Mobile Communications
Chapter 4: Wireless Telecommunication Systems

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

Subscribers [million]

- GSM total
- TDMA total
- CDMA total
- PDC total
- Analogue total
- W-CDMA
- Total wireless
- Prediction (1998)

Year:


Approx. 1.7 bn

Subscribers
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 will have **broadband**, 80% mobile!
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
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: data rates of approx. 50 kbit/s possible – will be covered later! (even 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) alphanumerical 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 now 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

Switching units

Management

Data bases

Monitoring

Not „visible“, but comprise the major part of the network (also from an investment point of view…)
GSM: overview

NSS with OSS

OMC, EIR, AUC

HLR

GMSC

MSC

VLR

VLR

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**
  - *U_m*: radio interface
  - *A_bis*: 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)
  
  - BSS = BSC + sum(BTS) + interconnection

- Mobile Stations (MS)
GSM: cellular network

segmentation of the area into cells

- 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 +49 channels</td>
<td>890-915</td>
<td>935-960</td>
</tr>
<tr>
<td></td>
<td></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 exclusive</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>
</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**
Example coverage of GSM networks (http://www.telemoveis.com/)

**MEO (GSM-900/1800)**

- Cobertura TMN
- Fonte: TMN (Novembro 2001)

**Vodafone (GSM-900/1800) Por**

- Cobertura Vodafone
- Fonte: Vodafone (Junho 2002)

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Prof. Dr.-Ing. Jochen H. Schiller  www.jochenschiller.de  MC - 2012  4.28
Example coverage of GSM networks (http://www.telemoveis.com/)

NOS (GSM-900/1800)
Portugal
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></td>
<td>X</td>
</tr>
<tr>
<td>Frequency hopping (FH)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Management of terrestrial channels</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Mapping of terrestrial onto radio channels</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Channel coding and decoding</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rate adaptation</td>
<td>X</td>
<td></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></td>
<td>X</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></td>
<td>X</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
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 a 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**

**GSM TDMA frame**

- **GSM time-slot (normal burst)**
  - **guard space**: 3 bits, 57 bits, 1, 26 bits, 1, 57 bits, 3
  - **guard space**: 546.5 µs, 577 µs

**higher GSM frame structures**

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

**GSM TDMA frame**

- **time**: 4.615 ms

**Frequency**

- **935-960 MHz**
  - 124 channels (200 kHz) downlink
- **890-915 MHz**
  - 124 channels (200 kHz) uplink
GSM hierarchy of frames

- hyperframe
  - superframe
    - multiframe
      - frame
        - slot
          - burst
  - superframe
    - hyperframe
      - multiframe
        - frame
          - slot
            - burst

3 h 28 min 53.76 s
6.12 s
120 ms
235.4 ms
4.615 ms
577 µs
GSM Logical Channels

- **Traffic Channels (TCH)**
  - Voice
    - TCH/F (full rate): 22.8 kbps
    - TCH/H (half rate): 11.4 kbps
  - Data
    - TCH/F4.8, TCH/F9.6, TCH/F14.4

- **Control Channels (CCH)**
  - Broadcast Control Channel (BCCH)
    - Frequency Correction Channel (FCCH)
    - Synchronization Channel (SCH)
  - Common Control Channel (CCCH)
    - Paging Channel (PCH)
    - Random Access Channel (RACH)
    - Access Grand Channel (AGCH)
  - Dedicated Control Channel (DCCH)
    - Slow Associated Control Channel (SACCH)
    - Fast Associated Control Channel (FACCH)

Bi-directional channels: Downlink slot precedes Uplink slot by 3 slots
GSM Logical Channels (cont.)

- TCH + SACCH

One slot in one frame

\[
\begin{align*}
\text{T T T T T T T T T S T T T T T T T T T T T T T} \\
\text{T T T T T T T T T S T T T T T T T T T T T T T}
\end{align*}
\]

\[
\begin{align*}
114 \text{ bit} / 4.615 \text{ ms} &= 24.7 \text{ kbps} \\
24.7 \text{ kbps} \times \frac{24}{26} &= 22.8 \text{ kbit/s}
\end{align*}
\]
GSM Delay Compensation

• E.g. MS located 35 km from BTS

   Slot length: 0.577 ms

   \[ \text{RTT} = 2 \times \left( \frac{35000}{300000000} \right) = 0.23 \text{ ms} \]  

• Variable timing advance
  • Tx shifted to 0-63 bits earlier
  • 63 \times 3.69 \text{ us} = 0.23 \text{ ms}

