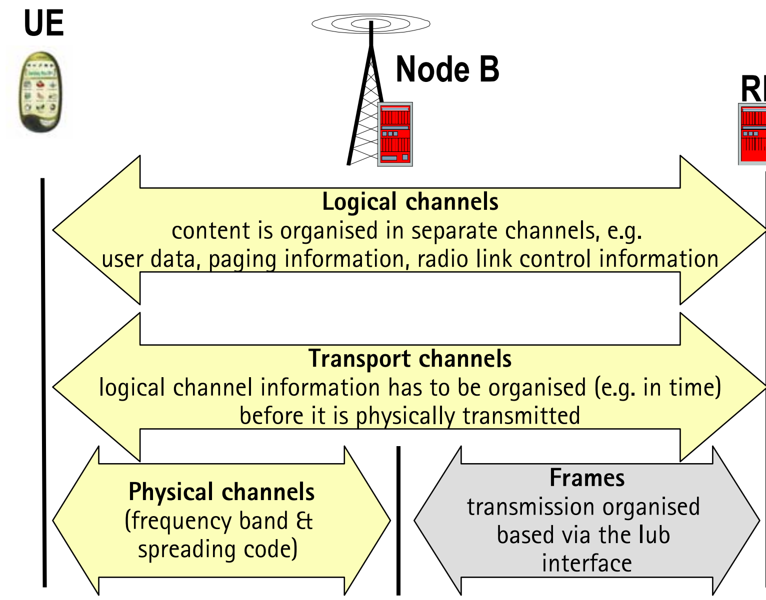


Figure 17. Physical, transport and logical channels in the network

The **physical channels** are present in the air interface, while the transport channels and the logical channel structure are valid in all the interfaces between the User Equipment (UE) and the Radio Network Controller (RNC). This is illustrated in Figure 17. Each physical channel is identified in the FDD mode by the frequency band, used for the transmission, and by a spreading code.

The following figure gives a few examples of the path of data and signalling through the channels. In the following, these different types of logical, transport and physical channels will be described more in detail.

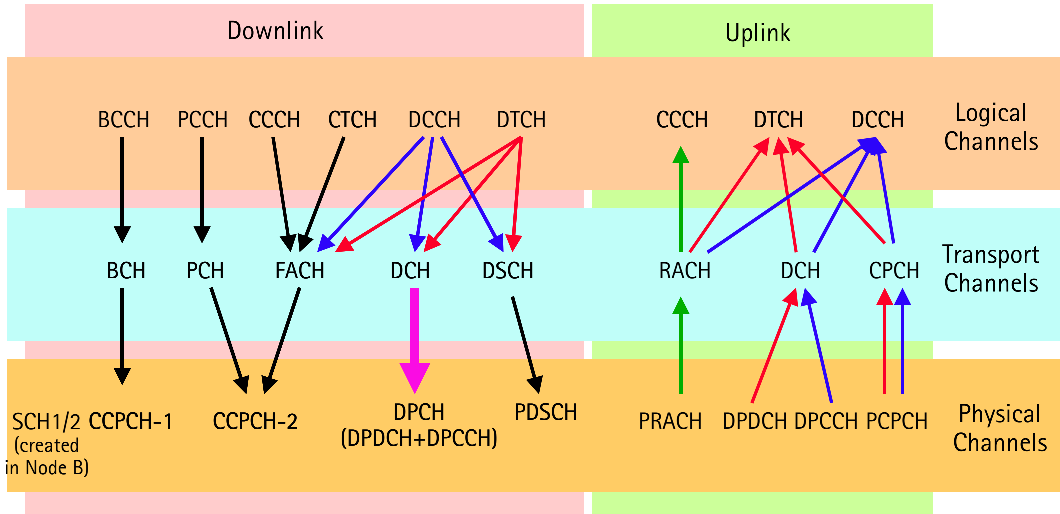


Figure 18. Mapping of user data and signalling (seen from the Node B point of view)

4.5.4 Description of the UMTS-FDD logical and transport channels

Concerning the logical channels, the User Equipment (UE) and the network have different tasks. Thus, the logical channel structure is different in the downlink and uplink direction. Roughly, the network has the following tasks to perform:

- **BCCH General network information delivery: DL**
  The network must inform the UE about the radio environment. This information consists of, for instance, the code value(s) used in the cell and in the neighbouring cells, and the allowed power levels. The network provides this kind of information for the UE through the logical channel called Broadcast Control Channel, **BCCH**.
- **PCCH Paging purposes: DL**
  When there is a need to reach a UE for communication (for instance, a mobile terminated call), the UE must be paged in order to find out its exact location. This network request is delivered on the logical channel called Paging Control Channel, **PCCH**.
- **Common control purposes**
  The network may have certain tasks, which are or may be common for all the UEs residing in the cell. For this purpose the network uses the logical channel called Common Control Channel, **CCCH**.

- **Dedicated control purposes**
  When there is a dedicated, active connection, the network sends control information through the logical channel called Dedicated Control Channel, **DCCH**.
- **Dedicated traffic**
  The dedicated user traffic for *one* user service in the downlink direction is sent through the **DTCH**, Dedicated Traffic Channel.
- **Common traffic purposes**
  When there is a need to transmit information either to all UEs or to specific group of UEs, then a downlink-only Common Traffic Channel can be used, **CTCH**.

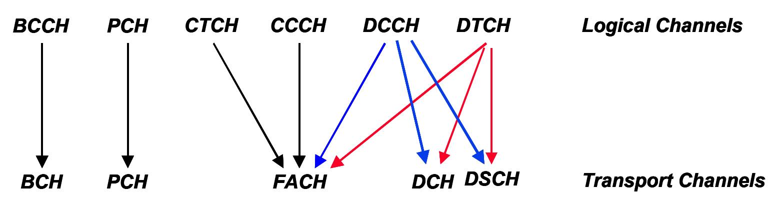


Figure 19. Downlink logical and transport channels

The logical channels must be mapped into the transport channel structure. Following **transport channels** are carrying the ready-made information flows in the downlink direction:

- Broadcast Channel (BCH) carrying the Logical BCCH.
- Paging Channel (PCH) carrying the Logical PCH.
- Forward Access Channel (FACH) carrying information coming from the Logical CCCH, CTCH and DCCH, that is, from common and dedicated control channels.
- Dedicated Channel (DCH) is the only dedicated transport channel; the other channels are common ones. The DCH carries information coming from the Logical DTCHs and DCCH. It should be noted that one DCH may carry several DTCHs, depending on the case. For example, a user may have a simultaneous voice call and video call active. The voice call uses one Logical DTCH, and the video call requires another Logical DTCH. Both of these, however, use the same DCH.
- Downlink Shared Channel (DSCH) carries dedicated information from DTCH and DCCH. This channel is shared by several users.

In the **uplink direction** the logical channel amount required is smaller. There are only three logical channels: CCCH, DTCH and DCCH. These abbreviations have the same meaning as in the downlink direction.

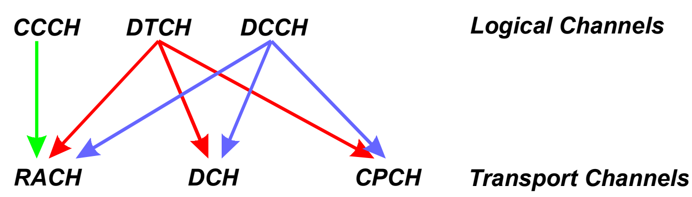


Figure 20. Uplink logical channels

The transport channels in the uplink direction are:

- Random Access Channel (RACH). This transport channel carries initial access information when required.
- Dedicated Channel (DCH). This channel carries the combination of the user traffic(s) and control information.
- Common Packet Channel (CPCH). This transport channel carries user packet(s) if the common resources of the system are used for this purpose.

4.5.5 UMTS-FDD transport to physical channels

When the information is collected from the logical channels and organised to the transport channels, it is in ready-to-transfer format. Before transmitting, the transport channels are arranged to the physical channels. A physical channel is defined by the used frequency band and the used CDMA code. There are some physical channels, which have no logical and transport channels, i.e. in the downlink direction, they are directly generated in the Node B. One example are the physical channels, which help the mobile phone to synchronise the Node B. These are the Primary and Secondary Synchronisation Channels (SCH-1 and SCH-2). Both physical channels are identified by well known scrambling codes. With the help of the Primary and Secondary Synchronisation Channels, the UE can perform chip, timeslot, frame and scrambling group synchronisation. There a 512 primary scrambling codes in use downlink. They are organised in 64 scrambling code groups, each group is holding 8 primary scrambling codes. The UE therefore only knows the scrambling code group, but not the scrambling code of the cell.

8 potential primary scrambling codes may be in use in the cell. How does the UE learn the correct scrambling code. For that, it uses the Common Pilot Channel (CPICH). The CPICH is always using the same channelisation code ($C_{CH,256,0}$), so that the UE can determine the cell's scrambling code by trial and error.

There are two Common Control Physical Channels: Primary channel (CCPCH-1) and secondary channel (CCPCH-2). Roughly, the CCPCH-1 carries broadcast control information (same type of information as the GSM BCCH). The UE knows the scrambling code of the cell. The channelisation code for the CCPCH-1 is always $C_{CH,256,1}$. Every other physical channel, both uplink and downlink requires a cdma code, which is the product of spreading code and channelisation code. The UE learns from the broadcast information, which codes are used downlink con the common control channels, and which codes to use for the random access.

The CCPCH-2 is a combination of two transport channels; it carries paging related information, as well as the information currently included in the Forward Access Channel.

The two dedicated physical channels are Dedicated Physical Data Channel (DPDCH) carrying user traffic and Dedicated Physical Control Channel (DPCCH) carrying related control information. When these are timely multiplexed together, the combination is called Dedicated Physical Channel (DPCH).

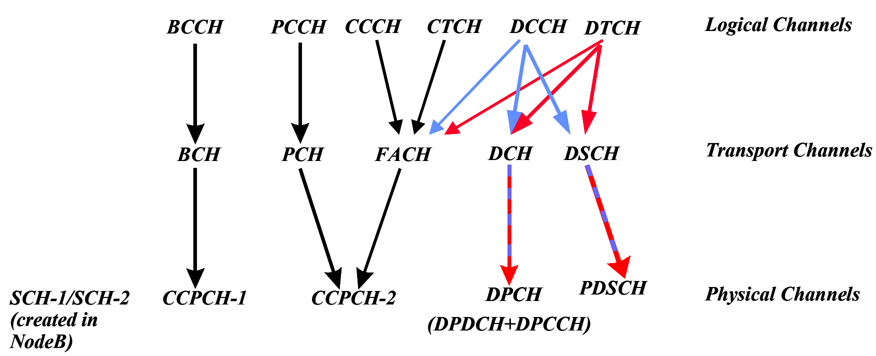


Figure 21. Downlink transport to the physical channel mapping

The transport channel RACH carries the initial access information when the UE accesses the network. This information is transferred to the network via the Physical Random Access Channel (PRACH). The random access is decomposed into two components. First the UE is sending a set of preambles, each with a higher output power then the preceding one. Why? In WCDMA all UE use the same frequency band at the same time. If a UE is making the random access with a too high output power level, the transmission of all UE in the cell and in the neighbouring cells is interfered. If the Node B as filtered out the preamble, it returns a short notice to the UE with the Acquisition Indication Channel (AICH; downlink only). Then, the second part of the random access begins, where the UE sends more information to UTRAN.

The user traffic and control information share a transport channel named Dedicated Channel (DCH). The information the DCH carries is divided into two physical channels: DPDCH and DPCCH, with the modulation method used.

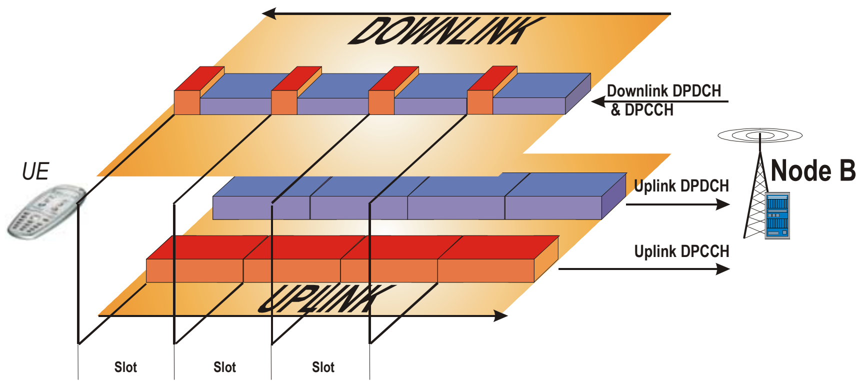


Figure 22. Dedicated traffic organisation uplink and downlink

When there is a need to send a short packet (and dedicated resources are not necessary), the information to be sent is carried by the transport channel CPCH. This information is sent through the Physical Common Packet Channel, (PCPCH).

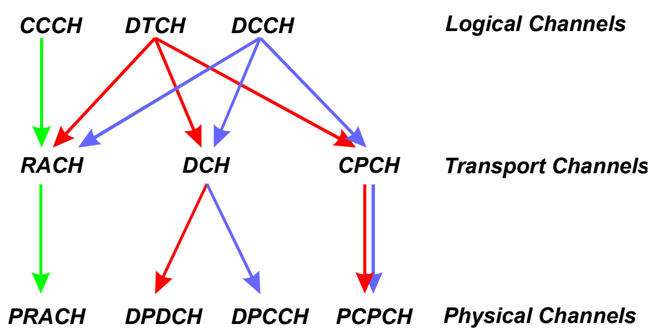
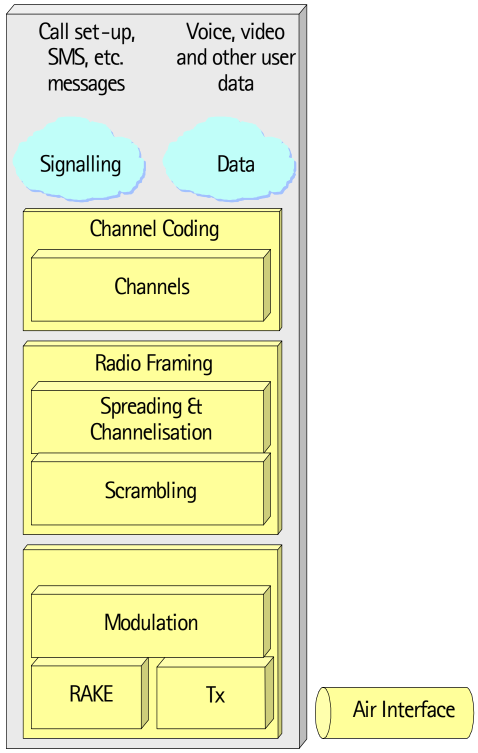


Figure 23. Physical uplink mapping

In uplink the physical channel is not time multiplexed since this in combination with Discontinuous Transmission (DTX) would cause audible interference to non mobile network equipment. The DPCCH is never turned of thus there is no transmission pulse causing additional interference. The DPDCH uses the DTX periods to save battery and add efficiency to transmissions.



Summary
We are approaching the end of this overview of the UMTS air interface.§ The bits have to be put into the right logical channel and mapped to the correct physical channel with the help of the transport channel. They have doubled, or even tripled, in the channel coding. The bit rate is then matched to the level allowed in UMTS. Then we spread the information over the fixed code rate 3.84 Mcps with the help of the channelisation code, and apply the scrambling code. The data is then organised in frames. Finally, it is time to modulate the data – we map it on an analogue radio wave.

