Mobile Communications
Chapter 4: Wireless Telecommunication Systems

Market
GSM
TETRA
UMTS/IMT-2000
LTE/LTE advanced
Mobile phone subscribers worldwide

2016: 7.8 bn total
4.7 bn unique human
4.7% growth/year
### Top mobile markets (2013/2014)

#### The 100 million club: the top 14 mobile markets by number of subscriptions

<table>
<thead>
<tr>
<th>Country</th>
<th>Mobile subscriptions in millions</th>
<th>Population in millions: source World Bank</th>
<th>% of population</th>
<th>3G/4G subscriptions in millions</th>
<th>% of population</th>
<th>Sources: subs: 3G subs</th>
<th>Last update</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>6,587.4m</td>
<td>7,046m</td>
<td>93.5%</td>
<td>1,076.6m</td>
<td>26.6%</td>
<td>Informa</td>
<td>06/13</td>
</tr>
<tr>
<td>China</td>
<td>1,246.3m</td>
<td>1,351m</td>
<td>92.3%</td>
<td>448.3m</td>
<td>33.2%</td>
<td>China Mobile China China Unicom China Telecom</td>
<td>02/14</td>
</tr>
<tr>
<td>India</td>
<td>Active: 772.6m; total: 893.3m</td>
<td>1,237m</td>
<td>62.5%</td>
<td>41.95m</td>
<td>3.4%</td>
<td>TRAI</td>
<td>01/14</td>
</tr>
<tr>
<td>United States</td>
<td>345.2m</td>
<td>313.9m</td>
<td>110.0%</td>
<td>287.4m</td>
<td>91.6%</td>
<td>Informa</td>
<td>06/13</td>
</tr>
<tr>
<td>Indonesia</td>
<td>285.0m</td>
<td>246.9m</td>
<td>115.4%</td>
<td>45.5m</td>
<td>18.4%</td>
<td>Informa</td>
<td>06/13</td>
</tr>
<tr>
<td>Brazil</td>
<td>272.6m</td>
<td>198.7m</td>
<td>137.2%</td>
<td>110.2m</td>
<td>55.5%</td>
<td>Anatel/Teleco</td>
<td>02/14</td>
</tr>
<tr>
<td>Russia</td>
<td>237.1m</td>
<td>143.5m</td>
<td>165.2%</td>
<td>41.2m</td>
<td>28.7%</td>
<td>Informa</td>
<td>06/13</td>
</tr>
<tr>
<td>Japan</td>
<td>137.9m</td>
<td>127.6m</td>
<td>108.0%</td>
<td>108.8m</td>
<td>85.3%</td>
<td>TCA</td>
<td>02/14</td>
</tr>
<tr>
<td>Vietnam</td>
<td>127.7m</td>
<td>88.8m</td>
<td>142.8%</td>
<td>18.0m</td>
<td>20.3%</td>
<td>Informa</td>
<td>06/13</td>
</tr>
<tr>
<td>Pakistan</td>
<td>126.1m</td>
<td>179.2m</td>
<td>70.4%</td>
<td>N/A</td>
<td>N/A</td>
<td>Informa</td>
<td>06/13</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Active: 128.6m; total: 175.0m</td>
<td>168.8m</td>
<td>76.2%</td>
<td>12.7m</td>
<td>7.5%</td>
<td>NCC Informa</td>
<td>02/14</td>
</tr>
<tr>
<td>Germany</td>
<td>113.6m</td>
<td>81.9m</td>
<td>138.7%</td>
<td>46.0m</td>
<td>56.2%</td>
<td>BNA Informa</td>
<td>06/13</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>116.0m</td>
<td>154.7m</td>
<td>75.0%</td>
<td>34.6m*</td>
<td>22.3%*</td>
<td>BTRC Informa</td>
<td>09/13</td>
</tr>
<tr>
<td>Philippines</td>
<td>109.5m</td>
<td>96.7m</td>
<td>113.2%</td>
<td>16.5m</td>
<td>17.1%</td>
<td>Informa</td>
<td>06/13</td>
</tr>
<tr>
<td>Mexico</td>
<td>102.7m</td>
<td>120.8m</td>
<td>117.6%</td>
<td>19.8m</td>
<td>16.4%</td>
<td>Informa</td>
<td>06/13</td>
</tr>
</tbody>
</table>

Source: Paul Lambert, Informa (Q2 2013); national telecoms regulators * Bangladesh: mobile Web subscribers (not necessarily 3G) via: mobithinking.com
World largest mobile network operators 2014

$10.25 ARPU/month
However: -2.8% growth/year

Source: GSMAIntelligence
Development of mobile telecommunication systems
Some press news…

16th April 2008: The GSMA, the global trade group for the mobile industry, today announced that total connections to GSM mobile communications networks have now passed the 3 Billion mark globally. The third billion landmark has been reached just four years after the GSM industry surpassed its first billion, and just two years from the second billionth connection. The 3 Billion landmark has been surpassed just 17 years after the first GSM network launch in 1991. Today more than 700 mobile operators across 218 countries and territories of the world are adding new connections at the rate of 15 per second, or 1.3 million per day.

11 February 2009: The GSMA today announced that the mobile world has celebrated its four billionth connection, according to Wireless Intelligence, the GSMA’s market intelligence unit. This milestone underscores the continued strong growth of the mobile industry and puts the global market on the path to reach a staggering six billion connections by 2013.

By 2014 3.4bn people have broadband, 80% mobile!
Some more data...