• Maximum GSM cell radius: 35 km!
GSM protocol layers for signaling

CM – Call Management
MM – Mobility Management
RR – Radio Resource Management
LAPD – Link Access Procedure for the D channel

BTSM – BTS Management
BSSAP – BSS Application Part

16/64 kbit/s
64 kbit/s / 2.048 Mbit/s
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

\[ \text{receive level} \]

\[ \text{BTS}_{\text{old}} \]

\[ \text{HO MARGIN} \]

\[ \text{BTS}_{\text{new}} \]

\[ \text{MS} \]

\[ \text{BTS}_{\text{old}} \]

\[ \text{BTS}_{\text{new}} \]
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

K_i: individual subscriber authentication key
SRES: signed response

K_i \rightarrow \text{RAND}
A3
SRES^* \rightarrow \text{MSC}

\text{SIM} \rightarrow \text{RAND}
A3
SRES \rightarrow \text{SIM}

SRES^* =? SRES

mobile network
SIM
AC
MSC
GSM - key generation and encryption

- Mobile network (BTS)
- MS with SIM

**AC**

- Ki: 128 bit
- RAND: 128 bit
- A8
- Cipher key: K_c: 64 bit
- BSS
- Data: A5

**SIM**

- RAND: 128 bit
- Ki: 128 bit
- A8
- Data: A5
- Encrypted data

**MS**

- Mobile network (BTS)
- MS with SIM
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

### Reliability class

<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>

### Delay class

<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</td>
<td>95 percentile</td>
</tr>
<tr>
<td>1</td>
<td>&lt; 0.5 s</td>
<td>&lt; 1.5 s</td>
</tr>
<tr>
<td>2</td>
<td>&lt; 5 s</td>
<td>&lt; 25 s</td>
</tr>
<tr>
<td>3</td>
<td>&lt; 50 s</td>
<td>&lt; 250 s</td>
</tr>
<tr>
<td>4</td>
<td>unspecified</td>
<td></td>
</tr>
</tbody>
</table>

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Prof. Dr.-Ing. Jochen H. Schiller  www.jochenschiller.de  MC - 2013
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>
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<td>128.4</td>
<td>149.8</td>
<td>171.2</td>
</tr>
</tbody>
</table>
GPRS architecture and interfaces
GPRS protocol architecture

**MS**
- apps.
- IP/X.25
- SNDCP
- LLC
- RLC
- MAC
- radio

**BSS**
- U_m
- RLC
- MAC
- radio
- BSSGP
- FR

**SGSN**
- G_b
- SNDCP
- LLC
- UDP/TCP
- BSSGP
- IP
- FR
- L1/L2

**GGSN**
- G_n
- IP/X.25
- GTP
- UDP/TCP
- IP
- L1/L2

**G_i**

**Abbreviations**
- LLC – Logical Link Control
- BSSGP – BSS GPRS Protocol
- SNDCP – Subnetwork Dependent Convergence Protocol
- RLC – Radio Link Protocol
- GTP – GPRS Tunneling Protocol
- FR – Frame Relay
DECT

- DECT (Digital European Cordless Telephone) standardized by ETSI (ETS 300.175-x) for cordless telephones
- standard describes air interface between base-station and mobile phone
- DECT has been renamed for international marketing reasons into “Digital Enhanced Cordless Telecommunication”
- Characteristics
  - frequency: 1880-1990 MHz
  - channels: 120 full duplex
  - duplex mechanism: TDD (Time Division Duplex) with 10 ms frame length
  - multiplexing scheme: FDMA with 10 carrier frequencies, TDMA with 2x 12 slots
  - modulation: digital, Gaußian Minimum Shift Key (GMSK)
  - power: 10 mW average (max. 250 mW)
  - range: approx. 50 m in buildings, 300 m open space
DECT system architecture reference model
DECT reference model

- close to the OSI reference model
- management plane over all layers
- several services in C(ontrol)- and U(ser)-plane

Diagram:
- C-Plane: signaling, interworking
- U-Plane: application processes
- Network layer
- Data link control
- Medium access control
- Physical layer
- OSI layer 1
- OSI layer 2
- OSI layer 3
DECT layers I

• **Physical layer**
  - modulation/demodulation
  - generation of the physical channel structure with a guaranteed throughput
  - controlling of radio transmission
    - channel assignment on request of the MAC layer
    - detection of incoming signals
    - sender/receiver synchronization
    - collecting status information for the management plane

