Mobile Communications
Chapter 1: Introduction

- A case for mobility
- History of mobile communication
- Market
- Areas of research

Computers for the next century?

Computers are integrated
- small, cheap, portable, replaceable - no more separate devices

Technology in the background
- computer are aware of their environment and adapt ("location awareness")
- computer recognize the location of the user and react appropriately (e.g., call forwarding, fax forwarding)

Advances in technology
- more computing power in smaller devices
- flat, lightweight displays with low power consumption
- new user interfaces due to small dimensions
- more bandwidth per cubic meter
- multiple wireless interfaces: wireless LANs, wireless WANs, regional wireless telecommunication networks etc. („overlay networks")

Mobile communication

Aspects of mobility:

- *user mobility*: users communicate (wireless) “anytime, anywhere, with anyone”
- *device portability*: devices can be connected anytime, anywhere to the network

Wireless	vs. mobile	Examples
✗	✗	stationary computer
✗	✓	notebook in a hotel
✓	✗	wireless LANs in historic buildings
✓	✓	Personal Digital Assistant (PDA)

The demand for mobile communication creates the need for integration of wireless networks into existing fixed networks:

- local area networks: standardization of IEEE 802.11, ETSI (HIPERLAN)
- Internet: Mobile IP extension of the internet protocol IP
- wide area networks: e.g., internetworking of GSM and ISDN

Applications I

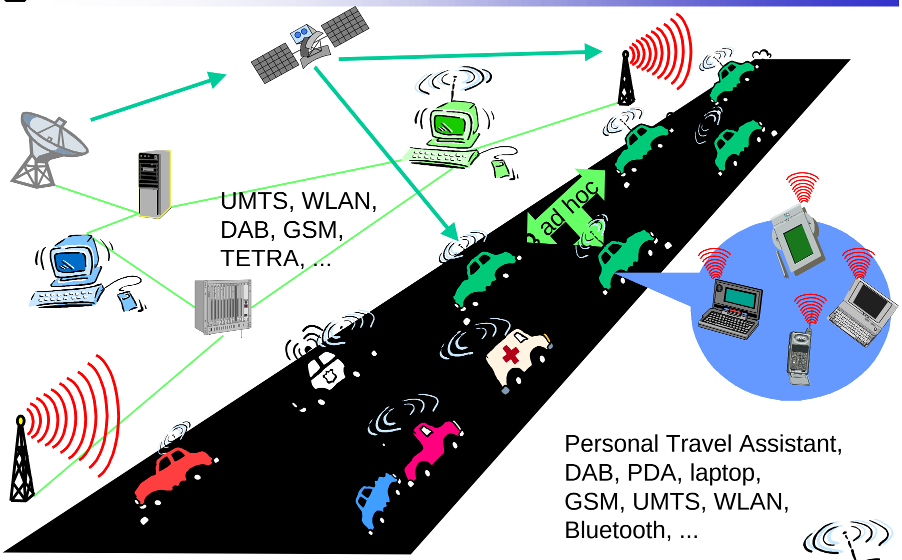
Vehicles

- transmission of news, road condition, weather, music via DAB
- personal communication using GSM
- position via GPS
- local ad-hoc network with vehicles close-by to prevent accidents, guidance system, redundancy
- vehicle data (e.g., from busses, high-speed trains) can be transmitted in advance for maintenance

Emergencies

- early transmission of patient data to the hospital, current status, first diagnosis
- replacement of a fixed infrastructure in case of earthquakes, hurricanes, fire etc.
- crisis, war, ...

Typical application: road traffic



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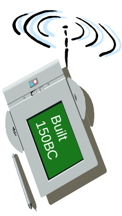
Applications II

- Travelling salesmen
  - direct access to customer files stored in a central location
  - consistent databases for all agents
  - mobile office
- Replacement of fixed networks
  - remote sensors, e.g., weather, earth activities
  - flexibility for trade shows
  - LANs in historic buildings
- Entertainment, education, ...
  - outdoor Internet access
  - intelligent travel guide with up-to-date location dependent information
  - ad-hoc networks for multi user games



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Location dependent services

Location aware services

- what services, e.g., printer, fax, phone, server etc. exist in the local environment

Follow-on services

- automatic call-forwarding, transmission of the actual workspace to the current location

Information services

- „push“: e.g., current special offers in the supermarket
- „pull“: e.g., where is the Black Forrest Cherry Cake?

Support services

- caches, intermediate results, state information etc. „follow“ the mobile device through the fixed network

Privacy

- who should gain knowledge about the location

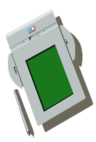
Mobile devices

Pager
• receive only
• tiny displays
• simple text messages

PDA
• simple graphical displays
• character recognition
• simplified WWW

Laptop
• fully functional
• standard applications

Sensors, embedded controllers



Mobile phones
• voice, data
• simple text displays

Palmtop
• tiny keyboard
• simple versions of standard applications

Effects of device portability

Power consumption

- limited computing power, low quality displays, small disks due to limited battery capacity
- CPU: power consumption ~ CV^2f
  - C: internal capacity, reduced by integration
  - V: supply voltage, can be reduced to a certain limit
  - f: clock frequency, can be reduced temporally

Loss of data

- higher probability, has to be included in advance into the design (e.g., defects, theft)

Limited user interfaces

- compromise between size of fingers and portability
- integration of character/voice recognition, abstract symbols

Limited memory

- limited value of mass memories with moving parts
- flash-memory or ? as alternative

Wireless networks in comparison to fixed networks

Higher loss-rates due to interference

- emissions of, e.g., engines, lightning

Restrictive regulations of frequencies

- frequencies have to be coordinated, useful frequencies are almost all occupied

Low transmission rates

- local some Mbit/s, regional currently, e.g., 9.6kbit/s with GSM

Higher delays, higher jitter

- connection setup time with GSM in the second range, several hundred milliseconds for other wireless systems

Lower security, simpler active attacking

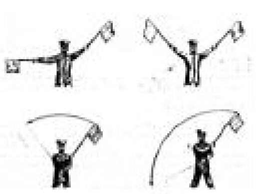
- radio interface accessible for everyone, base station can be simulated, thus attracting calls from mobile phones

Always shared medium

- secure access mechanisms important

Early history of wireless communication

Many people in history used light for communication
- heliographs, flags („semaphore“), ...
- 150 BC smoke signals for communication; (Polybius, Greece)
- 1794, optical telegraph, Claude Chappe



Here electromagnetic waves are of special importance:
- 1831 Faraday demonstrates electromagnetic induction
- J. Maxwell (1831-79): theory of electromagnetic Fields, wave equations (1864)
- H. Hertz (1857-94): demonstrates with an experiment the wave character of electrical transmission through space (1886, in Karlsruhe, Germany, at the location of today’s University of Karlsruhe)

History of wireless communication I

1895 Guglielmo Marconi
- first demonstration of wireless telegraphy (digital!)
- long wave transmission, high transmission power necessary (> 200kw)

1907 Commercial transatlantic connections
- huge base stations (30 100m high antennas)

1915 Wireless voice transmission New York - San Francisco

1920 Discovery of short waves by Marconi
- reflection at the ionosphere
- smaller sender and receiver, possible due to the invention of the vacuum tube (1906, Lee DeForest and Robert von Lieben)

1926 Train-phone on the line Hamburg - Berlin
- wires parallel to the railroad track

History of wireless communication II

1928 many TV broadcast trials (across Atlantic, color TV, TV news)

1933 Frequency modulation (E. H. Armstrong)

1958 A-Netz in Germany
- analog, 160MHz, connection setup only from the mobile station, no handover, 80% coverage, 1971 11000 customers

1972 B-Netz in Germany
- analog, 160MHz, connection setup from the fixed network too (but location of the mobile station has to be known)
- available also in A, NL and LUX, 1979 13000 customer in D

1979 NMT at 450MHz (Scandinavian countries)

1982 Start of GSM-specification
- goal: pan-European digital mobile phone system with roaming

1983 Start of the American AMPS (Advanced Mobile Phone System, analog)

1984 CT-1 standard (Europe) for cordless telephones

History of wireless communication III

1986 C-Netz in Germany
- analog voice transmission, 450MHz, hand-over possible, digital signaling, automatic location of mobile device
- still in use today (as T-C-Tel), services: FAX, modem, X.25, e-mail, 98% coverage

1991 Specification of DECT
- Digital European Cordless Telephone (today: Digital Enhanced Cordless Telecommunications)
- 1880-1900MHz, ~100-500m range, 120 duplex channels, 1.2Mbit/s data transmission, voice encryption, authentication, up to several 10000 user/km^2, used in more than 40 countries

1992 Start of GSM
- in D as D1 and D2, fully digital, 900MHz, 124 channels
- automatic location, hand-over, cellular
- roaming in Europe - now worldwide in more than 100 countries
- services: data with 9.6kbit/s, FAX, voice, ...

History of wireless communication IV

1994 E-Netz in Germany

- GSM with 1800MHz, smaller cells, supported by 11 countries
- as Eplus in D (1997 98% coverage of the *population*)

1996 HiperLAN (High Performance Radio Local Area Network)

- ETSI, standardization of type 1: 5.15 - 5.30GHz, 23.5Mbit/s
- recommendations for type 2 and 3 (both 5GHz) and 4 (17GHz) as wireless ATM-networks (up to 155Mbit/s)

1997 Wireless LAN - IEEE802.11

- IEEE-Standard, 2.4 - 2.5GHz and infrared, 2Mbit/s
- already many products (with proprietary extensions)

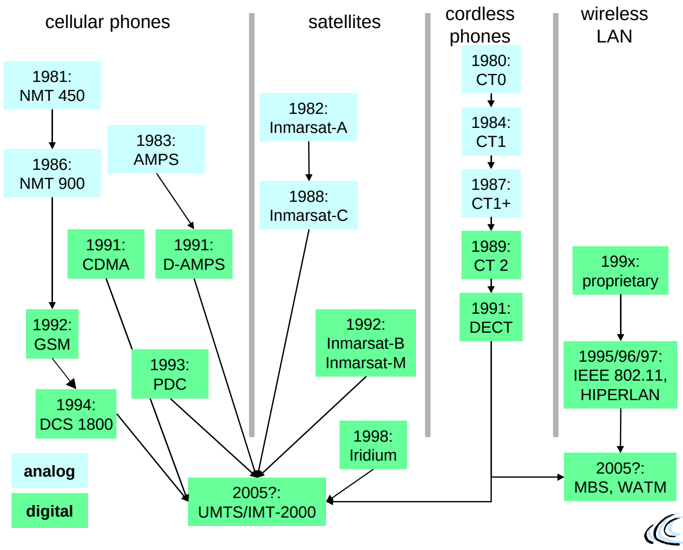
1998 Specification of GSM successors

- for UMTS (Universal Mobile Telecommunication System) as European proposals for IMT-2000

Iridium

- 66 satellites (+6 spare), 1.6GHz to the mobile phone

Wireless systems: overview of the development



The future: ITU-R - Recommendations for IMT-2000

- M.687-2
  - IMT-2000 concepts and goals
- M.816-1
  - framework for services
- M.817
  - IMT-2000 network architectures
- M.818-1
  - satellites in IMT-2000
- M.819-2
  - IMT-2000 for developing countries
- M.1034-1
  - requirements for the radio interface(s)
- M.1035
  - framework for radio interface(s) and radio sub-system functions
- M.1036
  - spectrum considerations
- M.1078
  - security in IMT-2000
- M.1079
  - speech/voiceband data performance
- M.1167
  - framework for satellites
- M.1168
  - framework for management
- M.1223
  - evaluation of security mechanisms
- M.1224
  - vocabulary for IMT-2000
- M.1225
  - evaluation of transmission technologies
- . . .

http://www.itu.int/imt

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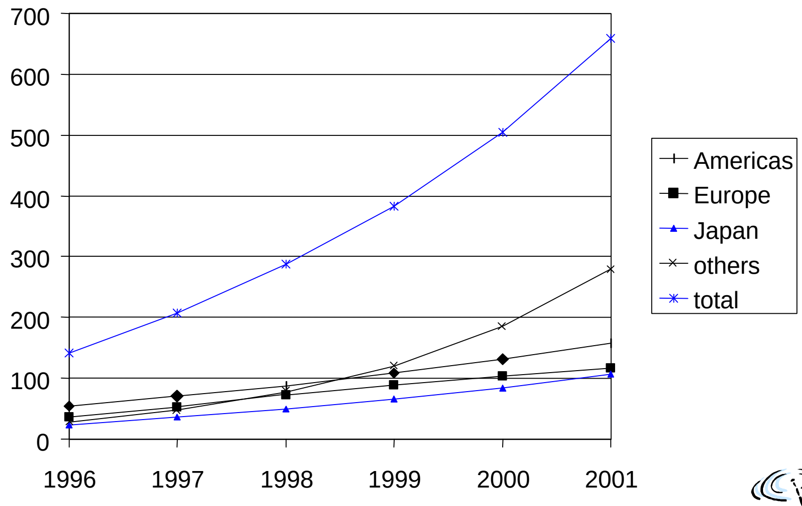
Worldwide wireless subscribers (prediction)



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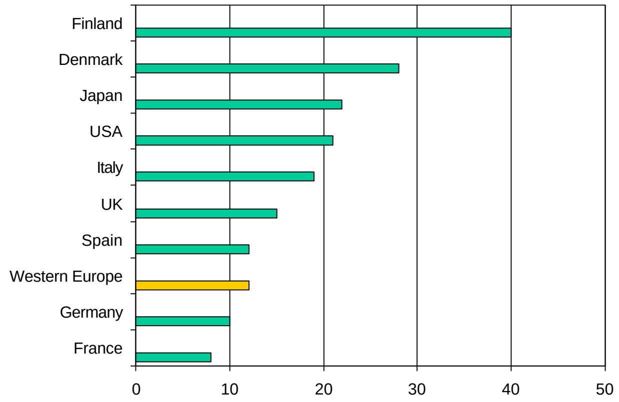
Mobile phones per 100 people 1997



1998: 40% growth rate in Germany

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Areas of research in mobile communication

Wireless Communication
- transmission quality (bandwidth, error rate, delay)
- modulation, coding, interference
- media access, regulations
- ...

Mobility
- location dependent services
- location transparency
- quality of service support (delay, jitter, security)
- ...

Portability
- power consumption
- limited computing power, sizes of display, ...
- usability
- ...

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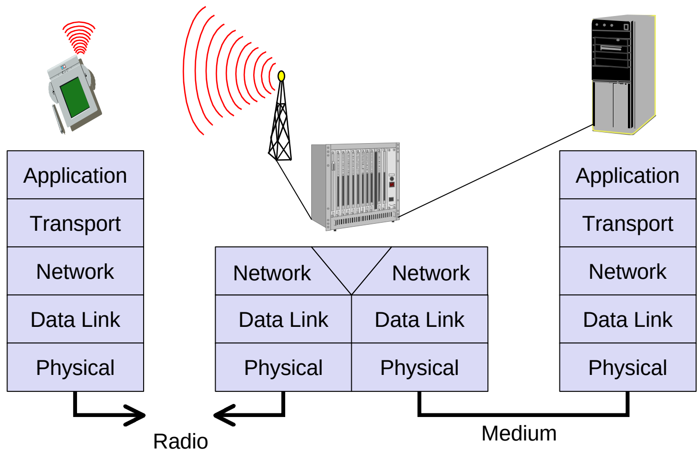
Simple reference model used here



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Influence of mobile communication to the layer model

Application layer	❑ service location ❑ new applications, multimedia ❑ adaptive applications
Transport layer	❑ congestion and flow control ❑ quality of service
Network layer	❑ addressing, routing, device location ❑ hand-over
Data link layer	❑ authentication ❑ media access ❑ multiplexing ❑ media access control
Physical layer	❑ encryption ❑ modulation ❑ interference ❑ attenuation ❑ frequency

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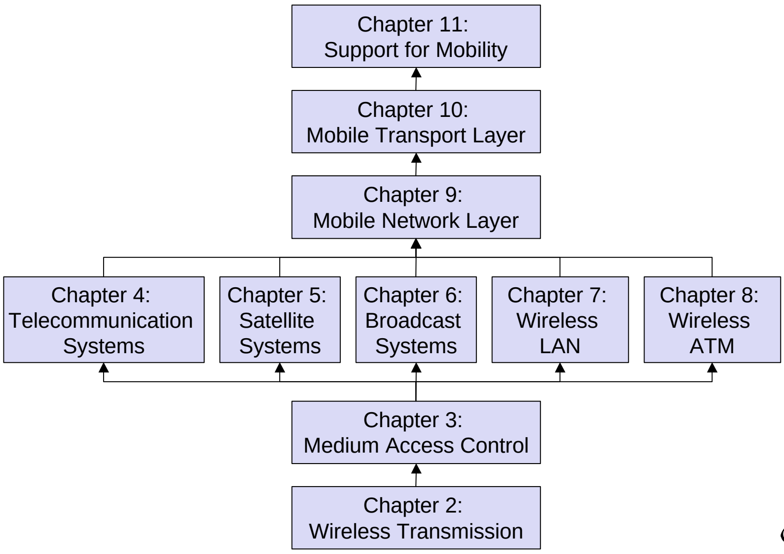
Overview of the chapters



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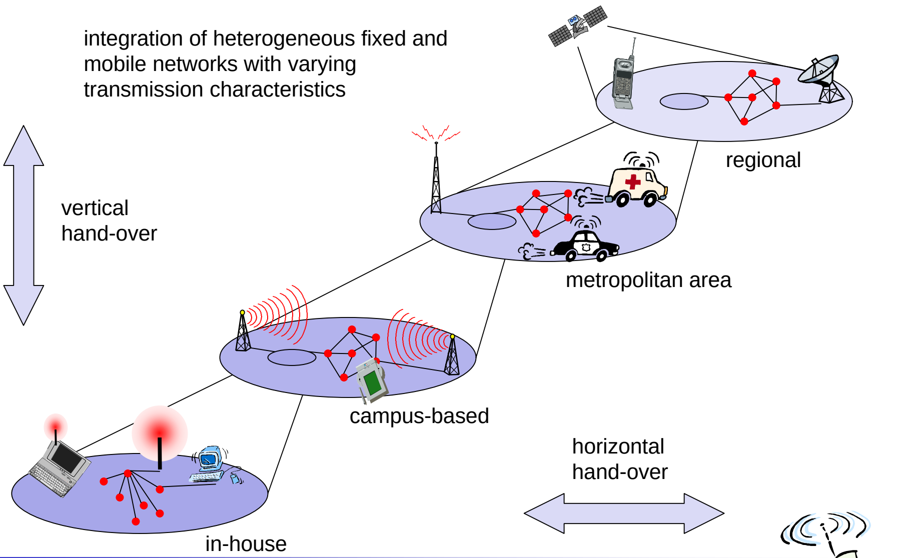
Overlay Networks - the global goal

integration of heterogeneous fixed and mobile networks with varying transmission characteristics

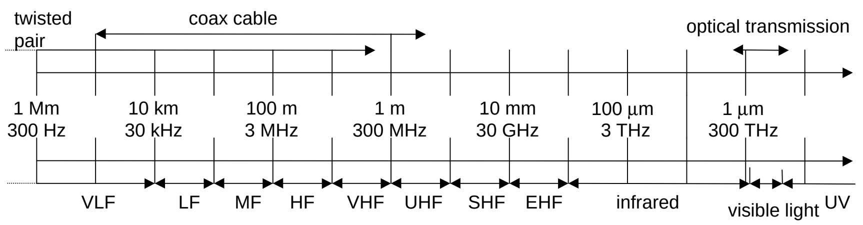


Mobile Communications: Introduction 1.23.1

Mobile Communications
Chapter 2: Wireless Transmission

- Frequencies
- Signals
- Antenna
- Signal propagation
- Multiplexing
- Spread spectrum
- Modulation
- Cellular systems

Frequencies for communication



VLF = Very Low Frequency
LF = Low Frequency
MF = Medium Frequency
HF = High Frequency
VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

Frequency and wave length:

$\lambda = c/f$

wave length λ, speed of light $c \cong 3x10^8$m/s, frequency f

Frequencies for mobile communication

- VHF-/UHF-ranges for mobile radio
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antenna, focussing
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF spectrum
  - some systems planned up to EHF
  - limitations due to absorption by water and oxygen molecules (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.

Mobile Communication: Wireless Transmission 2.2.1

Frequencies and regulations

ITU-R holds auctions for new frequencies, manages frequency bands worldwide (WRC, World Radio Conferences)

	Europe	USA	Japan
Mobile phones	**NMT** 453-457MHz, 463-467 MHz; **GSM** 890-915 MHz, 935-960 MHz; 1710-1785 MHz, 1805-1880 MHz	**AMPS**, **TDMA**, **CDMA** 824-849 MHz, 869-894 MHz; **TDMA**, **CDMA**, **GSM** 1850-1910 MHz, 1930-1990 MHz;	**PDC** 810-826 MHz, 940-956 MHz; 1429-1465 MHz, 1477-1513 MHz
Cordless telephones	**CT1+** 885-887 MHz, 930-932 MHz; **CT2** 864-868 MHz **DECT** 1880-1900 MHz	**PACS** 1850-1910 MHz, 1930-1990 MHz **PACS-UB** 1910-1930 MHz	**PHS** 1895-1918 MHz **JCT** 254-380 MHz
Wireless LANs	**IEEE 802.11** 2400-2483 MHz **HIPERLAN 1** 5176-5270 MHz	**IEEE 802.11** 2400-2483 MHz	**IEEE 802.11** 2471-2497 MHz

Mobile Communication: Wireless Transmission 2.3.1

Signals I

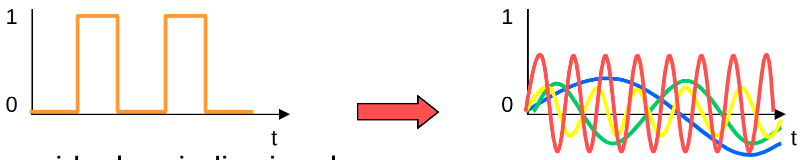
- physical representation of data
- function of time and location
- signal parameters: parameters representing the value of data
- classification
  - continuous time/discrete time
  - continuous values/discrete values
  - analog signal = continuous time and continuous values
  - digital signal = discrete time and discrete values
- signal parameters of periodic signals:
  period T, frequency f=1/T, amplitude A, phase shift φ
  - sine wave as special periodic signal for a carrier:

$$s(t) = A_t \sin(2 \pi f_t t + \varphi_t)$$

Mobile Communication: Wireless Transmission 2.4.1

Fourier representation of periodic signals

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



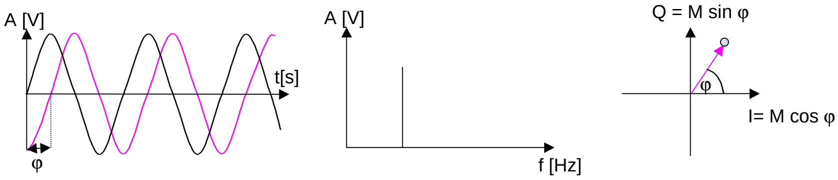
ideal periodic signal

real composition
(based on harmonics)

Mobile Communication: Wireless Transmission 2.5.1

Signals II

- Different representations of signals
  - amplitude (amplitude domain)
  - frequency spectrum (frequency domain)
  - phase state diagram (amplitude M and phase φ in polar coordinates)

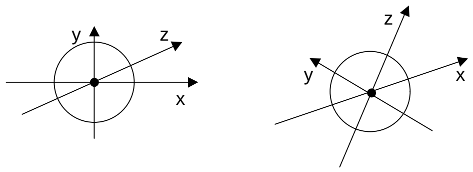


- Composed signals transferred into frequency domain using Fourier transformation
- Digital signals need
  - infinite frequencies for perfect transmission
  - modulation with a carrier frequency for transmission (analog signal!)

Mobile Communication: Wireless Transmission 2.6.1

Antennas: isotropic radiator

- Radiation and reception of electromagnetic waves, coupling of wires to space for radio transmission
- Isotropic radiator: equal radiation in all directions (three dimensional) - only a theoretical reference antenna
- Real antennas always have directive effects (vertically and/or horizontally)
- Radiation pattern: measurement of radiation around an antenna

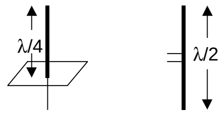


ideal
isotropic
radiator

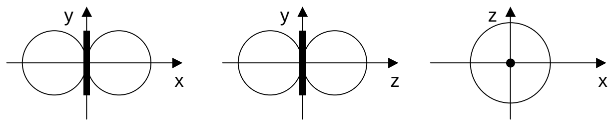
Mobile Communication: Wireless Transmission 2.7.1

Antennas: simple dipoles

- Real antennas are not isotropic radiators but, e.g., dipoles with lengths λ/4 on car roofs or λ/2 as Hertzian dipole
  ➔ shape of antenna proportional to wavelength



- Example: Radiation pattern of a simple Hertzian dipole



side view (xy-plane) side view (yz-plane) top view (xz-plane)

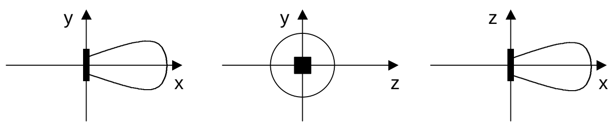
simple dipole

- Gain: maximum power in the direction of the main lobe compared to the power of an isotropic radiator (with the same average power)

Mobile Communication: Wireless Transmission 2.8.1

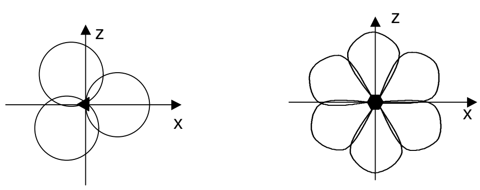
Antennas: directed and sectorized

Often used for microwave connections or base stations for mobile phones (e.g., radio coverage of a valley)



side view (xy-plane) side view (yz-plane) top view (xz-plane)

directed antenna



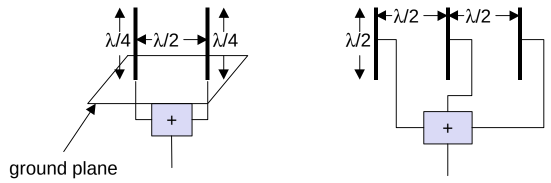
top view, 3 sector top view, 6 sector

sectorized antenna

Mobile Communication: Wireless Transmission 2.9.1

Antennas: diversity

- Grouping of 2 or more antennas
  - multi-element antenna arrays
- Antenna diversity
  - switched diversity, selection diversity
    - receiver chooses antenna with largest output
  - diversity combining
    - combine output power to produce gain
    - cophasing needed to avoid cancellation

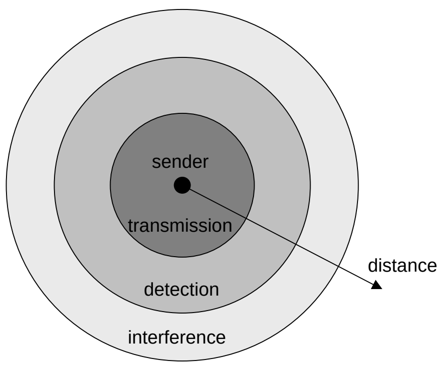


Signal propagation ranges

Transmission range
- communication possible
- low error rate

Detection range
- detection of the signal possible
- no communication possible

Interference range
- signal may not be detected
- signal adds to the background noise



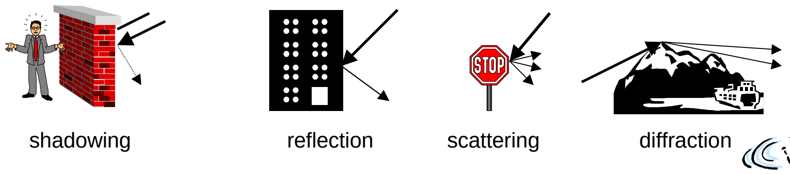
Signal propagation

Propagation in free space always like light (straight line)

Receiving power proportional to $1/d^2$
(d = distance between sender and receiver)

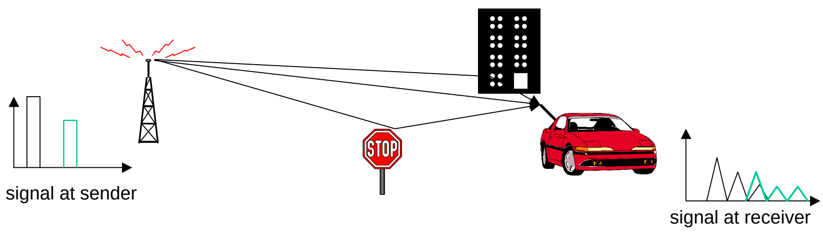
Receiving power additionally influenced by

- fading (frequency dependent)
- shadowing
- reflection at large obstacles
- scattering at small obstacles
- diffraction at edges



Multipath propagation

Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



Time dispersion: signal is dispersed over time

➔ interference with “neighbor” symbols, Inter Symbol Interference (ISI)

The signal reaches a receiver directly and phase shifted

➔ distorted signal depending on the phases of the different parts

Effects of mobility

Channel characteristics change over time and location

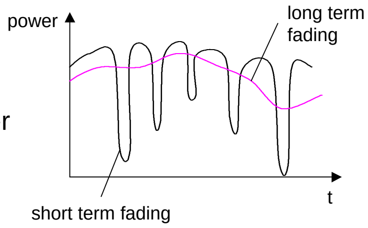
- signal paths change
- different delay variations of different signal parts
- different phases of signal parts

➔ quick changes in the power received (short term fading)

Additional changes in

- distance to sender
- obstacles further away

➔ slow changes in the average power received (long term fading)



Mobile Communication: Wireless Transmission 2.14.1

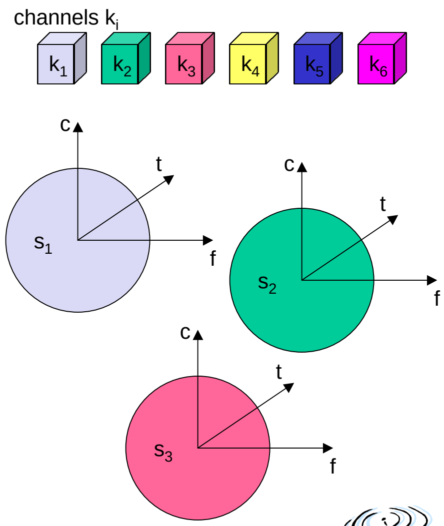
Multiplexing

Multiplexing in 4 dimensions

- space (s_i)
- time (t)
- frequency (f)
- code (c)

Goal: multiple use of a shared medium

Important: guard spaces needed!



