ΕΠΛ 427:
ΚΙΝΗΤΑ ΔΙΚΤΥΑ ΥΠΟΛΟΓΙΣΤΩΝ
(MOBILE NETWORKS)

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UMTS Network and Radio Resource Management

Δίκτυο UMTS και Αλγόριθμοι Διαχείρισης Ασύρματων Πόρων

Lecture Overview

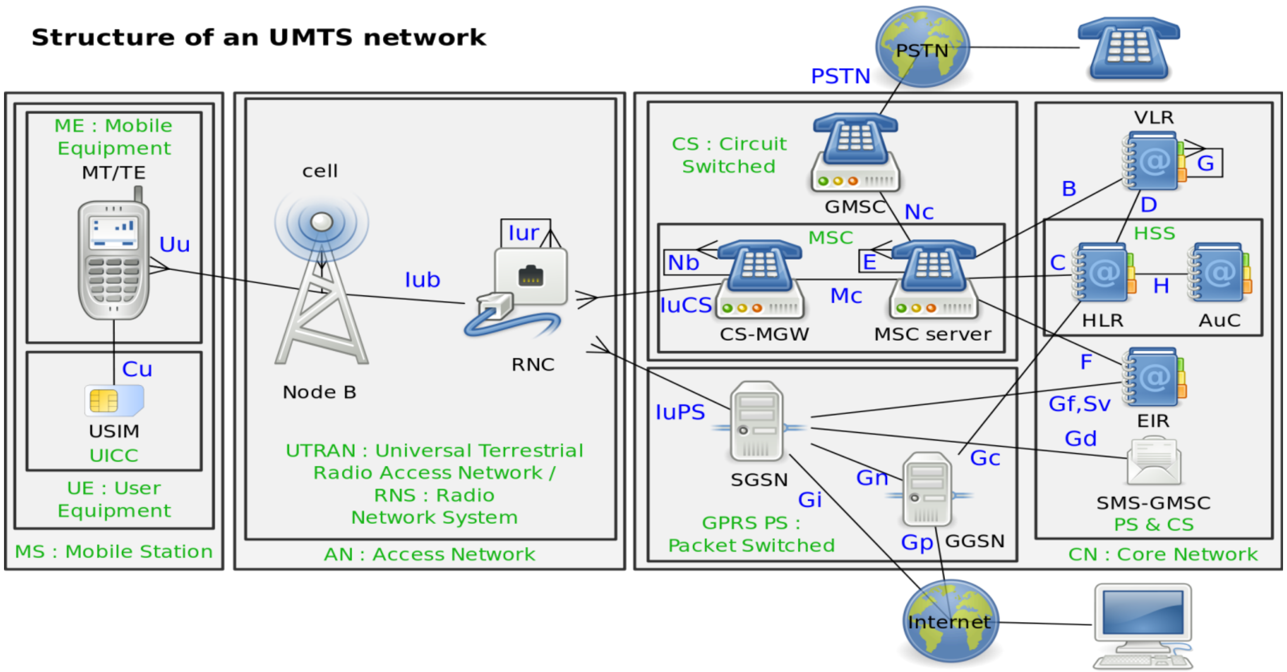
- **UMTS Network**
  - Introduction
  - Architecture
  - W-CDMA (Wideband-Code Division Multiple Access)
- **Radio Resource Management (RRM)**
  - Power Control
  - Handover Control
  - Admission Control
  - Load Control
  - Packet Scheduling

Universal Mobile Telecommunications System (UMTS) Network

- The **Universal Mobile Telecommunication System (UMTS)** is a **3rd Generation (3G)** wireless system that **utilizes a higher bandwidth** (i.e., 5 MHz Bandwidth) **than previous generation networks** to deliver **packet data** and **voice services** to mobile users and also **provide access to the web, with high data rates**.
- **Frequency bands indented for use on a worldwide basis** for UMTS are **around to 2 GHz**
  - Uplink: 1885-2025 MHz , Downlink: 2110-2200 MHz
  - In the US, 1710–1755 MHz and 2110–2155 MHz will be used instead, as the 1900 MHz band was already used.

Universal Mobile Telecommunications System (UMTS) Network

- **UMTS air interface** is **based on W-CDMA (Wideband-Code Division Multiple Access; 5MHz carrier bandwidth used)**, with the following **Bit rates achieved (for initial Release 99 specs):**
  - 144 Kbits/s in **high mobility** (vehicular) traffic
  - 384 Kbits/s for **pedestrian** traffic
  - 2048 Kbits/s for **indoor** and **low range outdoor**



Universal Mobile Telecommunications System (UMTS) Network

- **Greater Speeds Achieved with Latest Releases**
  - HSPA (WCDMA based)
  - HSPA+ (WCDMA based)
  - LTE (**OFDM based**)
  - LTE Advanced (**OFDM based)**

- **With LTE** and **LTE Advanced, OFDM is adopted in the air interface,** instead of W-CDMA

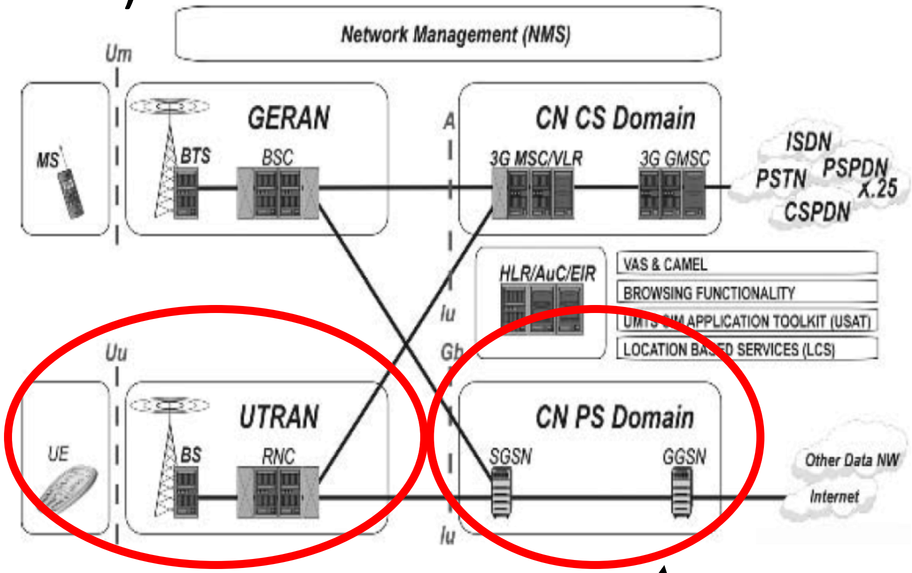
Radio interface	Peak downlink rate
W-CDMA	Up to 384kbps
HSPA	Up to 14.4Mbps
HSPA+	Up to 42Mbps
LTE	Up to 45Mbps (5MHz) Up to 326Mbps (20MHz)
LTE-Advanced	Up to 1Gbps downlink (using up to 50MHz)

Universal Mobile Telecommunications System (UMTS) Network

- **In contrast with the previous Generation Mobile Networks (e.g., GSM, GRPS, etc.), UMTS supports four different QoS classes of services** with **different priority** based on **QoS parameters** (e.g., **Guaranteed bit rate, Maximum Delay, Maximum BER,** etc.)
  - **Conversational:** Real Time services like Voice Call, Video Call, Video Gaming, etc.
  - **Streaming**: Real Time services like Video and Audio streaming, Mobile TV, etc.
  - **Interactive:** Non Real Time services like Web browsing, Database Access, etc.
  - **Background**: Non Real Time services like Emails, MMS, Downloading, etc.

Universal Mobile Telecommunications System (UMTS) Network

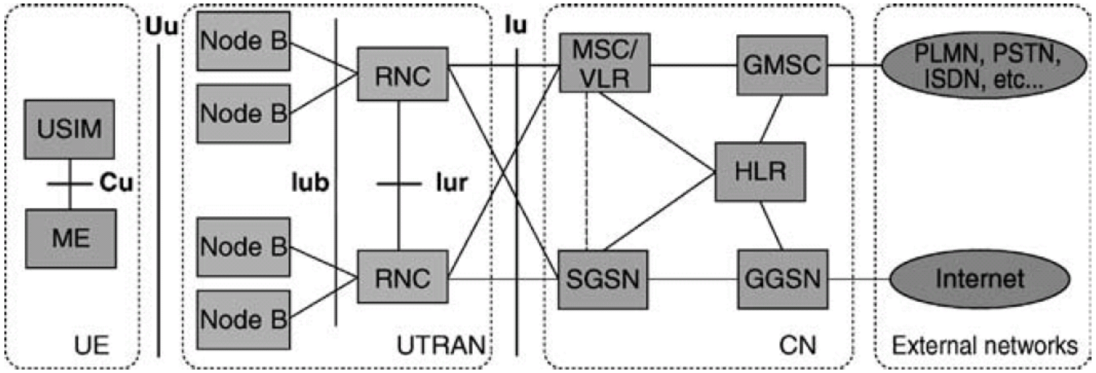
- UMTS **evolved from Global Systems for Mobile communications** (**GSM**) and it has an **Internet Protocol (IP) Core Network** based on General Packet Radio Service (**GPRS**).
- **3G Networks radio access equipment** as such, are **not compatible** with **GSM equipment.**
- **A new part that will maintain the 3G connections (i.e., the W-CDMA connections) in the radio interface is required (UMTS Terrestrial Radio Access Network (UTRAN))**



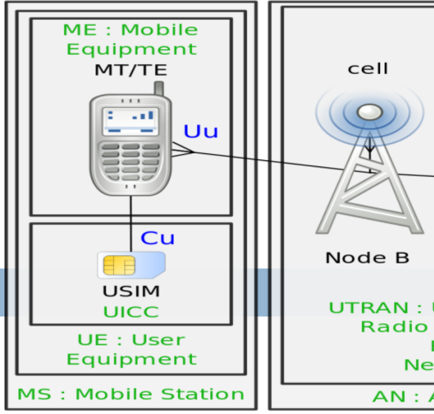
Internet Protocol (IP) Core Network based on GPRS

UMTS Network Architecture

- **The main components of a UMTS system are:**
  - The **Core Network (CN)**, which is responsible for **switching and routing calls** to the users, as well as **data connections** to other **external networks (all calls go through the CN).**
  - The **UMTS Terrestrial Radio Access Network (UTRAN)** that **handles all radio-related functionality (e.g., Radio Resource Management)**
  - The **User Equipment (UE)** that is the **interface** between the **user** and the **Network (through the Node-B)**.



UMTS Network Architecture
User Equipment (UE)



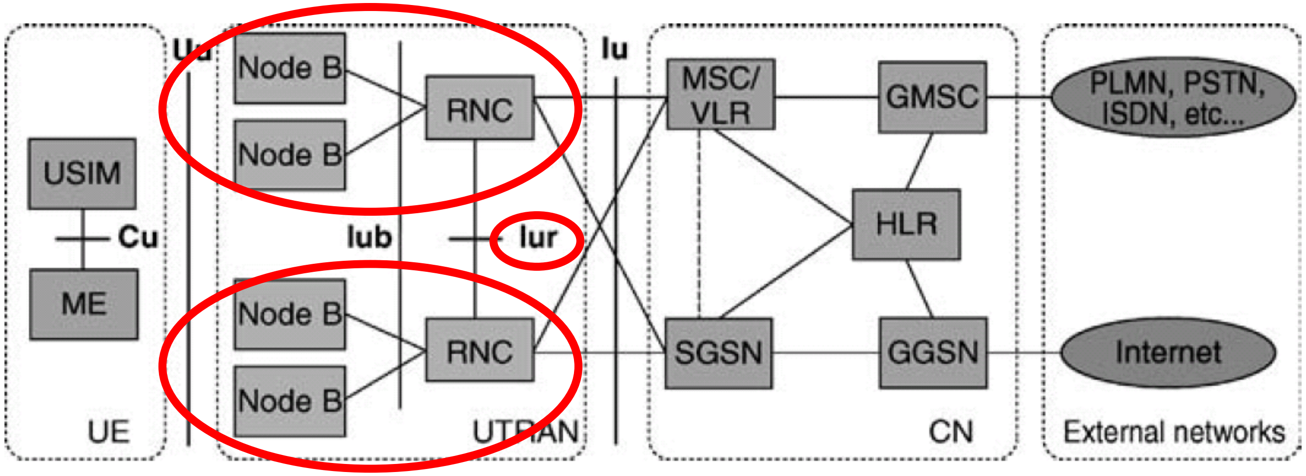
- The **User Equipment (UE)** consists of two parts:
  - **The Mobile Equipment (ME)** is the **radio terminal** used for **radio communication** over the **Uu interface (this is the interface implementing the WCDMA physical channels between the UE and the Node-B)**.

  - The **UMTS Subscriber Identity Module (USIM)** is a **smartcard** that **holds the subscriber identity (i.e., the IMSI)**, **performs authentication algorithms**, and **stores authentication and encryption keys** and **some subscription information** that is **needed at the terminal.**

UMTS Network Architecture

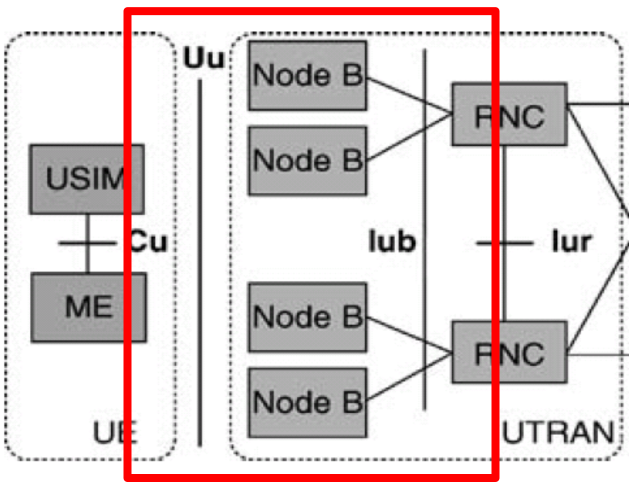
UMTS Terrestrial Radio Access Network (UTRAN)

- The **UTRAN** is **divided** into **Radio Network Subsystems (RNSs)**.
- One **RNS** consists of a **set of radio elements** called **Base Stations** (or officially **Node-Bs**) and their corresponding **controlling element** that is called **Radio Network Controller (RNC)**
- The **RNSs** are communicating with each other through **Iur interface**, forming **connection between two RNCs**. This **Iur** open interface carries both **signaling** and **traffic information (for example during a Soft Handover)**.



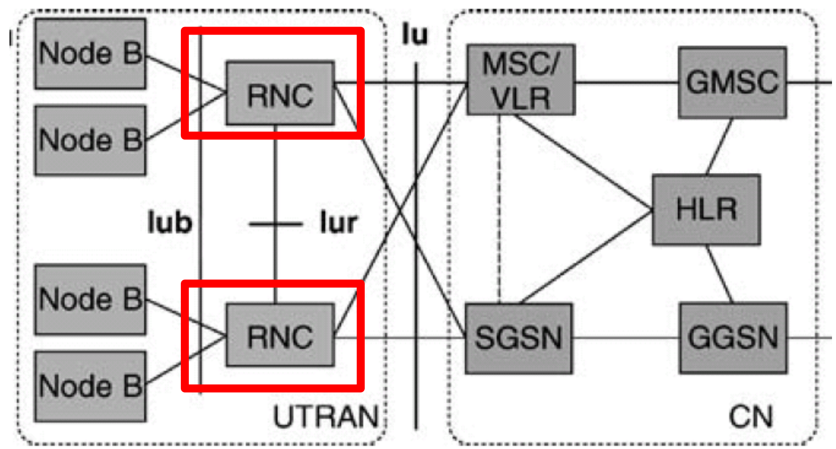
UMTS Network Architecture
UTRAN – Base Station (or Node-B)

- The **main task of the Node-B** is to **establish the physical implementation of the Uu interface** (**communication with UE**) and the **implementation of Iub interface** (**communication with RNC**).
  - **Realization** of the **Uu interface means** that the **Node-B implements WCDMA radio access Physical Channels** based on **some parameters determined by the RNC** (e.g., **QoS parameters required**, **Channel data rate**, **Spreading Code,** etc.)
  - In other words the **WCDMA Physical Channels form the physical existence of Uu interface between** the **UE** and the **UTRAN**.
  - The **WCDMA physical channels exist** in the **Uu interface**, and thus the **RNC is not necessarily aware of their structure at all.**



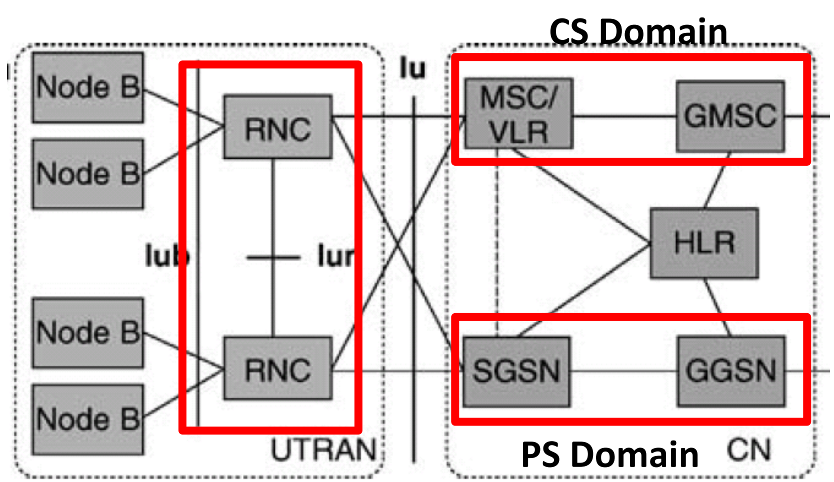
UMTS Network Architecture
UTRAN – Radio Network Controller (RNC)

- The **Radio Network Controller (or RNC)** is a **governing element** in the **UTRAN** and **responsible for controlling the radio resources** of the **Node-Bs** that are **connected to it**.
- The **major functionality of the RNC** is the **Radio Resource Management (RRM)**.
  - The **RRM** is a **collection of algorithms** used to **guarantee** the **QoS of the radio connections** by **efficient sharing** and **managing of radio resources**.



UMTS Network Architecture
UTRAN – Radio Network Controller (RNC)

- **The RNC, through the Iu Interface, connect to**:
  - **The** **MSC** (Mobile Switching Centre), in the **Circuit Switched (CS) Core Network**
  - **The** **SGSN** (Serving GPRS Support Node), in the **Packet Switched (PS) Core Network**.



UMTS Network Architecture
UTRAN – Radio Network Controller (RNC)

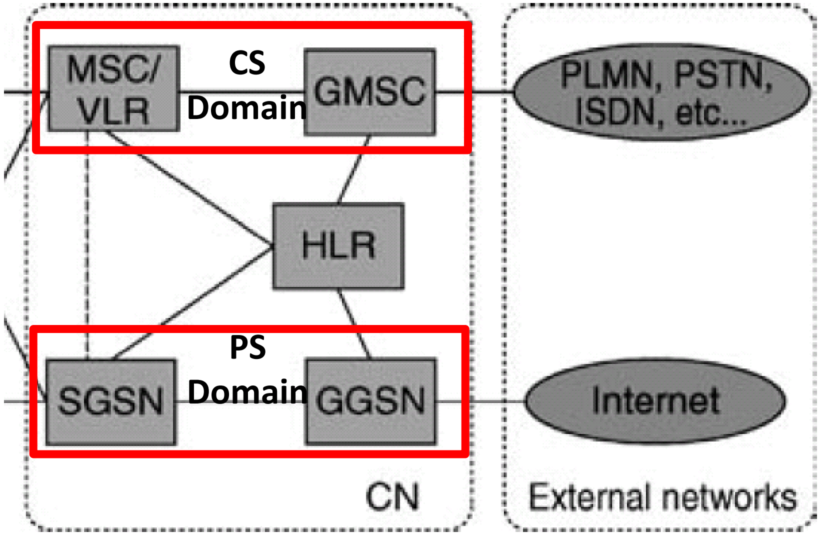
Question: Why both **Iub** and **Iu intefaces** need to exist in the system?

Answer:

- These **two interfaces** (**Iub & Iu**) **exist in the system** because **Iu** is **more stable in nature** than the **Iub.**
- This is **due to the fact that RNC must reconfigure the Iub inteface every time the UE moves from one Cell to another**, while the **Iu inteface remains stable**. The Iu interface will need to be reconfigured, only when the UE moves into a Cell that belongs to another RNC.

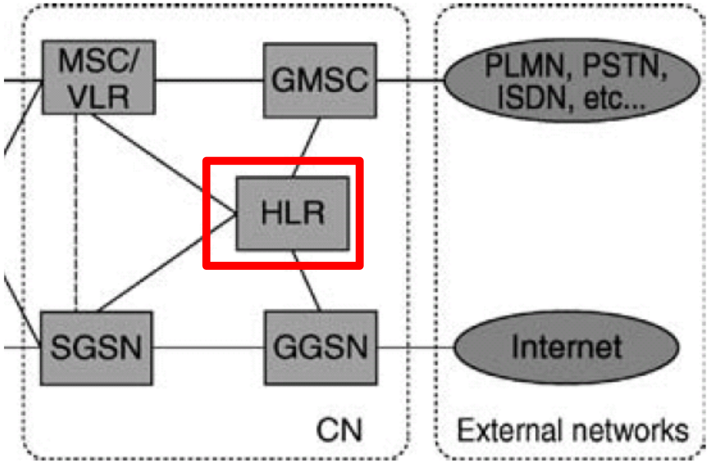
UMTS Network Architecture
Core Network

- The main elements of the Core Network are as follows:
  - Home Location Register (HLR) (Both CS and PS Domain)
  - MSC/VLR (In the CS Domain)
  - GMSC (In the CS Domain)
  - SGSN (In the PS Domain)
    - Considers the VLR in the CS Domain
  - GGSN (In the PS Domain)



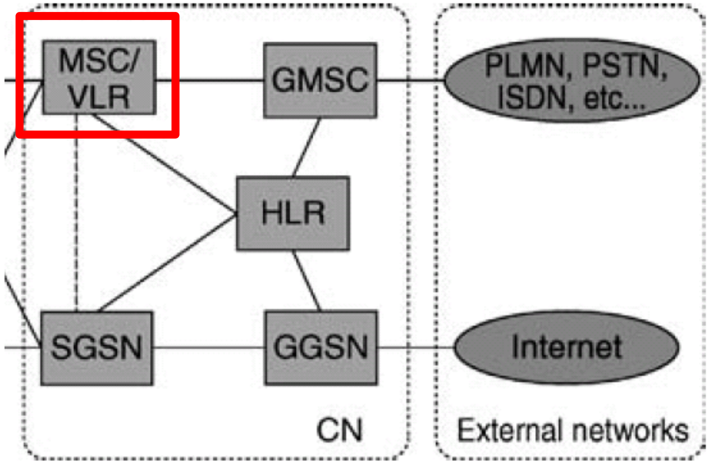
UMTS Network Architecture
Core Network

- **Home Location Register (HLR)**
  - A **database** located in the **user's home system** that stores **the master copy** of the **user's service profile**.
  - For the purpose of **routing/switching incoming transactions (i.e., calls) to the UE,** the **HLR** also **stores the UE's location** on the level of **VLR**.



UMTS Network Architecture
Core Network

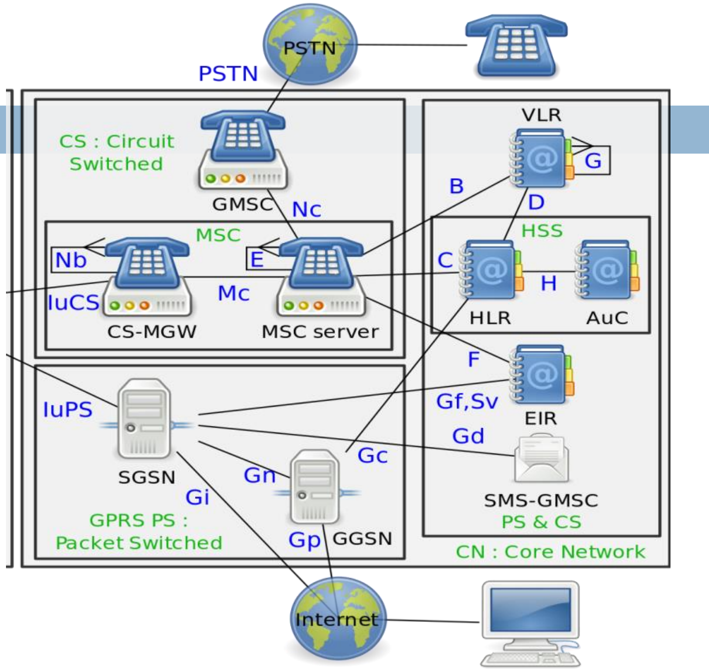
- **Mobile Switching Centre/Visitor Location Register (MSC/VLR)**
  - **Serves the UE** for **CS services** (**i.e., voice calls, SMS**).
  - The **MSC function** is used to **route/switch** the **incoming CS transactions** to the UE (**by consulting the VLR**)
  - The **VLR** holds a **copy of the visiting user's service profile**, as well as **more precise information on the UE's location within the serving Network**.