5 Managing the radio resources

5.1 Overview of Radio Resource Management functions

The Radio Network Controller (RNC) roughly covers the same functionality as the BSC in the GSM BSS. Based on the specifications, the aim is that the RNC should be able to maintain Radio Resource Management (RRM) independently. Unlike in the GSM systems, the Radio Access Network (RAN) has RNC-RNC interface (Iur) for this purpose.

Logically thinking, the RNC only has a few parts (see the figure below). From the implementation point of view, the RNC will be remarkably different to the GSM BSC, because wideband switching changes the element structure a lot.

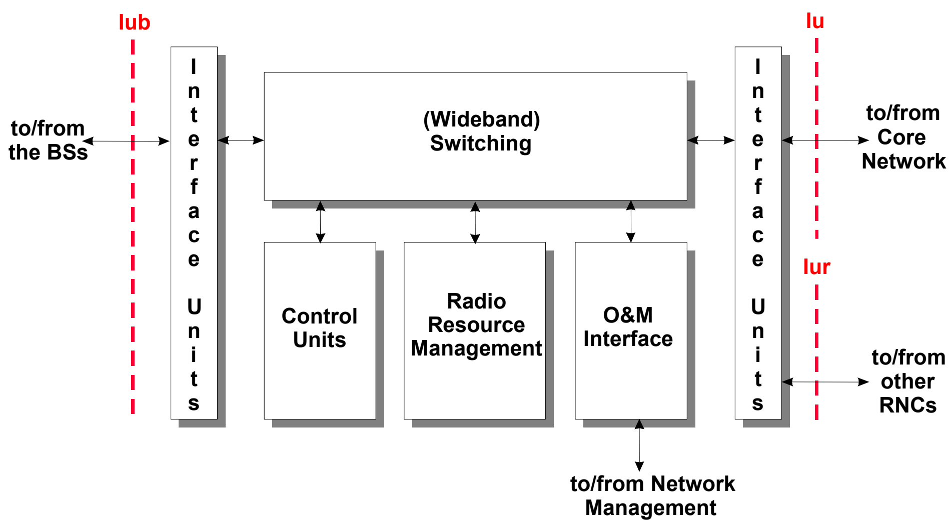


Figure 24. General diagram of the RNC

The RNC has different functions to control the radio resource connection. The functions are illustrated in the below figure and are divided into **network** and **connection** based functions. The connection based are related to task that RRM performs on an active bearer connection, whereas then network based functions are used continuous in a cell for all allocations.

For example, **admission control** (AC) and **load control** (LC) are used to manage the amount of power being transmitted and the number of subscribers in a cell.

This control is important when introducing new bearer allocations into the network. The **resource manager** (RM) is responsible for the allocation of the bearer.

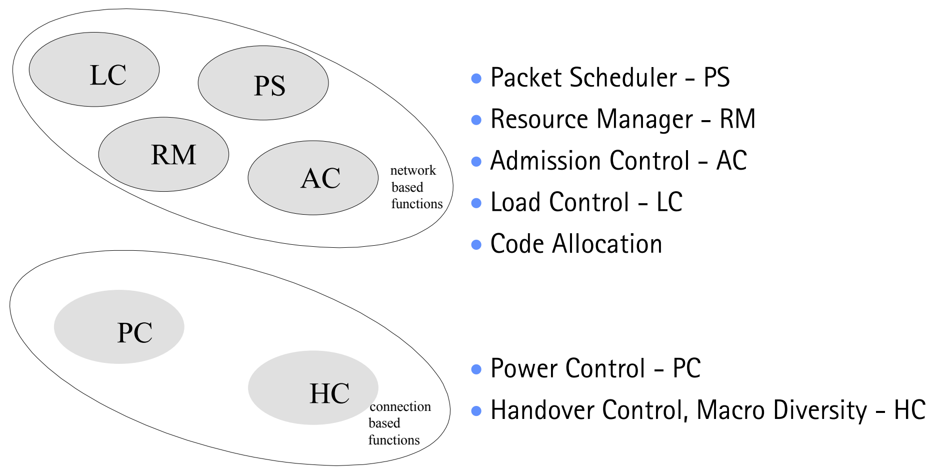


Figure 25. Summary of Radio Resource Management functions

As the UMTS network (unlike in GSM) uses packet data inherently (that is, it is built into the system, rather than being added), then the **packet scheduler** (PS) takes care of transmitting the data in a cell at the optimal time.

The connection based **power control** (PC) is critical for managing air interface bearers, as more interference in a cell (caused in the uplink from mobile to the network), the less overall capacity there is. Therefore, the network is constantly (~1500 per second) informing the mobile station what power level it should use.

Handovers are used to manage the reallocation of the bearer as the subscriber moves.

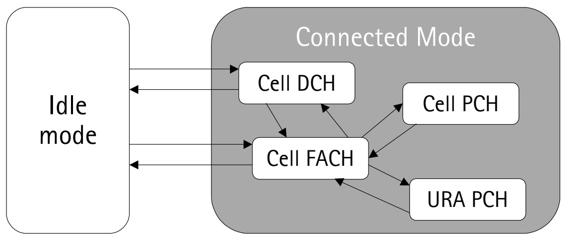
The 3G RAN Radio Resource Management thus consists of several entities, which will be explained in the following (in order of appearance):

- Radio Resource Control (RRC)
- Admission Control
- Code Allocation
- Power Control
- Packet Scheduler
- Handover Control and Macro Diversity

5.2 Radio Resource Control states

The Radio Resource Control (RRC) is an entity having two main states: **idle** and **connected**. From the UE – network connection point of view, the RRC changes its state from idle to connect. For any activity between the UE and the network, the RRC-connected state can be considered as a prerequisite.

When there is no RRC connection between the mobile and the network, but the mobile is switched on, it is said that the mobile is in idle mode. It means that the mobile is listening to one base station in readiness to start a connection, or waiting to be paged.



When a connection between the network and mobile is needed, then the mobile is known to be in connected mode, which has four service states.

Figure 26. The possible state changes of the RRC protocol

When we have a dedicated channel open for a subscriber (for example, if we are using video), we say that subscriber is in **Cell_DCH** state. (The DCH is derived from the name of the *channel* in the air interface). In this state the UE is sending measurement reports to the network, thus the system can control the dedicated bearer and perform handovers.

If the mobile is only sending small pieces of information, for example intermittent Internet based traffic or for signalling, then the RRC can be in a mode known as **Cell_FACH** (the FACH stands for Forward Access Channel) and is different from the previous state as no dedicated channel is used. The network does not perform handovers as the mobile moves from one cell to another. The UE just informs the network of its current location.

Depending on the bearer we have and how it is being used, the RNC will move the RRC between the different states. In addition to the Cell_FACH, if the network finds that the bearer is not being used for a long time, it can move the connection to a **Cell_PCH** mode (Paging Channel), where the mobile is still know to a cell level but can only be reached via the PCH. In this state the UE is using a Discontinous Repetition Function (DRX) to save battery. Again, unlike in the Cell_DCH, as the subscriber moves, the mobile informs the RNC which cell it has moved to. The final state is the **URA_PCH**. This state is similar to the **Cell_PCH**. But, instead of monitoring the connection on a cell level, it is now on a RNC level. URA stands for UTRA Registration Area and the UE monitors the broadcast channel for URA identities.

The RRC as an entity consists of two items, **MAC** (Medium Access Control) and **RLC** (Radio Link Control). Together these two are also called as Layer 2 processing. This refers to the position these procedures hold in the OSI model.

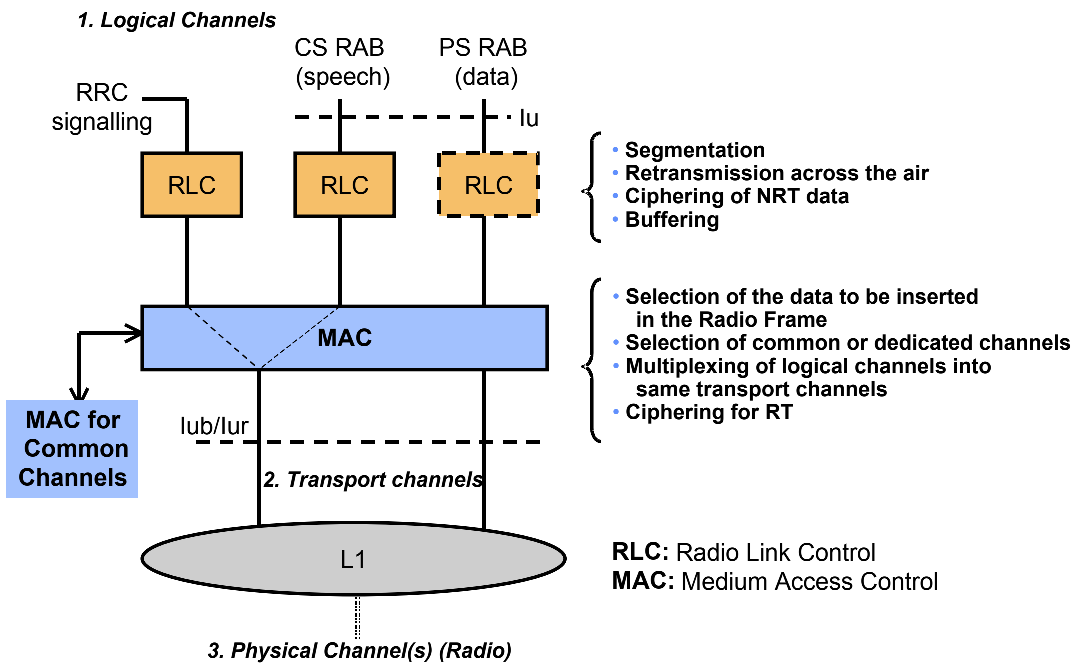


Figure 27. Layer 2 processing

The **Physical Layer** (Layer 1) offers Transport Channels to the MAC layer. There are different types of transport channels with different characteristics depending on the transmission. Common transport channels can be shared by multiple handsets (e.g. FACH, RACH, DSCH, BCH, PCH). Dedicated transport channels (DCH) are assigned to only one handset at a time.

The transmission functions of the physical layer include channel coding and interleaving, multiplexing of transport channels, mapping to physical channels, spreading, modulation and power amplification, with corresponding functions for reception. A frequency and a code characterize a physical channel.

The **Medium Access Control (MAC) protocol** (Layer 2) offers logical channels to the layers above. The logical channels are distinguished by the different type of information they carry, and thus include the Dedicated Control Channel (DCCH), Common Control Channel (CCCH), Dedicated Traffic Channel (DTCH), Common Traffic Channel (CTCH), Broadcast Control Channel (BCCH) and the Paging Control Channel (PCCH). The MAC layer performs scheduling and mapping of logical channel data onto the transport channels provided by the physical layer. For common transport channels, the MAC layer adds addressing information to distinguish data flows intended for different handsets. One major difference to GSM is the possibility to dynamically switch one logical channel (data flow) onto different transport channel types, e.g. based on the activity of the subscriber. **The Radio Link Control (RLC) protocol** (Layer 2) operates in one of three modes: transparent, unacknowledged or acknowledged mode. It performs segmentation/re-assembly functions and, in acknowledged mode, provides an assured mode delivery service by use of retransmission. RLC provides a service both for the RRC signalling (the Signalling Radio Bearer) and for the user data transfer (the Radio Access Bearer).

Above these layers the **Radio Resource Control (RRC) protocol** (Layer 3) provides control of the handset from the RNC. It includes functions to control radio bearers, physical channels, mapping of the different channel types, handover, measurement and other mobility procedures.

5.3 Admission control

WCDMA radio access has several limiting factors, some of them being absolute and others environment-dependent. The most important – and the most difficult – to control is the interference occurring in the radio path. Due to the nature and basic characteristics of WCDMA, every UE accessing the network generates a signal. Simultaneously, this signal can be interpreted to be interference from the other UEs point of view. When the WCDMA network is planned, one of the basic criteria for planning is to define the acceptable interference level, with which the network is expected to function correctly. This planning based value and the actual signals the UE transmit set practical limits for the Uu interface capacity.

To be more specific, a value called SIR (Signal-to-Interference Ratio) is used in this context. Based on radio network planning, the network is, in theory, able to stand as maximum one SIR of certain size within one cell. That is, in the BTS receiver, the interference and the signal must have a certain level of power difference in order to extract one signal (code) out from the other signals using the same carrier. If the power distance between interfering components and the signal is too small, the BTS is not able to extract an individual signal (code) out from the carrier any more. Every UE having a bearer active through this cell “consumes” a part of the SIR. The cell is used up to its maximum level when the BTS receiver is not able to extract the signal(s) from the carrier.

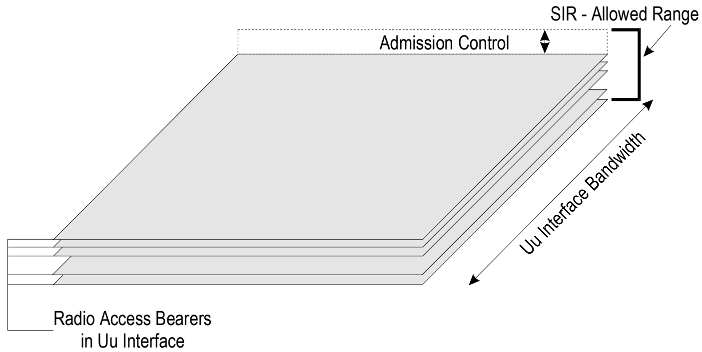


Figure 28. Admission control

The main task of admission control is to **estimate** whether a new call can have access to the system without sacrificing the bearer requirements of existing calls. Thus the AC algorithm should predict the load of the cell if the new call is admitted. It should be noted that the availability of the terrestrial transmission resources is verified, too, meaning that there is no limiting factor in the rest of the UTRAN either. Based on the admission control, the Radio Network Controller (RNC) either grants or rejects the access.

When applying mathematics, it can be found out that the Signal-to-Interference Ratio (SIR) or Interference Margin has direct relationship with the cell load. If we express the cell load with a Load_Factor (figure from 0 to 1, equals cell percentual load, that is, 10 % load gives value 0.1) and mark the Interference Margin with I, it leads to the following equation:

$$I = 10 \cdot Log\left(\frac{1}{1 - Load\_Factor}\right)$$

When placing together the Interference Margins calculated with different Load Factor values, we arrive at the graph below.

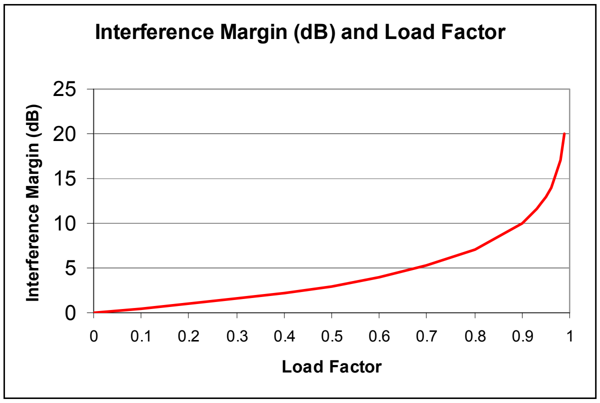


Figure 29. Interference Margin as a function of a cell load

Based on the graph it is fairly easy to indicate that when the cell load exceeds 70 %, the interference in that cell will be very difficult to control. This is why the WCDMA radio network is normally dimensioned with expected capacity equivalent to Load Factor value 0.5 (50 %). This value has a safety margin in it and the network will behave as expected.

