Lecture 12
UMTS
Universal Mobile Telecom. System
What is UMTS?

➔ UMTS stands for Universal Mobile Telecommunication System
➔ It is a part of the ITU “IMT-2000” vision of a global family of 3G mobile communication systems
  ➔ In 1998, at the end of the proposal submission phase, 17 proposals have been presented and accepted
  ➔ main differences due to existing 2G networks
  ➔ UMTS is the European proposal
➔ 3GPP group founded to coordinate various proposals and defining a common solution
  ➔ Compatibility guaranteed by multi-standard multi-mode or reconfigurable terminals
IMT-2000 Variants

⇒ IMT-2000 includes a family of terrestrial 3G systems based on the following radio interfaces

  ⇒ IMT-DS (Direct Spread)
     → UMTS FDD, FOMA (standardized by 3GPP)

  ⇒ IMT-MC (Multi Carrier)
     → CDMA 2000, evolution of IS-95 (standardized by 3GPP)

  ⇒ IMT-TC (Time Code)
     → UMTS TDD and TD-SCDMA (standardized by 3GPP)
UMTS: Initial Goals

1. UMTS will be compatible with 2G systems
2. UMTS will use the same frequency spectrum everywhere in the world
3. UMTS will be a global system
4. UMTS will provide multimedia and internet services
5. UMTS will provide QoS guarantees
IMT-2000 Features

⇒ Higher data rate through the Air Interface
  ⇒ At least 144 kb/s (preferably 384 kb/s)
    ⇒ For high mobility (speed up to 250 km/h) subscribers
    ⇒ In a wide area coverage (rural outdoor): larger than 1 km
  ⇒ At least 384 kb/s (preferably 512 kb/s)
    ⇒ For limited mobility (speed up to 120 km/h) subscribers
    ⇒ In micro and macro cellular environments
      (urban/suburban area): max 1 km
  ⇒ 2 Mb/s
    ⇒ For low mobility (speed up to 10 km/h) subscribers
    ⇒ In local coverage areas (indoor and low range outdoor): max 500 m
Universal Scenario
UMTS Network Architecture
UMTS Releases (1)

  - New radio interface WCDMA
  - New RAN architecture
  - New CN-AC interface
  - Open Service architecture for services
  - GSM-UMTS Internetworking

- **Release 4 – Minor release – March 2001**
  - UTRAN access with QoS enhancements
  - CS domain evolution, MSC servers and MGWs, based on IP protocols
  - IP Header Compression
  - Location services enhancements, MMS, WAP..
UMTS Releases (2)

- **Release 5 – Major core network release – March 2002**
  - IP Multimedia Services Subsystems
    - SIP signalling, registration, session initiation, IMS security architecture
    - Usage of IETF protocols (IPv6, SIP)
    - SIP-based service environment
    - QoS for IMS
  - WCDMA enhancements (IP transport)

- **Release 6 – IMS Part II – Dec 2003**
  - IMS Phase 2
    - Optimized voice communications
    - Presence, Instant Messaging, Group Management Conferencing
    - UMTS/VLAN inter-working
GSM/GPRS Network Architecture

Radio access network BSS

GSM/GPRS core network

- MS
- BTS
- BSC
- PCU
- BTS
- database
- VLR
- MSC
- GMSC
- HLR
- AuC
- EIR
- SGSN
- GGSN
- IP Backbone
- Internet
- PSTN, ISDN
3G Rel.’99 Network Architecture

Radio access network
UTRAN

- UE
- BS
- RNC
- Iub
- Iur

Core network (GSM/GPRS-based)

- MSC
- VLR
- SGSN
- Iu CS
- Iu PS
- Gn
- IP Backbone
- GGSN
- GMSC
- PSTN
- Internet
- HLR
- AuC
- EIR
- database
IMT 2000 Frequency Plan

TDD more efficient for asymmetric services

ITU allocations

Europe
- GSM 1800
- DECT
- UMTS
- MSS

China
- GSM 1800
- UMTS
- MSS

Japan Korea (w/o PHS)
- 1885 MHz
- 1980 MHz
- IMT 2000
- MSS

North America
- 1850-1950 MHz
- 2000 MHz
- 2100 MHz
- 2150 MHz
- 2200 MHz
- 2250 MHz

MSS: Mobile Satellite System
**QoS Classes and Services**

- **Conversational**: real-time services with constraints on maximum packet delay (telephony, videoconference, etc.)

