Mobile Communications II
From Cellular to Mobile Services

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Mobile Communications II
Chapter 5: UMTS

Universal Mobile Communication System

- Overview/Standardisations
- Architecture
- Data services
  - HSPA (High Speed Packet Access)
UMTS

- Goal to create an Universal Personal Communication (UPN) system
  - Home (stationary), Car (speed up to 500km/h), Satellite (slow mobility in rural areas), Pedestrian (10km/h, high speed, high quality)
- Initiative for a Future Public Land Mobile Telecommunication System (FPLMTS)
- First initiative already in 1988/89
- Additional spectrum was granted at WRC-2000 for IMT-2000
  - 800-1000MHz; 1700-1900 MHz; 2500-2700 MHz
- Original goal to define a world wide unique standard failed
  - Interests of the network operators was to move evolutionary towards IMT-2000 services (to keep investment cost in limits)
  - GSM-industry wanted to keep commercial lead in further developments
  - National interests prohibited the agreement
  - Frequency regulators and existing services prohibited the unique frequency band
## Faster and improved access to the Mobile Internet

<table>
<thead>
<tr>
<th>Wired</th>
<th>Wireless</th>
</tr>
</thead>
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<tr>
<td>Modem</td>
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<td>ADSL</td>
<td>ADSL+ / VDSL</td>
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<td>FTTU</td>
<td>WiMAX / LTE</td>
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<td>CDPD</td>
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<tr>
<td>EDGE</td>
<td>WCDMA</td>
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<tr>
<td>HSPA</td>
<td></td>
</tr>
<tr>
<td>56kbps</td>
<td>144kbps</td>
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<tr>
<td>1-8Mbps</td>
<td>&gt;20Mbps</td>
</tr>
<tr>
<td>&gt;1Mbps</td>
<td>&gt;100Mbps</td>
</tr>
<tr>
<td>384kbps</td>
<td>144kbps</td>
</tr>
<tr>
<td>&gt;1Mbps</td>
<td>&gt;5Mbps</td>
</tr>
<tr>
<td>19kbps</td>
<td>&gt;50Mbps</td>
</tr>
</tbody>
</table>

### Scenery

- **CIF Video/H.264**
  - 144 kbps
- **4CIF Video/H.264**
  - 300 – 700 kbps
- **Compressed HDTV Streams**
  - 5-20 Mbps
- **MP3 Audio**
  - 128 kbps
- **Full Screen (XGA)**
  - MPEG4 - MPEG2
  - 700 kbps – 4.3 Mbps

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Access to higher quality content, richer mobile experiences everywhere on a variety of mobile devices.
Highlight of Current Activities (5/10) - Road Map of Mobile Communication

CDMA2000

- **1xEV-DO Rev. 0**
  - DL: 2.4Mbps
  - UL: 153.6kbps

- **1xEV-D0 Rev. A**
  - DL: 3.1Mbps
  - UL: 1.8Mbps

- **1xEV-DV**
  - 3.1Mbps

CDMA2000

- **WCDMA**
  - **WCDMA R99/R4**
    - 384kb/s
  - **HSDPA**
    - 1.8M/14.4Mbps
  - **HSUPA**
    - 6-8Mbps

- **HSPA+**
  - DL: >40Mbps
  - UL: >10Mbps

- **LTE**
  - **LTE**
    - DL: 100Mbps
    - UL: 50Mbps
  - **LTE+**
    - DL: 100Mbps
    - UL: 50Mbps

- **TD-SCDMA**
  - **R4**
    - 384kb/s
  - **HSPA**
    - Single-Carrier
      - 2.8Mbps
      - 2.2Mbps

- **HSPA+**
  - >10Mbps

- **UMB-UMB+**
  - **LBC**
    - DL: 100Mbps-1Gbps
    - UL: 50-100Mbps
  - **SBC**
    - DL: 100Mbps-1Gbps
    - UL: 50-100Mbps