5.3.1 Planning uplink admission control

Given from the previous page that the RNC must control the interference on the uplink, and then parameters are used to act as boundaries. The first is the UL interference power, which is determined to the maximum limit where the cell is considered to be at maximum load. However, from the previous graph, a more realistic value to represent a sensible load is set; this is the **PRX_Target** (Receive Power level) value.

The area from 0 to this value is known as the planned load. Once the load is approaching this value, traffic reason handovers (**TRHO**) are performed.

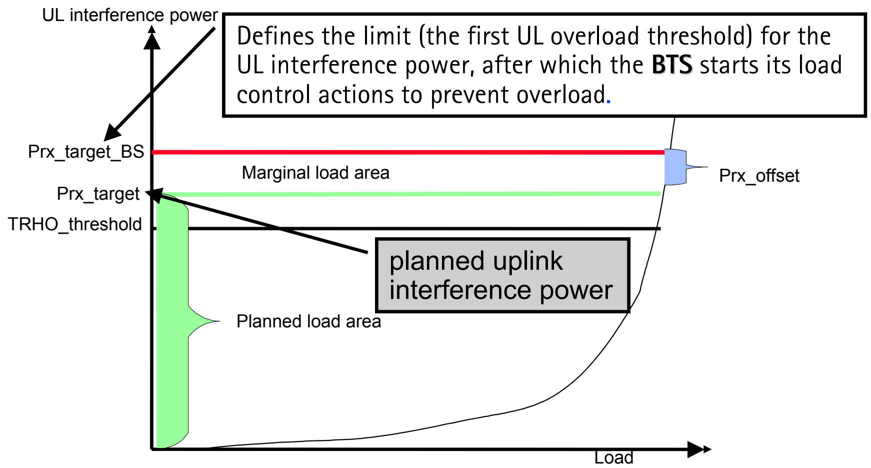


Figure 30. Admission control on the uplink

As UMTS traffic is variable and constantly changing, it is more than feasible that the traffic admission may exceed the PRX_Target. To handle this situation, there is a second level used called the **PRX_TARGET_BS**. This is a parameter used by the BTS to stop situations of congestion. Once this value is reached, the BTS takes actions to reduce the load in the cell.

All these activities are defined through network planning and optimisation.

5.4 Code allocation

Already earlier in this chapter, the different codes used in WCDMA were briefly explained. This section aims to further specify the properties and usage of the scrambling and channelisation codes in Radio Resource Management (RRM).

Both scrambling and channelisation codes used in the Uu interface connections are maintained by the RNC. In principle they could be maintained by the BTS, but then the system would experience lack of radio resource control, namely **soft handovers**, which will be explained later in this module. When the codes are maintained by the RNC, it is easier to allocate Iub data ports for multipath connections.

The Uu interface requires two kinds of codes for proper functionality. A part of the codes used must correlate with each other to a certain extent, and the others must be orthogonal (they do not correlate at all). Every cell uses one scrambling code. As you already know, this code acts like a cell ID. Under every scrambling code the RNC has a set of channelisation codes. This set is the same under every scrambling code.

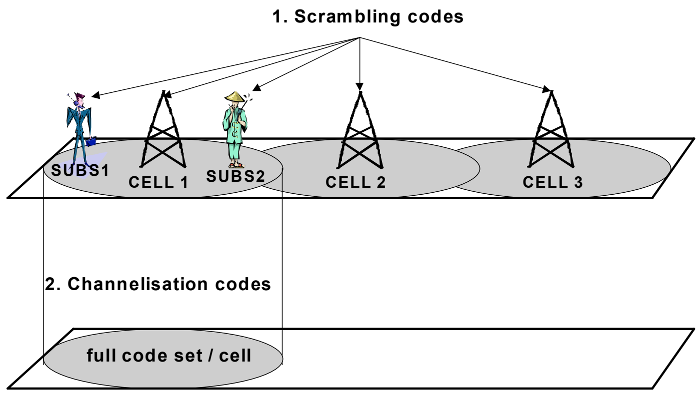


Figure 31. The RNC controls scrambling and channelisation codes

The BCH information is coded with a scrambling code value, and thus the UE must first find the correct scrambling code value first in order to access the cell. When a connection between the UE and the network is established, the channels used must be separated. The channelisation codes are used for this purpose. The information sent over the Uu interface is spread with a spreading code per channel. **Spreading code** by definition is the same as **scrambling code x channelisation code**.

5.4.1 Channelisation code allocation and handovers

The codes used in Uu interface can be handled in a code tree, where branches are consequently blocked when a certain code on a certain spreading factor level is taken into use. When having plenty of simultaneous connections, with multiple radio links and multiple channels (multiple codes), the code tree may easily become **fragmented**. Fragmentation means the phenomenon where the probability of the blocked branch of the code tree increases too much and thus it starts to prevent new accesses to the system. For example, if an active call uses high bit rate over the Uu interface, the spreading factor value in use is small. It furthermore means that a very high-level branch of the code tree is blocked (see the figure below). When this call is finished and simultaneously new calls access the system, the blocked code tree branch is not "released" before the new accesses. In this situation the system wastes capacity because the code channels allocated for new calls are not necessarily allocated in the best possible way.

In earlier parts of this module, we saw that the channelisation code used has the same length as the baseband data. As a part of the spreading operation, the baseband data and the code are combined and spread. The result is a fixed length code that is then scrambled. A low data rate communication can be spread much more over the bandwidth, which also means that a high spreading factor is used.

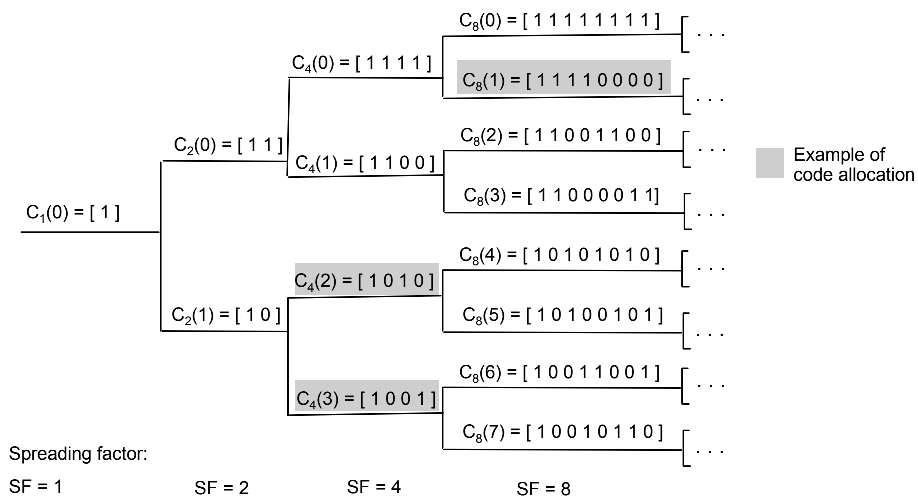


Figure 32. Channelisation codes

As codes are released in different branches, the tree can become fragmented and the RNC should always try to reorganise the tree to make the best use of the resources. Therefore in UMTS networks, it is possible that the channelisation codes could change during a connection.

Also, if the scrambling code in the uplink (that is, the user) is being used by another person in another RNC as the subscriber performs a soft handover, the handover is refused and the serving RNC must allocate a new scrambling code to the subscriber.

5.4.2 Scrambling code planning

There are totally 512 downlink scrambling codes used, that is, eight in each of the 64 code groups. All the cells that the UE is able to measure in one location should have different scrambling codes.

The first idea is to use different scrambling code groups in the neighbouring base stations. This would ensure the previous requirement in most cases.

The code group allocation will probably be done in the network planning. There should be the corresponding functionality in the network planning tool, which reminds of the frequency planning in GSM planning tools. The re-use could be 64, as there are 64 code groups. The scrambling code group planning for different frequency carriers can be done independently. It is for further studies whether or not more optimisation would be needed.

5.5 Power control

In the UTRAN, the power control and its accuracy is extremely essential (unlike in GSM networks) mainly due to the following reasons:

- The mobiles transmit simultaneously in time (not in different timeslots like in GSM).
- UTRAN uses very often only one frequency. Technically speaking, the frequency re-use factor would thus be 1.
- Inaccuracy in power control immediately increases interference, thus decreasing the capacity of the network.

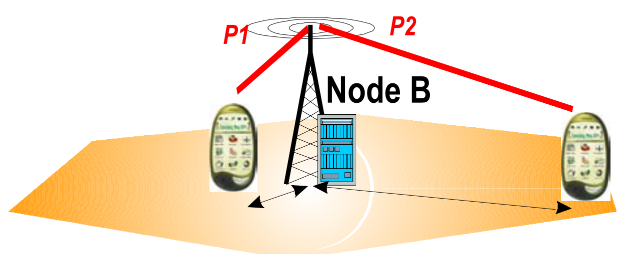


Figure 33. Power and distance

The physical facts related to the radio path and the distance are quite the same as in GSM, but because of the three reasons stated above, the power control mechanism must be very accurate and fast. Hence, the WCDMA power control mechanism differs from the GSM mechanism.

Due to the facts listed above, it is relatively easy to determine that the optimal situation from the Node B receiver point of view is that the power representing one UE’s signal is always equal when compared to the other User Equipments' signals, despite the distance between the UE and the Node B. If so, the SIR will be optimal and the Node B receiver is able to decode the maximal number of transmissions. The power control mechanisms used in the GSM are clearly inadequate to guarantee this situation in WCDMA. Thus, the WCDMA has a slightly different approach to the matter.

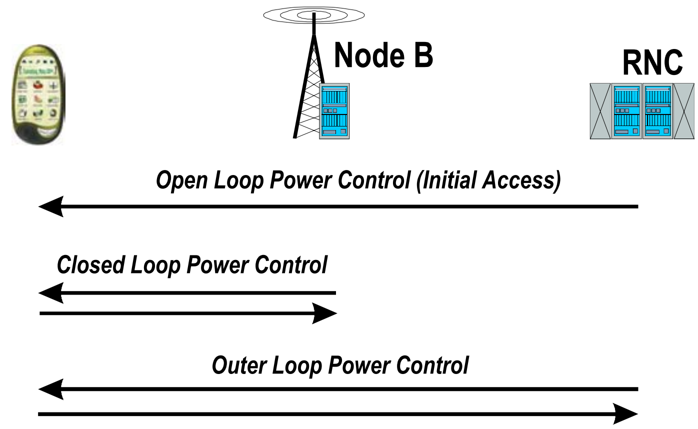


Figure 34. WCDMA power control mechanisms

Open loop power control

When the UE accesses to the network, the initial level for accessing is based on an estimate. This estimate in turn is based on the signal level received from the Node B when the UE is in idle mode. The basis for the UE estimate is the downlink power level that the UE detects from the physical channel CPICH.

In other words, the UE receives information about the used and allowed power levels from the cell's Pilot Channel when in idle mode. In addition, the UE evaluates the path loss occurring compared to the figures received from the CCH-1. Based on this difference, the UE is able estimate the correct-enough power level to initialise the connection.

Closed loop power control

When the radio connection is established, the power control method is changed. During the connection, the method used is called the closed loop power control. Within this method, the Node commands the UE either to increase or to decrease its transmission power with the pace of 1.5 kHz (1500 times per second) in the FDD mode. (In the TDD mode closed loop power control is performed 100 to 800 times a second.) The decision whether to increase or decrease the power is based on the received Signal-to-Interference Ratio (SIR) estimated by the Node B.

Outer loop power control

Due to the macro diversity (the UE is simultaneously attached to the network through more than one cell), the RNC must be aware of the current radio link conditions and quality. The RNC knows the allowed power levels of the cell and target SIR.

In order to maintain the quality of the radio link, the RNC uses this power control method to adjust the SIR of the connection. By doing this, the network is able to compensate changes in the air interface propagation conditions and to achieve the target quality for the connection. The target quality can be measured with the help of BER (Bit Error Ratio), and FER (Frame Error Ratio) observations.

5.6 Packet scheduler

Packet scheduler is a general feature, which takes care of scheduling radio resources for non-real-time (NRT) radio access bearers for **both** uplink and downlink directions.

Packet access is implemented for both dedicated (DCH) and common control transport channels (RACH/FACH – Random Access and Forward Access Channels). Packet scheduler makes the decision of the used channel type for the downlink direction. For uplink direction the decision of the used channel type is made by the UE (User Equipment).

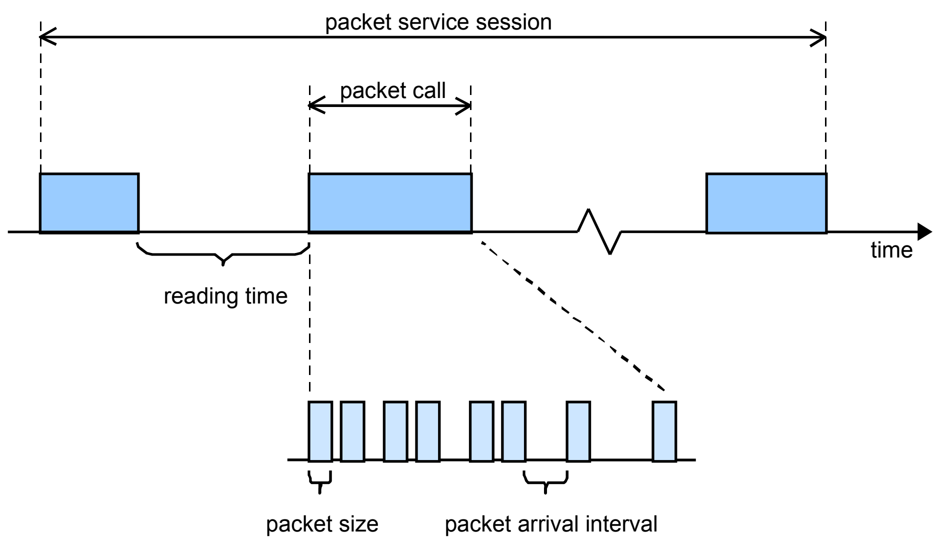


Figure 35. Function of the packet scheduler

In Release 3, the actions of the packet scheduler are driven by the load control function. The gap between real-time (RT) traffic and the load target of the cell can be filled by the packet scheduler.

As IPv6 is implemented, and quality of service (QoS) becomes a key part of the interface, the scheduler no longer sees the traffic as real-time and non-real-time, but instead uses a priority system on the packets being transmitted.

5.7 Handover control and macro diversity

UMTS handovers can be intra-system, (inside the WCDMA radio network) or inter-system, from WCDMA to GSM 900/1800. The inter-system handovers (ISHO) are of the traditional type, also used in GSM. We call this latter type of handover a hard handover, because the User Equipment (UE) does not keep up simultaneous connections; in practise it breaks the old connection and then establishes a new connection.