• **MAC layer**
  - maintaining basic services, activating/deactivating physical channels
  - multiplexing of logical channels
    - e.g., C: signaling, I: user data, P: paging, Q: broadcast
  - segmentation/reassembly
  - error control/error correction
DECT time multiplex frame

1 frame = 10 ms

12 down slots 12 up slots

Slot 0

Guard 419

Sync 310

D field 387

A field 630

B field 3190

X field 3

A: network control
B: user data
X: transmission quality

25.6 kbit/s
simplex bearer

32 kbit/s
unprotected mode

DATA
protected mode

DATA 64  C 16  DATA 64  C 16  DATA 64  C 16  DATA 64  C 16

420 bit + 52 µs guard time ("60 bit")
in 0.4167 ms
DECT layers II

- Data link control layer
  - creation and keeping up reliable connections between the mobile terminal and basestation
  - two DLC protocols for the control plane (C-Plane)
    - connectionless broadcast service: paging functionality
    - Lc+LAPC protocol: in-call signaling (similar to LAPD within ISDN), adapted to the underlying MAC service
  - several services specified for the user plane (U-Plane)
    - null-service: offers unmodified MAC services
    - frame relay: simple packet transmission
    - frame switching: time-bounded packet transmission
    - error correcting transmission: uses FEC, for delay critical, time-bounded services
    - bandwidth adaptive transmission
    - “Escape” service: for further enhancements of the standard
DECT layers III

- Network layer
  - similar to ISDN (Q.931) and GSM (04.08)
  - offers services to request, check, reserve, control, and release resources at the basestation and mobile terminal
  - resources
    - necessary for a wireless connection
    - necessary for the connection of the DECT system to the fixed network
  - main tasks
    - call control: setup, release, negotiation, control
    - call independent services: call forwarding, accounting, call redirecting
    - mobility management: identity management, authentication, management of the location register
Enhancements of the standard

- Several „DECT Application Profiles“ in addition to the DECT specification
  - GAP (Generic Access Profile) standardized by ETSI in 1997
    - assures interoperability between DECT equipment of different manufacturers (minimal requirements for voice communication)
    - enhanced management capabilities through the fixed network: Cordless Terminal Mobility (CTM)
  - DECT/GSM Interworking Profile (GIP): connection to GSM
  - ISDN Interworking Profiles (IAP, IIP): connection to ISDN
  - Radio Local Loop Access Profile (RAP): public telephone service
  - CTM Access Profile (CAP): support for user mobility
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

- Transportation: 24%
- Public safety & security: 39%
- Utilities: 8%
- Government: 7%
- Military: 6%
- PAMR: 6%
- Oil/Gas: 3%
- Industrial: 1%
- Others: 6%

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

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

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
- “Dual Watch” – alternating participation in Infrastructure and ad-hoc
- Managed Direct Mode
- 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**: 0 1 2 ... 57 58 59 61.2 s
- **Multiframe**: 0 1 2 ... 15 16 17 1.02 s
- **Frame**: 0 1 2 3 56.67 ms
- **Slot**: 0 509 14.17 ms

Control Frame (CF)
### TETRA – Data Rates

- **Infrastructure mode, V+D in kbit/s**
- **No. of time slots** | 1 | 2 | 3 | 4
- **No protection** | 7.2 | 14.4 | 21.6 | 28.8
- **Low protection** | 4.8 | 9.6 | 14.4 | 19.2
- **High protection** | 2.4 | 4.8 | 7.2 | 9.6

### 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**
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
IMT-2000 family

IMT-2000 Core Network
ITU-T

IMT-2000 Radio Access
ITU-R

Initial UMTS
(R99 w/ FDD)

Flexible assignment of
Core Network and Radio Access

GSM
(MAP)

ANSI-41
(IS-634)

IP-Network

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

3GPP

4.75

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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)

<table>
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<th>Spec version no.</th>
<th>Functional freeze date, indicative only</th>
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<td></td>
<td></td>
<td>Stage 3 freeze December 2007</td>
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<td>6.x.y</td>
<td>December 2004 - March 2005</td>
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<td>Rel-5</td>
<td>5.x.y</td>
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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

Slot structure NOT for user separation but synchronization for periodic functions!