- **Streaming**: information retrieving services with less strict delay constraints (e.g., audio/video)

- **Interactive**: real-time data services, with delay constraints on the RTT and reliability constraints

- **Background**: best-effort traffic (SMS, e-mail, ...) with reliability constraints

+ evolution towards an open platform for further application definitions (as in the Internet case)
Protocol Structures (1)

- From the protocol structure point of view the 3G network can be divided into two strata: access stratum and non-access stratum

- **Stratum** refers to the way of grouping protocols related to one aspect of the services provided by one or several domains (3GPP specifications)

- The **access stratum** contains the protocols handling activities between UE and access network

- The **non-access stratum** contains protocols handling activities between UE and Core Network
Protocol Structures (2)
UMTS Radio Interface (UTRAN)
UTRAN Architecture
It is able to handle 2 types of calls/connections
- Circuit switched
- Packet switched

The UTRAN consists of a set of Radio Network Subsystems (RNSs) connected to the CN through the Iu interface
- a RNS consists of a Radio Network Controller (RNC) and one or more Node Bs
  - a Node B is connected to the RNC through the Iub interface and it can support FDD mode, TDD mode or dualmode operation

RNCs of the Radio Network Subsystems can be interconnected together through the Iur interface to manage mobility inside UTRAN when MS moves from one RNS to another one (when the interface Iur is not implemented, CN is involved in HO procedures)
Transport technology on Iu, Iub and Iur interfaces is ATM, Asynchronous Transfer Mode

Cell transmission over physical layer (SDH, PCM etc)

Fast packet switching

Virtual circuit/virtual path based switching

Connection oriented technique
ATM Transmission

- The WCDMA Air interface provides an efficient and flexible radio access bearer for UMTS users.
- This means that the transmission network connecting the radio access devices together must be flexible too.
- E1, the synchronous, timeslot-based 2 Mbit/s transmission technology used by GSM could not provide the flexibility required.
- An alternative transmission technology was chosen: ATM or Asynchronous Transfer Mode.
GSM over E1

GSM TDMA employs 8 Timeslots which can allow up to 8 users to share the same radio channel.

GSM Cellular Transmission systems employ 2Mbit/s E1 links which are divided into 32 timeslots and can carry up to 4 GSM calls in most timeslots.

Transmission Timeslots
ATM transmission

- ATM does not base its transmission on timeslots, instead user information is carried across the network in containers called cells.
- Each cell is a fixed length of 53 octets (bytes) and consists of:
  - a 48 octet payload that carries user data
  - a 5 octet header that contains user identification
ATM transmission (2)

- Each user connection is allocated a unique label to identify their cells and ATM network elements are given instructions detailing where each customer’s cells should be delivered.
- If the user sends some information, it is placed in the payload of a cell and their label is added to the header; the network uses the label to determine the cell’s specified delivery destination.
- Users are not required to provide a fixed amount of data at regular intervals, as with 2 Mbit/s systems. Instead, users only fill cells when they have: bandwidth on demand.
Circuit Switching (i)

Time Division Multiplexing
Circuit Switching (ii)

Switching Table:

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
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<tbody>
<tr>
<td>A,1</td>
<td>B,2</td>
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<tr>
<td>A,3</td>
<td>B,4</td>
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<tr>
<td>A,4</td>
<td>A,2</td>
</tr>
<tr>
<td>B,1</td>
<td>B,1</td>
</tr>
<tr>
<td>B,4</td>
<td>B,3</td>
</tr>
<tr>
<td>B,6</td>
<td>A,1</td>
</tr>
<tr>
<td>B,7</td>
<td>B,5</td>
</tr>
</tbody>
</table>

Table setup: upon signalling
Statistical Multiplexing
the advantage of packet switching

Circuit switching:
Each slot uniquely Assigned to a flow

Packet switching:
Each packet grabs The first slot available

More flows than nominal capacity may be admitted!!
Packet switching overhead

- **Header**: contains lots of information
  - Routing, protocol-specific info, etc
  - Minimum: 28 bytes; in practice much more than 40 bytes
    - Overhead for every considered protocol: (for voice: 20 bytes IP, 8 bytes UDP, 12 bytes RTP)

- **Question**: how to minimize header while maintaining packet switching?

- **Solution**: label switching (virtual circuit)
  - ATM
  - MPLS
Label Switching (virtual circuit)

Condition: labels unique @ input

Advantage: labels very small!!
(ATM technology overhead:
only 5 bytes for all info!)

KEY advantage: no reserved phy slots!
(asynchronous transfer mode vs synchronous)

TABLE

<table>
<thead>
<tr>
<th>Label-IN</th>
<th>OUT</th>
<th>Label-OUT</th>
</tr>
</thead>
<tbody>
<tr>
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<td>A</td>
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<tr>
<td>14</td>
<td>B</td>
<td>61</td>
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<tr>
<td>16</td>
<td>B</td>
<td>12</td>
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<td>19</td>
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<td>22</td>
<td>B</td>
<td>32</td>
</tr>
<tr>
<td>33</td>
<td>A</td>
<td>13</td>
</tr>
</tbody>
</table>
ATM transmission (3)

ATM employs fixed sized 53 Octet cells each of which is divided into a 48 Octet Payload and a 5 Octet Header.

