UMTS WCDMA
• 1. Introduction to WCDMA
• 2. Radio Access Network Architecture
• 3. Radio Interface Protocols
• 4. WCDMA Evolution
1. Introduction to WCDMA

• 1.1 Summary of the Main Parameters in WCDMA
• 1.2 Power Control
• 1.3 Softer and Soft Handovers
### 1.1 Summary of the Main Parameters in WCDMA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
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• Multiple access method

✓ WCDMA is a wideband Direct-Sequence Code Division Multiple Access (DS-CDMA) system

✓ user information bits are spread over a wide bandwidth by

- multiplying user data with quasi-random bits (called chips) derived from CDMA spreading codes

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Note: Spread-Spectrum Transmission

- A technique in which the user’s original signal is transformed into another form that occupies a larger bandwidth than the original signal would normally need.

- The original data sequence is binary multiplied with a spreading code that typically has a much larger bandwidth than the original signal.

- The bits in the spreading code are called chips to differentiate them from the bits in the data sequence, which are called symbols.

![Figure 3.2. Spreading and despreading in DS-CDMA](image-url)
Note: Spread-Spectrum Transmission

- Each user has its own spreading code
- The **identical code** is used in both transformations on each end of the radio channel
  - ✔ spreading the original signal to produce a wideband signal
  - ✔ despreading the wideband signal back to the original narrowband signal

Figure 3.2. Spreading and despreading in DS-CDMA
Note: Spread-Spectrum Transmission

- Processing gain: the ratio between the transmission bandwidth and the original bandwidth
  - also known as the Spreading Factor (SF)
  - this ratio simply means how many chips are used to spread one data symbol
  - in the UTRAN, the spreading-factor values can be between 4 and 512
  - in the TDD mode also SF=1 is allowed

\[ \text{Spreading Factor (SF)} = \frac{\text{Chip Rate (chip/s)}}{\text{Information Rate (symb/s)}} \]
• **Duplexing method**
  ✓ **WCDMA supports both FDD and TDD modes of operation**
  ✓ **Frequency Division Duplex (FDD)**
    - separate 5 MHz carrier frequencies are used for **uplink** and **downlink** respectively
  ✓ **Time Division Duplex (TDD)**
    - only one 5 MHz is **timeshared** between uplink and downlink

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Figure 3.1. Allocation of bandwidth in WCDMA in the time–frequency–code space
• Basic station synchronization

✓ WCDMA supports the operation of asynchronous BSs

✓ no need for a global time reference such as a GPS

✓ deployment of indoor and micro BSs is easier when no GPS signal needs to be received

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• **Chip rate**

✓ chip rate of 3.84 Mcps leads to a carrier bandwidth (channel bandwidth) of approximately 5 MHz

✓ DS-CDMA systems with a bandwidth of about 1 MHz (narrowband CDMA systems)

✓ wide carrier bandwidth of WCDMA supports high user data rates

---

**Chip** : the length of time to transmit either a "0" or a "1" in a binary pulse code

**Chip rate** : number of chips per second

Formula $R = B / (1 + \text{rolloff factor})$

$R = \text{chip rate}$

$B = \text{Bandwidth that in WCDMA is 5MHz}$

Roll off [信號衰減] factor = 0.3

$R = 5 \text{MHz} / (1 + 0.3)$

$R = 3.84 \text{Mcps}$

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**Table 3.1.** Main WCDMA parameters

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• Frame length & slot length

✓ frame length
- 10ms (38400 chips/sec)

✓ slot length
- 15 slots / frame (2560 chips/slot)
- 0.67ms / slot

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• **Service multiplexing**

✓ multiple services with different quality of service requirements multiplexed on one connection

• **Multirate concept**

✓ use a variable spreading factor and multicode to support very high bit rates (up to 2 Mbps)

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Note: Multicode CDMA

- In multicode CDMA systems
  - each user can be provided with multiple spreading codes of fixed length, depending on users' rate requests

- Motivations for multicode CDMA
  - increase the information rate over a given spread bandwidth
  - allow for the flexibility of multiple data rates
Detection

✓ WCDMA employs **coherent detection** on uplink and downlink based on the use of **pilot symbols** or **common pilot**

✓ use of **coherent detection** on uplink will result in an overall increase of **coverage** and **capacity** on the uplink

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Coherent detection (or coherent demodulation) is used to lock phase unto carrier wave in order to enhance detection.