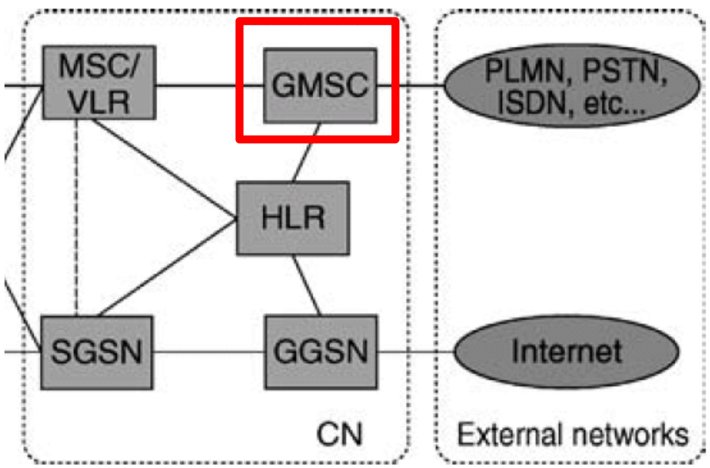


UMTS Network Architecture

Core Network

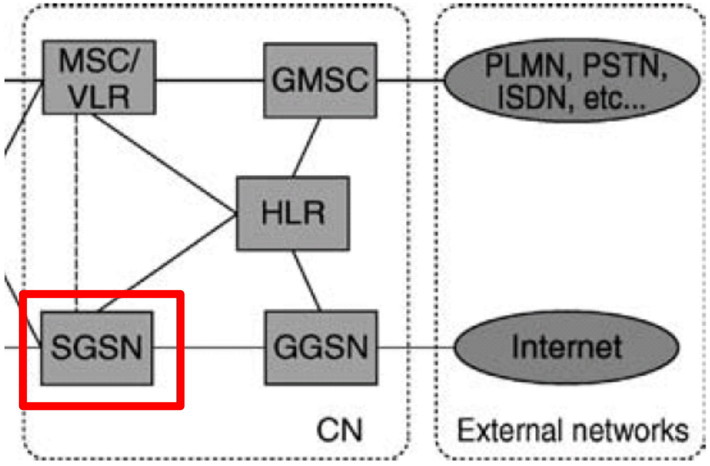
- **Gateway MSC (GMSC)**
  - Is the **switch at the point** where **UMTS PLMN** (Public Land Mobile Network) is **connected to other external CS Networks.**
  - CS Networks provide **connections for CS services**, like the **existing telephony service (e.g., the Public Switched Telephone Network (PSTN) and other PLMNs)**.
  - **All incoming** and **outgoing CS connections (i.e., voice calls, SMS, etc.)** go through **GMSC**.





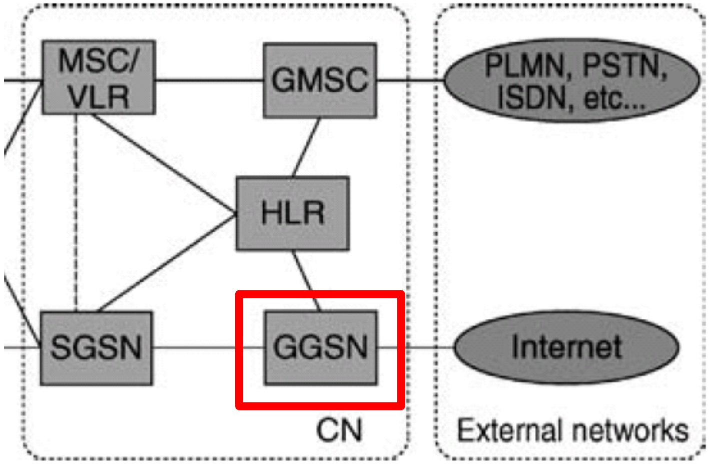
UMTS Network Architecture
Core Network

- **Serving GPRS Support Node (SGSN)**
  - **Serves the UE** for **Packet Switched (CS) services** (i.e., VoIP, Streaming Video, Gaming, Internet Services, etc.)
  - The **SGSN function** is used to **route/switch the incoming PS transactions** to the UE (the current location of the UE is acquired from the VLR)



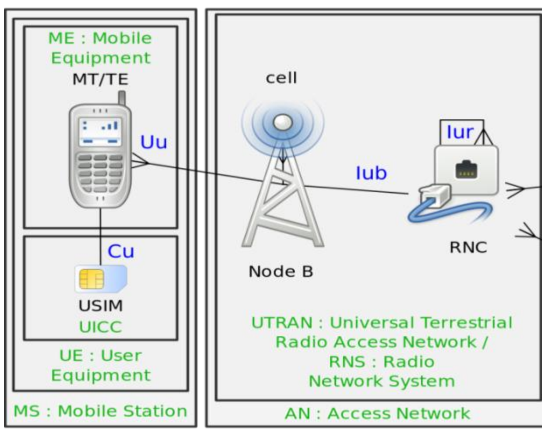
UMTS Network Architecture
Core Network

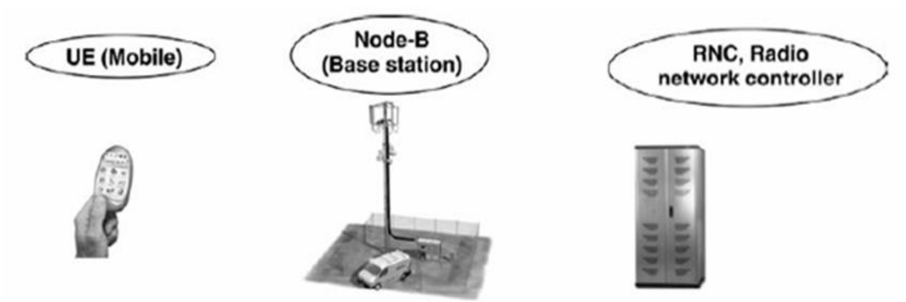
- **Gateway GPRS Support Node (GGSN)**
  - Is the **switch at the point** where **the UMTS Network** is **connected to external PS networks** (i.e., the Internet).
  - **PS Networks** provide **connections for packet data services**. The **Internet** is one example of a PS network.
  - All **incoming** and **outgoing PS connections** go through **GGSN**.



Radio Resource Management

- The **Radio Resource Management (RRM)** is a **responsibility solely taken care of by the UTRAN**.
- **RRM** is located in the **Node-B** and the **RNC** inside the UTRAN but also in the **UE**.
- The **control protocol** used for this purpose (e.g., to exchanged signalling) is the **Radio Resource Control (RRC)** protocol.



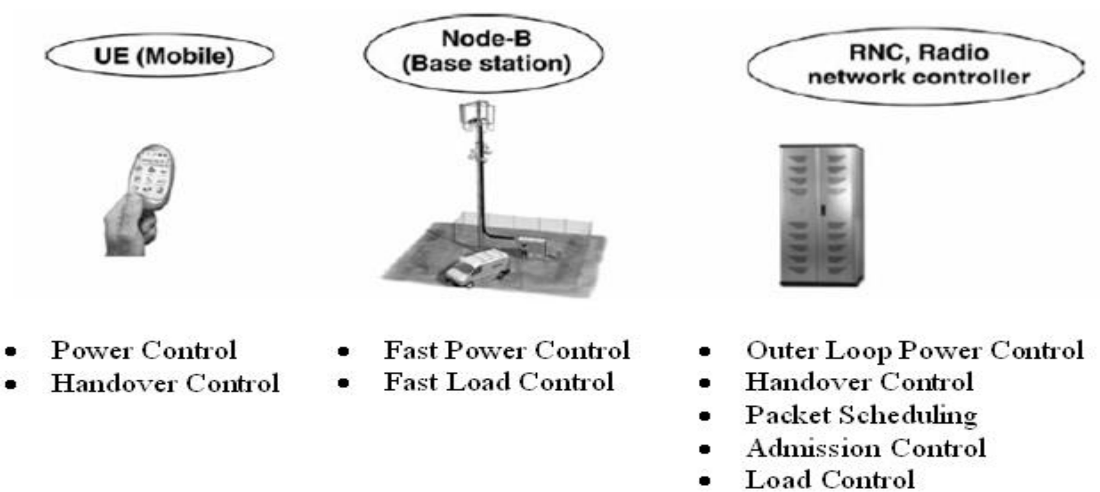


Radio Resource Management

- **More specifically RRM contains a set of algorithms devoted to:**
  - Achieve **optimal usage** of the **radio interface resources**
  - **Guarantee** Quality of Service (**QoS**)
  - **Maintain** the **planned coverage area**
  - To **increase** the **Network capacity**

Radio Resource Management

- **The family of RRM algorithms can be divided into:**
  - **Power Control**
  - **Handover Control**
  - Admission Control
  - Load Control
  - Packet Scheduling



Radio Resource Management

- **Connection based functions:**
  - **Power Control (PC)**
    - **Controls the transmission power used** by the **UE** and the **BS** in order to **keep the interference levels at minimum** in the air interface.
  - **Handover Control (HC)**
    - **Provide continuity of mobile services** to a user traveling **over cell boundaries in a cellular infrastructure**.

Radio Resource Management

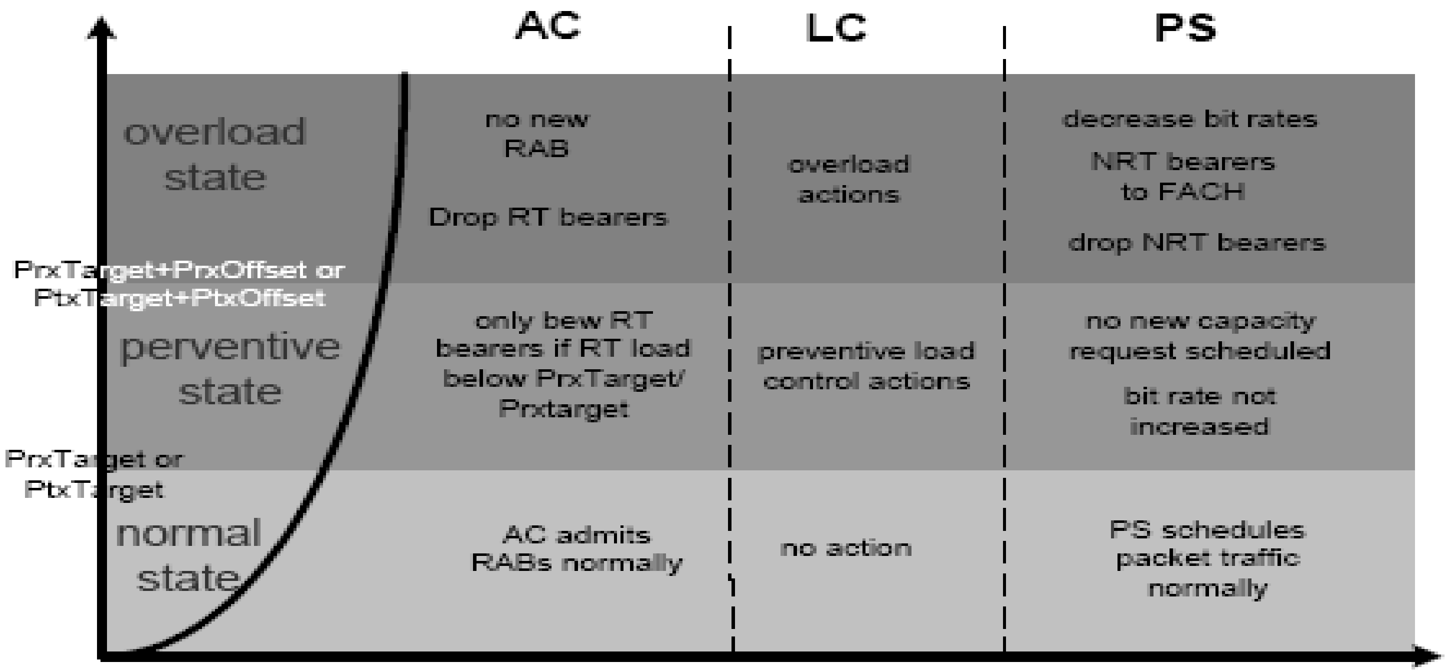
- **Network based functions:**
  - **Admission control (AC)**
    - **Handles all new connections requests** by **checking whether a new connection can be admitted** to the system.
    - Has the function to **provide resources for new call requests** or **regulate resources** for **already ongoing calls** (e.g., in case of congestion)
    - Occurs **when a new call is set up**, and also **during handovers (**as a new connection will be required in the new cell**)**.

Radio Resource Management

- **Load Control (LC)**
  - The main objective of Load Control is to **ensure that the network is not overloaded** and **remains in a stable state**.
  - **Manages situation** when **system load exceeds the threshold** and some **counter measures** have to be taken to **get system back to a feasible load**.
- **Packet Scheduling (PS)**
  - The main objective of Packet Scheduling is to **control the traffic in the network** by **regulating how much bit rate an application is allowed**, by **giving priority to packets** according to the **type of service**, mainly by controlling **Non Real Time (NRT) traffic (e.g., provides the appropriate radio resources**, etc.**)**

Radio Resource Management

- **Packet Scheduling, Admission Control** and **Load Control** algorithms **work together** in order **to prevent the Radio Network from congestion (Συμφόρηση)** and **maintain the requested QoS**.



RT: Real Time

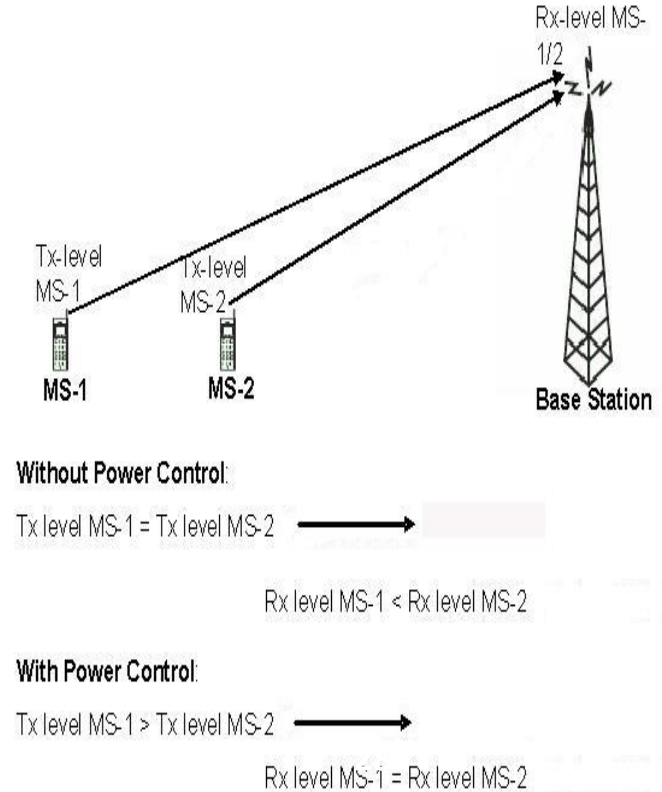
NRT: Non Real Time

Power Control (PC)

- **Power Control is one of the most important functions in WCDMA**, especially in the **Uplink**
  - Without it, a **single overpowered Mobile Station** could **block a whole Cell.**
- **The main reasons for implementing Power Control are**:
  - The **Near-Far problem**
  - The **interference depended capacity** of **W-CDMA**
  - The **limited power source of the UE** (**Battery**)

Power Control (PC)
The Near-Far Problem

- MS-1 and MS-2 **operate within the same frequency**, **separable at the Base Station** only by their **respective Spreading Codes**.
- **MS-1** at the **cell edge** suffers a **path loss, say 70 dB** above that of MS-2 which is near the Base Station.
- **If there were no mechanism for MS-1 and MS-2 to be Power Controlled to the same level at the Base Station, MS-2 could easily overshout MS-1 and thus block a large part of the cell**
  - The optimum strategy in the sense of **maximizing capacity** is to **equalize the received power per bit** of **all Mobile Stations** at all times (**Target SIR**).



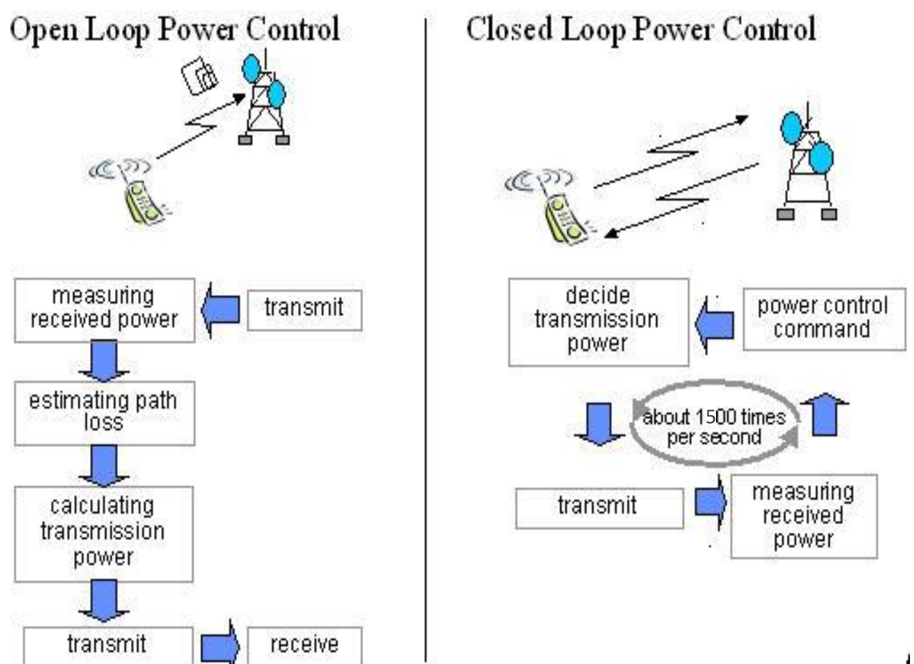
Power Control (PC)

- **Power Control is employed** in both in the **Uplink** (UL) & in the **Downlink** (DL)
  - **Uplink Power Control**: The Power Control Algorithm running in the **BS determines** the **Uplink transmission power of the UE**
  - **Downlink Power Control**: The Power Control Algorithm running in the **UE determines** the **Downlink transmission power of the BS**

Power Control (PC)

- To **efficiently manage** the power control in WCDMA, the system uses **two different defined Power Control mechanisms**:
  - **Open Loop Power Control (OLPC)**
  - **Closed Loop Power Control (CLPC)**

OLPC: Performed only once and this is when the UE is requesting Access to the Network. Then CLPC takes place.



CLPC: Performed continuously, once the connection of the UE with the Base Station is established.

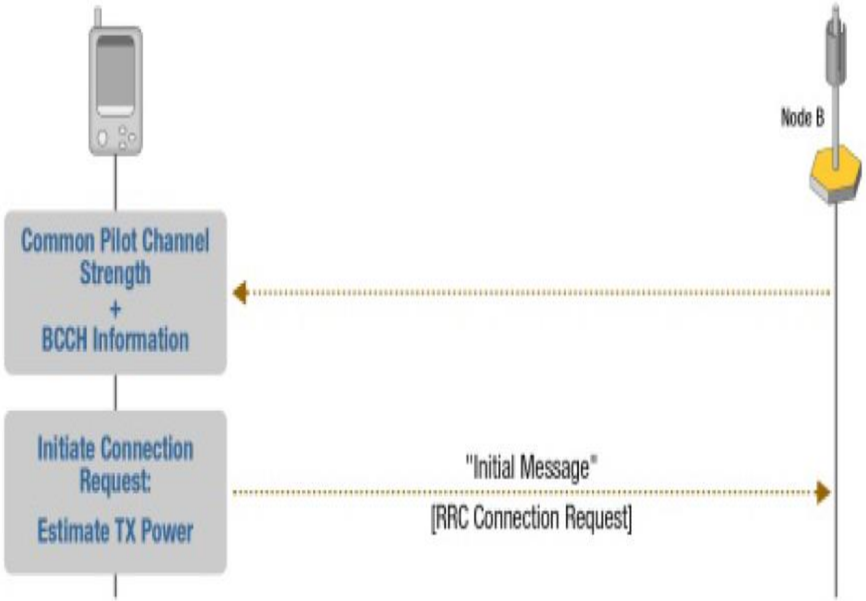
Open Loop Power Control

- ***CPICH (Common Pilot Channel)***
  - *This (downlink) channel is received by all the UEs within the cell.* ***Used for synchronization purposes,*** *between the MS and the BS. It is also used by the UE for* ***channel signal quality estimation reference. In order for all the UEs to be able to decode this channel,*** *a* ***Pre-defined bit sequence*** *(i.e., using a Pre-Defined* ***Spreading Code****) with a* ***fixed length (Spreading Factor (SF) = 256****) is used.*
- ***Target SIR***
  - *Defines the* ***minimum level that the signal power should have*** *over the noise and interference so as for the receiver to be able to decode the signal correctly.*

Open Loop Power Control (OLPC)

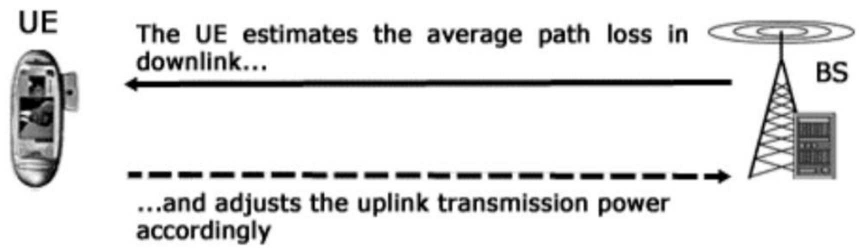
- This kind of Power Control is useful for **determining the initial value** of the **transmitted power that will be used when a UE is requesting access (i.e., connection) to the Network.**

1. *The UE **measures the (Downlink) CPICH Signal Strength** and **roughly estimates** the **Uplink Channel Conditions** (i.e., estimates **the path loss** that the signal will experience during propagation in the uplink)*
2. *Based on this assessment and some other info received from the Network (broadcasted in the BCCH), the UE **roughly estimates the initial transmission power that will be required** to send "Connection Request" to the Node B*



Open Loop Power Control (OLPC)

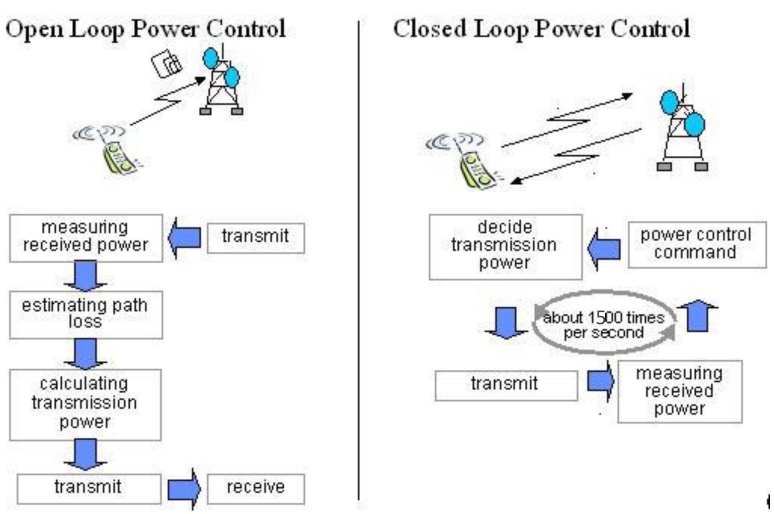
- **Open Loop Power Control** mechanisms attempt to **make a rough estimation of** the **Uplink Channel Conditions** **(i.e., the path loss that the signal will experience in the uplink)** by **measurements performed on the Downlink CPICH Signal Strength.**
  - **Based on this estimation, the UE adjusts its uplink transmission power accordingly.**

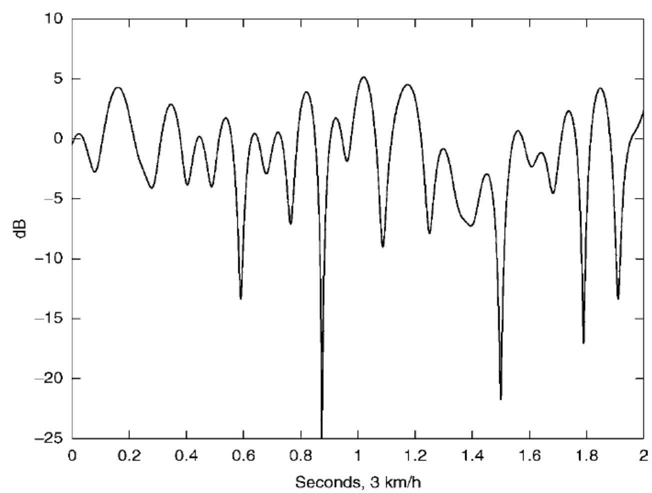


  - Such a method would be **far too inaccurate**.
  - The **prime reason** for this, is that the pathloss experienced on the signal is **essentially uncorrelated between Uplink** (1920 – 1980 MHz) **and Downlink** (2110 – 2170 MHz), due to the **large frequency separation** of **uplink** and **downlink bands** of WCDMA FDD mode.