Users are only allocated a cell if they have some data to send. This is known as Bandwidth on Demand.

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UMTS Protocols

Different protocol stacks for user and control plane

➔ **User plane (for transport of user data):**
  ➔ Circuit switched domain: data within “bit pipes”
  ➔ Packet switched domain: protocols for implementing various QoS or traffic engineering mechanisms

➔ **Control plane (for signalling):**
  ➔ Circuit switched domain: SS7 based (in core network)
  ➔ Packet switched domain: IP based (in core network)
  ➔ Radio access network: UTRAN protocols
U-Plane Protocol Stack (CS Domain)
U-Plane Protocol Stack (PS Domain)
Uu interface protocols

- **PHY**
- **MAC**
- **RLC**
- **RRC**
- **PDCP**

**Logical channels**

**Transport channels**

**Signalling radio bearers**

e.g. MM, CC, SM transparent to UTRAN

(User plane) radio bearers

L3

L2

L1
Main tasks of Uu interface protocols

- **MAC (Medium Access Control)**
  - Mapping between logical and transport channels
  - Segmentation of data into transport blocks

- **RLC (Radio Link Control)**
  - Segmentation and reassembly
  - Link control (flow and error control)

- **PDCP (Packet Data Convergence Protocol)**
  - IP packet header compression (user plane only);
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**PHY Layer Basics**

- 1 frequency in each cell, with 5 MHz bandwidth
- Reuse factor equal to 1: the same channel in all the cells, thanks to code division.
- Frequency division or time division duplexing
  - FDD+CDMA (UTRA FDD): most popular, paired bands (1920-1980 MHz in uplink and 2110-2170 MHz in downlink)
  - TDD+TDMA+CDMA (UTRA TDD): unpaired bands (1900-1920 MHz and 2010-2025 MHz)
Code Division Multiple Access

- unique “code” assigned to each user; i.e., code set partitioning
- all users share same frequency, but each user has own “chipping” sequence (i.e., code) to encode data
- encoded signal = (original data) X (chipping sequence)
- decoding: inner-product of encoded signal and chipping sequence
- allows multiple users to “coexist” and transmit simultaneously with minimal interference (if codes are “orthogonal”)
CDMA Encode/Decode

sender

data bits

\[ d_i = -1 \]

\[ d_9 = 1 \]

code

\[ -1 -1 -1 -1 -1 -1 -1 -1 -1 \]

slot 1

channel output \( Z_{i,m} \)

\[ \begin{align*}
Z_{i,m} &= d_i \cdot c_m \\
&= 1 \cdot 1 \\
&= 1
\end{align*} \]

slot 1 channel output

\[ -1 -1 -1 -1 -1 -1 -1 -1 -1 \]

slot 0 channel output

receiver

\[ d_i = \sum_{m=1}^{M} Z_{i,m} \cdot c_m \]

code

\[ 1 1 1 1 1 1 1 1 1 \]

slot 1 received input

\[ -1 -1 -1 -1 -1 -1 -1 -1 -1 \]

slot 0 received input

\[ d_i = -1 \]

\[ d_0 = 1 \]
CDMA: two-sender interference

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We call "Spreading Factor" (SF) the number of chips used to code each information bit.

The chip rate in UMTS is fixed to 3.84 Mcps.

Different data rates are possible according to the length of the code (i.e., according to the SF).
How to create orthogonal codes?

Digital/Analog Mapping
logic 0 ↔ analog +1
logic 1 ↔ analog - 1
Orthogonal Variable Spreading Factor

- OVSF Code Space: 8 users; one 8-bit code per user

Chip Rate = 3.840 Mcps

- 1
  - 1-1
    - 1-11-1
      - 111-1111-1
        - 11111111
          - 480 kb/s
    - 1-11-1-111
      - 111-1-111-1
        - 480 kb/s
  - 11
    - 11-1-1
      - 111-111
        - 480 kb/s
    - 1111
      - 1111
        - 480 kb/s

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OVSF Codes

- OVSF Code Space: 5 users; one user has 4x data bandwidth

User with 4x Bit Rate

1-1 1.92 Mb/s

1-1-1

1-11-1

1-11-1-1

1-111-1-1

11-1-1-1-11

11-1-1-1-1-1

1111-1-1-1-1

11111111

Chip Rate = 3.840 Mcps

= Unusable Code Space

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Orthogonal Data Channelization