Mobile Communication: Wireless Transmission 2.15.1

Frequency multiplex

Separation of the whole spectrum into smaller frequency bands

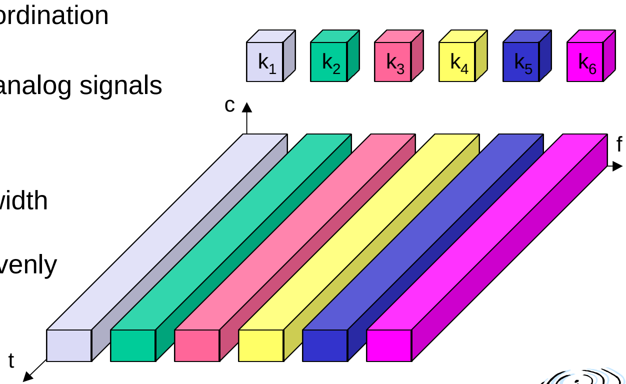
A channel gets a certain band of the spectrum for the whole time

Advantages:

- no dynamic coordination necessary
- works also for analog signals

Disadvantages:

- waste of bandwidth if the traffic is distributed unevenly
- inflexible
- guard spaces



Time multiplex

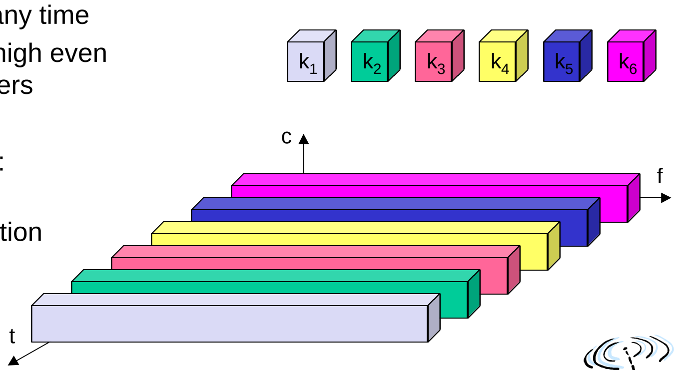
A channel gets the whole spectrum for a certain amount of time

Advantages:

- only one carrier in the medium at any time
- throughput high even for many users

Disadvantages:

- precise synchronization necessary



Time and frequency multiplex

Combination of both methods

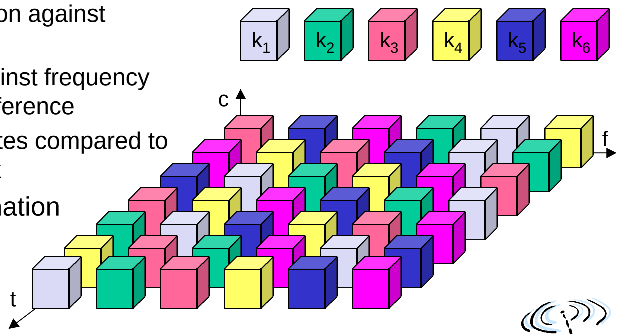
A channel gets a certain frequency band for a certain amount of time

Example: GSM

Advantages:

- better protection against tapping
- protection against frequency selective interference
- higher data rates compared to code multiplex

but: precise coordination required



Mobile Communication: Wireless Transmission 2.18.1

Code multiplex

Each channel has a unique code

All channels use the same spectrum at the same time

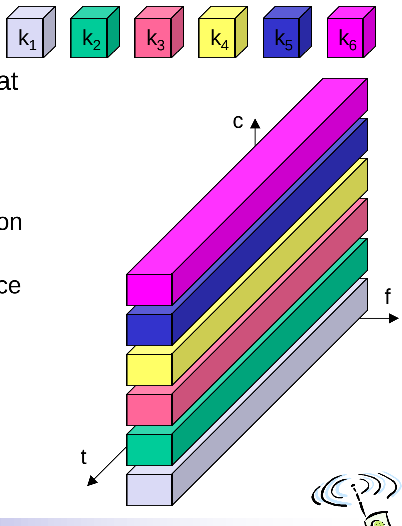
Advantages:

- bandwidth efficient
- no coordination and synchronization necessary
- good protection against interference and tapping

Disadvantages:

- lower user data rates
- more complex signal regeneration

Implemented using spread spectrum technology



Mobile Communication: Wireless Transmission 2.19.1

Modulation

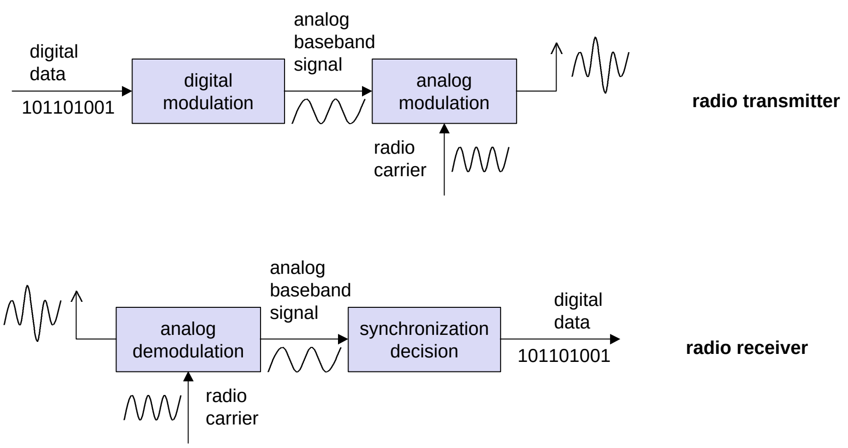
Digital modulation
- digital data is translated into an analog signal (baseband)
- ASK, FSK, PSK - main focus in this chapter
- differences in spectral efficiency, power efficiency, robustness

Analog modulation
- shifts center frequency of baseband signal up to the radio carrier

Motivation
- smaller antennas (e.g., $\lambda/4$)
- Frequency Division Multiplexing
- medium characteristics

Basic schemes
- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)

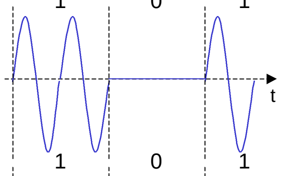
Modulation and demodulation



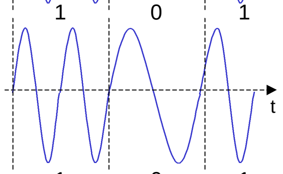
Digital modulation

Modulation of digital signals known as Shift Keying

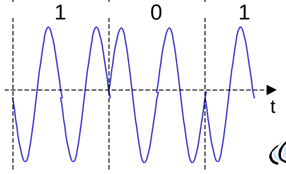
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference



- Frequency Shift Keying (FSK):
  - needs larger bandwidth



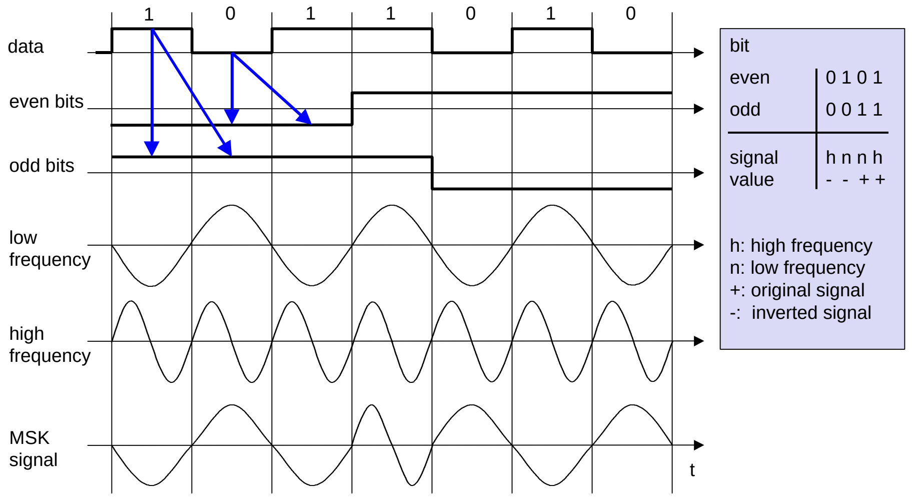
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference



Advanced Frequency Shift Keying

- bandwidth needed for FSK depends on the distance between the carrier frequencies
- special pre-computation avoids sudden phase shifts
  ➔ MSK (Minimum Shift Keying)
- bit separated into even and odd bits, the duration of each bit is doubled
- depending on the bit values (even, odd) the higher or lower frequency, original or inverted is chosen
- the frequency of one carrier is twice the frequency of the other
- even higher bandwidth efficiency using a Gaussian low-pass filter ➔ GMSK (Gaussian MSK), used in GSM

Example of MSK



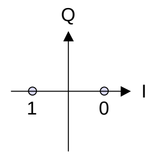
No phase shifts!

Mobile Communication: Wireless Transmission 2.24.1

Advanced Phase Shift Keying

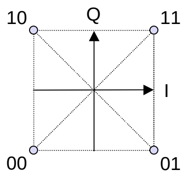
BPSK (Binary Phase Shift Keying):

- bit value 0: sine wave
- bit value 1: inverted sine wave
- very simple PSK
- low spectral efficiency
- robust, used e.g. in satellite systems

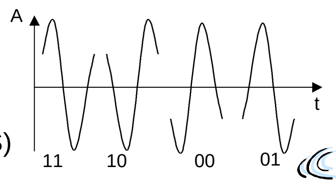


QPSK (Quadrature Phase Shift Keying):

- 2 bits coded as one symbol
- symbol determines shift of sine wave
- needs less bandwidth compared to BPSK
- more complex



Often also transmission of relative, not absolute phase shift: DQPSK - Differential QPSK (IS-136, PACS, PHS)



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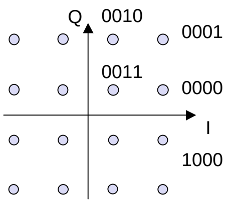
Quadrature Amplitude Modulation

Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation

- it is possible to code n bits using one symbol
- 2^n discrete levels, n=2 identical to QPSK
- bit error rate increases with n, but less errors compared to comparable PSK schemes



Example: 16-QAM (4 bits = 1 symbol)

Symbols 0011 and 0001 have the same phase, but different amplitude. 0000 and 1000 have different phase, but same amplitude.

➔ used in standard 9600 bit/s modems

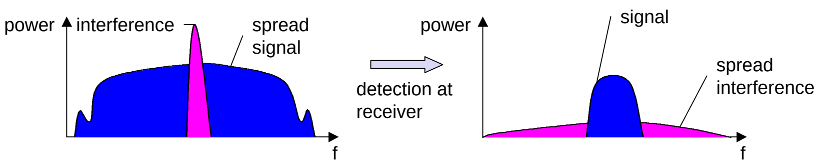
Mobile Communication: Wireless Transmission 2.26.1

Spread spectrum technology

Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference

Solution: spread the narrow band signal into a broad band signal using a special code

protection against narrow band interference



protection against narrowband interference

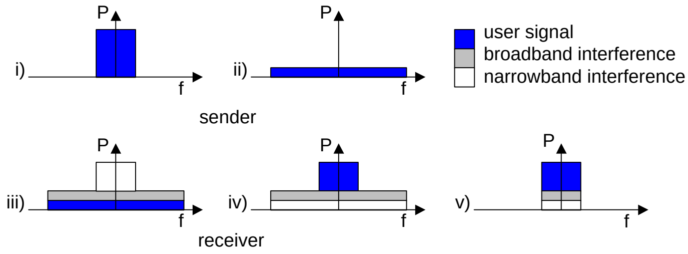
Side effects:

- coexistence of several signals without dynamic coordination
- tap-proof

Alternatives: Direct Sequence, Frequency Hopping

Mobile Communication: Wireless Transmission 2.27.1

Effects of spreading and interference



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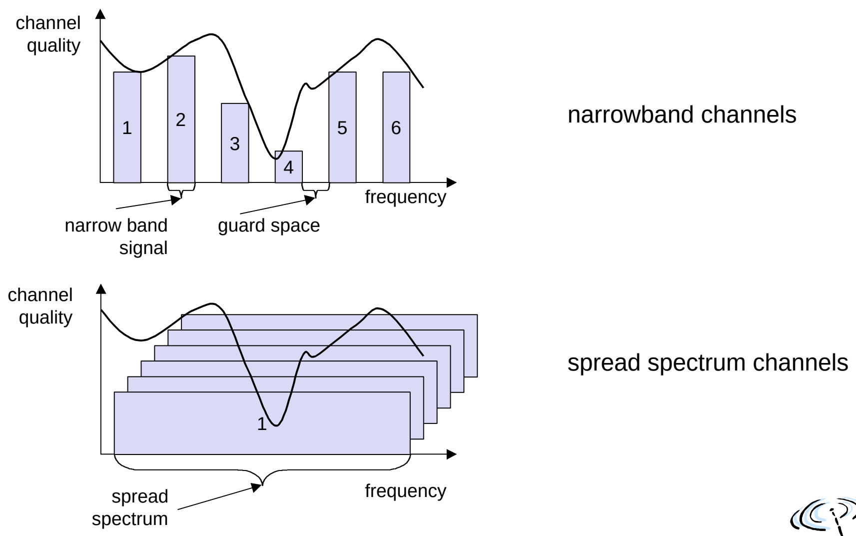
Spreading and frequency selective fading



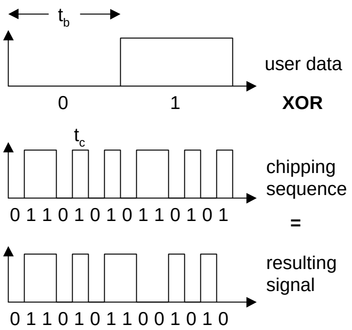
Mobile Communication: Wireless Transmission 2.29.1

DSSS (Direct Sequence Spread Spectrum) I

XOR of the signal with pseudo-random number (chipping sequence)
- many chips per bit (e.g., 128) result in higher bandwidth of the signal

Advantages
- reduces frequency selective fading
- in cellular networks
  - base stations can use the same frequency range
  - several base stations can detect and recover the signal
  - soft handover

Disadvantages
- precise power control necessary



t_b: bit period
t_c: chip period

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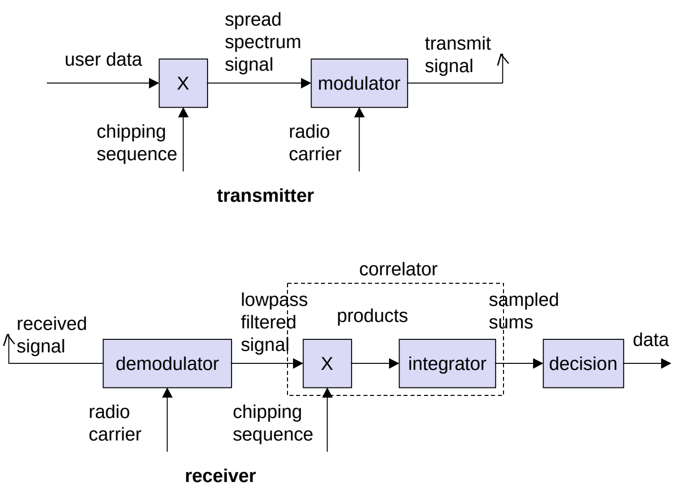
DSSS (Direct Sequence Spread Spectrum) II



Mobile Communication: Wireless Transmission 2.31.1

FHSS (Frequency Hopping Spread Spectrum) I

- Discrete changes of carrier frequency
  - sequence of frequency changes determined via pseudo random number sequence
- Two versions
  - Fast Hopping:
    several frequencies per user bit
  - Slow Hopping:
    several user bits per frequency
- Advantages
  - frequency selective fading and interference limited to short period
  - simple implementation
  - uses only small portion of spectrum at any time
- Disadvantages
  - not as robust as DSSS
  - simpler to detect

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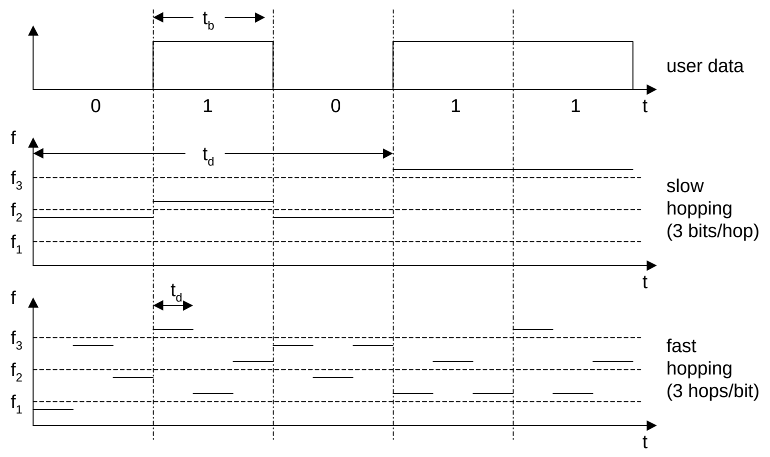
FHSS (Frequency Hopping Spread Spectrum) II



t_b: bit period t_d: dwell time

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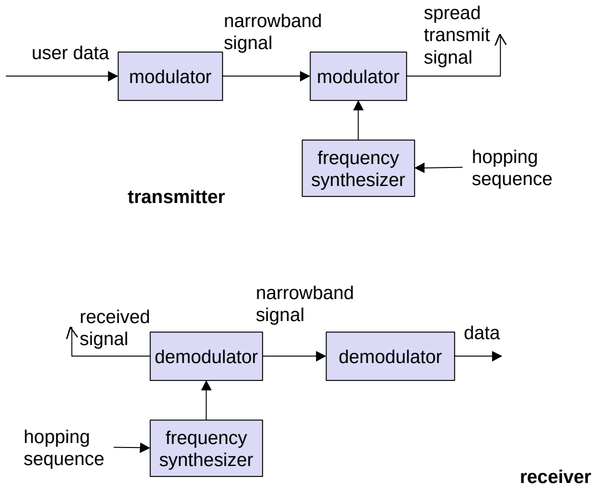
FHSS (Frequency Hopping Spread Spectrum) III



Mobile Communication: Wireless Transmission 2.34.1

Cell structure

Implements space division multiplex: base station covers a certain transmission area (cell)

Mobile stations communicate only via the base station

Advantages of cell structures:

- higher capacity, higher number of users
- less transmission power needed
- more robust, decentralized
- base station deals with interference, transmission area etc. locally

Problems:

- fixed network needed for the base stations
- handover (changing from one cell to another) necessary
- interference with other cells

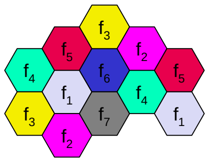
Cell sizes from some 100 m in cities to, e.g., 35 km on the country side (GSM) - even less for higher frequencies

Mobile Communication: Wireless Transmission 2.35.1

Frequency planning I

Frequency reuse only with a certain distance between the base stations

Standard model using 7 frequencies:



Fixed frequency assignment:

- certain frequencies are assigned to a certain cell
- problem: different traffic load in different cells

Dynamic frequency assignment:

- base station chooses frequencies depending on the frequencies already used in neighbor cells
- more capacity in cells with more traffic
- assignment can also be based on interference measurements

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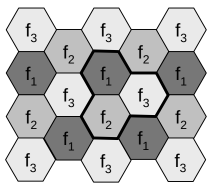
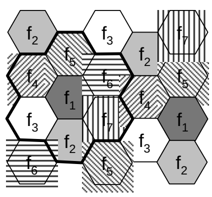
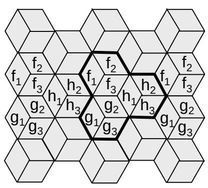
Frequency planning II



3 cell cluster

7 cell cluster





3 cell cluster
with 3 sector antennas

Mobile Communication: Wireless Transmission 2.37.1

Mobile Communications
Chapter 3 : Media Access

- Motivation
- SDMA, FDMA, TDMA
- Aloha
- Reservation schemes
- Collision avoidance, MACA
- Polling
- CDMA
- SAMA
- Comparison

Motivation

Can we apply media access methods from fixed networks?

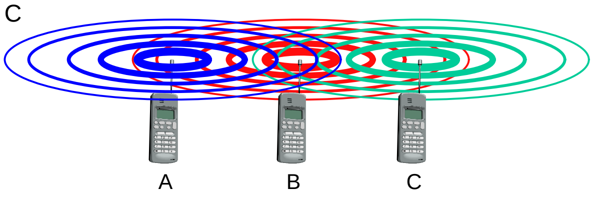
Example CSMA/CD
- **C**arrier **S**ense **M**ultiple **A**ccess with **C**ollision **D**etection
- send as soon as the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)

Problems in wireless networks
- signal strength decreases proportional to the square of the distance
- the sender would apply CS and CD, but the collisions happen at the receiver
- it might be the case that a sender cannot “hear” the collision, i.e., CD does not work
- furthermore, CS might not work if, e.g., a terminal is “hidden”

Motivation - hidden and exposed terminals

Hidden terminals

- A sends to B, C cannot receive A
- C wants to send to B, C senses a “free” medium (CS fails)
- collision at B, A cannot receive the collision (CD fails)
- A is “hidden” for C



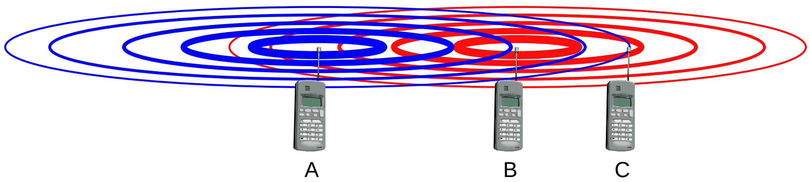
Exposed terminals

- B sends to A, C wants to send to another terminal (not A or B)
- C has to wait, CS signals a medium in use
- but A is outside the radio range of C, therefore waiting is not necessary
- C is “exposed” to B

Motivation - near and far terminals

Terminals A and B send, C receives

- signal strength decreases proportional to the square of the distance
- the signal of terminal B therefore drowns out A’s signal
- C cannot receive A



If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer

Also severe problem for CDMA-networks - precise power control needed!

Access methods SDMA/FDMA/TDMA

SDMA (Space Division Multiple Access)
- segment space into sectors, use directed antennas
- cell structure

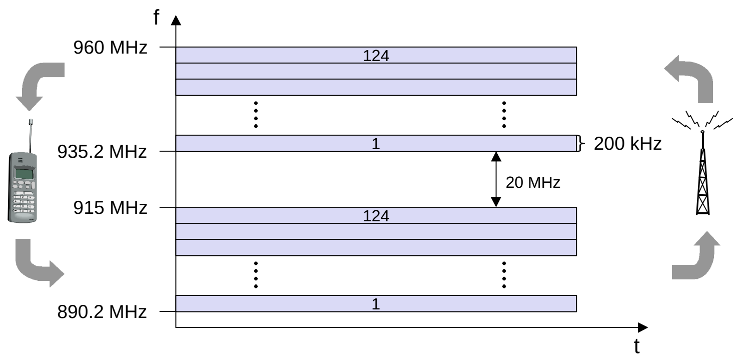
FDMA (Frequency Division Multiple Access)
- assign a certain frequency to a transmission channel between a sender and a receiver
- permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)

TDMA (Time Division Multiple Access)
- assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time

The multiplexing schemes presented in chapter 2 are now used to control medium access!

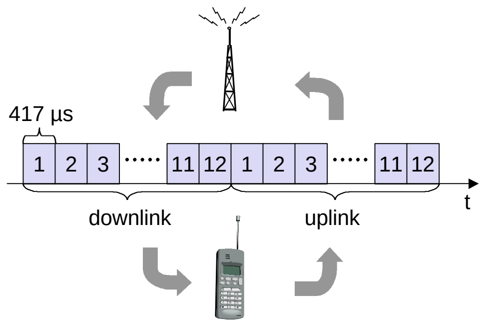
Mobile Communications: Media Access 3.4.1

FDD/FDMA - general scheme, example GSM



Mobile Communications: Media Access 3.5.1

TDD/TDMA - general scheme, example DECT

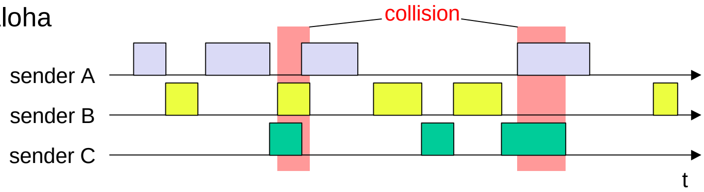


Aloha/slotted aloha

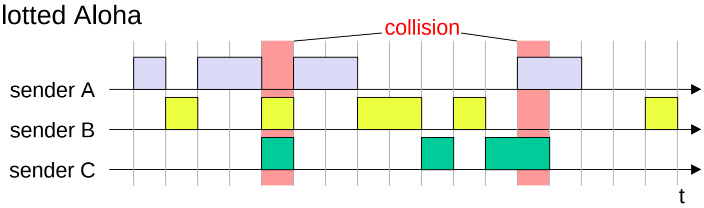
Mechanism

- random, distributed (no central arbiter), time-multiplex
- Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries

Aloha



Slotted Aloha



DAMA - Demand Assigned Multiple Access

Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length)

Reservation can increase efficiency to 80%

- a sender *reserves* a future time-slot
- sending within this reserved time-slot is possible without collision
- reservation also causes higher delays
- typical scheme for satellite links

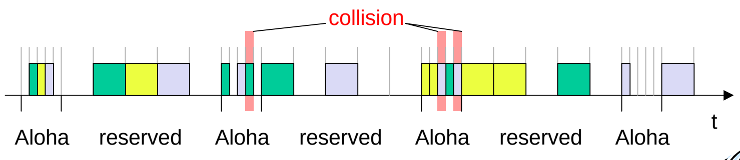
Examples for reservation algorithms:

- *Explicit Reservation according to Roberts (Reservation-ALOHA)*
- *Implicit Reservation (PRMA)*
- *Reservation-TDMA*

Access method DAMA: Explicit Reservation

Explicit Reservation (Reservation Aloha):

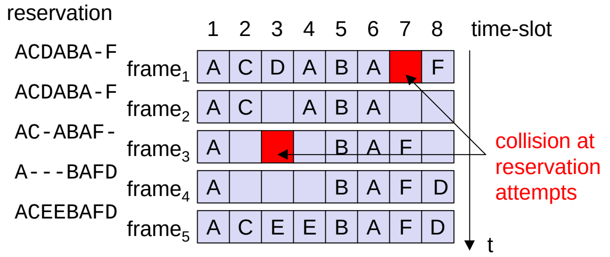
- two modes:
  - *ALOHA mode* for reservation:
    competition for small reservation slots, collisions possible
  - *reserved mode* for data transmission within successful reserved slots (no collisions possible)
- it is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time



Access method DAMA: PRMA

Implicit reservation (PRMA - Packet Reservation MA):

- a certain number of slots form a frame, frames are repeated
- stations compete for empty slots according to the slotted aloha principle
- once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
- competition for this slots starts again as soon as the slot was empty in the last frame

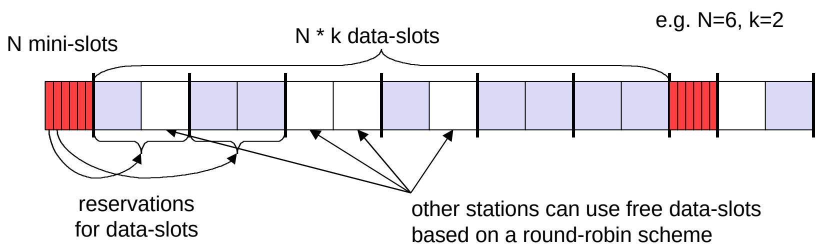


Mobile Communications: Media Access 3.10.1

Access method DAMA: Reservation-TDMA

Reservation Time Division Multiple Access

- every frame consists of N mini-slots and x data-slots
- every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).
- other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)



Mobile Communications: Media Access 3.11.1

MACA - collision avoidance

MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance

- RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
- CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive

Signaling packets contain

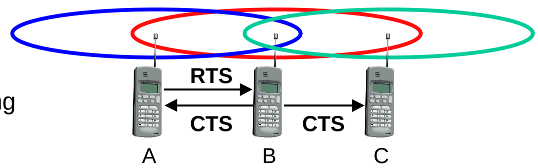
- sender address
- receiver address
- packet size

Variants of this method can be found in IEEE802.11 as DFWMAC (Distributed Foundation Wireless MAC)

MACA examples

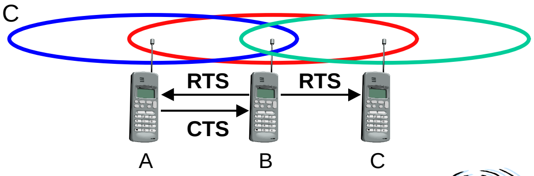
MACA avoids the problem of hidden terminals

- A and C want to send to B
- A sends RTS first
- C waits after receiving CTS from B

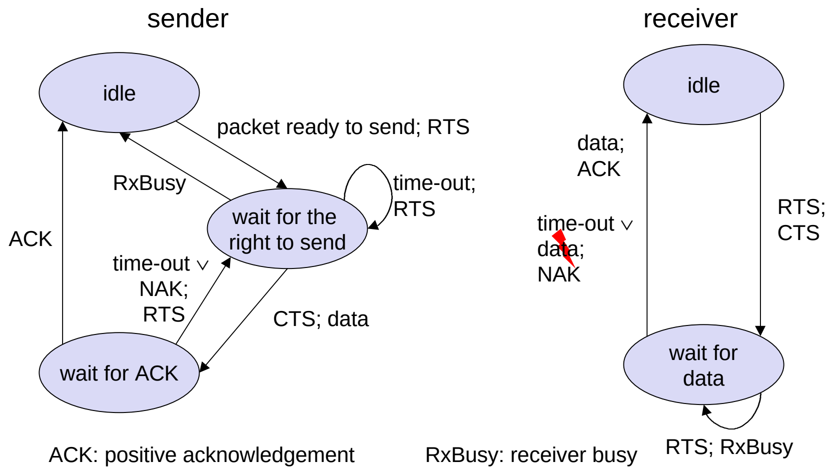


MACA avoids the problem of exposed terminals

- B wants to send to A, C to another terminal
- now C does not have to wait for it cannot receive CTS from A



MACA variant: DFWMAC in IEEE802.11



ACK: positive acknowledgement
NAK: negative acknowledgement

RxBusy: receiver busy

Polling mechanisms

If one terminal can be heard by all others, this “central” terminal (a.k.a. base station) can poll all other terminals according to a certain scheme

- now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)

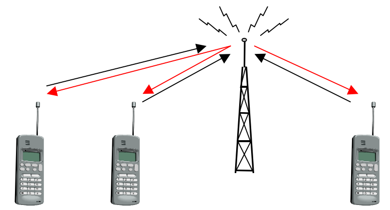
Example: Randomly Addressed Polling

- base station signals readiness to all mobile terminals
- terminals ready to send can now transmit a random number without collision with the help of CDMA or FDMA (the random number can be seen as dynamic address)
- the base station now chooses one address for polling from the list of all random numbers (collision if two terminals choose the same address)
- the base station acknowledges correct packets and continues polling the next terminal
- this cycle starts again after polling all terminals of the list

ISMA (Inhibit Sense Multiple Access)

Current state of the medium is signaled via a “busy tone”

- the base station signals on the downlink (base station to terminals) if the medium is free or not
- terminals must not send if the medium is busy
- terminals can access the medium as soon as the busy tone stops
- the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach)
- mechanism used, e.g., for CDPD (USA, integrated into AMPS)



Access method CDMA

CDMA (Code Division Multiple Access)

- all terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
- each sender has a unique random number, the sender XORs the signal with this random number
- the receiver can “tune” into this signal if it knows the pseudo random number, tuning is done via a correlation function

Disadvantages:

- higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
- all signals should have the same strength at a receiver

Advantages:

- all terminals can use the same frequency, no planning needed
- huge code space (e.g. 2^{32}) compared to frequency space
- interferences (e.g. white noise) is not coded
- forward error correction and encryption can be easily integrated

CDMA in theory

Sender A

- sends $A_d = 1$, key $A_k = 010011$ (assign: „0“= -1, „1“= +1)
- sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$

Sender B

- sends $B_d = 0$, key $B_k = 110101$ (assign: „0“= -1, „1“= +1)
- sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$

Both signals superimpose in space

- interference neglected (noise etc.)
- $A_s + B_s = (-2, 0, 0, -2, +2, 0)$

Receiver wants to receive signal from sender A

- apply key A_k bitwise (inner product)
  - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
  - result greater than 0, therefore, original bit was „1“
- receiving B
  - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. „0“

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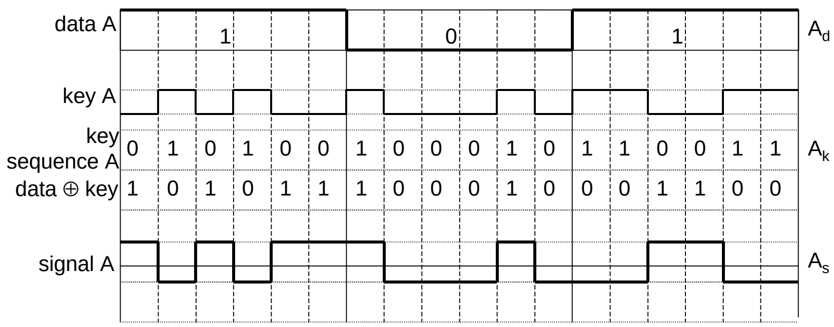
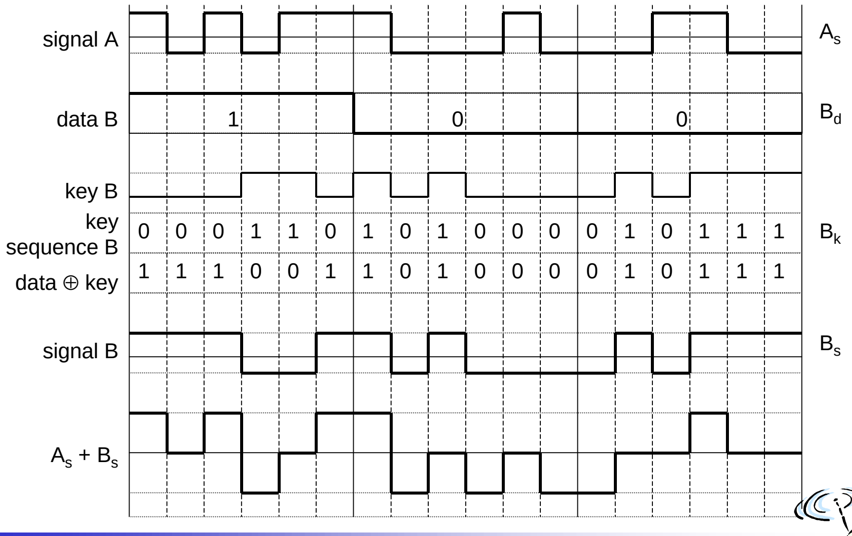
CDMA on signal level I



Real systems use much longer keys resulting in a larger distance between single code words in code space.