The received signal is mixed, in some type of nonlinear device, with a signal from a local oscillator, to produce an intermediate frequency, from which the modulating signal is recovered (detected).
• Multiuser detection and smart adaptive antennas
  ✓ supported by the standard
  ✓ deployed by network operator as a system option to increase capacity and/or coverage

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1.2 Power Control

- Fast power control is perhaps the most important aspect in WCDMA, in particular on the uplink

  ✓ without it, a single overpowered mobile could block a whole cell
Near-Far Effect in the Uplink Direction

Without power control:
- $\text{Tx level MS}_a = \text{Tx level MS}_b = \text{Tx level MS}_c$
- $\Rightarrow \text{Rx level MS}_a < \text{Rx level MS}_b < \text{Rx level MS}_c$

With power control:
- $\text{Tx level MS}_a > \text{Tx level MS}_b > \text{Tx level MS}_c$
- $\Rightarrow \text{Rx level MS}_a = \text{Rx level MS}_b = \text{Rx level MS}_c$
Power control in WCDMA

- open-loop power control
- close-loop power control
  - inner-loop power control
  - outer-loop power control
1.2.1 Open Loop Power Control in WCDMA

- Open loop power control in WCDMA
  ✓ attempt to make a **rough estimation** of path loss by measuring **downlink beacon signal**
  ✓ problem
    - far too **inaccurate**
    - **fast fading** is essentially **uncorrelated** between uplink and downlink due to large frequency separation of uplink and downlink band of WCDMA FDD mode
    - open-loop power control is used in WCDMA to provide a **coarse initial power setting** of MS at the beginning of a connection

*Open-loop power control
*Close-loop power control
  - Inner-loop power control
  - Outer-loop power control

**Beacons** are primarily radio, ultrasonic, optical, laser or other types of signals that indicate the proximity or location of a device or its readiness to perform a task. **Beacon signals** also carry several critical, constantly changing parameters, such as power-supply information, relative address, location, timestamp, **signal strength**, available bandwidth resources, temperature and pressure.
Uplink Open-Loop Power Control

Tx power level – System constant – Rx power level

MS 1

Faraway mobile

Base station

Nearby mobile

MS 2
1.2.2 Inner-Loop Power Control in WCDMA

- Inner-loop power control in WCDMA uplink

✓ BS performs frequent estimates of the received Signal-to-Interference Ratio (SIR) and compares it to a target SIR

  - if the measured SIR is higher than the target SIR, BS will command MS to lower the power
  - if SIR is too low, it will command MS to increase its power

*Open-loop power control
*Close-loop power control
  - Inner-loop power control
  - Outer-loop power control
✓ measure–command–react cycle
  - executed at a rate of 1500 times per second (1.5 kHz) for each MS
  - faster than any significant change of path loss could possibly happen
  - faster than the fast Rayleigh fading speed for low to moderate mobile speeds

✓ inner-loop power control
  - prevent any power imbalance among all the uplink signals received at BS

✓ inner-loop power control in downlink
  - adopt the same techniques as those used in uplink
  - operate at a rate of 1500 times per second
✓ downlink closed-loop power control

- provide a marginal amount of additional power to MS at the cell edge as they suffer from increased other-cell interference

- enhance weak signals caused by Rayleigh fading when other error-correcting methods doesn’t work effectively
The following figure depicts closed loop transmission power control in CDMA

✓ MS1 and MS2 operate within the same frequency, separable at the BS only by their respective spreading codes

✓ it may happen that MS1 at the cell edge suffers a path loss, say 70 dB above that of MS2 which is near the BS

✓ if there were no power control mechanism for MS1 and MS2 to the same level at BS

   - MS2 could easily overshout MS1 and thus block a large part of the cell, giving rise to the near–far problem of CDMA

Figure 3.8. Closed loop power control in CDMA
• The following figure shows how uplink closed loop power control works on a fading channel at low speed.

Figure 3.9. Closed-loop power control compensates a fading channel.
1.2.3 Outer-Loop Power Control in WCDMA

- Adjusts the target SIR setpoint in BS according to the individual radio link quality requirement, usually defined as bit error rate (BER) or block error rate (BLER).
- The required SIR or BLER depends on the mobile speed, multipath profile, and data rate.
- Should the transmission quality is decreasing, the RNC will command Node B to increase the target SIR.
- Outer-loop power control is implemented in RNC because there might be soft handover combining.
if FER increase then (SIR)set "up" else (SIR)set "down"
• Why should there be a need for changing the target SIR setpoint?

✓ the required SIR for, say, BLER = 1% depends on mobile speed and multipath profile

✓ if one were to set the target SIR setpoint for high mobile speeds, one would waste much capacity for those connections at low speeds

✓ the best strategy is to let the target SIR setpoint float around the minimum value that just fulfills the required target quality

• The target SIR setpoint will change over time as the speed and propagation environment changes
• Outer loop control is typically implemented by

✓ having BS tag each uplink user data frame with a frame reliability indicator, such as a CRC (Cyclic Redundancy Check) result obtained during decoding of that particular user data frame

✓ should the frame quality indicator shows the transmission quality is decreasing

- RNC will command BS to increase target SIR setpoint
1.3 Softer and Soft Handovers

**Active set (AS)**, represents the Node Bs to which the UE is in soft handover

**Neighbor set (NS)**, represents the links that UE monitors but which are not already in active set
• Softer handover

✓ MS is in the **overlapping** cell coverage area of two **adjacent sectors** of a BS

✓ communications between MS and BS take place concurrently via **two air interface channels**, one for each sector separately
• Use of two separate codes in the downlink direction, so MS can distinguish the signals

• The signals are received in the MS by means of Rake processing, and the fingers need to generate the respective code for each sector for the appropriate despreading operation

• Only one power control loop per connection is active
Note : Finger

- Due to multipath propagation, it is necessary to use multiple correlation receivers in order to recover the energy from all paths and/or antennas.