In this example, the receiver correlates the composite received signal using Orthogonal Code 3. The result is a perfect reconstruction of Data Channel #3, with no interference from the other data channels. To realize this perfect cross-correlation property, it is essential that the orthogonal codes be received in perfect timing relation to each other.
Orthogonal Codes

**Downlink:** Orthogonal Codes used to distinguish data channels Coming from each Base Station

**Uplink:** Orthogonal Codes used to distinguish data channels coming from each Mobile Station
Orthogonal CDMA: Summary

- CDMA allows multiple data streams to be sent on the same RF carrier
  - Perfect isolation between data streams
  - Timing between data streams must be exact
  - Maximum number of data channels = orthogonal code length
  - The longer the code, the slower the data rate

- Code space can be rapidly re-allocated to match user data rate requirements

- CDMA advantages are limited in practice
  - Multipath, small timing errors, and motion-related effects diminish the usable code space
Orthogonal codes: do they work?

(a) Same Orthogonal code; (b) Different Orthogonal codes; (c) Same code with non-zero time offset

Input Data

Orthogonal code in Transmitter

Transmitted Sequence

Orthogonal Code used in Receiver

Integrate Result

Divide by Code Length

Transmitter

Receiver

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Orthogonal codes have a limit: require perfect synchronization!

Could we do something different losing a perfect orthogonality?? Yes! Pseudo Noise Codes

PN Codes are repeating, defined-length blocks of 1’s and 0’s

- Approximately equal number of 1’s and 0’s
- The statistics appear randomly distributed within the block

Good Autocorrelation and Cross-Correlation properties

PN Code cross-correlation properties do not depend on time alignment (time offset)

Example of a 32-bit \(2^5\) PN code:

01101000110101001010011010100111
PN Code Generation

→ PN Codes: Generation using a Shift Register

- $\beta_n$ values are 0 or 1 (determined by the specified “generator polynomial”)

- Maximal-length (m-sequence) has a repetitive cycle of $(2^N - 1)$ bits

- A code of 16,777,215 bits can be replicated using only a 24-bit “key”
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PN Code Correlation Plots

Autocorrelation of 2000-bit PN sequence
Time offset = 0

Single, centered correlation peak indicates that two signals are identical, with zero time offset

Cross-correlation of two different PN sequences

time offset
Code Correlation: Key Points

→ **TX, RX use same codes, at the same time offset**
   → PN Codes: 100% correlation
   → Orthogonal Codes: 100% correlation

→ **TX, RX use different codes**
   → PN Codes: "Low" (noise-like) correlation at any time offset
       Avg. correlation proportional to 1/(code length)
   → Orthogonal Codes: 0% Correlation

→ **TX, RX use same codes, but at different time offsets**
   → PN Codes: "Low" (noise-like) correlation
   → Orthogonal Codes: Unpredictable results
In this example, the receiver correlates the composite received signal using PN code 3.

The result is the recovered transmission from Transmitter #3, plus some spread spectrum interference from transmitters #1, #2, and #4.
SSMA PN Code Planning

Uplink: PN Code used to distinguish each Mobile Station
Downlink: PN Code used to distinguish each Base Station

Cell Site “1” transmits using PN code 1

Cell Site “2” transmits using PN code 2
SSMA PN Code Planning

Spread Spectrum Code Planning Example

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SSMA: Summary

- **SSMA Utilization**
  - Used to distinguish the transmission source (Base Station or Mobile Station) in cellular CDMA systems
  - Provides good (but not 100%) separation between multiple transmissions in the same geographic area, on the same frequency
  - Works regardless of time-of-arrival delays
  - Code Planning instead of Frequency Planning
  - Frequency Reuse = 1

- **SSMA Limitations**
  - Imperfect signal separation
    - Number of simultaneous transmitters in one area is limited by the Spreading Factor
  - Not good for transmitting multiple data streams from one transmitter

Each Transmitter has a unique PN spreading code

Several Transmitters share the same frequency and time
Cellular CDMA (SSMA + OC)

- PN Codes are used:
  - To distinguish between Mobile Stations
  - To distinguish between Base Stations
- Orthogonal Codes are used:
  - To distinguish between data channels coming from each MS
  - To distinguish between data channels from each BS

Vehicle 1 Vehicle 2 Vehicle 3 ...