Mobile Communications: Media Access 3.19.1

CDMA on signal level II



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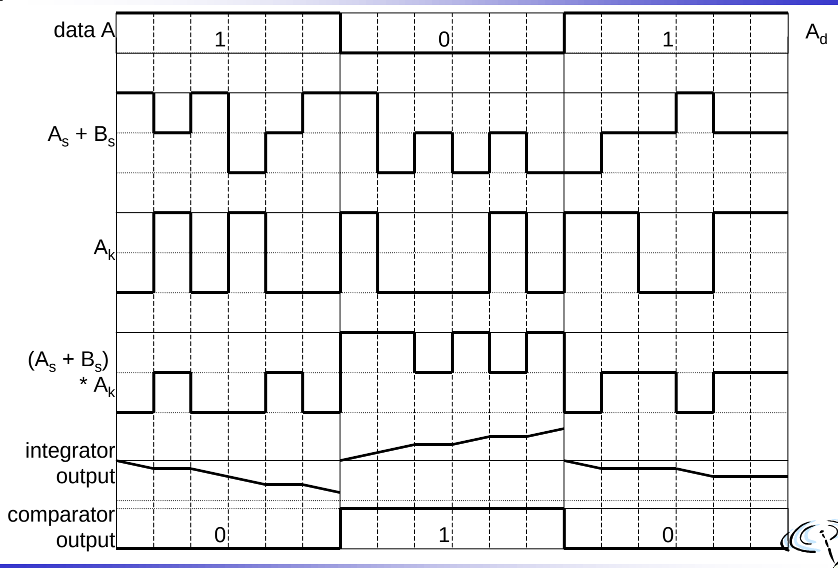
CDMA on signal level III



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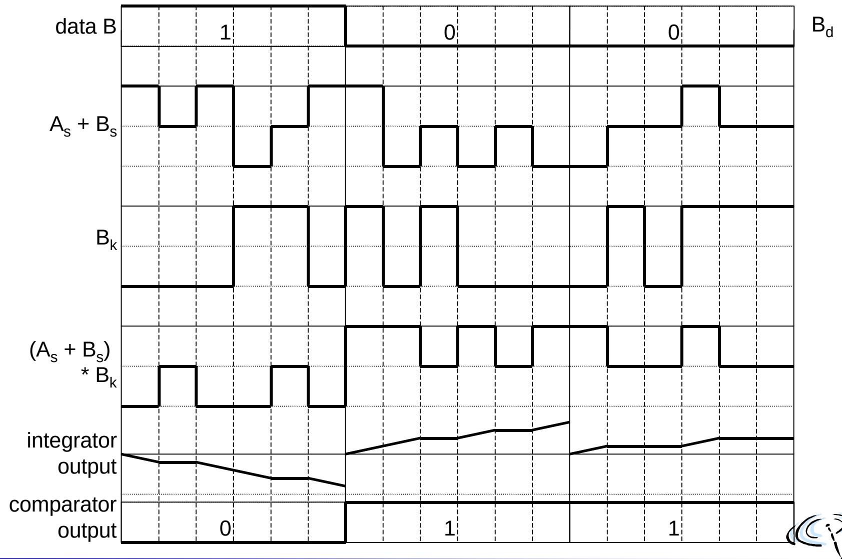
CDMA on signal level IV



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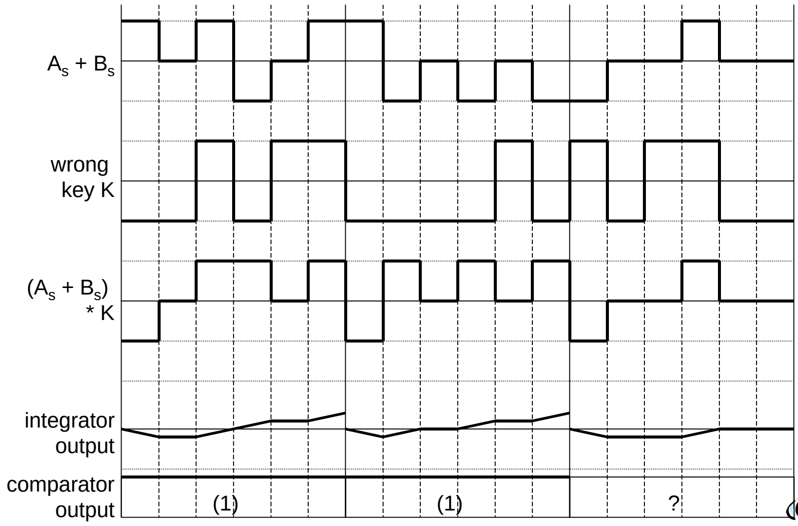
CDMA on signal level V

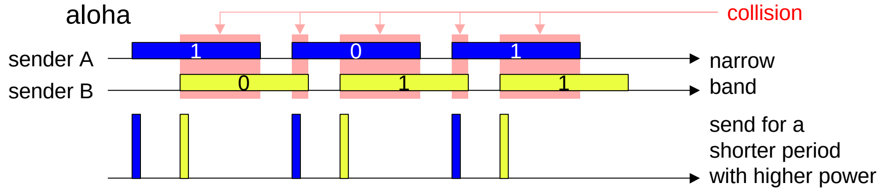


Mobile Communications: Media Access 3.23.1

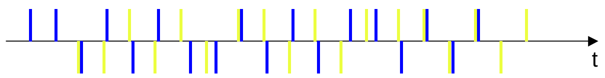
SAMA - Spread Aloha Multiple Access

Aloha has only a very low efficiency, CDMA needs complex receivers to be able to receive different senders with individual codes at the same time

Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha



spread the signal e.g. using the chipping sequence 110101 („*CDMA without CD*“)



Problem: find a chipping sequence with good characteristics

Comparison SDMA/TDMA/FDMA/CDMA

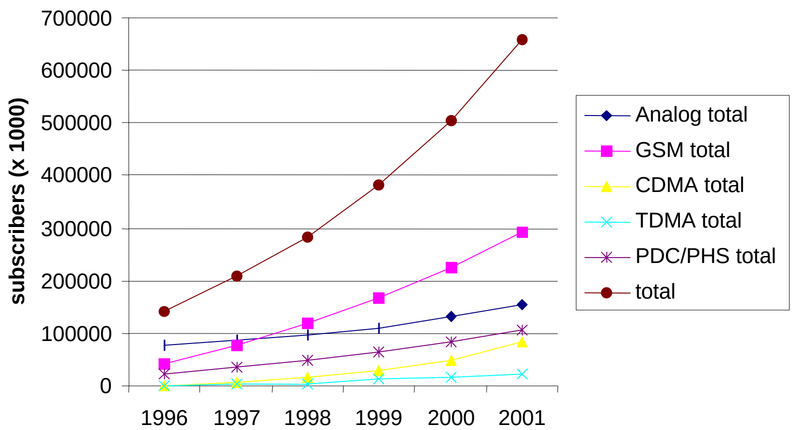
Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time-slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantages	very simple, increases capacity per km²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantages	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

Mobile Communications Chapter 4: Wireless Telecommunication Systems

- Market
- GSM
  - Overview
  - Services
  - Sub-systems
  - Components
- DECT
- TETRA
- UMTS/IMT-2000

Mobile Communications: Wireless Telecommunication Systems 4.0.1

Mobile phone subscribers worldwide



Mobile Communications: Wireless Telecommunication Systems 4.1.1

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 (more than 130 countries in Asia, Africa, Europe, Australia, America)
- more than 100 million subscribers

Mobile Communications: Wireless Telecommunication Systems 4.2.1

Performance characteristics of GSM

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

Mobile Communications: Wireless Telecommunication Systems 4.3.1

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

Mobile Communications: Wireless Telecommunication Systems 4.4.1

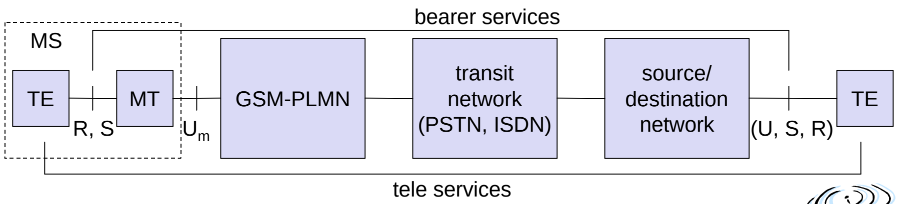
GSM: Mobile Services

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



Mobile Communications: Wireless Telecommunication Systems 4.5.1

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

Mobile Communications: Wireless Telecommunication Systems 4.6.1

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

Mobile Communications: Wireless Telecommunication Systems 4.7.1

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 using the signaling channel, thus allowing simultaneous use of basic services and SMS

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)
  - ...

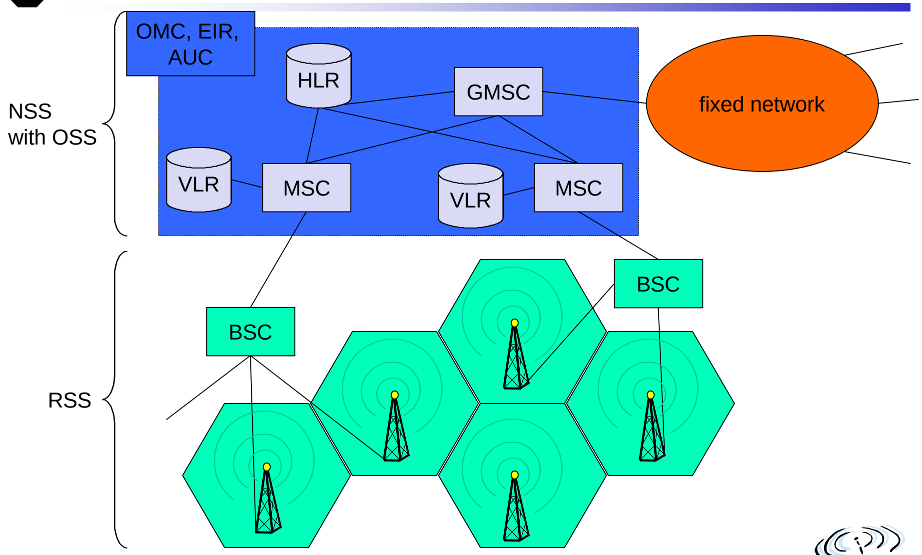
Architecture of the GSM system

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

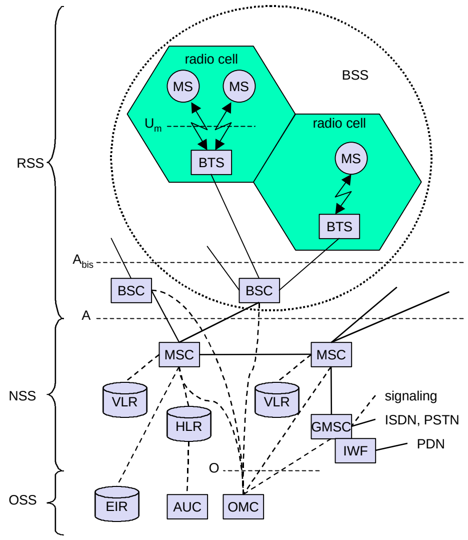
Mobile Communications: Wireless Telecommunication Systems 4.10.1

GSM: overview



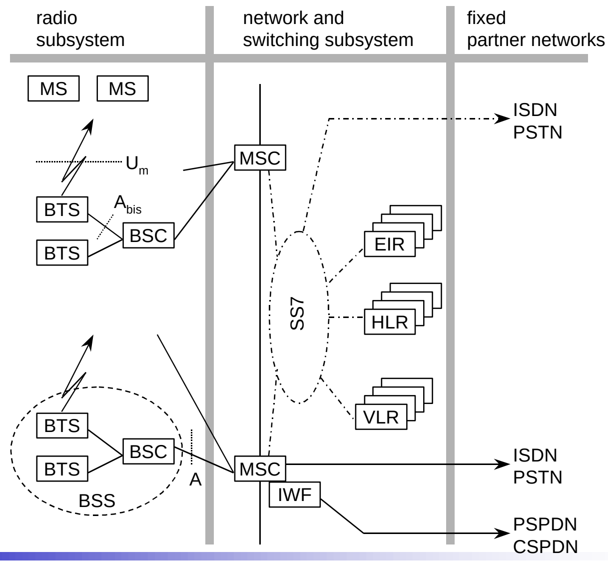
Mobile Communications: Wireless Telecommunication Systems 4.11.1

GSM: elements and interfaces



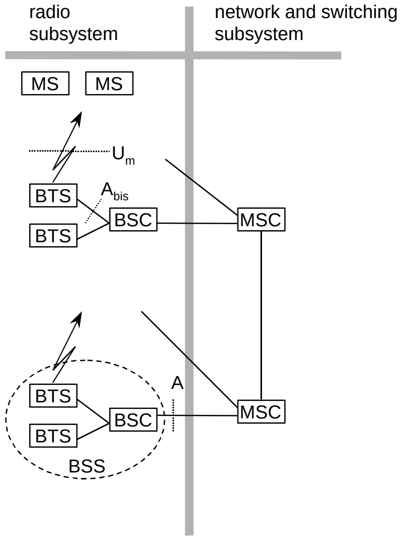
Mobile Communications: Wireless Telecommunication Systems 4.12.1

GSM: system architecture



Mobile Communications: Wireless Telecommunication Systems 4.13.1

System architecture: radio subsystem



Components

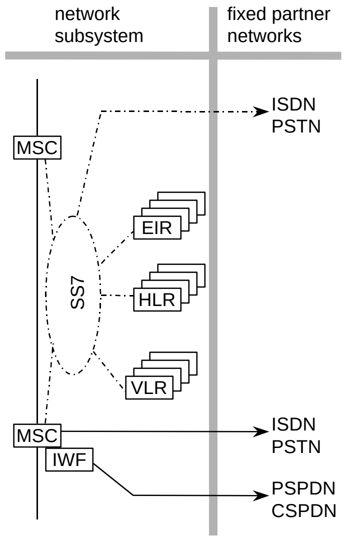
- *MS* (Mobile Station)
- *BSS* (Base Station Subsystem): consisting of
  - *BTS* (Base Transceiver Station): sender and receiver
  - *BSC* (Base Station Controller): controlling several transceivers

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

Mobile Communications: Wireless Telecommunication Systems 4.14.1

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 *R*egister)
- *VLR* (Visitor Location *R*egister)
- *EIR* (Equipment Identity Register)

Mobile Communications: Wireless Telecommunication Systems 4.15.1

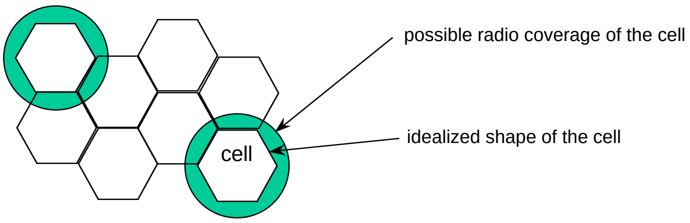
Radio subsystem

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

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

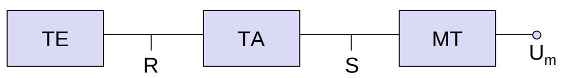
Functions	BTS	BSC
Management of radio channels		X
Frequency hopping (FH)	X	X
Management of terrestrial channels		X
Mapping of terrestrial onto radio channels		X
Channel coding and decoding	X	
Rate adaptation	X	
Encryption and decryption	X	X
Paging	X	X
Uplink signal measurements	X	
Traffic measurement		X
Authentication		X
Location registry, location update		X
Handover management		X

Mobile Communications: Wireless Telecommunication Systems 4.18.1

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 (U_m)
  - 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



Mobile Communications: Wireless Telecommunication Systems 4.19.1

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 Communications: Wireless Telecommunication Systems 4.20.1

Mobile Services Switching Center

The MSC (mobile 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

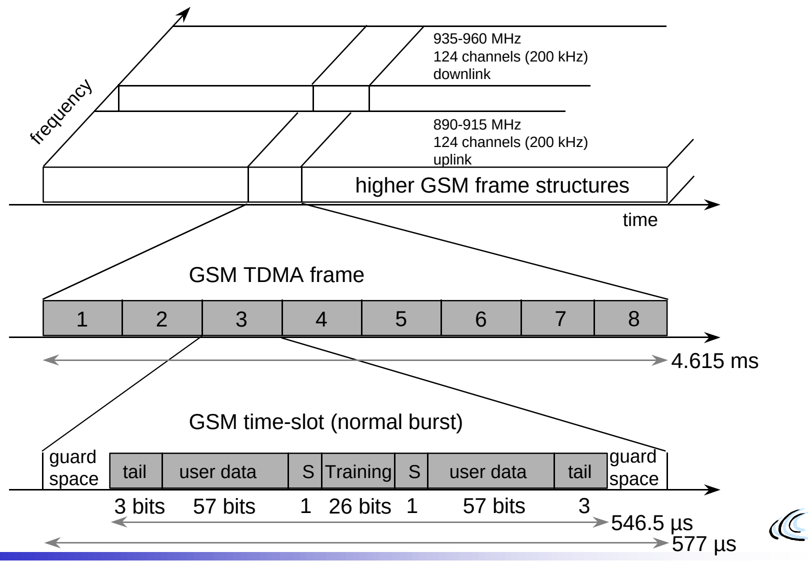
Mobile Communications: Wireless Telecommunication Systems 4.21.1

Operation subsystem

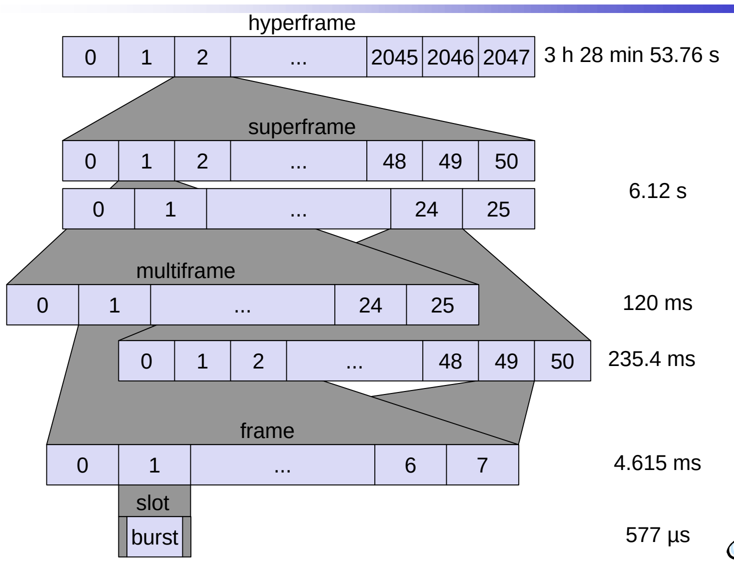
The OSS (Operation Subsystem) enables centralized operation, management, and maintenance of all GSM subsystems

- 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

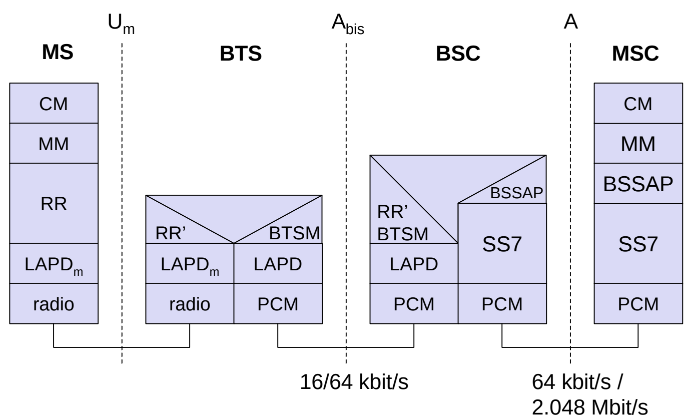


GSM hierarchy of frames



Mobile Communications: Wireless Telecommunication Systems 4.24.1

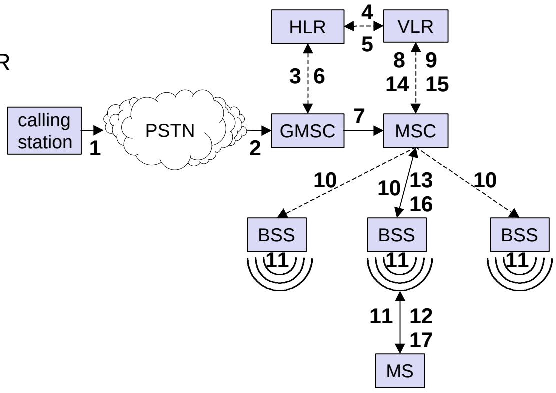
GSM protocol layers for signaling



Mobile Communications: Wireless Telecommunication Systems 4.25.1

Mobile Terminated Call

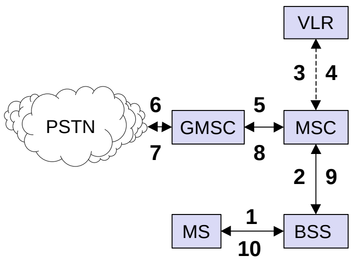
1: calling a GSM subscriber
2: forwarding call to GMSC
3: signal call setup to HLR
4, 5: request MSRN from VLR
6: forward responsible
   MSC to GMSC
7: forward call to
   current MSC
8, 9: get current status of MS
10, 11: paging of MS
12, 13: MS answers
14, 15: security checks
16, 17: set up connection



Mobile Communications: Wireless Telecommunication Systems 4.26.1

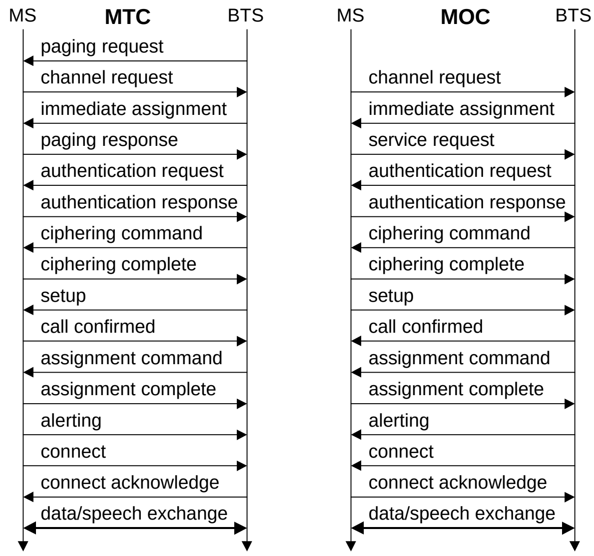
Mobile Originated Call

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



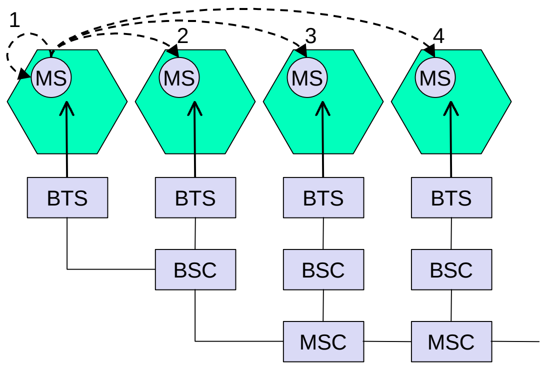
Mobile Communications: Wireless Telecommunication Systems 4.27.1

MTC/MOC



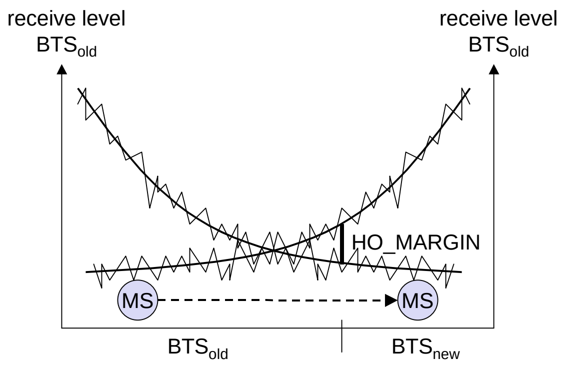
Mobile Communications: Wireless Telecommunication Systems 4.28.1

4 types of handover

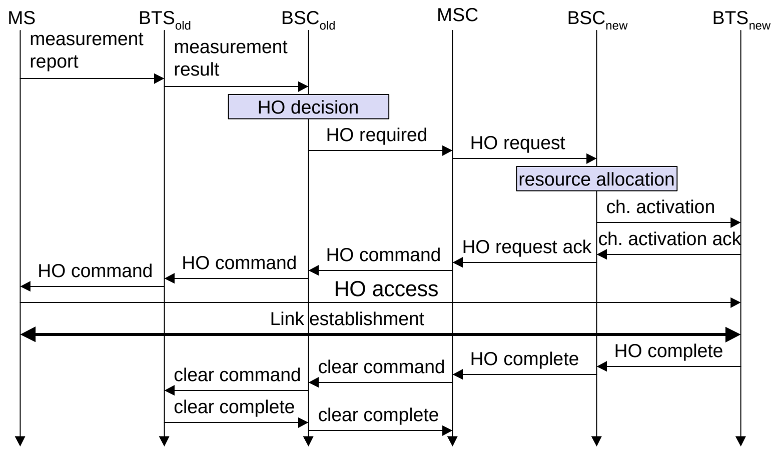


Mobile Communications: Wireless Telecommunication Systems 4.29.1

Handover decision



Handover procedure



Security in GSM

Security services

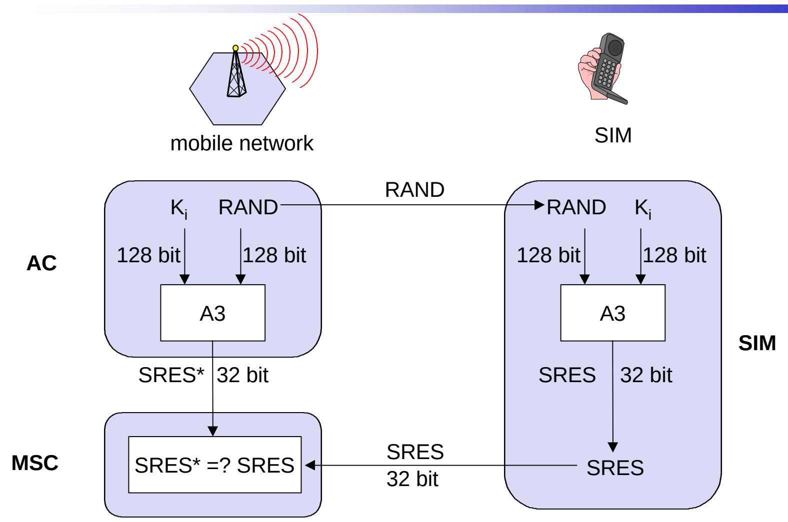
- access control/authentication
  - user → SIM (Subscriber Identity Module): secret PIN (personal identification number)
  - SIM → network: challenge response method
- confidentiality
  - voice and signaling encrypted on the wireless link (after successful authentication)
- anonymity
  - temporary identity 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)

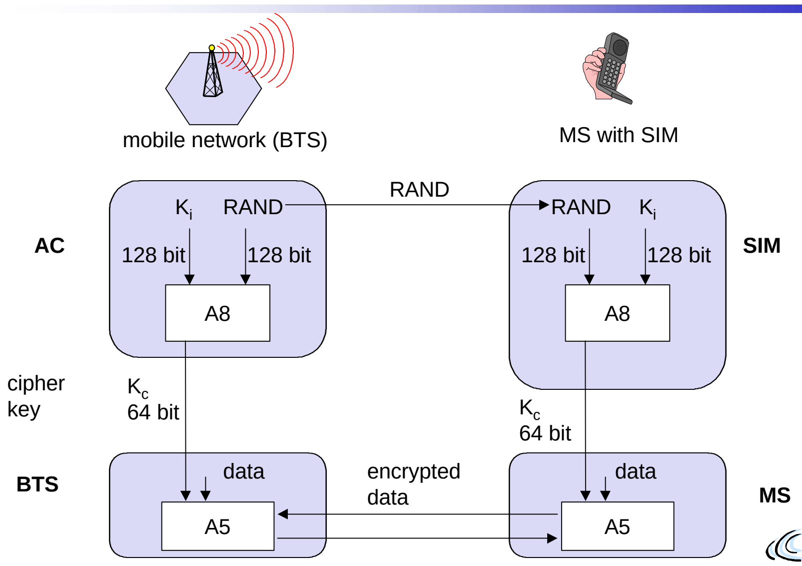
"secret":
• A3 and A8 available via the Internet
• network providers can use stronger mechanisms

GSM - authentication



K$_i$: individual subscriber authentication key SRES: signed response

GSM - key generation and encryption



Mobile Communications: Wireless Telecommunication Systems 4.34.1

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)
  - already standardized
  - bundling of several time-slots to get higher AIUR (Air Interface User Rate) (e.g., 57.6 kbit/s using 4 slots, 14.4 each)
  - advantage: ready to use, constant quality, simple
  - disadvantage: channels blocked for voice transmission

AIUR [kbit/s]	TCH/F4.8	TCH/F9.6	TCH/F14.4
4.8	1		
9.6	2	1	
14.4	3		1
19.2	4	2	
28.8		3	2
38.4		4	
43.2			3
57.6			4

Mobile Communications: Wireless Telecommunication Systems 4.35.1

Data services in GSM II

GPRS (General Packet Radio Service)

- packet switching
- using free slots only if data packets ready to send (e.g., 115 kbit/s using 8 slots temporarily)
- standardization 1998, introduction 2000?
- advantage: one step towards UMTS, more flexible
- disadvantage: more investment needed

GPRS network elements

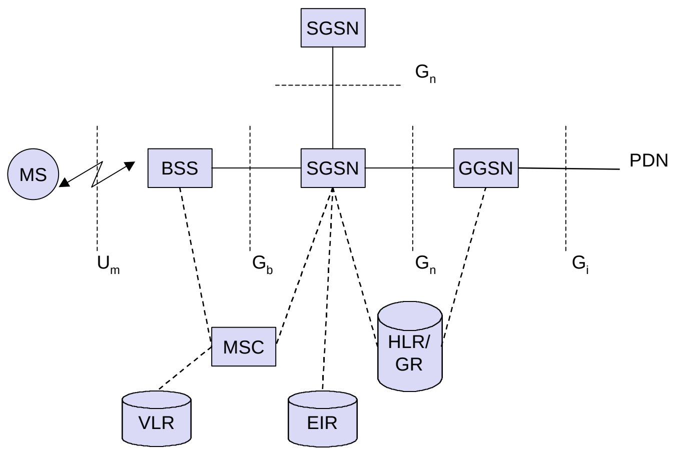
- GSN (GPRS Support Nodes): GGSN and SGSN
- GGSN (Gateway GSN)
  - interworking unit between GPRS and PDN (Packet Data Network)
- SGSN (Serving GSN)
  - supports the MS (location, billing, security)
- GR (GPRS Register)
  - user addresses

GPRS quality of service

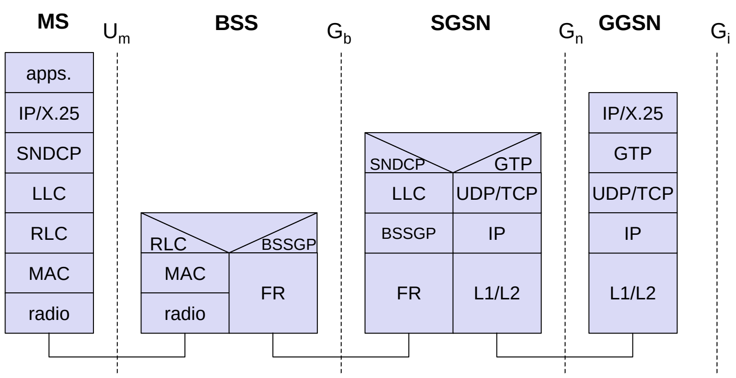
Reliability class	Lost SDU probability	Duplicate SDU probability	Out of sequence SDU probability	Corrupt SDU probability
1	10^{-9}	10^{-9}	10^{-9}	10^{-9}
2	10^{-4}	10^{-5}	10^{-5}	10^{-6}
3	10^{-2}	10^{-5}	10^{-5}	10^{-2}