**Timeline**

- **2001-2005**
- **2006-2007**
- **2008-2010**
Frequencies for IMT-2000

ITU allocation (WRC 1992)

Europe

- GSM 1800
- DECT
- UTRA FDD
- UTRA FDD
- MSS ↑
- MSS ↑

China

- GSM 1800
- IMT-2000
- cdma2000
- W-CDMA
- MSS ↑
- cdma2000
- W-CDMA
- MSS ↓

Japan

- PHS
- IMT-2000
- MSS ↑
- cdma2000
- W-CDMA
- MSS ↓

North America

- PCS
- IMT-2000
- MSS ↑
- rsv.
- MSS ↓
UMTS and IMT-2000

- Proposals for IMT-2000 (International Mobile Telecommunications)
  - UWC-136 (as an evolution of D-AMPS), cdma2000 (as an evolution of IS-95, CDMA One), W-CDMA (as an evolution of GSM/GPRS based systems), DECT as an extension of cordless telephony
  - UMTS (Universal Mobile Telecommunications System) from ETSI
- UMTS
  - UTRA (Universal Terrestrial Radio Access; Air Interface)
  - enhancements of GSM
    - EDGE (Enhanced Data rates for GSM Evolution): GSM up to 384 kbit/s
      - 8-PSK, in GSM Frequency range using same TDMA slot structure
    - CAMEL (Customized Application for Mobile Enhanced Logic)
      - Intelligent service environment for visitors in foreign networks
      - VHE (virtual Home Environment)
  - fits into GMM (Global Multimedia Mobility) initiative from ETSI
  - requirements
    - min. 144 kbit/s rural (goal: 384 kbit/s; speed up to 500km/h)
    - min. 384 kbit/s suburban (goal: 512 kbit/s; speed up to 120km/h)
    - up to 2 Mbit/s urban (pedestrian speed)
Standardisation Issues

• All activities towards 3G systems were transferred to 3GPP (3G partnership program)
• Instead of defining a single unique standard 3GPP decided to build a family of standards for IMT-2000
  – IMT-DS (direct spread): W-CDMA systems like UTRA-FDD
  – IMT-TC (time code): originally only UTRA-TDD but now also TD-SCDMA (time division synchronous) as the Chinese variant for low speed high performance communication
  – IMT-MC (Multi Carrier): members are CDMA-2000 but moved into 3GPP2 for the further evolution of IMT-2000 performance (mainly pushed by Qualcomm)
  – IMT-SC (Single Carrier): members are UWC136 (D-AMPS) mainly evolutionary path via EDGE (pushed by US-operators)
  – IMT-FT (Frequency Time): improved version of DECT
Flexible assignment of Core Network and Radio Access

IMT-2000 family

Interface for Internetworking

GSM (MAP)

ANSI-41 (IS-634)

IP-Network

Flexible assignment of Core Network and Radio Access

Initial UMTS (R99 w/ FDD)