### Worldwide device shipments by segment (millions of units) according to Gartner

<table>
<thead>
<tr>
<th>Type of device</th>
<th>2013 sales</th>
<th>2014 sales</th>
<th>2015 sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCs desktop / laptop</td>
<td>296.1</td>
<td>276.7</td>
<td>263.0</td>
</tr>
<tr>
<td>Tablets (ultramobile)</td>
<td>195.4</td>
<td>270.7</td>
<td>349.1</td>
</tr>
<tr>
<td>Mobile phones</td>
<td>1,807.0</td>
<td>1,895.1</td>
<td>1,952.9</td>
</tr>
<tr>
<td>Other ultramobiles (hybrid and clamshell)</td>
<td>21.1</td>
<td>37.2</td>
<td>62.0</td>
</tr>
<tr>
<td>Total</td>
<td>2,319.6</td>
<td>2,479.8</td>
<td>2,627.0</td>
</tr>
</tbody>
</table>

Source: © Gartner (March 2014)

### Top 10 mobile phone manufacturers in 2013 (millions of units) according to Gartner

<table>
<thead>
<tr>
<th>Vendor</th>
<th>2013 sales</th>
<th>2013 market share</th>
<th>2012 sales</th>
<th>2012 market share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>444.4</td>
<td>24.6%</td>
<td>384.6</td>
<td>22.0%</td>
</tr>
<tr>
<td>Nokia</td>
<td>250.8</td>
<td>13.9%</td>
<td>333.9</td>
<td>19.1%</td>
</tr>
<tr>
<td>Apple</td>
<td>150.8</td>
<td>8.3%</td>
<td>130.1</td>
<td>7.5%</td>
</tr>
<tr>
<td>LG</td>
<td>69.0</td>
<td>3.8%</td>
<td>58.0</td>
<td>3.3%</td>
</tr>
<tr>
<td>ZTE</td>
<td>59.9</td>
<td>3.3%</td>
<td>67.3</td>
<td>3.9%</td>
</tr>
<tr>
<td>Huawei</td>
<td>53.3</td>
<td>2.8%</td>
<td>47.3</td>
<td>2.7%</td>
</tr>
<tr>
<td>TCL</td>
<td>49.5</td>
<td>2.7%</td>
<td>37.2</td>
<td>2.1%</td>
</tr>
<tr>
<td>Lenovo</td>
<td>45.3</td>
<td>2.5%</td>
<td>28.2</td>
<td>1.5%</td>
</tr>
<tr>
<td>Sony</td>
<td>37.6</td>
<td>2.1%</td>
<td>31.4</td>
<td>1.8%</td>
</tr>
<tr>
<td>Yulong</td>
<td>32.6</td>
<td>1.8%</td>
<td>18.6</td>
<td>1.1%</td>
</tr>
<tr>
<td>Others</td>
<td>613.7</td>
<td>34.0%</td>
<td>609.6</td>
<td>34.9%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,807.0</td>
<td>100%</td>
<td>1,746.2</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: © Gartner (Feb 2014)

Source: mobithinking.com
How does it work?

How can the system locate a user?
Why don’t all phones ring at the same time?
What happens if two users talk simultaneously?
Why don’t I get the bill from my neighbor?
Why can an Australian use her phone in Berlin?

Why can’t I simply overhear the neighbor’s communication?
How secure is the mobile phone system?
What are the key components of the mobile phone network?
GSM: Overview

GSM

formerly: Groupe Spéciale Mobile (founded 1982)
now: Global System for Mobile Communication
Pan-European standard (ETSI, European Telecommunications Standardisation Institute)
simultaneous introduction of essential services in three phases (1991, 1994, 1996) by the European telecommunication administrations (Germany: D1 and D2)

⇒ seamless roaming within Europe possible

Today many providers all over the world use GSM (>220 countries in Asia, Africa, Europe, Australia, America)
more than 4.2 billion subscribers in more than 700 networks
more than 75% of all digital mobile phones use GSM
over 29 billion SMS in Germany in 2008, (> 10% of the revenues for many operators)
[be aware: these are only rough numbers…]

See e.g. www.gsmworld.com
Good bye SMS?

Die Talfahrt geht weiter

Zahl der pro Jahr versandten SMS in Deutschland in Milliarden

Quelle: Bundesnetzagentur
Performance characteristics of GSM (wrt. analog sys.)

Communication
mobile, wireless communication; support for voice and data services

Total mobility
international access, chip-card enables use of access points of different providers

Worldwide connectivity
one number, the network handles localization

High capacity
better frequency efficiency, smaller cells, more customers per cell

High transmission quality
high audio quality and reliability for wireless, uninterrupted phone calls at higher speeds (e.g., from cars, trains)

Security functions
access control, authentication via chip-card and PIN
Disadvantages of GSM

There is no perfect system!!

- no end-to-end encryption of user data
- no full ISDN bandwidth of 64 kbit/s to the user, no transparent B-channel

reduced concentration while driving

electromagnetic radiation

abuse of private data possible

roaming profiles accessible

high complexity of the system

several incompatibilities within the GSM standards
GSM: Mobile Services

GSM offers
several types of connections
voice connections, data connections, short message service
multi-service options (combination of basic services)

Three service domains
Bearer Services
Telematic Services
Supplementary Services
Bearer Services

Telecommunication services to transfer data between access points

Specification of services up to the terminal interface (OSI layers 1-3)

Different data rates for voice and data (original standard)
  data service (circuit switched)
    synchronous: 2.4, 4.8 or 9.6 kbit/s
    asynchronous: 300 - 1200 bit/s
  data service (packet switched)
    synchronous: 2.4, 4.8 or 9.6 kbit/s
    asynchronous: 300 - 9600 bit/s

Today (classical GSM!): data rates of approx. 50 kbit/s possible – will be covered later! (far more with new modulation)
Tele Services I

Telecommunication services that enable voice communication via mobile phones

All these basic services have to obey cellular functions, security measurements etc.

Offered services
  mobile telephony
    primary goal of GSM was to enable mobile telephony offering the traditional bandwidth of 3.1 kHz

Emergency number
  common number throughout Europe (112); mandatory for all service providers; free of charge; connection with the highest priority (preemption of other connections possible)

Multinumbering
  several ISDN phone numbers per user possible
Tele Services II

Additional services

Non-Voice-Teleservices
  group 3 fax
  voice mailbox (implemented in the fixed network supporting the mobile terminals)
  electronic mail (MHS, Message Handling System, implemented in the fixed network)

... 

