UMTS Networks I

Nach Folien von Dr. Christian Gayda, Dr. Cornelia Kappler
Vorgetragen von Sebastian Fudickar, Uni Potsdam, Informatik
Netzwerktechnologien Basistechnologien

VL UMTS Networks: Goals

- Understanding of
  - How do UMTS Networks work?
  - Why is UMTS the way it is?
  - Evolution of mobile communication
- Ability to read original literature (standards)

Course Overview

- Motivation
- Standardization issues
- UMTS architecture basics
- UE, UTRA, UTRAN, PS Domain
- Basic functionalities
- Mobility
- QoS
- Security and charging
- IMS
- Example signaling flows
- Business considerations
- UMTS - what comes next?

Textbooks and Literature

- „UMTS - The Fundamentals“
  B. Walke et al., Wiley, 83 €
  - also available in German
  - focus on radio issues
  - Question sections
- „UMTS Networks“, H. Kaaranen et al., Wiley, 83 €
- „UMTS - Grundlagen, Architektur und Standard“
  P. Lescuyer, dpunkt.verlag, 42 €
  - in German
  - focus on radio issues
- original literature by standardization bodies
  - 3GPP (www.3gpp.org), IETF (www.ietf.org),...
  - details will be given as needed

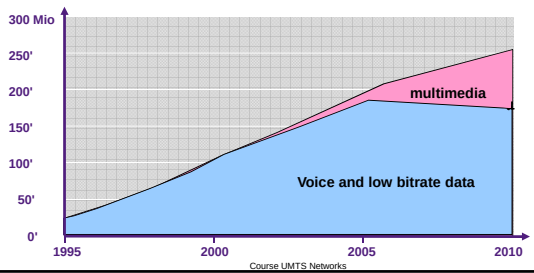
Motivation

- History
- Scenarios and applications
- UMTS requirements
- High level comparison with related technologies

History - market development I

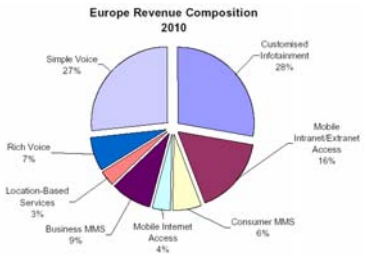
- The number of mobile subscribers has been steadily increasing
- Simultaneously, the Internet has taken off
- It is expected that mobile multimedia services will gain considerable importance

Number of mobile subscribers in Europe



History - market development II

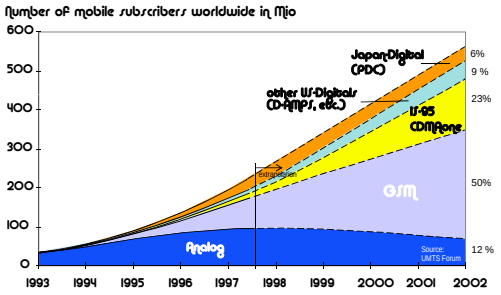
Expected multimedia service usage:



Source: UMTS Forum, Report number 13, April 2001

History - Market development III

- GSM is the leading mobile technology today
- The figure below is a trend analysis from 1997.
  In reality, in 2002 it was 450 Mio users of GSM, and 150 Mio other systems.

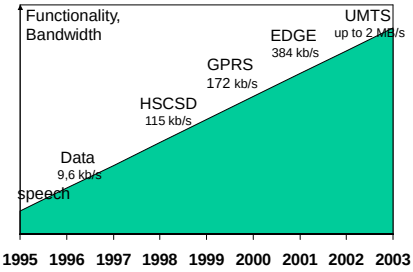


PDC - Personal Digital Communications D-AMPS - Digital American Mobile Phone System
IS-95 Interim Standard of the Telecommunications Industry Association (TIA)

History - Generations of mobile communication systems

	1st Generation (1G)	2nd Generation (2G)	3rd Generation (3G)	Beyond 3G (B3G)
Timeframe	50s - mid 90s	90s - 2020?	2001 - ...?	in 10 to 15 years?
Technology	NMT, AMPS,...	GSM (worldwide), IS-95 (Americas, Asia), PDC (Japan),...	IMT 2000 , e.g. UMTS, CDMA2000	?
Standards	proprietary, domestic	A number of international standards	one accessible standard	One accessible standard ?
Bandwidth		Initially < 10kbps, evolves to 384 kbps	up to 2 Mbps	Yet more
A/D	Analogue radio, digital network	Digital	Digital	Digital
CS/PS	Circuit switched	Circuit switched	Circuit and packet switched	All-IP
Cell radius	Up to 150 km	kilometers	Meters to kms	Meters to kms?
Mobility	Basic (national scope)	Advanced (continental scope)	Global (within same technology)	Global, intertechnology
Services	Speech	Speech, some data (MMS, SMS, WAP)	Speech, data, multimedia	Speech, data, multimedia, all Internet services