Open Loop Power Control (OLPC)

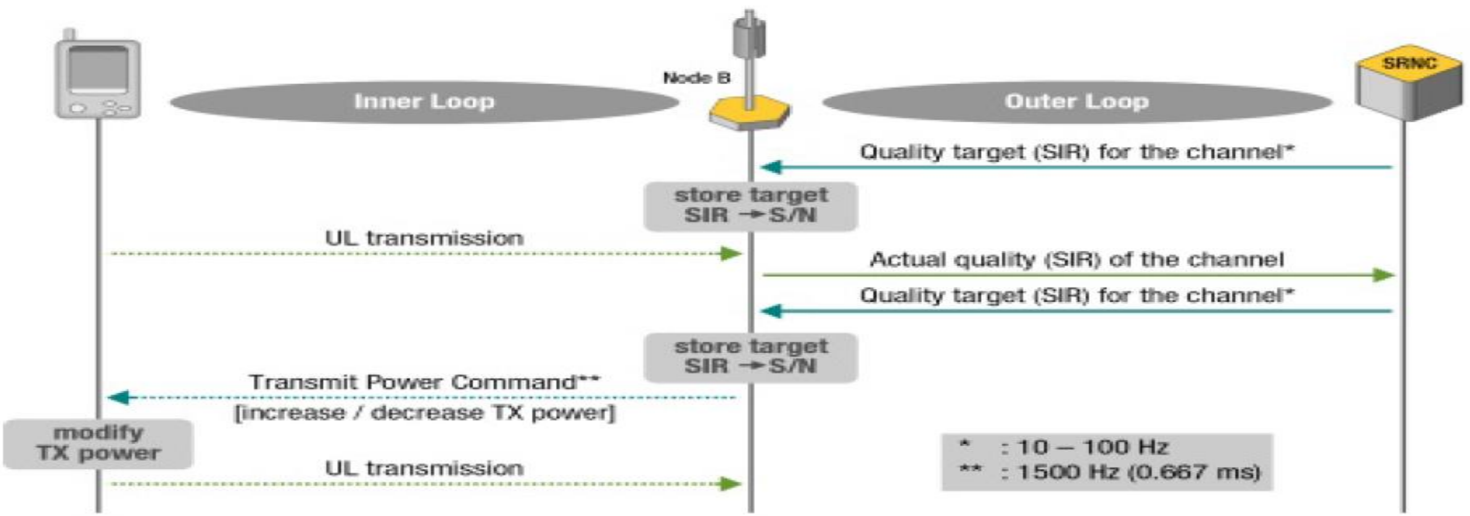
- Thus, **Open Loop Power Control alone** is **neither adequate nor accurate** for **adjusting the UE transmission power during the connection**.
- In order to **more efficiency** and **more accurately compensate the rapid changes in the signal strength (caused at the receiver, mainly due to Fast fading), once the connection is established, Close Loop Power Control is essential**.





Closed Loop Power Control (CLPC)

- **Once the connection is established,** the **CLPC takes place in order to determine the Uplink and Downlink transmission power used during the connection**. It includes:
- **Closed Loop Power Control** includes:
  - **Inner Loop Power Control** (or Fast Power Control)
  - **Outer Loop Power Control** (or Slow Power Control)



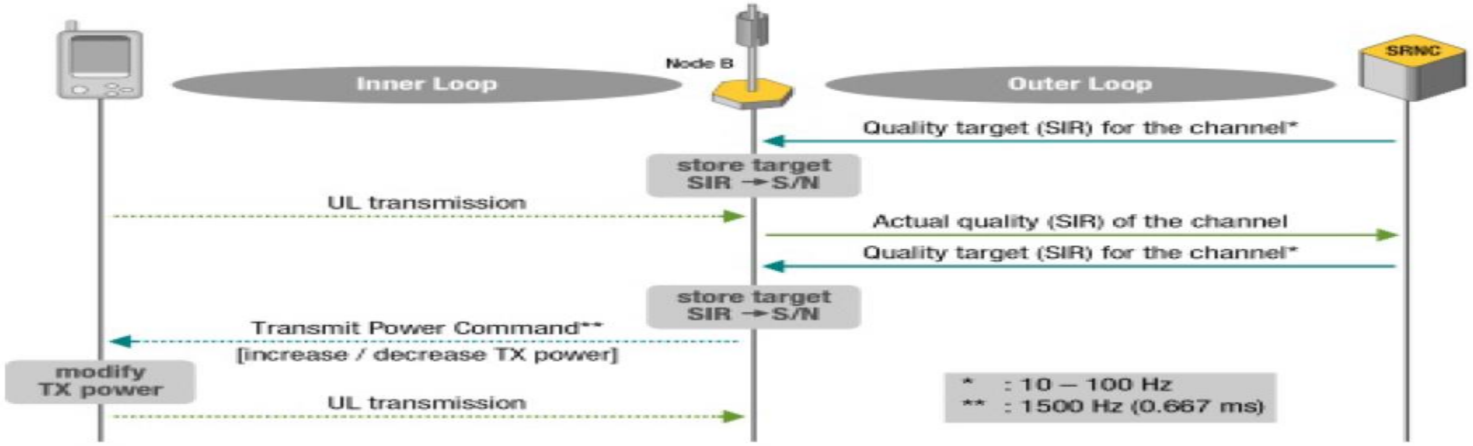
Uplink case:
BS adjusts the transmission power of UE

Closed Loop Power Control (CLPC)

- **The Inner and Outer Loop Power Control work together**, in order to **keep the Target SIR** in a **minimum but always acceptable level and thus:**
  - **Reduce Bit Error Rate**
  - **Reduce transmission power levels required by the Ms and the BS to the minimum**
  - **Increase the Terminal's** (UE) **Battery-life**
  - **Increase the overall system capacity** (by **minimizing the uplink** and **downlink interference caused**)

Closed Loop Power Control (CLPC)

- **Uplink Closed Loop Power Control Example:**
  - ***Inner Loop*** *→ Runs* ***between*** *the* ***UE*** *and the* ***Node-B****. The Node-B* ***compares*** *the* ***signal quality (measured SIR) receive from the UE*** *with the* ***Target SIR*** *and* ***commands the UE*** *to* ***increase or decrease*** *its* ***transmission power accordingly***
  - ***Outer Loop*** *→ Runs* ***between*** *the* ***Node-B*** *and the* ***RNC****.* ***Every time a frame is received by the NodeB (from the UE)****, this frame is* ***forwarded to the RNC****. The RNC* ***checks the quality of that frame*** *(i.e., if it is* ***received correctly or not****) and* ***sets the new Target SIR****. This* ***new Target SIR*** *is* ***provided to the Node-B*** *to be* ***considered during the Inner Loop Power Control****.*



Closed Loop Power Control (CLPC)

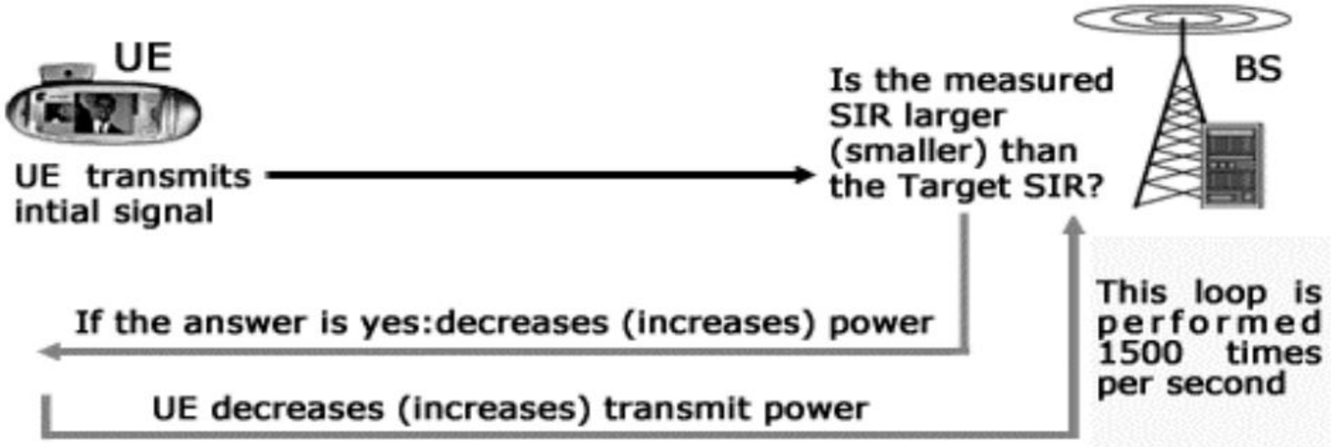
- **Inner Loop Power Control**
  - **Adjusts the transmission power used by the UE (in the Uplink) and the Base Station (Downlink) based on a Target SIR* value.**
  - **Performed with a frequency of 1500Hz** (1500 times per sec)

- **Outer Loop Power Control**
  - **Sets the Target SIR for the Inner loop Power Control**
  - **Performed with a frequency** of **10–100Hz** (10-100 times per sec)

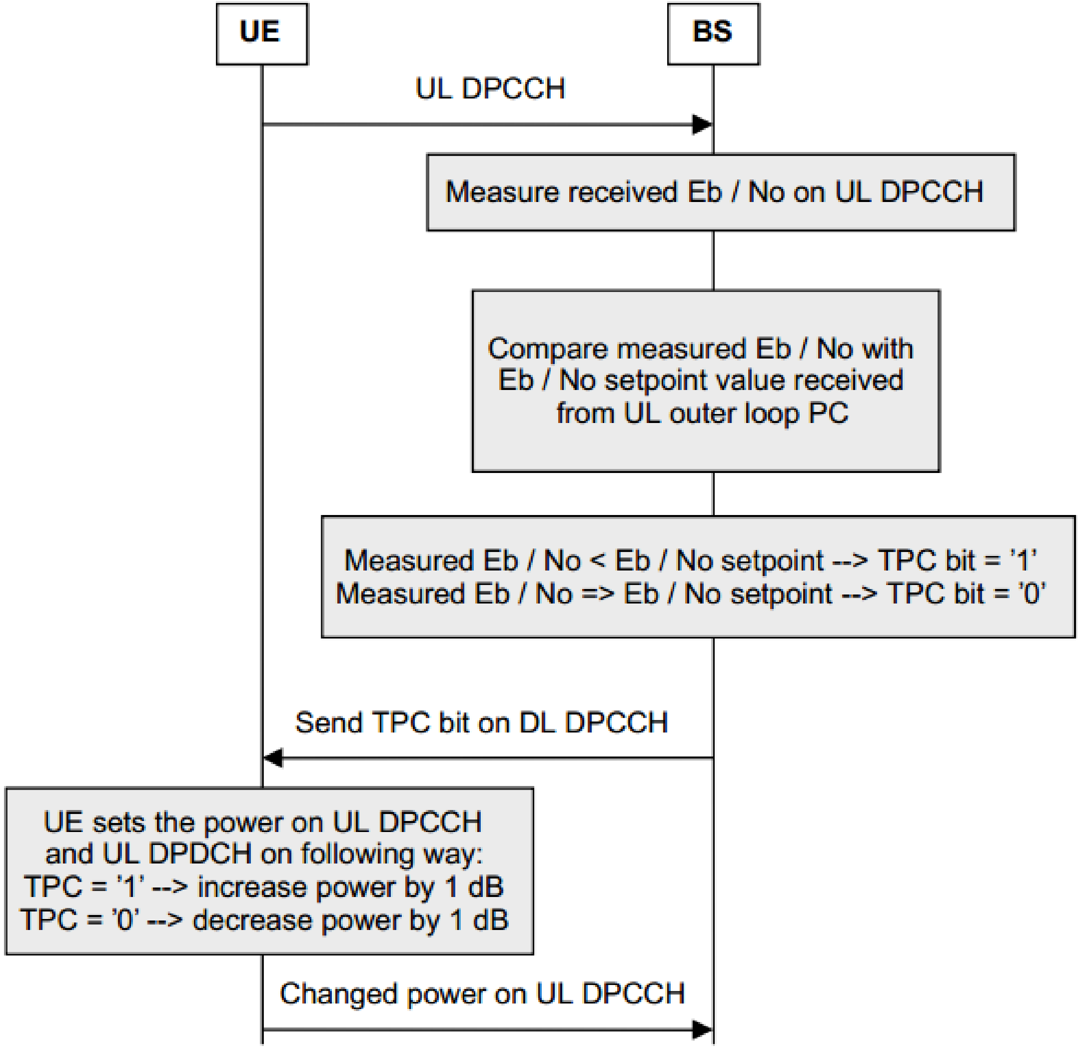
**** Target SIR defines the minimum level that the signal power should have over the noise and interference so as for the receiver to be able to decode the signal correctly.***

Inner Loop Power Control Uplink

- **The Base Station measures the Signal-to-Interference Ratio (SIR) of the signal received from the UE** and **compares** it to the **Target SIR (this value is set by the Outer Loop Power Control)**.
  - If the **measured SIR** is **higher than** the **Target SIR**, the Base Station will **send a Transmission Power Command (TPC)** to the Mobile Station **to reduce its transmission power**
  - If the **measured SIR** is **lower than** the **Target SIR** it will command the Mobile Station to **increase its transmission power**.



Inner Loop Power Control Uplink

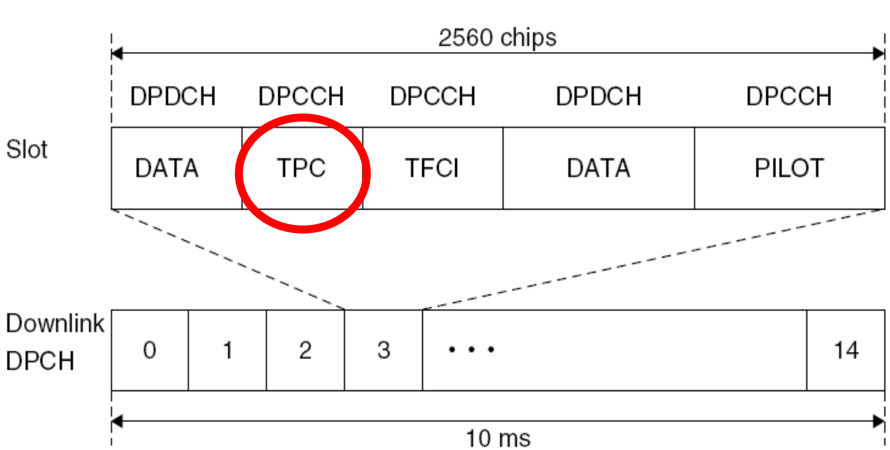


Inner Loop Power Control Downlink

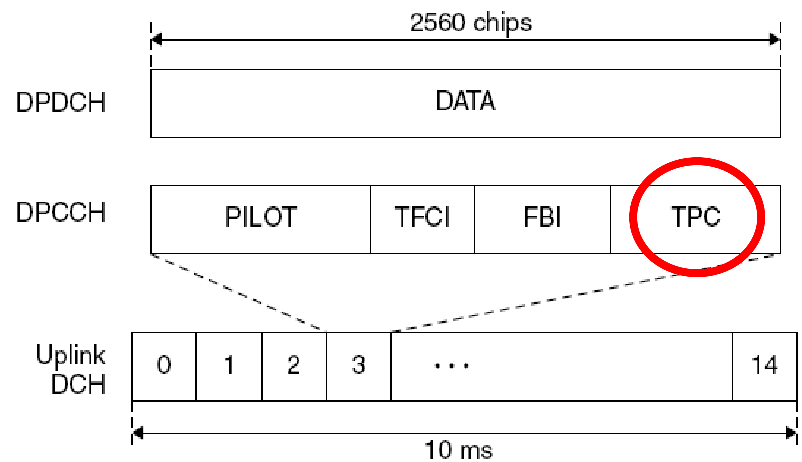
- In the **Downlink**, the **roles** of the **BS** and the **UE** are **interchanged**.
  - The **UE measures the received Signal-to-Interference Ratio (SIR) of the signal received from the BS** and **compares** it with the **Target SIR** and sends the **Transmission Power Command (TPC)** to the BS to adjust its transmission power accordingly.
  - On the **Downlink** though, the **motivation is different**:
    - On the downlink there is **No Near–Far problem,** due to the **One-to-Many scenario**. **All the signals within one cell originate from one Base Station to all mobiles**.
    - It is, however, desirable to **provide additional power to Mobile Stations at the cell edge**, as they **suffer from increased other-cell interference**.
    - Also is used for **enhancing weak signals caused by Fast Fading**.

Inner Loop Power Control

- **Inner Loop Power Control** is executed with a cycle of **1.5 kHz (1500 times per second – One per slot) for each Mobile Station (1dB to 2dB increase/decrease step for every TPC command)**
- **Open Loop Power Control** is executed with a cycle of **10-100 Hz (10-100 times per second – E.g., one per frame)** for each Mobile Station. **The size of the WCDMA frame is equal to 10ms**.



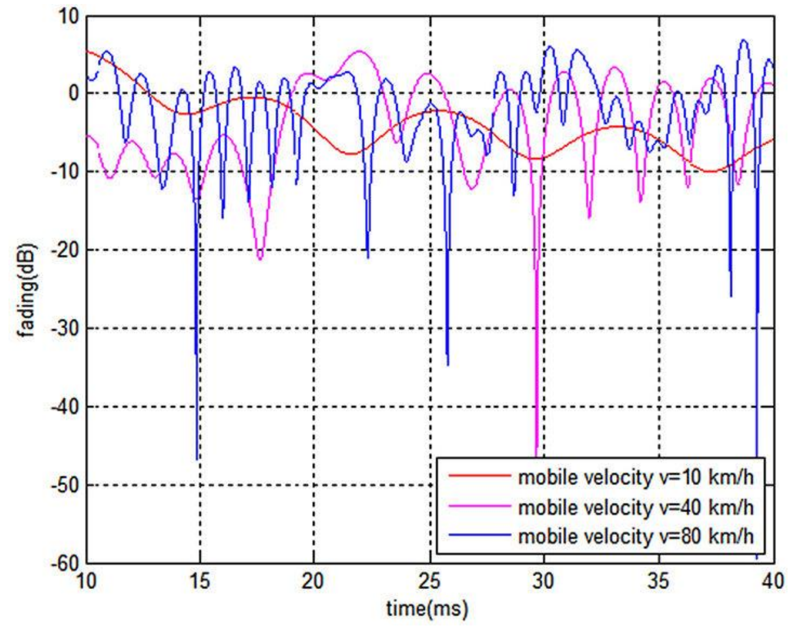
Downlink Dedicated Physical Channel (Downlink DPCH) control/data multiplexing



Uplink dedicated channel structure

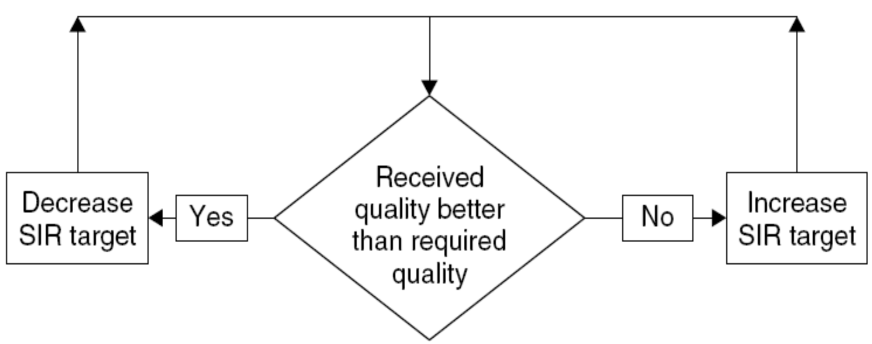
Inner Loop Power Control

- **Inner Loop Power Control operates every 0.666 ms** (once every slot; **10ms frame/15 slots per frame**)
  - **Faster than any significant change of path loss could possibly occur on the signal at the Receiver,** and
  - **Faster than** the **speed of Fast Fading** for **low to moderate mobile velocity**.
- Thus **with Inner Loop Power Control**, only **very little residual fading is left** and the **channel becomes an essentially non-fading channel as seen from the Receiver** (**Base Station or the UE**).

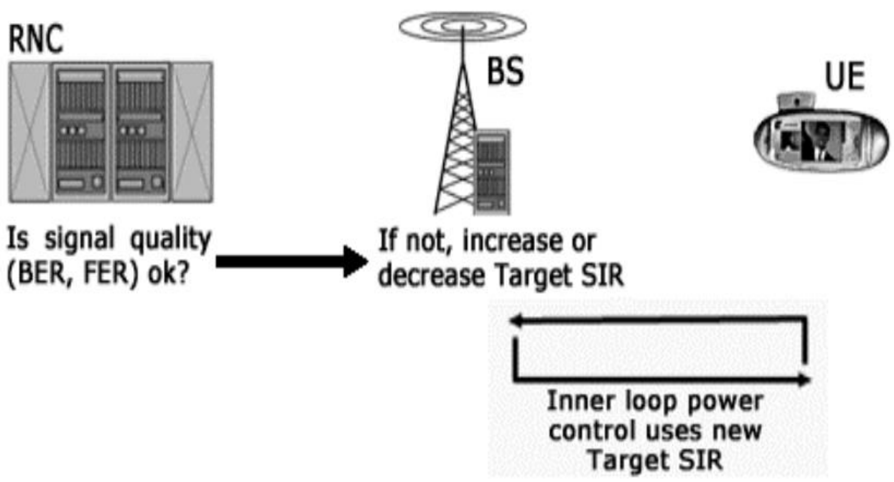


Outer Loop Power Control

- The **Outer Loop Power Control** is needed to **keep the quality of the communication at the required level** by **setting the Target SIR** for the **Inner Loop Power Control**.

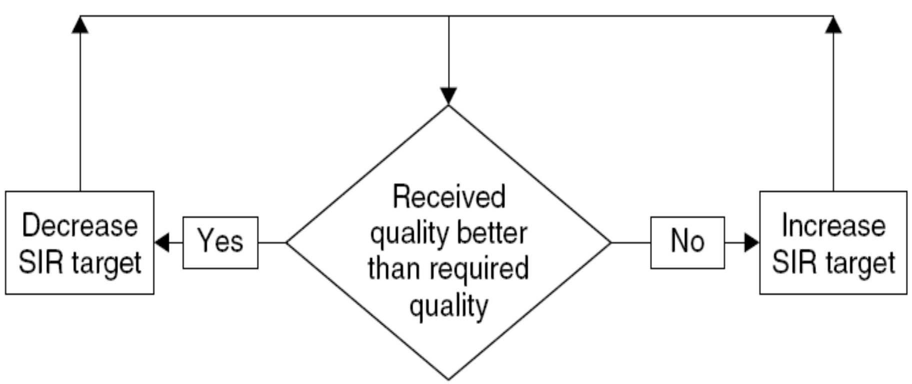


General outer loop power control algorithm

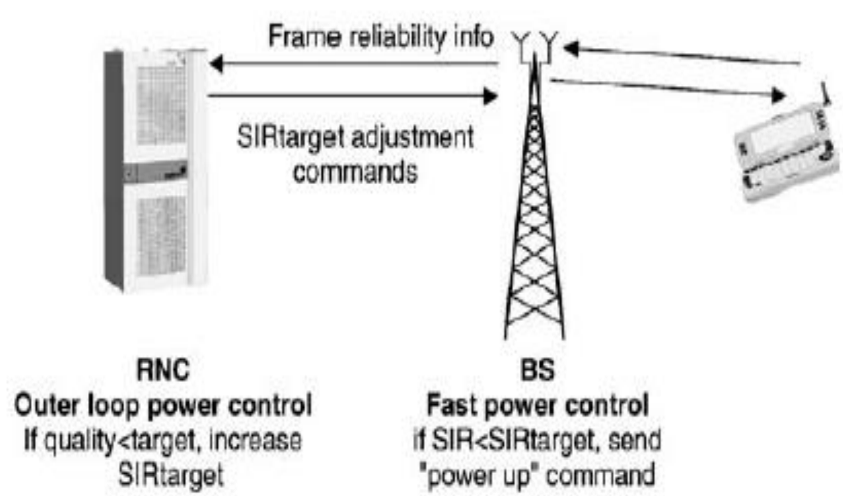


Outer Loop Power Control

- **In the Uplink, the Base Station** **tag each data frame** **received by the UE** with a **Frame Reliability Indicator** **and forwards the frame to the RNC.**
  - The **Frame Reliability Indicator** **value** is **estimated based on the Cyclic Redundancy Check (CRC) result obtained** **during decoding of that particular user data frame**.