Short Message Service (SMS)
  alphanumeric data transmission to/from the mobile terminal (160 characters) using the signaling channel, thus allowing simultaneous use of basic services and SMS
  (almost ignored in the beginning then the most successful add-on! – but more and more replaced by IP-based messaging)
Supplementary services

Services in addition to the basic services, cannot be offered stand-alone

Similar to ISDN services besides lower bandwidth due to the radio link

May differ between different service providers, countries and protocol versions

Important services
  - identification: forwarding of caller number
  - suppression of number forwarding
  - automatic call-back
  - conferencing with up to 7 participants
  - locking of the mobile terminal (incoming or outgoing calls)
  ...
Architecture of the GSM system

GSM is a PLMN (Public Land Mobile Network)

several providers setup mobile networks following the GSM standard within each country

components
- MS (mobile station)
- BS (base station)
- MSC (mobile switching center)
- LR (location register)

subsystems
- RSS (radio subsystem): covers all radio aspects
- NSS (network and switching subsystem): call forwarding, handover, switching
- OSS (operation subsystem): management of the network
Ingredients 1: Mobile Phones, PDAs & Co.

The visible but **smallest part** of the network!
Ingredients 2: Antennas

Still visible – cause many discussions…
Ingredients 3: Infrastructure 1

Base Stations

Cabling

Microwave links
Ingredients 3: Infrastructure 2

Not "visible", but comprise the major part of the network (also from an investment point of view…)

Switching units

Data bases

Management

Monitoring
GSM: overview

NSS with OSS

OMC, EIR, AUC

HLR

GMSC

VLR

MSC

VLR

MSC

RSS

BSC

fixed network
GSM: elements and interfaces
GSM: system architecture
System architecture: radio subsystem

Components
- **MS** (Mobile Station)
- **BSS** (Base Station Subsystem):
  consisting of
  - **BTS** (Base Transceiver Station): sender and receiver
  - **BSC** (Base Station Controller): controlling several transceivers

Interfaces
- **Um**: radio interface
- **Abis**: standardized, open interface with 16 kbit/s user channels
- **A**: standardized, open interface with 64 kbit/s user channels
System architecture: network and switching subsystem

- **Components**
  - MSC (Mobile Services Switching Center):
  - IWF (Interworking Functions)
  - ISDN (Integrated Services Digital Network)
  - PSTN (Public Switched Telephone Network)
  - PSPDN (Packet Switched Public Data Net.)
  - CSPDN (Circuit Switched Public Data Net.)

- **Databases**
  - HLR (Home Location Register)
  - VLR (Visitor Location Register)
  - EIR (Equipment Identity Register)
Radio subsystem

The Radio Subsystem (RSS) comprises the cellular mobile network up to the switching centers

Components

-Base Station Subsystem (BSS):
  -Base Transceiver Station (BTS): radio components including sender, receiver, antenna - if directed antennas are used one BTS can cover several cells
  -Base Station Controller (BSC): switching between BTSs, controlling BTSs, managing of network resources, mapping of radio channels ($U_m$) onto terrestrial channels (A interface)

\[ \text{BSS} = \text{BSC} + \text{sum(BTS)} + \text{interconnection} \]

-Mobile Stations (MS)
GSM: cellular network

- use of several carrier frequencies
- not the same frequency in adjoining cells
- cell sizes vary from some 100 m up to 35 km depending on user density, geography, transceiver power etc.
- hexagonal shape of cells is idealized (cells overlap, shapes depend on geography)
- if a mobile user changes cells handover of the connection to the neighbor cell
### GSM frequency bands (examples)

<table>
<thead>
<tr>
<th>Type</th>
<th>Channels</th>
<th>Uplink [MHz]</th>
<th>Downlink [MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM 850</td>
<td>128-251</td>
<td>824-849</td>
<td>869-894</td>
</tr>
<tr>
<td>GSM 900</td>
<td>0-124, 955-1023</td>
<td>876-915</td>
<td>921-960</td>
</tr>
<tr>
<td></td>
<td>124 channels</td>
<td>890-915</td>
<td>935-960</td>
</tr>
<tr>
<td></td>
<td>+49 channels</td>
<td>880-915</td>
<td>925-960</td>
</tr>
<tr>
<td>GSM 1800</td>
<td>512-885</td>
<td>1710-1785</td>
<td>1805-1880</td>
</tr>
<tr>
<td>GSM 1900</td>
<td>512-810</td>
<td>1850-1910</td>
<td>1930-1990</td>
</tr>
<tr>
<td>GSM-R</td>
<td>955-1024, 0-124</td>
<td>876-915</td>
<td>921-960</td>
</tr>
<tr>
<td></td>
<td>69 channels</td>
<td>876-880</td>
<td>921-925</td>
</tr>
<tr>
<td></td>
<td>921-960</td>
<td>921-925</td>
<td></td>
</tr>
</tbody>
</table>

- Additionally: GSM 400 (also named GSM 450 or GSM 480 at 450-458/460-468 or 479-486/489-496 MHz)
- Please note: frequency ranges may vary depending on the country!
- Channels at the lower/upper edge of a frequency band are typically not used
Example coverage of GSM networks (www.gsmworld.com)

- **T-Mobile (GSM-900/1800) Germany**
- **O₂ (GSM-1800) Germany**
- **AT&T (GSM-850/1900) USA**
- **Vodacom (GSM-900) South Africa**
Base Transceiver Station and Base Station Controller

Tasks of a BSS are distributed over BSC and BTS
BTS comprises radio specific functions
BSC is the switching center for radio channels

<table>
<thead>
<tr>
<th>Functions</th>
<th>BTS</th>
<th>BSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management of radio channels</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Frequency hopping (FH)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Management of terrestrial channels</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Mapping of terrestrial onto radio channels</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Channel coding and decoding</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rate adaptation</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Encryption and decryption</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Paging</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Uplink signal measurements</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Traffic measurement</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Authentication</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Location registry, location update</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Handover management</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Mobile station

Terminal for the use of GSM services

A mobile station (MS) comprises several functional groups

- MT (Mobile Terminal):
  - offers common functions used by all services the MS offers
  - corresponds to the network termination (NT) of an ISDN access
  - end-point of the radio interface (Um)

- TA (Terminal Adapter):
  - terminal adaptation, hides radio specific characteristics

- TE (Terminal Equipment):
  - peripheral device of the MS, offers services to a user
  - does not contain GSM specific functions

- SIM (Subscriber Identity Module):
  - personalization of the mobile terminal, stores user parameters – more and more replaced by eSIM
Network and switching subsystem

NSS is the main component of the public mobile network GSM
- switching, mobility management, interconnection to other networks, system control