History - Migration GSM to UMTS



History - regional differences

USA
- missed digitization in mobile
- fragmented spectrum / market
- wants to catch up / overtake

Europe
- GSM unexpected success -> technology lead over Japan and US
- roaming capability seen as major success factor
- wants to repeat the GSM success in 3rd generation (3G)

Japan
- missed mobile boom but caught up (i-mode)
- high bitrate data services (e.g. SMS with graphical chinese characters)

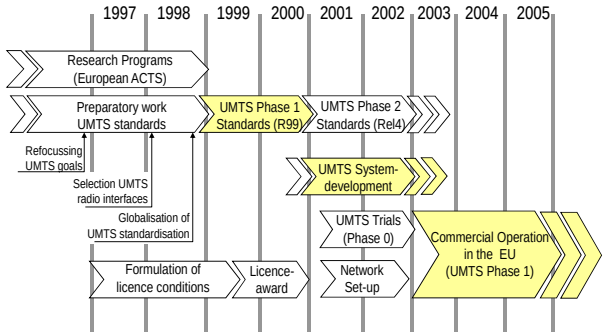
- Vision of a single 3rd Generation standard allowing worldwide roaming
  - •business opportunity for operators
  - •decreased overhead (costs) for equipment providers

History of UMTS Standardization

- Vision of a single 3rd Generation standard allowing worldwide roaming
  - ITU (International Telecommunication Union) defined concept for IMT-2000 (International Mobile Telecommunications at 2000 MHz)
    - requirements
    - unified proposals from different regional standardization bodies
  - IMT-2000 is a *family* of compatible systems
    - multimode terminals will be able to access all of them
    - "compatible" means
      - roaming
      - same, personalized, services
  - UMTS is a member of the IMT-2000 family

History: UMTS Time Line

Time schedule for the introduction of UMTS



Motivation

- History
- Scenarios and applications
- UMTS requirements
- High level comparison with related technologies

Scenarios and Applications

UMTS will offer:

- anywhere, anytime communication
- multimedia services
  - telephony
  - videoconferencing
  - entertainment
    - •interactive gaming, music on demand, video streaming,...
  - remote monitoring and control e.g. of the home
  - mobile banking
  - ...
- personalized services
  - same environment on all mobile devices and in all networks
- location-based services
  - what movies are playing here?
  - where is the next italian restaurant / McDonalds / ...
- mobile Internet access
- mobile Intranet access

Convergence of Information Technology and Mobile Telecommunication Systems

Motivation

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Requirements on UMTS

- global access with single device
  - global standard
  - unified spectrum
  - high coverage
  - seamless handover
- support of multimedia services
  - high data rates
  - services with variable bandwidths
  - symmetrical and asymmetrical data transfer
  - circuit-switched and packet-switched transfer
  - high speech (and multimedia) quality - as good as GSM
- extendable multi-service network
  - easy to deploy new services
  - gateway to Internet
- high security
  - tight control over network resources by network owner
- sophisticated charging functionality
- backwards compatibility to 2G systems (GSM)

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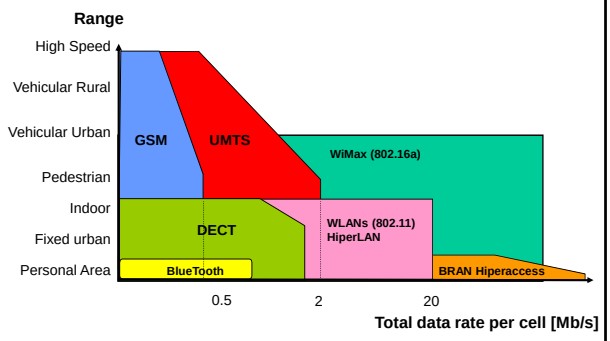
Comparison with related technologies I



Comparison with related technolgies II

- Basically, both UMTS and WLAN have the same goal: offers high-speed wireless access to fixed networks
- However, requirements on UMTS are much higher
- WLAN has been perceived as a competition to UMTS
- Today, WLAN seen as complimentary technology
  - UMTS for universal coverage
  - WLAN for hot-spots