Delay class	SDU size 128 byte		SDU size 1024 byte	
	mean	95 percentile	mean	95 percentile
1	< 0.5 s	< 1.5 s	< 2 s	< 7 s
2	< 5 s	< 25 s	< 15 s	< 75 s
3	< 50 s	< 250 s	< 75 s	< 375 s
4	unspecified			

GPRS architecture and interfaces



GPRS protocol architecture

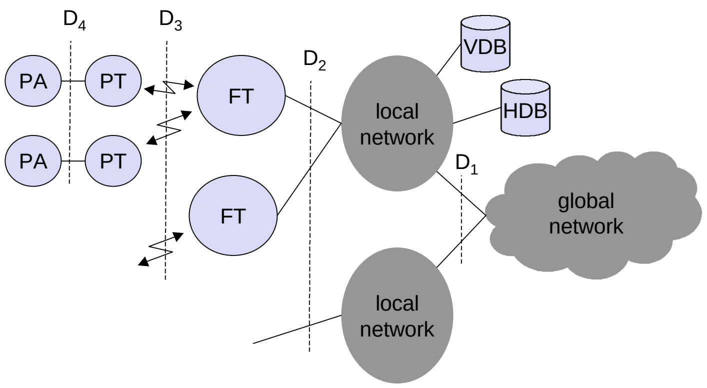


DECT

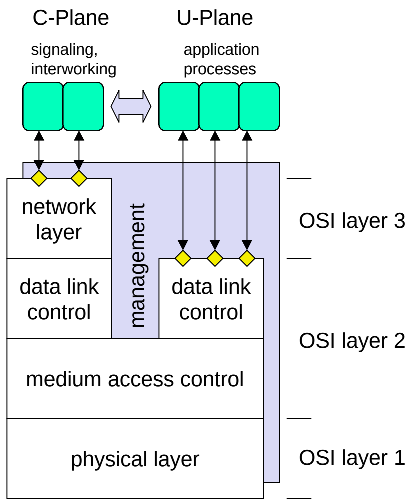
DECT (Digital European Cordless Telephone) standardized by ETSI (ETS 300.175-x) for cordless telephones

- 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
  - multplexing 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: ca 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

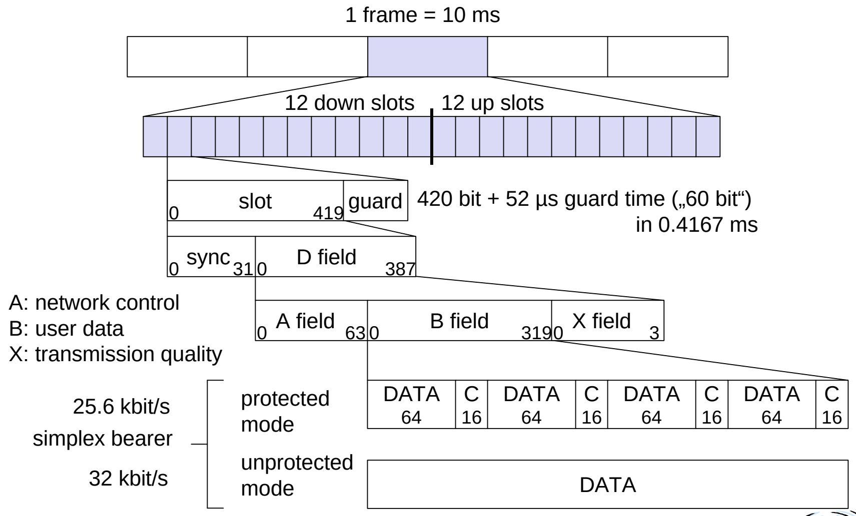
Mobile Communications: Wireless Telecommunication Systems 4.42.1

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

Mobile Communications: Wireless Telecommunication Systems 4.43.1

DECT time multiplex frame



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

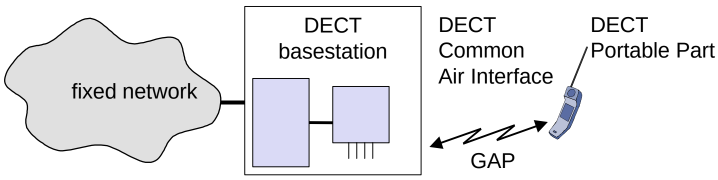
- Network layer
  - similar to ISDN (Q.931) and GSM (04.08)
  - offers services to request, check, reserve, control, and release resources at the basestation and mobile terminal
  - resources
    - necessary for a wireless connection
    - necessary for the connection of the DECT system to the fixed 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

Mobile Communications: Wireless Telecommunication Systems 4.46.2

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

Mobile Communications: Wireless Telecommunication Systems 4.47.1

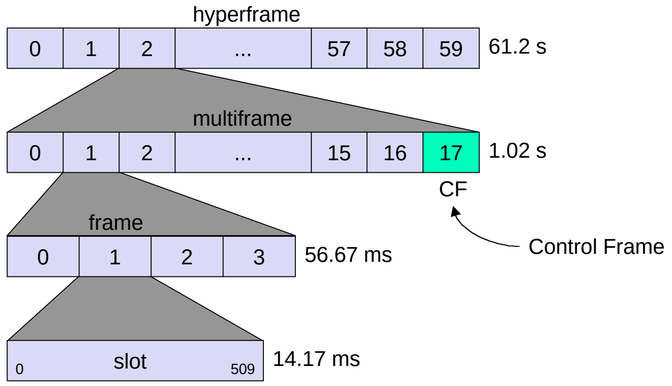
TETRA - Terrestrial Trunked Radio

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
- offers Voice+Data and Packet Data Optimized service
- point-to-point and point-to-multipoint
- ad-hoc and infrastructure networks
- several frequencies: 380-400 MHz, 410-430 MHz
- FDD, DQPSK
- group call, broadcast, sub-second group-call setup

Mobile Communications: Wireless Telecommunication Systems 4.48.1

TDMA structure of the voice+data system



Mobile Communications: Wireless Telecommunication Systems 4.49.1

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 (UMTS 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 city

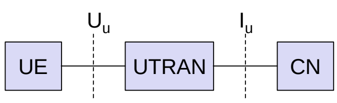
Mobile Communications: Wireless Telecommunication Systems 4.50.1

UMTS architecture

UTRAN (UTRA Network)
- cell level mobility
- Radio Network Subsystem (RNS)

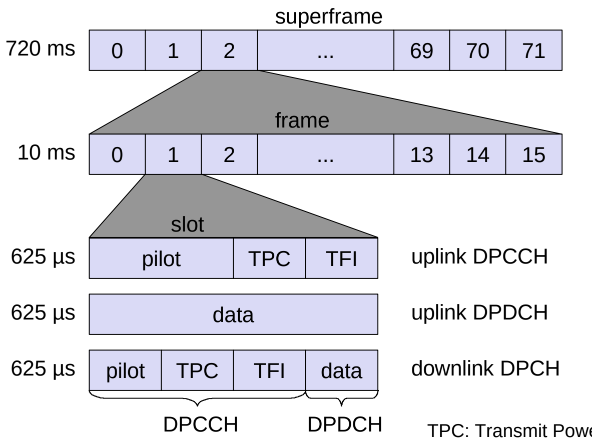
UE (User Equipment)

CN (Core Network)
- inter system handover



Mobile Communications: Wireless Telecommunication Systems 4.51.1

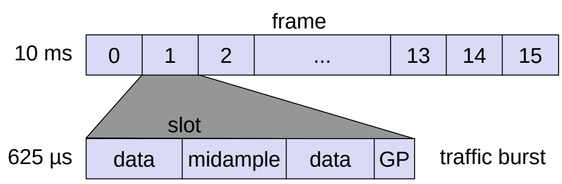
UMTS FDD frame structure



W-CDMA
- 1920-1980 MHz uplink
- 2110-2170 MHz downlink
- chipping rate:
  4.096 Mchip/s
- soft handover
- localization of
  MS (ca. 20 m precision)
- complex power control
  (1600 power control
  cycles/s)

TPC: Transmit Power Control
TFI: Transport Format Identifier
DPCCH: Dedicated Physical Control Channel
DPDCH: Dedicated Physical Data Channel
DPCH: Dedicated Physical Channel

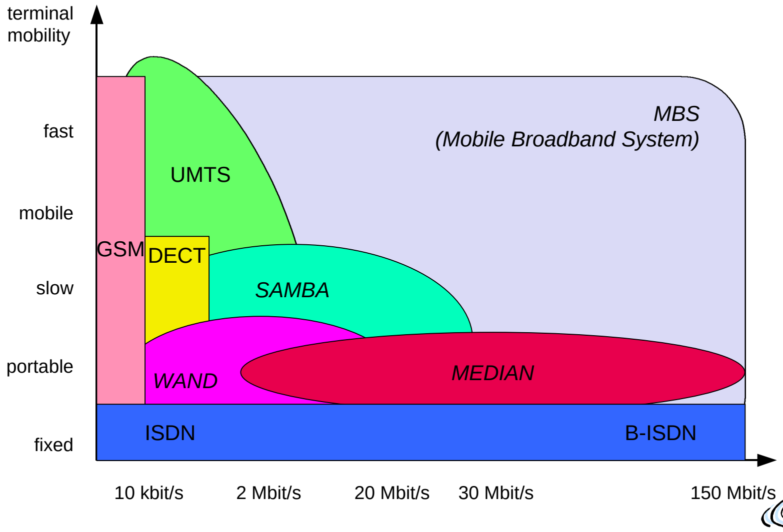
UMTS TDD frame structure



GP: Guard Period

W-TDMA/CDMA
- 2560 chips per slot
- symmetric or asymmetric
  slot assignment to up/downlink
- tight synchronization needed
- simpler power control
  (100-800 power control
  cycles/s)

Future mobile telecommunication networks



Mobile Communications
Chapter 5: Satellite Systems

- History
- Basics
- Localization
- Handover
- Routing
- Systems

5.0.1

History of satellite communication

1945	Arthur C. Clarke publishes an essay about „Extra Terrestrial Relays“
1957	first satellite SPUTNIK
1960	first reflecting communication satellite ECHO
1963	first geostationary satellite SYNCOM
1965	first commercial geostationary satellite Satellit „Early Bird“ (INTELSAT I): 240 duplex telephone channels or 1 TV channel, 1.5 years lifetime
1976	three MARISAT satellites for maritime communication
1982	first mobile satellite telephone system INMARSAT-A
1988	first satellite system for mobile phones and data communication INMARSAT-C
1993	first digital satellite telephone system
1998	global satellite systems for small mobile phones

Mobile Communications: Satellite Systems 5.1.1

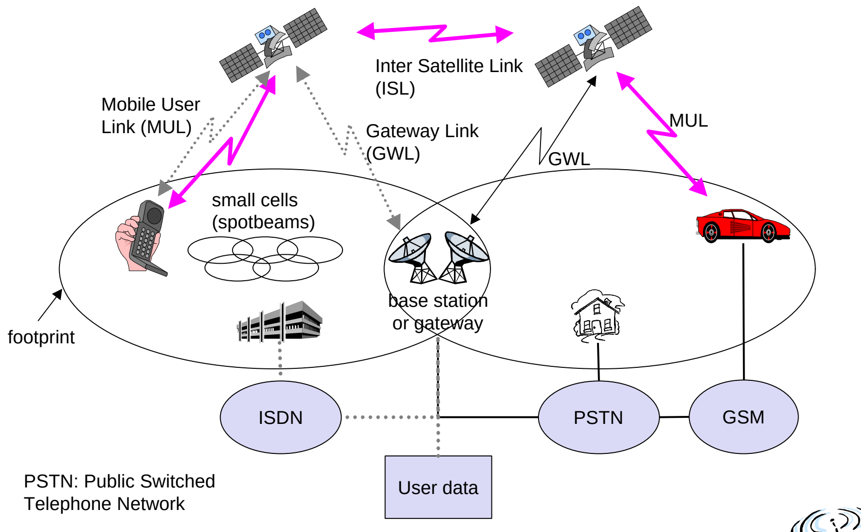
Applications

- Traditionally
  - weather satellites
  - radio and TV broadcast satellites
  - military satellites
  - satellites for navigation and localization (e.g., GPS)
- Telecommunication
  - global telephone connections } replaced by fiber optics
  - backbone for global networks }
  - connections for communication in remote places or underdeveloped areas
  - global mobile communication

➔ satellite systems to extend cellular phone systems (e.g., GSM or AMPS)

Mobile Communications: Satellite Systems 5.2.1

Typical satellite systems



Mobile Communications: Satellite Systems 5.3.1

Basics

Satellites in circular orbits

- attractive force $F_g = m\ g\ (R/r)^2$
- centrifugal force $F_c = m\ r\ \omega^2$
- m: mass of the satellite
- R: radius of the earth (R = 6370 km)
- r: distance to the center of the earth
- g: acceleration of gravity (g = 9.81 m/s²)
- ω: angular velocity (ω = 2 π f, f: rotation frequency)

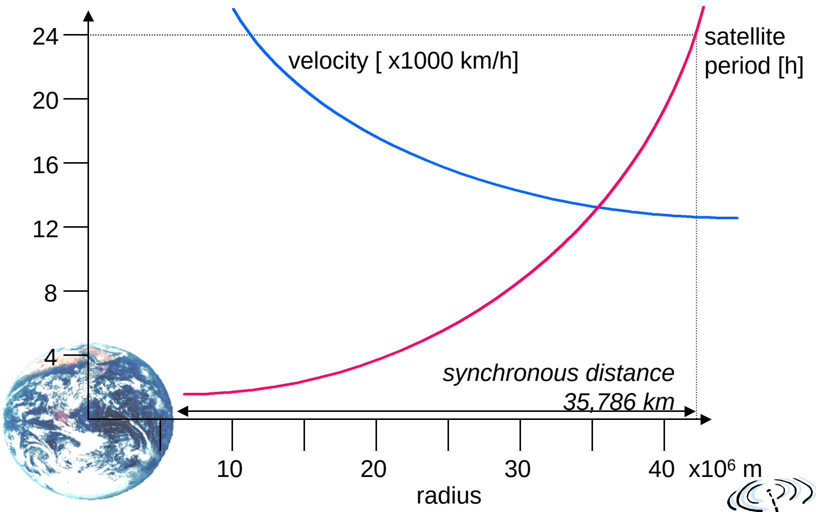
Stable orbit

- $F_g = F_c$

$$r = \sqrt[3]{\frac{gR^2}{(2p\ f)^2}}$$

Mobile Communications: Satellite Systems 5.4.1

Satellite period and orbits



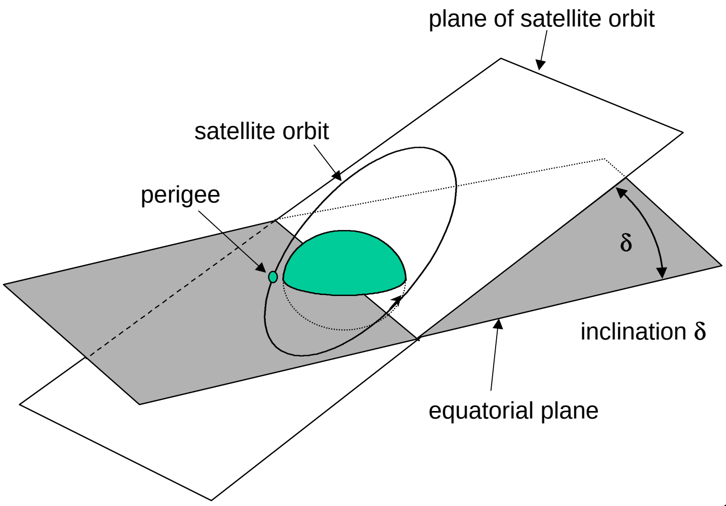
Mobile Communications: Satellite Systems 5.5.1

Basics

- elliptical or circular orbits
- complete rotation time depends on distance satellite-earth
- inclination: angle between orbit and equator
- elevation: angle between satellite and horizon
- LOS (Line of Sight) to the satellite necessary for connection
  - ➔ high elevation needed, less absorption due to e.g. buildings
- Uplink: connection base station - satellite
- Downlink: connection satellite - base station
- typically separated frequencies for uplink and downlink
  - transponder used for sending/receiving and shifting of frequencies
  - transparent transponder: only shift of frequencies
  - regenerative transponder: additionally signal regeneration

Mobile Communications: Satellite Systems 5.6.1

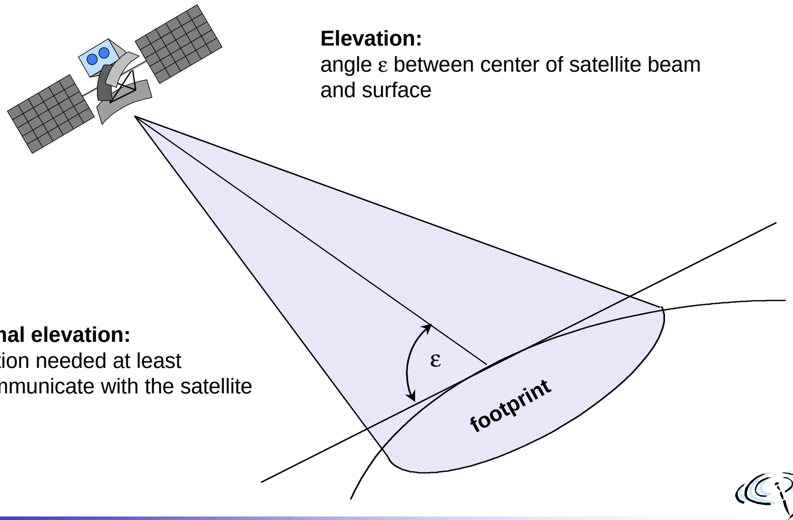
Inclination



Mobile Communications: Satellite Systems 5.7.1

Elevation

Elevation:
angle ε between center of satellite beam and surface



minimal elevation:
elevation needed at least to communicate with the satellite

Mobile Communications: Satellite Systems 5.8.1

Link budget of satellites

Parameters like attenuation or received power determined by four parameters:

- sending power
- gain of sending antenna
- distance between sender and receiver
- gain of receiving antenna

L: Loss
f: carrier frequency
r: distance
c: speed of light

$$L = \left(\frac{4\pi r f}{c}\right)^2$$

Problems

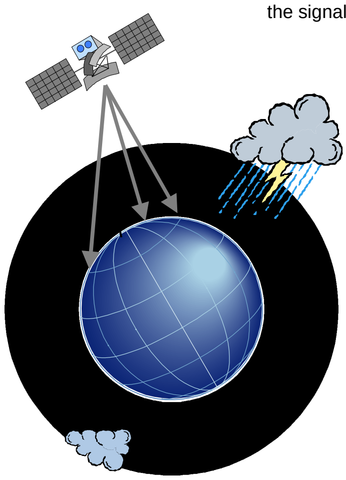
- varying strength of received signal due to multipath propagation
- interruptions due to shadowing of signal (no LOS)

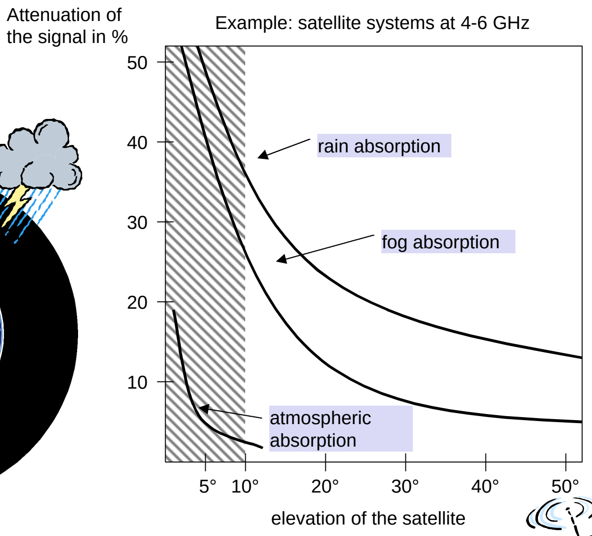
Possible solutions

- Link Margin to eliminate variations in signal strength
- satellite diversity (usage of several visible satellites at the same time) helps to use less sending power

Mobile Communications: Satellite Systems 5.9.1

Atmospheric attenuation



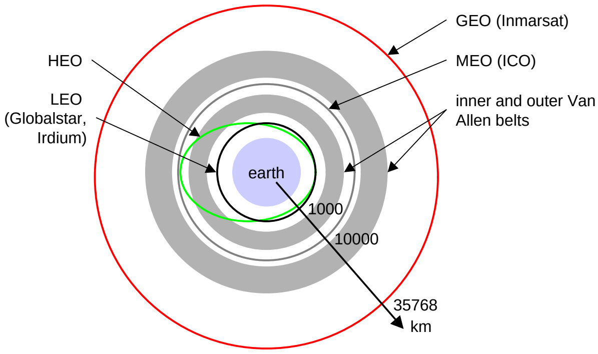


Orbits I

Four different types of satellite orbits can be identified depending on the shape and diameter of the orbit:

- GEO: geostationary orbit, ca. 36000 km above earth surface
- LEO (Low Earth Orbit): ca. 500 - 1500 km
- MEO (Medium Earth Orbit) or ICO (Intermediate Circular Orbit): ca. 6000 - 20000 km
- HEO (Highly Elliptical Orbit) elliptical orbits

Orbits II



Van-Allen-Belts:
ionized particels
2000 - 6000 km and
15000 - 30000 km
above earth surface

Mobile Communications: Satellite Systems 5.12.1

Geostationary satellites

Orbit 35.786 km distance to earth surface, orbit in equatorial plane (inclination 0°)

➔ complete rotation exactly one day, satellite is synchronous to earth rotation

- fix antenna positions, no adjusting necessary
- satellites typically have a large footprint (up to 34% of earth surface!), therefore difficult to reuse frequencies
- bad elevations in areas with latitude above 60° due to fixed position above the equator
- high transmit power needed
- high latency due to long distance (ca. 275 ms)

➔ not useful for global coverage for small mobile phones and data transmission, typically used for radio and TV transmission

Mobile Communications: Satellite Systems 5.13.1

LEO systems

Orbit ca. 500 - 1500 km above earth surface

- visibility of a satellite ca. 10 - 40 minutes
- global radio coverage possible
- latency comparable with terrestrial long distance connections, ca. 5 - 10 ms
- smaller footprints, better frequency reuse
- but now handover necessary from one satellite to another
- many satellites necessary for global coverage
- more complex systems due to moving satellites

Examples:

Iridium (start 1998, 66 satellites)

Globalstar (start 1999, 48 satellites)

MEO systems

Orbit ca. 5000 - 12000 km above earth surface

comparison with LEO systems:

- slower moving satellites
- less satellites needed
- simpler system design
- for many connections no hand-over needed
- higher latency, ca. 70 - 80 ms
- higher sending power needed
- special antennas for small footprints needed

Example:

ICO (Intermediate Circular Orbit, Inmarsat) start ca. 2000

Routing

One solution: inter satellite links (ISL)

- reduced number of gateways needed
- forward connections or data packets within the satellite network as long as possible
- only one uplink and one downlink per direction needed for the connection of two mobile phones

Problems:

- more complex focussing of antennas between satellites
- high system complexity due to moving routers
- higher fuel consumption
- thus shorter lifetime

Iridium and Teledesic planned with ISL

Other systems use gateways and additionally terrestrial networks

Localization of mobile stations

Mechanisms similar to GSM

Gateways maintain registers with user data

- HLR (Home Location Register): static user data
- VLR (Visitor Location Register): (last known) location of the mobile station
- SUMR (Satellite User Mapping Register):
  - satellite assigned to a mobile station
  - positions of all satellites

Registration of mobile stations

- Localization of the mobile station via the satellite's position
- requesting user data from HLR
- updating VLR and SUMR

Calling a mobile station

- localization using HLR/VLR similar to GSM
- connection setup using the appropriate satellite

Handover in satellite systems

Several additional situations for handover in satellite systems compared to cellular terrestrial mobile phone networks caused by the movement of the satellites

- Intra satellite handover
  - handover from one spot beam to another
  - mobile station still in the footprint of the satellite, but in another cell
- Inter satellite handover
  - handover from one satellite to another satellite
  - mobile station leaves the footprint of one satellite
- Gateway handover
  - Handover from one gateway to another
  - mobile station still in the footprint of a satellite, but gateway leaves the footprint
- Inter system handover
  - Handover from the satellite network to a terrestrial cellular network
  - mobile station can reach a terrestrial network again which might be cheaper, has a lower latency etc.

Overview of LEO/MEO systems

	Iridium	**Globalstar**	**ICO**	**Teledesic**
# satellites	66 + 6	48 + 4	10 + 2	288
altitude (km)	780	1414	10390	ca. 700
coverage	global	±70° latitude	global	global
min. elevation	8°	20°	20°	40°
frequencies [GHz (circa)]	1.6 MS 29.2 ↑ 19.5 ↓ 23.3 ISL	1.6 MS ↑ 2.5 MS ↓ 5.1 ↑ 6.9 ↓	2 MS ↑ 2.2 MS ↓ 5.2 ↑ 7 ↓	19 ↓ 28.8 ↑ 62 ISL
access method	FDMA/TDMA	CDMA	FDMA/TDMA	FDMA/TDMA
ISL	yes	no	no	yes
bit rate	2.4 kbit/s	9.6 kbit/s	4.8 kbit/s	64 Mbit/s ↓ 2/64 Mbit/s ↑
# channels	4000	2700	4500	2500
Lifetime [years]	5-8	7.5	12	10
cost estimation	4.4 B$	2.9 B$	4.5 B$	9 B$

Mobile Communications
Chapter 6: Broadcast Systems

- Unidirectional distribution systems
- DAB
  - architecture
- DVB
  - Container
  - High-speed Internet

Unidirectional distribution systems

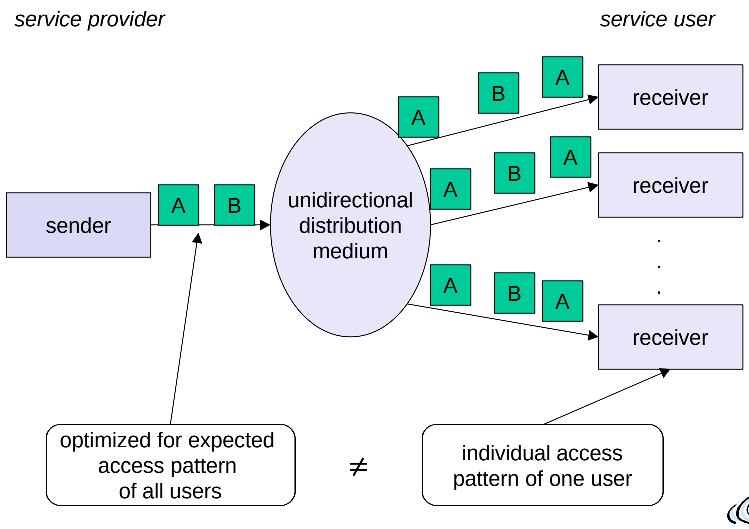
Asymmetric communication environments

- bandwidth limitations of the transmission medium
- depends on applications, type of information
- examples
  - wireless networks with basestation and mobile terminals
  - client-server environments (diskless terminal)
  - cable TV with set-top box
  - information services (pager, SMS)

Special case: unidirectional distribution systems

- high bandwidth from server to client (downstream), but no bandwidth viceversa (upstream)
- problems of unidirectional broadcast systems
  - a sender can optimize transmitted information only for one group of users/terminals
  - functions needed to individualize personal requirements/applications

Unidirectional distribution



Structuring transmissions - broadcast disks

Sender

- cyclic repetition of data blocks
- different patterns possible (optimization possible only if the content is known)

flat disk	A	B	C	A	B	C	•••
skewed disk	A	A	B	C	A	A	•••
multi-disk	A	B	A	C	A	B	•••

Receiver

- use of caching
  - cost-based strategy: what are the costs for a user (waiting time) if a data block has been requested but is currently not cached
  - application and cache have to know content of data blocks and access patterns of user to optimize

DAB: Digital Audio Broadcasting

- Media access
  - COFDM (Coded Orthogonal Frequency Division Multiplex)
  - SFN (Single Frequency Network)
  - 192 to 1536 subcarriers within a 1.5 MHz frequency band
- Frequencies
  - first phase: one out of 32 frequency blocks for terrestrial TV channels 5 to 12 (174 - 230 MHz, 5A - 12D)
  - second phase: one out of 9 frequency blocks in the L-band (1452- 1467.5 MHz, LA - LI)
- Sending power: 6.1 kW (VHF, Ø 120 km) or 4 kW (L-band, Ø 30 km)
- Date-rates: 2.304 Mbit/s (net 1.2 to 1.536 Mbit/s)
- Modulation: Differential 4-phase modulation (D-QPSK)
- Audio channels per frequency block: typ. 6, max. 192 kbit/s
- Digital services: 0.6 - 16 kbit/s (PAD), 24 kbit/s (NPAD)

Mobile Communications: Broadcast Systems 6.4.1

DAB transport mechanisms

MSC (Main Service Channel)
- carries all user data (audio, multimedia, ...)
- consists of CIF (Common Interleaved Frames)
- each CIF 55296 bit, every 24 ms (depends on transmission mode)
- CIF contains CU (Capacity Units), 64 bit each

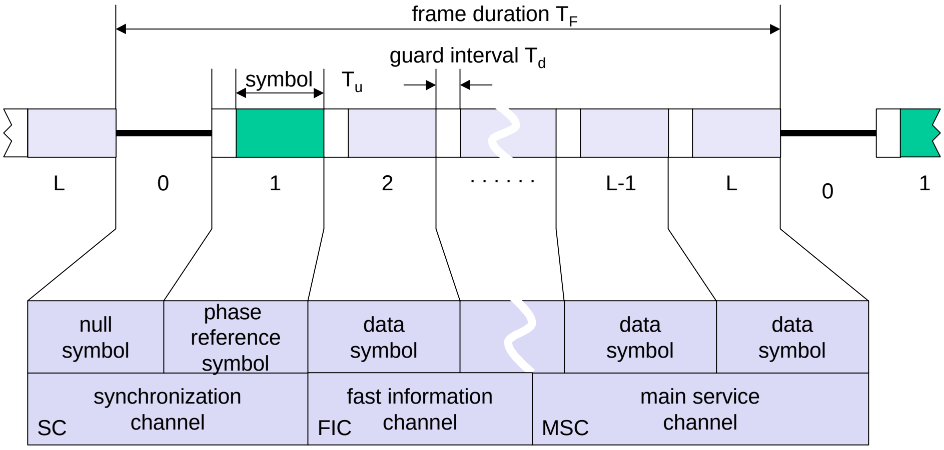
FIC (Fast Information Channel)
- carries control information
- consists of FIB (Fast Information Block)
- each FIB 256 bit (incl. 16 bit checksum)
- defines configuration and content of MSC

Stream mode
- transparent data transmission with a fixed bit rate

Packet mode
- transfer addressable packets

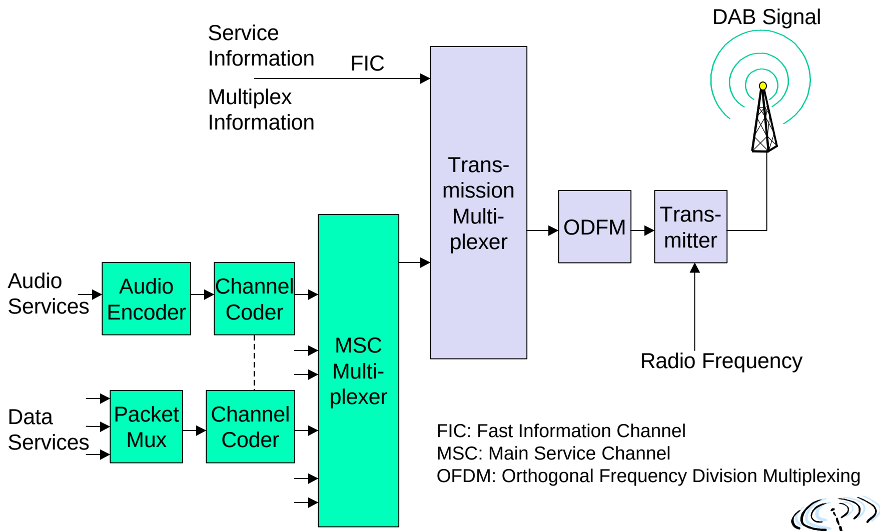
Mobile Communications: Broadcast Systems 6.5.1

Transmission frame



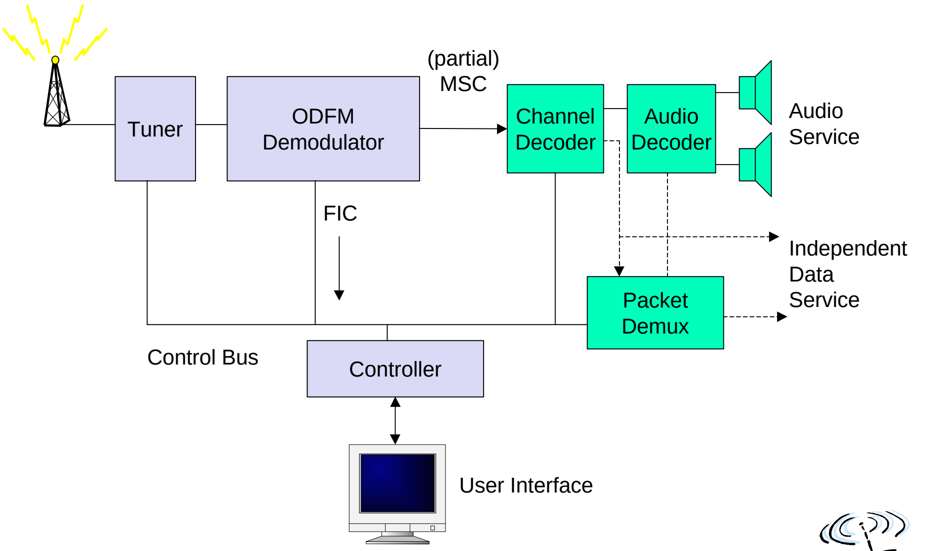
Mobile Communications: Broadcast Systems 6.6.1

DAB sender



Mobile Communications: Broadcast Systems 6.7.1

DAB receiver



Mobile Communications: Broadcast Systems 6.8.1

Audio coding

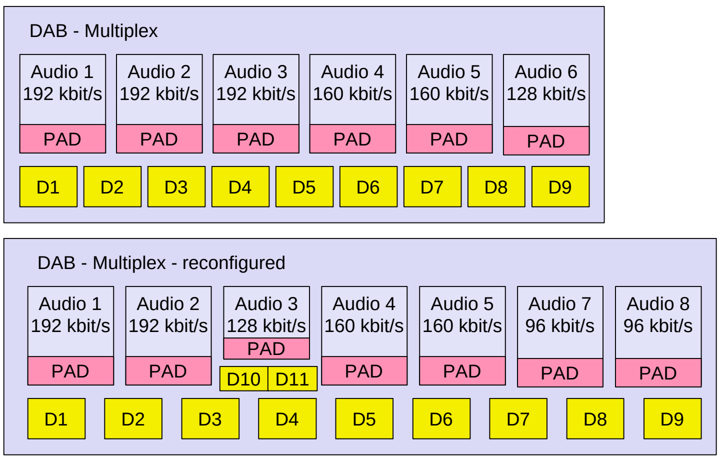
- Goal
  - audio transmission almost with CD quality
  - robust against multipath propagation
  - minimal distortion of audio signals during signal fading
- Mechanisms
  - fully digital audio signals (PCM, 16 Bit, 48 kHz, stereo)
  - MPEG compression of audio signals, compression ratio 1:10
  - redundancy bits for error detection and correction
  - burst errors typical for radio transmissions, therefore signal interleaving - receivers can now correct single bit errors resulting from interference
  - low symbol-rate, many symbols
    - transmission of digital data using long symbol sequences, separated by guard spaces
    - delayed symbols, e.g., reflection, still remain within the guard space

Mobile Communications: Broadcast Systems 6.9.1

Bit rate management

- a DAB ensemble combines audio programs and data services with different requirements for transmission quality and bit rates
- the standard allows dynamic reconfiguration of the DAB multiplexing scheme (i.e., during transmission)
- data rates can be variable, DAB can use free capacities for other services
- the multiplexer performs this kind of bit rate management, therefore, additional services can come from different providers

Example of a reconfiguration



Multimedia Object Transfer Protocol (MOT)

Problem

- broad range of receiver capabilities
  audio-only devices with single/multiple line text display, additional color graphic display, PC adapters etc.
- different types of receivers should at least be able to recognize all kinds of program associated and program independent data and process some of it

Solution

- common standard for data transmission: MOT
- important for MOT is the support of data formats used in other multimedia systems (e.g., online services, Internet, CD-ROM)
- DAB can therefore transmit HTML documents from the WWW with very little additional effort

MOT structure

MOT formats

- MHEG, Java, JPEG, ASCII, MPEG, HTML, HTTP, BMP, GIF, ...

