3G - Layer 1 (and 2)
UMTS/IMT-2000 Based on Wideband CDMA

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Outline

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- Key W-CDMA Features
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  - Channels
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"...find enabling techniques to introduce multimedia capabilities into mobile communications."

"...the silver bullet has been identified. With the strong growth of the Internet, providing multimedia capabilities to mobile communications is equivalent to providing good Internet access to mobile users”.

In 1998 the basic technology of the UMTS terrestrial radio access (UTRA) was selected

- For the paired bands 1920-1980 and 2110-2170 MHz, wideband CDMA (W-CDMA) shall be used in FDD operation.
IMT 2000 Requirements

- A platform for distributing converged fixed, mobile, voice, data, Internet and multimedia services.
- Provide seamless global roaming, enabling users to move across borders while using the same number and handset.
- Provide higher transmission rates:
  - A minimum speed of 2 Mbit/s for stationary or walking users.
  - 348 kbit/s in a moving vehicle.
- In addition, IMT-2000 has the following key characteristics:
  - Flexibility: avoid having to support a wide range of different interfaces and technologies. The IMT-2000 standard accommodates five possible radio interfaces based on three different access technologies (FDMA, TDMA and CDMA)
  - Affordability: 3G systems have to be affordable, in order to encourage their adoption by consumers and operators.
  - Compatibility with existing systems: IMT-2000 services have to be compatible with existing systems.
  - Modular Design: IMT 2000 systems must be easily expandable in order to allow for growth in users, coverage areas, and new services, with minimum initial investment.
EMT 2000 Technologies

- **EDGE**: based on 8PSK (as opposed to GMSK in GSM) satisfies the IMT 2000 requirements.

- **Universal Mobile Telecommunications System (UMTS)**
  - W-CDMA is the first and most common deployment. Support peak rate of 2 Mb/s in the downlink and 1 Mb/s in the uplink.
  - HSPA, is a revision and upgrade to W-CDMA UMTS. Support 14 Mbit/s in the downlink and 5.76 Mbit/s in the uplink.
  - HSPA+, is a revision and upgrade to HSPA. 168 Mbit/s and 22 Mbit/s represent theoretical peak speeds.

- **CDMA2000**
  - Evolved from the original IS-95 CDMA system.
  - CDMA2000 EVDO rel 0: Support peak rate of 2.4 Mb/s in the downlink and 1 Mb/s in the uplink.
Key W-CDMA Features

- Air interface based on direct-sequence CDMA.
- Improved performance over 2G system:
  - Improved capacity.
  - Improved coverage, enabling migration from 2G deployment.
- High degree of service flexibility:
  - Support of a wide range of services (bit-rates).
  - Fast and efficient packet-access scheme.
- High degree of operator flexibility:
  - Support of asynchronous inter-base-station operation.
  - Support of different deployment scenarios, including hierarchical cell structure and hot spot scenarios.
  - Support of emerging technologies such as adaptive antennas and multi-user detection.

<table>
<thead>
<tr>
<th>Table: W-CDMA Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip rate</td>
</tr>
<tr>
<td>Roll-off factor $\alpha$</td>
</tr>
<tr>
<td>Bandwidth</td>
</tr>
<tr>
<td>Carrier width</td>
</tr>
<tr>
<td>Frame length</td>
</tr>
</tbody>
</table>
| Data modulation | QPSK (downlink)  
BPSK (uplink) |
| Channel coding | Conv. and turbo |
| Spreading factors | 4-512 (downlink)  
4-256 (uplink) |
| Power Control | Open and fast closed loop (1.6 kHz) |
| Spreading | OVSF for channel separation  
Gold sequences for cell and user separation |
Spreading and Scrambling
Spreading and Scrambling

- Spreading means increasing the signal bandwidth
- In W-CDMA, spreading includes two operations
  - Channelization (increases signal bandwidth) - using orthogonal codes.
  - Scrambling (does not affect the bandwidth) - using pseudo-noise codes.

channelization codes (SF)    scrambling codes

Data  bit rate  chip rate  chip rate
Channelization codes are orthogonal codes based on Orthogonal Variable Spreading Factor (OVSF) codes.

The codes are fully orthogonal when time synchronized.

Can separate transmissions from a single source.

In the downlink, it can separate different users within one cell.

Limited orthogonal codes must be reused in every cell.

- Problem: Interference if two cells use the same code or are out of sync.
- Solution: Scrambling codes to reduce inter-base-station interference.