PN Spreading Codes and Orthogonal Codes are simultaneously utilized
Cellular CDMA (SSMA + OC)

2 data channels
(voice, control)
PN1 + OC1 + OC2

1 data channels
(control)
PN1 + OC3

2 data channels
(14 kbps data, control)
PN4 + OC1 + OC2

3 data channels
(voice, video, control)
PN2 + OC1 + OC2 + OC3

4 data channels
(384 kbps data, voice, video, control)
PN2 + OC4 + OC5 + OC6 + OC7

1 data channels
(voice, control)
PN3 + OC1 + OC2

3 data channels
(voice, video, control)
PN5 + OC1 + OC2 + OC3

4 data channels
(384 kbps data, voice, video, control)
PN6 + OC1 + OC2 + OC3 + OC4
The Need of Power Control

- *Pseudo-noise code work properly if interfering signals have comparable power!*

- Let \( r \) be the sum of two interfering signals obtained from data \( d_1 \) (by user 1) and \( d_2 \) (by user 2), and \( \mathbf{pn}_1 \) and \( \mathbf{pn}_2 \) be the vectors containing the pseudo code used by user 1 and user 2:
  \[
  r = d_1 \mathbf{pn}_1 + d_2 \mathbf{pn}_2
  \]
- Being \( \langle \mathbf{pn}_1, \mathbf{pn}_2 \rangle = \varepsilon \approx 0 \), receiver interested in data transmitted by user 1 can correlate \( r \) with \( \mathbf{pn}_1 \):
  \[
  \langle r, \mathbf{pn}_1 \rangle = d_1 \langle \mathbf{pn}_1, \mathbf{pn}_1 \rangle + d_2 \langle \mathbf{pn}_1, \mathbf{pn}_2 \rangle \approx d_1 + \varepsilon
  \]
- But, when the interfering signal is much higher than the useful one, the residual interference of pseudo-noise correlation can destroy the data:
  \[
  r = d_1 \mathbf{pn}_1 + K d_2 \mathbf{pn}_2
  \]
  \[
  \langle r, \mathbf{pn}_1 \rangle = d_1 \langle \mathbf{pn}_1, \mathbf{pn}_1 \rangle + K d_2 \langle \mathbf{pn}_1, \mathbf{pn}_2 \rangle \approx d_1 + K \varepsilon = ???
  \]
Power Control Strategies

➔ To correct the power level on the uplink
   ➔ Closed loop power control
   ➔ Open loop power control
   ➔ Outer loop power control

➔ To correct the power level on the downlink
   ➔ Downlink power control
Closed Loop Power Control

The antenna controller controls the UE

1. **3-phase mechanism**
   1. UE transmits
   2. Antenna controller measures the received power level and compares this with a **threshold**
   3. Antenna controller tells the UE whether it has to increase or decrease its transmit power (executed periodically)

2. **“Closed Loop” since is a mechanism with feedback**
3. **It is quite accurate, however it performs better if the initial power level is not too far from the desired value**
Open Loop Power Control

UE controls itself

- **2-phase mechanism**
  1. UE measures the interference level on the signal transmitted from the antenna controller
  2. UE uses an internal algorithm to correct the power level transmitted on the uplink so that the estimated SINR is above a certain threshold

- "Open Loop" since there is not feedback
- It is quite inaccurate
Outer Loop Power Control

It is a ‘control on the control’ performed at the BS

→ Outer loop power control modifies the threshold value that is employed in the closed and open loop power control

→ Used to adapt the radio transmission to the desired level of QoS (e.g., packet error rate)
Downlink Power Control

UE controls the antenna controller by sending a feedback (closed loop), but more slowly than the uplink feedback

➔ 3-phase mechanism:

➔ UE measures the power received from the antenna controller and asks the antenna controller for an increase or a reduction in the transmitted power

➔ The power level used by the antenna controller is derived by averaging the feedback from all users -> not a very accurate power control

➔ Performed @ lower frequency (more slowly) because the communication on downlink is less critical than on uplink
## FDD-WCDMA Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Multiple access scheme</td>
<td>WCDMA</td>
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<tr>
<td>Channel spacing</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Chip rate</td>
<td>3.84 Mchip/s</td>
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<tr>
<td>Number of slots per frame</td>
<td>15</td>
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<tr>
<td>Frame length</td>
<td>10 ms</td>
</tr>
<tr>
<td>Multirate concept</td>
<td>multicode</td>
</tr>
<tr>
<td>Modulation</td>
<td>Down-link: QPSK</td>
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<tr>
<td></td>
<td>Up-link: Dual Code BPSK</td>
</tr>
<tr>
<td>Detection</td>
<td>Coherent</td>
</tr>
<tr>
<td>TX - RX frequency separation</td>
<td>130 MHz minimum</td>
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# TDD-WCDMA Parameters

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<thead>
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<th>Multiple access scheme</th>
<th>TDMA/WCDMA</th>
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<td>Channel spacing</td>
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<tr>
<td>Modulation</td>
<td>QPSK</td>
</tr>
<tr>
<td>Detection</td>
<td>Coherent, based on midamble</td>
</tr>
</tbody>
</table>
Physical, Transport, Logical Channels
Logical Channels

Logical Channels are the services offered by the MAC layer to the RLC layer.