Header core

- size of header and body, content type

Header extension

- handling information, e.g., repetition distance, segmentation, priority
- information supports caching mechanisms

Body

- arbitrary data

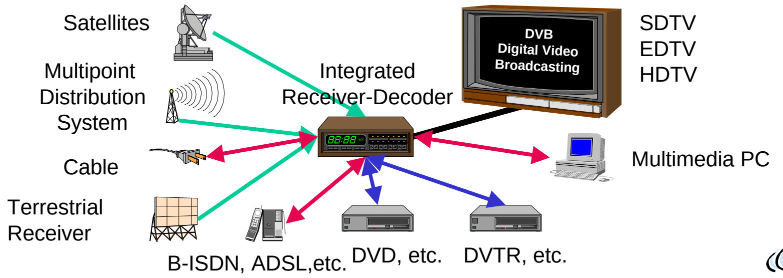
7 byte		
header core	header extension	body

DAB allows for many repetition schemes

- objects, segments, headers

Digital Video Broadcasting

- 1991 foundation of the ELG (European Launching Group)
  goal: development of digital television in Europe
- 1993 renaming into DVB (Digital Video Broadcasting)
  goal: introduction of digital television based on
  - satellite transmission
  - cable network technology
  - later also terrestrial transmission

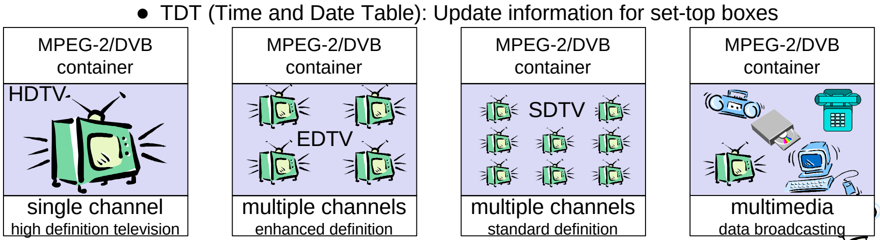


Mobile Communications: Broadcast Systems 6.14.1

DVB Container

DVB transmits MPEG-2 container

- high flexibility for the transmission of digital data
- no restrictions regarding the type of information
- DVB Service Information specifies the content of a container
  - NIT (Network Information Table): lists the services of a provider, contains additional information for set-top boxes
  - SDT (Service Description Table): list of names and parameters for each service within a MPEG multiplex channel
  - EIT (Event Information Table): status information about the current transmission, additional information for set-top boxes
  - TDT (Time and Date Table): Update information for set-top boxes

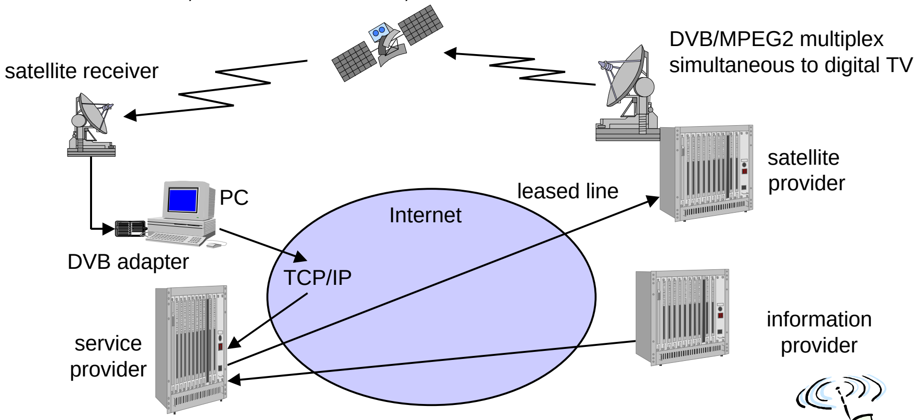


Mobile Communications: Broadcast Systems 6.15.1

Example: high-speed Internet

Asymmetric data exchange

- downlink: DVB receiver, data rate per user 6-38 Mbit/s
- return channel from user to service provider: e.g., modem with 33 kbit/s, ISDN with 64 kbit/s, ADSL with several 100 kbit/s etc.



Mobile Communications
Chapter 7: Wireless LANs

- Characteristics
- IEEE 802.11
  - PHY
  - MAC
  - Roaming
- HIPERLAN
  - Standards
  - PHY
  - MAC
  - Ad-hoc networks
- Bluetooth

Mobile Communications: Wireless LANs 7.0.1

Characteristics of wireless LANs

Advantages
- very flexible within the reception area
- Ad-hoc networks without previous planning possible
- (almost) no wiring difficulties (e.g. historic buildings, firewalls)
- more robust against disasters like, e.g., earthquakes, fire - or users pulling a plug...

Disadvantages
- typically very low bandwidth compared to wired networks (1-10 Mbit/s)
- many proprietary solutions, especially for higher bit-rates, standards take their time (e.g. IEEE 802.11)
- products have to follow many national restrictions if working wireless, it takes a vary long time to establish global solutions like, e.g., IMT-2000

Mobile Communications: Wireless LANs 7.1.1

Design goals for wireless LANs

- global, seamless operation
- low power for battery use
- no special permissions or licenses needed to use the LAN
- robust transmission technology
- simplified spontaneous cooperation at meetings
- easy to use for everyone, simple management
- protection of investment in wired networks
- security (no one should be able to read my data), privacy (no one should be able to collect user profiles), safety (low radiation)
- transparency concerning applications and higher layer protocols, but also location awareness if necessary

Comparison: infrared vs. radio transmission

Infrared
- uses IR diodes, diffuse light, multiple reflections (walls, furniture etc.)

Advantages
- simple, cheap, available in many mobile devices
- no licenses needed
- simple shielding possible

Disadvantages
- interference by sunlight, heat sources etc.
- many things shield or absorb IR light
- low bandwidth

Example
- IrDA (Infrared Data Association) interface available everywhere

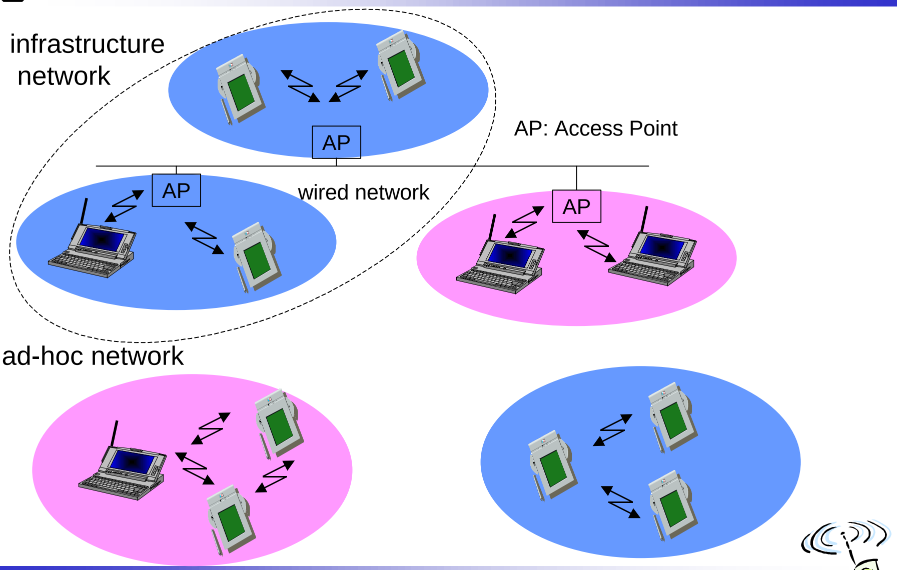
Radio
- typically using the license free ISM band at 2.4 GHz

Advantages
- experience from wireless WAN and mobile phones can be used
- coverage of larger areas possible (radio can penetrate walls, furniture etc.)

Disadvantages
- very limited license free frequency bands
- shielding more difficult, interference with other electrical devices

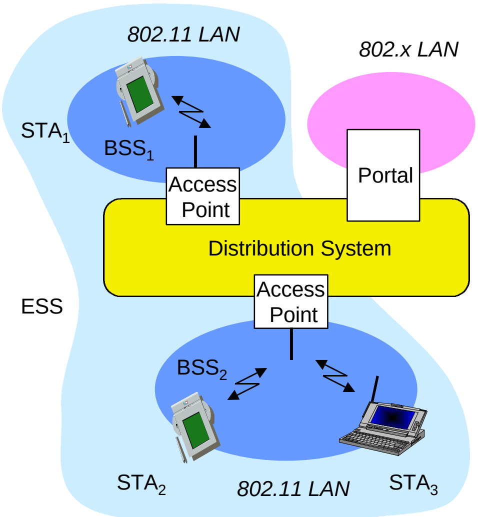
Example
- WaveLAN, HIPERLAN, Bluetooth

Comparison: infrastructure vs. ad-hoc networks



Mobile Communications: Wireless LANs 7.4.1

802.11 - Architecture of an infrastructure network



Station (STA)
- terminal with access mechanisms to the wireless medium and radio contact to the access point

Basic Service Set (BSS)
- group of stations using the same radio frequency

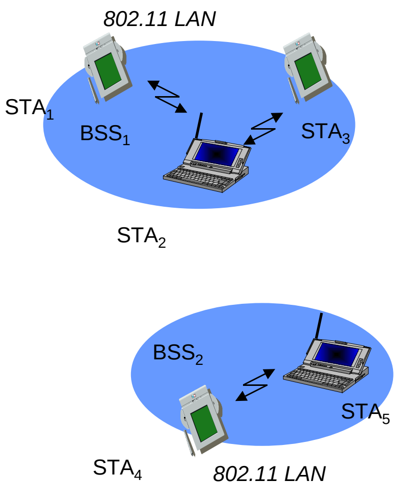
Access Point
- station integrated into the wireless LAN and the distribution system

Portal
- bridge to other (wired) networks

Distribution System
- interconnection network to form one logical network (EES: Extended Service Set) based on several BSS

Mobile Communications: Wireless LANs 7.5.1

802.11 - Architecture of an ad-hoc network

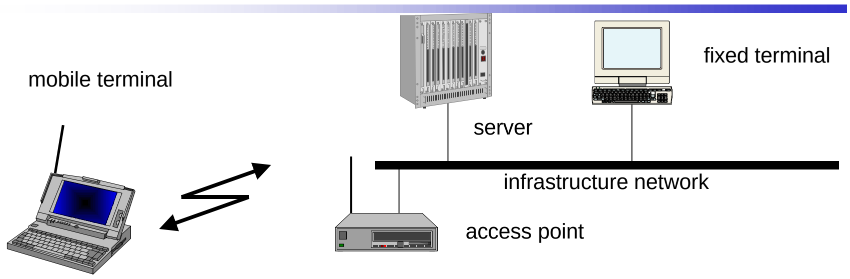


Direct communication within a limited range

- Station (STA):
  terminal with access mechanisms to the wireless medium
- Basic Service Set (BSS):
  group of stations using the same radio frequency

Mobile Communications: Wireless LANs 7.6.1

IEEE standard 802.11



Mobile terminal:

application
TCP
IP
LLC
802.11 MAC
802.11 PHY

Access point:

LLC	
802.11 MAC	802.3 MAC
802.11 PHY	802.3 PHY

Fixed terminal:

application
TCP
IP
LLC
802.3 MAC
802.3 PHY

Mobile Communications: Wireless LANs 7.7.1

802.11 - Layers and functions

MAC
- access mechanisms, fragmentation, encryption

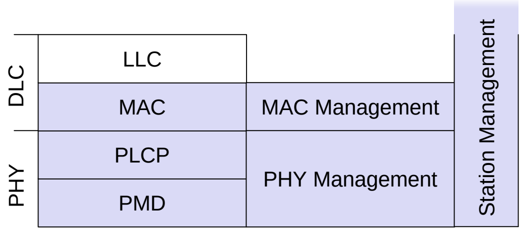
MAC Management
- synchronization, roaming, MIB, power management

PLCP Physical Layer Convergence Protocol
- clear channel assessment signal (carrier sense)

PMD Physical Medium Dependent
- modulation, coding

PHY Management
- channel selection, MIB

Station Management
- coordination of all management functions



802.11 - Physical layer

3 versions: 2 radio (typ. 2.4 GHz), 1 IR
- data rates 1 or 2 Mbit/s

FHSS (Frequency Hopping Spread Spectrum)
- spreading, despreading, signal strength, typ. 1 Mbit/s
- min. 2.5 frequency hops/s (USA), two-level GFSK modulation

DSSS (Direct Sequence Spread Spectrum)
- DBPSK modulation for 1 Mbit/s (Differential Binary Phase Shift Keying), DQPSK for 2 Mbit/s (Differential Quadrature PSK)
- preamble and header of a frame is always transmitted with 1 Mbit/s, rest of transmission 1 or 2 Mbit/s
- chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1 (Barker code)
- max. radiated power 1 W (USA), 100 mW (EU), min. 1mW

Infrared
- 850-950 nm, diffuse light, typ. 10 m range
- carrier detection, energy detection, synchonization

FHSS PHY packet format

Synchronization
- synch with 010101... pattern

SFD (Start Frame Delimiter)
- 0000110010111101 start pattern

PLW (PLCP_PDU Length Word)
- length of payload incl. 32 bit CRC of payload, PLW < 4096

PSF (PLCP Signaling Field)
- data of payload (1 or 2 Mbit/s)

HEC (Header Error Check)
- CRC with $x^{16}+x^{12}+x^5+1$

80	16	12	4	16	variable	bits
synchronization	SFD	PLW	PSF	HEC	payload	
PLCP preamble		PLCP header				

Mobile Communications: Wireless LANs 7.10.1

DSSS PHY packet format

Synchronization
- synch., gain setting, energy detection, frequency offset compensation

SFD (Start Frame Delimiter)
- 1111001110100000

Signal
- data rate of the payload (0A: 1 Mbit/s DBPSK; 14: 2 Mbit/s DQPSK)

Service
- future use, 00: 802.11 compliant

Length
- length of the payload

HEC (Header Error Check)
- protection of signal, service and length, $x^{16}+x^{12}+x^5+1$

128	16	8	8	16	16	variable	bits
synchronization	SFD	signal	service	length	HEC	payload	
PLCP preamble		PLCP header					

Mobile Communications: Wireless LANs 7.11.1

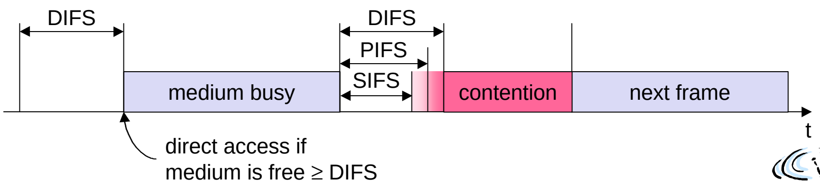
802.11 - MAC layer I - DFWMAC

Traffic services
- Asynchronous Data Service (mandatory)
  - exchange of data packets based on "best-effort"
  - support of broadcast and multicast
- Time-Bounded Service (optional)
  - implemented using PCF (Point Coordination Function)

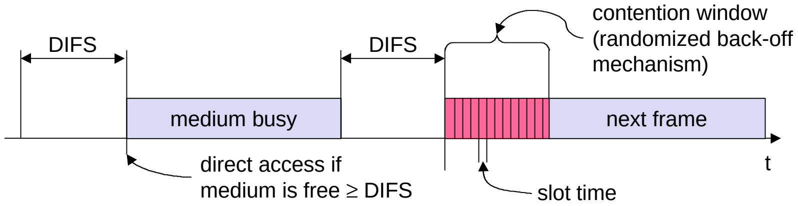
Access methods
- DFWMAC-DCF CSMA/CA (mandatory)
  - collision avoidance via randomized „back-off" mechanism
  - minimum distance between consecutive packets
  - ACK packet for acknowledgements (not for broadcasts)
- DFWMAC-DCF w/ RTS/CTS (optional)
  - Distributed Foundation Wireless MAC
  - avoids hidden terminal problem
- DFWMAC- PCF (optional)
  - access point polls terminals according to a list

802.11 - MAC layer II

Priorities
- defined through different inter frame spaces
- no guaranteed, hard priorities
- SIFS (Short Inter Frame Spacing)
  - highest priority, for ACK, CTS, polling response
- PIFS (PCF IFS)
  - medium priority, for time-bounded service using PCF
- DIFS (DCF, Distributed Coordination Function IFS)
  - lowest priority, for asynchronous data service



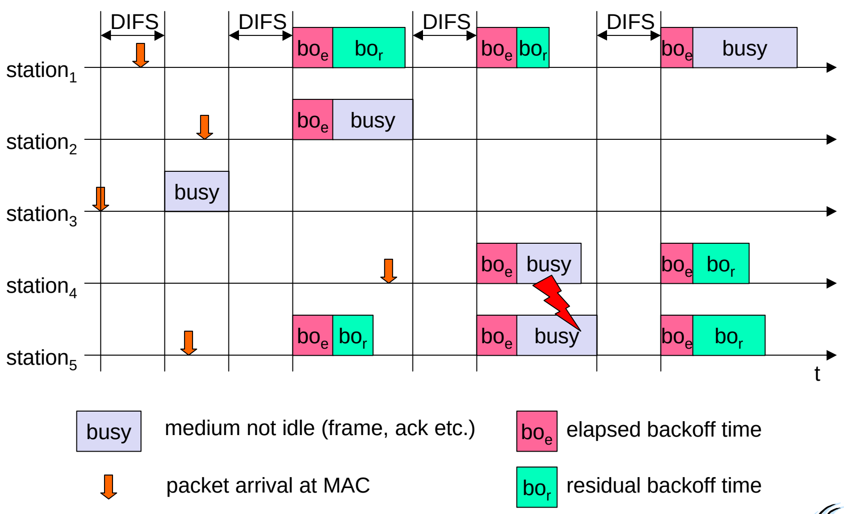
802.11 - CSMA/CA access method I



- station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- if the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending (IFS depends on service type)
- if the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
- if another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)

Mobile Communications: Wireless LANs 7.14.1

802.11 - competing stations - simple version

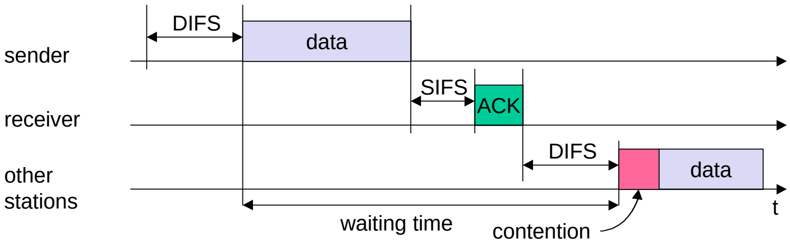


Mobile Communications: Wireless LANs 7.15.1

802.11 - CSMA/CA access method II

Sending unicast packets

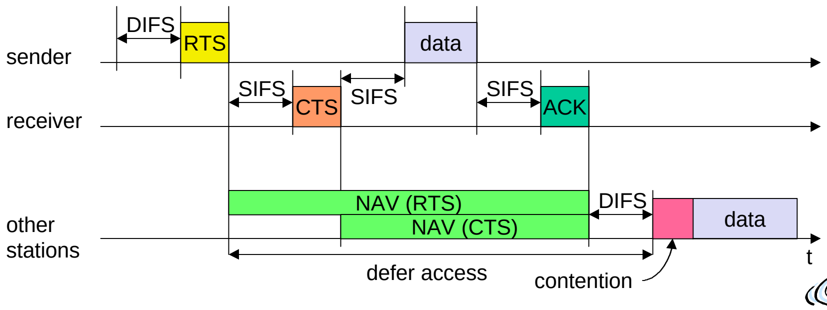
- station has to wait for DIFS before sending data
- receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
- automatic retransmission of data packets in case of transmission errors



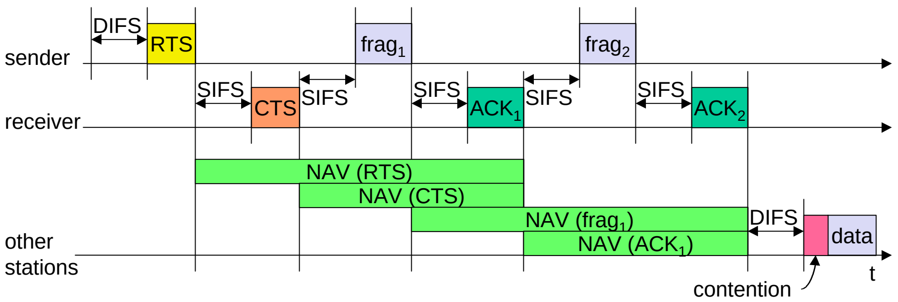
802.11 - DFWMAC

Sending unicast packets

- station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
- acknowledgement via CTS after SIFS by receiver (if ready to receive)
- sender can now send data at once, acknowledgement via ACK
- other stations store medium reservations distributed via RTS and CTS

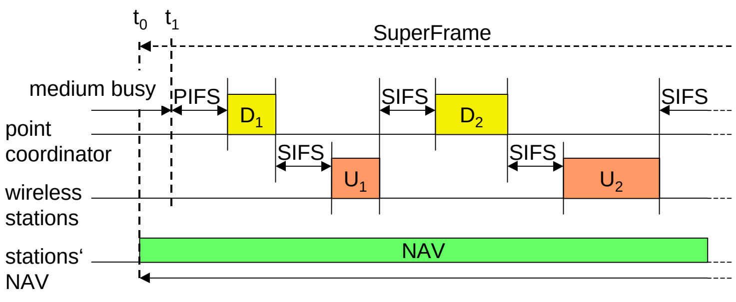


Fragmentation



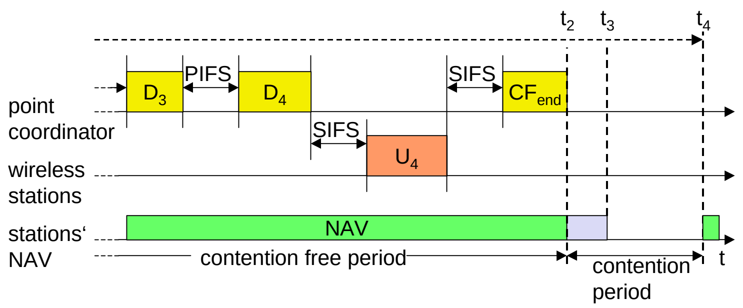
Mobile Communications: Wireless LANs 7.18.1

DFWMAC-PCF I



Mobile Communications: Wireless LANs 7.19.1

DFWMAC-PCF II



802.11 - Frame format

Types
- control frames, management frames, data frames

Sequence numbers
- important against duplicated frames due to lost ACKs

Addresses
- receiver, transmitter (physical), BSS identifier, sender (logical)

Miscellaneous
- sending time, checksum, frame control, data

bytes	2	2	6	6	6	2	6	0-2312	4
	Frame Control	Duration ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	Data	CRC

version, type, fragmentation, security, ...

MAC address format

scenario	to DS	from DS	address 1	address 2	address 3	address 4
ad-hoc network	0	0	DA	SA	BSSID	-
infrastructure network, from AP	0	1	DA	BSSID	SA	-
infrastructure network, to AP	1	0	BSSID	SA	DA	-
infrastructure network, within DS	1	1	RA	TA	DA	SA

DS: Distribution System
AP: Access Point
DA: Destination Address
SA: Source Address
BSSID: Basic Service Set Identifier
RA: Receiver Address
TA: Transmitter Address

802.11 - MAC management

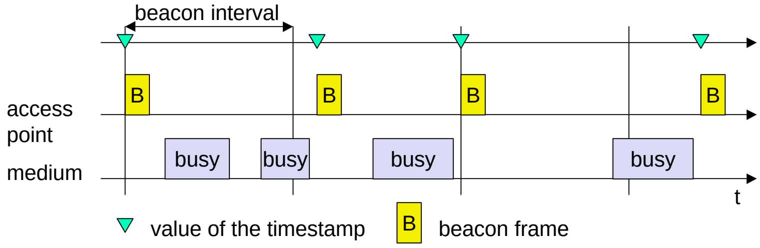
Synchronization
- try to find a LAN, try to stay within a LAN
- timer etc.

Power management
- sleep-mode without missing a message
- periodic sleep, frame buffering, traffic measurements

Association/Reassociation
- integration into a LAN
- roaming, i.e. change networks by changing access points
- scanning, i.e. active search for a network

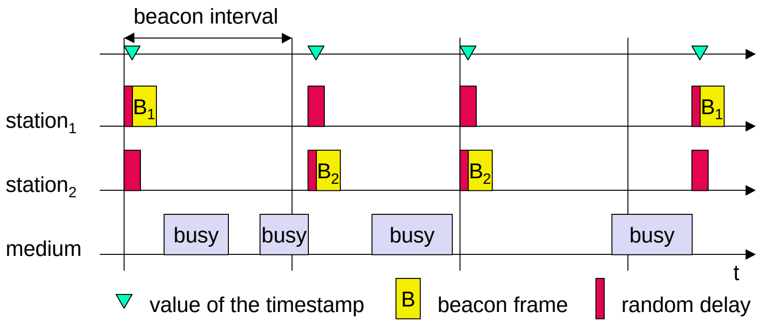
MIB - Management Information Base
- managing, read, write

Synchronization using a Beacon (infrastructure)



Mobile Communications: Wireless LANs 7.24.1

Synchronization using a Beacon (ad-hoc)



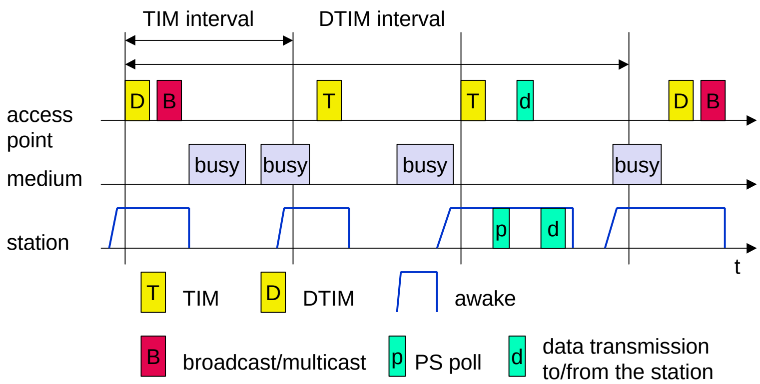
Mobile Communications: Wireless LANs 7.25.1

Power management

- Idea: switch the transceiver off if not needed
- States of a station: sleep and awake
- Timing Synchronization Function (TSF)
  - stations wake up at the same time
- Infrastructure
  - Traffic Indication Map (TIM)
    - list of unicast receivers transmitted by AP
  - Delivery Traffic Indication Map (DTIM)
    - list of broadcast/multicast receivers transmitted by AP
- Ad-hoc
  - Ad-hoc Traffic Indication Map (ATIM)
    - announcement of receivers by stations buffering frames
    - more complicated - no central AP
    - collision of ATIMs possible (scalability?)