Components
- Mobile Services Switching Center (MSC)
  controls all connections via a separated network to/from a mobile terminal within the domain of the MSC - several BSC can belong to a MSC
- Databases (important: scalability, high capacity, low delay)
  - Home Location Register (HLR)
    central master database containing user data, permanent and semi-permanent data of all subscribers assigned to the HLR (one provider can have several HLRs)
  - Visitor Location Register (VLR)
    local database for a subset of user data, including data about all user currently in the domain of the VLR
Mobile Services Switching Center

The MSC (mobile services switching center) plays a central role in GSM
- switching functions
- additional functions for mobility support
- management of network resources
- interworking functions via Gateway MSC (GMSC)
- integration of several databases

Functions of an MSC
- specific functions for paging and call forwarding
- termination of SS7 (signaling system no. 7)
- mobility specific signaling
- location registration and forwarding of location information
- provision of new services (fax, data calls)
- support of short message service (SMS)
- generation and forwarding of accounting and billing information
Operation subsystem

The OSS (Operation Subsystem) enables centralized operation, management, and maintenance of all GSM subsystems.

Components
- Authentication Center (AUC)
  - generates user specific authentication parameters on request of a VLR
  - authentication parameters used for authentication of mobile terminals and encryption of user data on the air interface within the GSM system
- Equipment Identity Register (EIR)
  - registers GSM mobile stations and user rights
  - stolen or malfunctioning mobile stations can be locked and sometimes even localized
- Operation and Maintenance Center (OMC)
  - different control capabilities for the radio subsystem and the network subsystem
GSM - TDMA/FDMA

- Higher GSM frame structures
- GSM TDMA frame
- GSM time-slot (normal burst)

- Frequency:
  - 935-960 MHz: 124 channels (200 kHz) downlink
  - 890-915 MHz: 124 channels (200 kHz) uplink

- Time:
  - GSM TDMA frame: 4.615 ms
  - GSM time-slot (normal burst): 546.5 µs 577 µs

- Details:
  - Tail user data
  - Guard space
  - User data
  - Training
  - Tail user data
  - Guard space

- Parameters:
  - 3 bits
  - 57 bits
  - 26 bits
  - 57 bits
  - 3
GSM hierarchy of frames

- Hyperframe: 0 1 2 ... 2045 2046 2047
  - Duration: 3 h 28 min 53.76 s

- Superframe:
  - Multiframe: 0 1 ... 24 25
  - Duration: 6.12 s

- Frame:
  - Slot: ... 6 7
  - Burst: 577 µs

- Multiframe:
  - Frame: 0 1 2 ... 48 49 50
  - Duration: 120 ms

- Burst: 4.615 ms

- Frame:
  - Burst: 235.4 ms

- Superframe:
  - Multiframe: 0 1 ... 48 49 50
  - Duration: 4.615 ms

- Burst: 6.12 s

- Hyperframe:
  - Superframe: 0 1 2 ... 48 49 50
  - Duration: 120 ms
GSM protocol layers for signaling

- **MS**
  - CM
  - MM
  - RR
  - LAPDm
  - radio

- **BTS**
  - RR'
  - LAPDm
  - radio
  - LAPD
  - PCM

- **BSC**
  - RR'
  - BTSM
  - LAPD
  - PCM
  - SS7
  - BSSAP

- **MSC**
  - CM
  - MM
  - BSSAP
  - SS7
  - PCM

Bit rates:
- **Um**
  - 16/64 kbit/s
- **A_bis**
  - 64 kbit/s / 2.048 Mbit/s

Networks:
- **Um**
  - MS BTS BSC MSC
- **A_bis**
  - SS7
- **A**
  - BSSAP
Mobile Terminated Call

1: calling a GSM subscriber
2: forwarding call to GMSC
3: signal call setup to HLR
4, 5: request MSRN from VLR
6: forward responsible MSC to GMSC
7: forward call to current MSC
8, 9: get current status of MS
10, 11: paging of MS
12, 13: MS answers
14, 15: security checks
16, 17: set up connection
Mobile Originated Call

1, 2: connection request
3, 4: security check
5-8: check resources (free circuit)
9-10: set up call
4 types of handover
Handover decision

receive level $\text{BTS}_{\text{old}}$ versus receive level $\text{BTS}_{\text{new}}$

$\text{HO MARGIN}$
Handover procedure

Hard handover
Security in GSM

Security services
- access control/authentication
  - user ↔ SIM (Subscriber Identity Module): secret PIN (personal identification number)
  - SIM ↔ network: challenge response method
- confidentiality
  - voice and signaling encrypted on the wireless link (after successful authentication)
- anonymity
  - temporary identity TMSI
    (Temporary Mobile Subscriber Identity)
  - newly assigned at each new location update (LUP)
  - encrypted transmission

3 algorithms specified in GSM
- A3 for authentication ("secret", open interface)
- A5 for encryption (standardized)
- A8 for key generation ("secret", open interface)

“secret”:
- A3 and A8 available via the Internet
- network providers can (and do) use stronger mechanisms
GSM - authentication

mobile network

SIM

AC

MSC

Ki: individual subscriber authentication key  SRES: signed response

K_i  RAND  128 bit  128 bit

A3

SRES* 32 bit

RAND

SIM

Ki  RAND  128 bit  128 bit

A3

SRES  32 bit

SRES

SRES* =? SRES

32 bit
GSM - key generation and encryption

mobile network (BTS)

MS with SIM

AC

Kᵢ 128 bit 128 bit
RANDC

SIM

Kᵢ 128 bit 128 bit
RANDC

BSS

cipher key

Kᵢ 64 bit

data

A5

MS

data

A5

encrypted data
Data services in GSM I

Data transmission standardized with only 9.6 kbit/s
-advanced coding allows 14.4 kbit/s
-not enough for Internet and multimedia applications
HSCSD (High-Speed Circuit Switched Data)
-mainly software update
-bundling of several time-slots to get higher AIUR (Air Interface User Rate, e.g., 57.6 kbit/s using 4 slots @ 14.4)
-advantage: ready to use, constant quality, simple
-disadvantage: channels blocked for voice transmission