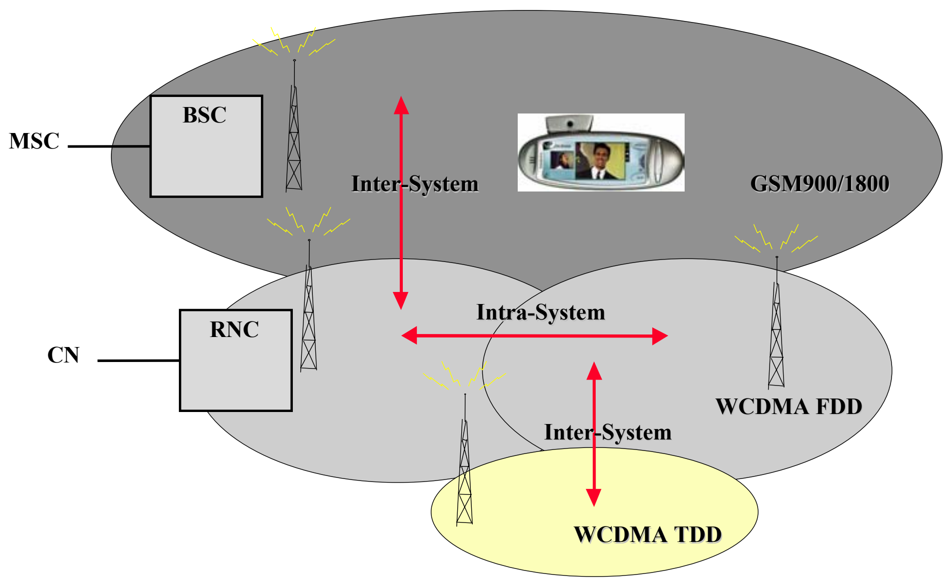


Figure 36. The intra-system and inter-system handovers

The intra-system handovers of UMTS are classified as being inside the same WCDMA band (intra-frequency) or being from one frequency band to another. The inter-frequency handover could be a handover from one cell layer to another. The inter-frequency handovers are hard handovers and are similar to the inter-system handovers. The intra-frequency handovers, on the other hand, could be so-called soft handovers. In a soft handover, the signal is received in both the new and the old channel for a period of time. In the next section we look at the different types of handovers.

One characteristic of a UMTS network is that the network will communicate with the UE through different base stations (Node Bs). An **active set** is a list of cells, through which the UE has a connection to the network, that is, through which the *radio link set-up* has been made. This is, the UE may have active radio connection between itself and the network through three cells simultaneously. In soft handover, the UE is connected to (at least) two Node Bs at the same time. In the uplink direction, the two signals come via the base stations to the Radio Network Controller (RNC). In the RNC the signal to be transported forward to the core network is selected. The selection is done frame by frame for the speech, and in smaller blocks for data. In the downlink direction, the UE uses the RAKE receiver to combine signals from two different base stations.

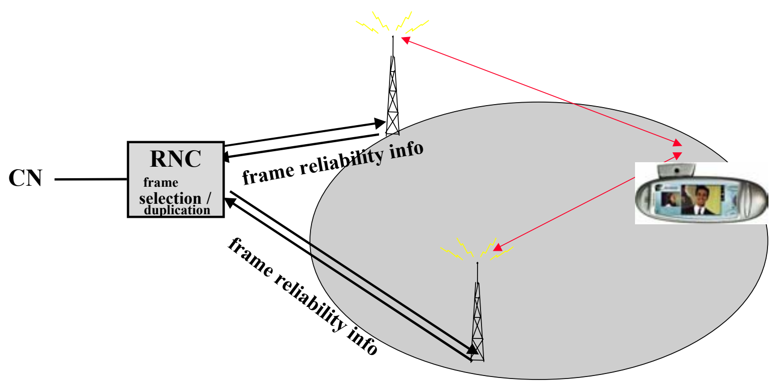


Figure 37. Soft handover and active Node B set

The subscriber is moving from cell site 1, Node B1 to cell site 2, Node B2. First the UE has a connection through Node B1. The power level (and Signal to Interference Ratio) decreases as the UE moves towards Node B2. At some point the Node B2 signal is high enough and the UE starts to talk via **both** Node B1 and Node B2. The signal via Node B2 is getting better and the signal via Node B1 is getting worse. When the UE talks via two Node Bs, we have **macro diversity** (further explanation later).

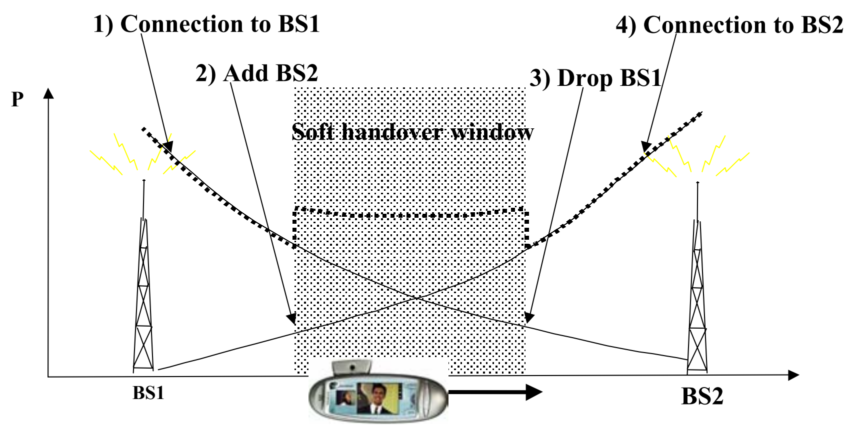


Figure 38. The UE is moving from cell cite 1 to cell site 2. In the middle we have the soft handover window

In the next few sections, a clearer subdivision of the different types of handovers is presented. After that, the terms micro diversity and macro diversity are explained.

5.7.1 Soft handover

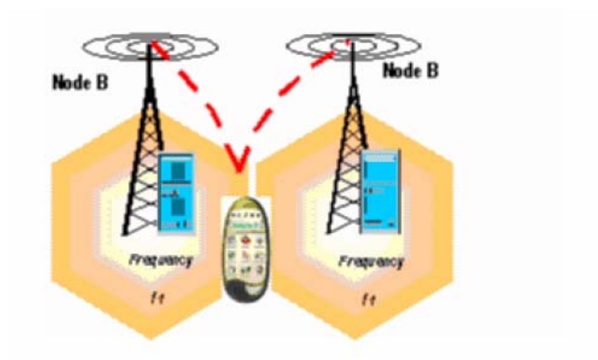


Figure 39. Principle of WCDMA soft handover

Soft handover is performed between two cells belonging to different Node Bs but not necessarily to the same RNC. The source and target cell of the soft handover has the same frequency. In case of a circuit switched call, the terminal is actually performing soft handovers all the time if the radio network environment has small cells.

5.7.2 Softer handover

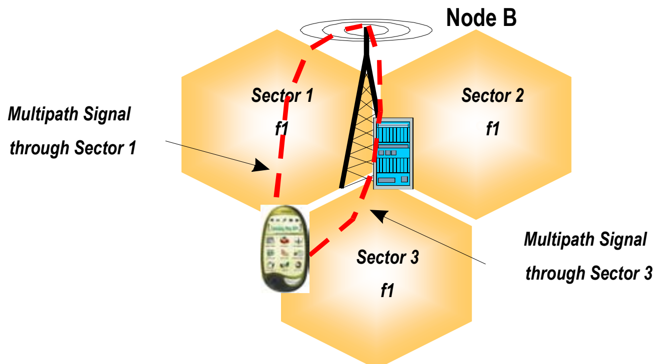


Figure 40. Principle of WCDMA softer handover

In softer handover the UE transmits and receives signals via two air interface channel concurrently, one for each sector separately. Both channels are received at the same Node B by maximal ratio combining RAKE processing.

5.7.3 Hard / Inter-frequency handover

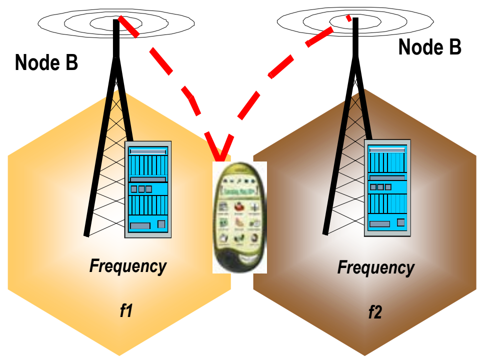


Figure 41. Principle of UMTS hard handover

The UMTS hard handover is a 'GSM-like' handover made between two WCDMA frequencies. In case of a hard handover, the connection through the old cell is cleared and the connection with the radio network continues through the new cell. Hard handover is not recommended unless there is a desperate need: this handover type increases interference easily.

5.7.4 Hard / Intra-frequency handover

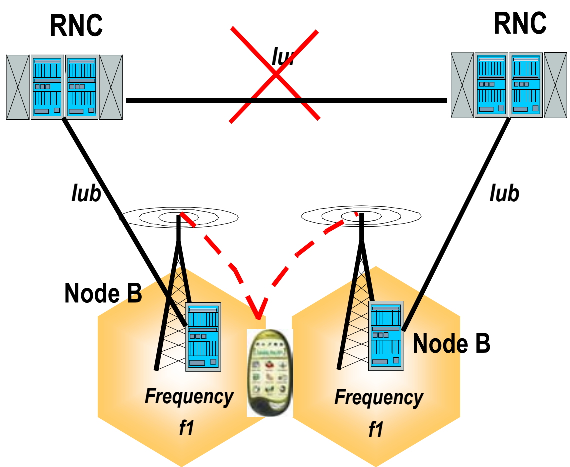


Figure 42. Hard / Intra-frequency handover

This type of a handover is performed if the Iur interface is not available (for example, between the RNCs coming from two manufacturers).

5.7.5 Inter-system handover

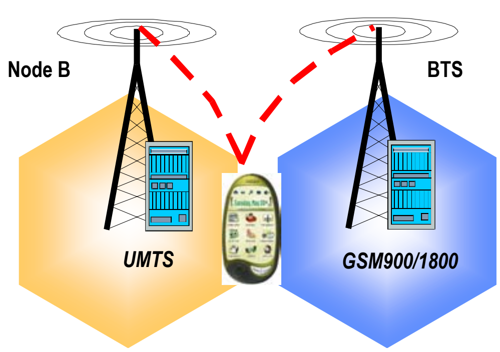


Figure 43. UMTS/GSM inter-system handover

Because of the possible co-existence of the different radio accesses in the UMTS network, the UE should be able to fluently change the radio access technology when required. In order to present this kind of situation, the 3GPP Specifications identify the combination of UMTS and GSM as one source for inter-system handovers.

The possibility to perform an inter-system handover is enabled in the UMTS by a special functioning mode, slotted mode. When the UE uses Uu interface in the slotted mode, the contents of the Uu interface frame is "compressed" in order to open a time window, through which the UE is able to peek and decode the GSM BCCH information.

Additionally, both the WCDMA RAN and GSM BSS must be able to send each other's identity information on the BCCH and BCH channels, so that the UE is able to perform the decoding properly.

5.7.5.1 Intersystem handover from GSM

The handover between GSM and UTRAN and GSM can be performed for a number of reasons but an example is to provide specific high bit rate services.

The handover is possible because a dual mode UE receives the UTRAN neighbour cell parameters on GSM system information messages. The parameters enable the UE to measure the neighbouring UTRA FDD cell. The values are: Downlink centre frequency, Downlink bandwidth (currently only 5MHz), Downlink scrambling code or scrambling code group for the Primary Common Pilot channel (CPICH), Reference time difference for the UTRA cell.

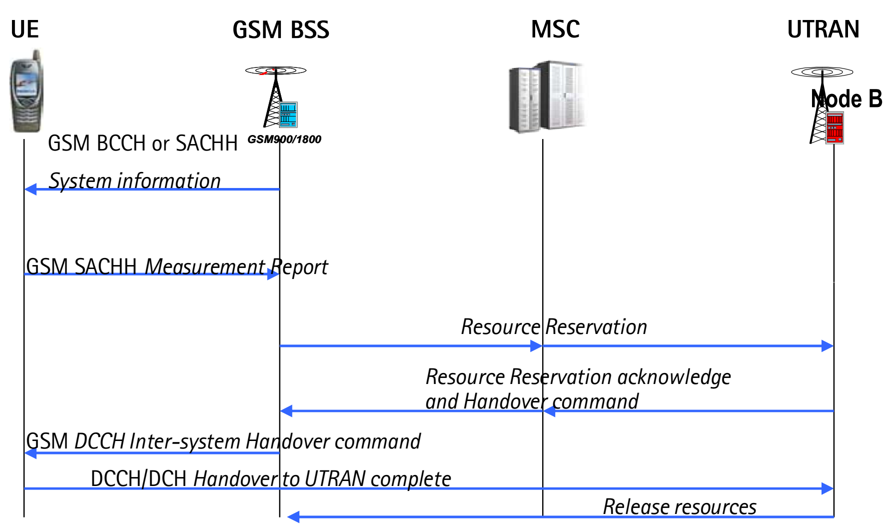


Figure 44 Intersystem handover from BSS to UTRAN

The handover is described in the figure 44.

- The UE/MS creates a measurement report that the BSC evaluates to make the handover decision.
- If the BSC decides to hand over to a UTRA cell resource reservation messages are sent to the UTRAN.
- The UTRAN acknowledges the resource reservation and provides a UTRAN handover command.
- The BSC sends the GSM intersystem handover command to the UE. In this command is included a UMTS Handover to UTRAN command which contains all the information needed to set up a connection to the UTRA cell. Since the amount of UTRA configuration information might be too large for a GSM message the message actually contains reference number to UTRA parameters not the real values.
- The UE completes the procedure by a Handover to UTRAN complete message to the RNC.
- As a last stage the RNC commands resources to be released by the BSC.

5.7.5.2 Intersystem handover from UTRAN

UMTS has already been deployed widely but there will still be reasons to perform Intersystem handovers to GSM. This could be because of services used, coverage or even traffic reasons.

The UE receives the GSM neighbour cell parameters on either System information message or in a Measurement control message. The parameters allow the UE to measure candidate GSM cells. The handover is described in the figure 44

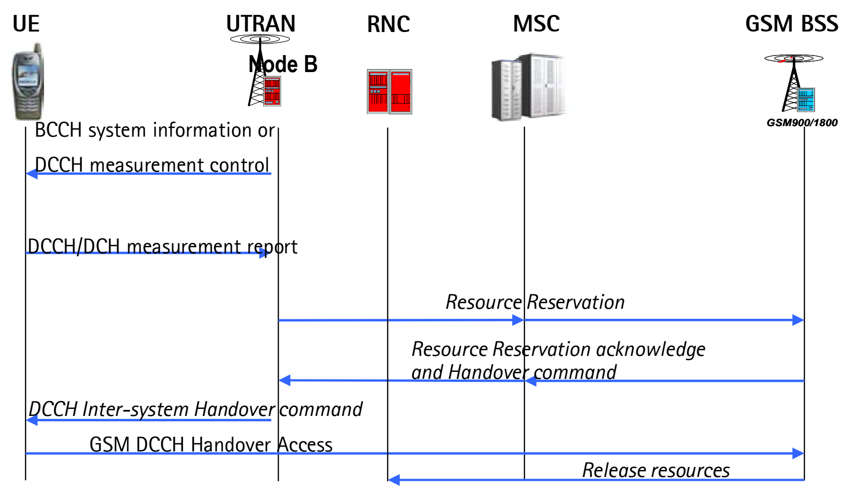


Figure 45 Intersystem handover from UTRAN to BSS

- Based on the measurement report including both UTRAN and BSS values the RNC makes the handover decision.
- Resource reservation messages are sent to the BSC.
- The BSC acknowledges the resource reservation and includes a GSM handover command.
- The RNC sends an Intersystem handover command message to the UE, included in this message is the GSM Handover command.
- The UE switches to GSM RR protocol and sends the GSM handover access message to the BSC.
- The BSC finally initiates resource release with message to the UTRAN

5.7.6 Micro diversity

Referring to the soft handover and active set, there are two terms describing the handling of the multipath components: micro diversity and macro diversity. Micro diversity means the situation where the propagating multipath components are combined in the Node B.