Comparison with related technolgies III

	UMTS	WLAN	Bluetooth
Bandwidth	384 kb/s - 2 Mb/s	54 Mb/s	Max 721 kb/s
Cell Radius	30m - 20 km	50 - 300 m	0.1 - 10 m
Mobility	High	Low	Very low
Standard Availability	1999	2000	1999
Frequency Band	2 GHz	2.4 or 5 GHz	2.4 GHz
Frequency Licence	Necessary	No	No
Application	Public environments	Public hot spots (Airports, Convention Centers, Cafes, Universities, industrial application?)	Substitution of infrared communication; low cost network for small offices and residential applications

Summary - Motivation

- It is expected that mobile multimedia services will gain considerable importance
- Vision is a single 3rd Generation standard
- Main features
  - worldwide roaming
  - extendable support for multimedia service
  - backwards compatibility with 2G
- WLAN is now seen as a complementary technology

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- QoS
- Security and charging
- IMS
- Example signaling flows
- Standardization issues
- UMTS - what comes next?

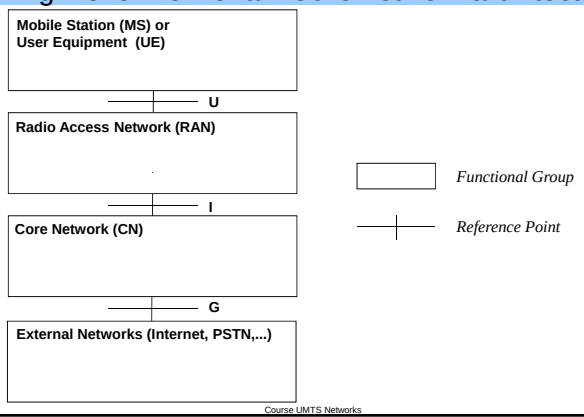
UMTS architecture basics

- Principles of network architectures
- For comparison: GSM architecture
- For comparison: GPRS architecture
- Conceptual UMTS architecture
  - UE
  - UTRAN
  - PS Domain
  - CS Domain
  - IMS

Principles of network architectures

- A network architecture is defined by
  - functional groups
    - defined by a set of functions
  - reference points
    - conceptual points separating functional groups
- The concept of functional groups may be applied in a hierarchical manner
- The functions of a functional group may be performed by one or more physical piece of equipment
- In a specific implementation, not all functions need to be implemented
- A reference point may represent a physical interface between pieces of equipment

Principles of network architectures
High level view of a mobile network architecture



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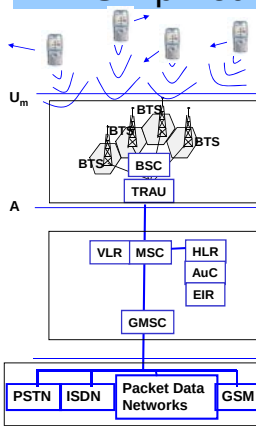
  - IMS

For comparison: GSM

- GSM is a *circuit switched* network
  - as opposed to packet switched networks based e.g. on IP
  - for all services (e.g. voice, fax, wap, sms) an end-to-end connection is established
  - all services are reserved the identical bandwidth
    - wasteful particularly on radio interface
  - all services are charged on a per-time unit basis

Simplified GSM architecture



Mobile Station (MS)
- User interface and Radio interface
- Service control
- User Identity Module (unique identification of user)

Base Station Subsystem (RAN)
- receive / send data from / to MS via radio link (BSS)
- control Radio specific signaling (BSC)
- Radio resource management (BSC)
- Transcoding and rate adaptation (TRAU)

Core Network (CN)
- Routing (MSC)
- Mobility management (MSC)
- Collection of charging information (MSC)
- Subscriber management (MSC)
- Interworking with external networks (GMSC)
- Data storage (suscriber profiles, current MSC (HLR, AuC, EIR / VLR)

External Networks

UMTS architecture basics

- Principles of network architectures
- For comparison: GSM architecture
- For comparison: GPRS architecture
- Conceptual UMTS architecture
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  - UTRAN
  - PS Domain
  - CS Domain
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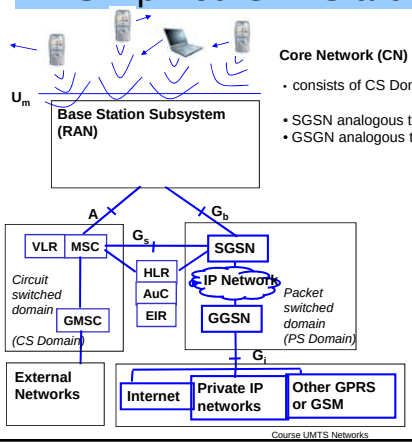
For comparison: GPRS