IMT-2000 Core Network
ITU-T

IMT-2000 Radio Access
ITU-R

IMT-DS (Direct Spread)
UTRA FDD (W-CDMA) 3GPP

IMT-TC (Time Code)
UTRA TDD (TD-CDMA); TD-SCDMA 3GPP

IMT-MC (Multi Carrier)
cdma2000 3GPP2

IMT-SC (Single Carrier)
UWC-136 (EDGE) UWCC/3GPP

IMT-FT (Freq. Time)
DECT ETSI

ANSI-41: Systems Interworking
More Standardisation

- 3GPP develops standards in form of releases
- Release-99 has been introduced, Release 5 and Release 6 are now widely implemented (HSDPA/HSUPA), LTE is in the roll-out process
- LTE-Advanced Release 10
- The evolution towards a “full IP based IMT-2000” is reflected in the different release states
  - Release 4: introduces QoS within the core network, mobile execution environments (MExE), new service architectures
  - Release 5: introduces a fundamentally different core network as a full IP based network (convergence from today’s CS-Architectures); IETF will be more and more important for service levels of IMT-Releases; parts of SS7 signalling architecture will be replaced by SIP (session initialisation protocol) for multi-media streaming; additionally introduction of HSDPA (High speed downlink packet access 8-10Mb/s)
  - Release 6: additionally MIMO structures for performance increase and better radio spectrum use
- Currently first role-out of LTE (Long Term Evolution) is on-going.
- LTE+ (advanced) standardization is completed.
  - Data communication up to 140 Mb/s should become possible using MIMO and distributed MIMO techniques.
  - Multi-Hop communication should allow better coverage at the cell edges
Licensing Example: UMTS in Germany, 18. August 2000

- **UTRA-FDD:**
  - Uplink 1920-1980 MHz
  - Downlink 2110-2170 MHz
  - duplex spacing 190 MHz
  - 12 channels, each 5 MHz

- **UTRA-TDD:**
  - 1900-1920 MHz,
  - 2010-2025 MHz;
  - 5 MHz channels

- **Coverage:** 25% of the population until 12/2003, 50% until 12/2005

**Sum:** 50.81 billion €
UMTS architecture (Release 99 used here!)

- **UTRAN** (UTRA Network) (UTRA: Universal Terrestrial Radio Access)
  - Cell level mobility
  - Radio Network Subsystem (RNS)
  - Encapsulation of all radio specific tasks
- **UE** (User Equipment)
- **CN** (Core Network)
  - Inter system handover
  - Location management if there is no dedicated connection between UE and UTRAN
UMTS domains and interfaces I

UMTS domains describe functionalities

- **User Equipment Domain**
  - Assigned to a single user in order to access UMTS services
  - USIM contains all personal data as well as an UMTS SIM Application Toolkit (interpreter for flexible creation of new services)
- **Infrastructure Domain**
  - Shared among all users
  - Offers UMTS services to all accepted users
UMTS domains and interfaces II

- Universal Subscriber Identity Module (USIM)
  - Functions for encryption and authentication of users
  - Located on a SIM inserted into a mobile device
- Mobile Equipment Domain
  - Functions for radio transmission
  - User interface for establishing/maintaining end-to-end connections
- Access Network Domain
  - Access network dependent functions
- Core Network Domain
  - Core network dependent functions
  - Serving Network Domain
    - Network currently responsible for communication
  - Home Network Domain
    - Location and access network dependent functions
Spreading and scrambling of user data

- Constant chipping rate of 3.84 Mchip/s
- Different user data rates supported via different spreading factors
  - higher data rate: less chips per bit and vice versa
- User separation via unique, quasi orthogonal scrambling codes
  - users are not separated via orthogonal spreading codes
  - much simpler management of codes: each station can use the same orthogonal spreading codes
  - precise synchronization not necessary as the scrambling codes stay quasi-orthogonal

Separation of connections
Separation of users

3,84Mchip/s
OVSF (Orthogonal Variable Spreading Factor) coding

Generator

SF=n  SF=2n

1

1,1

1,1,1

1,1,1,1

1,1,1,1,1

1,1,1,1,1,1

...
Example of OVSF use for 4 connections with different bit-rates

SF=1   SF=2   SF=4   SF=8

1,1,1,1,1,1,1,1
1,1,1,1,1,1,1,1
1,1,1,1,1,1,1,1
1,1,1,1,1,1,1,1
1,1,1,1,1,1,1,1
1,1,1,1,1,1,1,1
1,1,1,1,1,1,1,1
1,1,1,1,1,1,1,1
...
UMTS FDD frame structure

W-CDMA
- 1920-1980 MHz uplink
- 2110-2170 MHz downlink
- chipping rate: 3.840 Mchips/s
- soft handover
- QPSK
- complex power control (1500 power control cycles/s)
- spreading: UL: 4-256; DL: 4-512