<table>
<thead>
<tr>
<th>AIUR [kbit/s]</th>
<th>TCH/F4.8</th>
<th>TCH/F9.6</th>
<th>TCH/F14.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.6</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>14.4</td>
<td>3</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>19.2</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>28.8</td>
<td></td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>38.4</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>43.2</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>57.6</td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>
Data services in GSM II

GPRS (General Packet Radio Service)
- packet switching
- using free slots only if data packets ready to send
  (e.g., 50 kbit/s using 4 slots temporarily)
- standardization 1998, introduction 2001
- advantage: one step towards UMTS, more flexible
- disadvantage: more investment needed (new hardware)

GPRS network elements
- GSN (GPRS Support Nodes): GGSN and SGSN
- GGSN (Gateway GSN)
  - interworking unit between GPRS and PDN (Packet Data Network)
- SGSN (Serving GSN)
  - supports the MS (location, billing, security)
- GR (GPRS Register)
  - user addresses
## GPRS quality of service

<table>
<thead>
<tr>
<th>Reliability class</th>
<th>Lost SDU probability</th>
<th>Duplicate SDU probability</th>
<th>Out of sequence SDU probability</th>
<th>Corrupt SDU probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$10^{-9}$</td>
<td>$10^{-9}$</td>
<td>$10^{-9}$</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>2</td>
<td>$10^{-4}$</td>
<td>$10^{-5}$</td>
<td>$10^{-5}$</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>3</td>
<td>$10^{-2}$</td>
<td>$10^{-5}$</td>
<td>$10^{-5}$</td>
<td>$10^{-2}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Delay class</th>
<th>SDU size 128 byte</th>
<th>SDU size 1024 byte</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean, 95 percentile</td>
<td>mean, 95 percentile</td>
</tr>
<tr>
<td>1</td>
<td>$&lt; 0.5$ s, $&lt; 1.5$ s</td>
<td>$&lt; 2$ s, $&lt; 7$ s</td>
</tr>
<tr>
<td>2</td>
<td>$&lt; 5$ s, $&lt; 25$ s</td>
<td>$&lt; 15$ s, $&lt; 75$ s</td>
</tr>
<tr>
<td>3</td>
<td>$&lt; 50$ s, $&lt; 250$ s</td>
<td>$&lt; 75$ s, $&lt; 375$ s</td>
</tr>
<tr>
<td>4</td>
<td>unspecified</td>
<td>unspecified</td>
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</tbody>
</table>
Examples for GPRS device classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Receiving slots</th>
<th>Sending slots</th>
<th>Maximum number of slots</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
GPRS user data rates in kbit/s

<table>
<thead>
<tr>
<th>Coding scheme</th>
<th>1 slot</th>
<th>2 slots</th>
<th>3 slots</th>
<th>4 slots</th>
<th>5 slots</th>
<th>6 slots</th>
<th>7 slots</th>
<th>8 slots</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS-1</td>
<td>9.05</td>
<td>18.1</td>
<td>27.15</td>
<td>36.2</td>
<td>45.25</td>
<td>54.3</td>
<td>63.35</td>
<td>72.4</td>
</tr>
<tr>
<td>CS-2</td>
<td>13.4</td>
<td>26.8</td>
<td>40.2</td>
<td>53.6</td>
<td>67</td>
<td>80.4</td>
<td>93.8</td>
<td>107.2</td>
</tr>
<tr>
<td>CS-3</td>
<td>15.6</td>
<td>31.2</td>
<td>46.8</td>
<td>62.4</td>
<td>78</td>
<td>93.6</td>
<td>109.2</td>
<td>124.8</td>
</tr>
<tr>
<td>CS-4</td>
<td>21.4</td>
<td>42.8</td>
<td>64.2</td>
<td>85.6</td>
<td>107</td>
<td>128.4</td>
<td>149.8</td>
<td>171.2</td>
</tr>
</tbody>
</table>
GPRS architecture and interfaces
GPRS protocol architecture
TETRA - Terrestrial Trunked Radio

Trunked radio systems
- many different radio carriers
- assign single carrier for a short period to one user/group of users
- taxi service, fleet management, rescue teams
- interfaces to public networks, voice and data services
- very reliable, fast call setup, local operation

TETRA - ETSI standard
- formerly: Trans European Trunked Radio
- point-to-point and point-to-multipoint
- encryption (end-to-end, air interface), authentication of devices, users and networks
- group call, broadcast, sub-second group-call setup
- ad-hoc (“direct mode”), relay and infrastructure networks
- call queuing with pre-emptive priorities
TETRA – Contracts by Sector (percentage)

Used in over 70 countries, more than 20 device manufacturers
TETRA – Network Architecture

- TETRA infrastructure
- NMS
- switch
- BS
- switch
- switch
- BS
- switch
- PSTN, ISDN, Internet, PDN
- ISI
- other TETRA networks
- AI: Air Interface
- BS: Base Station
- DMO: Direct Mode Operation
- ISI: Inter-System Interface
- NMS: Network Management System
- PEI: Peripheral Equipment Interface

AI: Air Interface
BS: Base Station
DMO: Direct Mode Operation
ISI: Inter-System Interface
NMS: Network Management System
PEI: Peripheral Equipment Interface
TETRA – Direct Mode I

Direct Mode enables ad-hoc operation and is one of the most important differences to pure infrastructure-based networks such as GSM, cdma2000 or UMTS.

- Individual Call
- Group Call
- Managed Direct Mode
- “Dual Watch” – alternating participation in Infrastructure and ad-hoc
- Authorizing mobile station
TETRA – Direct Mode II

An additional repeater may increase the transmission range (e.g. police car)
TETRA – Technology

Services
- Voice+Data (V+D) and Packet Data Optimized (PDO)
- Short data service (SDS)

Frequencies
- Duplex: FDD, Modulation: DQPSK
- Europe (in MHz, not all available yet)
- Other countries
  - 380-390 UL / 390-400 DL; 410-420 UL / 420-430 DL, 806-821 UL / 851-866 DL
TDMA structure of the voice+data system

- Hyperframe
  - Multiframe
    - Frame
      - Slot
### TETRA – Data Rates

Infrastructure mode, V+D in kbit/s

<table>
<thead>
<tr>
<th>No. of time slots</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>No protection</td>
<td>7.2</td>
<td>14.4</td>
<td>21.6</td>
<td>28.8</td>
</tr>
<tr>
<td>Low protection</td>
<td>4.8</td>
<td>9.6</td>
<td>14.4</td>
<td>19.2</td>
</tr>
<tr>
<td>High protection</td>
<td>2.4</td>
<td>4.8</td>
<td>7.2</td>
<td>9.6</td>
</tr>
</tbody>
</table>