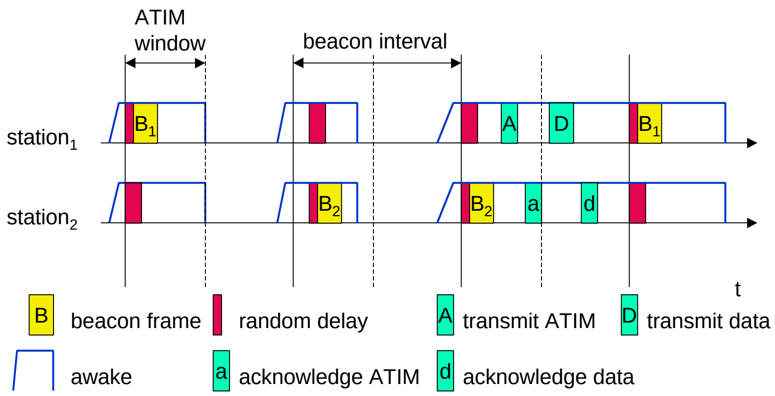
Mobile Communications: Wireless LANs 7.26.1

Power saving with wake-up patterns (infrastructure)



Mobile Communications: Wireless LANs 7.27.1

Power saving with wake-up patterns (ad-hoc)



802.11 - Roaming

No or bad connection? Then perform:

Scanning
- scan the environment, i.e., listen into the medium for beacon signals or send probes into the medium and wait for an answer

Reassociation Request
- station sends a request to one or several AP(s)

Reassociation Response
- success: AP has answered, station can now participate
- failure: continue scanning

AP accepts Reassociation Request
- signal the new station to the distribution system
- the distribution system updates its data base (i.e., location information)
- typically, the distribution system now informs the old AP so it can release resources

Future developments

IEEE 802.11a

- compatible MAC, but now 5 GHz band
- transmission rates up to 20 Mbit/s
- close cooperation with BRAN (ETSI Broadband Radio Access Network)

IEEE 802.11b

- higher data rates at 2.4 GHz
- proprietary solutions already offer 10 Mbit/s

IEEE WPAN (Wireless Personal Area Networks)

- market potential
- compatibility
- low cost/power, small form factor
- technical/economic feasibility
  ➔ Bluetooth

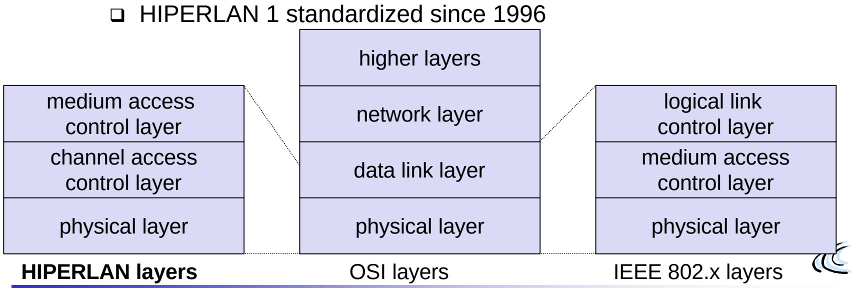
ETSI - HIPERLAN

ETSI standard

- European standard, cf. GSM, DECT, ...
- Enhancement of local Networks and interworking with fixed networks
- integration of time-sensitive services from the early beginning

HIPERLAN family

- one standard cannot satisfy all requirements
  - range, bandwidth, QoS support
  - commercial constraints
- HIPERLAN 1 standardized since 1996



Overview: original HIPERLAN protocol family

	HIPERLAN 1	HIPERLAN 2	HIPERLAN 3	HIPERLAN 4
Application	wireless LAN	access to ATM fixed networks	wireless local loop	point-to-point wireless ATM connections
Frequency	5.1-5.3GHz			17.2-17.3GHz
Topology	decentralized ad-hoc/infrastructure	cellular, centralized	point-to-multipoint	point-to-point
Antenna	omni-directional		directional	
Range	50 m	50-100 m	5000 m	150 m
QoS	statistical	ATM traffic classes (VBR, CBR, ABR, UBR)		
Mobility	<10m/s		stationary	
Interface	conventional LAN	ATM networks		
Data rate	23.5 Mbit/s	>20 Mbit/s		155 Mbit/s
Power conservation	yes		not necessary	

Check out Wireless ATM for new names!

Mobile Communications: Wireless LANs 7.32.1

HIPERLAN 1 - Characteristics

Data transmission
- point-to-point, point-to-multipoint, connectionless
- 23.5 Mbit/s, 1 W power, 2383 byte max. packet size

Services
- asynchronous and time-bounded services with hierarchical priorities
- compatible with ISO MAC

Topology
- infrastructure or ad-hoc networks
- transmission range can be larger then coverage of a single node („forwarding" integrated in mobile terminals)

Further mechanisms
- power saving, encryption, checksums

Mobile Communications: Wireless LANs 7.33.1

HIPERLAN 1 - Services and protocols

CAC service
- definition of communication services over a shared medium
- specification of access priorities
- abstraction of media characteristics

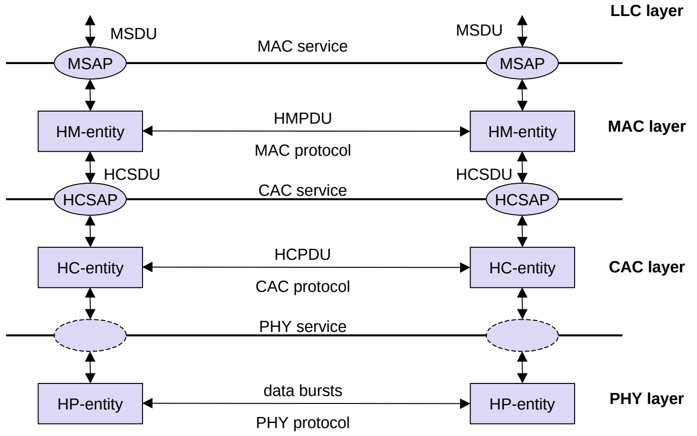
MAC protocol
- MAC service, compatible with ISO MAC and ISO MAC bridges
- uses HIPERLAN CAC

CAC protocol
- provides a CAC service, uses the PHY layer, specifies hierarchical access mechanisms for one or several channels

Physical protocol
- send and receive mechanisms, synchronization, FEC, modulation, signal strength

Mobile Communications: Wireless LANs 7.34.1

HIPERLAN layers, services, and protocols



Mobile Communications: Wireless LANs 7.35.1

HIPERLAN 1 - Physical layer

Scope
- modulation, demodulation, bit and frame synchronization
- forward error correction mechanisms
- measurements of signal strength
- channel sensing

Channels
- 3 mandatory and 2 optional channels (with their carrier frequencies)
- mandatory
  - channel 0: 5.1764680 GHz
  - channel 1: 5.1999974 GHz
  - channel 2: 5.2235268 GHz
- optional (not allowed in all countries)
  - channel 3: 5.2470562 GHz
  - channel 4: 5.2705856 GHz

HIPERLAN 1 - Physical layer frames

Maintaining a high data-rate (23.5 Mbit/s) is power consuming - problematic for mobile terminals
- packet header with low bit-rate comprising receiver information
- only receiver(s) address by a packet continue receiving

Frame structure
- LBR (Low Bit-Rate) header with 1.4 Mbit/s
- 450 bit synchronization
- minimum 1, maximum 47 frames with 496 bit each
- for higher velocities of the mobile terminal (> 1.4 m/s) the maximum number of frames has to be reduced

	HBR				
LBR	synchronization	$data_0$	$data_1$	. . .	$data_{m-1}$

Modulation
- GMSK for high bit-rate, FSK for LBR header

HIPERLAN 1 - CAC sublayer

Channel Access Control (CAC)

- assure that terminal does not access forbidden channels
- priority scheme, access with EY-NPMA

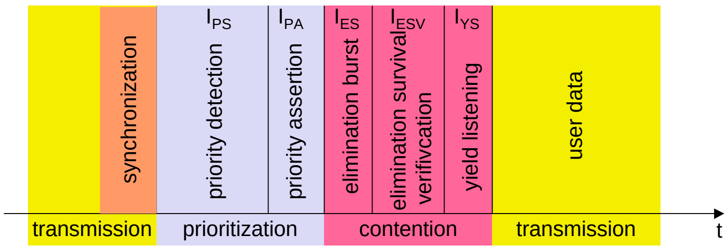
Priorities

- 5 priority levels for QoS support
- QoS is mapped onto a priority level with the help of the packet lifetime (set by an application)
  - if packet lifetime = 0 it makes no sense to forward the packet to the receiver any longer
  - standard start value 500ms, maximum 16000ms
  - if a terminal cannot send the packet due to its current priority, waiting time is permanently subtracted from lifetime
  - based on packet lifetime, waiting time in a sender and number of hops to the receiver, the packet is assigned to one out of five priorities
  - the priority of waiting packets, therefore, rises automatically

HIPERLAN 1 - EY-NPMA I

EY-NPMA (Elimination Yield Non-preemptive Priority Multiple Access)

- 3 phases: priority resolution, contention resolution, transmission
- finding the highest priority
  - every priority corresponds to a time-slot to send in the first phase, the higher the priority the earlier the time-slot to send
  - higher priorities can not be preempted
  - if an earlier time-slot for a higher priority remains empty, stations with the next lower priority might send
  - after this first phase the highest current priority has been determined



HIPERLAN 1 - EY-NPMA II

Several terminals can now have the same priority and wish to send

- contention phase
  - Elimination Burst: all remaining terminals send a burst to eliminate contenders (11111010100010011100000110010110, high bit- rate)
  - Elimination Survival Verification: contenders now sense the channel, if the channel is free they can continue, otherwise they have been eliminated
  - Yield Listening: contenders again listen in slots with a nonzero probability, if the terminal senses its slot idle it is free to transmit at the end of the contention phase
  - the important part is now to set the parameters for burst duration and channel sensing (slot-based, exponentially distributed)
- data transmission
  - the winner can now send its data (however, a small chance of collision remains)
  - if the channel was idle for a longer time (min. for a duration of 1700 bit) a terminal can send at once without using EY-NPMA
- synchronization using the last data transmission

HIPERLAN 1 - DT-HCPDU/AK-HCPDU

LBR

0	1	2	3	4	5	6	7 (bit)
1	0	1	0	1	0	1	0
0	1	HI	HDA				
HDA				HDACS			
BLIR = n						BL-	
IRCS			1				

HBR

bit 0–7	byte
TI | BLI = n	1
PLI = m	2
HID	3 - 6
DA	7 - 12
SA	13 - 18
UD	19 - (52n-m-4)
PAD	(52n-m-3) - (52n-4)
CS	(52n-3) - 52n

Data HCPDU

LBR

0	1	2	3	4	5	6	7 (bit)
1	0	1	0	1	0	1	0
0	1	HI	AID				
AID			AIDCS				

Acknowledgement HCPDU

HI: HBR-part Indicator
HDA: Hashed Destination HCSAP Address
HDACS: HDA CheckSum
BLIR: Block Length Indicator
BLIRCS: BLIR CheckSum
TI: Type Indicator
BLI: Block Length Indicator
HID: HIPERLAN IDentifier
DA: Destination Address
SA: Source Address
UD: User Data (1-2422 byte)
PAD: PADding
CS: CheckSum
AID: Acknowledgement IDentifier
AIDS: AID CheckSum

HIPERLAN 1 - MAC layer

Compatible to ISO MAC

Supports time-bounded services via a priority scheme

Packet forwarding

- support of directed (point-to-point) forwarding and broadcast forwarding (if no path information is available)
- support of QoS while forwarding

Encryption mechanisms

- mechanisms integrated, but without key management

Power conservation mechanisms

- mobile terminals can agree upon awake patterns (e.g., periodic wake-ups to receive data)
- additionally, some nodes in the networks must be able to buffer data for sleeping terminals and to forward them at the right time (so called stores)

HIPERLAN 1 - DT-HMPDU

bit 0 1 2 3 4 5 6 7	byte
LI = n	1 - 2
TI = 1	3
RL	4 - 5
PSN	6 - 7
DA	8 - 13
SA	14 - 19
ADA	20 - 25
ASA	26 - 31
UP / ML	32
ML	33
KID / IV	34
IV	35 - 37
UD	38 - (n-2)
SC	(n-1) - n

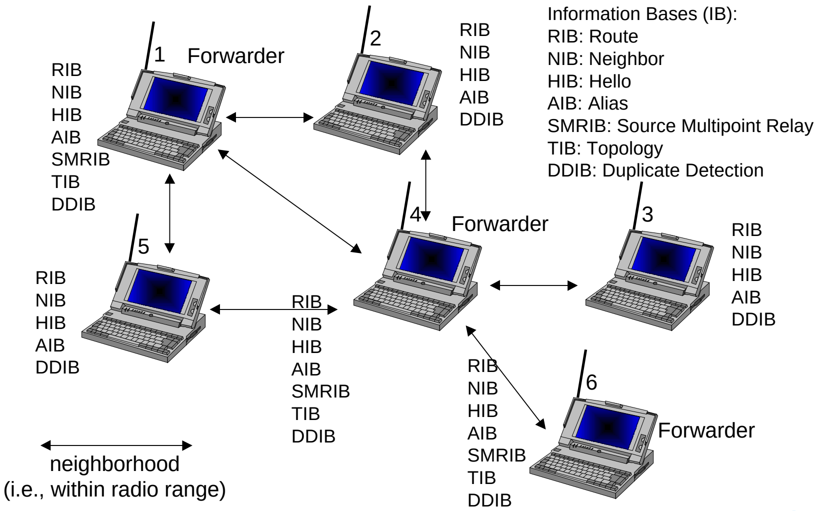
Data HMPDU n= 40–2422

LI: Length Indicator
TI: Type Indicator
RL: Residual Lifetime
PSN: Sequence Number
DA: Destination Address
SA: Source Address
ADA: Alias Destination Address
ASA: Alias Source Address
UP: User Priority
ML: MSDU Lifetime
KID: Key Identifier
IV: Initialization Vector
UD: User Data, 1–2383 byte
SC: Sanity Check (for the unencrypted PDU)

Information bases

- Route Information Base (RIB) - how to reach a destination
  - [destination, next hop, distance]
- Neighbor Information Base (NIB) - status of direct neighbors
  - [neighbor, status]
- Hello Information Base (HIB) - status of destination (via next hop)
  - [destination, status, next hop]
- Alias Information Base (AIB) - address of nodes outside the net
  - [original MSAP address, alias MSAP address]
- Source Multipoint Relay Information Base (SMRIB) - current MP status
  - [local multipoint forwarder, multipoint relay set]
- Topology Information Base (TIB) - current HIPERLAN topology
  - [destination, forwarder, sequence]
- Duplicate Detection Information Base (DDIB) - remove duplicates
  - [source, sequence]

Ad-hoc networks using HIPERLAN 1



Bluetooth

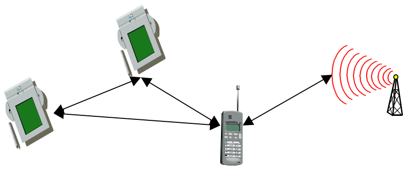
Consortium: Ericsson, Intel, IBM, Nokia, Toshiba - many members

Scenarios

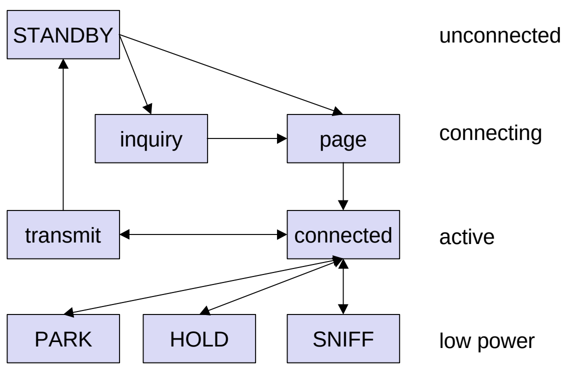
- connection of peripheral devices
  - loudspeaker, joystick, headset
- support of ad-hoc networking
  - small devices, low-cost
- bridging of networks
  - e.g., GSM via mobile phone - Bluetooth - laptop

Simple, cheap, replacement of IrDA, low range, lower data rates

- 2.4 GHz, FHSS, TDD, CDMA



States of a Bluetooth device (PHY layer)



Bluetooth MAC layer

Synchronous Connection-Oriented link (SCO)
- symmetrical, circuit switched, point-to-point

Asynchronous Connectionless Link (ACL)
- packet switched, point-to-multipoint, master polls

Access code
- synchronization, derived from master, unique per channel

Packet header
- 1/3-FEC, MAC address (1 master, 7 slaves), link type, alternating bit ARQ/SEQ, checksum

72	54	0-2745	bits
access code	packet header	payload	

3	4	1	1	1	8	bits
MAC address	type	flow	ARQN	SEQN	HEC	

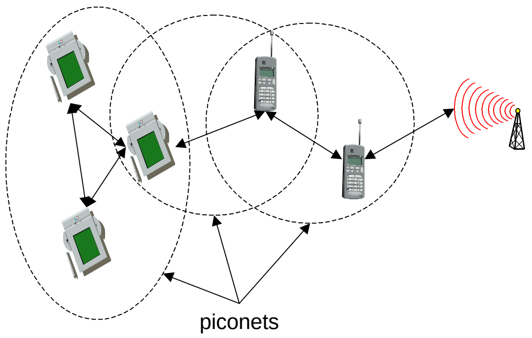
Scatternets

Each piconet has one master and up to 7 slaves

Master determines hopping sequence, slaves have to synchronize

Participation in a piconet = synchronization to hopping sequence

Communication between piconets = devices jumping back and forth between the piconets



Mobile Communications
Chapter 8: Wireless ATM

- ATM
  - Basic principle
  - B-ISDN
  - Protocols
  - Adaptation layer
- Wireless ATM
  - Reference model
- Enhanced functionality
- Architecture
  - Radio Access Layer
  - BRAN
- Handover
- Addressing
- QoS

Mobile Communications: Wireless ATM 8.0.1

Why wireless ATM?

- seamless connection to wired ATM, a integrated services high-performance network supporting different types a traffic streams
- ATM networks scale well: private and corporate LANs, WAN
- B-ISDN uses ATM as backbone infrastructure and integrates several different services in one universal system
- mobile phones and mobile communications have an ever increasing importance in everyday life
- current wireless LANs do not offer adequate support for multimedia data streams
- merging mobile communication and ATM leads to wireless ATM from a telecommunication provider point of view
- goal: seamless integration of mobility into B-ISDN

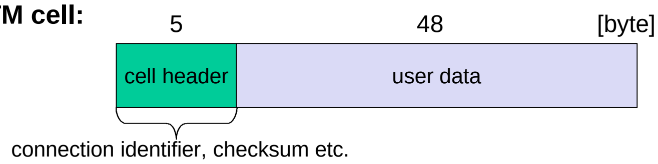
Problem: high complexity of the system

Mobile Communications: Wireless ATM 8.1.1

ATM - basic principle

- favored by the telecommunication industry for advanced high-performance networks, e.g., B-ISDN, as transport mechanism
- statistical (asynchronous, on demand) TDM (ATDM, STDM)
- cell header determines the connection the user data belongs to
- mixing of different cell-rates is possible
  - ➜ different bit-rates, constant or variable, feasible
- interesting for data sources with varying bit-rate:
  - e.g., guaranteed minimum bit-rate
  - additionally bursty traffic if allowed by the network

ATM cell:



Mobile Communications: Wireless ATM 8.2.1

Cell-based transmission

- asynchronous, cell-based transmission as basis for ATM
- continuous cell-stream
- additional cells necessary for operation and maintenance of the network (OAM cells; Operation and Maintenance)
- OAM cells can be inserted after fixed intervals to create a logical frame structure
- if a station has no data to send it automatically inserts idle cells that can be discarded at every intermediate system without further notice
- if no synchronous frame is available for the transport of cells (e.g., SDH or Sonet) cell boundaries have to be detected separately (e.g., via the checksum in the cell header)

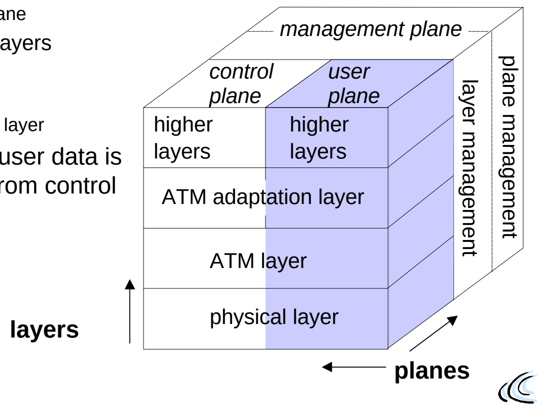
Mobile Communications: Wireless ATM 8.3.1

B-ISDN protocol reference model

3 dimensional reference model

- three vertical planes (columns)
  - user plane
  - control plane
  - management plane
- three hierarchical layers
  - physical layer
  - ATM layer
  - ATM adaptation layer

Out-of-Band-Signaling: user data is transmitted separately from control information



ATM layers

Physical layer, consisting of two sub-layers

- physical medium dependent sub-layer
  - coding
  - bit timing
  - transmission
- transmission convergence sub-layer
  - HEC (Header Error Correction) sequence generation and verification
  - transmission frame adaptation, generation, and recovery
  - cell delineation, cell rate decoupling

ATM layer

- cell multiplexing/demultiplexing
- VPI/VCI translation
- cell header generation and verification
- GFC (Generic Flow Control)

ATM adaptation layer (AAL)

ATM adaptation layer (AAL)

Provides different service classes on top of ATM based on:

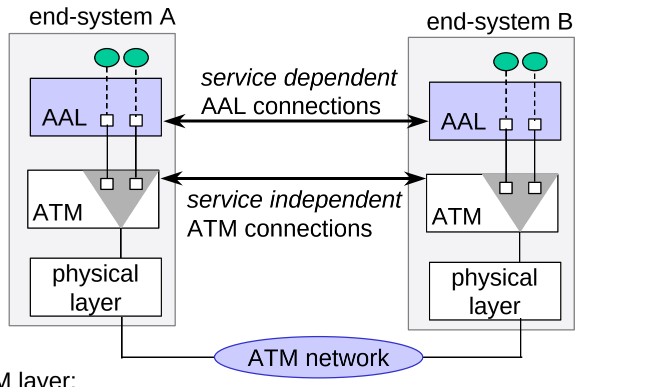
- bit rate:
  - constant bit rate: e.g. traditional telephone line
  - variable bit rate: e.g. data communication, compressed video
- time constraints between sender and receiver:
  - with time constraints: e.g. real-time applications, interactive voice and video
  - without time constraints: e.g. mail, file transfer
- mode of connection:
  - connection oriented or connectionless

AAL consists of two sub-layers:

- Convergence Sublayer (CS): service dependent adaptation
  - Common Part Convergence Sublayer (CPCS)
  - Service Specific Convergence Sublayer (SSCS)
- Segmentation and Reassembly Sublayer (SAR)
- sub-layers can be empty

Mobile Communications: Wireless ATM 8.6.1

ATM and AAL connections



- ATM layer:
  - service independent transport of ATM cells
  - multiplex and demultiplex functionality
- AAL layer: support of different services

Mobile Communications: Wireless ATM 8.7.1

ATM Forum Wireless ATM Working Group

- ATM Forum founded the *Wireless ATM Working Group* June 1996
- Task: development of specifications to enable the use of ATM technology also for wireless networks with a large coverage of current network scenarios (private and public, local and global)
- compatibility to existing ATM Forum standards important
- it should be possible to easily upgrade existing ATM networks with mobility functions and radio access
- two sub-groups of work items

Radio Access Layer (RAL) Protocols
- radio access layer
- wireless media access control
- wireless data link control
- radio resource control
- handover issues

Mobile ATM Protocol Extensions
- handover signaling
- location management
- mobile routing
- traffic and QoS Control
- network management

WATM services

Office environment
- multimedia conferencing, online multimedia database access

Universities, schools, training centers
- distance learning, teaching

Industry
- database connection, surveillance, real-time factory management

Hospitals
- reliable, high-bandwidth network, medical images, remote monitoring

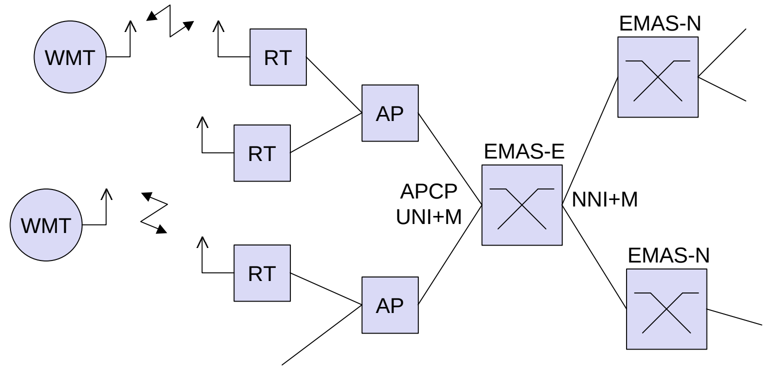
Home
- high-bandwidth interconnect of devices (TV, CD, PC, ...)

Networked vehicles
- trucks, aircraft etc. interconnect, platooning, intelligent roads

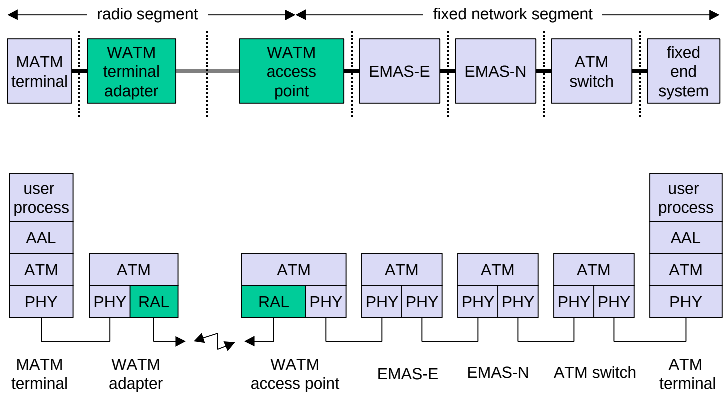
WATM components

WMT (Wireless Mobile ATM Terminal)
RT (Radio Transceiver)
AP (Access Point)
EMAS-E (End-user Mobility-supporting ATM Switch - Edge)
EMAS-N (End-user Mobility-supporting ATM Switch - Network)
APCP (Access Point Control Protocol)
UNI+M (User-to-Network Interface with Mobility support)
NNI+M (Network-to-Network Interface with Mobility support)

Reference model

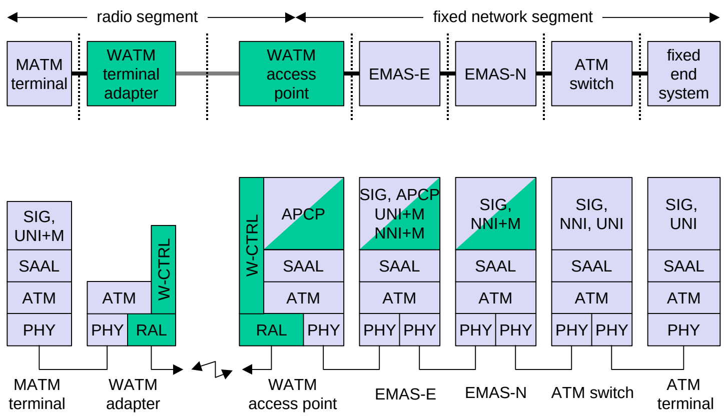


User plane protocol layers



Mobile Communications: Wireless ATM 8.12.1

Control plane protocol layers



Mobile Communications: Wireless ATM 8.13.1

Enhanced functionality I

Additional protocols needed for the support of mobility

- Mobile Connection Management Protocol
  - supports a user for connection setup, specifies, reserves, and controls QoS for a connection
  - controls the assignment of VCIs to connections on the wireless and wired segment
  - supports setup of new or partially new paths during handover
- Mobile Handover Management Protocol
  - support of user mobility
    - find a new base station
    - redirect the data stream during handover
    - return unused VCIs after a handover
    - provide buffers and functions to sort packets out of sequence (ATM guarantees in-sequence delivery of cells!)
- standard functions of user and control plane still needed

Enhanced functionality II

- Mobile Location Management Protocol
  - terminals can change their access points, therefore, several location functions are needed
    - where is a mobile user, what is the current access point, what is the current sub-network of a mobile terminal etc.
- Mobile Routing Protocol
  - access points change over time
    - dynamic topologies influence routing protocols, not supported by traditional routing protocols
    - routing has to support wireless and fixed part of the network
  - example: connection setup between two mobile hosts
    - with the help of the addresses and location registries the current access points can be located
    - routing within fixed network without changes

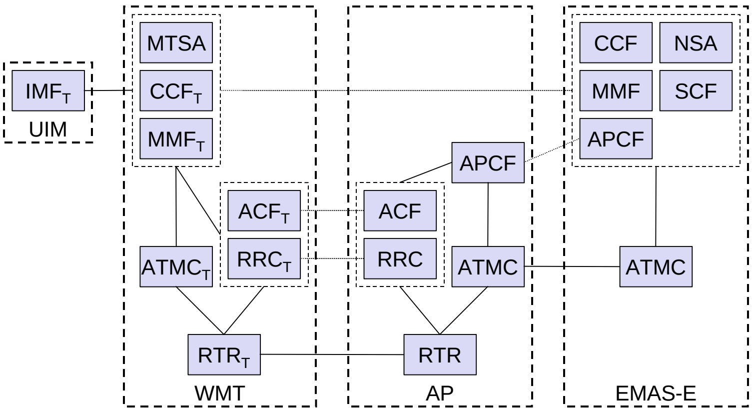
Enhanced functionality III

- Mobile Media Access Control Protocol
  - a single base station serves as access point for many mobile terminals within radio range
    - coordination of channel access
    - coordination of QoS requirements
    - traditional access schemes do not support different traffic classes with a larger variety of QoS requirements
- Mobile Data-Link Control Protocol
  - transmission and acknowledgement of frames
  - frame synchronization and retransmission
  - flow control

Also fixed networks need many of these functions, however, wireless networks require many adaptations and different mechanisms due to higher error rates and frequent interruptions.

Mobile Communications: Wireless ATM 8.16.1

Functional model for the modular access scheme



Mobile Communications: Wireless ATM 8.17.1

Wireless mobile terminal side

- Mobility Management Function (MMF_T)
  - analysis and monitoring of the network, paging response, location update
- Call control and Connection control Function (CCF_T)
  - call set-up and release, access control, connection control
- Identity Management Function (IMF_T)
  - security related information, user dependent
- Mobile Terminal Security Agent (MTSA)
  - additional security information, user independent
- Radio Transmission and Reception (RTR_T)
  - LLC, MAC, PHY layers for radio transmission
- Radio Resource Control function (RRC_T)
  - trigger handovers, monitor radio access, control radio resources
- Association Control Function (ACF_T)
  - set-up and release access to access point
- ATM Connection function ($ATMC_T$)
  - responsible for ATM connections, standard services (CBR, VBR, ABR, UBR)

Mobile Communications: Wireless ATM 8.18.1

Mobility supporting network side

- Access Point Control Function (APCF)
  - paging, handover, AP management
- Call control and Connection control Function (CCF)
  - call set-up and release, connection control, requests network and radio resources
- Network Security Agent (NSA)
  - identity management, authentication, encryption, confidentiality control
- Service Control Function (SCF)
  - management of service profiles, consistency checks
- Mobility Management Function (MMF)
  - location management, handover, location data, subscriber identity
- Association Control Function (ACF)
  - set-up and release access to mobile terminal
- Radio Resource Control function (RRC)
  - management of radio channels, initiate handover
- Radio Transmission and Reception function (RTR)
  - LLC, MAC, PHY layers, support of ATM traffic parameters
- ATM Connection function (ATMC)
  - responsible for ATM connections, standard services (CBR, VBR, ABR, UBR)

Mobile Communications: Wireless ATM 8.19.1

Radio Access Layer (RAL) requirements: PHY layer

- Definition of cell characteristics
  - frequencies, efficient re-use of frequencies, antennas, power, range
- Carrier frequency, symbol rate, modulation, coding, training sequences etc.
- Data and control interfaces to the radio unit

- Requirements
  - Bit Error Rate (BER) <= 10^{-4}, availability 99.5 %
  - data rate: 25 Mbit/s
  - range: indoor 30-50 m, outdoor 200-300 m
  - power: 100 mW

Radio Access Layer (RAL) requirements: MAC layer

- Supports
  - simultaneous access of several mobile terminals to the medium
  - several ATM service classes (CBR, VBR, ABR, UBR) including QoS control
- MAC protocol and syntax definition, MAC control algorithms
- Interfaces to PHY and LLC layer
- Support of user mobility

- Requirements
  - MAC efficiency: 60-75 % (over 90% is possible)
  - data rates
    - peak 25 Mbit/s
    - sustained 6 Mbit/s
    - still efficient for low rates (e.g., 32 kbit/s CBR)

Radio Access Layer (RAL) requirements: LLC layer

- Layer between ATM and MAC/PHY layers to solve specific problems of the wireless transmission
- Definition of LLC protocol and syntax
  - wireless header, control messages
- Special functions for ATM service classes
  - error control
    - error detection and correction
    - selective retransmission
  - forward error correction
- Requirements
  - mandatory: ARQ (Automatic Repeat Request)
  - optional: FEC for real-time services
  - optional: meta-signaling to support handover

ETSI Broadband Radio Access Network (BRAN)

Motivation
- deregulation, privatization, new companies, new services
- How to reach the customer?
  - alternatives: xDSL, cable, satellite, radio

Radio access
- flexible (supports traffic mix, multiplexing for higher efficiency, can be asymmetrical)
- quick installation
- economic (incremental growth possible)

Market
- private customers (Internet access, tele-xy...)
- small and medium sized business (Internet, MM conferencing, VPN)

Scope of standardization
- access networks, indoor/campus mobility, 25-155 Mbit/s, 50 m-5 km
- coordination with ATM Forum, IETF, ETSI, IEEE, ...