- Such a collection of correlation receivers, termed fingers, is what comprises the CDMA Rake receiver.
• In the **uplink** direction

✓ the code channel of MS is received in each sector

✓ use maximal ratio combining Rake processing
Note: RAKE Receiver

- Multiple versions of the transmitted signal are seen at the receiver through propagation channels.
- If these multi-path components are delayed in time more than a chip duration, they appear like uncorrelated noise at a CDMA receiver.
- To utilize the advantages of diversity techniques, channel parameters are necessary to be estimated:
  - arrival time of each path, amplitude, phase.
Note: Maximal Ratio Combiner (MRC)

- The combiner that achieves the best performance is one in which each output is multiplied by the corresponding complex-valued (conjugate) channel gain.

- The effect of this multiplication is to compensate for the phase shift in the channel and to weight the signal by a factor that is proportional to signal strength.
• Soft handover

✓ MS is in the **overlapping** cell coverage area of two sectors belonging to **different BSs**

✓ communications between MS and BS take place concurrently via **two air interface channels** from each BS separately

✓ both channels (signals) are received at the MS by **maximal ratio combining Rake processing**

✓ **two power control loops per connection** are active, one for each BS
• In the uplink direction

✓ the code channel of the MS is received from both BSs, but the received data is then routed to RNC for combining

✓ the same frame reliability indicator is used to select the better frame between the two possible candidates within RNC

✓ this selection takes place every 10~80 ms
UL Receiver Diversity (Space Diversity)
DL Receiver Diversity (Space Diversity)
• Other handover types of WCDMA
  ✓ **inter-frequency** hard handovers
    - e.g., to hand a mobile over from one WCDMA frequency carrier to another
    - one application for this is high capacity BSs with several carriers
  ✓ **inter-system** hard handover
    - takes place between WCDMA FDD system and another system, such as WCDMA TDD or GSM
Handover from WCDMA to GSM

1. Handover triggering thresholds are set from NMS to RNC

2. HO trigger fulfilled in RNC (=load/service/coverage reason)

3. RNC commands selected mobile(s) to make IS-measurements

4. RNC selects target cell based on:
   - mobile measurements
   - service priorities
   - load

Initiate inter-system measurements
Command inter-system handover
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2. Radio Access Network Architecture

- 2.1 System Architecture
- 2.2 UTRAN Architecture
- 2.3 General Protocol Model for UTRAN Terrestrial Interfaces
- 2.4 UMTS Core Network Architecture and Evolution
- 2.5 Radio Resources Management
2.1 System Architecture

- Functional network elements
  
  ✓ User Equipment (UE)
    - interfaces with user and radio interface
  
  ✓ Radio Access Network (RAN, UMTS Terrestrial RAN = UTRAN)
    - handles all radio-related functionality
  
  ✓ Core Network (CN)
    - switches and routes calls and data connections to external networks

Figure 5.1. UMTS high-level system architecture
• PLMN (Public Land Mobile Network)

✓ operated by a single operator

✓ distinguished from each other with unique identities

✓ operational either on their own or together with other sub-networks

✓ connected to other PLMNs as well as to other types of network, such as ISDN, PSTN, the Internet, etc.

**Figure 5.2.** Network elements in a PLMN
• UE consists of two parts

✓ Mobile Equipment (ME)
  - the radio terminal used for radio communication over $Uu$ interface

✓ UMTS Subscriber Identity Module (USIM)
  - a smartcard that holds the subscriber identity
  - performs authentication algorithms
  - stores authentication and encryption keys
  - some subscription information that is needed at the terminal
• UTRAN consists of two elements

✓ Node B
  - converts data flow between *Iub* and *Uu* interfaces
  - participates in radio resource management

✓ Radio Network Controller (RNC)
  - owns and controls radio resources in its domain
  - the service access point for all services UTRAN provides the CN
    • e.g., management of connections to UE

![Figure 5.2. Network elements in a PLMN](image)
Main elements of CN

✓ HLR (Home Location Register)
✓ MSC/VLR (Mobile Services Switching Centre/Visitor Location Register)
✓ GMSC (Gateway MSC)
✓ SGSN (Serving GPRS (General Packet Radio Service) Support Node)
✓ GGSN (Gateway GPRS Support Node)

Figure 5.2. Network elements in a PLMN
• HLR (Home Location Register)
  ✓ a database located in user’s home system that stores the master copy of user’s service profile
  ✓ service profile consists of, e.g.,
    - information on allowed services, forbidden roaming areas
    - supplementary service information such as status of call forwarding and the call forwarding number
  ✓ it is created when a new user subscribes to the system, and remains stored as long as the subscription is active
  ✓ for the purpose of routing incoming transactions to UE (e.g. calls or short messages)
    - HLR also stores the UE location on the level of MSC/VLR and/or SGSN, i.e. on the level of the serving system
• MSC/VLR (Mobile Services Switching Centre/Visitor Location Register)

✓ the switch (MSC) and database (VLR) that serve the UE in its **current location** for Circuit Switched (CS) services