FBI: Feedback Information
TPC: Transmit Power Control
TFCI: Transport Format Combination Indicator
DPCCH: Dedicated Physical Control Channel
DPDCH: Dedicated Physical Data Channel
DPCH: Dedicated Physical Channel

Slot structure NOT for user separation but for synchronisation for periodic functions!
UMTS TDD frame structure (burst type 2) (TD-CDMA)

**TD-CDMA**
- 2560 chips per slot
- spreading: 1-16
- symmetric or asymmetric slot assignment to UL/DL (min. 1 per direction)
- tight synchronization needed
- simpler power control (100-800 power control cycles/s)

Rarely used mode
UTRAN architecture

RNC: Radio Network Controller
RNS: Radio Network Subsystem

- UTRAN comprises several RNSs
- Node B can support FDD or TDD or both
- RNC is responsible for handover decisions requiring signalling to the UE
- Cell offers FDD or TDD
UTRAN functions

- Admission control
- Congestion control
- System information broadcasting
- Radio channel encryption
- Handover
- SRNS moving (Serving RNS)
- Radio network configuration
- Channel quality measurements
- Macro diversity
- Radio carrier control
- Radio resource control
- Data transmission over the radio interface
- Outer loop power control (FDD and TDD)
- Channel coding
- Access control
Integrated Core network: architecture

- BTS
- BSS
- Node B
- RNC
- RNS
- VLR
- MSC
- GMSC
- EIR
- HLR
- AuC
- GR
- SGSN
- GGSN
- PSTN
- CN

Connections:
- A_{bis}
- I_u
- I_uCS
- I_uPS
- G_n
- G_i
Core network: protocols
Towards All-IP Networks

Layer 1: PDH, SDH, SONET
Layer 2: ATM
Layer 3: IP

RNS
MSC
VLR
GMSC
GGSN
HLR
VLR
SS 7
GPRS backbone (IP)
GSM-CS backbone
PSTN/ISDN
PDN (X.25), Internet (IP)
GSM-CS
UTRAN
CN
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Thursday, 16 January 2014
Winter Term 2013 – Mobile Communications II

Chair Systems
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Core network

- The Core Network (CN) and thus the Interface $I_u$, too, are separated into two logical domains:
  - Circuit Switched Domain (CSD)
    - Circuit switched service incl. signaling
    - Resource reservation at connection setup
    - GSM components (MSC, GMSC, VLR)
    - $I_u$CS
  - Packet Switched Domain (PSD)
    - GPRS components (SGSN, GGSN)
    - $I_u$PS

- Release 99 uses the GSM/GPRS network and adds only a new radio access!
  - Helps to save a lot of money …
  - Much faster deployment
  - Not as flexible as newer releases (5, 6)
UMTS protocol stacks (user plane)

RLC: Radio Link Control
SAR: Segmentation & Reassembly
ATM: Asynchronous Transfer Mode
GTP: GPRS Tunneling Protocol
PDCP: Packet Data Conversions Protocol
AAL2: ATM-Adaptation Layer 2 (High Quality)
AAL5: AAL with best effort service
Support of mobility: macro diversity

• Multicasting of data via several physical channels
  – Enables soft handover
  – FDD mode only

• Uplink
  – simultaneous reception of UE data at several Node Bs
  – Reconstruction of data at Node B, SRNC or DRNC

• Downlink
  – Simultaneous transmission of data via different cells
  – Different spreading codes in different cells

SRNC: Serving RNC
DRNC: Drift RNC
Support of mobility: handover

- From and to other systems (e.g., UMTS to GSM)
  - This is a must as UMTS coverage will be poor in the beginning
- RNS controlling the connection is called SRNS (Serving RNS)
- RNS offering additional resources (e.g., for soft handover) is called Drift RNS (DRNS)
- End-to-end connections between UE and CN only via I_u at the SRNS
  - Change of SRNS requires change of I_u
  - Initiated by the SRNS
  - Controlled by the RNC and CN