Control Channels

- Broadcast Control Channel (BCCH) - DL
- Paging Control Channel (PCCH) - DL
- Common Control Channel (CCCH) - DL&UL, used when there isn’t a UE connection or for cell reselection
- Dedicated Control Channel (DCCH) - DL&UL

Traffic Channel

- Dedicated Traffic Channel (DTCH) – DL&UL
- Common Traffic Channel (CTCH) – DL
A Transport Channel is defined by how and with which characteristics (quality level) data is transferred over the air interface:

- Dedicated Channels (DCH) uplink & downlink
- Common Channels (CCH) uplink or downlink
- Shared Channels (SCH) uplink or downlink

PhyCH mapping TrCH
Transport Channels

- Packets (e.g., RLC PDU) transferred over transport channels are called Transport Blocks (TBs).

- Transport Block Sets (TBSs) are formed when multiple transport blocks can be transmitted simultaneously (TBSs) with a common Transport Format (error protection, coding rate, CRC...).

- A Transport Block or a Transport Block Set is passed to the PHY layer every Transmission Time Interval (TTI) (TTI = k Frame, with k = 1, 2, ...).
Transport Formats and Blocks

Transport Formats of different channels belonging to the same station need to be compatible!

*The total bandwidth is fixed.*
Transport Channels Types

⇒ Dedicated Transport Channels
  ⇒ Dedicated Channel (DCH) – DL&UL

⇒ Common Transport Channels
  ⇒ Broadcast Channel (BCH) – DL
    ⇒ For system information
  ⇒ Paging Channel (PCH) - DL
  ⇒ Random Access Channel (RACH) – UL
    ⇒ For short and single packet transmissions

⇒ Shared Transport Channels
  ⇒ Common Packet Channel (CPCH) – UL
    ⇒ Shared among different users for bursty transfers
  ⇒ Downlink Shared Channel (DSCH) – DL
    ⇒ Shared among different users for bursty & pt2pt transmissions, associated to a DCH which carries control information
  ⇒ Forward Access Channel (FACH) – DL
    ⇒ Short & bursty transmissions
Transport Channel Mapping

- Infrequent, small packets:
  - PCH, FACH and RACH
- Infrequent, large packets:
  - DSCH, CPCH
- Frequent packets:
  - DCH

Logical channels:

MAC SAPs

Transport channels:

BCCH, PCCH, DCCH/CTCH, CCCH, DTCH

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Physical Channel in FDD

- A physical channel corresponds to:
  - a specific carrier frequency
  - a code (scrambling code, channelization code)
  - on the uplink, a relative phase (0, \(\pi/2\))

- Physical transmission is organized in Radio Frames and Slots
  - Slots do not define phy channels, but are used for periodic control
  - Each Radio Frame consists of 15 slots

\[
\frac{1}{3840000} \times 2560 \times 15 = 10 \text{ ms}
\]

\[
\frac{1}{3840000} \times 2560 = 667 \mu s
\]
Physical Channels in FDD

- **DCH: Dedicated Channel**
  - Dedicated Physical Data Channel (DPDCH)
  - Dedicated Physical Control Channel (DPCCH)

- **RACH: Random Access Channel**

- **CPCH: Common Packet Channel**
  - Physical Common Packet Channel (PCPCH) – CSMA/CD access
  - Common Pilot Channel (CPICH) - macrodiversity

- **BCH: Broadcast Channel**
  - Primary Common Control Physical Channel (P-CCPCH)

- **FACH/PCH: Forward Access Channel**
  - Secondary Common Control Physical Channel (S-CCPCH)
  - Synchronization Channel (SCH)

- **DSCH: Downlink Shared Channel**

- **Indicators:**
  - Acquisition Indicator Channel (AICH)
  - Access Preamble Acquisition Indicator Channel (AP-AICH)
  - Paging Indicator Channel (PICH)
  - CPCH Status Indicator Channel (CSICH)
  - Collision-Detection/Channel-Assignment Indicator Channel (CN/CA-ICH)
Uplink Dedicated Physical Channel (FDD)

- **Data Channel (DPDCH)**
- **Control Channel (DPCCH)**

Frame = 10 ms

- **Pilot** = known bit sequence
- **TFCI** = Transport Format Combination ID
- **FBI** = Feedback information
- **TPC** = Power Control Information