✓ the part of the network that is accessed via MSC/VLR is often referred to as **CS domain**

✓ MSC
  - used to switch **CS transactions**

✓ 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 system

![Network elements in a PLMN](image)

*Figure 5.2. Network elements in a PLMN*
• GMSC (Gateway MSC)
  ✓ the switch at the point where UMTS PLMN is connected to external CS networks
  ✓ all incoming and outgoing CS connections go through GMSC

• SGSN (Serving GPRS (General Packet Radio Service) Support Node)
  ✓ functionality is similar to that of MSC/ VLR but is typically used for Packet Switched (PS) services
  ✓ the part of the network that is accessed via SGSN is often referred to as PS domain

• GGSN (Gateway GPRS Support Node)
  ✓ functionality is close to that of GMSC but is in relation to PS services

Figure 5.2. Network elements in a PLMN
• External networks can be divided into two groups

✓ CS networks
  - provide **circuit-switched connections**, like the existing **telephony** service
  - ISDN and PSTN are examples of CS networks

✓ PS networks
  - provide connections for **packet data services**
  - **Internet** is one example of a PS network

*Figure 5.2. Network elements in a PLMN*
• Main open interfaces

✓ Cu interface
- the electrical interface between USIM smartcard and ME

✓ Uu interface
- the WCDMA radio interface
- the interface through which UE accesses the fixed part of the system
- the most important open interface in UMTS

✓ Iu interface
- connects UTRAN to CN

✓ Iur interface
- allows soft handover between RNCs

✓ Iub interface
- connects a Node B and an RNC

Figure 5.2. Network elements in a PLMN
2.2 UTRAN Architecture

- 2.2.1 Radio Network Controller
- 2.2.2 Node B (Base Station)
Figure 5.3. UTRAN architecture
• UTRAN
  ✓ consists of one or more Radio Network Sub-systems (RNS)

• RNS
  ✓ a subnetwork within UTRAN
  ✓ consists of one Radio Network Controller (RNC) and one or more Node Bs

• RNCs
  ✓ may be connected to each other via $I_{ur}$ interface
  ✓ RNCs and Node Bs are connected with $I_{ub}$ interface

![UTRAN architecture](image.png)
• Main characteristics of UTRAN

✓ support of UTRA and all related functionality
  - support soft handover and WCDMA-specific Radio Resource Management algorithms

✓ use of ATM transport as the main transport mechanism in UTRAN

✓ use of IP-based transport as the alternative transport mechanism in UTRAN from Release 5 onwards
2.2.1 Radio Network Controller

- RNC (Radio Network Controller)
  ✓ the network element responsible for radio resources control of UTRAN
  ✓ it interfaces CN (normally to one MSC and one SGSN)
  ✓ terminates RRC (Radio Resource Control) protocol that defines the messages and procedures between mobile and UTRAN
  ✓ it logically corresponds to the GSM BSC
Radio Resource Control (RRC) messages

- the major part of the control signaling between UE and UTRAN
- carry all parameters required to set up, modify and release Layer 2 and Layer 1 protocol entities

The mobility of user equipment in the connected mode is controlled by RRC signaling

- measurements, handovers, cell updates, etc.
Signaling and Traffic Connections between Mobile and SGSN
Traffic Bearers Structure Supporting Packet-Switched Services

- 3GPP Bearer
  - a dedicated path between mobile and its serving GGSN
  - for a mobile to send or receive packets over a 3GPP PS CN
  - a 3GPP Bearer in a UMTS network would be a UMTS Bearer
  - constructed by concatenating
    - Radio Access Bearer (RAB)
      - connects a mobile over a RAN to the edge of CN (i.e., a SGSN)
    - CN Bearer
      - carries user traffic between the edge of CN and a GGSN
3GPP Bearers for Supporting Packet-Switched Services
# UMTS QoS Classes

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>Conversational class</th>
<th>Streaming class</th>
<th>Interactive class</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fundamental characteristics</strong></td>
<td>Preserve time relation between information entities of the stream</td>
<td>Preserve time relation between information entities of the stream</td>
<td>Request response pattern</td>
<td>Destination is not expecting the data within a certain time</td>
</tr>
<tr>
<td></td>
<td>Conversational pattern (stringent and low delay)</td>
<td></td>
<td>Preserve data integrity</td>
<td>Preserve data integrity</td>
</tr>
<tr>
<td><strong>Example of the application</strong></td>
<td>Voice, videotelephony, video games</td>
<td>Streaming multimedia</td>
<td>Web browsing, network games</td>
<td>Background download of emails</td>
</tr>
</tbody>
</table>
• The **signaling connection** between mobile and SGSN is constructed by concatenating

✓ Signaling Radio Bearer
  - between mobile and RAN (e.g., the RNC in UTRAN)

✓ $I_u$ Signaling Bearer
  - between RAN and SGSN
• **Signaling and traffic connections between mobile and SGSN**

✓ Radio Resource Control (RRC) connection

✓ Radio Access Network Application Part (RANAP) connection
• Radio Resource Control (RRC) connection