In the uplink, it can only separate the physical channels of one user because the different users are not synchronized in time.

Two users might use the same codes.

To separate between different users in the uplink, scrambling codes are used.

One code tree is used with one scrambling code on top of the tree.
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Scrambling

- In the scrambling process the code sequence is multiplied with a pseudo-noise scrambling code.
- The scrambling code can be a long code (Gold code) or a short code (256 chips, can be used to support multi-user detection).
- In the downlink, scrambling codes are used to reduce inter-BS interference. There are 512 different codes and each BS has one scrambling code.
- In the uplink, scrambling codes are used to separate users.
Channels
Channels

- Three different channel concepts: logical, transport and physical channels.
- Logical channels define what type of data is transferred.
- Transport channels define how and with which type of characteristics the data is transferred by the physical layer.
- Physical data define the exact physical characteristics of the radio channel.
Transport Channels to Physical Channels (1/2)

- Transport channels contain the data generated by the higher layers and are mapped in the physical layer to different physical channels.
- Data is sent by transport blocks from the MAC layer to the physical layer and is generated by the MAC layer every 10 ms.
- Can have multiple parallel transport channels from the MAC to the PHY.
  - Multiple transport channels in parallel can be multiplexed together by the PHY to form a single Coded Composite Transport Channel (CCTrCh).
- The transport format of each transport channel is identified by the Transport Format Indicator (TFI), which is used in the interlayer communication between the MAC and PHY.
Two types of transport channels: dedicated channels and common channels.

- **Dedicated channel** - reserved for a single user only
  - Support fast power control and soft handover.

- **Common channel** - can be used by any user at any time.
  - Don’t support soft handover but some support fast power control.

<table>
<thead>
<tr>
<th>Transport Channel</th>
<th>Physical Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>(UL/DL) 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>(UL) Random access channel RACH</td>
<td>Physical random access channel PRACH</td>
</tr>
<tr>
<td>(UL) Common packet channel CPCH</td>
<td>Physical common packet channel PCPCH</td>
</tr>
<tr>
<td>(DL) Broadcast channel BCH</td>
<td>Primary common control physical channel P-CCPCH</td>
</tr>
<tr>
<td>(DL) Forward access channel FACH</td>
<td>Secondary common control physical channel S-CCPCH</td>
</tr>
<tr>
<td>(DL) Paging channel PCH</td>
<td>Physical downlink shared channel PDSCH</td>
</tr>
</tbody>
</table>
Uplink Dedicated Channel (DCH)

- In the uplink, user data and control data use dual channel QPSK.
  - The I and Q channels are used as two independent BPSK channels.
- Dedicated Physical Control Channel (DPCCH) has a fixed spreading factor of 256 and carries physical layer control information.
- Dedicated Physical Data Channel (DPDCH) has a spreading factor from 4 to 256 and its data rate may vary on a frame-by-frame basis.

<table>
<thead>
<tr>
<th>DPDCH SF</th>
<th>DPDCH channel bit rate (kbps)</th>
<th>Max. user data rate with (\frac{3}{4}) rate coding (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>256</td>
<td>15</td>
<td>7.5 kbps</td>
</tr>
<tr>
<td>128</td>
<td>30</td>
<td>15 kbps</td>
</tr>
<tr>
<td>64</td>
<td>60</td>
<td>30 kbps</td>
</tr>
<tr>
<td>32</td>
<td>120</td>
<td>60 kbps</td>
</tr>
<tr>
<td>16</td>
<td>240</td>
<td>120 kbps</td>
</tr>
<tr>
<td>8</td>
<td>480</td>
<td>240 kbps</td>
</tr>
<tr>
<td>4</td>
<td>960</td>
<td>480 kbps</td>
</tr>
<tr>
<td>4, with 6 parallel codes</td>
<td>5740</td>
<td>2.3 Mbps</td>
</tr>
</tbody>
</table>

3.84 M/s/256=15 kbps

One radio frame = 10 ms

- Slot #1
- Slot #m
- Slot #15

Layer 2 data

Layer 1 control (pilot + TPC + TFI)

2560 chips, 0.625 ms, 10×2^k bits

TPC: Transmit power control bits
TFI: Transport format indicator (rate information)
Uplink Multiplexing and Channel Coding Chain

TrCH 1
- CRC attachment
- TrBlk concatenation/code block segmentation
- Channel coding
- Radio frame equalization
- 1st interleaving
- Radio frame segmentation
- Rate matching

TrCH 2
- DPDCH#1 DPDCH#2 … DPDCH#N
- PhyCH mapping
- 2nd (intra-frame) interleaving
- Other TrCHs
- PhyCH segmentation
- CCTrCh
- TrCH multiplexing
Downlink Dedicated Channel (DCH)

- In the downlink, user data and control data are time multiplexed and modulated using normal QPSK modulation.
- With multicode transmission the SF is the same for codes.