SRNC: Serving RNC
DRNC: Drift RNC
Example handover types in UMTS/GSM

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Cell breathing

- CDM systems: cell size depends on current load
- Additional traffic appears as noise to other users
- If the noise level is too high users drop out of cells
Cell breathing and noise increase in UMTS voice

Cell range [km]

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6

Noise increase

0 2 4 6 8 10 12 14 16 18 20

Number of users

0 10 20 30 40 50

Cell breathing
UMTS Conclusions

- UMTS is part of the IMT-2000 initiative driven by 3GPP
- It is a continuously changing system that develops evolutionary towards an ALL-IP network for integrated data, voice and multi-media services
- In Europe currently Release 5/6 are introduced
- Release 99 has been the evolution path from GSM to UMTS that saved a lot of financial resources and was a smooth transfer path
- UMTS is a big step forward towards UPN even though it will not be achieved in a single step
- The creation of 3GPP to moderate the convergence process was a good means to approach a user demanded long term goal
### UMTS data services (originally)

- Data transmission service profiles

<table>
<thead>
<tr>
<th>Service Profile</th>
<th>Data rate</th>
<th>Transport mode</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Interactive MM</td>
<td>128 kbit/s</td>
<td>Circuit switched</td>
<td>Bidirectional, video telephone</td>
</tr>
<tr>
<td>High MM</td>
<td>2 Mbit/s</td>
<td>Packet switched</td>
<td>Low coverage, max. 6 km/h</td>
</tr>
<tr>
<td>Medium MM</td>
<td>384 kbit/s</td>
<td>Circuit switched</td>
<td>asymmetrical, MM, downloads</td>
</tr>
<tr>
<td>Switched Data</td>
<td>14.4 kbit/s</td>
<td>Circuit switched</td>
<td></td>
</tr>
<tr>
<td>Simple Messaging</td>
<td>14.4 kbit/s</td>
<td>Packet switched</td>
<td>SMS successor, E-Mail</td>
</tr>
<tr>
<td>Voice</td>
<td>16 kbit/s</td>
<td>Circuit switched</td>
<td></td>
</tr>
</tbody>
</table>
Options for Packet Data transmission in Release 99

- **DCH (Dedicated Channel)**
  - Spreading codes assigned per user
  - Closed loop power control
  - Macro diversity

- **FACH/RACH (Common Channel) (Forward Access Channel, Random Access Channel)**
  - Common spreading code
  - Header defines user
  - No closed loop power control

- **DSCH (Downlink Shared Channel)**
  - not implemented for FDD
  - Common spreading code shared by many users
  - User assignment by Physical Layer signaling
  - Closed loop power control with DPCH
What Limitations of R99 will HSDPA Address?

- Release 99 Downlink Limitations
  - Limited Peak Data Rate
    - Maximum implemented Downlink of 384 kbps
  - Capacity and Throughput
    - Modulation and coding
      - QPSK is maximum modulation format
      - Convolution coding (R=1/2, 1/3) or turbo coding (R=1/3) are required
    - Link adaptation due to channel conditions
      - Fast closed inner loop power control, but
      - Slower outer loop
  - Minimum TTI (Transition Time Interval) of 10 ms because of Slot structure
  - Slow Rate and Type Switching
HSDPA Enabling Technologies

• How will HSDPA address the limitations of Release 99?
  – Extension of DSCH (downlink shared channel)
  – Multi-Code operation (more than one spreading code can be accumulated)
  – Adaptive modulation and coding
    • QPSK and 16-QAM
    • Coding from R=1/3 to R=1
    • Fast feedback of channel condition
  – Improve transmission efficiency
    • Fast retransmission and Physical Layer HARQ
  – Fast resource management
    • Node B scheduling
  – Reduce transmission latency
    • 2 ms TTI
Common Channel for data transfer using the HS-PDSCH