- GSM is a *circuit switched* network
- since an overall increase of *data traffic* is expected, GSM was evolved to become more flexible -> GPRS (General Packet Radio Service)
- GPRS is called 2.5 Generation
- GPRS adds technology for supporting data traffic:
  - a packet switched domain to the core network
  - a shared channel on the radio link
    - shared channel means several users share the same radio channel
    - as opposed to a dedicated channel as in GSM

  => more efficient usage of resources,because of statistical multiplexing
  - higher transmission rates (max 171,2 kb/s)
    - GSM originally has up to 14,4 kb/s
  - allows a direct connection to e.g. the Internet
  - charging per data volume possible
    - in GSM always charging per time unit

Simplified GPRS architecture I



Core Network (CN)

- consists of CS Domain and PS Domain in parallel

- SGSN analogous to MSC; but packet switched
- GSGN analogous to GMSC, but packet switched

UMTS architecture basics

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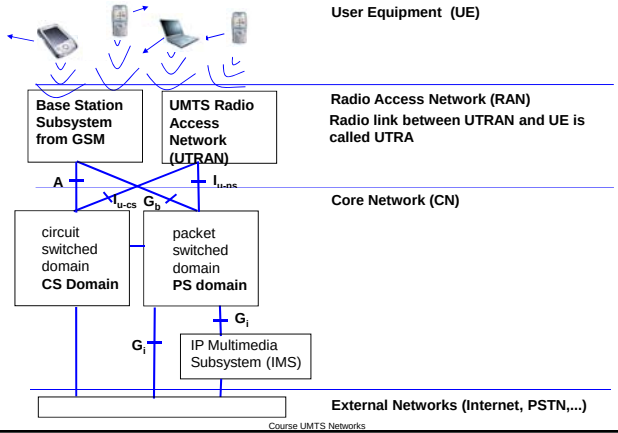
UMTS - Main changes from GPRS

- Add a new radio access network, the UTRAN
  UTRAN - UMTS Terrestrial Radio Access Network
  - UTRAN and GSM radio access network can coexist and connect to the same Core Network
- The CS Domain may also be based on packet based transport
  - slow evolution towards „all-IP“ -- may be some day abandon the circuit switched domain all together
- Introduction of the IMS IMS - IP Multimedia Subsystem
  - support of IP-based multimedia services
    - multimedia services are e.g. Video, voice, possibly simultaneously with data etc.
      - e.g. IMS vital for locating IP-address of addressees
    - the PS domain just provides QoS, it does not provide multimedia services (app. layer)
    - the PS domain serves as access system to the IMS
      - the IMS in principle is access-system independent
      - the PS domain hides mobility from the IMS

UMTS basic network architecture



Summary - Architecture

- The mobile networks we are looking at consist of
  - UE / MS, RAN and CN
  - they provide access to external networks
- GSM is circuit switched
- GPRS adds support for packet switching
- UMTS evolves from GPRS by
  - adding a new RAN
  - adding the IMS
- A UMTS Network consists of
  - UE
  - UTRAN
  - Core Network (CS Domain, PS Domain and IMS)

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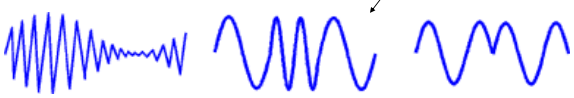
Radio Communication Fundamentals II - Modulation

- Information is encoded by *modulating* (change midway) a wave of the carrier frequency f

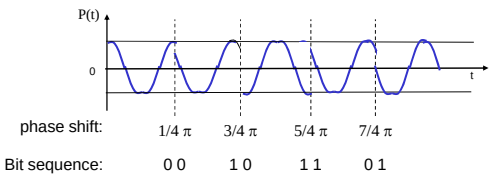
  $P(t) = P_0 \cos(2\pi ft + \varphi)$

  - Phase φ - Phase Shift Keying
  - Frequency f - Frequency Shift Keying
  - modulate Amplitude P_0 - Amplitude Shift Keying

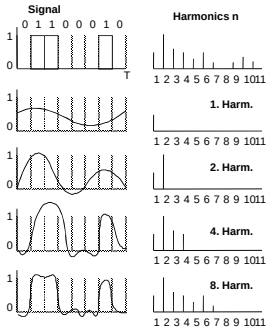


Modulation in UMTS: QPSK

- UMTS uses *Quaternary Phase Shift Keying*
  - the four possible sequences of two Bits are coded:
    - 0 0 - phase shift of 1/4 π
    - 1 0 - phase shift of 3/4 π
    - 1 1 - phase shift of 5/4 π
    - 0 1 - phase shift of 7/4 π