TETRA Release 2 – Supporting higher data rates
- TEDS (TETRA Enhanced Data Service)
- up to 100-500 kbit/s
  - depends on modulation (DQPSK, D8PSK, 4/16/64QAM) and channel width (25/50/100/150 kHz)
- backward compatibility

Unclear future of TETRA
- Data rates to low compared to e.g. LTE
- Specialized devices too expensive (no COTS)
UMTS and IMT-2000

Proposals for IMT-2000 (International Mobile Telecommunications)
- UWC-136, cdma2000, WP-CDMA
- UMTS (Universal Mobile Telecommunications System) from ETSI

UMTS
- UTRA (was: UMTS, now: Universal Terrestrial Radio Access)
- enhancements of GSM
  - EDGE (Enhanced Data rates for GSM Evolution): GSM up to 384 kbit/s
  - CAMEL (Customized Application for Mobile Enhanced Logic)
  - VHE (virtual Home Environment)
- fits into GMM (Global Multimedia Mobility) initiative from ETSI
- requirements
  - min. 144 kbit/s rural (goal: 384 kbit/s)
  - min. 384 kbit/s suburban (goal: 512 kbit/s)
  - up to 2 Mbit/s urban
Frequencies for IMT-2000

ITU allocation (WRC 1992)

Europe
- GSM 1800
- DECT
- UTRA FDD
- IMT-2000
- MSS
- UTRA FDD
- IMT-2000
- MSS

China
- GSM 1800
- IMT-2000
- MSS
- cdma2000 W-CDMA
- PHS
- IMT-2000
- MSS
- cdma2000 W-CDMA
- rsv.

Japan
- PHS
- cdma2000 W-CDMA
- rsv.

North America
- PCS
- MSS
- rsv.
- MSS
IMT-2000 family

- **IMT-2000 Core Network ITU-T**
  - **Initial UMTS (R99 w/ FDD)**

- **IMT-2000 Radio Access ITU-R**
  - **IME-DS (Direct Spread)**
    - UTRA FDD (W-CDMA)
      - 3GPP
  - **IME-TC (Time Code)**
    - UTRA TDD (TD-CDMA)
      - CDMA2000
      - TD-SCDMA
      - 3GPP2
  - **IME-MC (Multi Carrier)**
    - cdma2000
    - 3GPP
  - **IME-SC (Single Carrier)**
    - UWC-136 (EDGE)
    - UWCC/3GPP
  - **IME-FT (Freq. Time)**
    - DECT
    - ETSI

Interface for Internetworking

Flexible assignment of Core Network and Radio Access

GSM (MAP)

ANSI-41 (IS-634)

IP-Network
GSM, UMTS, and LTE Releases

Stages
- (0: feasibility study)
- 1: service description from a service-user's point of view
- 2: logical analysis, breaking the problem down into functional elements and the information flows amongst them
- 3: concrete implementation of the protocols between physical elements onto which the functional elements have been mapped
- (4: test specifications)

Note
- "Release 2000" was used only temporarily and was eventually replaced by "Release 4" and "Release 5"

Additional information:
- [www.3gpp.org/releases](http://www.3gpp.org/releases)
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 of the population
- 25% until 12/2003
- 50% until 12/2005

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

UTRAN (UTRA Network)
- 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

User Equipment Domain
- Assigned to a single user in order to access UMTS 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
- Access network independent functions
- Serving Network Domain
  - Network currently responsible for communication
- Home Network Domain
  - Location and access network independent 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
OVSF (Orthogonal Variable Spreading Factor) coding

SF=n  SF=2n

SF=1  SF=2  SF=4  SF=8
UMTS FDD frame structure

**W-CDMA**
- 1920-1980 MHz uplink
- 2110-2170 MHz downlink
- chipping rate: 3.840 Mchip/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 synchronization for periodic functions!
## Typical UTRA-FDD uplink data rates

<table>
<thead>
<tr>
<th>User data rate [kbit/s]</th>
<th>12.2 (voice)</th>
<th>64</th>
<th>144</th>
<th>384</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPDCH [kbit/s]</td>
<td>60</td>
<td>240</td>
<td>480</td>
<td>960</td>
</tr>
<tr>
<td>DPCCH [kbit/s]</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Spreading</td>
<td>64</td>
<td>16</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>
UMTS TDD frame structure (burst type 2)

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)
UTRAN architecture

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

RNC: Radio Network Controller
RNS: Radio Network Subsystem
UTRAN functions

Admission control
Congestion control
System information broadcasting
Radio channel encryption
Handover
SRNS moving
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
Core network: protocols

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

GPRS backbone (IP)

UTRAN

CN

PSTN/ISDN
PDN (X.25), Internet (IP)

MSC
GSM-CS backbone

GMSC
HLR

VLR

RNS

SGSN

GGSN

PSTN/ISDN
PDN (X.25), Internet (IP)
Core network: architecture
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_uCS

Packet Switched Domain (PSD)
- GPRS components (SGSN, GGSN)
  - I_uPS

Release 99 uses the GSM/GPRS network and adds a new radio access!
- Helps to save a lot of money …
- Much faster deployment
- Not as flexible as newer releases (5, 6, … 12, 13, 14, …)
UMTS protocol stacks (user plane)

Circuit switched

<table>
<thead>
<tr>
<th></th>
<th>UE</th>
<th>UTRAN</th>
<th>IuCS</th>
<th>3G</th>
</tr>
</thead>
<tbody>
<tr>
<td>apps. &amp;</td>
<td>RLC</td>
<td></td>
<td>SAR</td>
<td>MSC</td>
</tr>
<tr>
<td>protocols</td>
<td>MAC</td>
<td></td>
<td>AAL2</td>
<td></td>
</tr>
<tr>
<td>radio</td>
<td></td>
<td></td>
<td>ATM</td>
<td></td>
</tr>
</tbody>
</table>