Node B

HS-PDSCH: High Speed Physical Downlink Shared Channel
Multi-Code Operation

- Fixed Spreading Factor SF=16
  - (Typical Spreading Factor for 128 kbps in Release 99)
- 1-15 codes can be reserved for HS-PDSCH
- Can be TDM (Time division multiplexing) and/or CDM (Code division multiplexing) between users
Adaptive Modulation and Coding

- Coding from $R=1/3$ to $R=1$
- HSDPA supports 16-QAM modulation
  - 4 bits per symbol versus 2 bits per symbol with QPSK

![Diagram of spreading and modulator](image)

2 bits → Spreading → Modulator (QPSK) → 3,84 Mcps

4 bits → Spreading → Modulator (16-QAM) → 3,84 Mcps
**• Release 99**
  - Use fast power control with fixed data rate (DCH)

**• HSDPA**
  - Adapt the modulation and coding to the link quality

**Fast Link adaptation:**
- Rate #3: e.g. 16-QAM, R=3/4
- Rate #2: e.g. QPSK, R=3/4
- Rate #1: e.g. QPSK, R=1/2
Scheduling Comparison: More distribution between RNC and Node B

RELEASE 99
Scheduling
RLC ARQ
Resource Allocation

RELEASE 5 (HSDPA)
Scheduling
RLC ARQ
Resource Allocation

RELEASE 5 (HSDPA)
Link Adaptation
HARQ
Resource Allocation

RNC
Node B

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HSDPA Scheduling and Retransmissions

- **Scheduling**
  - Done at the Node B
  - No interaction with the RNC
  - Based on channel quality feedback from the UE

- **Retransmissions**
  - HARQ (link level retransmissions)
  - Done at the Node B
  - Based on UE feedback (ACK/NACK)
  - Soft combining at the UE
Hybrid Automatic Repeat Request (HARQ)

- Scheme:
  - combining ARQ and Forward Error Correction
- FEC decoding based on all unsuccessful transmissions
- Simple Stop-and-Wait (SAW) protocol
- Two basic schemes:
  - Chase Combining
    - same data block is sent at each retransmission
  - Incremental Redundancy (IR)
    - Additional Redundant Information sent at each retransmission
HARQ – Illustration

First Transmission

New Data Block

Data Combined

DECODER

NAK

NAK

ACK

 Fail

Pass

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### Comparison Summary

<table>
<thead>
<tr>
<th>Mode</th>
<th>DCH</th>
<th>FACH</th>
<th>HSDPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Type</td>
<td>Dedicated</td>
<td>Common</td>
<td>Common</td>
</tr>
<tr>
<td>Power Control</td>
<td>Closed Inner Loop at 1500 Hz - Slow Outer Loop</td>
<td>None</td>
<td>Fixed Power with link adaptation</td>
</tr>
<tr>
<td>Soft Handover</td>
<td>Supported</td>
<td>Not Supported</td>
<td>Not Supported</td>
</tr>
<tr>
<td>Suitability for Bursty Data</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Data Rate / Traffic Volume</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

DCH: Dedicated Channel  
FACH: Forward Access Channel
Impact of HSDPA inclusion to UMTS network architecture
HSDPA Channels

- New HSDPA Channels
  - Transport Channel
    - High Speed Downlink Shared Channel (HS-DSCH)
      - Downlink Transport Channel
  - Physical Channels
    - High Speed Shared Control Channel (HS-SCCH)
      - Downlink Control Channel
    - High Speed Physical Downlink Shared Channel (HS-PDSCH)
      - Downlink Data Channel
    - High Speed Dedicated Physical Control Channel (HS-DPCCH)
      - Uplink Control Channel
Review: How do we get to 14.4 Mbps?