Radio Communication Fundamentals III - Fourier Analysis

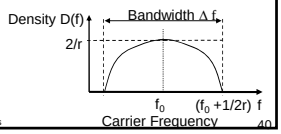


- Fourier Analysis: each signal can be described as an integral (sum) of sine waves

$$P(t) = \sum_{n=1}^{\infty} P_n \sin(2\pi n f t + \varphi_n)$$

⇒ the modulated wave is a superposition of many waves of different frequencies of a frequency band Δf

- it can be shown that $\Delta f \geq r$ (bandwidth ≥ data rate)



Radio Communication Fundamentals V - Scarcity of radio resources

- Radio spectrum is a scarce resource
  - shared by many systems

⇒ it is necessary to clearly separate radio resources used by different entities, e.g.

  - technologies
  - users of the same technology "*Multiple Access*"
  - "user -> network" (uplink) from "network -> user" (downlink): "*Duplex*"

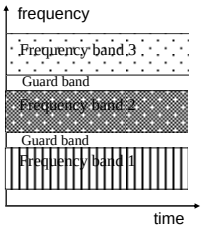
⇒ it is necessary to efficiently use radio resources

- Four possibilities for separating radio resources
  - frequency division
  - time division
  - space division
  - code division

Dividing Radio Resources

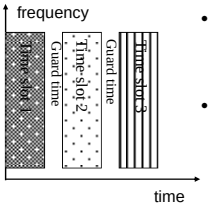
- Frequency division
- Time division
- Space division
  - Cellular networks
- Code division
- Examples: GSM and UMTS

Frequency Division



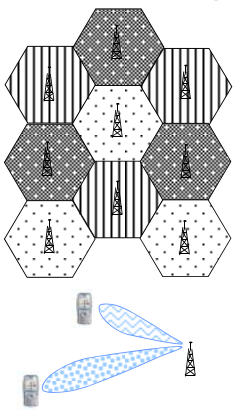
- Radio Spectrum is divided into frequency bands
- power emitted outside these bands must be strictly below a certain level
- to be on the safe side, unused guard bands limit interference between frequency bands
- receivers use filtering to receive carrier frequency of interest
- already introduced in 1900 to organize usage of radio transmitters, e.g. on ships
- usually used in combination with other division techniques

Time Division



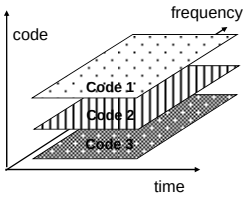
- Radio Spectrum usage is divided into time slots
  - each sender is assigned a time slot
- to avoid collisions, all participating entities need to be synchronized
  - network needs to periodically synchronize terminals
  - need to consider finite traveling time of synchronization signal, depending on distance between terminal and synchronizing entity!
- guard times between slots prevent collisions due to imperfect synchronization
- usually used in combination with other division techniques

Space Division



- Usage of radio resources restricted to certain geographic areas (cells)
- transmission power is limited
  - due to decrease of power with distance to sender, interference is limited
- re-use of same radio resource only at appropriate distance
- in combination with e.g Frequency Division, very large areas can be covered
  - reuse frequency band only in distant cells
- New antenna techniques (adaptive antenna arrays) allow forming "beam" towards specific mobile

Code Division I

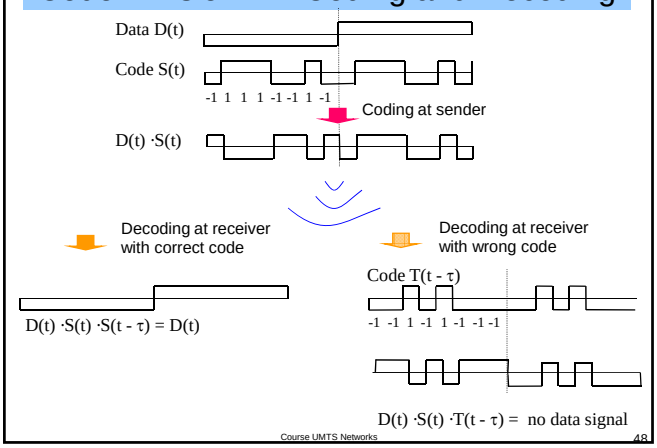


- Several signals are sent in the same (wide) frequency band and the same time slot
- each signal is created by spreading a narrowband signal through the use of a unique user code to a multiple of the original bandwidth (*spreading*)
- the receiver correlates the sum of the received signal with the (time-shifted) user code, and thereby re-obtains the original narrowband signal (*de-spreading*)
- power level of different signal needs to be aligned
- codes need to be uncorrelated, otherwise interference
- replanning cells becomes easier with this technique

Code Division II - What are these codes?