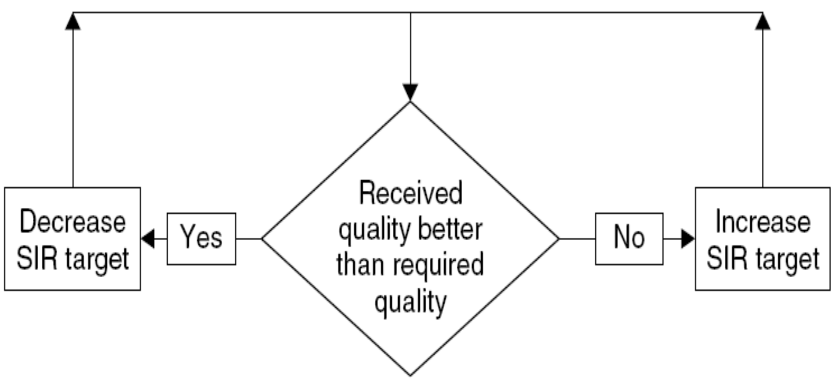


General outer loop power control algorithm



Outer Loop Power Control

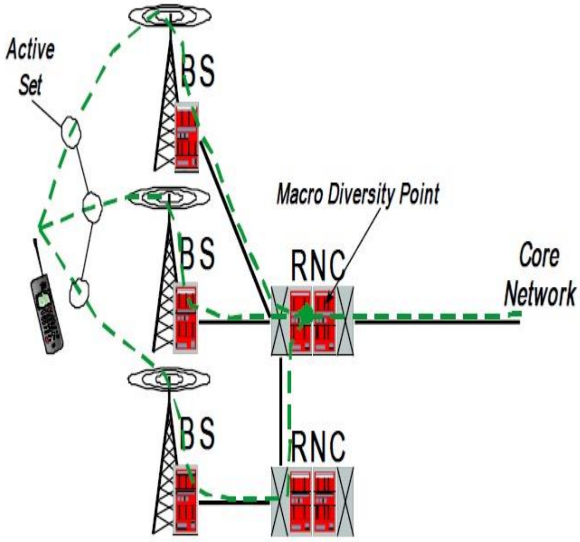
- If the **Frame Reliability Indicator value** indicates to the Radio Network Controller (RNC) that:
  - **The transmission quality is ok (i.e., there are not any errors in the frame received)**, **the RNC** in turn **will command the Node-B to decrease the Target SIR by a certain amount**.
  - **The transmission quality is below the one required (i.e., there are errors in the frame received), the RNC** in turn **will command the Node-B to increase the Target SIR by a certain amount.**



General outer loop power control algorithm

Outer Loop Power Control

- **In the Uplink**, the reason for having Outer Loop Power Control **reside in the RNC** and **not in the Node-B** is that **this function might be performed after a possible Soft Handover (which allows concurrent connection with more than one Base Station)**.
- In the **Downlink** the Outer Loop Power Control **performed in the UE follows the same concept**.
  - However, **in the Downlink both Inner and Outer Loop Power Control runs in the UE,** since during Soft Handover, **all the frames received by the concurrent connections are received from one unit (the UE)**



Gain of Outer Loop Power Control

- **As illustrated in the figure below, the average SIR Target** value **is not fixed** but **depends on the environment used:**
  - The **lowest average SIR Target** (or Eb/No Target) is **needed in the Non-fading channel** and
  - The **highest average SIR Target** is needed in the ITU Pedestrian A channel with **high UE speed (120Km/h)**.

Average SIR targets in different environments

Multipath	UE speed (km/h)	Average E_b/N_0 target (dB)
Non-fading	—	5.3
ITU Pedestrian A	3	5.9
ITU Pedestrian A	20	6.8
ITU Pedestrian A	50	6.8
ITU Pedestrian A	120	7.1
3-path equal powers	3	6.0
3-path equal powers	20	6.4
3-path equal powers	50	6.4
3-path equal powers	120	6.9

Gain of Outer Loop Power Control

- Why should there be a **need for changing the Target SIR set-point during time**?
- **The Target SIR required for receiving the signal correctly** depends on:
  - **UE velocity (i.e., pedestrian, vehicular, high vehicular)**
  - **Multipath Profile (based on the propagation environment)**

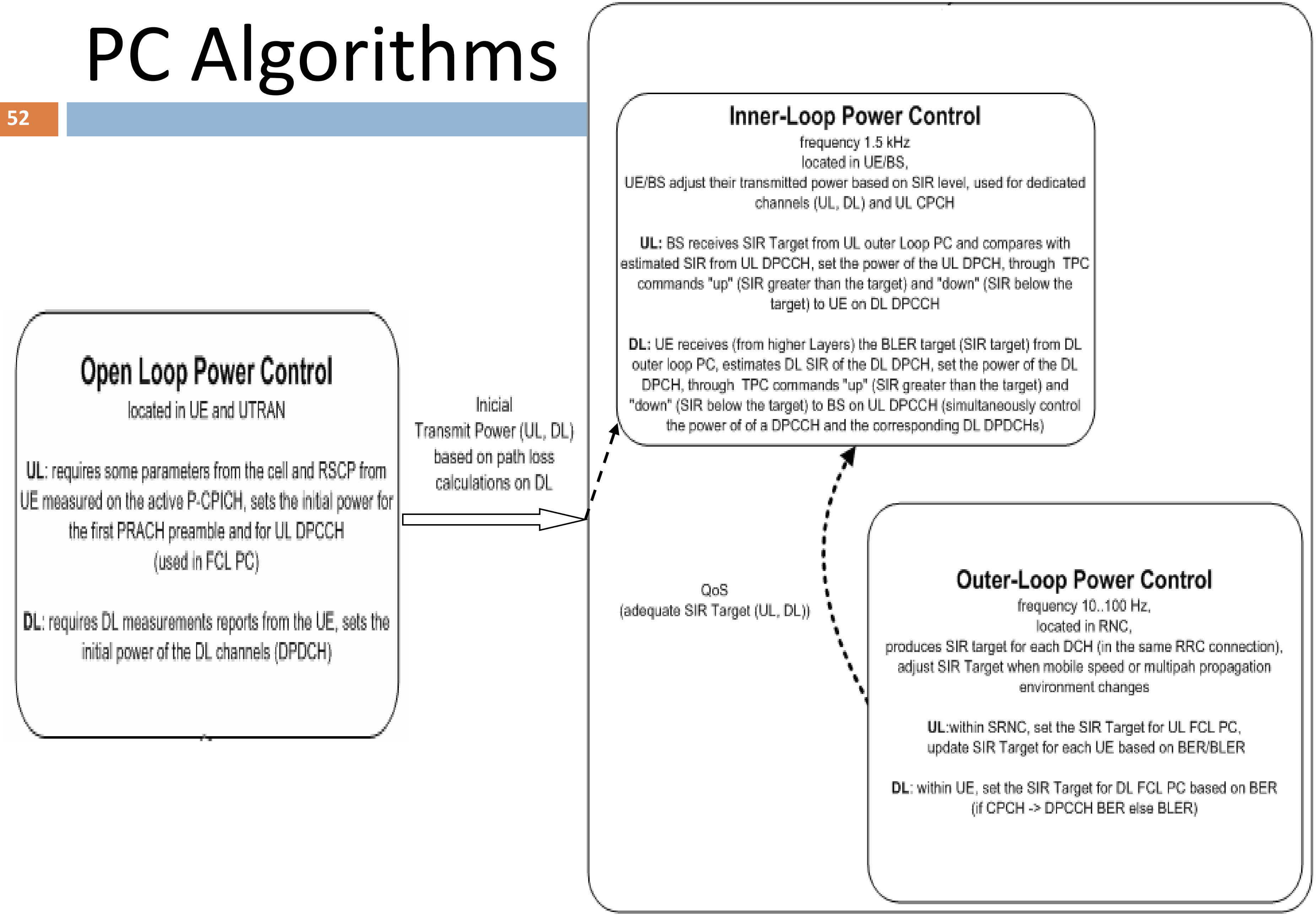
Gain of Outer Loop Power Control

- For **fading channels** and **with higher mobility speeds**, **the Target SIR needs to be higher** to **provide the required quality**.
  - If we were to **select a fixed Target SIR of 5.3 dB** according to the **non-fading channel**, the **frame error rate of the connection would be too high** in **fading channels** and **speech quality would be degraded**.
  - If we were to **select a fixed Target SIR of 7.1 dB**, the **quality would be good enough** but **unnecessary high powers would be used** in most situations (**waste capacity**).
- **Thus we can conclude that there is clearly a need to adjust the Target SIR of the Inner loop power control by Outer Loop Power Control.**

Gain of Outer Loop Power Control

- **Setting the Target SIR for the worst case** (i.e., high mobile speeds and areas with a lot of high buildings, etc.) one would **waste much transmission power** for **those connections with better channel conditions in the same cell (i.e., at low mobile speeds** and **open space area)**.
- On the other hand, **setting the Target SIR for the best case**, this would mean **bad quality of those connections with worse channel conditions in the cell (i.e.,** at **high mobile speeds** and areas with **high buildings**)
- Thus, the **best strategy** is to **let the Target SIR set-point float around** the **minimum value** that **just fulfils the required Target quality** *(i.e., the signal should have the minimum power required to be received by the receiver for decoding the signal correctly)*

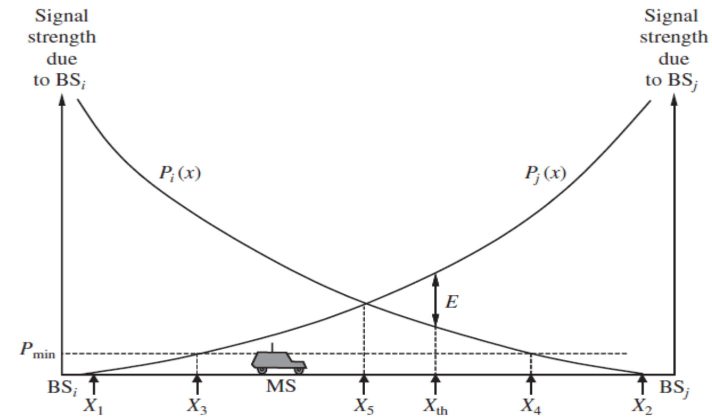
Interaction between Open and Close PC Algorithms



Handover Control

- **Handover Control** aims to **provide continuity of mobile services** to a **user traveling over cell boundaries** in a **cellular infrastructure**.
- For a **user having an ongoing communication** and **crossing the Cell's edge**, it is **more favorable to use the radio resources in the new cell** (Target cell), because **the quality of the signal strength perceived in the "old" cell** (Current cell) **is decreasing as the user moves towards the Target cell**.
- **The whole process** of **tearing down the existing connection in the Current cell** and **establishing a new connection in the Target cell** is called **"Handover".**

Handover Reasons



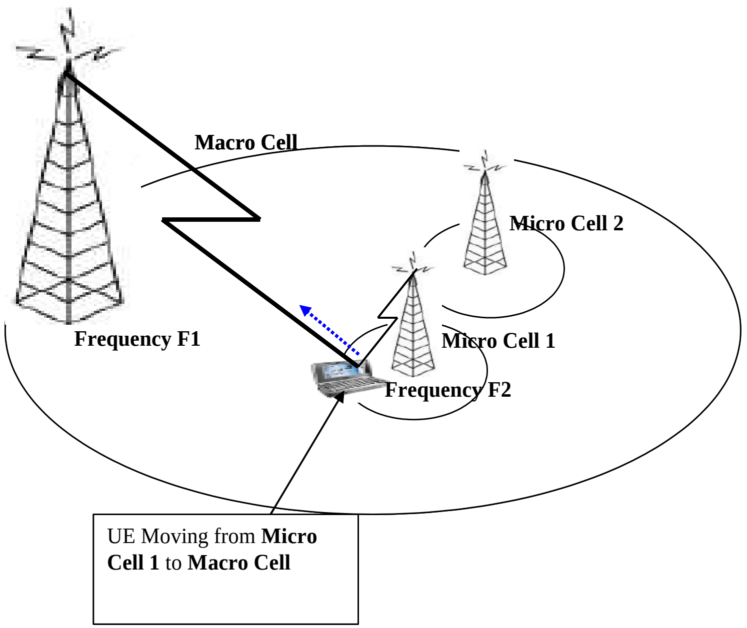
- The **basic reason behind a Handover** is that **the connection does not fulfil the desired QoS criteria set anymore** and **thus either the UE or the UTRAN initiates actions in order to improve the connection**.
- **Overall, the reasons behind a Handover can be due to**:
  - **Signal Quality Received by the UE (Main Reason)**
    - **The UE continually measures the signal strength received from its Serving Cell (as well as the signal quality of its Neighbouring cells)** aiming to **detect any signal deterioration**.
    - When the **quality or the strength of the radio signal falls below certain parameters set by the RNC**, a **Handover** is **initiated (by the UE)**.

Handover Reasons

- **Traffic level in a cell**
  - A **Handover is initiated (by the Network) when the intra-cell traffic** is **approaching the maximum cell capacity** or a **maximum threshold**.
  - This **sort of Handover helps to distribute the system load more uniformly within the network**.
  - Usually, the **UEs that are handover** to Neighbouring (less loaded cells) are **those that are located at the edge** of **the high loaded cell**.

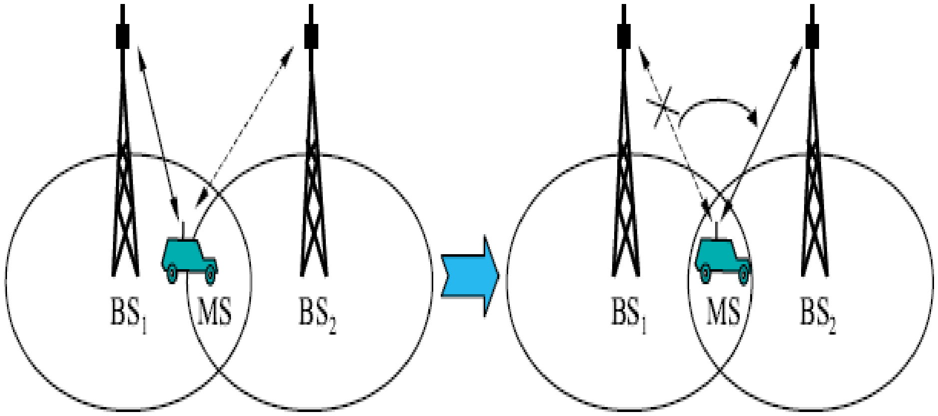
Handover Reasons

- **User Speed**
  - The **frequency of Handovers** is **proportional** to the **UE's speed** and the **size of the cell**.
  - To **avoid frequent and unnecessary Handovers**, UEs with **high motion speed** may be **handed over from micro cells** to **macro cells.**
  - In the same way, **UEs moving slowly or not at all**, can be **handed over from macro cells to micro cells**.



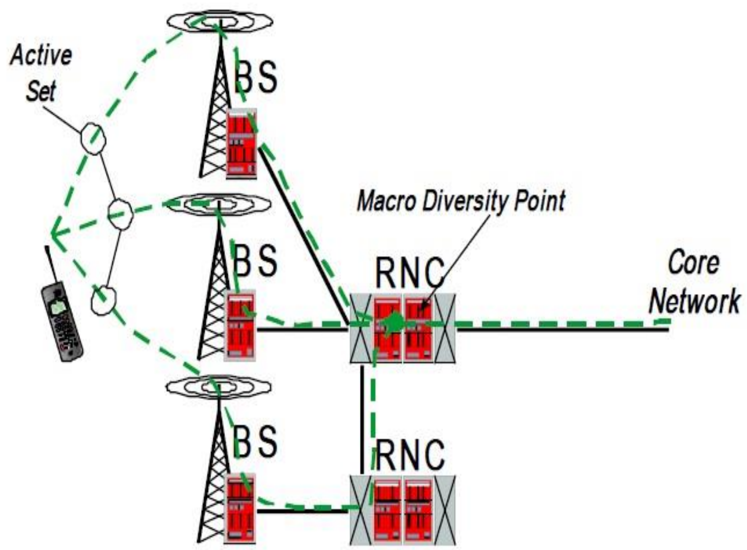
Handover Types
Hard Handover

- **During a Hard Handover, the old connection with the old Cell is released before the new connection with the new Cell is established ("break-before-make" connection).**



Handover Types
Soft Handover (and Macro-Diversity)

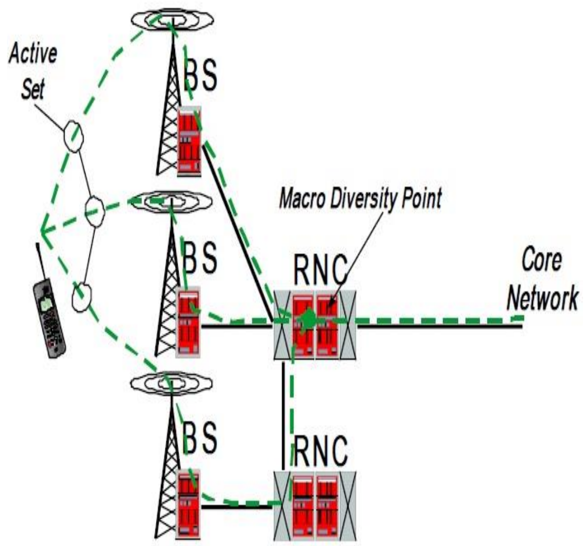
- **Soft Handover** refers to the process that **allows a Mobile Station** to be **served simultaneously by several cells (BSs).**
- This feature is **possible in WDMA** because **all Cells use the same frequencies** → Note that the channels in WCDMA are separated only by the use of **Spreading Codes**.
- **With Soft Handover several radio links are active at the same time providing a "Macro-diversity" gain on the received signal (or frame).**



Handover Types

Soft Handover in the Downlink (Soft Combining)

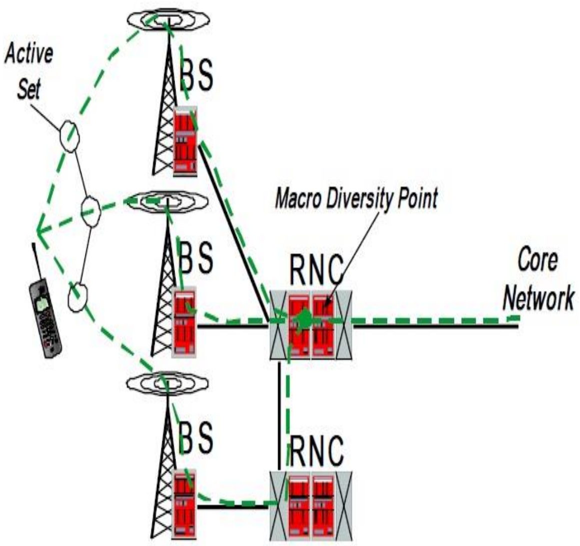
- **In the Downlink, the MS can combine the different received (de-spreaded) signals to increase the reliability of demodulation → This is termed as Soft Combining Gain.**
  - **By combining the signals from different links, a stronger signal can be generated thus Increasing the Received SIR, which reduces the transmit power requirements** *(even when compared to the power required over the best link only)*



Handover Types

Soft Handover in the Uplink (Selective Combining)

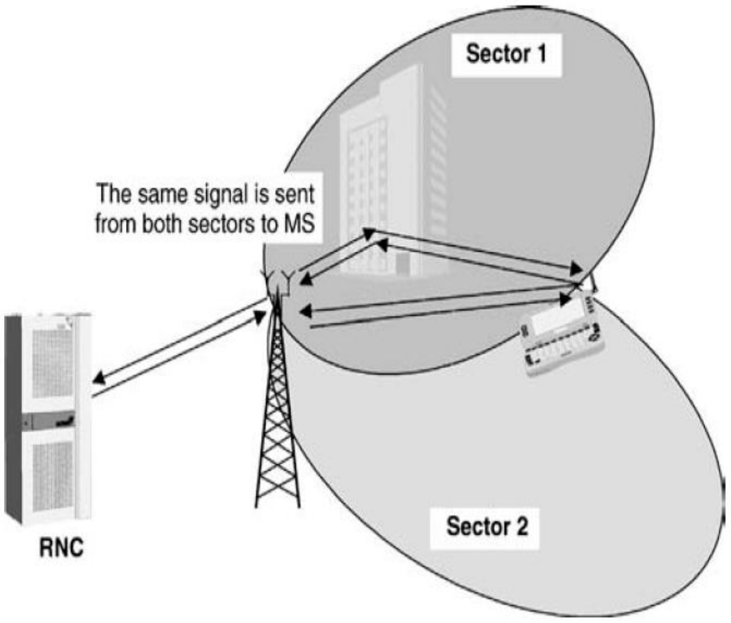
- **On the Uplink**, since the **Cells in the Soft Handover do not belong to the same Node-B**, **it is Not possible to combine the signals before they are demodulated.**



- **Instead, all the frames are sent to the RNC, which decides which one to use** (i.e., **the first frame which is received correctly is chosen**).
- This process **still provides a gain compared to a single link, since it increases the probability of having at least one link without error → This is termed as "Selective Combining" Gain**

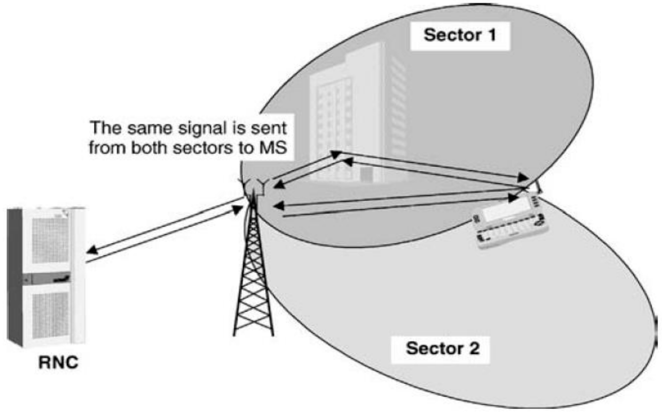
Handover Types
Softer Handover

- **Softer Handover** is a **special case of Soft Handover** where the **radio links** that **are added and removed belong to the same Node-B (Base Station)**.
- During Softer Handover, a **UE is in the overlapping cell coverage area** of **two adjacent sectors of the same Node-B.**
- The **communication between** the **UE** and the **Node-B usually takes place concurrently via two connections, one for each sector separately** → From the **UE's point of view** this is **just another Soft Handover case.**



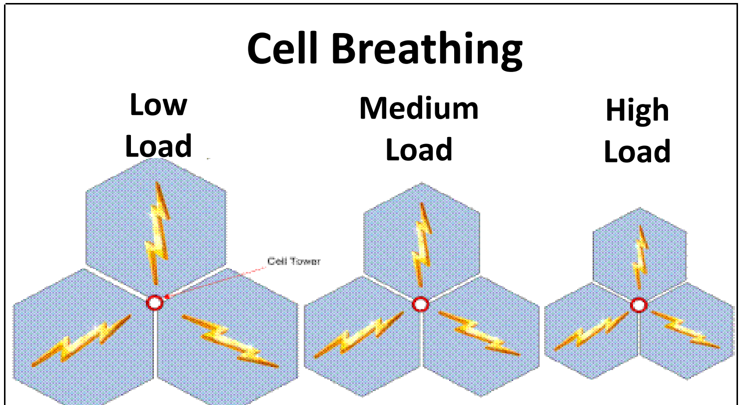
Handover Types
Softer Handover

- The **different of Softer and Soft Handover** is **only meaningful to the Network (i.e., in the Uplink)**, as a **Softer Handover** is an **internal procedure for a Node-B.**
- **The uplink Softer Handover branches can be combined within the Node-B, similarly to the case of the UE, resulting in a stronger signal and thus increasing the reliability of demodulation → "Soft Combining" Gain can be achieved at the Node-B**



Admission Control

- **If the air interface loading (i.e., the active connections) is not controlled and allowed to increase excessively:**
  - The **Coverage area of the cell will be reduced below the planned values (due to the high interference that will be caused – causing the cell breathing phenomenon), and thus**
  - The **Quality of Service of the existing connections will not be guaranteed, especially for those located on the cell's edge**.
- **Before admitting a new UE, Admission Control needs to check that the admittance will not sacrifice the planned coverage area** or the **Quality of the existing connections**.