✓ includes **Signaling Radio Bearers** and **Traffic Radio Bearers** for the same mobile

✓ used to **establish, maintain, and release** Radio Bearers

✓ a mobile will use a **common RRC connection** to carry **signaling and user traffic** for both PS and CS services
• Radio Access Network Application Part (RANAP) connection

✓ includes $I_u$ Signaling Bearers and $I_u$ Traffic Bearers for the same mobile

✓ used to establish, maintain, modify, change, and release all these $I_u$ Bearers
2.2.2 Node B (Base Station)

- Main function of Node B
  ✓ perform the air interface **L1 processing**, e.g.,
    - channel coding and interleaving
    - rate adaptation
    - spreading / despreading
- It also performs some basic **radio resource management** operations such as **inner loop** power control
- It logically corresponds to the **GSM BS**
Note : Interleaving

- The transmission of pulses from **two or more digital sources** in **time division sequence** over a single path
2.3 General Protocol Model for UTRAN Terrestrial Interfaces

- 2.3.1 General
- 2.3.2 Horizontal Layers
- 2.3.3 Vertical Planes
2.3.1 General

- The general protocol model for UTRAN terrestrial interfaces
  - the Layers and Planes are logically independent of each other
  - parts of the protocol structure may be changed in the future while other parts remain intact

![Diagram of the general protocol model for UTRAN terrestrial interfaces]

*Figure 5.5. General protocol model for UTRAN terrestrial interfaces*
Figure 5.5. General protocol model for UTRAN terrestrial interfaces
2.3.2 Horizontal Layers

- The protocol structure consists of two main layers
  - radio network layer
  - transport network layer

Figure 5.5. General protocol model for UTRAN terrestrial interfaces
2.3.3 Vertical Planes

- 2.3.3.1 Control Plane
- 2.3.3.2 User Plane
- 2.3.3.3 Transport Network Control Plane
- 2.3.3.4 Transport Network User Plane

Figure 5.5. General protocol model for UTRAN terrestrial interfaces
2.3.3.1 Control Plane

- Used for all UMTS-specific control signaling
- Two parts
  - ✓ application protocol
    - RANAP (RAN application part) in \( Iu \)
    - RNSAP (RNS application part) in \( Iur \)
    - NBAP (Node B application part) in \( Iub \)
  - ✓ signaling bearer
    - transport the application protocol messages

Figure 5.3. UTRAN architecture

Figure 5.5. General protocol model for UTRAN terrestrial interfaces
• Application protocol is used for

✓ setting up bearers to UE, i.e.

- radio access bearer in \textit{Iu} (RANAP)
- radio link in \textit{Iur} (RNSAP) and \textit{Iub} (NBAP)
2.3.3.2 User Plane

- Transport all information sent and received by the user
  - **coded voice** in a voice call
  - **packets** in an Internet connection
- Two parts
  - **data stream(s)**
  - **data bearer(s)** for data stream(s)
2.3.3.3 Transport Network Control Plane

- Used for all control signaling within transport layer
- Does not include any radio network layer information

✓ ALCAP (Access Link Control Application Part) protocol: set up the transport bearers (data bearer) for user plane

✓ Signaling bearer needed for ALCAP

Figure 5.5. General protocol model for UTRAN terrestrial interfaces
• Transport network control plane

✓ acts between control plane and user plane

✓ makes it possible for application protocol in radio network control plane to be completely independent of the technology selected for data bearer in user plane

Figure 5.5. General protocol model for UTRAN terrestrial interfaces
2.3.3.4 Transport Network User Plane

- Transport Network User Plane
  - data bearer(s) in user plane
  - signaling bearer(s) for application protocol

Figure 5.5. General protocol model for UTRAN terrestrial interfaces
Core Network, overview

- Changes from Release ’99 to Release 5
- A seamless transition from GSM to all-IP 3G core network
- Responsible for switching and routing calls and data connections within, and to the external networks (e.g. PSTN, ISDN, and Internet)
- Divided into CS network and PS network
Core Network, Release ‘99

- CS domain

  ✓ Mobile Switching Center (MSC)
    - switching CS transactions
  ✓ Visitor Location Register (VLR)
    - holds a copy of the visiting user’s service profile, and the precise info of UE’s location
  ✓ Gateway MSC (GMSC)
    - the switch that connects to external networks
• PS domain
  ✓ serving GPRS Support Node (SGSN)
    - similar function as MSC/VLR
  ✓ Gateway GPRS Support Node (GGSN)
    - similar function as GMSC

• Register
  ✓ Home Location Register (HLR)
    - stores master copies of users service profiles
    - stores UE location on the level of MSC/VLR/SGSN
Core Network, R5

• CS domain
  ✓ MSC and GMSC
    - control function, can control multiple MGW, hence scalable

• PS domain
  ✓ very similar to R’99 with some enhancements
• The first phase of IP Multimedia Subsystem (IMS)

✓ enable standardized approach for IP based service provision

✓ Media Resource Function (MRF)

- provides media related functions such as media manipulation (e.g. voice stream mixing) and playing of tones and announcements
✓ **Call Session Control Function (CSCF)**