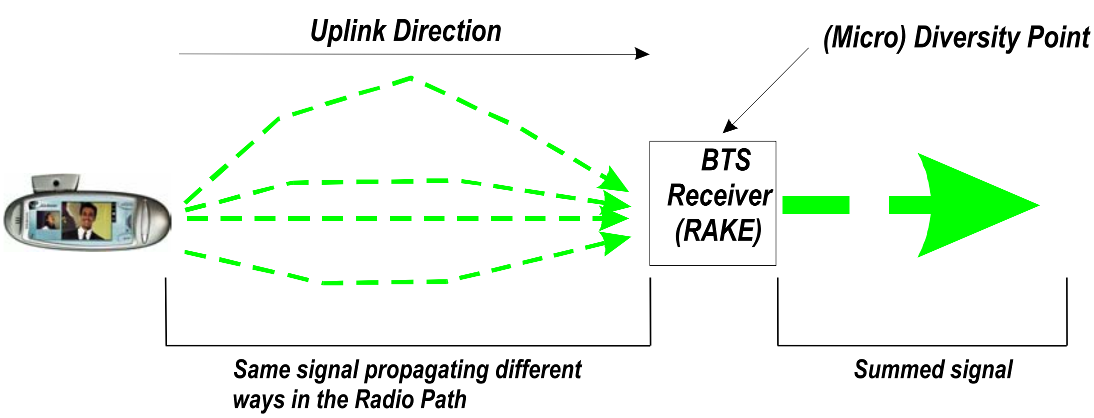


Figure 46. Micro diversity in Node B

WCDMA utilises what is called Multipath Propagation. This means that the Node B receiver is able to determine, differentiate and sum up several signals received from the radio path. The receiver able to do this is a special type of equipment called a RAKE receiver.

In reality, a signal sent to the radio path is reflected from, for example, ground, water and buildings, and in the receiving end one sent signal can be "seen" as many copies, everyone of them coming to the receiver at a slightly different phase and time. The micro-diversity functionality at the Node B level combines (sums up) different signal paths received from one cell and, in case of sectored Node B, the outcomes from different sectors (softer handover).

5.7.7 Macro diversity

Because of the fact that the UE may use cells belonging to different Node Bs or even different RNCs, the macro-diversity functionality also exists on the RNC level. The following picture presents a case in which the UE has a 3-cell active set in use and one of those cells is connected to another RNC. In this case, the Node Bs do signal summing concerning the radio paths of their own. In the RNC level, the serving RNC evaluates the frames coming from the Node Bs and chooses the best signal to send towards the CN domains.

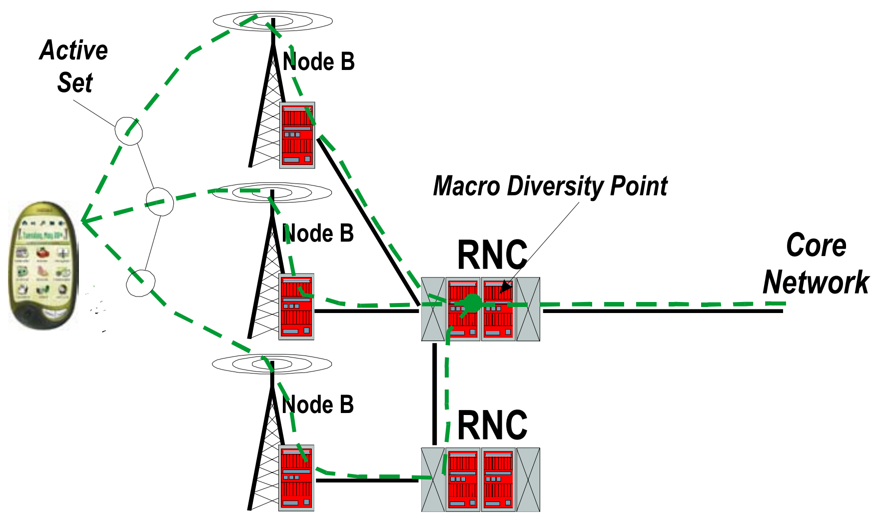


Figure 47. Macro diversity in RNC

Concerning soft and softer handovers, the idea is that the subjective call quality will be better when the 'final' signal is constructed from several sources (multipath). In GSM the subjective call quality depends relatively much on the transmission power used. It can be roughly stated that the more power, the better quality. In UMTS, the terminals cannot use so much power because transmission levels that are too high will start blocking the other users away. Thus, the better way to gain better subjective call quality is to utilise multipath propagation.

As a conclusion it can be stated that soft and softer handovers consume radio access capacity because the UE is occupying more than one radio link connection in the Uu interface. On the other hand, the added capacity gained from the interference reduction is bigger and hence the system capacity is actually increased if soft and softer handovers are used.

5.7.8 Handover decision-making mechanism

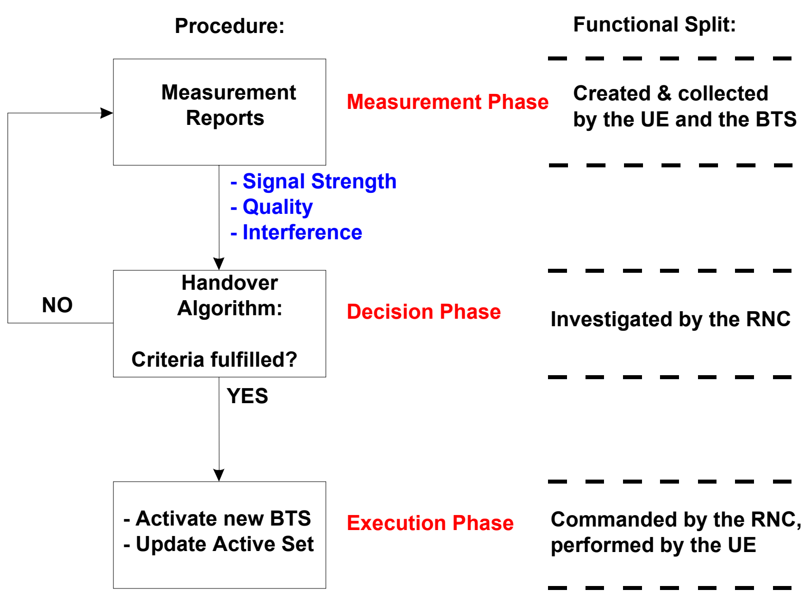


Figure 48. Handover decision-making mechanism

During the connection, the UE continuously measures some items (signal strength, quality, interference) concerning the neighbouring cells and reports the status of these items to the network up to the RNC. These items are measured from the neighbouring cells PICHs. The RNC checks whether the values indicated in the measurement reports trigger any criteria set. If they trigger, the new Node B is added to the Active Set.

An Active Set is a list of cells, through which the UE has a connection to the network, that is, through which the radio link set-up has been made. The minimum size of the Active Set is one cell, and the maximum size is three cells. The UE may have active radio connection between itself and the network through three cells simultaneously.

5.8 Load control in the RNC

The aim of this chapter is to put the Radio Resource Management mechanisms Admission Control, Packet Scheduler and Load Control into further context, as they are all important components when controlling the load in the UTRAN network.

The purpose of load control is to optimise the capacity of a cell and prevent an overload situation. Load control hence consists of Admission Control (**AC**) and Packet Scheduler (**PS**) algorithms, and Load Control (**LC**), which updates the load status of the cell based on resource measurements and estimations provided by AC and PS.

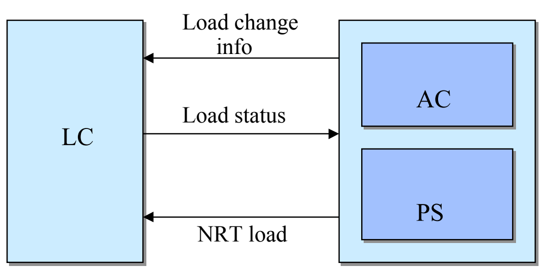


Figure 49. How load control works logically in the RNC

The task of the load control is to guard that the system is not overloaded and that it remains stable. If the system is overloaded, LC returns the system to normal load state in a fast and controlled way. LC can be divided into two functions:

- Preventive control – guards the system from overload
- Overload control – returns the system from an overload state to normal state.

Since interference is the main resource criteria for the CDMA system, the load control measures:

- UL total received wideband interference power
- DL total transmission power
- Periodically under one RNC on cell basis.

Radio Resource Manager (RRM) acts according to these measurements and parameters set by radio network planning.

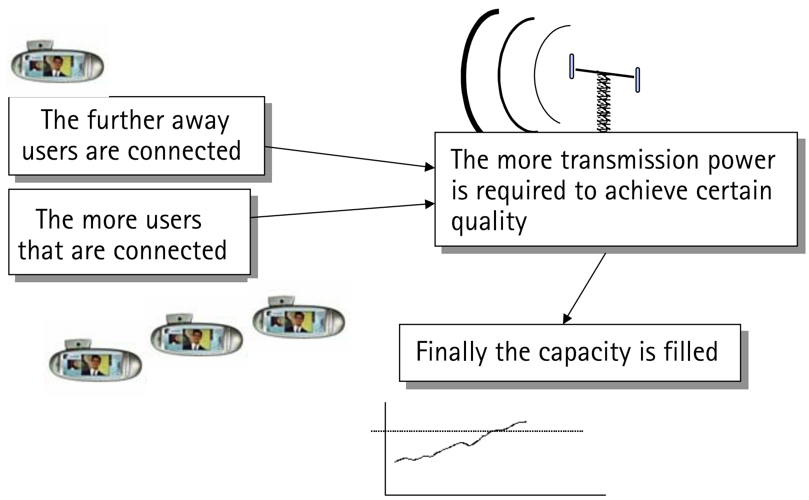


Figure 50. Capacity in the uplink is limited by interference

In the downlink, the capacity is limited by the transmission power of the site. As more subscribers are added to a cell and as subscribers move further away from the site towards the cell edge, the more power is needed to achieve a certain quality. There becomes a point where the capacity of a cell is filled in the downlink, as there is no longer enough power/signal quality to assure a quality connection.

In the uplink, the capacity is limited to amount of power or interference that is present in a cell. Therefore, the loading of a cell is based upon the combination of these two directions.

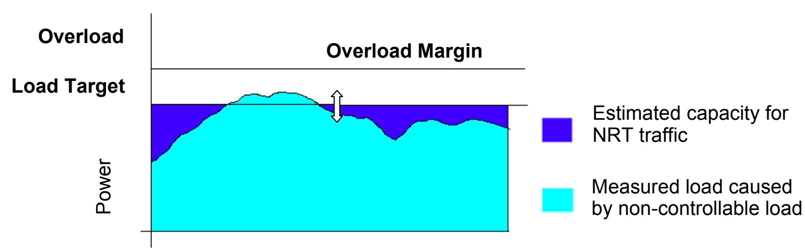


Figure 51. Model of cell loading against traffic profile

The traffic in a cell can be categorised by priority, depending of the traffic type (Conversational, Streaming, Interactive, and Background). We can also make a more simple subdivision – Real Time (RT) and Non-Real Time (NRT) traffic. The previous figure gives this simplified example of Release 99 implementation of real time and non-real time services.

In practise the real time traffic is given priority over non-real time. In fact the system works on the concept that the packets are scheduled to fill in the gaps between the real-time traffic and what is the load target.

The traffic profile in UMTS is variable and therefore there are overload values that are used. As in the previous figure, the system can handle moments of traffic peaks, but if the traffic is constantly above a certain limit, then load reduction measures, such as handovers, are taken.

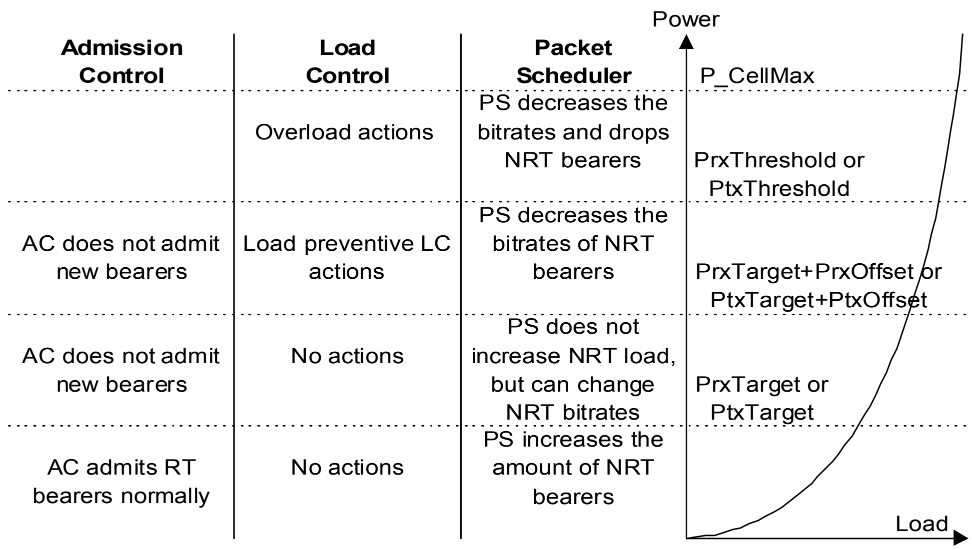


Figure 52. How the AC, LC and PS work together

The above figure illustrates the relationship of their actions, given a certain load. The parameters on the right-hand side specify the behaviour of the load control.

When the cell is under little load, the AC will allocate real time bearers, and the PS is flexible with the packet load. As the load increases, then no more real time bearers are allocated; also the PS does not increase the load. If the load should continue to grow, or at the most stay the same (remember, that the subscribers are still moving, which is affecting the power levels), then the LC may take actions such as traffic reason handovers. Also the PS decreases the bit rate of the non-real time bearers in an effort to decrease load.

If this has little effect, eventually under extreme conditions of the cell being overloaded, the LC may take actions such as dropping the NRT bearers.