- Multi-code transmission
  - Node B must allocate all 15 OVSF (Orthogonal Variable Spreading Factor) codes of length 16 to one UE

- Consecutive assignments
  - Node B must allocate all time slots to one UE
  - UE must decode all transmissions correctly on the first transmission

- Lower Coding Gain
  - Effective code rate = 1
  - Requires very good channel conditions to decode

- 16-QAM
  - Requires very good channel conditions
Review: How do we get to 14.4 Mbps?

- TTI of 10 ms is shortened to 2 ms (STTI, Short Transmission Time Interval)
- in STTI 3 slots
- in each slot 2560 symbols → 7680 symbols in STTI
- QAM-16 → 4 chips per symbol → 7680 * 4 = 30720 chips per STTI
- spreading factor 16 → 30720/16 = 1920 bit per STTI
- max. 15 channels → 1920 bit * 15 = 28800 bit per STTI

- 28800 bit per 2ms → 14.4 Mbit per second
## 3GPP standards evolution (RAN & GERAN)

<table>
<thead>
<tr>
<th>Release</th>
<th>Commercial introduction</th>
<th>Main feature of Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel-99</td>
<td>2003</td>
<td>Basic 3.84 Mcps W-CDMA (FDD &amp; TDD)</td>
</tr>
<tr>
<td>Rel-4</td>
<td>Trials</td>
<td>1.28 Mcps TDD (aka TD-SCDMA)</td>
</tr>
<tr>
<td>Rel-5</td>
<td>2006</td>
<td>HSDPA</td>
</tr>
<tr>
<td>Rel-6</td>
<td>2007</td>
<td>HSUPA (E-DCH)</td>
</tr>
<tr>
<td>Rel-7</td>
<td>2008+</td>
<td>HSPA+ (64QAM DL, MIMO, 16QAM UL). Many smaller features plus LTE &amp; SAE Study items</td>
</tr>
<tr>
<td>Rel-8</td>
<td>HSPA+ 2009, LTE 2010+</td>
<td>LTE Work item – OFDMA air interface SAE Work item New IP core network Edge Evolution, more HSPA+</td>
</tr>
<tr>
<td>Rel-9</td>
<td>2011 – 2014</td>
<td>LTE Evolved MBMS, IMT-Advanced (4G)</td>
</tr>
</tbody>
</table>
### Mobile WiMAX and HSPA+

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HSPA(^1)</th>
<th>WiMAX</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Rel-7</td>
<td>Rel-8</td>
</tr>
<tr>
<td>Frequency</td>
<td>2000 MHz</td>
<td></td>
</tr>
<tr>
<td>Duplex</td>
<td>FDD</td>
<td>FDD</td>
</tr>
<tr>
<td>Channel BW</td>
<td>2 x 5 MHz</td>
<td>2 x 5 MHz</td>
</tr>
<tr>
<td>BS Antenna</td>
<td>(1x2) SIMO</td>
<td>(2x2) MIMO</td>
</tr>
<tr>
<td>MS Antenna</td>
<td>(1x2) SIMO</td>
<td></td>
</tr>
<tr>
<td>DL Mod-Coding(^2)</td>
<td>64QAM-5/6</td>
<td>16QAM-3/4</td>
</tr>
<tr>
<td></td>
<td>64QAM-5/6</td>
<td>64QAM-5/6</td>
</tr>
<tr>
<td>UL Mod-Coding(^2)</td>
<td>16QAM-3/4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>64QAM-5/6</td>
<td>64QAM-5/6</td>
</tr>
<tr>
<td>DL Peak User Rate</td>
<td>17.5 Mbps</td>
<td>21 Mbps</td>
</tr>
<tr>
<td></td>
<td>36 Mbps</td>
<td>48 Mbps(^3)</td>
</tr>
<tr>
<td>UL Peak User Rate</td>
<td>8.3 Mbps</td>
<td>8.3 Mbps</td>
</tr>
<tr>
<td></td>
<td>17 Mbps</td>
<td>24 Mbps(^4)</td>
</tr>
</tbody>
</table>