<table>
<thead>
<tr>
<th>Spreading factor</th>
<th>Channel symbol rate (kbps)</th>
<th>Channel bit rate (kbps)</th>
<th>DPDCH channel bit rate range (kbps)</th>
<th>Max. user data rate with 1/2 rate coding (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>512</td>
<td>7.5</td>
<td>15</td>
<td>3-6</td>
<td>1-3 kbps</td>
</tr>
<tr>
<td>256</td>
<td>15</td>
<td>30</td>
<td>12-24</td>
<td>6-12 kbps</td>
</tr>
<tr>
<td>128</td>
<td>30</td>
<td>60</td>
<td>42-51</td>
<td>20-24 kbps</td>
</tr>
<tr>
<td>64</td>
<td>60</td>
<td>120</td>
<td>90</td>
<td>45 kbps</td>
</tr>
<tr>
<td>32</td>
<td>120</td>
<td>240</td>
<td>210</td>
<td>105 kbps</td>
</tr>
<tr>
<td>16</td>
<td>240</td>
<td>480</td>
<td>432</td>
<td>215 kbps</td>
</tr>
<tr>
<td>8</td>
<td>480</td>
<td>960</td>
<td>912</td>
<td>456 kbps</td>
</tr>
<tr>
<td>4</td>
<td>960</td>
<td>1920</td>
<td>1872</td>
<td>936 kbps</td>
</tr>
<tr>
<td>4, with 3 parallel codes</td>
<td>2880</td>
<td>5760</td>
<td>5616</td>
<td>2.3 Mbps</td>
</tr>
</tbody>
</table>
Downlink Multiplexing and Channel Coding Chain

**TrCH 1**
- CRC attachment
- TrBlk concatenation/code block segmentation
- Channel coding
- Rate matching
- 1\textsuperscript{st} insertion of DTX indication
- 1\textsuperscript{st} interleaving
- Radio frame segmentation

**TrCH 2**
- DPDCH\#1 DPDCH\#2 ... DPDCH\#N
- PhyCH mapping
- 2\textsuperscript{nd} (intra-frame) interleaving
- Other TrCHs
- PhyCH segmentation
- 2\textsuperscript{nd} insertion of DTX indication
- TrCH multiplexing
- CCTrCh
Channel Coding and Rate Matching
The transport channels can choose between three types of channel coding: convolutional, turbo, or no coding.

- Convolutional coding with constraints length 9 and coding rate 1/3 or 1/2.
- The turbo coding scheme is a parallel concatenated convolutional code (PCCC) with eight-state constituent encoders and rate 1/3.
Rate Matching

- Rate matching is applied in order to match the bit rate of the CCTrCh to one of the limited set of bit-rates of the physical channel.
- Static rate matching is done after channel coding to adjust the rate of each transport channel so that the maximum bit rate of the CCTrCh matches the physical channel.
- Can be done by the addition, removal or redefinition of a transport channel.
- Should be done such that the transport channels achieve their QoS requirements at approximately the same SIR.
- Dynamic rate matching is done for each radio frame.
- Uses symbol repetition to ensure that the bit rate of the CCTrCh exactly matches the bit rate of the physical channel.

![Diagram](chart.png)

- Data (80 bits)
- CRC (8)
- Tail (8)
- Conv. coding Rate 1/3, K=9
- 3*96 = 288 bits
- Unequal repetition (9→10)
- 288*10/9 = 320 bits
  \[ \Rightarrow 32 \text{ kbps DPDCH} \]
PHY Signaling and PHY operations
Cell Search with Asynchronous Base Stations