6 UMTS terrestrial transmission

Transmission has a very considerable role in RAN because the transmission capacity required in the interfaces Iub (Node B to RNC), Iur (RNC to RNC) and Iu (RNC to 3G-SGSN, and RNC to MGW or 3G-MSC) is remarkably greater than in the case of GSM. A common approach concerning transmission is **ATM** (Asynchronous Transfer Mode) as a basic media. This is mainly because of three reasons:

- In GSM networks, the "basic" unit concerning transmission is the timeslot. One timeslot is defined in G.703-specifications, and it is able to carry 64 kbit/s traffic. When smaller bit amounts are required, the timeslot is divided into traffic channels. One typical case is inside the BSS, where several 16 kbit/s traffic channels are combined into one 64 kbit/s timeslot. This approach is good in cases where the information flow transferred is 64 kbit/s or less. In UMTS, however, this is not the case due to the wideband services that are offered.
- Another issue is the nature of the traffic. In GSM, the traffic is normally symmetric, meaning that the basic bearer level service uses certain, fixed and constant amounts of bits in both directions. In some cases this is good, but for most of the services offered this is waste of the limited capacity.
- Because most of the services that the UMTS will offer are asymmetric and based on packet type data transfer, the G.703 PCM-environment is not the best possible. ATM as a system offers better opportunities to use the transmission capacity more effectively. For instance, the nature of the traffic (symmetric/asymmetric) can be taken into account, and the connections can be adjusted according to the needs present. Hence, there are no "traffic channels" (in conventional sense) available. Instead, the ATM offers a bit tube suitable to its size for data transfer purposes.

7 Review questions

Please take some time to answers these questions. You can use the material in this module as a reference.

1. In UMTS, there are two methods used for transport through the air interface. The first is UMTS-FDD. What is the second one?
   a. TDD, Time Doubled Division
   b. CDD, Code Division Duplex
   c. TDD, Time Division Duplex
   d. CDD, Code Divided Data

2. Which of the following sentences best describes the phenomenon called cell breathing?
   a. When more capacity is used, the cell spreads in size.
   b. When more capacity is used, the cell shrinks in size.
   c. The cell will adjust its size in line with the furthest users. For example, if the user is 5 km away, the cell is 5 km. If the user is 2 km away, the cell is 2 km.
   d. Cell breathing is the height of the cell: from 2 - 3 km towards the atmosphere.

3. There are two types of codes used in UMTS. These are the channelisation and scrambling codes. Why are the scrambling codes used?
   a. To separate downlink physical channels in a cell.
   b. To separate user data and signalling in the network.
   c. As security to check if the User Equipment (UE) is not stolen.
   d. To separate different cells in the downlink direction.

4. In UMTS, there are three layers of channels (logical, transport and physical). Which of the following is **not** a physical channel?
   a. BCCH
   b. CCPCH
   c. DPCH
   d. DPDCH

5. Which of the following statements about channelisation is true?
    a. The lower the bit rate, the more data can be spread.
    b. Before spreading, an error-protection code needs to be added to the baseband data to ensure a safe path through the air interface.
    c. The channelisation code is added as part of the spreading function.
    d. The channelisation code depends on the spreading factor used.
    e. All of the above.

6. What type of modulation is used in UMTS?
    a. GMSK
    b. QPSK
    c. 8PSK
    d. BPSK

7. For which of the following tasks is the RAKE receiver **not** responsible?
    a. Multipath Propagation Delay
    b. Listening to surrounding BTSs
    c. Channel coding
    d. Speech coding

8. Which of the following is a true statement about Admission Control?
    a. The UEs handle resource allocation.
    b. The RNC makes the decision of resource allocation, based upon interference.
    c. The RNC will not limit the number of the users on a cell.
    d. As more users are allocated a code, the load on a cell remains the same.

9. The RNC is responsible for the allocation of codes. Which of the following sentences (only one) is true?
    a. Each cell has a scrambling code that acts like a cell ID.
    b. Channelisation codes are dependent upon the subscribers' identity.
    c. Scrambling codes are generated randomly.
    d. Scrambling codes are used in channelisation.

10. When a mobile is in idle mode, which of the following power controls is used?

    a. Closed loop power control

    b. Outer loop power control

    c. Internal loop power control

    d. Open loop power control

11. Select the right handover type.

1. Soft	2. Softer	3. Hard
4. Inter-system	5. Not possible	

    a. Sector 1 to Sector 2 (same Node B) _____

    b. Node B x to Node B y _____

    c. RNC to RNC with Iur interface _____

    d. RNC to RNC with no Iur interface _____

    e. UMTS-FDD to UMTS-TDD _____

    f. WCDMA to GSM _____

    g. WCDMA to IS-95 _____

12. What is the difference between micro and macro diversity?

    a. There is no difference.

    b. Micro diversity is the combination of signals between the Node B and the UE, whereas macro diversity is the combination of signals from many Node Bs in the RNC.

    c. Macro diversity is the combination of signals between the Node B and the UE, whereas micro diversity is the combination of signals from many Node Bs in the RNC.

    d. Macro and micro diversity are UE-specific functions.

13. In WCDMA, what is meant by the active set?

    a. A group of UEs.

    b. A group of Active RNCs.

    c. A group of cells communicating with a UE.

    d. It is the same as a location area.

8 Appendix 1: Overview of UMTS-TDD solution

The DS-WCDMA-TDD is a variant investigated to be more suitable for indoor coverage arrangements

The frame structure used is the same as in DS-WCDMA-FDD, but the downlink - uplink division is made in time inside the frames.

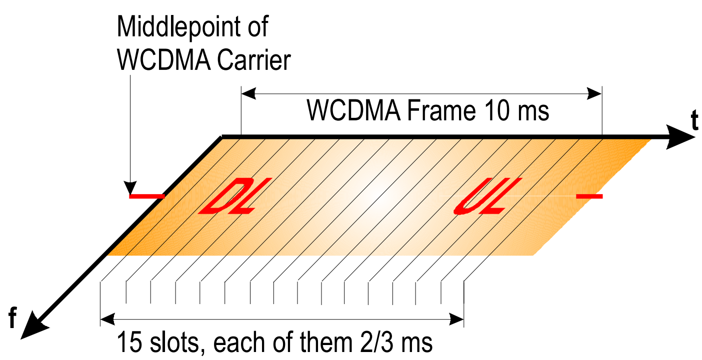


Figure 53. DS-WCDMA-TDD–Time Division Duplex (TDD)

In case of indoor coverage, the services requiring high bit rates and asymmetry will be used. Thus, the DS-WCDMA-TDD is more suitable for this purpose. The DS-WCDMA-FDD is naturally able to support those services, but it may waste capacity, and thus it may be rather ineffective as pertaining to the above-mentioned services. The DS-WCDMA-TDD will be more effective, because the asymmetric data transfer can be taken into account by defining the Frame Division Point between the downlink and uplink directions.

The assumption is that the terminals supporting WCDMA in general are able to support both FDD and TDD. In order to guarantee fluent coexistence and interworking between the modes, the frame structure used is similar in both modes, that is, the basic frame contains 15 timeslots; each of them being 2/3 ms in time. The following picture shows a sample of how a DS-WCDMA-TDD frame can be split between the downlink and uplink directions.

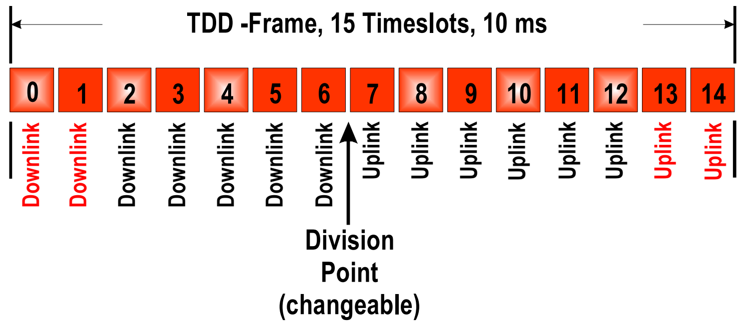


Figure 54. TDD-frame and division point

The first two timeslots are always reserved for obligatory downlink traffic. The same applies to the two last timeslots: they are reserved for uplink traffic. The Frame Division Point can be adjusted by the network, and its definition is based on the traffic model indicating the data traffic asymmetry. In addition, the frame may contain several division points.

In the DS-WCDMA-TDD variant, the timeslots are “real” timeslots, unlike in the FDD variant. For instance, a speech connection requires two timeslots to work: one in the uplink and the other in the downlink direction.

From the CDMA point of view of, the TDD system has 16 long codes allocated. These are used for placing, in theory, 15 subscribers into the same timeslot. Due to radio technical reasons, the practical subscriber amount using the same timeslot may be about 7 – 10 users.

There are three alternatives to add capacity in a connection:

- More timeslots are allocated for the connection.
- More codes are allocated for the connection.
- Both actions listed above simultaneously.

8.1 DS-WCDMA-TDD channelisation

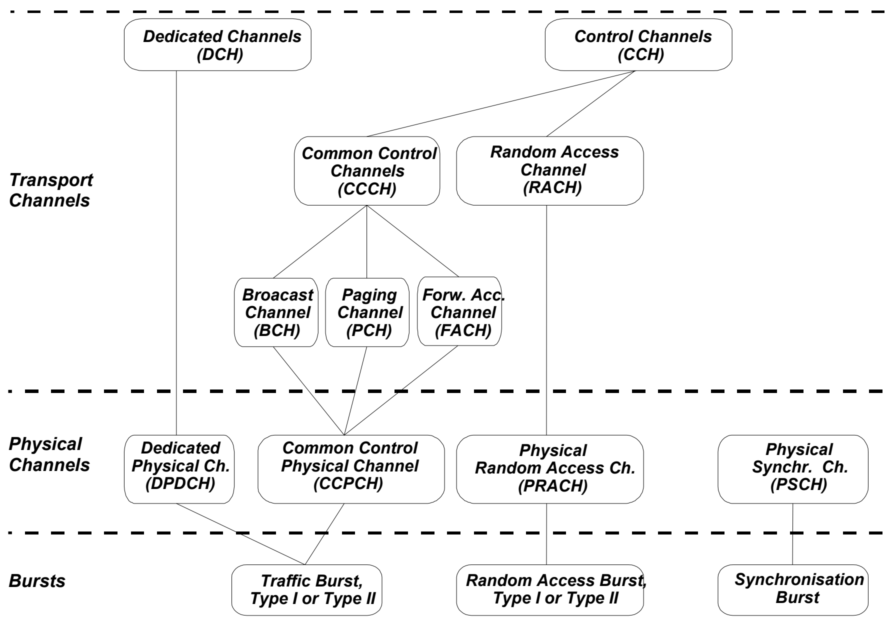


Figure 55. DS-WCDMA-TDD channelisation

The logical channels are the same as in the FDD variant, and they are used in a very similar way. Though, there are some minor exceptions.

In the DS-WCDMA-TDD variant, the traffic and signalling is carried with bursts. There are two types of bursts used: Burst Type 1 and Burst Type 2. Both of these provide the same final capacity for the end user, but they are used in different environments. Both of the bursts look very much like the GSM normal burst, that is, they contain two data parts and a training sequence (midamble) in the middle, as well as a guard period at the end of the burst.

- Burst Type 1 has longer midamble and shorter data parts. This type can handle time delay problems, but may suffer from interference.
- Burst Type 2 has shorter midamble and longer data parts. This type can stand interference well, but is very sensitive to time delays.

9 Appendix 2: Low chip rate TDD mode (TD-SCDMA)

One FDD-mode and one TDD-mode radio interface solution were specified with UMTS Release 99. In March 2001, UMTS Release 4 was frozen. Among other things, a third radio interface solution was specified. This radio solution is called **low chip rate TDD-mode**. Sometimes, it is also referred to as **TD-SCDMA**. (Time Division – Synchronous Code Division Multiple Access).

Main characteristics of the low chip rate TDD mode:

- carrier bandwidth: 1.6 MHz
- chip rate: 1.28 Mchip/s
- spreading factors: 1, 2, 4, 8, and 16
- modulation uplink: QPSK and 8PSK
  modulation downlink: OQPSK and 8PSK
- framing structure: 10 ms frames, divided into two 5 ms subframes
  Each subframe has 7 time slots. Next to the 7 timeslots, there is a Downlink Pilot Time Slot (DwPTS), an Uplink Pilot Time Slot (UpPTS) and a Guard Period (GP). In contrast to the high chip rate TDD mode, there is only one switching point in a 5 ms subframe.
- number of burst types: 1
  The burst has a 144 chip long midample and a 16 chip long guard period. There are two data carrying fields, each 352 chips long.

What are the capabilities of the low chip rate TDD mode? Within macro cells, data rates of up to 384 kbps were specified. Maximum speed of 120 km/h are allowed. In micro cells, data rate of 384 kbps are possible, while in pico cells, 2 Mbps can be archived. 2 Mbps with a chip rate of 1.28 Mchip/s are only possible with the modulation scheme 8PSK. The maximum cell radius can vary. Depending on the configuration, it can be (theoretically) 11.25 km, 22.5 km, 30 km, and 42.25 km.

10 Appendix 3: UMTS radio network planning

In this course module, we have been dealing with quite general information that is useful to everybody within the operator's technical organisation. In the remaining parts of this module, we will have a closer look at some important issues related to radio network planning.

10.1 Introduction to UMTS radio network planning

Major steps in all UMTS network planning will be in most part identical to current 2nd generation network planning. These steps are summarised as follows:

1. **Basic network dimensioning**

   This will be in most parts similar to previous cellular networks, but the difference will be that the main traffic type for the next five years is estimated to be medium to high speed data, not low speed (8-16 kbit/s) speech. Hence, new packet switched services conveyed by the GPRS/packet core network will have an effect on dimensioning.

2. **Site selection**

   Because most new WCDMA operators are also 2nd generation PDC or GSM operators, the site selection will be done in co-operation with site acquisition and existing sites.

3. **Detailed network planning**

   More detailed WCDMA network planning will be done after preliminary site selection, including issues like coverage/capacity planning, propagation model tuning, parameter planning, and soft/softer handover overhead analysis and optimisation.

   Preliminary capacity simulations estimate around 250 - 300 Erlangs per cell using three sectors. This could be enhanced further by, for instance, using beam forming intelligent antennas or several scrambling codes (frequencies) within the same cell.

   Because actual capacity of a single cell is dependent from much larger variety of different, and changeable, factors and parameters than with current 2nd-generation systems, we call this *soft capacity*.

4. **Network testing and tuning**

   Interference level testing (intra-cell, inter-cell, etc.) and related power level tuning will play a major part in the process of trying to get maximum capacity from any WCDMA type of network.

10.2 Issues of UMTS planning compared with GSM planning

The frequency planning is a very important planning area in GSM networks. The frequency band available for GSM purposes is relatively limited and it must be used as efficiently as possible.

As there is a limited amount of carriers available, the operator must repeat those frequently. The aim of frequency planning is to create and maintain suitable methods of how this frequency repeating can be done so that the same frequencies are not repeated too often and too close to each other. In other words, the frequency planning aims to maintain radio connection quality at an adequate level with limited resources.

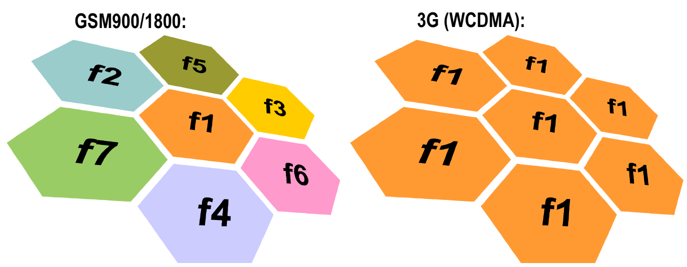


Figure 56. Frequency re-use pattern (GSM example, Re-use factor = 7)

As a basic assumption, the WCDMA frequency re-use factor is 1, that is, every cell uses the same frequency. This has a remarkable effect on the radio network planning and the principles are completely different than in case of GSM. In GSM systems, interference is a bad obstacle, but in WCDMA systems a certain level of interference is actually required to have an optimally functioning UTRAN.