Packet switched

<table>
<thead>
<tr>
<th></th>
<th>UE</th>
<th>UTRAN</th>
<th>IuPS</th>
<th>3G</th>
<th>G_{n}</th>
<th>3G</th>
</tr>
</thead>
<tbody>
<tr>
<td>apps. &amp;</td>
<td>PDCP</td>
<td>RLC</td>
<td></td>
<td>SGSN</td>
<td>G_{n}</td>
<td>GGSN</td>
</tr>
<tr>
<td>protocols</td>
<td></td>
<td>UDP/IP</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>IP, PPP,</td>
<td></td>
<td>MAC</td>
<td>AAL5</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>…</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>UDP/IP</td>
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<td>MAC</td>
<td>AAL5</td>
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<tr>
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<td>L1</td>
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<td></td>
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<tr>
<td>L2</td>
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<td>L1</td>
<td></td>
<td></td>
<td>L1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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
Support of mobility: handover

From and to other systems (e.g., UMTS to GSM)
- This is a must as UMTS coverage is/was 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
Example handover types in UMTS/GSM
Breathing Cells

GSM
- Mobile device gets exclusive signal from the base station
- Number of devices in a cell does not influence cell size

UMTS
- Cell size is closely correlated to the cell capacity
- Signal-to-noise ratio determines cell capacity
- Noise is generated by interference from
  - other cells
  - other users of the same cell
- Interference increases noise level
- Devices at the edge of a cell cannot further increase their output power (max. power limit) and thus drop out of the cell
  - no more communication possible
- Limitation of the max. number of users within a cell required

- Cell breathing complicates network planning
Breathing Cells: Example

Cell breathing and noise increase in UMTS voice

- Cell range [km]
- Noise increase
- Number of users
UMTS services (originally)

Data transmission service profiles

<table>
<thead>
<tr>
<th>Service Profile</th>
<th>Bandwidth</th>
<th>Transport mode</th>
<th>Description</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>

Virtual Home Environment (VHE)
- Enables access to personalized data independent of location, access network, and device
- Network operators may offer new services without changing the network
- Service providers may offer services based on components which allow the automatic adaptation to new networks and devices
- Integration of existing IN services
Early 3G Networks: Japan

FOMA (Freedom Of Mobile multimedia Access) in Japan

Examples for FOMA phones

With Videophone you can enjoy conversations while facing each other.
Early 3G networks: Australia

cdma2000 1xEV-DO in Melbourne/Australia

Examples for 1xEV-DO devices
Isle of Man – Start of UMTS in Europe as Test
UMTS in Monaco

Key applications
- Multimedia services (music, video, ...)
- Location based services
- Mobile office

Europe's first urban UMTS network

Monaco

Jardin exotique
La Colle
Herculis
Ministère d'etat
La Costa
Le Sporting
Beach Plaza

Core Network

Siemens Mobile
NEC
Monaco Telecom
Early UMTS in Europe

Vodafone/Germany

Orange/UK
Some current GSM enhancements

EMS/MMS
- EMS: 760 characters possible by chaining SMS, animated icons, ring tones, was soon replaced by MMS (or simply skipped)
- MMS: transmission of images, video clips, audio
  - see WAP 2.0 – not really successful, typically substituted by email with attached multimedia content
- Today, more and more IP-based messaging used, less specialized services offered by the network

EDGE (Enhanced Data Rates for Global [was: GSM] Evolution)
- 8-PSK instead of GMSK, up to 384 kbit/s
- new modulation and coding schemes for GPRS ➔ EGPRS
  - MCS-1 to MCS-4 uses GMSK at rates 8.8/11.2/14.8/17.6 kbit/s
  - MCS-5 to MCS-9 uses 8-PSK at rates 22.4/29.6/44.8/54.4/59.2 kbit/s
Some current UMTS enhancements

HSDPA (High-Speed Downlink Packet Access)
- initially up to 10 Mbit/s for the downlink, later > 20 Mbit/s using MIMO- (Multiple Input Multiple Output-) antennas
- can use 16-QAM instead of QPSK (ideally > 13 Mbit/s)
- user rates e.g. 3.6 or 7.2 Mbit/s

HSUPA (High-Speed Uplink Packet Access)
- initially up to 5 Mbit/s for the uplink
- user rates e.g. 1.45 Mbit/s

HSPA+ (Evolved HSPA)
- Rel-7/Rel-8/Rel-9/…
- Downlink 28/42/84/> 100 Mbit/s
- Uplink 11/23/>23 Mbit/s
- 2x2 MIMO, 64 QAM

Dual-/Multi-Carrier HSPA (DC-/MC-HSPA)
- Connect 2 (Rel-8/9) or more carriers (Rel-11) e.g. of two cells offering up to 672 Mbit/s (4x4 MIMO)
Long Term Evolution (LTE)

Initiated in 2004 by NTT DoCoMo, focus on enhancing the Universal Terrestrial Radio Access (UTRA) and optimizing 3GPP’s radio access architecture

Targets: Downlink 100 Mbit/s, uplink 50 Mbit/s, RTT<10ms
2007: E UTRA progressed from the feasibility study stage to the first issue of approved Technical Specifications
2008: stable for commercial implementation
2009: first public LTE service available (Stockholm and Oslo)
2010: LTE starts in Germany

LTE is not 4G – sometimes called 3.9G
- Does not fulfill all requirements for IMT advanced
May 2011, Berlin gets LTE
Key LTE features

Simplified network architecture compared to GSM/UMTS
- Flat IP-based network replacing the GPRS core, optimized for the IP-Multimedia Subsystem (IMS), no more circuit switching
Network should be in parts self-organizing
Scheme for soft frequency reuse between cells
- Inner part uses all subbands with less power
- Outer part uses pre-served subbands with higher power
Much higher data throughput supported by multiple antennas
Much higher flexibility in terms of spectrum, bandwidth, data rates
Much lower RTT – good for interactive traffic and gaming
Smooth transition from W-CDMA/HSPA, TD-SCDMA and cdma2000 1x EV-DO – but completely different radio!
Large step towards 4G – IMT advanced

See [www.3gpp.org](http://www.3gpp.org) for all specs, tables, figures etc.!
High flexibility