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Dedicated Physical Channel

→ **Dedicated data channels are organized into 15 bursts per frame transmitted without guard time**
  → each burst carries from 10 up to 640 bit according to the spreading factor
  → at most 640*15=9600 bit/10ms=960Kbit/s (spreading factor equal to 4)
  → If more than one channel is active (up to 6) at a given station, all employ the same spreading factor, with a maximum total rate of 5740 Kbit/s

→ **One dedicated control channel is associated to each connection on the uplink for transmitting PHY information**
  → PHY info: pilot bits for channel assessment; transport format indicator; feedback for soft handover; power control command
  → the spreading factor is fixed to 256, i.e. 10 bits in a DPCCH burst, 15Kbit/s
    → At least one power control bit per burst, i.e. 1.5 Kb/s for power control!
  → Different burst configurations are possible, with fields of different length (e.g. TFCI is valid for the entire frame and it is transmitted only once every 10 ms)
Uplink Multicode Transmission

Up to 6 DPDCH in parallel

Different channelization (spreading) codes but same spreading factor for all branches

One DPCCH per connection

Weighting of branches for power adjustment

One DPDCH branch is either mapped to the I- or the Q-branch of the modulation and thus transmitted via BPSK

(the sum is transmitted via QPSK)

C: spreading code
β: weight
Downlink Physical Channels
(not separated by the phase of the carriers)

Frame = 10 ms
Downlink Dedicated PhyCH

⇒ Each burst contains 2560 chips (10/15ms), with a spreading factor between 4 and 512
  ⇒ Each burst includes the data field and the control TPC/TFCI/Pilot fields
  ⇒ 17 possible burst configurations (negotiated during connection set-up)

⇒ Several DPCH can operate in parallel (multicode transmission)
  ⇒ Since one PHY feedback is required per each connection, only one DPCH channel fills the PHY info, while in the other channels the fields remain empty
  ⇒ The power in the PHY fields can be increased for compensating the empty fields

⇒ In each channel: maximum rate 1920 Kbit/s and minimum rate 6Kbit/s
  ⇒ For voice, usually a spreading factor equal to 128 is used, corresponding to a gross rate of 51Kbit/s
How to look for other carriers?

- For handover or for switching to GSM, it is required to receive other synchronization signals.
  where is the GSM empty slot??

- While involved in a multicode transmission, each station can start a ‘compressed’ mode for having ‘free time’
  ⇒ The transmission pause can be up to 7 time slots within one frame or between two consecutive frames
  ⇒ For not losing information:
    → Halve the spreading factor before and after the pause
    → Reduce the data rate
Uplink Variable Rate

10 ms

Rate can be varied on a per-frame basis

1-rate

1/2-rate

1/4-rate

0-rate

Variable rate

R = 1
R = 1/2
R = 0
R = 0
R = 1/2

: DPCCH (Pilot+TPC+TFCl+FBI)

: DPDCH (Data)
Downlink Variable Rate

Rate can be varied on a per-frame basis

- 1-rate
- 1/2-rate
- 1/4-rate
- 0-rate

0.666 ms

- : DPCCH-part (Pilot+TPC+TFCI)
- : DPDCH-part (Data)

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Random Access PhyCH

- Random access can occur at defined times called **access slots**
  - Each access slot lasts 5120 chips, i.e. twice a normal slot
  - 15 access lots exist within 20 ms

- Random access includes a contention and a transmission phase

  - **Contention:**
    - the station uses slotted aloha for transmitting in a slot a code sequence called preamble
    - 16 preambles exist for parallel access without collision
    - Power ramping for solving the near-far problem

  - **Transmission:**
    - In case of success, i.e. positive acknowledgement, the station can transmit a message for 10 or 20 ms after 3 or 4 time slots.
    - Organized in 15 random access bursts with TFCI and pilot bits, with a minimum spreading factor of 32, i.e. 80 bits/burst= max 2400 bits
Contention Process

- A mobile station that wants to access the PRACH, selects: a slot, a preamble
- At the first trial, the preamble is transmitted at a lower power and an ACK is waited on the Acquisition Indication Channel (AICH)
- In case of negative ACK or lack of ACK, it selects a new slot, a new preamble and an higher power
Start-up Operations

What does the mobile need to know?
1) Strongest base station
2) Slot border
3) Frame border
4) Primary scrambling code
5) BCCH information

Introduction to synchronisation
Cell Search: How to find the scrambling code?

→ **First:** use the Primary Synchronization Code (PSC) in the P-SCH to understand the time slots of the cell.
   - It is the same in all cells (like slot 0 for GSM) and is 256 chips long.
   - A matched filter is used for detecting it in the PSCH and finding the timings.