However, when working with GSM and UMTS networks, the use of GSM for coverage provision, handovers and the direction of traffic to GSM vs. UMTS must be considered.

UMTS networks work in a multi-service environment, where the bit rates vary from around 8 kbit/s to (theoretically) 2 Mbit/s depending on the subscribers' activities. Furthermore, UMTS provides bearers based upon quality classes where traffic is asymmetric in the uplink and downlink directions.

10.2.1 Basic difference between GSM and WCDMA

There are many obvious differences between the GSM and UMTS air interface. For the reasons of simplicity, we can say that there are two distinct categories of differences in UMTS: the **multi-services** to a subscriber and the **air interface** itself.

The UMTS multi-service environment can support bit rates from 12.2 kbit/s to 2 Mbit/s, at variable rate (unlike the GSM fixed rate). In Nokia's RAN 1 release the maximum bit rate is 384 kbit/s. The services in **RAN 1** are divided to Real Time (RT) and Non-Real Time (NRT), each of these having a different quality class and different error ratios, BLER (Bit Loss Error Ratio), and BER (Bit Error Ratio). The delay sensitivity is from 100 ms to seconds. There is asymmetric traffic in the uplink and downlink traffic. As a result, more transmission capacity is needed.

In WCDMA the size of the cell actually changes. As more capacity (that is, more voice calls or higher data rates) is applied to a cell, the actual diameter will shrink. This phenomenon is thus referred to as *cell breathing*. Features are used in the Nokia solution to reduce its effects.

In WCDMA, we also have several different physical channels, while as in GSM, we only have one (the timeslot).

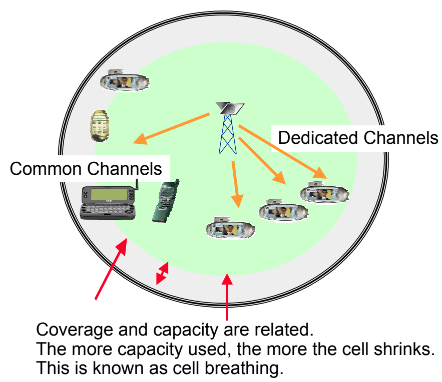


Figure 57. A cell shrinks as capacity decreases

In WCDMA, **cell capacity** is based upon load and neighbour cell **interference**. Also neighbouring cells using the same frequency, and therefore the concept of gain through soft handovers are introduced. The usage of soft handovers increases the load in a cell, but the overall effect is a gain since the interference is reduced.

Also, in CDMA, fast power control commands are used to ensure high capacity. Very fast and accurate TX power control is required.

High bit rates

Spectral efficiency

Different quality requirements

Efficient packet data

Downlink capacity

	WCDMA	GSM
Carrier spacing	5 MHz	200 kHz
Frequency re-use 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 58. Differences between WCDMA and GSM

10.2.2 UMTS radio planning air interface concepts

Mobile networks today use intelligent multi-layers to handle subscribers in a better way. These layers can be defined to be:

Mega	100 – 250 km, high speed and low data rates
Macro	1 – 100 km, high speed and low data rates
Micro	100 – 1000 m, medium speed and data rates
Pico	< 100m, slow speed and high data rates

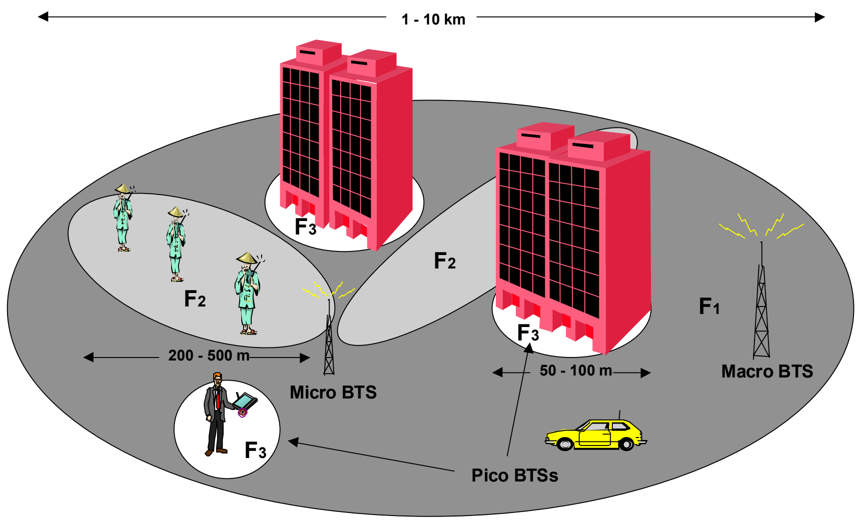


Figure 59. Different WCDMA cells and base stations

Macro cell

The macro cell is used to provide wide area coverage and is also used for high-speed mobiles. Data transfer rates will be limited to less than 384 kbit/s. UMTS operational mode will be FDD.

Micro cell

The micro cells are used at street level to provide extra capacity where needed and also to provide higher data rates for slow movers (~ 1-2 Mb/s). Higher speed movers will be limited to 144 - 384 kbit/s rates. UMTS operational mode will be FDD.

Pico cell

The pico cell is to be deployed mainly indoors, in areas where there is a demand for high data rate services such as wireless LANs or multimedia conferencing. Data rates up to 2 Mb/s will be supported, but with very limited radius. WCDMA operational mode can be TDD or FDD.

10.2.3 Additional notes on UMTS spectrum allocation

Within UMTS spectrum there is flexible radio frequency (RF) channel spacing that allows optimisation according to the deployment scenario within an operator’s designated band. RF carrier spacing of 4.2 MHz to 5 MHz (200 kHz raster) can be used depending on the site co-ordination and planned load in each layer. However, 5 MHz carrier spacing is needed between two operators.

Any potential interference from other systems falling into the 3 dB WCDMA carrier bandwidth (4.1 MHz) will lead to cell size reduction (or capacity loss)

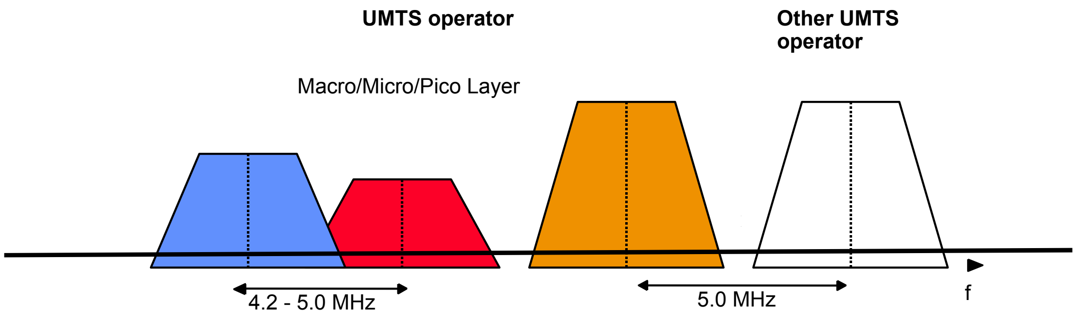


Figure 60. Frequency allocation

10.2.4 UMTS power, coverage and capacity relationship

Unlike in GSM, in UMTS the capacity and coverage are related to each other. WCDMA planning focuses much on **power** and its relationship to the **interference margin**. Power control on the uplink is the key to the WCDMA capacity, downlink is less critical. The receiver's performance depends on the bit rate, geographical environment, soft handover capability and the fast power control.

The power of separate users is controlled in such a way that the *received power* from all users is roughly equal and the total power in the system is minimal. Users can occupy the same carrier, and the interference averaging takes place.

If the power control is not performed properly, there will be severe problems; for example, the so-called near-far-problem (see the following figure). Normally the uplink power control range is 70 - 90 dB, and the receiver can handle power differences not exceeding the spreading ratio (normally 6-20 dB).

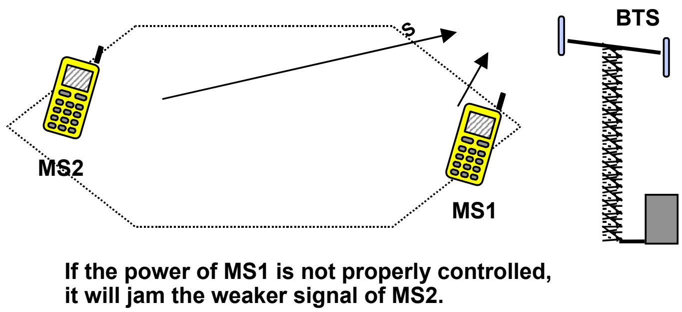


Figure 61. Power control, the near-far example

In UMTS, the ratio of noise (Eb/No) is a new important parameter that is used to determine the *configuration* of a cell. It varies in different service bit rates and environment. This value means the minimum needed **bit** to **noise** density ratio in signal detection.

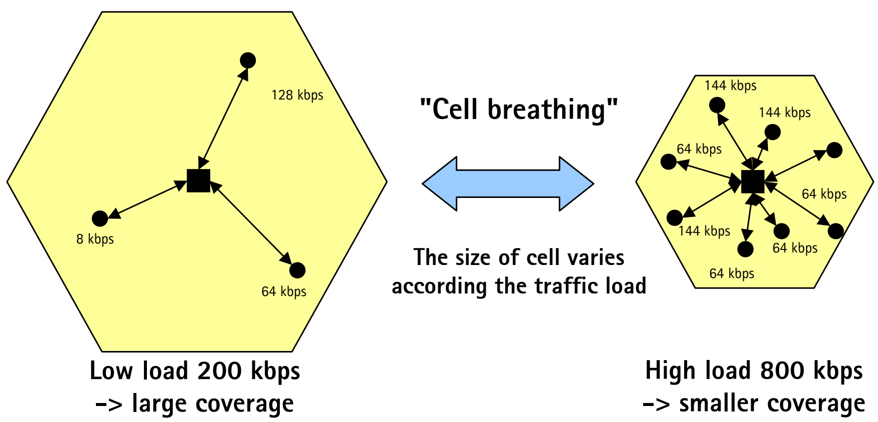


Figure 62. Effects of cell breathing

Another important parameter is the processing gain W/R, where W is the WCDMA bandwidth (3.84 MHz) and the Rb is the service bit rate (kbit/s). The higher bit rate means **less** processing gain and thus higher transmit power or **smaller** coverage. As a result, the cell range is limited by the highest bit rate that requires full coverage.

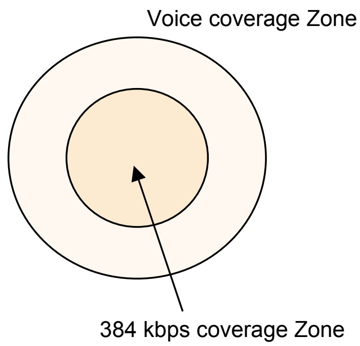


Figure 63. Cell breathing

In GSM, the calculation on the number of traffic channels was directly related to the number of timeslots available for traffic in a TRX. In UMTS, as the service requirements change per user, we specify cell capability based upon **load** that directly corresponds to the supported traffic per cell. In simple terms, more traffic means more interference and, as a result, decreased cell range. Therefore, based upon mathematical models we could estimate that the maximum recommended load would be close to 70 %, however the desired load should typically be 30 - 50 %. This is illustrated in the below figure. Remember that load is not related to the number of subscribers, but to how the resources are being utilised.

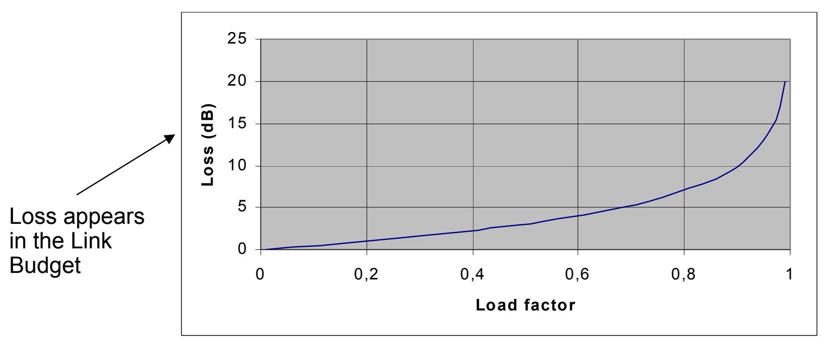


Figure 64. Estimation of the load

As more real time (RT) bearers are required (e.g. voice and video services) because of the quality of service (QoS) requirements, the total capacity is lower. This is compared to the non-real time (NRT) traffic (e.g. packet data), as this has a greater efficiency and also a greater total capacity.

10.2.5 Planning capacity and coverage

When thinking about the coverage, one of the questions you probably have on your mind is how data is available. Remember that in a real network, the area of the cell is going to effectively modify the size of the cell, as more power is needed. If, like in the example in Chapter 4.5.2, we take the case that the user requires a **speech channel**, and we decide to use 12.2 kbps. This means that we need a channel bit rate of around 20 - 24 kbps, after convolutional coding. This is the actual baseband data rate, after channel coding.

The bearer that we require must be in the range of 42 - 51 (see the following figure). The reason is of all the extra security and overhead that is applied to the bearer. The channel bit rate and symbol rate refer to the actual modulated signal and to how far the information has been spread.

Spreading factor	Channel symbol rate (ksps)	Channel bit rate (kbps)	DPDCH channel bit rate range (kbps)	Maximum user data rate with ½-rate coding (approx.)
512	7.5	15	3–6	1–3 kbps
256	15	30	12–24	6–12 kbps
128	30	60	42–51	20–24 kbps
64	60	120	90	45 kbps
32	120	240	210	105 kbps
16	240	480	432	215 kbps
8	480	960	912	456 kbps
4	960	1920	1872	936 kbps
4, with 3 parallel codes	2880	5760	5616	2.3 Mbps

Half rate speech
Full rate speech
128 kbps
384 kbps
2 Mbps

- The number of orthogonal channelization codes = Spreading factor
- The maximum throughput with 1 scrambling code ~2.5 Mbps or ~100 full rate speech users

Figure 65. Physical layer bit rates

The spreading factor (SF) being used is 128. This is only a fraction of the code tree. The subscribers are not limited by the number of codes – there are far more codes available. The limiting factor is in the air interface.

The maximum throughput with a single scrambling code on a cell is approximately 2.5 Mbps, which is equivalent to around 100 full rate users. This is a theoretical figure, as when the power levels are taken into consideration, and then more capacity is used.

For very high user data rates (above 512 kbps), multiple channels are need. This means that the terminal may support three separate channels. Remember that the radio access bearers (RABs) are located in the radio resource connection, so what we are doing is adding an extra bearer for the subscriber. This situation will eat the maximum out of the cell. Therefore, this is likely only possible in indoor situations or where the subscriber is close to a site.

This is shown in the below (estimated) figure, where to obtain the 2 Mb user data rates, the area is down to probably less than 1 km in the uplink. In the downlink the problem is less severe.

If we think of a subscriber's behaviour, the majority of traffic usage is in the downlink anyway. If we think of the Internet traffic, very few bits are sent from the terminal to the network.