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
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

GSM backbone (IP)
GPRS backbone (IP)

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

UTRAN
CN

MSC
VLR
GMSC
HLR

RNS
SGSN
GGSN
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)
UMTS protocol stacks (user plane)

Circuit switched

- UE
  - apps. & protocols
  - RLC
  - MAC
  - radio

- UTRAN
  - MAC
  - AAL2
  - radio
  - ATM

- 3G
  - MSC
  - SAR
  - AAL2
  - ATM

Packet switched

- UE
  - apps. & protocols
  - IP, PPP,
  - …
  - PDCP
  - RLC
  - MAC
  - radio

- UTRAN
  - PDCP
  - RLC
  - UDP/IP
  - MAC
  - AAL5
  - radio
  - ATM

- 3G
  - SGSN
  - GTP
  - UDP/IP
  - AAL5
  - L2
  - L1

- 3G
  - GGSN
  - IP, PPP,
  - …
  - GTP
  - UDP/IP
  - L2
  - L1

IP tunnel

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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 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
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-nose 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
UMTS services (originally)

- **Data transmission service profiles**

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

Europe's first urban UMTS network

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

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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 / chapter 10 – not really successful, typically substituted by email with attached multimedia content
  - Today, more and more IP-based messaging used

• **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></td>
<td>BS receive</td>
<td>BS transmit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$F_{UL,low} - F_{UL,high}$</td>
<td>$F_{DL,low} - F_{DL,high}$</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1920 MHz – 1980 MHz</td>
<td>2110 MHz – 2170 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>2</td>
<td>1850 MHz – 1910 MHz</td>
<td>1930 MHz – 1990 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>3</td>
<td>1710 MHz – 1785 MHz</td>
<td>1805 MHz – 1880 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>4</td>
<td>1710 MHz – 1755 MHz</td>
<td>2110 MHz – 2155 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>5</td>
<td>824 MHz – 849 MHz</td>
<td>869 MHz – 894 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>6</td>
<td>830 MHz – 840 MHz</td>
<td>875 MHz – 885 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>7</td>
<td>2500 MHz – 2570 MHz</td>
<td>2620 MHz – 2690 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>8</td>
<td>880 MHz – 915 MHz</td>
<td>925 MHz – 960 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>9</td>
<td>1749.9 MHz – 1784.9 MHz</td>
<td>1844.9 MHz – 1879.9 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>10</td>
<td>1710 MHz – 1770 MHz</td>
<td>2110 MHz – 2170 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>11</td>
<td>1427.9 MHz – 1447.9 MHz</td>
<td>1475.9 MHz – 1495.9 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>12</td>
<td>699 MHz – 716 MHz</td>
<td>729 MHz – 746 MHz</td>
<td>FDD</td>
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<tr>
<td>13</td>
<td>777 MHz – 787 MHz</td>
<td>746 MHz – 756 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>14</td>
<td>786 MHz – 798 MHz</td>
<td>758 MHz – 768 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>15</td>
<td>Reserved</td>
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<td>FDD</td>
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<td>16</td>
<td>Reserved</td>
<td>Reserved</td>
<td>FDD</td>
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<tr>
<td>17</td>
<td>704 MHz – 716 MHz</td>
<td>734 MHz – 746 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>18</td>
<td>815 MHz – 830 MHz</td>
<td>860 MHz – 875 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>19</td>
<td>830 MHz – 845 MHz</td>
<td>875 MHz – 890 MHz</td>
<td>FDD</td>
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<tr>
<td>20</td>
<td>852 MHz – 862 MHz</td>
<td>791 MHz – 821 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>21</td>
<td>1447.9 MHz – 1462.9 MHz</td>
<td>1495.9 MHz – 1510.9 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>1900 MHz – 1920 MHz</td>
<td>1900 MHz – 1920 MHz</td>
<td>TDD</td>
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<tr>
<td>34</td>
<td>2010 MHz – 2025 MHz</td>
<td>2010 MHz – 2025 MHz</td>
<td>TDD</td>
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<td>35</td>
<td>1850 MHz – 1910 MHz</td>
<td>1850 MHz – 1910 MHz</td>
<td>TDD</td>
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<td>36</td>
<td>1930 MHz – 1990 MHz</td>
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<td>TDD</td>
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<td>37</td>
<td>1910 MHz – 1930 MHz</td>
<td>1910 MHz – 1930 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>38</td>
<td>2570 MHz – 2620 MHz</td>
<td>2570 MHz – 2620 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>39</td>
<td>1880 MHz – 1920 MHz</td>
<td>1880 MHz – 1920 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>40</td>
<td>2300 MHz – 2400 MHz</td>
<td>2300 MHz – 2400 MHz</td>
<td>TDD</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)
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)