Cell Coverage Size Increase or Decrease with air interface load

Admission Control

- **Admission Control accepts** or **rejects a request to establish a new connection** in the **Radio Access Network**.
- **It** is **executed when a new connection is set up or an existing connection needs to be modified/regulated (in case of cell overloading), or during a handover**.
- The **Admission Control functionality** is **located in the RNC where the load information from several cells can be obtained**.

Admission Control

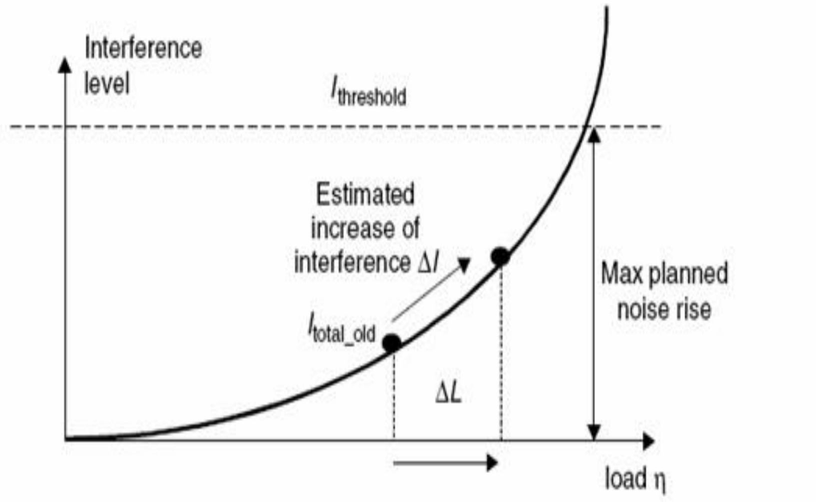
- The Admission Control algorithm **estimates the load increase that the establishment of the new connection would cause in the Radio Network**.
  - This is **estimated separately** for the **uplink** and **Downlink directions**.
- The **new connection can be admitted only if both uplink and downlink Admission Control admit it, otherwise it is rejected because** of the **excessive interference that it would produce in the network**.
  - The **threshold limits for Admission Control are set by the Network Operator during Radio Network Planning.**

Admission Control

- There are **two type of strategies for Admission Control**:
  - **Interference (Power) - Based**
  - **Throughput - Based**

Interference Based Uplink Admission Control

- The **interference-based Uplink Admission Control algorithm** estimates the increase in the **uplink Interference (*ΔI*) that will be caused due to a new uplink connection with a UE**
  - For the **estimation of the uplink *ΔI*** the **uplink load curve** is **also taken into account, in order to estimate the load factor (*ΔL*) that will be caused by adding the UE.**
  - ***ΔL*** **is the load factor *of the new* connection requested by the *UE*.**
- **Then the new resulting Total Interference level is estimated ($I_{total\_old} + \Delta I$)**



Uplink load curve and the estimation of the load increase due to a new UE

Interference Based Uplink Admission Control

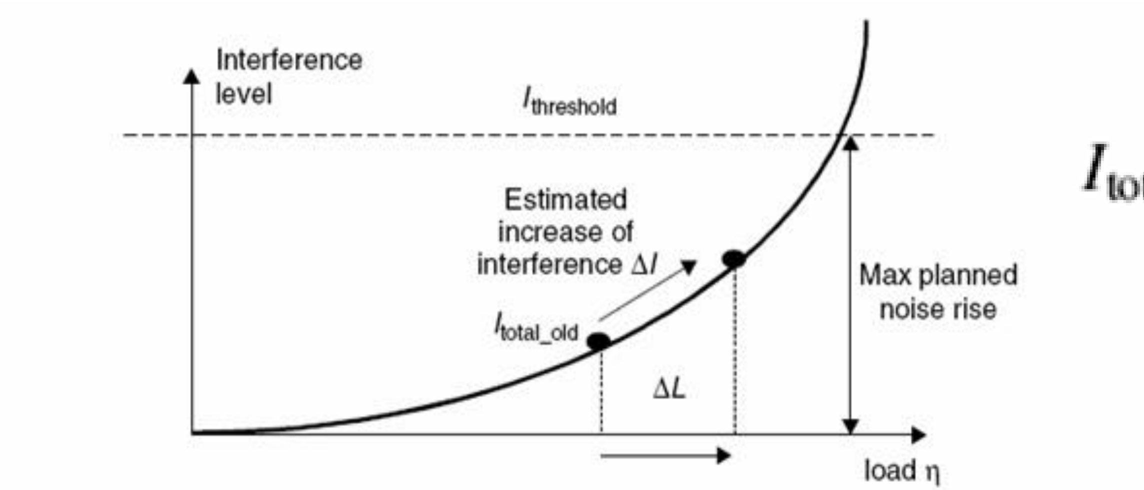
- The **load factor of the new UE *ΔL*,** is **the estimated load factor of the new connection** and **can be obtained as**:

$$\Delta L = \frac{1}{1 + \dfrac{W}{\upsilon \cdot E_b/N_0 \cdot R}}$$

  - ***W*** *is the* ***Chip Rate (in case of WCDMA is 3.84 Mcps),***
  - ***R*** *is the* ***Bit Rate*** *of the* ***connection requested*** *by the new UE,*
  - ***Eb/No (or Target SIR)*** *is the* ***"assumed" required Eb/No (i.e., the Target SIR required to be received by the BS for decoding the signal correctly)*** *of the* ***new connection***
  - ***υ*** *is the "****assumed"*** ***voice/data activity*** *of the* ***new connection*** *(typically takes values between* ***0.4 – 0.6;*** *meaning that compared to the total session time only during the 40 – 60% of the time, data or voice is actually sent in the channel).*

Interference Based Uplink Admission Control

- If the **new resulting Total Interference level** (***I_{total_old} + ΔI***) **is lower than the threshold value** (***$I_{threshold}$***) **then the new UE will be admitted in the uplink, otherwise** it **will be rejected**.
  - The **threshold value *$I_{threshold}$*** is the **maximum uplink interference that is allowed to be introduced in the system** and **can be set by the Network Operator during Radio Network Planning**.



Uplink load curve and the estimation of the load increase due to a new UE

$$I_{\text{total\_old}} + \Delta I < I_{\text{threshold}}$$

Interference Based Downlink Admission Control

- The **downlink Admission Control** strategy is **similar as in the uplink** → The **UE is** **not admitted if the new total Downlink Transmission Power used by the NodeB** ($P_{total\_old} + \Delta P_{total}$) **exceeds the predefined Target value** ($P_{threshold}$):

$$P_{\text{total\_old}} + \Delta P_{\text{total}} > P_{\text{threshold}}$$

  - The threshold value $P_{threshold}$ is set by the **Network Operator** during **Radio Network Planning and specifies the total Downlink Power allowed to be used by the BS**.
  - Note that ΔP_{total} **includes two values**:
    - The **downlink transmission power that will be devoted for the new UE requesting** the connection, and also
    - The **Additional downlink transmission power that will be devoted for the existing UEs in the system, due to the additional interference cause for the new connection of the new UE**.

Interference Based Downlink Admission Control

- The increase (***ΔP_{total}***) in the BS's downlink transmission power **can be estimated based on a priori knowledge** of:
  - The ***Required Target SIR (with which the MS should receive the signal for decoding it correctly) of the new connection,***
  - The ***Requested Bit Rate of the connection***, and
  - The **$CPICH_{Ec/No}$ *Pilot Report* the UE sent to the RNC**.
    - The **$CPICH_{Ec/No}$ *Pilot Report*** implicitly **provides information to the RNC regarding** the **path loss towards the new UE** as well as the **interference level experienced by the UE.**

Throughput Based Downlink and Uplink Admission Control

- In the **throughput-based admission control strategy**, the new UE requesting connection is **admitted if**:
  - In the Uplink case: $\eta_{UL} + \Delta L < \eta_{UL\_threshold}$
  - In the Downlink case $\eta_{DL} + \Delta L < \eta_{DL\_threshold}$
    - Where η_{UL} and η_{DL} are the **Uplink** and **Downlink** **load factors before the admittance of the new connection.**
    - The **load factor** of **the new UE ΔL is calculated using the same formula used by the previous approach**

$$\Delta L = \frac{1}{1 + \frac{W}{\upsilon \cdot E_b/N_0 \cdot R}}$$

- ***W** is the **Chip Rate**,*
- ***R** is the **Bit Rate** of the **connection requested** by the new UE,*
- ***Eb/No** is the **"assumed" required Eb/No (for decoding the signal correctly)** of the **new connection***
- ***υ** is the **assumed voice activity** of the **new connection** (typically takes values between **0.4 – 0.6**).*

Ερωτήσεις;

Additional Slides

Wideband – Code Division Multiple Access (W-CDMA)

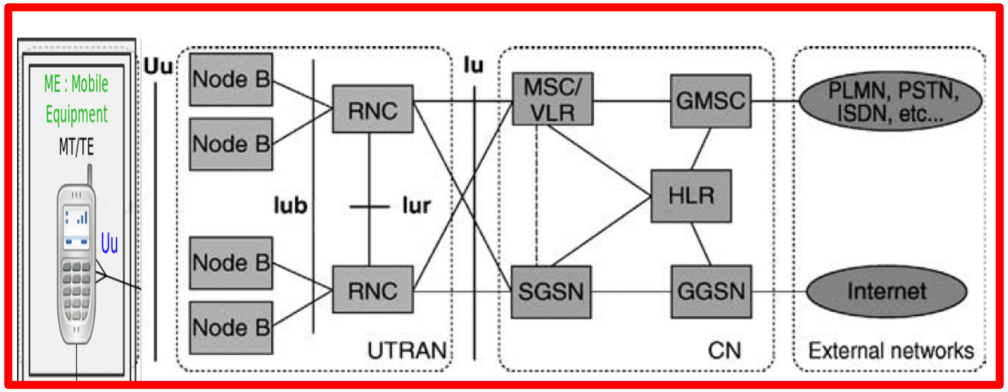
- In order for the UMTS network to **support a variety of multimedia mobile services** at **high data rates** in the radio access layer **resulted in the choice** of **Code Division Multiple Access (CDMA)** as the **multiple access scheme** used in 3rd Generation (3G) networks.
- W-CDMA is a 3G standard **based on CDMA** that **increases the throughput** of data transmission of CDMA **by using a wider 5MHz carrier bandwidth** (**CDMA** uses a carrier bandwidth of **1.25 MHz**)
  - Hence the name **W (Wideband)** - CDMA.

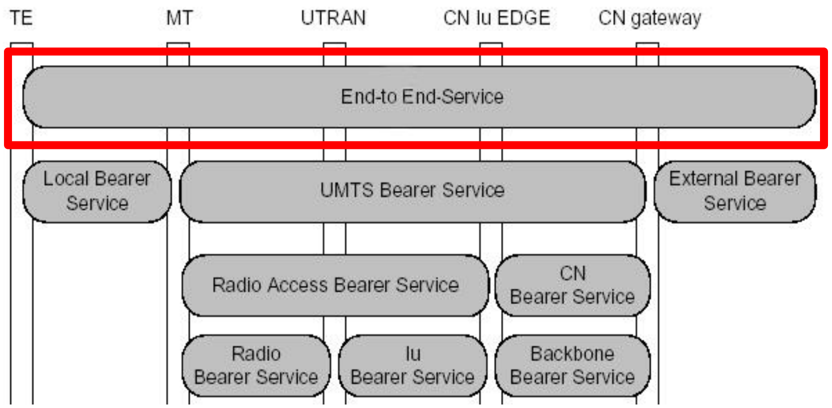
Wideband – Code Division Multiple Access (W-CDMA)

- **WCDMA**, with data rates up to 2Mbits **has the capacity to easily handle bandwidth-intensive applications** such as **video, data, and image transmission** necessary for **mobile internet services**
  - Note that 2Mbits is achieved with UMTS Release 99
  - Much higher data rates achieved with latest releases of UMTS technologies based on WCDMA like **HSPA** (up to 14.4 Mbps) and **HSPA+** (up to 42Mbps)

End-to-End Service QoS Provision

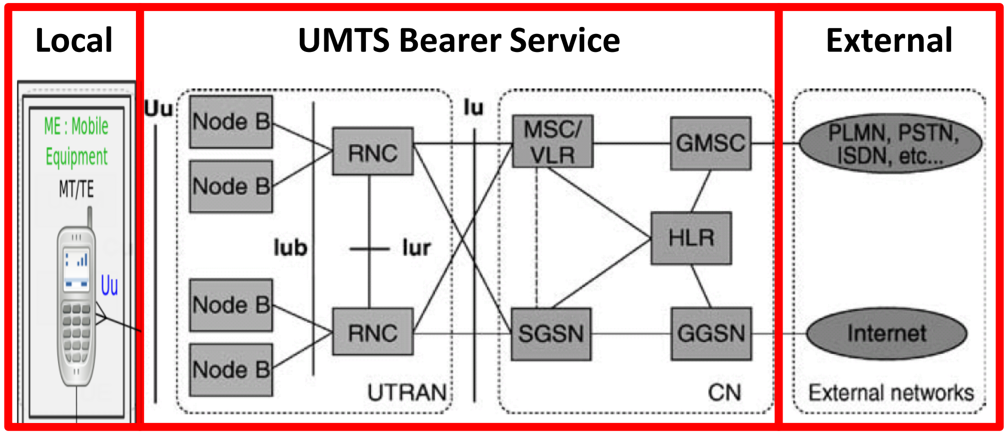
- If we think of an **End-to-End Service** between users, the used service sets its requirements concerning QoS and these **QoS requirements must be met everywhere in the network.**
  - E.g., Minimum bit rate, Maximum delay allowed, Guaranteed bit rate, Maximum bit error rate allowed, etc.

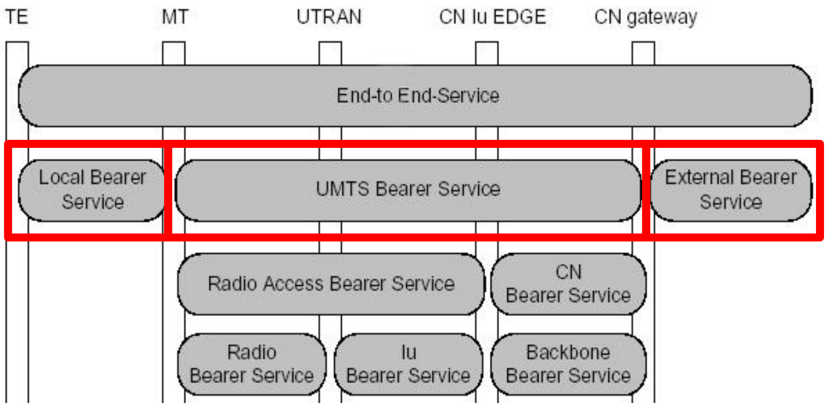




End-to-End Service QoS Provision

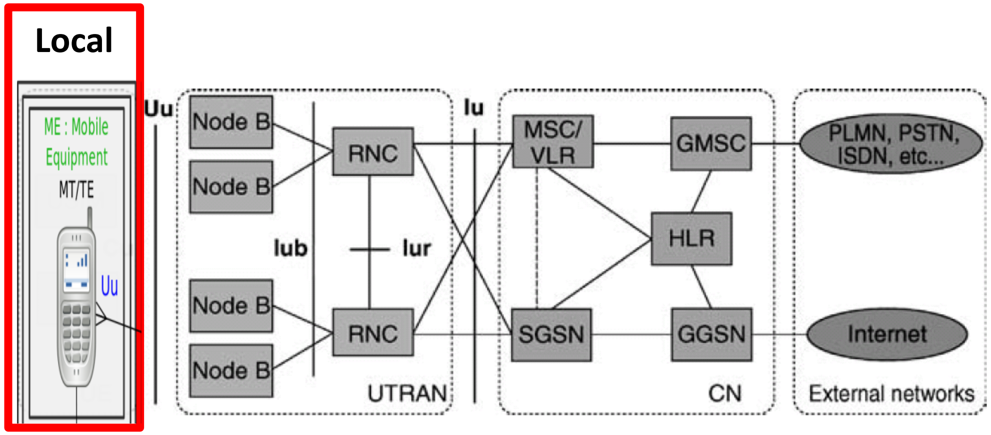
- The **various parts of the UMTS network** contribute to **fulfilling the QoS requirements** of the services in different ways.
- Specifically, the **End-to-End Service QoS provision** have been **divided into three entities**:
  - **Local Bearer Service** (between TE and MT),
  - **UMTS Bearer Service** (between MT and CN) and
  - **External Bearer Service** (between CN and other networks).

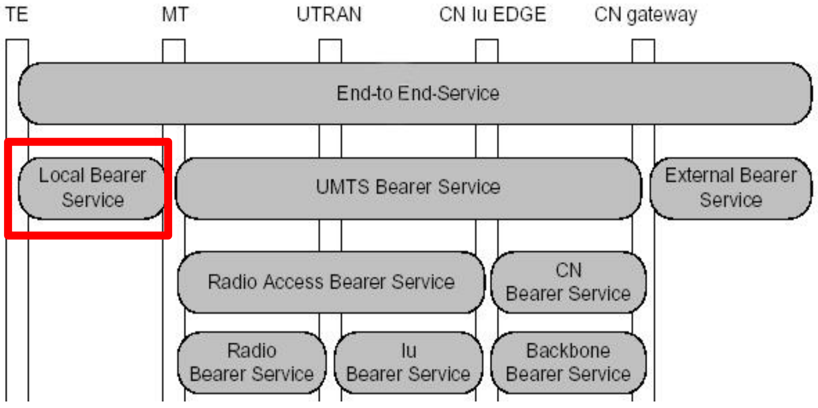




End-to-End Service QoS Provision
Local Bearer Service

- The **Local Bearer service contains the QoS mechanisms** on **how the end-user service** is **mapped between** the **Mobile Termination (MT)** and **Terminal Equipment (TE)** **(e.g., how the service will be displayed on the TE based on its capabilities)**.
- **MT** is the **part of the UE** that **controls incoming and outgoing radio transmission** **(i.e., from and to the network; Uu Interface)** and **adapts the Terminal Equipment capabilities** to those of incoming **radio transmission**.





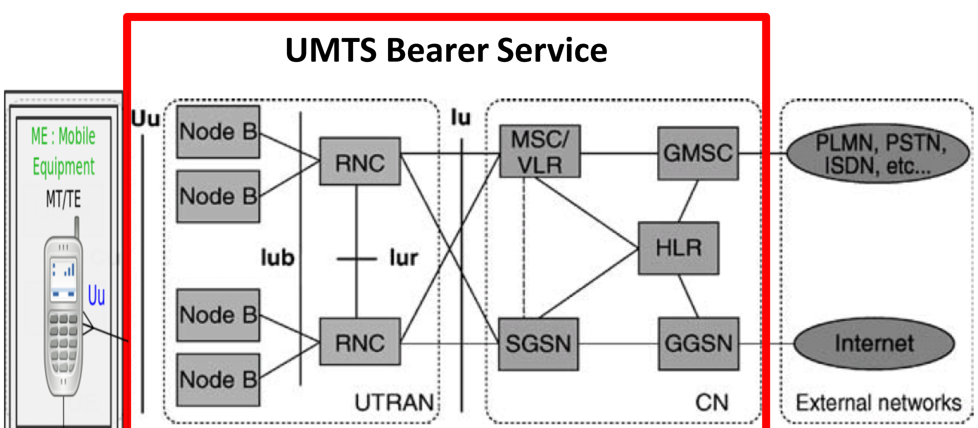
End-to-End Service QoS Provision
Local Bearer Service

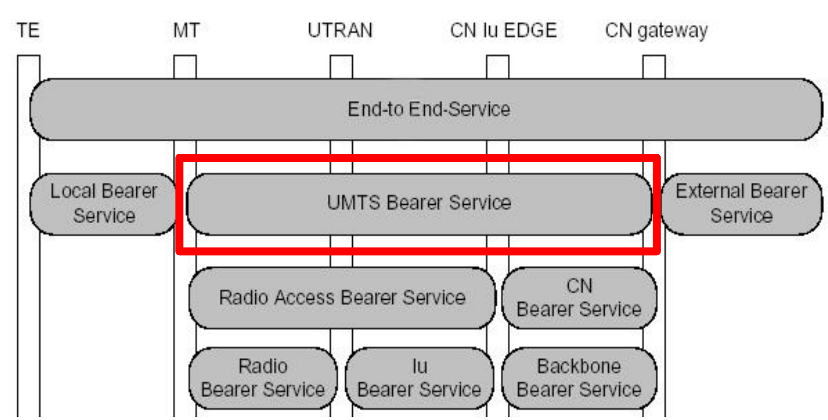
- **For example**, if **we have two Terminal Equipments (TE):**
  - One TE that has a **numeric keypad** and **limited screen size with fixed character amount**, and
  - One TE that **supports java**, thus **utilizes more flexible user interface alternatives** like **colour screen**, **full keypad** and more powerful applications,

  and we are **using both of them to browse on the internet on the same site**, the **quality of the webpage displayed on the screen of the second TE will be better** (with more color, and pictures) **even though we are browsing the same webpage**.

End-to-End Service QoS Provision
UMTS Bearer Service

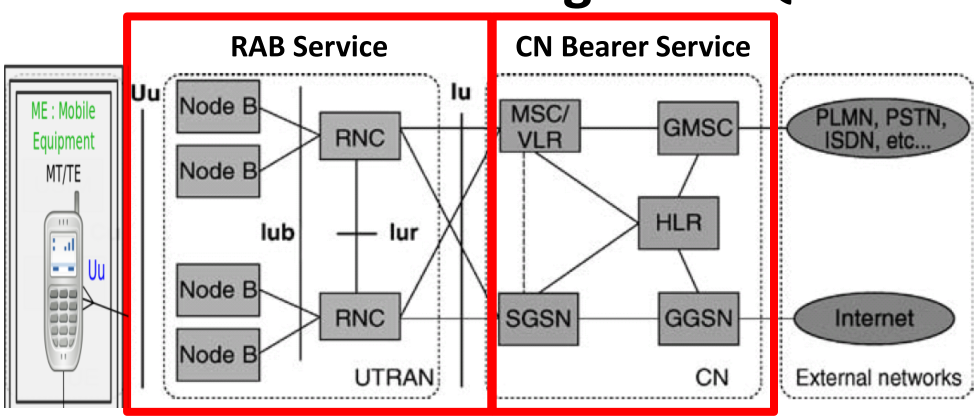
- The **UMTS Bearer Service** contains the **QoS mechanisms to guarantee the QoS over the UMTS network → Both in the UTRAN** and the **CN**.
- **However, within the UMTS network, the QoS handling in the UTRAN is different and more complex than in the CN.**
- Thus **UMTS Bearer Service is further divided into Radio Access Bearer Service and CN Bearer Service.**

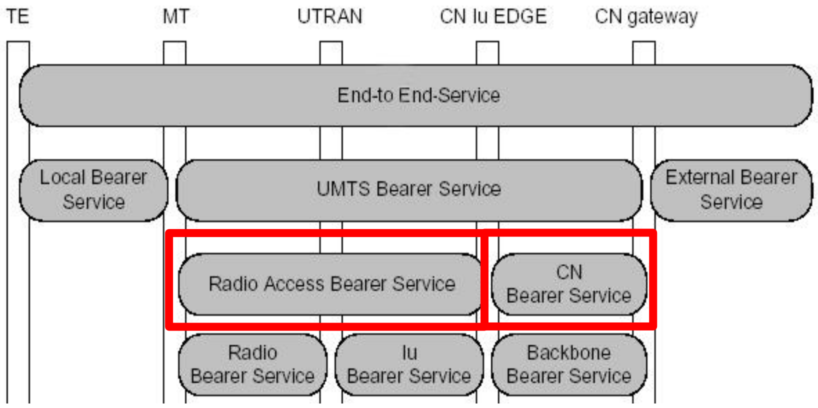




End-to-End Service QoS Provision
UMTS Bearer Service

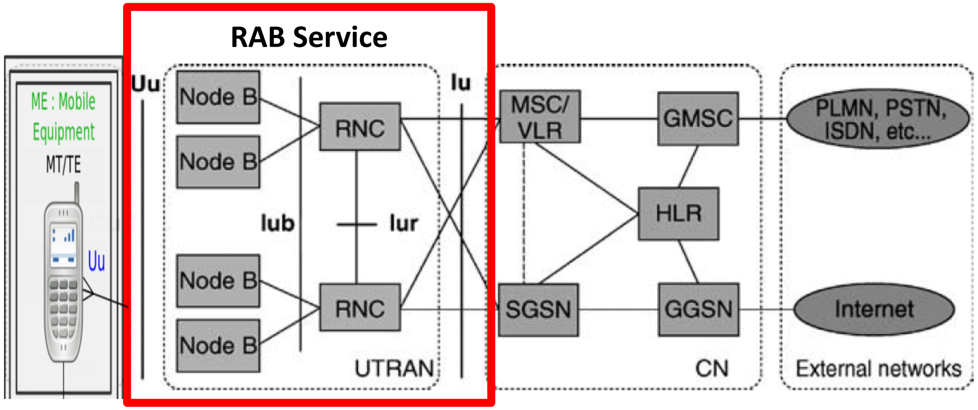
- **This division** between **Radio Access Bearer (RAB) Service** and **CN Bearer Service** is **required for the following reason**:
  - The **CN Bearer Service is quite constant** in nature **since the Backbone Bearer Service providing physical connections is also stable**.
  - On the other hand, **within UTRAN**, the **Radio Access Bearer (RAB) Service is more complicated as it experiences more changes as a function of time** due to the **mobility of the UE and this sets different challenges for QoS**.