- several roles of SIP servers or proxies, collectively called **Call Session Control Function**, are used to process SIP signaling packets in the IMS
  
  - **Proxy-CSCF (P-CSCF)**: a SIP proxy
  
  - **Serving-CSCF (S-CSCF)**: the central node of the signaling plane
  
  - **Interrogating-CSCF (I-CSCF)**: located at the edge of an administrative domain. Remote servers can find it, and use it as a forwarding point (e.g., registering) for SIP packets to this domain
✓ Media Gateway Control Function (MGCF)

- used to choose where a breakout to the CS domain
- it performs protocol conversion between ISDN User Part (ISUP) and the IMS call-control protocols
2.5 Radio Resources Management

- Network Based Functions
  - Admission Control (AC)
    - handles all new incoming traffic
    - check whether new connection can be admitted to the system and generates parameters for it
  - Load Control (LC)
    - 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 Scheduler (PS)
    - handles all non real time traffic (packet data users)
    - it decides when a packet transmission is initiated and the bit rate to be used
• Connection Based Functions

✓ Handover Control (HC)
  - handles and makes the handover decisions
  - controls the active set of BSs of MS

✓ Power Control (PC)
  - maintains radio link quality
  - minimize and control the power used in radio interface, thus maximizing the call capacity
Network Based Functions

RT / NRT: Real-time / Non-Real-time
RAB: Radio Access Bearer

PrxTarget or PtxTarget
PrxTarget + PrxOffset or PtxTarget + PtxOffset

overload state
no new RAB
Drop RT bearers

preventive state
only bear RT bearers if RT load below PrxTarget/PrxTarget
preventive load control actions

normal state
AC admits RABs normally
no action

PS
decrease bit rates
NRT bearers to FACH
drop NRT bearers

ac
no action

no new capacity request scheduled
bit rate not increased

PS schedules
packet traffic normally
Connection Based Function

- Power Control
  - ✓ prevent excessive interference and near-far effect
  - ✓ open-loop power control
    - rough estimation of path loss from receiving signal
    - initial power setting, or when no feedback channel is exist
  - ✓ fast close-loop power control
    - feedback loop with 1.5kHz cycle to adjust uplink / downlink power to its minimum
    - even faster than the speed of Rayleigh fading for moderate mobile speeds
  - ✓ outer loop power control
    - adjust the target SIR setpoint in BS according to the target BER
    - commanded by RNC

Outer Loop Power Control
If quality < target, increases SIR_{TARGET}

Fast Power Control
If SIR < SIR_{TARGET}, send “power up” command to MS
• Handover
  ✓ softer handover
    - a MS is in the overlapping coverage of 2 sectors of a BS
    - concurrent communication via 2 air interface channels
    - 2 channels are maximally combined with rake receiver
  ✓ soft handover
    - a MS is in the overlapping coverage of 2 different BSs
    - concurrent communication via 2 air interface channels
    - downlink: maximal combining with rake receiver
    - uplink: routed to RNC for selection combining, according to a frame reliability indicator by the BS
• 1. Introduction to WCDMA
• 2. Radio Access Network Architecture
• 3. Radio Interface Protocols
• 4. WCDMA Evolution
3. Radio Interface Protocols

• 3.1 Introduction

• 3.2 Protocol Architecture
3.1 Introduction

- The protocol layers above physical layer
  - Data Link Layer (Layer 2)
  - Network Layer (Layer 3)
- In UTRA FDD radio interface, Layer 2 is split into sublayers
  - in control plane, Layer 2 contains two sub-layers
    - Medium Access Control (MAC) protocol
    - Radio Link Control (RLC) protocol

Figure 7.1. UTRA FDD Radio Interface protocol architecture
✓ in user plane, in addition to MAC and RLC, two additional service-dependent protocols

- Packet Data Convergence Protocol (PDCP)
- Broadcast/Multicast Control Protocol (BMC)

• In UTRA FDD radio interface, Layer 3 consists of one protocol

✓ Radio Resource Control (RRC), which belongs to control plane

Figure 7.1. UTRA FDD Radio Interface protocol architecture
3.2 Protocol Architecture

Figure 7.1. UTRA FDD Radio Interface protocol architecture
- Physical layer
  - ✓ offers services to MAC layer via transport channels
  - ✓ transport channels are characterized by how and with what characteristics data is transferred

- MAC layer
  - ✓ offers services to RLC layer by means of logical channels
  - ✓ logical channels are characterized by what type of data is transmitted
• RLC layer

✓ offers services to higher layers via Service Access Points (SAPs)

✓ SAPs describe

- how the RLC layer handles the data packets, and

- if, for example, the **Automatic Repeat Request (ARQ)** function is used

---

**Automatic Repeat Request (ARQ)**: protocol for dealing with data words that are corrupted by errors whereby the receiving system requests a re-transmission of the word(s) in error
• On the control plane

✓ RLC services are used by **RRC layer** for **signaling transport**

• On the user plane

✓ RLC services are used by either of the following

- the **service-specific protocol** layers PDCP or BMC

- other **higher-layer u-plane functions** (e.g. speech codec)