Broadband network types

Common characteristics

- ATM QoS (CBR, VBR, UBR, ABR)

HIPERLAN 2

- short range (< 200 m), indoor/campus, 25 Mbit/s
- extension of HIPERLAN 1, access to telecommunication systems, multimedia applications, mobility (<10 m/s)

HIPERACCESS

- wider range (< 5 km), outdoor, 25 Mbit/s
- fixed radio links to customers ("last mile"), alternative to xDSL or cable modem, quick installation

HIPERLINK

- intermediate link, 155 Mbit/s
- connection of HIPERLAN access points or connection between HIPERACCESS nodes

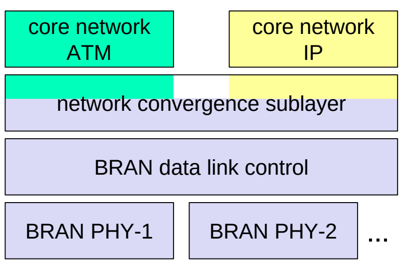
BRAN and legacy networks

Independence

- BRAN as access network independent from the fixed network
- interworking of TCP/IP and ATM under study

Layered model

- Network Convergence Sub-layer as superset of all requirements for IP and ATM

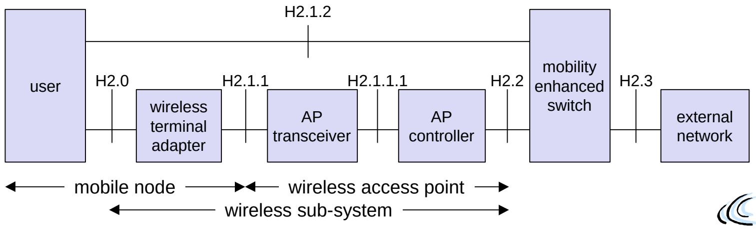


Coordination

- IETF (TCP/IP)
- ATM forum (ATM)
- ETSI (UMTS)
- CEPT, ITU-R, ... (radio frequencies)

ETSI Broadband Radio Access Network (BRAN)

- wireless access with bit rates ≥ 25 Mbit/s
- connection to private and public networks
- scope of specifications
  - physical layer
  - data link control layer
  - interworking, especially to fixed ATM networks and TCP/IP protocols
- coordination with ATM Forum, IEEE 802.11, IETF, ITU-R, ...
- reference points



Handover

Procedure to hand over connection(s) from a mobile ATM terminal from one access point to another access point

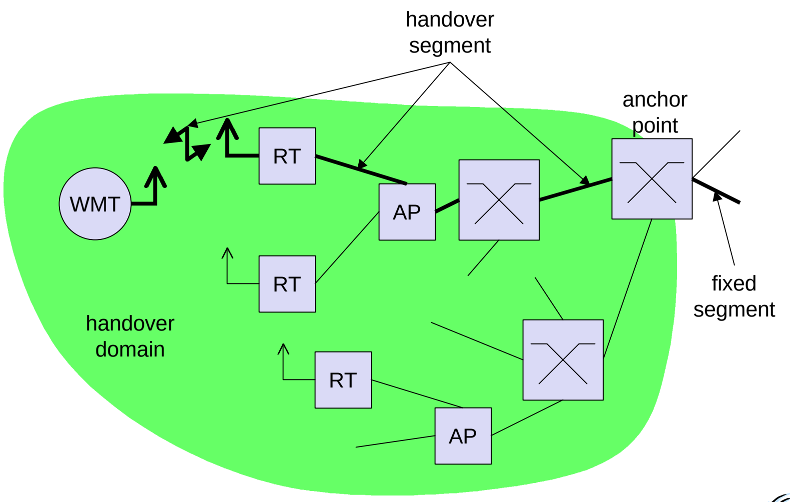
Support of an handover domain

- several access points cover a certain area
- common handover protocol and strategy
- all access points and switches belong to one administrative domain

Requirements

- multiple connection handover
- point-to-point and point-to-multipoint
- QoS support
- data integrity and security
- signaling and routing support
- high performance and low complexity

Simple handover reference model



Types of handover

Hard handover
- only one connection to one access point possible

Terminal initiated
- WTM initiates HO based on, e.g., signal quality

Network initiated
- Network initiates HO based on, e.g., network load

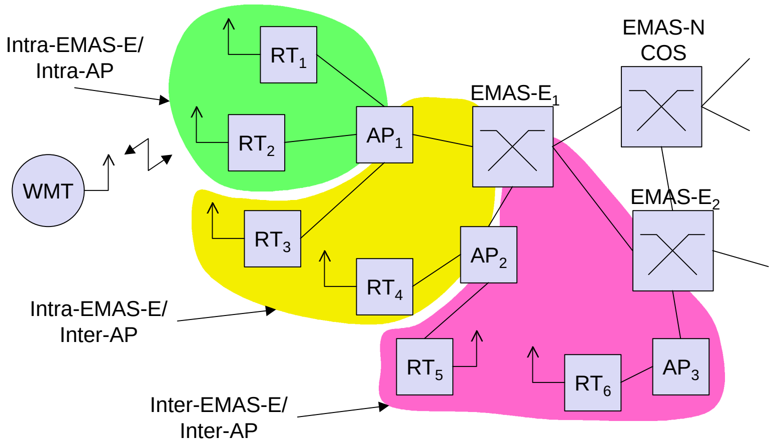
Network initiated, terminal assisted
- WTM provides information about radio conditions

Network controlled
- HO decision always at network

Backward handover
- standard type, WMT initiates HO, everything is prepared for HO *before* HO takes place

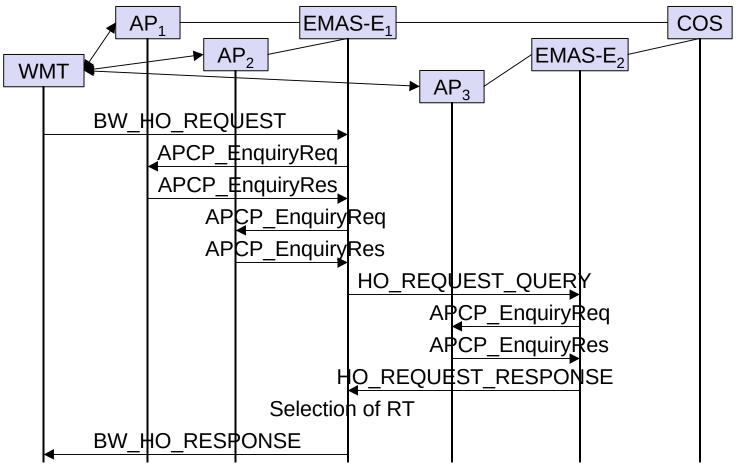
Forward handover
- WMT suddenly arrives at a new AP, connection loss possible

Handover scenarios



Mobile Communications: Wireless ATM 8.30.1

Backward handover with multiple possible APs



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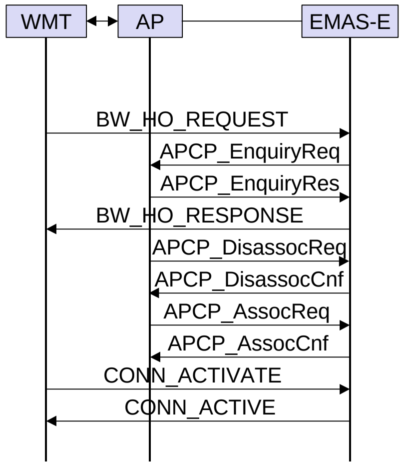
BW handover - Intra-EMAS-E/Intra-AP



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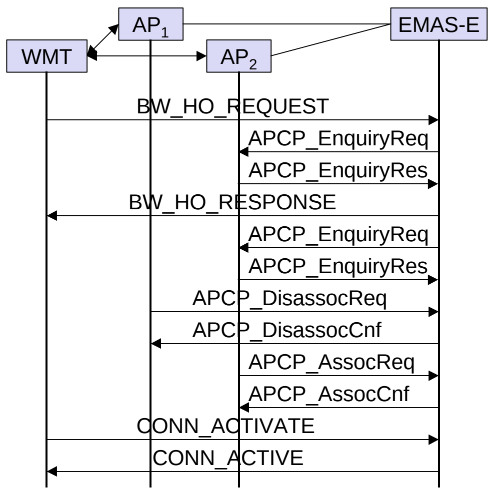
BW handover - Intra-EMAS-E/Inter-AP



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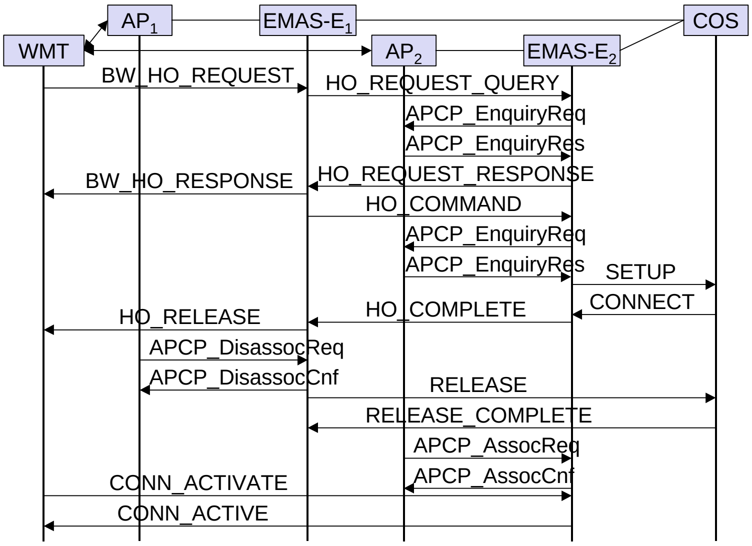
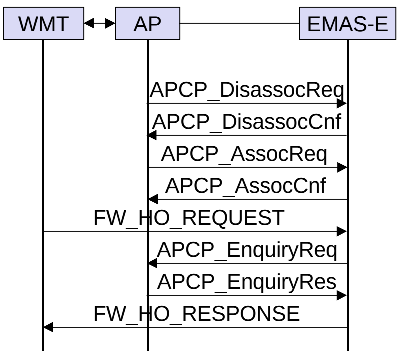
BW handover - Inter-EMAS-E/Inter-AP



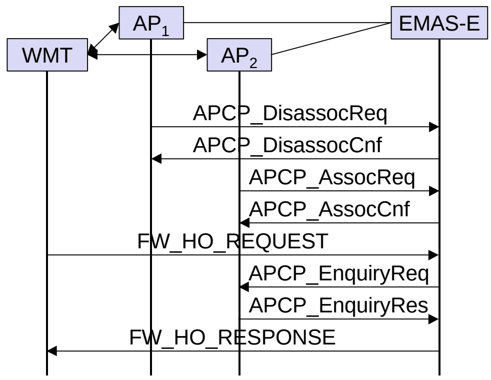
Mobile Communications: Wireless ATM 8.34.1

FW handover - Intra-EMAS-E/Intra-AP



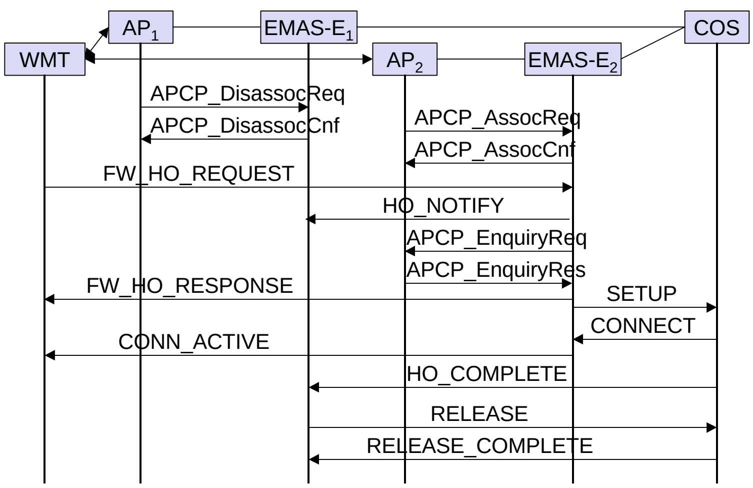
Mobile Communications: Wireless ATM 8.35.1

FW handover - Intra-EMAS-E/Inter-AP



Mobile Communications: Wireless ATM 8.36.1

BW handover - Inter-EMAS-E/Inter-AP



Mobile Communications: Wireless ATM 8.37.1

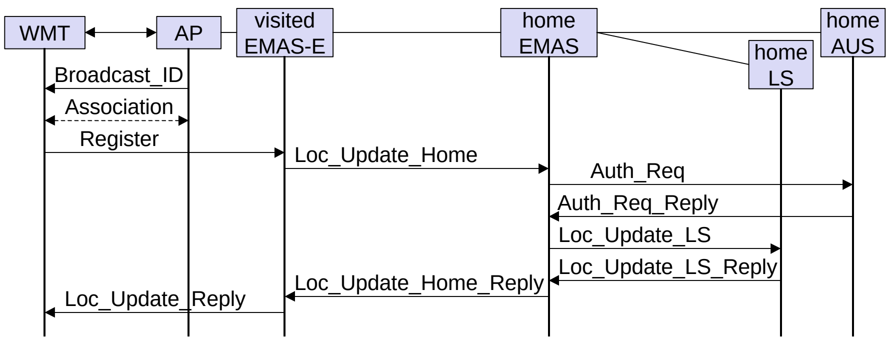
Location management

Requirements

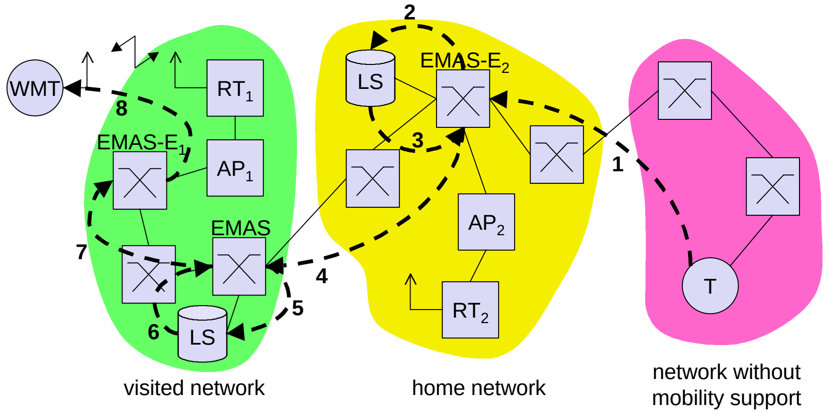
- transparent for users
- privacy of location and user information
- cell and network identification
- minimum of additional signaling required
- access control, accounting
- roaming
- scalability

- standardized method for registration (i.e, a new user joins the network)
- mobile terminals get temporary, routable addresses
- common protocol for database/registry updates
- location management must cooperate with unchanged ATM routing

Registration and location update



Incoming connection setup, WMT in foreign network



LS: Location Server

Mobile Communications: Wireless ATM 8.40.1

Addressing

- should support all formats of ATM end-system addresses (AESA)
- uses a permanent, location independent address which has to correspond with a routable address from the “home network”
- supports the assignment of temporary, routable addresses during registration of the mobile terminal in a foreign domain

Mobile Communications: Wireless ATM 8.41.1

Mobile Quality of Service (M-QoS)

Main difference to, e.g., Mobile IP

M-QoS main reason for high complexity

M-QoS parts

- Wired QoS
  - same as in wired ATM networks
- Wireless QoS
  - delay and error rates higher, multiplexing and reservation important
- Handover QoS
  - blocking, cell loss during handover, duration of handover

Hard handover QoS

- no QoS guarantee after handover
- disconnect if not enough resources in new cell

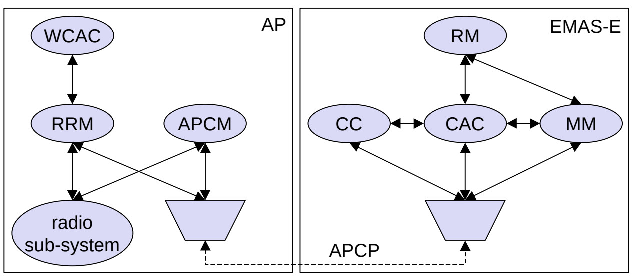
Soft handover QoS

- only statistical guarantees
- applications have to adapt

Access Point Control Protocol

Interface between a wireless aware segment and an unchanged segment of the ATM network

- Switch protocol to control wireless access points
  - reservation and release of resources
  - preparation of access points for new connections
  - handover support
  - announcement of new mobile terminals



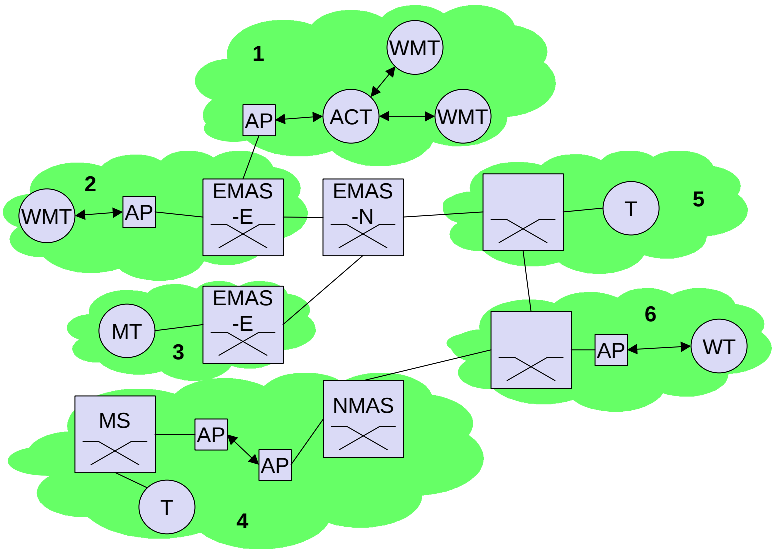
RM: switch resource management
CC: call control
CAC: connection admission control
MM: mobility management
RRM: radio resource management
WCAC: wireless CAC
APCM: AP connection management
APCP: AP control protocol

Reference model with further access scenarios I

1: wireless ad-hoc ATM network
2: wireless mobile ATM terminals
3: mobile ATM terminals
4: mobile ATM switches
5: fixed ATM terminals
6: fixed wireless ATM terminals

WMT: wireless mobile terminal
WT: wireless terminal
MT: mobile terminal
T: terminal
AP: access point
EMAS: end-user mobility supporting ATM switch (-E: edge, -N: network)
NMAS: network mobility supporting ATM switch
MS: mobile ATM switch

Reference model with further access scenarios II



Mobile Communications Chapter 9: Network Protocols/Mobile IP

- ❑ Motivation
- ❑ Data transfer
- ❑ Encapsulation
- ❑ Security
- ❑ IPv6
- ❑ Problems
- ❑ DHCP
- ❑ Ad-hoc networks
- ❑ Routing protocols

Motivation for Mobile IP

Routing
- ❑ based on IP destination address, network prefix (e.g. 129.13.42) determines physical subnet
- ❑ change of physical subnet implies change of IP address to have a topological correct address (standard IP) or needs special entries in the routing tables

Specific routes to end-systems?
- ❑ change of all routing table entries to forward packets to the right destination
- ❑ does not scale with the number of mobile hosts and frequent changes in the location, security problems

Changing the IP-address?
- ❑ adjust the host IP address depending on the current location
- ❑ almost impossible to find a mobile system, DNS updates take to long time
- ❑ TCP connections break, security problems

Requirements to Mobile IP (RFC 2002)

Transparency
- mobile end-systems keep their IP address
- continuation of communication after interruption of link possible
- point of connection to the fixed network can be changed

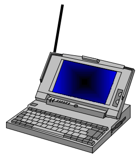
Compatibility
- support of the same layer 2 protocols as IP
- no changes to current end-systems and routers required
- mobile end-systems can communicate with fixed systems

Security
- authentication of all registration messages

Efficiency and scalability
- only little additional messages to the mobile system required (connection typically via a low bandwidth radio link)
- world-wide support of a large number of mobile systems in the whole Internet

Mobile Communications: Network Protocols/Mobile IP 9.2.1

Terminology



Mobile Node (MN)
- system (node) that can change the point of connection to the network without changing its IP address

Home Agent (HA)
- system in the home network of the MN, typically a router
- registers the location of the MN, tunnels IP datagrams to the COA

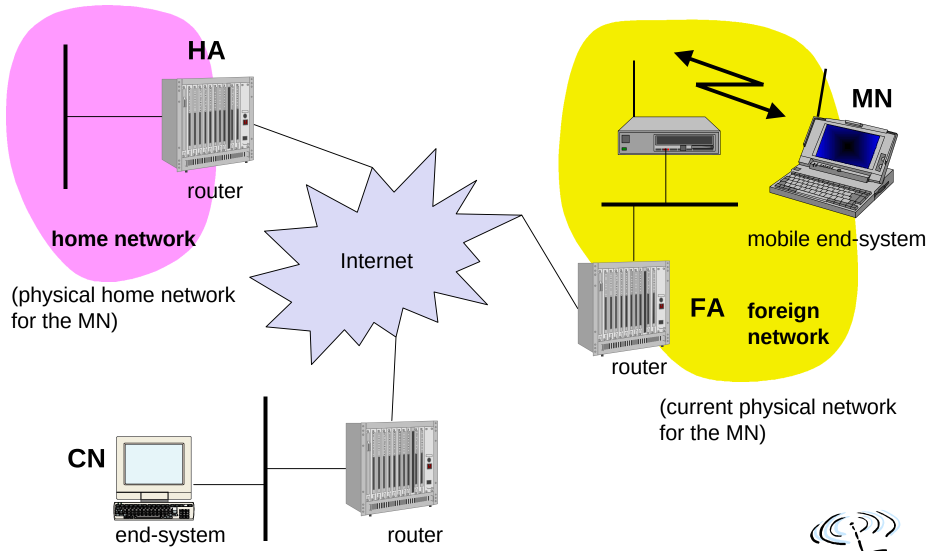
Foreign Agent (FA)
- system in the current foreign network of the MN, typically a router
- forwards the tunneled datagrams to the MN, typically also the default router for the MN

Care-of Address (COA)
- address of the current tunnel end-point for the MN (at FA or MN)
- actual location of the MN from an IP point of view
- can be chosen, e.g., via DHCP

Correspondent Node (CN)
- communication partner

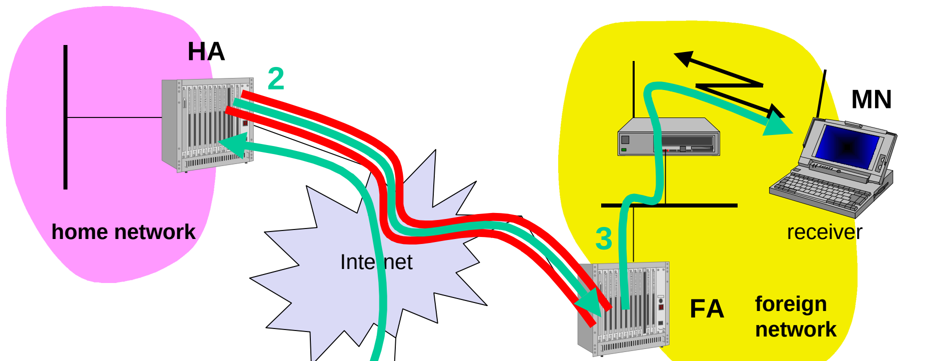
Mobile Communications: Network Protocols/Mobile IP 9.3.1

Example network



Mobile Communications: Network Protocols/Mobile IP 9.4.1

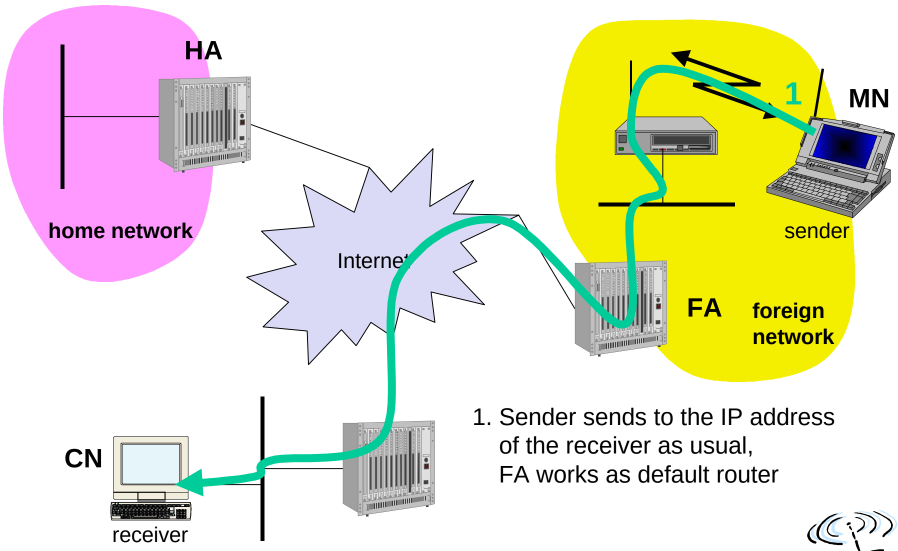
Data transfer to the mobile system



1. Sender sends to the IP address of MN, HA intercepts packet (proxy ARP)
2. HA tunnels packet to COA, here FA, by encapsulation
3. FA forwards the packet to the MN

Mobile Communications: Network Protocols/Mobile IP 9.5.1

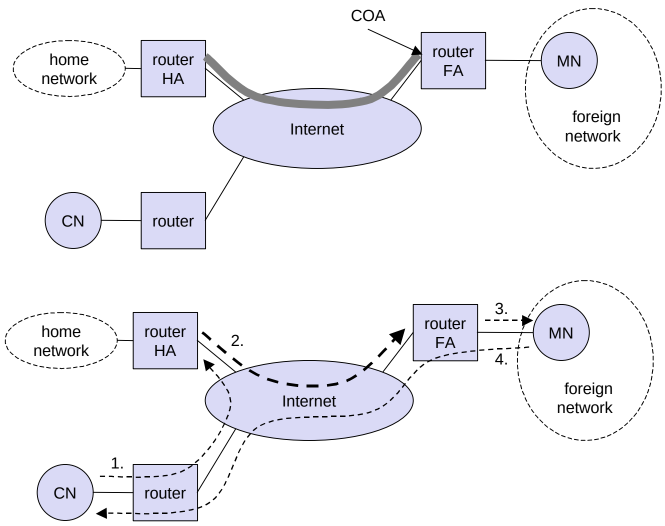
Data transfer from the mobile system



1. Sender sends to the IP address of the receiver as usual, FA works as default router

Mobile Communications: Network Protocols/Mobile IP 9.6.1

Overview



Mobile Communications: Network Protocols/Mobile IP 9.7.1

Network integration

Agent Advertisement
- HA and FA periodically send advertisement messages into their physical subnets
- MN listens to these messages and detects, if it is in the home or a foreign network (standard case for home network)
- MN reads a COA from the FA advertisement messages

Registration (always limited lifetime!)
- MN signals COA to the HA via the FA, HA acknowledges via FA to MN
- these actions have to be secured by authentication

Advertisement
- HA advertises the IP address of the MN (as for fixed systems), i.e. standard routing information
- routers adjust their entries, these are stable for a longer time (HA responsible for a MN over a longer period of time)
- packets to the MN are sent to the HA,
- independent of changes in COA/FA

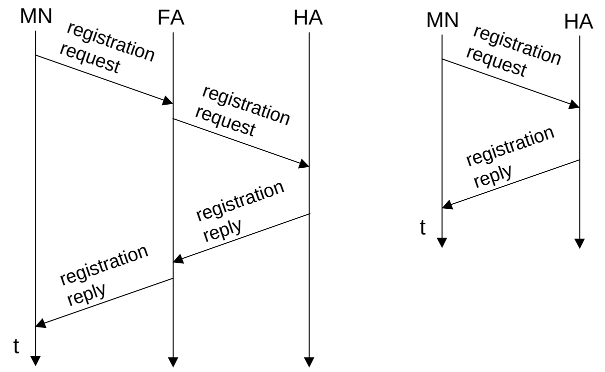
Mobile Communications: Network Protocols/Mobile IP 9.8.1

Agent advertisement

0 … 7	8 … 15	16 … 23	24 … 31
type	code	checksum	
#addresses	addr. size	lifetime	
router address 1			
preference level 1			
router address 2			
preference level 2			
. . .			
type	length	sequence number	
registration lifetime		R B H F M G V	reserved
COA 1			
COA 2			
. . .			

Mobile Communications: Network Protocols/Mobile IP 9.9.1

Registration



Mobile Communications: Network Protocols/Mobile IP 9.10.1

Mobile IP registration request

0 – 7	8 – 15	16 – 23	24 – 31
type	S B D M G V rsv	lifetime	
home address			
home agent			
COA			
identification			
extensions . . .			

Mobile Communications: Network Protocols/Mobile IP 9.11.1

Encapsulation

	original IP header	original data
new IP header	new data	
outer header	inner header	original data

Mobile Communications: Network Protocols/Mobile IP 9.12.1

Encapsulation I

Encapsulation of one packet into another as payload

- e.g. IPv6 in IPv4 (6Bone), Multicast in Unicast (Mbone)
- here: e.g. IP-in-IP-encapsulation, minimal encapsulation or GRE (Generic Record Encapsulation)

IP-in-IP-encapsulation (mandatory in RFC 2003)

- tunnel between HA and COA

ver.	IHL	TOS	length
IP identification		flags	fragment offset
TTL		*IP-in-IP*	IP checksum
IP address of HA			
Care-of address COA			
ver.	IHL	TOS	length
IP identification		flags	fragment offset
TTL		lay. 4 prot.	IP checksum
IP address of CN			
IP address of MN			
TCP/UDP/ ... payload			

Mobile Communications: Network Protocols/Mobile IP 9.13.1

Encapsulation II

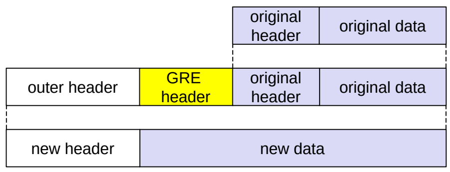
Minimal encapsulation (optional)

- avoids repetition of identical fields
- e.g. TTL, IHL, version, TOS
- only applicable for unfragmented packets, no space left for fragment identification

ver.	IHL	TOS	length	
IP identification			flags	fragment offset
TTL		*min. encap.*	IP checksum	
IP address of HA				
care-of address COA				
lay. 4 protoc.	S	reserved	IP checksum	
IP address of MN				
original sender IP address (if S=1)				
TCP/UDP/ ... payload				

Mobile Communications: Network Protocols/Mobile IP 9.14.1

Generic Routing Encapsulation



ver.	IHL	TOS					length		
IP identification							flags	fragment offset	
TTL		*GRE*					IP checksum		
IP address of HA									
Care-of address COA									
C	R	K	S	s	rec.	rsv.	ver.	protocol	
checksum (optional)								offset (optional)	
key (optional)									
sequence number (optional)									
routing (optional)									
ver.	IHL	TOS					length		
IP identification							flags	fragment offset	
TTL		lay. 4 prot.					IP checksum		
IP address of CN									
IP address of MN									
TCP/UDP/ ... payload									

Mobile Communications: Network Protocols/Mobile IP 9.15.1

Optimization of packet forwarding

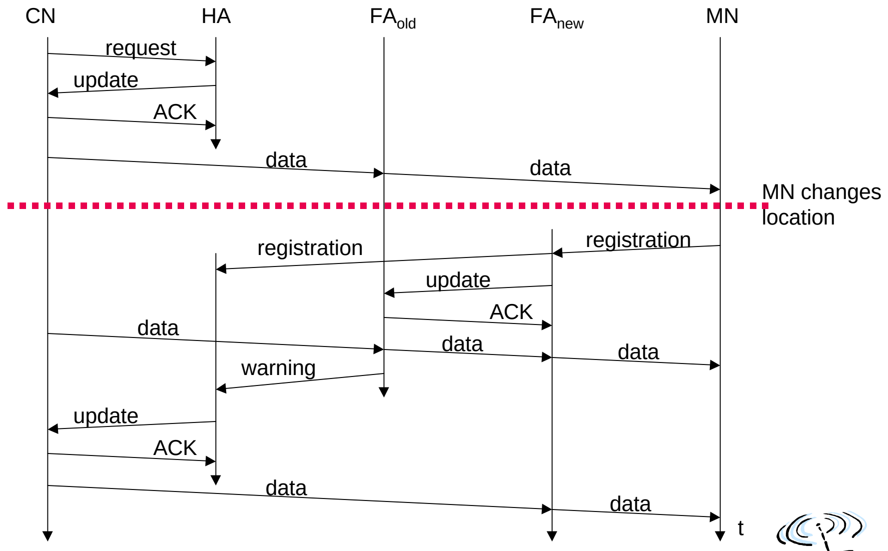
Triangular Routing
- sender sends all packets via HA to MN
- higher latency and network load

“Solutions”
- sender learns the current location of MN
- direct tunneling to this location
- HA informs a sender about the location of MN
- big security problems!