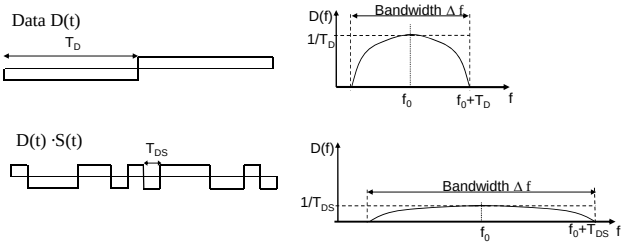
- Sequences S of 1 and -1 (*chips*)
  $S = \{S_1, S_2, \ldots, S_n\}, S_i \in \{-1, 1\}$
- Correlation: $C(j) = \sum_i S_i T_{i+j}$
  - measures how "different" two codes S and T are
  - uncorrelated codes result in little interference
  - e.g.
    $S = \{-1, 1, 1, 1, -1, -1, 1, -1\}$
    $T = \{-1, -1, 1, -1, 1, -1, -1, -1\}$
    $C(0) = 0$, $C(1) = 2$, $C(3) = 0, \ldots$
    but Autocorrelation $A(j)$ e.g. of S:
    $A(0) = 8$, $A(1) = 0$, $A(2) = 4, \ldots$

Code Division III - Coding and Decoding



Code Division III - Spreading

- Chip rate greater bit rate
  - therefore bandwidth becomes higher after spreading



Code Division IV- near-far effect

- De-spreading at receiver works best when power levels of different signals are aligned. However:
- When senders A and B emit with same power, the signal of B at the Antenna is stronger

⇒ *power control* is applied constantly

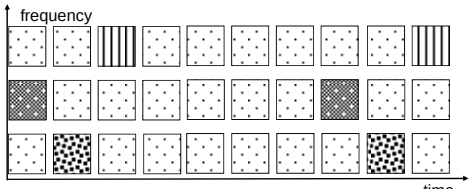
- Antenna Controller tells sender with what power to send

Dividing Radio Resources: Summary

	Uplink / downlink (D - Duplex)	**Different users** (MA - Multiple Access)
Frequency Division (FD)	FDD	FDMA
Time Division (TD)	TDD	TDMA
Code Division (CD)	-	CDMA
Space Division (SD)	-	SDMA

- The different techniques for dividing radio resources can be combined, e.g.
  - pick one technique for separating uplink / downlink
  - pick one technique for separating different users
- e.g. FDD - CDMA

GSM: FDD + TDMA + FDMA



- GSM uses a both Frequency Division and Time Division
- Uplink and Downlink use different frequencies: FDD
- Uplink and Downlink frequency band is subdivided into frequency channels, each of these channels is divided into time slots:
  - each user sends on a particular frequency band, on a particular time slot
- In GSM 900 have
  - 25 MHz per direction
  - 124 frequency channels à 200 kHz per direction
  - each frequency band has 8 time slots

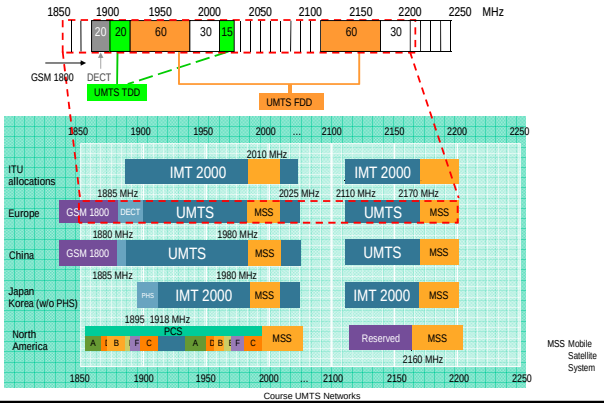
UMTS: WCDMA I

- UMTS uses two different methods for separating radio resources
  - FDD + CDMA (UTRA FDD) (most popular method)
  - TDD + TDMA + CDMA (UTRA TDD)
- FDD + CDMA for UMTS is called WCDMA (Wideband CDMA), because compared to cdmaOne it uses a higher chip rate
  - chip rate is 3,84 Mega chips / s
    - chip rate is fixed, all UMTS channels are spread the same, independent of their rate
    - in cdma2000, chip rate can vary
- Qualcomm owns key patents in UTRA FDD and cdma2000...
  - They managed to standardize them

UMTS: WCDMA II - why CDMA?