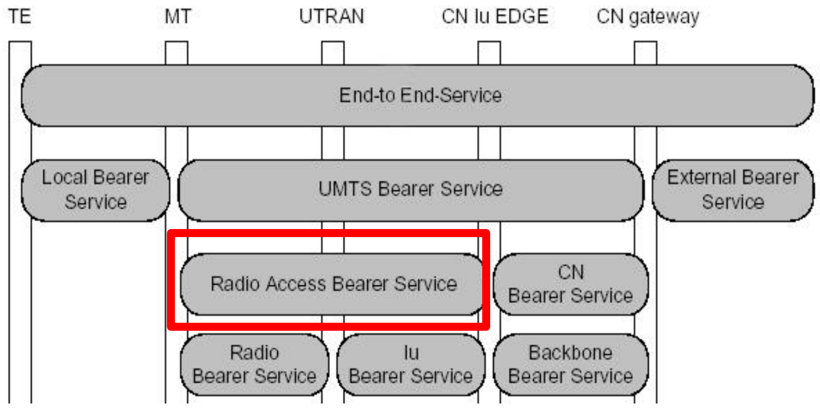




End-to-End Service QoS Provision
UMTS Bearer Service – Radio Access Bearer

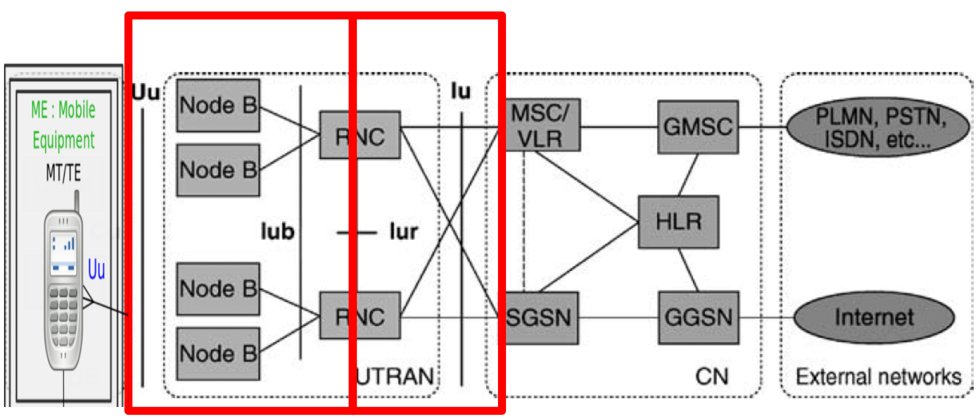
- Thus, the **main task of UTRAN** is to **create and maintain Radio Access Bearers (RABs)** for **communication** between the **User Equipment (UE)** and the **Core Network (CN)** so that **End-to-End QoS requirements** are **fulfilled in all respects**.
- **With RAB**, the **CN elements are given an "illusion" about a fixed communication path to the UE**, thus **releasing them from the need** to **take care of radio communication aspects.**

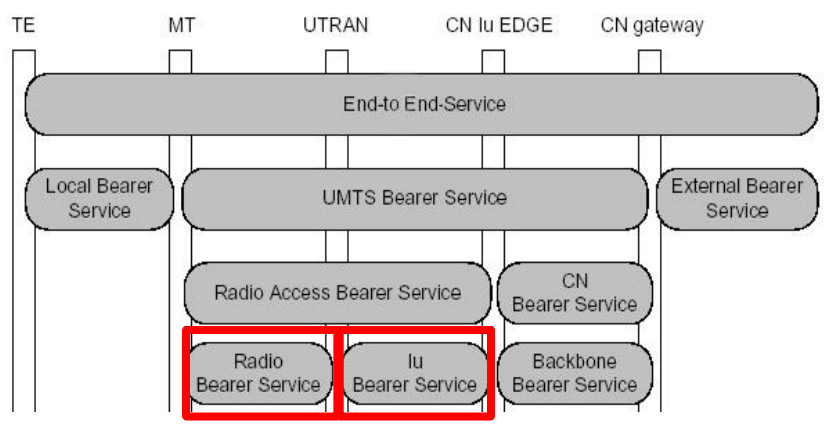




End-to-End Service QoS Provision
UMTS Bearer Service – Radio Access Bearer

- The **Radio Access Bearer (RAB) Service** is **further divided into**:
  - **Iu bearer Service** for guaranteeing the QoS between the RNC and the CN (establishment of **Iu Bearer)**
  - **Radio Bearer Service** for guaranteeing the QoS **over the radio path (i.e., between the RNC and the MT,** by **establishing a Radio Bearer)**.





End-to-End Service QoS Provision
UMTS Bearer Service

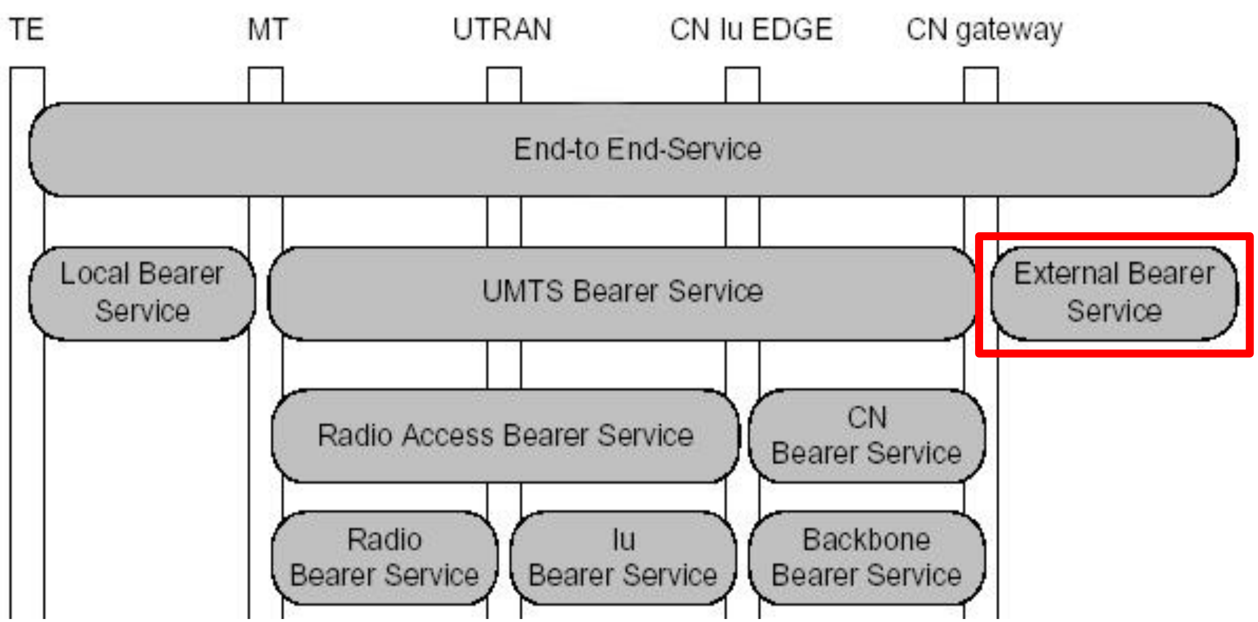
Question: Why both **Radio Bearer** and **Iu Bearer** need to exist in the system?

Answer:

- These **two Bearers** (**Radio Bearer & Iu Bearer**) **exist in the system** because **Iu Bearer** is **more stable in nature** than the **Radio Bearer.**
- This is **due to the fact that RNC must reconfigure the Radio Bearer every time the UE moves from one Cell to another**, while the **Iu Bearer remains stable**. The Iu Bearer will need to be reconfigured, only when the UE moves into a Cell that belongs to another RNC.

End-to-End Service QoS Provision External Bearer Service

- Since UMTS network **attaches itself to external networks**, the **end-user QoS** must be **handled towards the other networks too**.
- This is taken care by the **External Bearer Service**.



Open Loop Power Control

- The **UE gains access to the Network by** performing a **Connection Setup request using the RACH**.
  - The **UE measures** the **downlink power level of CPICH** (**CPICH_RSCP - Received Signal Code Power of CPICH**) and **the initial RACH power level is set** with the **proper margin** **(constant value)** due to the **Open Loop inaccuracy**.
- The **UE calculates the power** for the **first RACH preamble as:**

$$\text{Preamble\_Initial\_Power} = \text{Primary CPICH DL TX power} - \boxed{\text{CPICH\_RSCP}} + \text{UL interference} + \text{constant value}$$

*The value for the **CPICH_RSCP** is measured **by the UE**. All other parameters (Primary CPICH DL TX power, UL interference, constant value) are being received on **System Information** which is **broadcasted in the cell**.*

Open Loop Power Control

- When **establishing the first DPCCH** (Dedicated Physical Control Channel) the **UE will start** transmitting at a **power level according** to:

$$\text{DPCCH\_Initial\_power} = \text{DPCCH\_Power\_offset} - \boxed{\text{CPICH\_RSCP}}$$

  - **DPCCH_Power_offset** value is **received by the UE from UTRAN** on various **signalling messages**.
  - **CPICH_RSCP** is **measured by the UE**

*Note that the **CPICH_RSCP** is **subtracted** from the **DPCCH_Power_offset** → Thus **the better the downlink channel conditions measured by the UE, the lower will be the uplink DPCCH_Initial_power** used by the UE.*

Open Loop Power Control

- The **DPCCH_Power_offset** is **estimated by UTRAN** (more specifically by the RNC) by using the following formula

$$DPCCH\_Power\_offset = CPICH\_Tx\_power + UL\_Interference + SIR_{DPCCH} - \underbrace{10\log(SF_{DPDCH})}_{\text{Processing Gain}}$$

  - **CPICH_Tx_power** is the transmission power used by the BS on the CPICH and it is fixed.
  - **UL_Interference** is the uplink Interference caused in the cell
  - **SIR_{DPCCH}** is the **initial Target SIR** produced by the **Admission Control** (AC) for **that particular connection (**based on the QoS requirements of the connection**)**
  - **SF_{DPDCH}** is the **Spreading Factor** of the corresponding DPDCH (Dedicated Physical Data Channel). → **$10\log(SF_{DPDCH})$ is the Processing Gain that can be achieved during Despreading.**

Open Loop Power Control Downlink (DL)

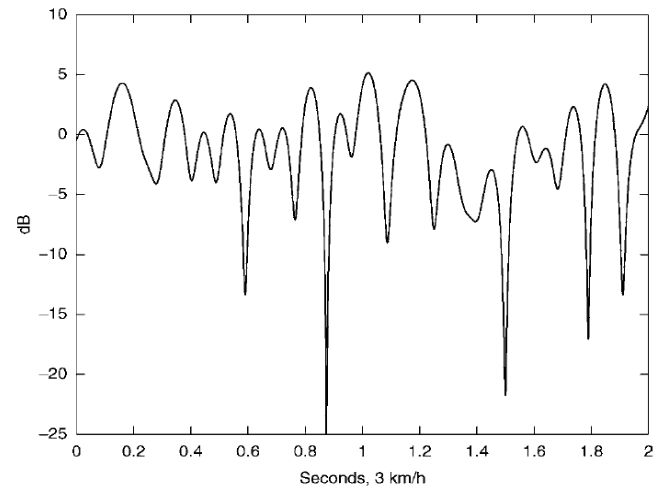
- **In Downlink**, the Open Loop Power Control is used to **set the initial power of the Downlink channels (i.e., from the BS to the UE)** based on the **Downlink measurement reports**, received by the RNC, from the UE.
- A possible algorithm for calculating the **initial Downlink power value of the DPDCH** is set up is

$$P_{Tx}^{Initial} = \frac{R \bullet (Eb/No)_{DL}}{W} \bullet \left(\frac{CPICH\_Tx\_power}{(Ec/No)_{CPICH}} - \alpha \bullet Ptx\_Total\right)$$

  - ***R:*** *Is the **Bit Rate** that the Channel will support*
  - ***W****: Is the **Chip Rate supported** (i.e., in the case of WCDMA this is 3.84Mcps)*
  - ***(Eb/No)$_{DL}$****: Denotes the value that the **signal's energy** per bit (Eb) divided by **the interference and noise power density** (No) should have for achieving a certain BER so as to **satisfy the required QoS** for the **specific service** (i.e., the SNIR required)*
  - ***(Ec/No)$_{CPICH}$****: Is reported by the UE to the Node-B and indicates the downlink channel conditions*
  - ***α:*** *Is the **DL Orthogonality factor (If a = 1 then we have perfect Orthogonality between different signals)***
  - ***Ptx_Total:*** *Is the **total carrier power used by the Node-B.** This is measured at the Node-B and reported to the RNC.*

Closed Loop Power Control

- **Closed Loop Power Control** is used for **adjusting the transmission power once the radio connection has been established**
- **It has to ensure that the transmission power used by the Transmitter will be that much so that the signal will be received by the Receiver with the requested Target SIR**.
- Thus, its main target it's to **adjust the Transmitter's signal transmission power** according to the **rapid changes** in the **radio signal strength experienced by the Receiver (due to signal pathloss, fast fading, etc.).**
  - The **weaker the signal experienced by the Receiver**, the **more power will be used by the Transmitter** in order for the **signal to reach** the Receiver with **the Target SIR**
- Hence, it **should be fast enough to respond to these changes**.

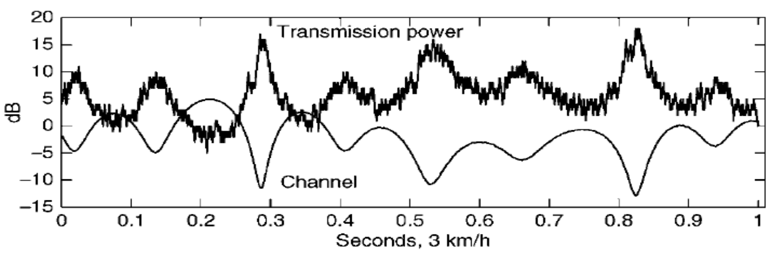


Radio Signal Strength Experienced by the Receiver during the connection (due to pathloss, fast fading, etc.)

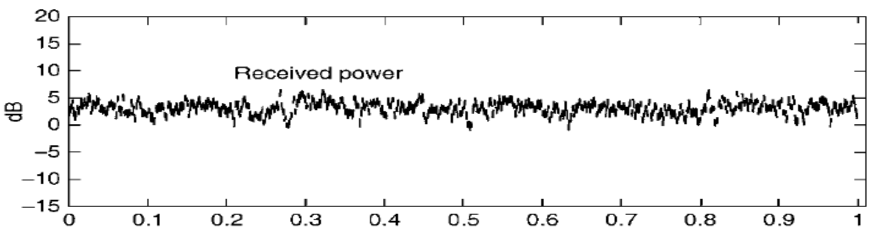
Inner Loop Power Control

- While this **fading removal is highly desirable** from the **Receiver point of view**, it **comes at the expense of increased average transmit power at the Transmitting end**.
- This means for example that for a channel **in a deep fade**, **will require the Transmitter (i.e., the Mobile Station) to use a large transmission power** to send its signal to the Base Station (so as the **signal to be received with the Target SIR required** at the Receiver), and thus it **will cause increased interference to other cells**.

In deep fades (experienced at the Receiver) Transmitter needs to use a large transmission power

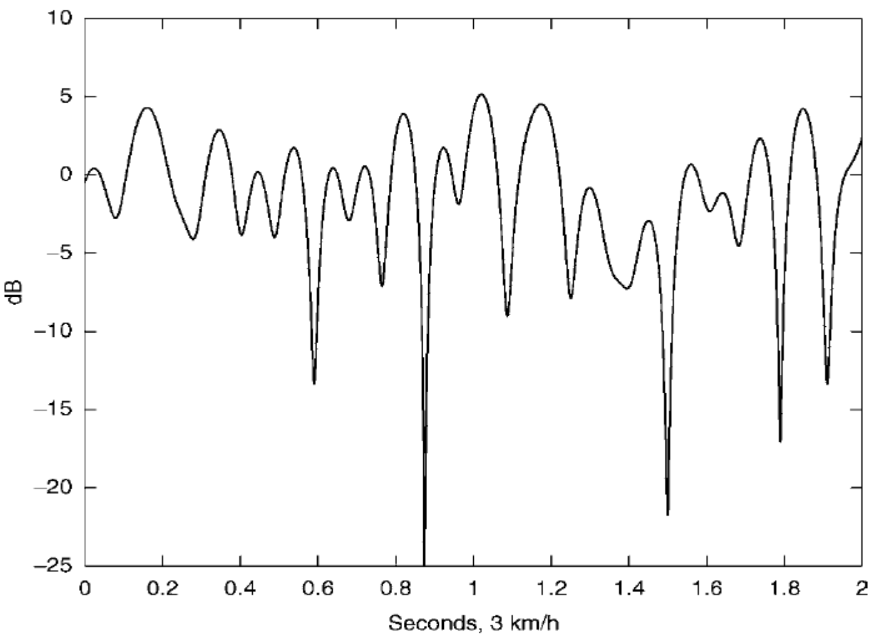


Fading is removed at the Receiver. Received Signal Strength ≈Target SIR



Inner Loop Power Control

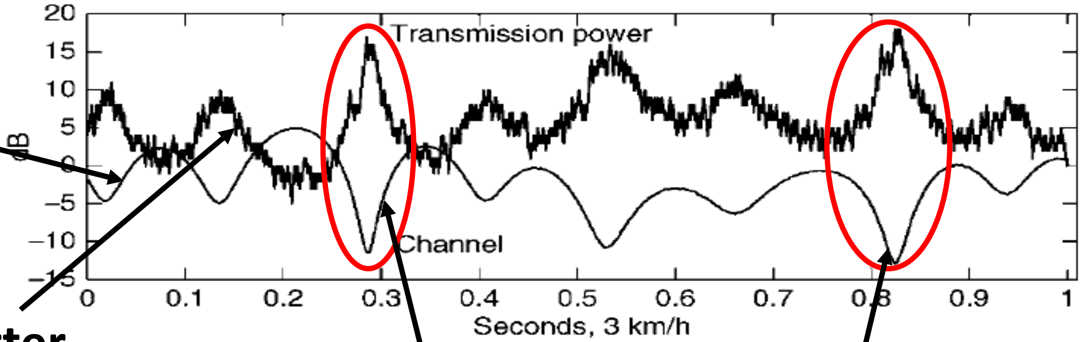
- **Fast Fading**
  - The following figure shows a **typical** **fast fading pattern** as would **be discerned for the arriving signal energy** at a **particular delay position** as the **receiver moves**.
  - We see that the **received signal power** can **drop considerably (by 20–30 dB)** **when phase cancellation of multipath reflections occurs**



Fast Rayleigh fading as caused by multipath propagation

Inner Loop Power Control

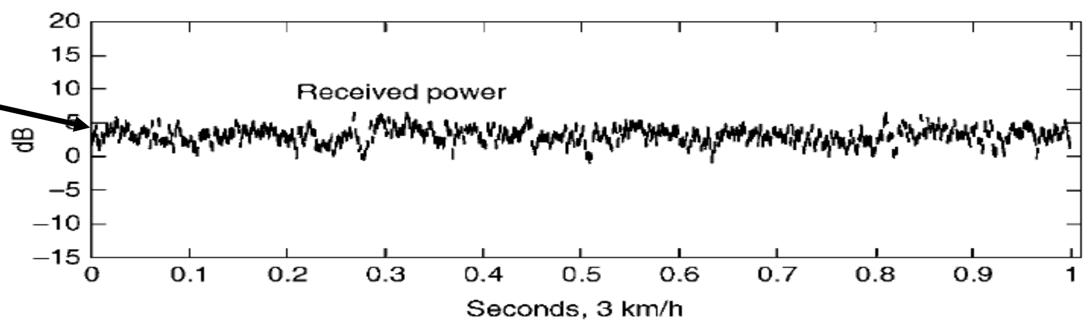
Channel Quality experienced at the Receiver (e.g., BS) due to pathloss, fast fading, etc.



Signal Power used by the Transmitter (e.g., MS) to send the signal to the Receiver (e.g., BS) is adjusted (by the Inner Loop Power Control) according to the Channel Conditions experienced at the Receiver (BS)

Deep fades in the Channel Quality experienced at the Receiver (BS) → Transmitter (MS) will use a large transmission power so as the signal to be received with the required Target SIR at the Receiver (MS)

With Inner Loop Power Control Fast Fading is compensated and Signal Strength (SIR) received at the Receiver (BS) meets the Target SIR requirements



Gain of Fast Power Control

- The **Target SIR** values as well as the **Required Relative transmission powers,** with and without fast power control are shown in Table 9.1 and Table 9.2.
- In Tables 9.1 and 9.2 the negative gains at 50 km/h indicate that an ideal slow power control would give better performance than the realistic fast power control. The negative gains are due to:
  - Inaccuracies in the SIR estimation,
  - Power control signalling errors,
  - The delay in the power control loop.