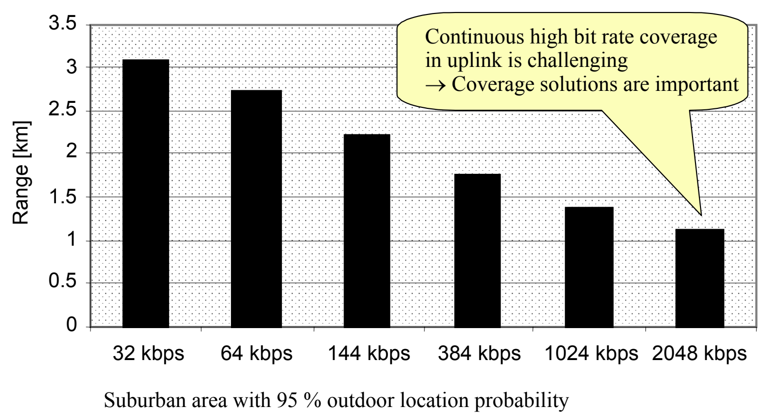


Figure 66. Simulated uplink coverage of different bit rates

Downlink coverage will be limited by:

- uplink dimensioning
- downlink power amplifier rating
- adjacent cell loading

If a cell is planned to have high uplink bit rates also from the cell edge it will automatically have high downlink capacity since the cell will be small. Cells can also have different coverage areas for different bit rates. This is not an exact concept but the figure below shows the function. The UL main limitation is User Equipment UL power capability.

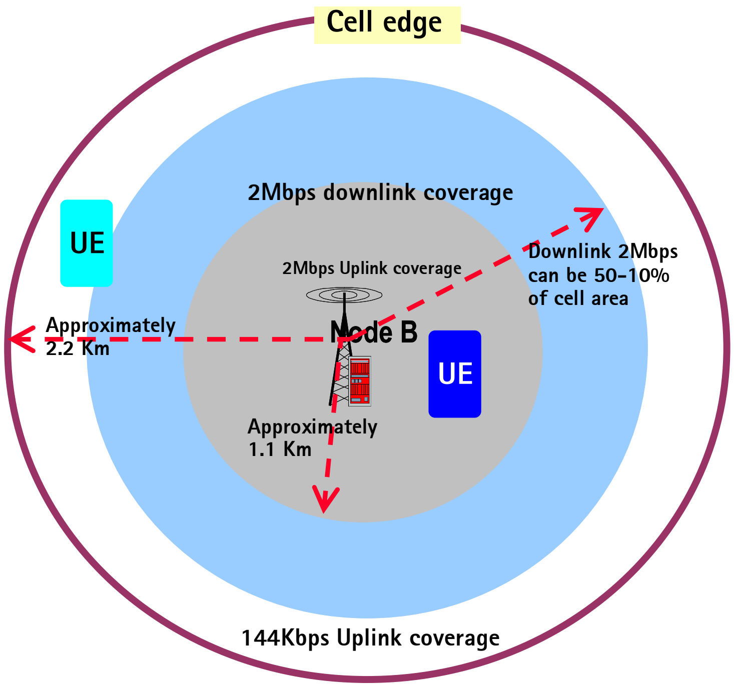


Figure 67 Macrocell example

In this simplified example a large number of calculations and assumptions have been purposely left for further studies. The basic features of WCDMA are however clearly recognizable in this cell study. The cell described has its coverage purposely limited to a certain size. Instead emphasis has been on high bit rates. By lowering the bit rates requirements the cell could gain more coverage as has been described earlier. To enable high capacity in a WCDMA cell many actions can be performed both in uplink and downlink. Suggested actions are beyond the scope of this example. In the cell described here the following assumptions have been made:

- There are six sectors under one Node B
- All users are evenly distributed over the cell area
- 3dB interference margin is assumed; but other values could be considered
- Max UpLink output power 21dBm(125mW)
- Several types of gains assumed:
    - Variable processing gains for various bitrates
    - Multipath gains
    - User speed less than 3Km/h

Based on these assumptions and reservations the figure below gives an example of the benefits of WCDMA cells and their performance.

The capacity in a WCDMA cell can be presented as a sum of the performance, thus figures will be alternative to each other. The cell in this example is capable of for example 98 FR speech user or 96 data users with 144 Kbps each. It is worth keeping in mind the load factor examples given earlier. The numbers below could be varied in an unlimited number of combinations as long as the total load is kept under control.

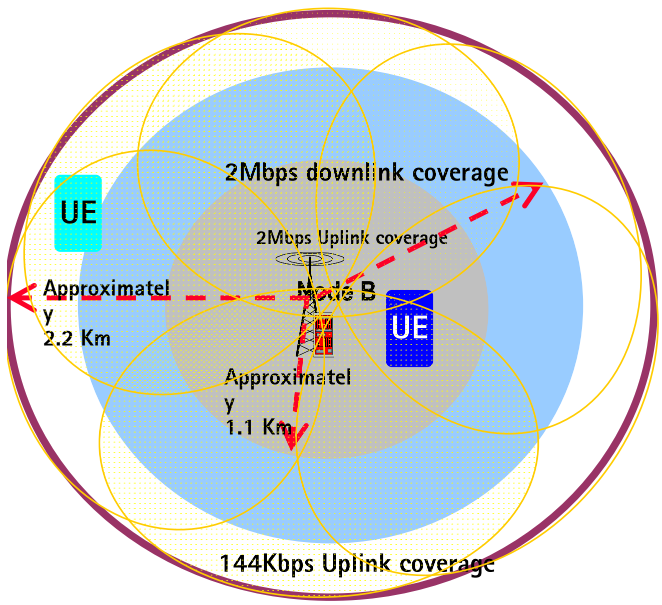


Figure 68 Cell capacity example

Capacity examples based on the cell described in the figure above:

- 98 Full Rate speech users/sector supported
- 588 Full Rate speech user on the cell area
- 96 144 Kbps users supported on the full cell area
- DL 6 2Mbps users supported on 50-100 % of cell area
- UL 6 2Mbps supported on 50 % of cell area.

10.2.6 Effect of processing gain and planning load

Unlike in GSM, gain in signal strength can be achieved by decreasing the power. This is also why soft handovers are used to increase the overall gain of the system.

The following figure illustrates the effectiveness on gain in relationship to the power being used.

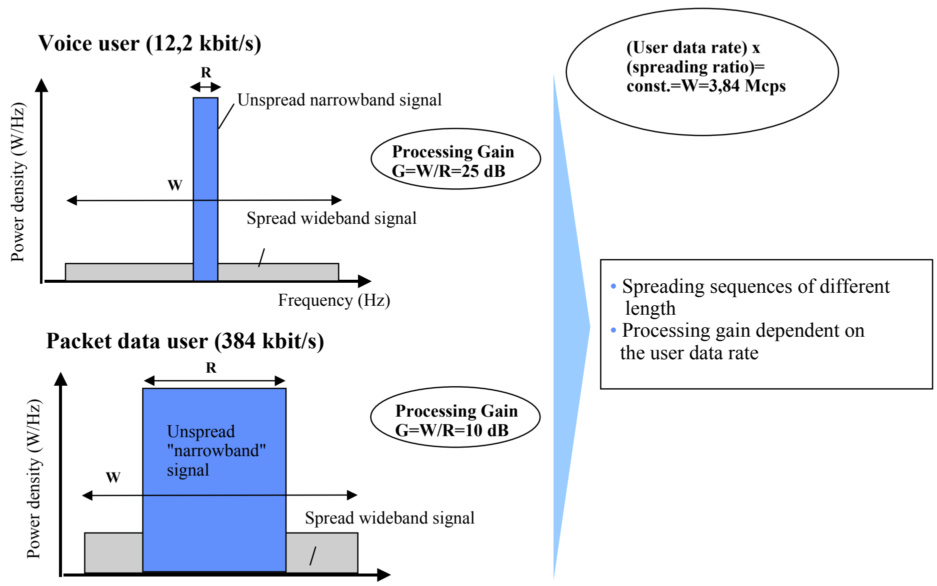


Figure 69. Processing gain

The behaviour of a cell depends on the services the subscriber is using, the location, and also the environment. Through using soft capacity it can be seen that significant gains are possible for the capacity on a carrier. As a proportion, the largest gains are possible when using non-real time (NRT) data.

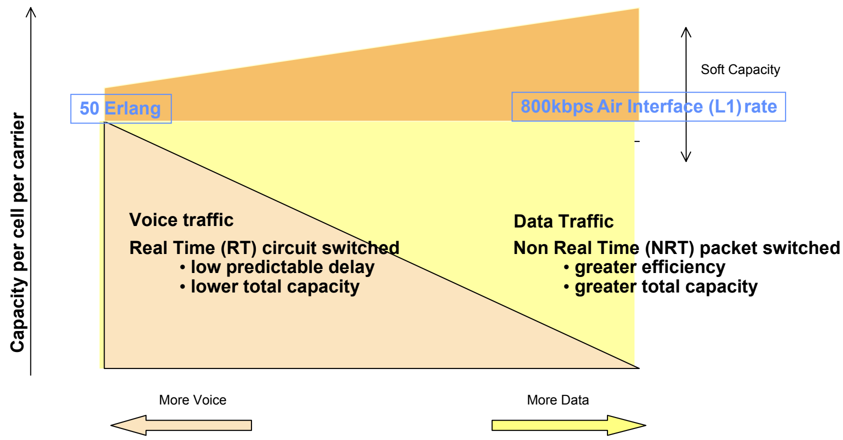


Figure 70. Distribution of capacity on a cell, based upon usage

10.3 Cellular network planning (Iub interface)

In GSM, the system is based on end-to-end circuit switched connections and thus one channel is always one channel, no matter about the used bit rate. Within the GSM BSS the channel is 16 kb/s and, starting from the A interface the bit rate is 64 kb/s. Another point is that there are no (or at least there should not be) any concentrating equipment within the BSS. That is, the equipment should have numerically equal channel amount incoming and outgoing because the air interface in GSM concentrates traffic already.

However in UMTS, the involvement of packet switching makes things more difficult from the transmission planning point of view. The capacity of the air interface is not fixed and is heavily dependent on the nature of traffic. Because of the varying nature of the air interface, a “fixed-like-rate” transmission is not suitable for the WCDMA purposes as such.

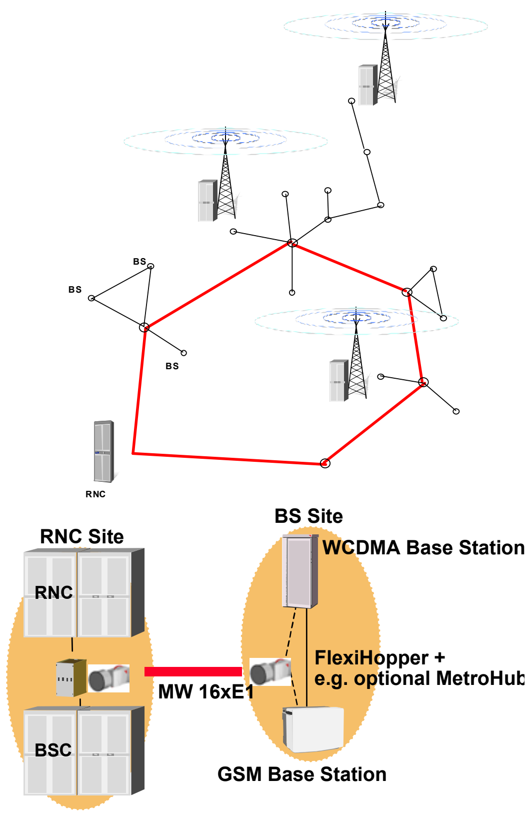


Figure 71. Iub configuration

In WCDMA, the selected transmission is based on ATM (Asynchronous Transfer Mode). ATM is very useful if it can be used with heavily loaded connections, like loops containing several BTSs and RNC as loop master. In this kind of case, the physical layer (in optimal case) could be SDH (Synchronic Digital Hierarchy) based transmission system. The Nokia Iub configuration solution supports different transmission network topologies such as loops, point-to-point, stars and multidrop.

For existing operators, transmission sharing between 2G and 3G is an important issue. One solution could be to use separate PDH and SDH equipment (E1 or STM-1) for UMTS.

Alternatively, fractional E1's could be use to add full and/or partial E1's filled with WCDMA traffic to the existing GSM traffic.

Also, co-sharing could be achieved by using circuit emulation to add the GSM traffic to the WCDMA (ATM) traffic.

As both ATM and SDH are their own systems as such, they require some own control information for their functions. From the transmission planning point of view, a point of interest is the extra bit amount included into the bit stream and its affect on transmission network dimensioning. It should be noted that there should in any case be enough transmission to equal to the WCDMA air interface capacity.

One ATM cell consists of two parts, 48-byte long payload carrying the piece of information and the 5-byte-long header containing cell address information. Thus,

- One ATM cell carries 384 information bits.
- One ATM cell requires 40 bits of address information.
- Excessive bits (overhead), relatively, are thus 40 / (384 + 40) = 0.094 ≈ 9.5 % of the whole bit stream the ATM virtual channel carries.

In the Nokia solution the Iub traffic concentration is done by the integrated ATM cross-connect (AXC) into each BTS. A stand-alone version of AXC is also available either on the BTS or on RNC side and physically uses a 19" subrack. The capacity of this cross-connect is up to 64 K connections and 1.2 Gbit/s. The AXC is composed by an ATM switch unit (AXU) and up to five interface units (IFUs).

Figure 72. Nokia AXC solution

10.4 RNC capacity planning

The WCDMA RNC capacity is a compromise of several issues:

The average bit throughput

This can be estimated, and if the RNC does not concentrate traffic, it should be able to forward all of the bit streams coming in from the Iub side.

Circuit switched / Packet switched ratio

The RNC has two kinds of connections to the core network. In order to define those, the ratio between circuit and packet switched traffic should be known.

Radio network structure

The RNCs in the RAN have direct connections to each other. Depending on the radio network and especially the inter-RNC soft handover amount occurring, the Iur interface dimensioning may have a remarkable effect on RAN capacity. This is especially important when the cells are covering small areas; that is, the radio network is constructed in a capacity driven manner.

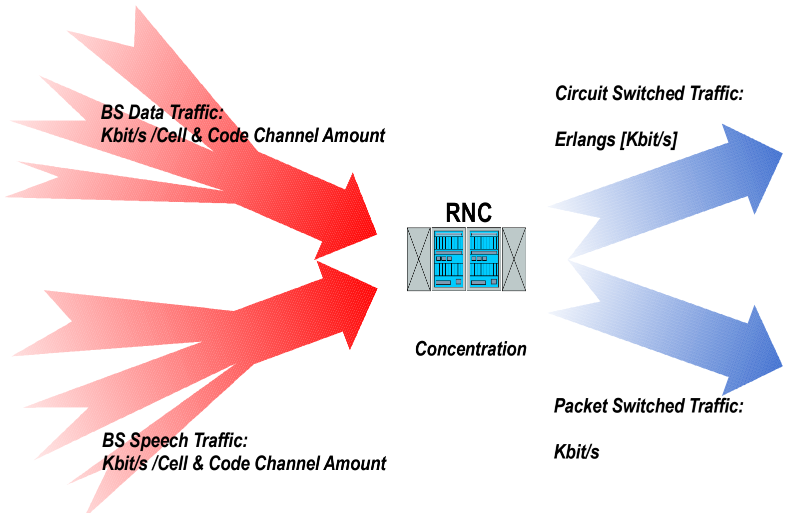


Figure 73. WCDMA RNC dimensioning