- To support an efficient cell search with asynchronous operation each W-CDMA base station transmits a special synchronization signal.
- The synchronization consists of two signals transmitted in parallel: Primary synchronization code (PSC) and secondary synchronization code (SSC).
- The PSC is transmitted repeatedly. PSC is a Gold code of length 256 chips and is the same for all the base stations in the network. By detecting the PSC the user acquires slot synchronization with the target BS.
- The SSC is a repeatedly transmitted sequence of length 15. There are 64 unique SSC sequences and each SSC sequence has 15 SSCs. The sequences have unique cyclic shifts. The user needs to know 15 successive SSCs to determine the code group in order to know the frame synchronization.
- The code groups (SSC sequences) also determine which code group the BS scrambling code belongs to. Each code group has 8 scrambling codes and the correct one is found by searching each one on symbol-by-symbol correlation.
Soft Handover

- Base-stations are usually mutually asynchronous, inter-base station synchronization is needed for a soft handover.
- Soft handover consists of the following steps:
  - From the cell search, the user can estimate the timing offset between the downlink dedicated channel of the current BS and the primary common control physical channel (primary CCPCH) of the target BS.
  - The estimated timing offset is transferred to the target BS using the current link with the old BS through the radio network controller (RNC).
  - The target BS uses the estimated timing offset to adjust the timing of the new downlink dedicated channel relative to that of the primary CCPCH.
  - Due to an (approx.) fixed offset between the downlink and uplink frame timing, the target BS can estimate the timing of the uplink to receive.
Compressed Mode

- Compressed mode is needed when making measurements from another channel
  - E.g. in a HCS or in a handover to GSM.
- The transmission and reception are halted for a short time to perform measurements on the other frequencies.
- Three methods for compressed mode:
  - Lowering the data rate from higher layers.
  - Increasing the data rate by changing the spreading factor.
  - Reducing the symbol rate by puncturing at the physical layer MUX chain.
- More power is needed in compressed mode.
Fast Closed Loop PC - Inner Loop

- Uplink PC is used for near-far problem. Downlink PC is to ensure coverage at cell edge.
- One PC command per slot.
- Step 1 dB or 0.5 dB.
- The SIR target for fast closed loop PC is set by the outer loop PC.
- Two special cases for fast closed loop PC:
  - Soft handover: how to react to multiple PC commands from several sources. At the mobile, a "power down" command has higher priority than a "power up" command.
  - Compressed mode: Large step size is used after a compressed frame to allow the power level to converge quickly to the correct value after the break.
Closed Loop PC - Outer Loop PC
- Set the SIR target in order to maintain a certain frame error rate (FER). Operated by the RNC.

Open Loop PC
- No feedback information.
- Make rough estimate of path loss based on a downlink beacon signal.
- Provide a coarse initial power setting of the mobile at the beginning of a connection.
Layer 2
W-CDMA Radio Link Control (RLC)/Media Access Control (MAC)
The RLC and MAC are responsible for efficiently transferring data of both real-time and non-real time services.

Non-real time services include the possibility of automatic repeat request (ARQ), to ensure reliable data transfer.

MAC layer controls, but does not carry out, the multiplexing of data streams from different services.

The RLC segments data streams from higher layers into small packets suitable for radio transmission.

All RLC blocks have the same size. Transmission rate of RLC blocks changes with radio transmission rate.
Model of operation

Packet Data service

- Two ways to transmit packets: on the RACH or on a dedicated channel.
- On the RACH:
  - Usually used to transmit small amounts of packets.
  - There is a risk of collision on the common RACH and no power control, leading to higher $E_b/N_0$ requirements.
- Through a dedicated channel:
  - Used when the user has large packets to transmit.
  - If no dedicated channel available: user sends a resource request message. Receives resource allocation message.

Real Time Services

- Similar to packet data service.
- The user has more freedom in choosing transport formats to support variable bit rate services such as speech.

Mized Services

- The MAC supports mixed services.
- The PHY is capable of multiplexing bitstreams from different services. The MAC controls this process by controlling the data stream delivered to the PHY over the transport channels.
- For multi-service transmission, the MAC gets assigned a specific output power/rate threshold.
- The aggregate rate of both services must be below this threshold.
High Speed Packet Access
High Speed Downlink Packet Access

- New frame size: 2 ms with 3 slots.
- Channel feedback for each frame.
- Adaptive modulation and coding: can utilize 16 QAM.
- Hybrid ARQ. Done between BS and mobile (as opposed to between RNC and mobile). Reduces latency.
- BS fast scheduler: based on channel feedback with proportional fair scheduler.
References and further reading


   http://www.etsi.org/deliver/etsi_tr/101100_101199/101146/03.00.00_60/tr_101146v030000p.pdf


   http://www.etsi.org/deliver/etsi_ts/125300_125399/125308/05.07.00_60/ts_125308v050700p.pdf