E-UTRA (Evolved Universal Terrestrial Radio Access)
- Operating bands 700-2700MHz
- Channel bandwidth 1.4, 3, 5, 10, 15, or 20 MHz
- TDD and FDD

Modulation
- QPSK, 16QAM, 64QAM

Multiple Access
- OFDMA (DL), SC-FDMA (UL)

Peak data rates
- 300 Mbit/s DL
- 75 Mbit/s UL
- Depends on UE category

Cell radius
- From <1km to 100km

<table>
<thead>
<tr>
<th>E-UTRA Operating Band</th>
<th>Uplink (UL) operating band</th>
<th>Downlink (DL) operating band</th>
<th>Duplex Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS receive</td>
<td>£UL_low - £UL_high</td>
<td>BS transmit</td>
<td>£DL_low - £DL_high</td>
</tr>
<tr>
<td>1</td>
<td>1920 MHz</td>
<td>1980 MHz</td>
<td>2110 MHz</td>
</tr>
<tr>
<td>2</td>
<td>1850 MHz</td>
<td>1910 MHz</td>
<td>1930 MHz</td>
</tr>
<tr>
<td>3</td>
<td>1710 MHz</td>
<td>1785 MHz</td>
<td>2110 MHz</td>
</tr>
<tr>
<td>4</td>
<td>1710 MHz</td>
<td>1755 MHz</td>
<td>2110 MHz</td>
</tr>
<tr>
<td>5</td>
<td>824 MHz</td>
<td>849 MHz</td>
<td>869 MHz</td>
</tr>
<tr>
<td>6</td>
<td>830 MHz</td>
<td>840 MHz</td>
<td>875 MHz</td>
</tr>
<tr>
<td>7</td>
<td>2500 MHz</td>
<td>2570 MHz</td>
<td>2620 MHz</td>
</tr>
<tr>
<td>8</td>
<td>880 MHz</td>
<td>915 MHz</td>
<td>925 MHz</td>
</tr>
<tr>
<td>9</td>
<td>1749.9 MHz</td>
<td>1784.9 MHz</td>
<td>1844.9 MHz</td>
</tr>
<tr>
<td>10</td>
<td>1710 MHz</td>
<td>1770 MHz</td>
<td>2110 MHz</td>
</tr>
<tr>
<td>11</td>
<td>1427.9 MHz</td>
<td>1447.9 MHz</td>
<td>1475.9 MHz</td>
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<tr>
<td>12</td>
<td>699 MHz</td>
<td>716 MHz</td>
<td>729 MHz</td>
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<tr>
<td>13</td>
<td>777 MHz</td>
<td>787 MHz</td>
<td>746 MHz</td>
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<td>14</td>
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<td>15</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
</tr>
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<td>16</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
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<td>17</td>
<td>704 MHz</td>
<td>716 MHz</td>
<td>734 MHz</td>
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<td>830 MHz</td>
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<td>875 MHz</td>
</tr>
<tr>
<td>20</td>
<td>832 MHz</td>
<td>862 MHz</td>
<td>791 MHz</td>
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<tr>
<td>21</td>
<td>1447.9 MHz</td>
<td>1462.9 MHz</td>
<td>1495.9 MHz</td>
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<tr>
<td>22</td>
<td>Reserved</td>
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<td>Reserved</td>
</tr>
<tr>
<td>23</td>
<td>1900 MHz</td>
<td>1920 MHz</td>
<td>1900 MHz</td>
</tr>
<tr>
<td>24</td>
<td>2010 MHz</td>
<td>2025 MHz</td>
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</tr>
<tr>
<td>25</td>
<td>1850 MHz</td>
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<td>1850 MHz</td>
</tr>
<tr>
<td>26</td>
<td>1930 MHz</td>
<td>1990 MHz</td>
<td>1930 MHz</td>
</tr>
<tr>
<td>27</td>
<td>1910 MHz</td>
<td>1930 MHz</td>
<td>1910 MHz</td>
</tr>
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<td>28</td>
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<td>2570 MHz</td>
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<tr>
<td>29</td>
<td>1880 MHz</td>
<td>1920 MHz</td>
<td>1880 MHz</td>
</tr>
<tr>
<td>30</td>
<td>2300 MHz</td>
<td>2400 MHz</td>
<td>2300 MHz</td>
</tr>
</tbody>
</table>

Note 1: Band 6 is not applicable
LTE frame structure

Radio frame (10 ms)

FDD

UL

0 1 2 ... 7 8 9

Subframe (1 ms)

DL

0 1 2 ... 7 8 9

Synchronization is part of subframe 0 and 5

TDD

UL/DL

0 1 2 ... 7 8 9

Downlink Pilot Time Slot (data plus pilot signal)

Guard Period

Uplink Pilot Time Slot (random access plus pilot signal)
LTE multiple access

Scheduling of UEs in time and frequency (simplified)
LTE architecture

- **Mobility Management Entity**
- **Packet-data network Gateway**
- **Serving Gateway**
- **Home Subscriber Server**
- **Policy and Charging Rules Function**

**E-UTRAN**
- eNode B
- X2-U/-C
- UE1
- UE2

**EPC (Evolved Packet Core)**
- MME
- S-GW
- P-GW
- S1-MME
- S1-U
- S10
- S3
- S4
- S6
- S11
- S7
- Rx+
- S8 (roaming)
- SGi
- S5

**Internet, Operators...**
- GPRS
- HSS
- PCRF
IMT Advanced – from www.itu.int

Key features of ‘IMT-Advanced’:

• a high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
• compatibility of services within IMT and with fixed networks;
• capability of interworking with other radio access systems;
• high quality mobile services;
• user equipment suitable for worldwide use;
• user-friendly applications, services and equipment;
• worldwide roaming capability; and,
• enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research).

These features enable IMT-Advanced to address evolving user needs and the capabilities of IMT-Advanced systems are being continuously enhanced in line with user trends and technology developments.
LTE advanced

GSM – UMTS - LTE
- LTE advanced as candidate for IMT-advanced

Worldwide functionality & roaming

Compatibility of services

Interworking with other radio access systems

Enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility)

3GPP will be contributing to the ITU-R towards the development of IMT-Advanced via its proposal for LTE-Advanced.

Relay Nodes to increase coverage

100 MHz bandwidth (5x LTE with 20 MHz)