Figure 7.1. UTRA FDD Radio Interface protocol architecture
• RLC services
  ✓ called **Signaling Radio Bearers** in the **control** plane
  ✓ called **Radio Bearers** in the **user** plane for services not utilizing PDCP or BMC protocols

• RLC protocol operates in three modes
  ✓ Transparent mode (TM)
  ✓ Unacknowledged mode (UM)
  ✓ Acknowledged mode (AM)
• **Transparent mode** handles three types of signaling message

✓ **system information** messages on the **broadcast** control channel

✓ **paging** messages on the **paging** control channel

✓ **RRC connection** establishment messages on the **common** control channel
• In the **transmitter**

✓ the RLC receives signaling messages directly from the **RRC protocol**, and stores them in a **buffer**

✓ the **MAC protocol** grabs the messages from the buffer as **RLC PDUs**, *without any modification*

• In the **receiver**

✓ the RLC passes the received messages directly up to the **RRC**

PDU : Protocol Data Unit
• **Unacknowledged mode** handles data streams on the **dedicated traffic channel** for which **timely delivery** is more important than reliability, such as **voice over IP** and **streaming video**.
• **Acknowledged mode** handles two types of information

✓ **data streams** on the **dedicated traffic channel** such as web pages and emails, for which **reliability** is more important than speed of delivery

✓ **mobile-specific signaling messages** on the **dedicated control channel**

• **Re-transmits** any packets that have not reached the receiver correctly
• Packet Data Convergence Protocol (PDCP)

✓ exists only for PS domain services

✓ main function is header compression

✓ the services offered by PDCP are called Radio Bearers
• Broadcast Multicast Control protocol (BMC)

✓ used to convey over the radio interface messages originating from Cell Broadcast Center

✓ in Release’99 of the 3GPP specifications, the only specified broadcasting service is SMS Cell Broadcast service, which is derived from GSM

✓ the service offered by BMC protocol is also called a Radio Bearer

Figure 7.1. UTRA FDD Radio Interface protocol architecture
• RRC layer

- ✓ offers services to higher layers via service access points (SAP), which are used by
  - the higher layer protocols in the UE side
  - the Iu RANAP protocol in the UTRAN side
- ✓ all higher layer signaling (mobility management, call control, session management, etc.) is encapsulated into RRC messages for transmission over radio interface
The control interfaces between RRC and all the lower layer protocols are used by RRC layer to

✓ configure characteristics of the lower layer protocol entities
  - including parameters for the physical, transport and logical channels

✓ command the lower layers to
  - perform certain types of measurement
  - report measurement results and errors to RRC
Logical Channels

- MAC layer provides data transfer services on logical channels, control and traffic channels:
  - Control channel to transfer control plane information
  - Traffic channels to transfer user plane information

- Control channels
  - Broadcast control channels (BCCH) - downlink broadcast control
  - Paging control channel (PCCH) - downlink paging information
  - Dedicated control channel (DCCH) - dedicated between mobile & network
  - Common control channel (CCCH) - common between mobile & network
  - Shared channel control information (SHCCH) - for UL & DL (TDD only)

- Data channels
  - Dedicated traffic channel (DTCH) - P2P ch. dedicated to one mobile (UL & DL)
  - Common traffic channel (CTCH) - P2MP ch. for unidirectional data
### Mapping of Transport Channels and Physical Channels

<table>
<thead>
<tr>
<th>Transport Channel</th>
<th>Physical Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast Channel (BCH)</td>
<td>Primary Common Control Physical Channel (PCCPCH)</td>
</tr>
<tr>
<td>Forward Access Channel (FACH)</td>
<td>Secondary Common Control Physical Channel (SCCPCH)</td>
</tr>
<tr>
<td>Paging Channel (PCH)</td>
<td></td>
</tr>
<tr>
<td>Random Access Channel (RACH)</td>
<td>Physical Random Access Channel (PRACH)</td>
</tr>
<tr>
<td>Dedicated Channel (DCH)</td>
<td>Dedicated Physical Data Channel (DPDCH)</td>
</tr>
<tr>
<td></td>
<td>Dedicated Physical Control Channel (DPCCH)</td>
</tr>
<tr>
<td>Downlink Shared Channel (DSCH)</td>
<td>Physical Downlink Shared Channel (PDSCH)</td>
</tr>
<tr>
<td>Common Packet Channel (CPCH)</td>
<td>Physical Common Packet Channel (PCPCH)</td>
</tr>
<tr>
<td></td>
<td>Synchronization Channel (SCH)</td>
</tr>
<tr>
<td></td>
<td>Common Pilot Channel (CPICH)</td>
</tr>
<tr>
<td></td>
<td>Acquisition Indication Channel (AICH)</td>
</tr>
<tr>
<td></td>
<td>Paging Indication Channel (PICH)</td>
</tr>
<tr>
<td></td>
<td>CPCH Status Indication Channel (CSICH)</td>
</tr>
<tr>
<td></td>
<td>Collision Detection/Channel Assignment Indicator</td>
</tr>
<tr>
<td></td>
<td>Channel (CD/CA-ICH)</td>
</tr>
</tbody>
</table>
• 1. Introduction to WCDMA
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4. WCDMA Evolution