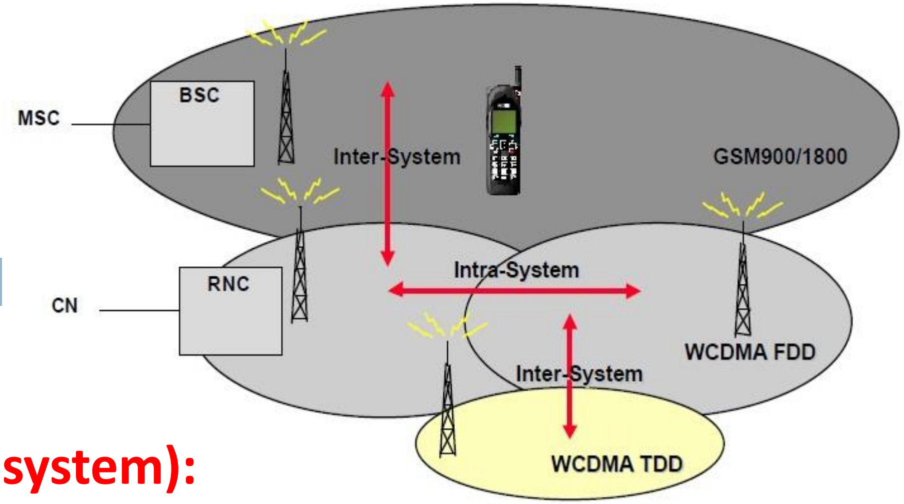
Table 9.1. Target SIR values with and without fast power control

	Slow power control (dB)	Fast 1.5 kHz power control (dB)	Gain from fast power control (dB)
ITU Pedestrian A 3 km/h	11.3	5.5	5.8
ITU Vehicular A 3 km/h	8.5	6.7	1.8
ITU Vehicular A 50 km/h	6.8	7.3	−0.5

Table 9.2. Required relative transmission powers with and without fast power control

	Slow power control (dB)	Fast 1.5 kHz power control (dB)	Gain from fast power control (dB)
ITU Pedestrian A 3 km/h	11.3	7.7	3.6
ITU Vehicular A 3 km/h	8.5	7.5	1.0
ITU Vehicular A 50 km/h	6.8	7.6	−0.8

Handover Control

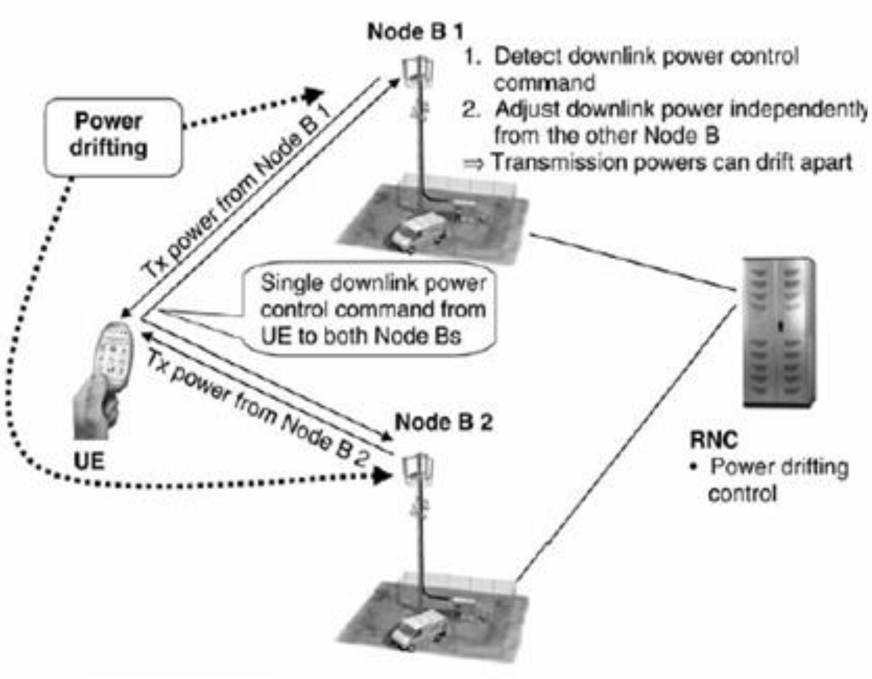


Type of Handovers:

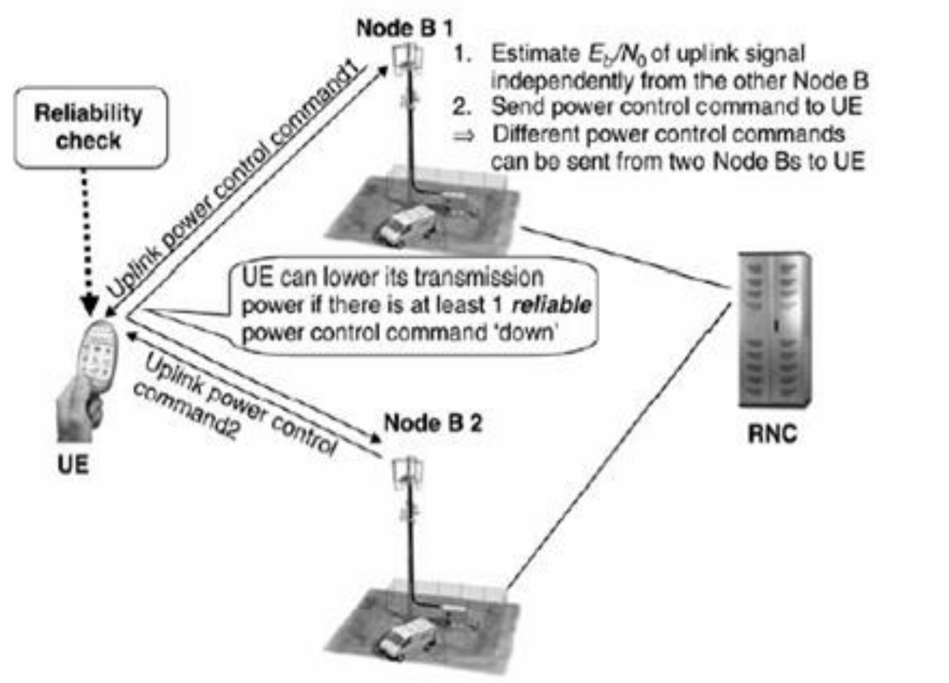
- **Intra-system Handovers (in the same system):**
  - **Intra-frequency Handover:** The **carrier frequency** of the **new radio access** in the **new Cell** **is the same** **with the old carrier frequency** in the **old Cell** to **which the UE was connected**.
    - Soft Handover, Hard Handover can be used
  - **Inter-frequency Handover**: The **carrier frequency** of the **new radio access** in the **new Cell** **is different** **from the old carrier frequency** in the **old Cell** to **which the UE was connected**.
    - Only Hard Handover can be used
- **Inter-system Handovers:**
  - Handovers **between different Radio Access Technologies** (RATs).
  - For example handover **between UMTS and GSM**, or between **WCDMA FDD** and **WCDMA TDD**.

Power Control in Soft Handover

- **Fast power control** in **soft handover** has two **major issues** that are **different from the single-link case**:
  - **Power Drifting** in the Node B powers in the downlink, and
  - **Reliable detection** of the uplink power control commands in the UE.



Downlink power drifting in soft handover



Reliability check of the uplink power control commands in UE in soft handover

Power Drifting

- UE sends a **single command to control the downlink transmission powers**; this is **received by all Node Bs in the Active set**.
  - The **Node-Bs detect** the **command independently**, since the **power control commands cannot be combined in RNC** because it would **cause too much delay** and **signalling in the network.**
- Due to **signalling errors** in the **air interface**, the **Node-Bs may detect this power control command** in a different way.
  - It is possible that **one of the Node-Bs lowers its transmission power to that UE,** while **the other Node-B increases its transmission power**.
  - This **behaviour leads to a situation** where the **downlink powers start drifting apart**

Power Drifting

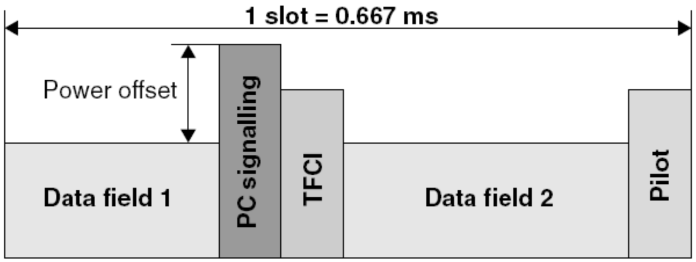
- **Power drifting is not desirable**, since it mostly **degrades the downlink soft handover performance.**
- **Solution**:
  - *RNC can receive information from the Node Bs concerning the transmission power levels of the soft handover connections. These levels are averaged over a number of power control commands, e.g. over 500 ms or equivalently over 750 power control commands. Based on those measurements, RNC can send a reference value for the downlink transmission powers to the Node Bs. The soft handover Node Bs use that reference value in their downlink power control for that connection to reduce the power drifting. The idea is that a small correction is periodically performed towards the reference power. The size of this correction is proportional to the difference between the actual transmitted power and the reference power. This method will reduce the amount of power drifting.*

Reliability of Uplink Power Control Commands

- **All the Node-Bs in the active set** send an **independent power control command to the UEs to control the uplink transmission power**.
- It is **enough if one of the Node Bs** in the active set **receives the uplink signal correctly.**
  - Therefore, the **UE can lower its transmission power** if one of the **Node Bs sends a power-down command**.
- **Maximal ratio combining** can be **applied to the data bits in soft handover in the UE**, because the **same data is sent from all soft handover Node Bs,** but **not to the power control bits** because they **contain different information from each of the Node Bs**.
  - Therefore, the **reliability of the power control bits** is **not as good as for the data bits,** and a **threshold in the UE is used to check** the **reliability of the power control commands**.

Reliability of Uplink Power Control Commands

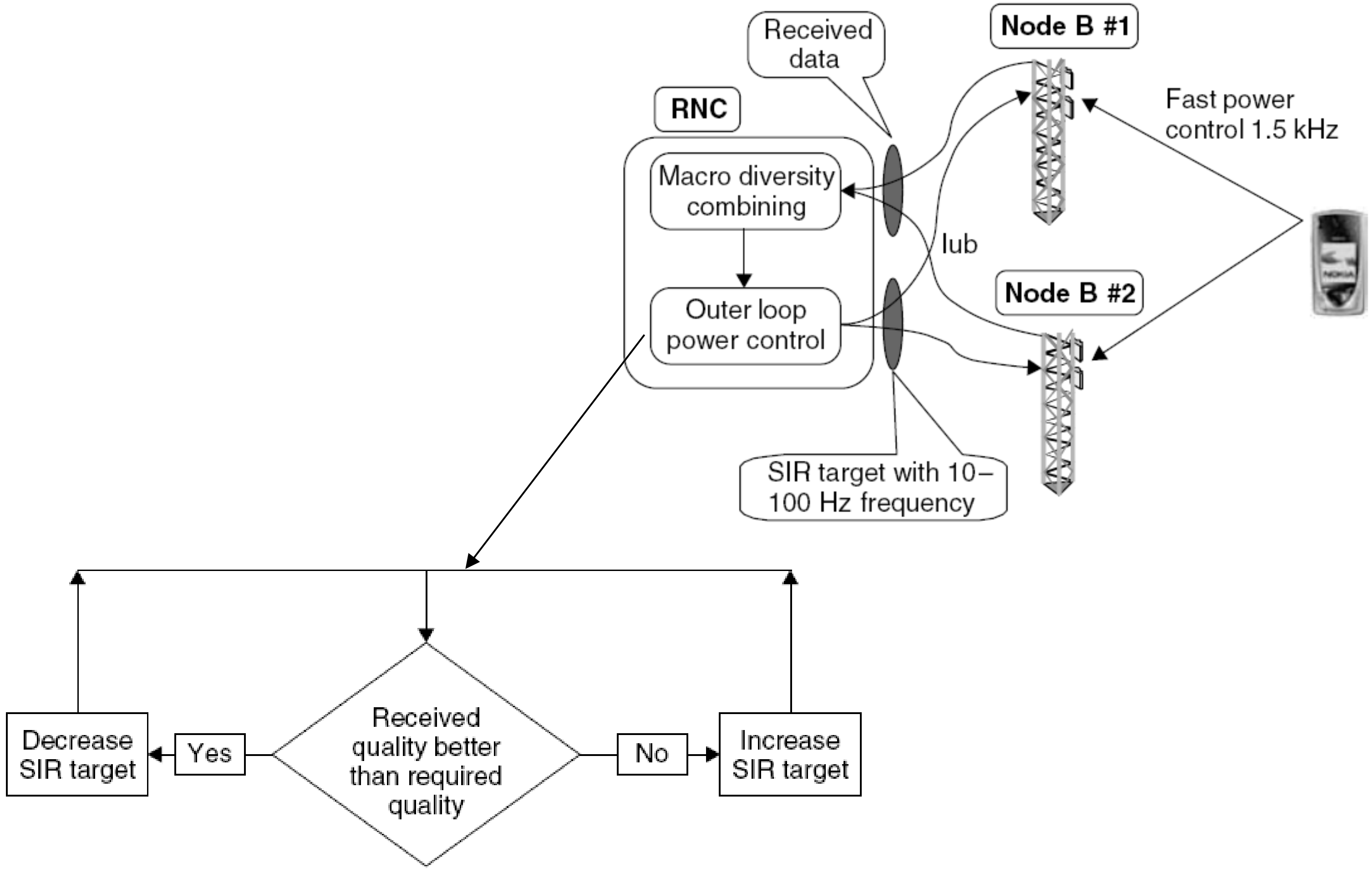
- Very **unreliable power control commands should be discarded** because they are **corrupted by interference**.



ıre 9.8. Power offset for improving downlink signalling quality

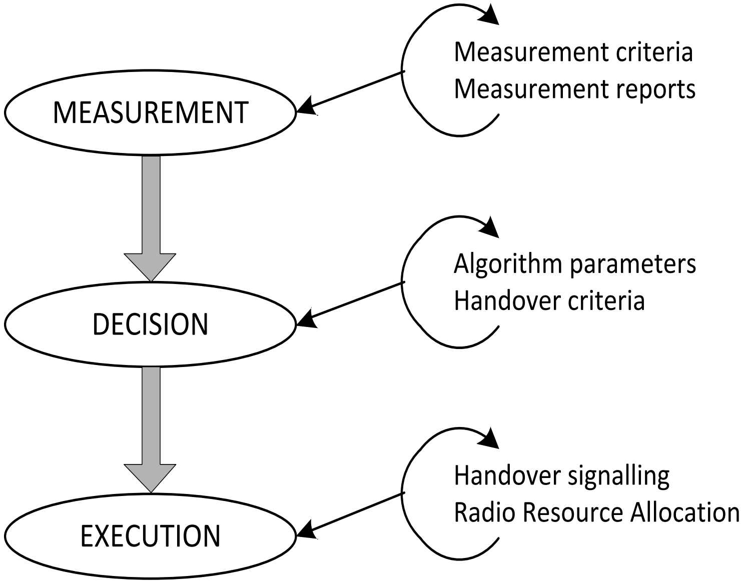
- **Solution:**
  - *The power control signalling quality can be improved* ***by setting a higher power for the dedicated physical control channel (DPCCH)*** *than for the dedicated physical data channel (DPDCH) in the downlink if the UE is in soft handover. This power offset between DPCCH and DPDCH can be different for different DPCCH fields: power control bits, pilot bits and TFCI.*
  - *The reduction of the UE transmission power is typically up to 0.5 dB with power offsets.*

Power Control in Soft Handover



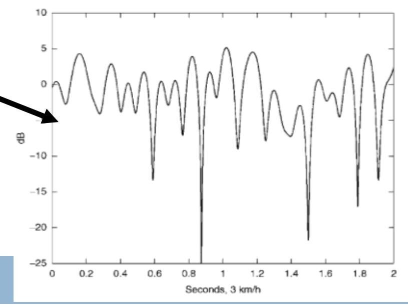
Handover Process

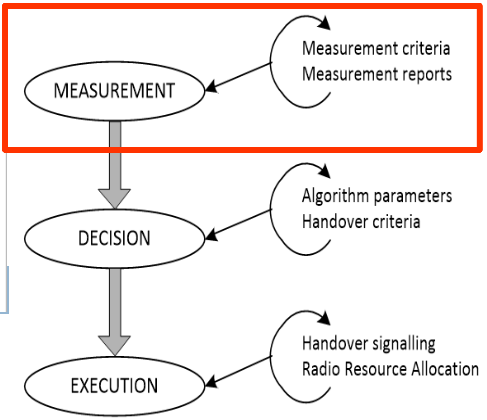
- The **basic handover process** consists of three main phases
  - **Measurement Phase**
  - **Decision Phase**
  - **Execution of the Handover**



Handover Process

The **effect of Fast Fading** needs to be **removed** from the **measurements** that will be **reported to the RNC**

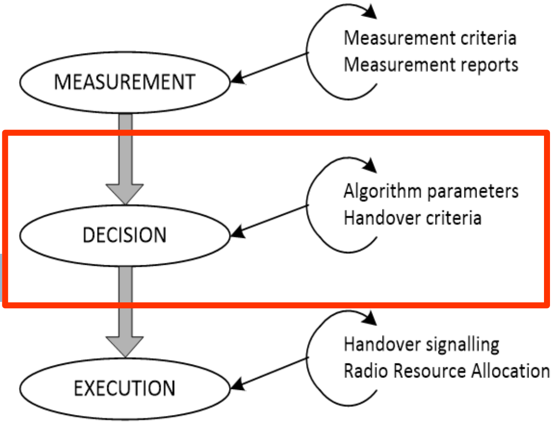




Measurement Phase:

- **For handover purposes, during the connection** the **UE continuously measures** the **CPICH signal strength** of the **Current** and **Neighboring Cells** and **reports the results to its Serving RNC**.
- **These reports** constitutes **the basic input to the handover algorithm**.
- **Note that the CPICH signal strength of the radio channel may vary drastically due to fast fading and signal path loss, resulting from the cell environment** and **user mobility.**
  - **This could cause frequent and unnecessary handovers, if in the measurements the effect of fast fading is considered**
  - **Therefore cell measurements are filtered in the UE** in order to **average out the effect of fast fading (remember that fast fading effect is compensated (εξουδετερώνεται) by Fast power control)**.

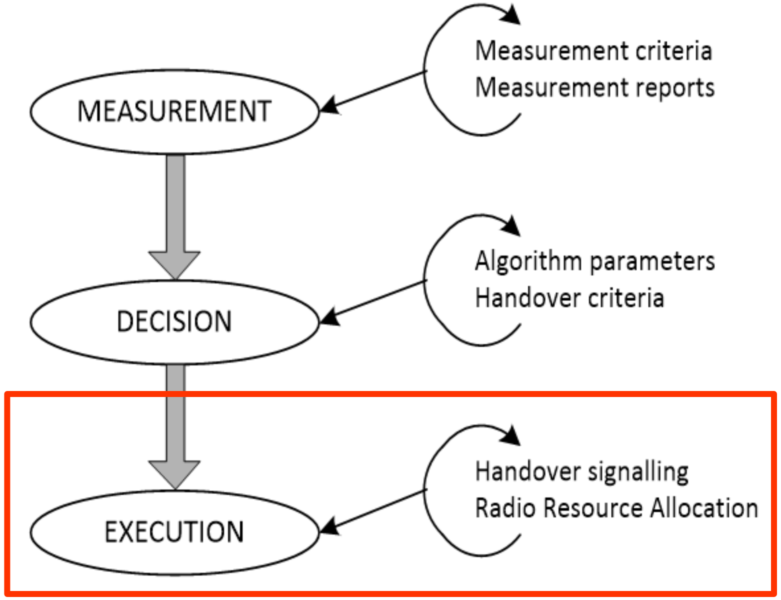
Handover Process



- **Decision Phase:**
  - **Consists of (by the RNC):**
    - **The comparison** of the values included in the **handover measurement report received from the UE with the Handover Criteria (E.g., Handover thresholds used).**
    - The **assessment of the overall QoS of the connection** and **its comparison with the requested QoS attributes (so as to indicate if the handover is really required to be performed immediately)**
  - **Depending on the outcome** of this comparison, the **handover procedure may** or **may not be Triggered (i.e., if the QoS of the connection with the Old cell meets the QoS criteria, the RNC may decide to postpone the handover if the Target cell is overloaded)**.

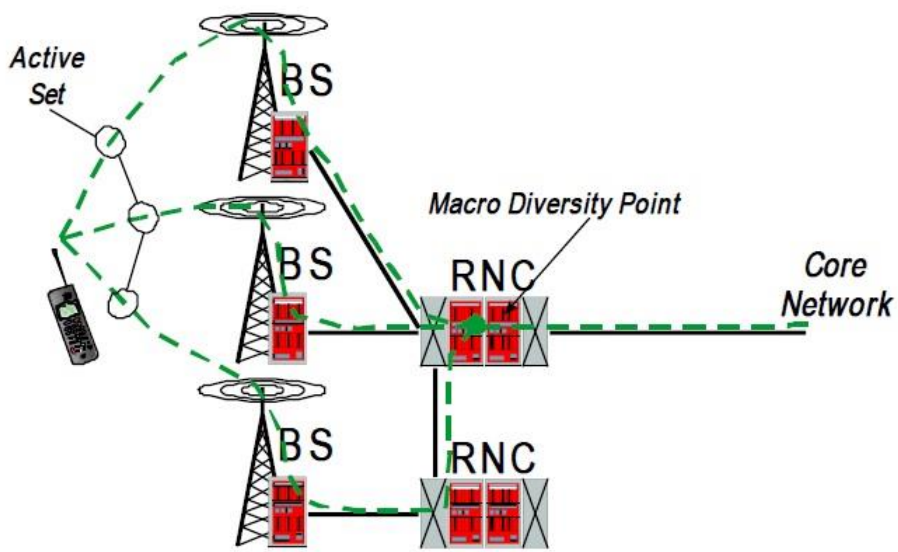
Handover Process

- **Execution of the Handover**
  - The **required signaling is performed** in order to **inform the UE about the handover decision**
  - The **required resources** in the **new cell** **are allocated**.
  - The **resources used** in the **old cell** **are released**



Handover Types
Soft Handover (and Macro-Diversity)

- **Question: What is the different between Soft Handover (SHO) and Macro-Diversity?**
- **Answer: Soft Handover is the procedure. Once it is performed, the result is a Macro-diversity situation.**



Handover Types
Soft Handover (and Macro-Diversity)

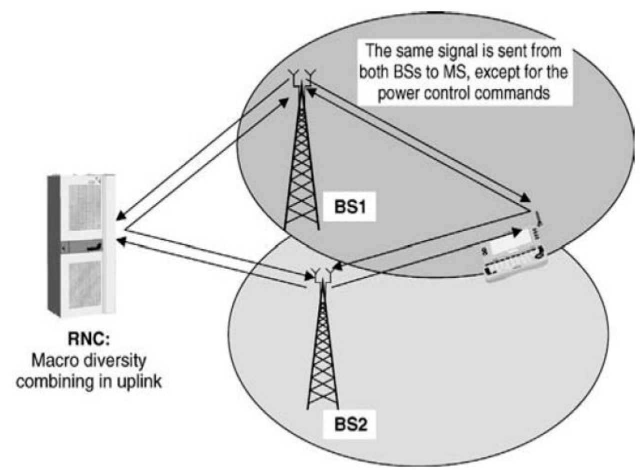
- The typical Handover threshold values used by the Soft Handover Algorithm for **adding** and **dropping** BSs from the **Active Set (includes a List of BSs having a connection with the UE)** in order to **achieve a macro-diversity gain** are shown below:

Typical handover parameters

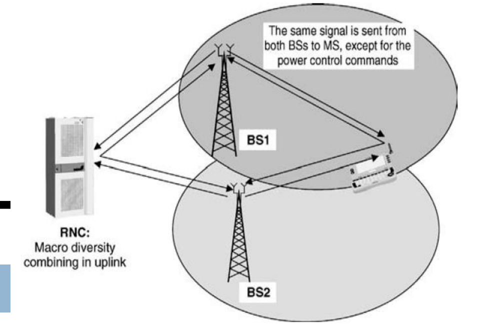
Window_add	Window_drop
1–3 dB	2–5 dB

Handover Types
Soft Handover (and Macro-Diversity)

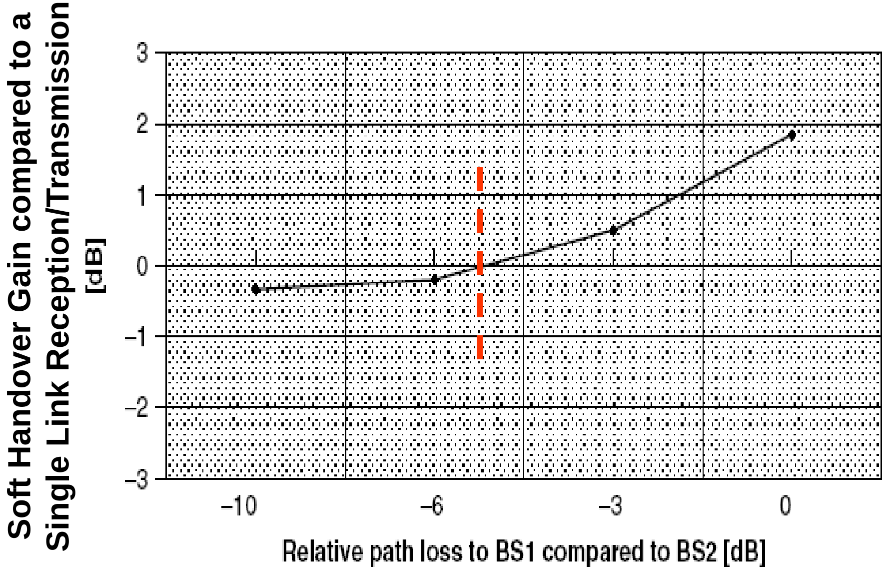
- The gain of macro-diversity is highest when the path losses of the Soft Handover branches (i.e., the connections with the different Base Stations) are about equal (i.e., the CPICH signal strength received from the different Base Stations taking part in the Soft Handover are about equal).
- If one of the participating Base Stations, taking part in the Soft Handover process, is clearly stronger than others, then macro-diversity cannot provide much gain (More specifically in this case Soft Handover will make things worse – more interference will be caused due to the bad links)
- If the relative path loss difference between the participating BSs is very large, the Soft Handover is not beneficial as this can cause for example an increase in the UE Transmission Power (Therefore Soft Handover should be used with care).