→ **Second:** use the Secondary Synchronization Code (SSC) in the S-SCH to find the code group of the cell
   - The evaluation of 3 consecutive 256 chips blocks allow to find the code group.

→ **Finally:** tests all the scrambling codes of the group to find the right one!
   - Quick: 8 codes per group!
Physical Channels Required for Synchronization

<table>
<thead>
<tr>
<th>Information</th>
<th>Spreading Code</th>
<th>Scrambling Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Info</td>
<td>$C_{CH,x,y}$</td>
<td>Primary Secondary</td>
</tr>
<tr>
<td>User Info</td>
<td>$C_{CH,a,b}$</td>
<td>Primary Secondary</td>
</tr>
<tr>
<td>User Info</td>
<td>$C_{CH,n,m}$</td>
<td>Primary Secondary</td>
</tr>
<tr>
<td>Predefined pattern</td>
<td>$C_{CH,256.0}$</td>
<td>Primary</td>
</tr>
<tr>
<td>BCH Info</td>
<td>$C_{CH,256.1}$</td>
<td>Primary</td>
</tr>
<tr>
<td>Predefined code word (256 chips)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequence of predefined code words (256 chips)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Physical channels used for synchronisation

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Primary Sync Channel

- Conveys primary Synchronisation code ($C_{PSC}$) for base station selection and time slot synchronisation
- $C_{PSC}$
  - Known code word (256 chips)
  - Identical for all Base stations
  - Identical in all time slots

Physical channels used for synchronisation
BS Selection

Sync step 1: BS selection and slot synchronisation
Secondary Sync Channel

- Transmits secondary synchronisation Codes ($C_{SSC}$) for frame synchronisation and identification of current Scrambling Code Group
- $C_{SSC}$
  - 16 defined code words of 256 chips
  - 16 code words build identifiers for scrambling code groups

Physical channels used for synchronisation
Frame Sync with secondary scrambling codes

15 Slots = 1 Frame = 10 ms (38400 chips)

CPICH
P-CCPCH
P-SCH
S-SCH

256 chips

Table of secondary synchronisation codes

\[ C_{ssc,1} \]
\[ C_{ssc,2} \]
\[ C_{ssc,3} \]
\[ C_{ssc,4} \]
\[ \vdots \]
\[ \vdots \]
\[ C_{ssc,13} \]
\[ C_{ssc,14} \]
\[ C_{ssc,15} \]
\[ C_{ssc,16} \]

256 chips
Start-up Summary

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Downlink Shared Channel (DSCH)

- The number of orthogonal codes in downlink is limited and the code is reserved according to the maximum bit rate in transport format set ⇒ variable bit rate connections consume a lot of code resources
- DSCH is shared between a group of downlink users to save orthogonal downlink codes
- DSCH can be allocated with 10-ms resolution to the different users
- DSCH is suitable for downlink packet data transmission
- DSCH is used together with a low bit rate DCH

Within a frame, transmissions differentiated on a code basis

DCH = Dedicated CHannel
WCDMA Air Interface

Common Channels - RACH (uplink) and FACH (downlink)
- Random Access, No Scheduling
- Low Setup Time
- No Feedback Channel, No Fast Power Control, Use Fixed Transmission Power
- Poor Link-level Performance and Higher Interference
- Suitable for Short, Discontinuous Packet Data

RACH

FACH

Common Channel - CPCH (uplink)
- Extension for RACH
- Reservation across Multiple Frames
- Can Utilize Fast Power Control, Higher Bit Rate
- Suitable for Short to Medium Sized Packet Data

CPCH
WCDMA Air Interface

Dedicated Channel - DCH (uplink & downlink)
- Dedicated, Requires Long Channel Setup Procedure
- Utilizes Fast Power Control
- Better Link Performance and Smaller Interference
- Suitable for Large and Continuous Blocks of Data, up to 2Mbps
- Variable Bitrate in a Frame-by-Frame Basis

Shared Channel - DSCH (downlink)
- Time Division Multiplexed, Fast Allocation
- Utilizes Fast Power Control
- Better Link Performance and Smaller Interference
- Suitable for Large and Bursty Data, up to 2Mbps
- Variable Bitrate in a Frame-by-Frame Basis
WCDMA Air Interface

Summary

- 5 MHz Bandwidth -> High Capacity, Multipath Diversity
- Variable Spreading Factor -> Bandwidth on Demand
The voice application involves user and signaling data, which are mapped into two dedicated channels.

- The data channel is organized into 2 transport blocks of 244 bits every 20ms, while the signaling data into 1 transport block of 100 bits every 40ms.
- One dedicated Physical channel is enough: spreading factor equal to 64, with a gross rate of 60 Kbit/s.
Channel Mapping