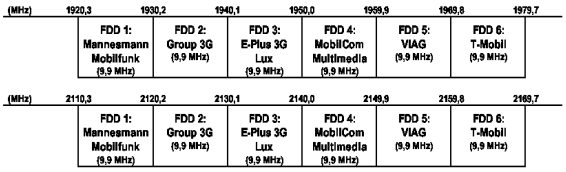
- very resource efficient
  - possibly more efficient than FDMA and TDMA
- resistance against interference and noise:
  any undesired signal will be spread when decoding
- interception by adversary more difficult
  - needs to know code
  - signal strength can be lower than thermal noise => hide signal
- can reuse frequencies in neighboring cells
  - simplifies network planning
  - simplifies introduction of more antennas
- allows flexible bandwidth assignement
  - by varying spreading factor (chips per bit)

IMT 2000 Worldwide Frequency Plans

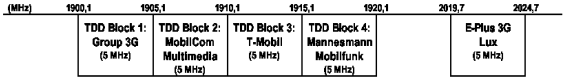


IMT-2000 Licences in Germany

FDD Frequencies



TDD Frequencies



Source: www.regtp.de

Summary - UTRA

- UMTS uses QPSK as modulation technique
- UMTS employs WCDMA
  - Signal is spread using orthogonal codes
  - The higher the bit rate of a signal, the less it is spread
  - Because of near-far effect, power control is important
  - Multiple propagation paths of signal can be combined to improve reception quality
    - Reception with different antennas: Macrodiversity

Course Overview

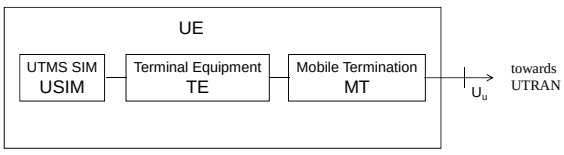
- Motivation
- Standardization issues
- UMTS architecture basics
- UE, UTRA, UTRAN, PS Domain
- Basic functionalities
- Mobility
- QoS
- Security and charging
- IMS
- Example signaling flows
- Business considerations
- UMTS - what comes next?

User Equipment (UE)

- Architecture
- USIM
- UE Tasks

UE Architecture

- USIM (Universal Subscriber Identity Module)
  - User subscription dependent part of the UE
- TE
  - provides end-user application functions
  - terminates upper layers
  - communicates with peer TE on the other end of the communication session
- MT
  - terminates radio transmission
  - adapts TE capabilities to those of radio transmission



USIM

- User subscription dependent part of the UE
- implemented into integrated circuit card
- same concept as in GSM
- without USIM only emergency calls are possible
- contains all necessary user-specific data
  - user identity (IMSI - International Mobile Station Identity)
  - temporary user identities (TMSI for CS Domain, P-TMSI for PS Domain)
    - assigned after initial registration
    - used to protect user identity against eavesdroppers
  - users phone number (MSISDN - Mobile Station International ISDN number)
  - preferred language
    - used for displaying information
  - security keys
  - current location
  - list of unaccessable networks

UE Tasks: technology related

- With Node B
  - Rate matching
  - Spreading and modulation
  - Power control
  - Error Correction
- With RNC
  - Signaling for connection set-up and release
  - Signaling for handover
  - Encryption / Decryption
  - Measurements to detect necessity for handover
    - S/N ratio, error rate, signal strength,...
  - Power control
- With CN
  - mobility management
  - session management
  - location management
  - identity management
  - service negotiation
- Sending data…

UE features: user-related

- Large display
- camera with MPEG codec
- long battery lifetime
- gaming-capable
  - fast processor, substantial memory
- small and light
- User API

Summary - UE

- UE is composed of USIM, TE, MT
- USIM contains all subscriber-related information
- UE has to perform a high number of complex tasks communicating with Node B, RNC and CN

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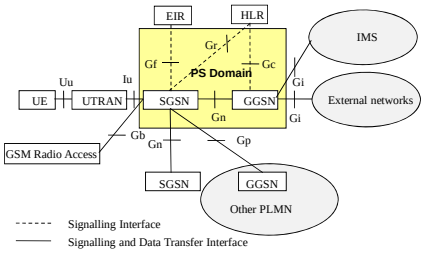
Packet-switched Domain

- Architecture
- SGSN Functions
- GGSN Functions
- Protocols

cf.
TS 23.002 "Network Architecture",
TS 23.060 "General Packet Radio Service (GPRS)"