• 4.1 High Speed Downlink Packet Access (HSDPA)

• 4.2 High Speed Uplink Packet Access (HSUPA)
4.1 High Speed Downlink Packet Access (HSDPA)

- HSDPA was added to Release 5 to support higher downlink data rates.
- It is mainly intended for non-real time traffic, but can also be used for traffic with tighter delay requirements.
- Peak data rates up to 10 Mbps (theoretical data rate 14.4 Mbps).
- Reduced retransmission delays.
- Improved QoS control (Node B based packet scheduler).
- Spectrally and code efficient solution.
HSDPA Features

• Agreed features in Release 5
  ✓ Adaptive Modulation and Coding (AMC)
    - QPSK or 16QAM
  ✓ multicode operation
    - support of 1-15 code channels (SF=16)
  ✓ short frame size (TTI = 2 ms)
  ✓ fast retransmissions using Hybrid Automatic Repeat Request (HARQ)
  ✓ fast packet scheduling at Node B
    - e.g. round robin, proportional fair

TTI: Transmission Time Interval
Proportional fair
* a compromise-based scheduling algorithm
* it's based upon maintaining a balance between two competing interests
  (1) trying to maximize total [wired/wireless network] throughput
  (2) at the same time allowing all users at least a minimal level of service
* this is done by assigning each data flow a data rate or a scheduling priority that is inversely proportional to its anticipated resource consumption
• Features agreed in Release 7

✓ higher order modulation (64 QAM)

✓ Multiple Input Multiple Output (MIMO)
**HSDPA Functionality**

- Scheduling responsibility has been moved from RNC to **Node B**
- Due to this and the **short TTI length** (2 ms) the scheduling is **dynamic** and **fast**
- Support for several **parallel transmissions**
  - ✓ when packet A is sent it starts to wait for an acknowledgement from the receiver, during which other packets can be sent via a **parallel SAW** (stop-and-wait) channels
• UE informs the Node B regularly of its channel quality by CQI (Channel Quality Indicator) messages

• Node B can use channel state information for several purposes
  ✓ transport format (TFRC) selection
    - modulation and coding scheme
  ✓ scheduling decisions
    - non-blind scheduling algorithms can be utilized
  ✓ HS-SCCH (High Speed-Shared Control Channel) power control

TFRC: Transport Format and Resource Combination
HSDPA Channels

- **User data** is sent on High Speed Downlink Shared Channel (HS-DSCH)
- **Control information** is sent on High Speed-Shared Common Control Channel (HS-SCCH)
- HS-SCCH is sent two slot before HS-DSCH to inform the scheduled UE of the transport format of the incoming transmission on HS-DSCH

![Diagram of HSDPA TTI]

HSDPA TTI = 3 slots = 2 ms
4.2 High Speed Uplink Packet Access (HSUPA)

- **Peak data rates** increased to significantly higher than 2 Mbps, theoretically reaching 5.8 Mbps
- **Reduced delay** from retransmissions
- **Solutions**
  - ✓ Layer1 hybrid ARQ
  - ✓ NodeB based scheduling for uplink
  - ✓ frame sizes 2 ms & 10 ms
- **Schedule in 3GPP**
  - ✓ part of Release 6
  - ✓ in 3GPP specs with the name Enhanced uplink DCH (Enhanced Dedicated Channel, E-DCH)
# HSPA Peak Data Rates

## Downlink HSDPA (Rel. 5)
* Theoretical up to 14.4 Mbps
* Initial capability 1.8 – 3.6 Mbps

<table>
<thead>
<tr>
<th># of codes</th>
<th>Modulation</th>
<th>Max data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 codes</td>
<td>QPSK</td>
<td>1.8 Mbps</td>
</tr>
<tr>
<td>5 codes</td>
<td>16-QAM</td>
<td>3.6 Mbps</td>
</tr>
<tr>
<td>10 codes</td>
<td>16-QAM</td>
<td>7.2 Mbps</td>
</tr>
<tr>
<td>15 codes</td>
<td>16-QAM</td>
<td>10.1 Mbps</td>
</tr>
<tr>
<td>15 codes</td>
<td>16-QAM</td>
<td>14.4 Mbps</td>
</tr>
</tbody>
</table>

## Uplink HSUPA
* Theoretical up to 5.76 Mbps
* Initial capability 1.46 Mbps

<table>
<thead>
<tr>
<th># of codes</th>
<th>TTI</th>
<th>Max data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x SF4</td>
<td>2 ms, 10 ms</td>
<td>1.46 Mbps</td>
</tr>
<tr>
<td>2 x SF2</td>
<td>10 ms</td>
<td>2.0 Mbps</td>
</tr>
<tr>
<td>2 x SF2</td>
<td>2 ms</td>
<td>2.9 Mbps</td>
</tr>
<tr>
<td>2 x SF2 + 2 x SF4</td>
<td>2 ms</td>
<td>5.76 Mbps</td>
</tr>
</tbody>
</table>