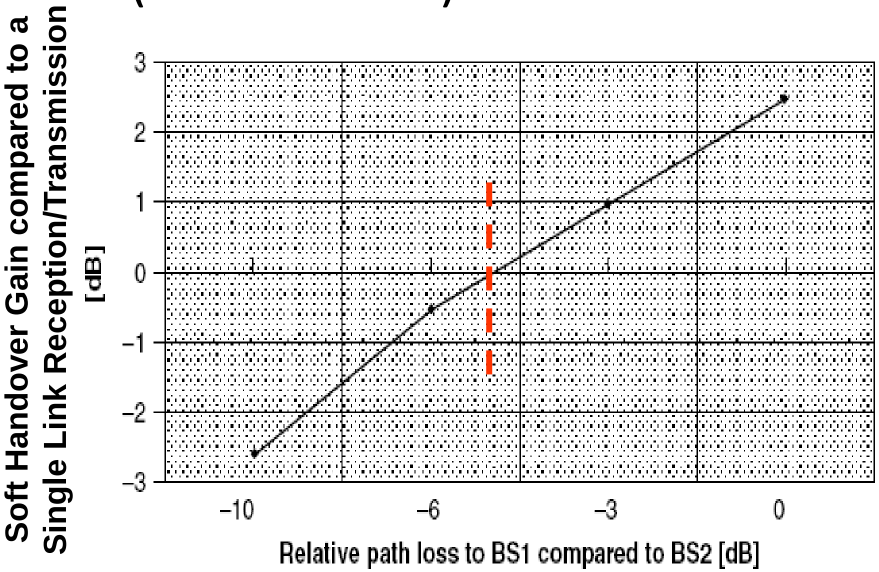
Handover Types
Soft Handover (and Macro-



- **Example:** The figures below show the simulation results of 8 kbps speech in an ITU Pedestrian A channel, at 3 km/h, assuming that the UE is in Soft Handover with two Node-Bs (BS1 and BS2)



Soft handover gain in uplink transmission power (positive value = gain, negative value = loss)

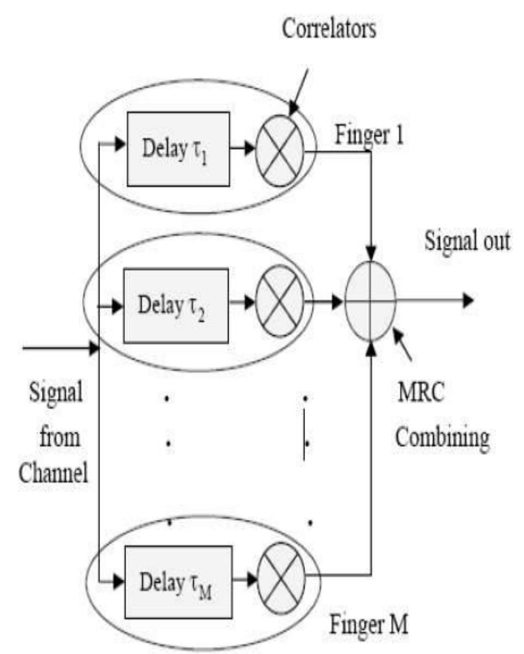


Soft handover gain in downlink transmission power (positive = gain, negative = loss)

Both for the Uplink and Downlink connections, if the signal strength received from BS_2 is weaker than ~5dB (or more) then Soft Handover is not beneficial

Handover Types
Soft Handover (and Macro-Diversity)

- **Macro-diversity in the Downlink (From BSs to MS)**
  - **In the Downlink, the macro-diversity components (i.e., the signals received by the different BSs taking part in the Soft Handover process) are received in the Mobile Station** by means of **RAKE processing.**
  - **RAKE Processing:** The **macro-diversity components** are **determined (by the RAKE receiver fingers), differentiated** and **summed up** from the **Mobile Station RAKE, combined into a stronger signal (i.e., increases the received SIR; Soft Combining).**
  - **Thus, the more RAKE fingers the Mobile Station has, the better receiving performance it has, providing that all fingers find a separate diversity component.**



Handover Types
Soft Handover (and Macro-Diversity)

- **Macro-diversity in the Uplink (From MS to BSs)**
  - **In the uplink**, the **macro-diversity is performed differently (Selective Combining).**
  - **The frame is transmitted from the MS to all the BSs included in the Active Set.**
  - **The more the Base Stations that can receive the frame from the Mobile Station**, **the better the probability that some of them will receive it successfully**.
    - **Therefore the UE transmission power level can be lower if macro-diversity is used in the Uplink.**

Handover Types
Soft Handover (and Macro-Diversity)

- **Soft Handover Benefits:**
  - **Mobile Stations at the cell edges can collect more signal energy if it is in Soft Handover compared to having only a single link to a Base Station → It increases the reliability of the transmission**
  - **Reduces the transmit power requirement of each link used (both at the Base Station and at the Mobile Station) → Reduces the overall uplink and downlink interference levels caused in the Networks**
  - **Mobile Stations at the boundary among several cells uses the minimum transmit power** on either link **→ Saves Mobile Station's battery.**
  - **If a Mobile Station is in Soft Handover, the connection is not totally lost if one branch gets shadowed.**

Handover Types
Soft Handover (and Macro-Diversity)

- **Soft Handover Drawbacks (mostly in the downlink):**
  - **Since information must be sent over multiple links, that repetition decreases the efficiency of resource utilization (i.e., channels).**
  - **More transmitted signals may mean more energy in the air,** which means **more interference to the radio environment in the downlink direction**.
  - **The control procedure in the UTRAN, has to be very clever in order to meet the conflicting demands of mobility and low interference levels. → Soft Handover branches should be added to a connection only when the estimated resulting total interference level is less that it would be without Soft Handover.**

Handover Types
Soft Handover (and Macro-Diversity)

- **Macro-diversity in the Downlink (From BSs to MS)**
  - However **there is a tradeoff**, from the **Network point of view**.
    - **Having many macro-diversity components received by the MS** might sometimes **decreases the Network's performance**.
  - For example, even though that **every new signal transmission** (i.e., each macro-diversity component) can **increase the downlink transmission performance of the network** (as less transmission power will be required by each Base Station), **if too many Base Stations are used** in the **Soft Handover procedure**, **the downlink interference levels in the air interface will increase** instead of decrease and thus **converse the usefulness of the Soft Handover**.

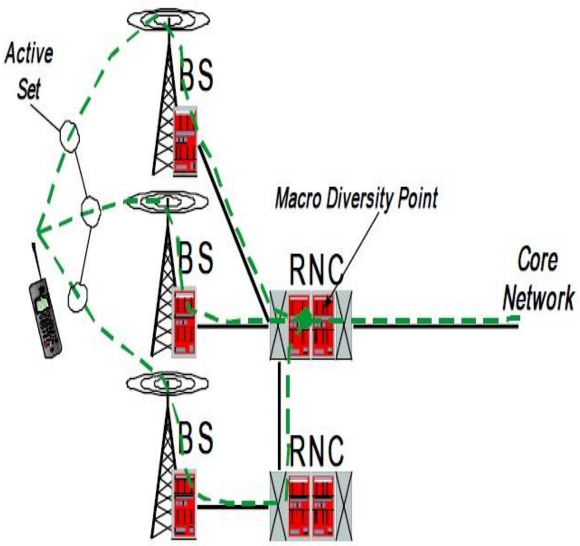
Handover Types
Soft Handover (and Macro-Diversity)

- **Macro-diversity in the Uplink (From MS to BSs)**
  - **In the uplink**, the **effects of macro-diversity are only positive**, as **the more the Base Stations that can receive the signal from the Mobile Station, the better the probability that some of them will receive it successfully**.
    - **Therefore the UE transmission power level can be lower if macro-diversity is used in the Uplink.**
  - Also macro-diversity in the uplink **does not generate more transmissions or interference**, **as the same signal will be received** by **all the Base Stations included** in the **Active Set.**

Handover Types

Soft Handover (Soft and Selective Combining)

- **Soft and Selective Combining Gain (Achieved in Macro-diversity situation)**
  - The **received Signal to Interference ratio (SIR) can be increased** when the **MS is in Soft Handover**.
  - If the **Received SIR increases (at the Receiver)**, means that the **transmit power (at the Transmitter) can be decreased → Reduce interference (and thus increase capacity) and Save Battery (in case the Transmitter is the MS).**



Handover Process Description

The **Handover procedure** is **composed of a number of single functions**:

- **Handover Measurements** (by the UE) → **CPICH Ec/No measurements of the set of cells monitored**
- **Filtering of Measurements** (by the UE) → So as to **average out the effect of fast fading.**
- **Reporting of Measurement results** (the UE reports to the RNC)
- The **Handover Algorithm is executed** (in the RNC)
  - If **Active Set size = 1** then **Hard Handover** will be **performed**.
  - If **Active Set size > 1** then **Soft Handover** will be **performed**.
- **Execution of Handover** (**Based on the decision taken by the Handover Algorithm running in the RNC**)

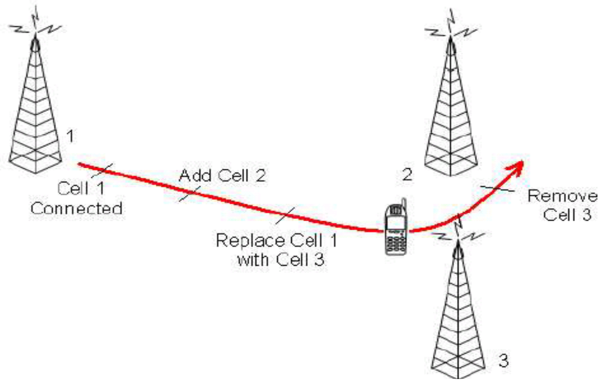
Handover Process Description

- **Active set: List of cells having a connection with the User Equipment (UE).**
  - In **case of Hard Handover**, the **Active Set size is equal to 1**. This is due to the fact that **during Hard Handover the mobile UE** can **have radio links only with one Base Station.**
  - In **case of the Soft Handover** the **Active Set size usually varies from 2 to 3**.

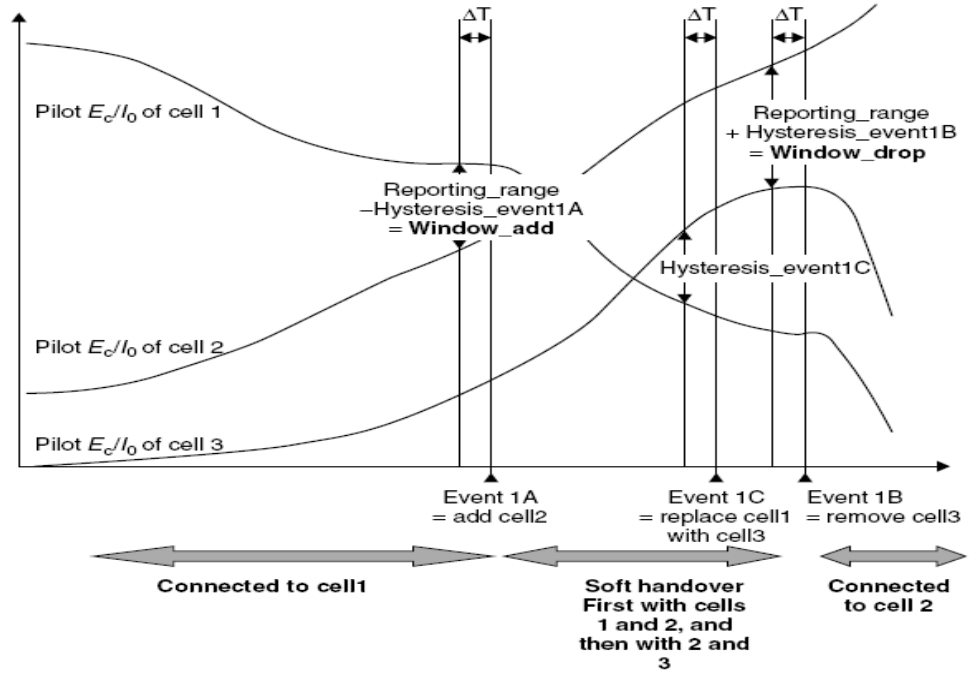
- **Monitored set: List of (Neighbouring) cells** whose **Common Pilot channel (CPICH) signal quality** is **continuously measured but not strong enough to be added to the Active Set.**

Handover Process Description

- The **handover decision making** is **based on a comparison** made **between an observed value (i.e., the measured CPICH Ec/No of the Serving and Neighboring cells)** and **a predetermined threshold**, where the **threshold value is typically chosen in a manner so as to maximize the system capacity**.
- **Based on the CPICH Ec/No measurements of the set of cells Monitored**, the **Handover Algorithm (running in the RNC) decides** which of the **three basic actions to perform**; it is possible to ***Add, Remove*** or ***Replace*** a **Node-B** in the **Active cell.**
- **In the case where** the **Active Set size is set equal to 1**, the UE can have **radio link connections only with one Node B** → Thus **only Hard Handover can be performed**.
  - That means that **during the movement of the UE from one Cell to another, only the *Replacement action*** can be performed.



- *Reporting_range* is the threshold for soft handover
- *Hysteresis_event1A* is the addition hysteresis
- *Hysteresis_event1B* is the removal hysteresis
- *Hysteresis_event1C* is the replacement hysteresis
- *Reporting_range - Hysteresis_event1A* is also called Window_add
- *Reporting_range + Hysteresis_event1B* is also called Window_drop
- *ΔT* is the time to trigger
- *Best_ Pilot_Ec/Io* is the strongest measured cell in the Active Set
- *Worst_Old_Pilot_Ec/Io* is the weakest measured cell in the Active Set
- *Best_candidate_Pilot_Ec/Io* is the strongest measured cell in the Monitored Set
- *Pilot_Ec/Io* is the measured and filtered quantity.

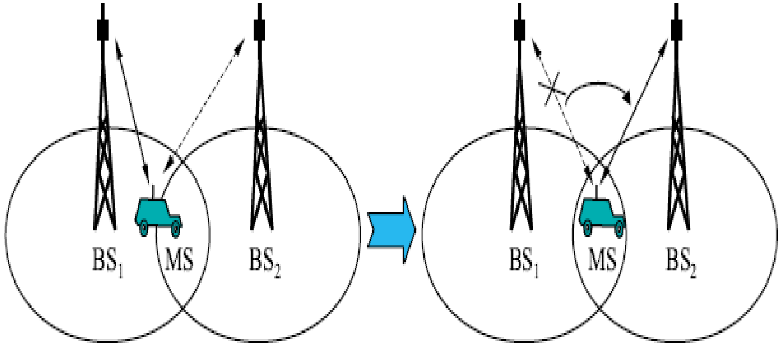


General scheme of the WCDMA soft handover algorithm

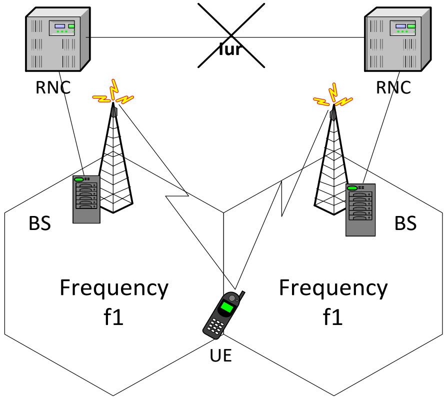
- If ***Best_candidate_Pilot_Ec/Io > Best_Pilot_Ec/Io – (Reporting_range - Hysteresis_event1A)*** **for a period of ΔT** and the **Active Set** is **not full**, the **cell is added** to **the Active Set**. This event is called Event 1A or ***Radio Link Addition***.
- If the **Active Set is full** and ***Best_candidate_Pilot_Ec/Io > Worst_Old_Pilot_Ec/Io + Hysteresis_event1C*** for a **period of ΔT**, then **the weakest cell in the Active Set is replaced by the strongest candidate cell** (i.e., **the strongest cell** in the **Monitored Set**). This event is called Event 1C or ***Combined Radio Link Addition and Removal***. In the example shown above, the maximum size of the Active Set is assumed to be two.
- If ***Worst_Old_Pilot_Ec/Io < Best_Pilot_Ec/Io – (Reporting_range + Hysteresis_event1B)*** **for a period of ΔT**, then the **cell is removed from the Active Set**. This event is called Event 1B or **Radio Link Removal**.

Handover Types
Hard Handover

- During a **Hard Handover**, **the old connection with the old Cell is released before the new connection with the new Cell is established** (**“break-before-make” connection**).

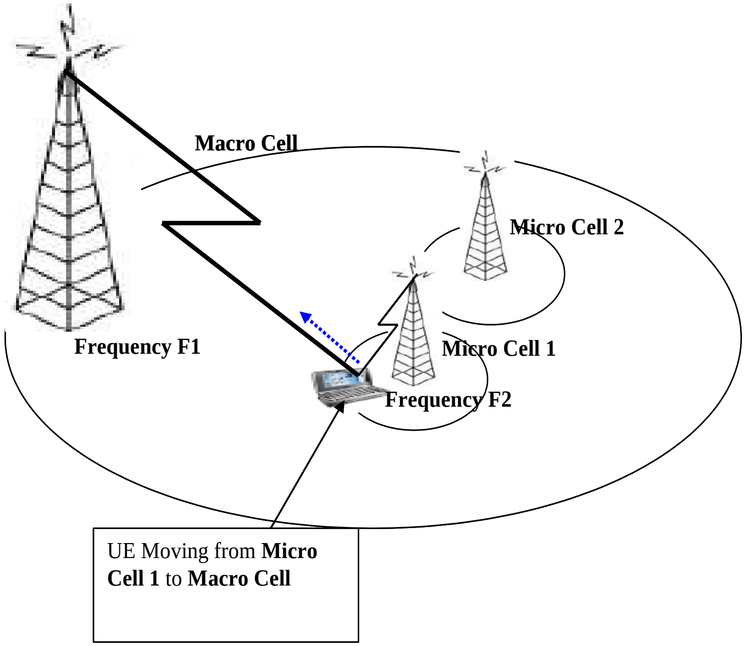


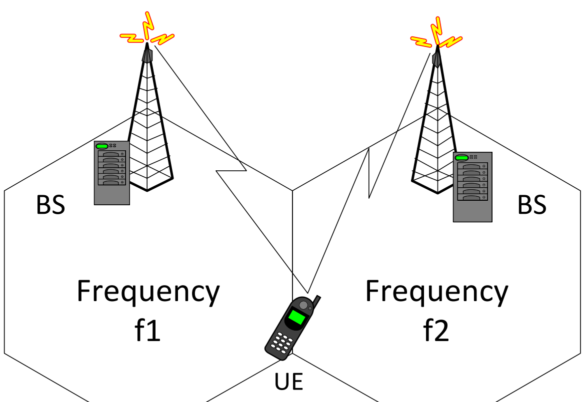
- **Intra-frequency Hard Handover**
  - The **new carrier frequency**, to which the UE is accessed after the handover procedure **is the same as the original carrier frequency but no network support for Soft Handover exists.**
  - This is due to the **lack of direct communication (Iur interface) between the two RNCs controlling the BSs**.



Handover Types
Hard Handover

- **Inter-frequency Hard Handover**
  - The **carrier frequency of the new radio access is different from the old carrier frequency to which the UE is connected.** For example:
    - Handover in **Hierarchical Cell Structure (HCS)** between separate cell layers (From **Micro** to **Macro Cells**)
    - Handover between **different Frequency Carriers**





Load Control (LC)

- One **important task of the RRM functionality** is to **ensure that the system is not overloaded** and **remains stable**.
- If the **system is properly planned**, and **the Admission Control** and **Packet Scheduler work sufficiently well**, **overload situations should be exceptional**.
- However, If **overload is encountered**, the **Load Control functionality returns the system quickly back to the Targeted load** (the targeted load is **defined by Network Operator during the Radio Network Planning**.
- **Load Control** functionality is mainly **located in the RNC but also in the Node-B.**

Load Control (LC)

- **Possible load control actions**, in order to **reduce load** are listed below:
  - **Downlink fast load control**: **Deny Downlink power-up TPC commands (i.e., commands instructing the BS to increase its downlink transmission power) received from the UE**.
  - **Uplink fast load control**: **Reduce the Uplink Target SIR** used by the **uplink Fast Power Control (this will reduce the uplink transmission power used by the UE → Results in uplink interference reduction)**.

Load Control (LC)

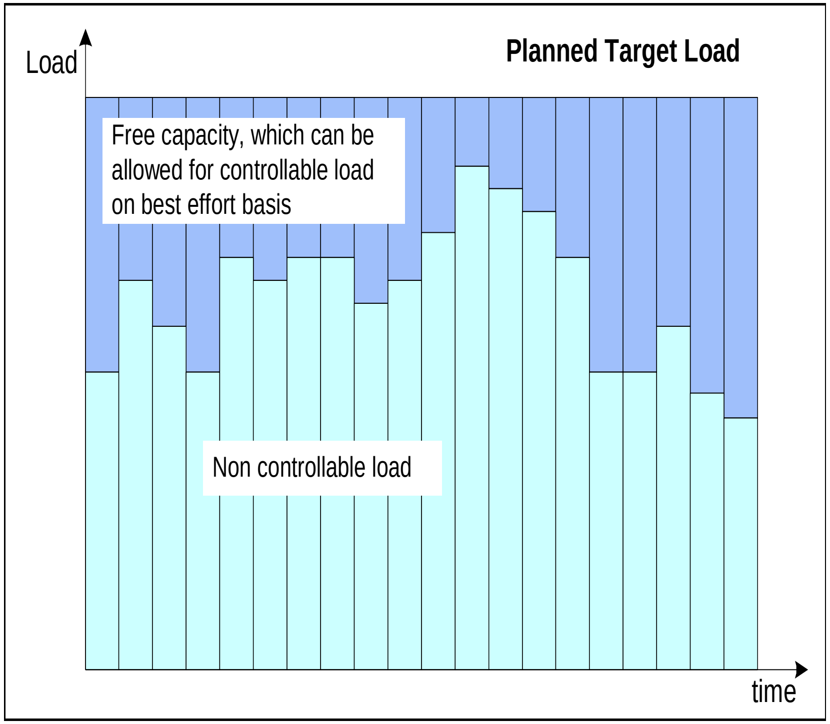
- **Handover UEs to another WCDMA carrier or to another system (e.g., GSM/GPRS).**
- **Decrease Bit Rates of UEs using Real Time services (i.e., decrease from 128kbps to 64kbps streaming video; this will improve the system performance as a tradeoff of a lower quality video).**
- **Drop low priority calls** in **a controlled fashion**

Load Control (LC)

- The **first two in this list** are **fast actions** that **are carried out within a Node-B** **(in collaboration with the RNC)**.
  - These actions can take place **within one time slot**, i.e. **with 1.5 kHz frequency**.
- The **other load control actions** are **typically slower**.
  - **Packet traffic and bit rates** is **reduced by the Packet Scheduler**.
  - **Inter-frequency** (handover to another WCDMA carrier) and **inter-system handovers** (handover to GSM) can also be used for **load balancing**.

Packet Scheduling (PS)

- The **cell's radio resources are shared between** **Real Time (RT)** **and** **Non Real Time (NRT) traffic connections.**
  - **RT and NRT traffic proportion,** **fluctuates rapidly during time**.
  - A **characteristic of the** **load caused** by **RT traffic** is that it **cannot be efficiently controlled**.
    - The **load caused by RT traffic**, is called **Non-controllable load**.
  - The **remaining free capacity** from the **Planned Target Load** **can be used for NRT traffic connections**.
    - The **load caused by the NRT traffic** is called **Controllable load**.



Packet Scheduling (PS)

- The **main objective of Packet Scheduling** is to **control the traffic in the network (e.g.,** by **regulating how much data an application is allowed**, by **giving priority to packets of different services**, etc.**)** and **provide the appropriate radio resources for radio connections.**
- **Some functions of the PS are**:
  - **Determines** the **available radio interface resources** for **Non Real Time radio connections (Controllable Load)**.
  - **Share the available radio interface resources between the Non Real Time radio connections**.
  - **Decides when a packet transmission is initiated** and the **Bit Rate to be used**.

Packet Scheduling (PS)

- **Admission Control** and **Packet Scheduling** both **participate in the handling of connections for Non Real Time services**.
  - **Admission Control** takes care of **admission** and **release** of **connections**.
    - **Radio resources are not reserved for the whole duration** of **the connection** but **only when there is actual data to transmit**.
  - **Packet Scheduling allocates appropriate radio resources** for the **duration of a packet call** (i.e., **for the active data transmission**).
- **Packet Scheduling** is **done on a Cell basis**.
  - **Since asymmetric traffic is supported** and **the load may vary a lot between Uplink and Downlink**, **capacity is allocated separately for both directions**.