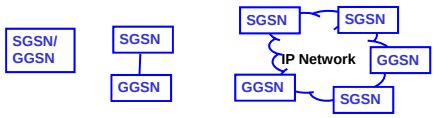
PS Domain Architecture I

- Logical architecture
  - SGSN and GGSN perform
    - mobility management
    - session management
    - location management
    - identity management
    - service negotiation
  - HLR Home Location Register
    - subscription information
    - routing information
  - EIR Equipment Identity Register
    - equipment information
      - list of stolen or lost equipment



PS Domain Architecture II

- Possible physical architectures



- SGSN and GGSN may or may not be colocated, there doesn't need be a 1:1 relationship
  - SGSNs and GGSNs of one operator are connected by an IP-based network

SGSN Functions

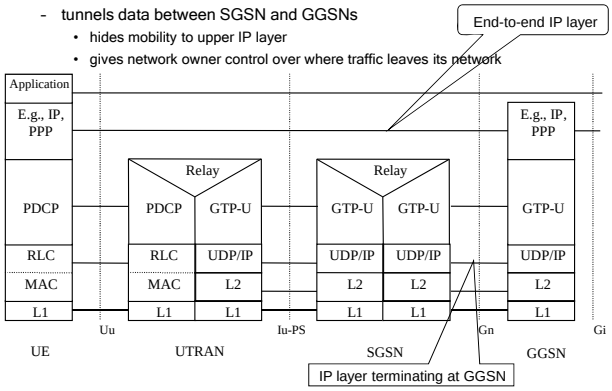
- Authentication and Authorization
  - based on data in HLR
- Admission control
  - does PS domain have enough resources for supporting a new session?
  - Can negotiate lower QoS
- Charging data collection
- Mobility Management
  - SGSN may change due to mobility
- temporary storage of data on subscribers attached
  - e.g. location
- Routing
  - finding the appropriate GGSN through which session leaves for external networks / the IMS
  - establishes a tunnel (*PDP context*) to GGSN

GGSN Functions

- Gateway to other packet-based networks
  - protocol conversion
  - may act as Policy Enforcement Point (PEP) for the IMS blocking undesired data flows
- Mobility management
  - even GGSN may change due to mobility
- Routing
  - of data packets to corresponding SGSN / packet-based network

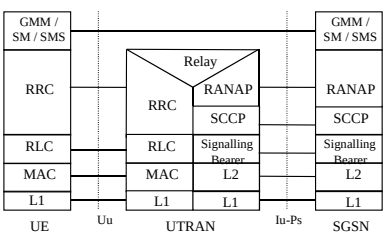
Protocols - User Plane

- GTP-U: GPRS Tunneling Protocol - User Plane
  - tunnels data between SGSN and GGSNs
    - hides mobility to upper IP layer
    - gives network owner control over where traffic leaves its network



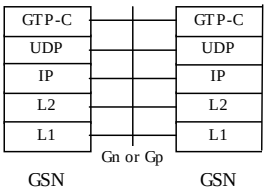
Protocols - Control Plane I

- Control Plane between UE and SGSN
  - GMM / SM
    GPRS Mobility Management / Session Management
    - attaching and detaching of UEs, security, location management
  - RANAP
    RAN Application Protocol
    - establishes separate logical connection to each UE for control traffic
  - SCCP part of SS7 protocol stack (CS control protocol)
  - Signaling Bearer either is rest of SS7 protocol stack or an adaptation to run SCCP on top of ATM or IP



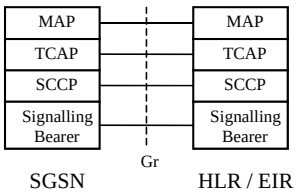
Protocols - Control Plane II

- Control Plane for SGSN - GGSN or SGSN-SGSN interface
  - GTP-C
    GPRS Tunneling Protocol for the control plane
    - tunnels signaling messages between SGSNs and GGSNs and between SGSNs



Protocols - Control Plane III

- Control Plane for SGSN - HLR interface
  - MAP (Mobile Application Part)
    - TCAP for managing control conntections between two nodes (from GSM)
    - Runs over SCCP / signaling bearer just as RANAP



Summary – PS Domain

- PS Domain is home to SGSN and GGSN
  - mobility management
  - session management
  - location management
  - identity management
  - service negotiation
  - GGSN is gateway to other packet-based networks
  - Important interfaces Gi, Gn and Iu
- Protocols used on user plane
  - one end-to-end IP layer, and a tunneled IP layer local to the PS domain
  - tunneling protocol is GTP-U
- Protocols used on control plane
  - GMM / SM, SMS, RANAP and SCCP