Change of FA
- packets on-the-fly during the change can be lost
- new FA informs old FA to avoid packet loss, old FA now forwards remaining packets to new FA
- this information also enables the old FA to release resources for the MN

Mobile Communications: Network Protocols/Mobile IP 9.16.1

Change of foreign agent



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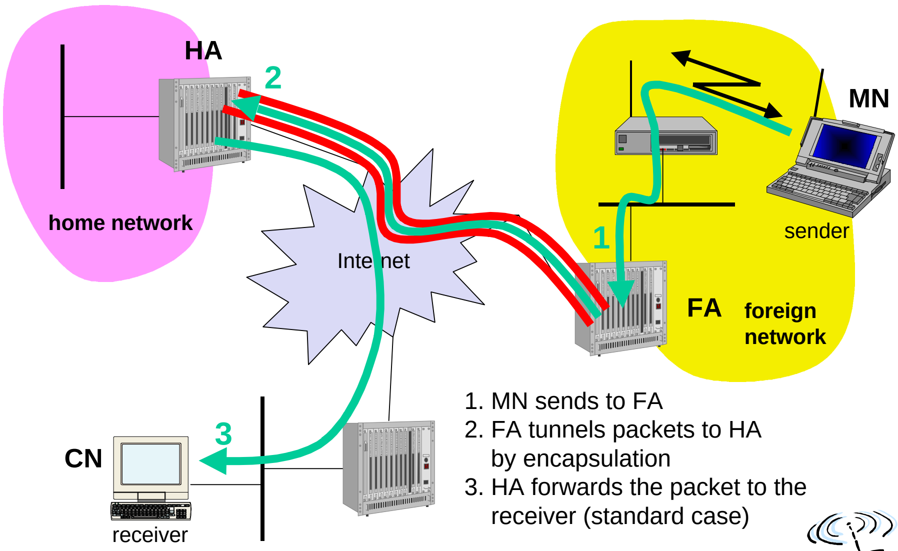
Reverse tunneling (RFC 2344)



1. MN sends to FA
2. FA tunnels packets to HA by encapsulation
3. HA forwards the packet to the receiver (standard case)

Mobile Communications: Network Protocols/Mobile IP 9.18.1

Mobile IP with reverse tunneling

Router accept often only “topological correct“ addresses (firewall!)
- a packet from the MN encapsulated by the FA is now topological correct
- furthermore multicast and TTL problems solved (TTL in the home network correct, but MN is to far away from the receiver)

Reverse tunneling does not solve
- problems with *firewalls*, the reverse tunnel can be abused to circumvent security mechanisms (tunnel hijacking)
- optimization of data paths, i.e. packets will be forwarded through the tunnel via the HA to a sender (double triangular routing)

The new standard is backwards compatible
- the extensions can be implemented easily and cooperate with current implementations without these extensions

Mobile Communications: Network Protocols/Mobile IP 9.19.1

Mobile IP and IPv6

Mobile IP was developed for IPv4, but IPv6 simplifies the protocols

- security is integrated and not an add-on, authentication of registration is included
- COA can be assigned via auto-configuration (DHCPv6 is one candidate), every node has address autoconfiguration
- no need for a separate FA, **all** routers perform router advertisement which can be used instead of the special agent advertisement
- MN can signal a sender directly the COA, sending via HA not needed in this case (automatic path optimization)
- „soft" hand-over, i.e. without packet loss, between two subnets is supported
  - MN sends the new COA to its old router
  - the old router encapsulates all incoming packets for the MN and forwards them to the new COA
  - authentication is always granted

Problems with mobile IP

Security

- authentication with FA problematic, for the FA typically belongs to another organization
- no protocol for key management and key distribution has been standardized in the Internet
- patent and export restrictions

Firewalls

- typically mobile IP cannot be used together with firewalls, special set-ups are needed (such as reverse tunneling)

QoS

- many new reservations in case of RSVP
- tunneling makes it hard to give a flow of packets a special treatment needed for the QoS

Security, firewalls, QoS etc. are topics of current research and discussions!

Security in Mobile IP

Security requirements (Security Architecture for the Internet Protocol, RFC 1825)

- Integrity
  any changes to data between sender and receiver can be detected by the receiver
- Authentication
  sender address is really the address of the sender and all data received is really data sent by this sender
- Confidentiality
  only sender and receiver can read the data
- Non-Repudiation
  sender cannot deny sending of data
- Traffic Analysis
  creation of traffic and user profiles should not be possible
- Replay Protection
  receivers can detect replay of messages

IP security architecture I

- Two or more partners have to negotiate security mechanisms to setup a security association
  - typically, all partners choose the same parameters and mechanisms
- Two headers have been defined for securing IP packets:
  - Authentication-Header
    - guarantees integrity and authenticity of IP packets
    - if asymmetric encryption schemes are used, non-repudiation can also be guaranteed

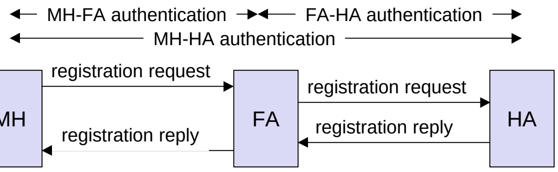
IP header	authentication header	UDP/TCP data

  - Encapsulation Security Payload
    - protects confidentiality between communication partners

not encrypted		encrypted
IP header	ESP header	encrypted data

IP security architecture II

- Mobile Security Association for registrations
  - parameters for the mobile host (MH), home agent (HA), and foreign agent (FA)
- Extensions of the IP security architecture
  - extended authentication of registration

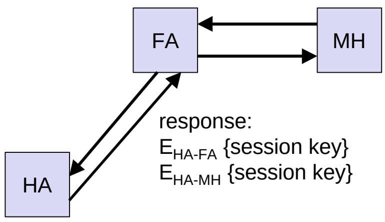


  - prevention of replays of registrations
    - time stamps: 32 bit time stamps + 32 bit random number
    - nonces: 32 bit random number (MH) + 32 bit random number (HA)

Mobile Communications: Network Protocols/Mobile IP 9.24.1

Key distribution

Home agent distributes session keys



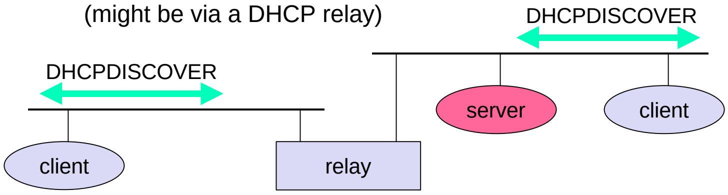
- foreign agent has a security association with the home agent
- mobile host registers a new binding at the home agent
- home agent answers with a new session key for foreign agent and mobile node

Mobile Communications: Network Protocols/Mobile IP 9.25.1

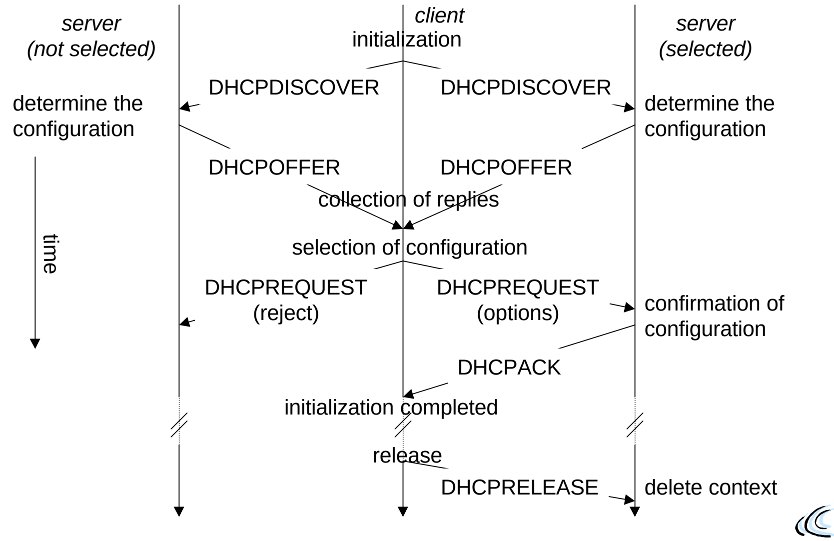
DHCP: Dynamic Host Configuration Protocol

Application
- simplification of installation and maintenance of networked computers
- supplies systems with all necessary information, such as IP address, DNS server address, domain name, subnet mask, default router etc.
- enables automatic integration of systems into an Intranet or the Internet, can be used to acquire a COA for Mobile IP

Client/Server-Model
- the client sends via a MAC broadcast a request to the DHCP server (might be via a DHCP relay)



DHCP - protocol mechanisms



DHCP characteristics

Server

- several servers can be configured for DHCP, coordination not yet standardized (i.e., manual configuration)

Renewal of configurations

- IP addresses have to be requested periodically, simplified protocol

Options

- available for routers, subnet mask, NTP (network time protocol) timeserver, SLP (service location protocol) directory, DNS (domain name system)

Big security problems!

- no authentication of DHCP information specified

Mobile Communications: Network Protocols/Mobile IP 9.28.1

Ad hoc networks

Standard Mobile IP needs an infrastructure

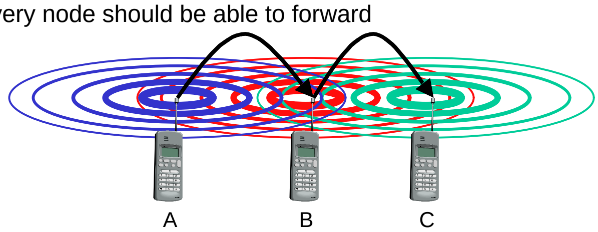
- Home Agent/Foreign Agent in the fixed network
- DNS, routing etc. are not designed for mobility

Sometimes there is no infrastructure!

- remote areas, ad-hoc meetings, disaster areas
- cost can also be an argument against an infrastructure!

Main topic: routing

- no default router available
- every node should be able to forward



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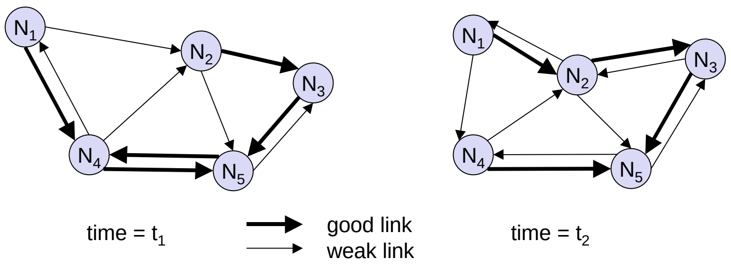
Routing examples for an ad-hoc network



Traditional routing algorithms

Distance Vector

- periodic exchange of messages with all physical neighbors that contain information about who can be reached at what distance
- selection of the shortest path if several paths available

Link State

- periodic notification of all routers about the current state of all physical links
- router get a complete picture of the network

Example

- ARPA packet radio network (1973), DV-Routing
- every 7.5s exchange of routing tables including link quality
- updating of tables also by reception of packets
- routing problems solved with limited flooding

Problems of traditional routing algorithms

Dynamic of the topology
- frequent changes of connections, connection quality, participants

Limited performance of mobile systems
- periodic updates of routing tables need energy without contributing to the transmission of user data, sleep modes difficult to realize
- limited bandwidth of the system is reduced even more due to the exchange of routing information
- links can be asymmetric, i.e., they can have a direction dependent transmission quality

Problem
- protocols have been designed for fixed networks with infrequent changes and typically assume symmetric links

Mobile Communications: Network Protocols/Mobile IP 9.32.1

DSDV (Destination Sequenced Distance Vector)

Expansion of distance vector routing

Sequence numbers for all routing updates
- assures in-order execution of all updates
- avoids loops and inconsistencies

Decrease of update frequency
- store time between first and best announcement of a path
- inhibit update if it seems to be unstable (based on the stored time values)

Mobile Communications: Network Protocols/Mobile IP 9.33.1

Dynamic source routing I

Split routing into discovering a path and maintainig a path

Discover a path

- only if a path for sending packets to a certain destination is needed and no path is currently available

Maintaining a path

- only while the path is in use one has to make sure that it can be used continuously

No periodic updates needed!

Dynamic source routing II

Path discovery

- broadcast a packet with destination address and unique ID
- if a station receives a broadcast packet
  - if the station is the receiver (i.e., has the correct destination address) then return the packet to the sender (path was collected in the packet)
  - if the packet has already been received earlier (identified via ID) then discard the packet
  - otherwise, append own address and broadcast packet
- sender receives packet with the current path (address list)

Optimizations

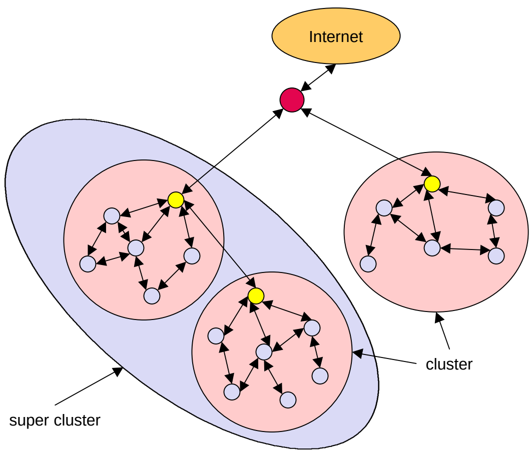
- limit broadcasting if maximum diameter of the network is known
- caching of address lists (i.e. paths) with help of passing packets
  - stations can use the cached information for path discovery (own paths or paths for other hosts)

Dynamic Source Routing III

Maintaining paths

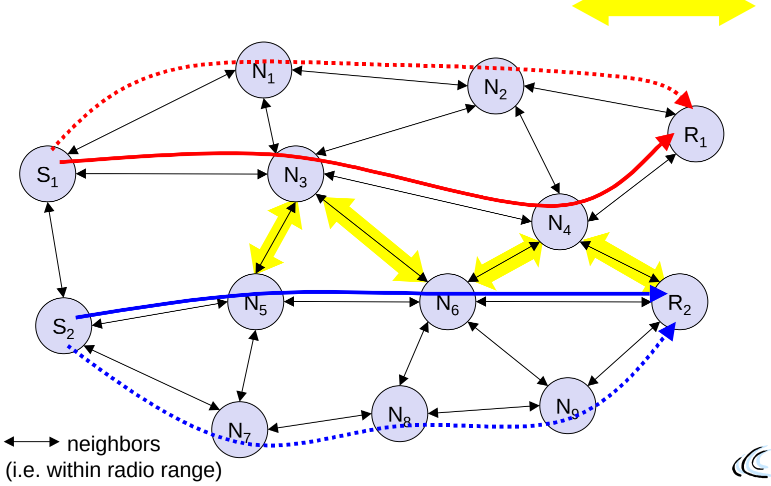
- after sending a packet
  - wait for a layer 2 acknowledgement (if applicable)
  - listen into the medium to detect if other stations forward the packet (if possible)
  - request an explicit acknowledgement
- if a station encounters problems it can inform the sender of a packet or look-up a new path locally

Clustering of ad-hoc networks



Interference-based routing

Routing based on assumptions about interference between signals



Examples for interference based routing

Least Interference Routing (LIR)

- calculate the cost of a path based on the number of stations that can receive a transmission

Max-Min Residual Capacity Routing (MMRCR)

- calculate the cost of a path based on a probability function of successful transmissions and interference

Least Resistance Routing (LRR)

- calculate the cost of a path based on interference, jamming and other transmissions

LIR is very simple to implement, only information from direct neighbors is necessary

Mobile Communications
Chapter 10: Mobile Transport Layer

- Motivation
- TCP-mechanisms
- Indirect TCP
- Snooping TCP
- Mobile TCP
- Fast retransmit/recovery
- Transmission freezing
- Selective retransmission
- Transaction oriented TCP

Motivation I

Transport protocols typically designed for
- Fixed end-systems
- Fixed, wired networks

Research activities
- Performance
- Congestion control
- Efficient retransmissions

TCP congestion control
- packet loss in fixed networks typically due to (temporary) overload situations
- router have to discard packets as soon as the buffers are full
- TCP recognizes congestion only indirect via missing acknowledgements, retransmissions unwise, they would only contribute to the congestion and make it even worse
- slow-start algorithm as reaction

Motivation II

TCP slow-start algorithm

- sender calculates a congestion window for a receiver
- start with a congestion window size equal to one segment
- exponential increase of the congestion window up to the congestion threshold, then linear increase
- missing acknowledgement causes the reduction of the congestion threshold to one half of the current congestion window
- congestion window starts again with one segment

TCP fast retransmit/fast recovery

- TCP sends an acknowledgement only after receiving a packet
- if a sender receives several acknowledgements for the same packet, this is due to a gap in received packets at the receiver
- however, the receiver got all packets up to the gap and is actually receiving packets
- therefore, packet loss is not due to congestion, continue with current congestion window (do not use slow-start)

Influences of mobility on TCP-mechanisms

TCP assumes congestion if packets are dropped

- typically wrong in wireless networks, here we often have packet loss due to *transmission errors*
- furthermore, *mobility* itself can cause packet loss, if e.g. a mobile node roams from one access point (e.g. foreign agent in Mobile IP) to another while there are still packets in transit to the wrong access point and forwarding is not possible

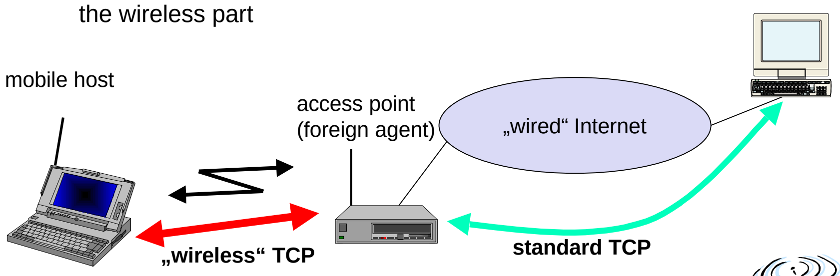
The performance of an unchanged TCP degrades severely

- however, TCP cannot be changed fundamentally due to the large base of installation in the fixed network, TCP for mobility has to remain compatible
- the basic TCP mechanisms keep the whole Internet together

Indirect TCP I

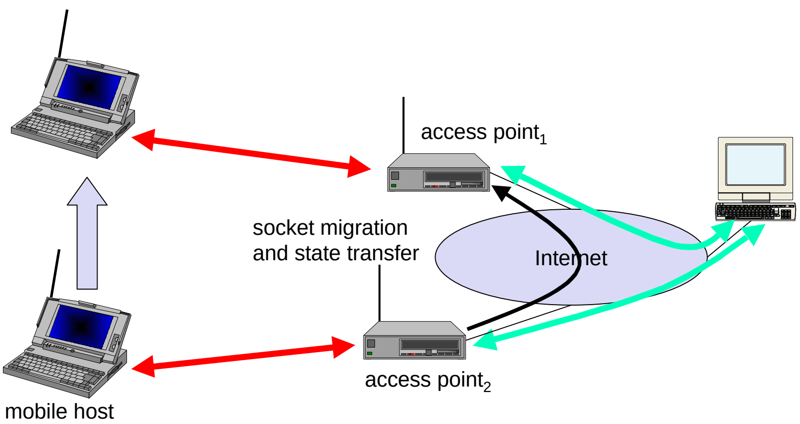
Indirect TCP or I-TCP segments the connection

- no changes to the TCP protocol for hosts connected to the wired Internet, millions of computers use (variants of) this protocol
- optimized TCP protocol for mobile hosts
- splitting of the TCP connection at, e.g., the foreign agent into 2 TCP connections, no real end-to-end connection any longer
- hosts in the fixed part of the net do not notice the characteristics of the wireless part



Mobile Communications: Mobile Transport Layer 10.4.1

I-TCP socket and state migration



Mobile Communications: Mobile Transport Layer 10.5.1

Indirect TCP II

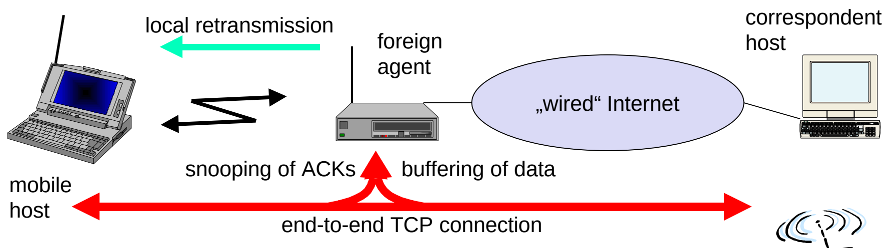
Advantages
- no changes in the fixed network necessary, no changes for the hosts (TCP protocol) necessary, all current optimizations to TCP still work
- transmission errors on the wireless link do not propagate into the fixed network
- simple to control, mobile TCP is used only for one hop between, e.g., a foreign agent and mobile host
- therefore, a very fast retransmission of packets is possible, the short delay on the mobile hop is known

Disadvantages
- loss of end-to-end semantics, an acknowledgement to a sender does now not any longer mean that a receiver really got a packet, foreign agents might crash
- higher latency possible due to buffering of data within the foreign agent and forwarding to a new foreign agent

Mobile Communications: Mobile Transport Layer 10.6.1

Snooping TCP I

„Transparent“ extension of TCP within the foreign agent
- buffering of packets sent to the mobile host
- lost packets on the wireless link (both directions!) will be retransmitted immediately by the mobile host or foreign agent, respectively (so called “local” retransmission)
- the foreign agent therefore “snoops” the packet flow and recognizes acknowledgements in both directions, it also filters ACKs
- changes of TCP only within the foreign agent



Mobile Communications: Mobile Transport Layer 10.7.1

Snooping TCP II

Data transfer to the mobile host
- FA buffers data until it receives ACK of the MH, FA detects packet loss via duplicated ACKs or time-out
- fast retransmission possible, transparent for the fixed network

Data transfer from the mobile host
- FA detects packet loss on the wireless link via sequence numbers, FA answers directly with a NACK to the MH
- MH can now retransmit data with only a very short delay

Integration of the MAC layer
- MAC layer often has similar mechanisms to those of TCP
- thus, the MAC layer can already detect duplicated packets due to retransmissions and discard them

Problems
- snooping TCP does not isolate the wireless link as good as I-TCP
- snooping might be useless depending on encryption schemes

Mobile TCP

Special handling of lengthy and/or frequent disconnections

M-TCP splits as I-TCP does
- unmodified TCP fixed network to supervisory host (SH)
- optimized TCP SH to MH

Supervisory host
- no caching, no retransmission
- monitors all packets, if disconnection detected
  - set sender window size to 0
  - sender automatically goes into persistent mode
- old or new SH reopen the window

Advantages
- maintains semantics, supports disconnection, no buffer forwarding

Disadvantages
- loss on wireless link propagated into fixed network
- adapted TCP on wireless link

Fast retransmit/fast recovery

Change of foreign agent often results in packet loss
- TCP reacts with slow-start although there is no congestion

Forced fast retransmit
- as soon as the mobile host has registered with a new foreign agent, the MH sends duplicated acknowledgements on purpose
- this forces the fast retransmit mode at the communication partners
- additionally, the TCP on the MH is forced to continue sending with the actual window size and not to go into slow-start after registration

Advantage
- simple changes result in significant higher performance

Disadvantage
- further mix of IP and TCP, no transparent approach

Mobile Communications: Mobile Transport Layer 10.10.1

Transmission/time-out freezing

Mobile hosts can be disconnected for a longer time
- no packet exchange possible, e.g., in a tunnel, disconnection due to overloaded cells or mux. with higher priority traffic
- TCP disconnects after time-out completely

TCP freezing
- MAC layer is often able to detect interruption in advance
- MAC can inform TCP layer of upcoming loss of connection
- TCP stops sending, but does now not assume a congested link
- MAC layer signals again if reconnected

Advantage
- scheme is independent of data

Disadvantage
- TCP on mobile host has to be changed, mechanism depends on MAC layer

Mobile Communications: Mobile Transport Layer 10.11.1

Selective retransmission

TCP acknowledgements are often cumulative

- ACK n acknowledges correct and in-sequence receipt of packets up to n
- if single packets are missing quite often a whole packet sequence beginning at the gap has to be retransmitted (go-back-n), thus wasting bandwidth

Selective retransmission as one solution

- RFC2018 allows for acknowledgements of single packets, not only acknowledgements of in-sequence packet streams without gaps
- sender can now retransmit only the missing packets

Advantage

- much higher efficiency

Disadvantage

- more complex software in a receiver, more buffer needed at the receiver

Mobile Communications: Mobile Transport Layer 10.12.1

Transaction oriented TCP

TCP phases

- connection setup, data transmission, connection release
- using 3-way-handshake needs 3 packets for setup and release, respectively
- thus, even short messages need a minimum of 7 packets!

Transaction oriented TCP

- RFC1644, T-TCP, describes a TCP version to avoid this overhead
- connection setup, data transfer and connection release can be combined
- thus, only 2 or 3 packets are needed

Advantage

- efficiency

Disadvantage

- requires changed TCP
- mobility not longer transparent

Mobile Communications: Mobile Transport Layer 10.13.1

Comparison of different approaches for a “mobile” TCP

Approach	Mechanism	Advantages	Disadvantages
Indirect TCP	splits TCP connection into two connections	isolation of wireless link, simple	loss of TCP semantics, higher latency at handover
Snooping TCP	“snoops” data and acknowledgements, local retransmission	transparent for end-to-end connection, MAC integration possible	problematic with encryption, bad isolation of wireless link
M-TCP	splits TCP connection, chokes sender via window size	Maintains end-to-end semantics, handles long term and frequent disconnections	Bad isolation of wireless link, processing overhead due to bandwidth management
Fast retransmit/ fast recovery	avoids slow-start after roaming	simple and efficient	mixed layers, not transparent
Transmission/ time-out freezing	freezes TCP state at disconnect, resumes after reconnection	independent of content or encryption, works for longer interrupts	changes in TCP required, MAC dependant
Selective retransmission	retransmit only lost data	very efficient	slightly more complex receiver software, more buffer needed
Transaction oriented TCP	combine connection setup/release and data transmission	Efficient for certain applications	changes in TCP required, not transparent

Mobile Communications: Mobile Transport Layer 10.14.1

Mobile Communications Chapter 11: Support for Mobility

- File systems
- Data bases
- WWW and Mobility
- WAP - Wireless Application Protocol

File systems - Motivation

Goal

- efficient and transparent access to shared files within a mobile environment while maintaining data consistency

Problems

- limited resources of mobile computers (memory, CPU, ...)
- low bandwidth, variable bandwidth, temporary disconnection
- high heterogeneity of hardware and software components (no standard PC architecture)
- wireless network resources and mobile computer are not very reliable
- standard file systems (e.g., NFS, network file system) are very inefficient, almost unusable

Solutions

- replication of data (copying, cloning, caching)
- data collection in advance (hoarding, pre-fetching)

File systems - consistency problems

THE big problem of distributed, loosely coupled systems

- are all views on data the same?
- how and when should changes be propagated to what users?

Weak consistency

- many algorithms offering strong consistency (e.g., via atomic updates) cannot be used in mobile environments
- invalidation of data located in caches through a server is very problematic if the mobile computer is currently not connected to the network
- occasional inconsistencies have to be tolerated, but conflict resolution strategies must be applied afterwards to reach consistency again

Conflict detection

- content independent: version numbering, time-stamps
- content dependent: dependency graphs

File systems for limited connectivity I

Symmetry

- Client/Server or Peer-to-Peer relations
- support in the fixed network and/or mobile computers
- one file system or several file systems
- one namespace for files or several namespaces

Transparency

- hide the mobility support, applications on mobile computers should not notice the mobility
- user should not notice additional mechanisms needed

Consistency model

- optimistic or pessimistic

Caching and Pre-fetching

- single files, directories, subtrees, partitions, ...
- permanent or only at certain points in time

File systems for limited connectivity II

Data management
- management of buffered data and copies of data
- request for updates, validity of data
- detection of changes in data

Conflict solving
- application specific or general
- errors

Several experimental systems exist
- Coda (Carnegie Mellon University), Little Work (University of Michigan), Ficus (UCLA) etc.

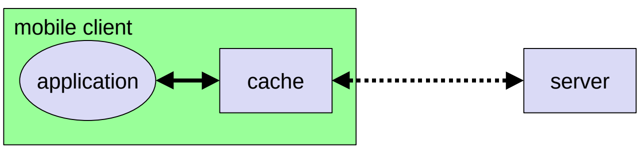
Many systems use ideas from distributed file systems such as, e.g., AFS (Andrew File System)

Mobile Communications: Support for Mobility 11.4.1

File systems - Coda I

Application transparent extensions of client and server
- changes in the cache manager of a client
- applications use cache replicates of files
- extensive, transparent collection of data in advance for possible future use („Hoarding“)

Consistency
- system keeps a record of changes in files and compares files after reconnection
- if different users have changed the same file a manual reintegration of the file into the system is necessary
- optimistic approach, coarse grained (file size)



Mobile Communications: Support for Mobility 11.5.1

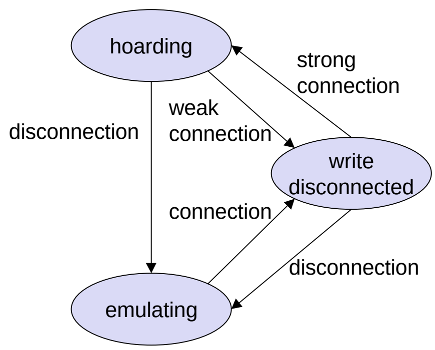
File systems - Coda II

Hoarding
- user can pre-determine a file list with priorities
- contents of the cache determined by the list and LRU strategy (Last Recently Used)
- explicit pre-fetching possible
- periodic updating

Comparison of files
- asynchronous, background
- system weighs speed of updating against minimization of network traffic

Cache misses
- modeling of user patience: how long can a user wait for data without an error message?
- function of file size and bandwidth

States of a client



File systems - Little Work

- Only changes in the cache manager of the client
- Connection modes and use

	Connected	Partially Connected	Fetch only	Disconnected
Method	normal	delayed write to the server	optimistic replication of files	abort at cache miss
Network requirements	continuous high bandwidth	continuous bandwidth	connection on demand	none
Application	office, WLAN	packet radio	cellular systems (e.g., GSM) with costs per call	independent

File systems - further examples

Mazer/Tardo

- file synchronization layer between application and local file system
- caching of complete subdirectories from the server
- “Redirector” responses to requests locally if necessary, via the network if possible
- periodic consistency checks with bi-directional updating

Ficus

- not a client/server approach
- optimistic approach based on replicates, detection of write conflicts, conflict resolution
- use of „gossip“ protocols: a mobile computer does not necessarily need to have direct connection to a server, with the help of other mobile computers updates can be propagated through the network

MIo-NFS (Mobile Integration of NFS)

- NFS extension, pessimistic approach, only token holder can write
- connected/loosely connected/disconnected

Database systems in mobile environments

Request processing

- power conserving, location dependent, cost efficient
- example: find the fastest way to a hospital

Replication management

- similar to file systems

Location management

- tracking of mobile users to provide replicated or location dependent data in time at the right place (minimize access delays)
- example: with the help of the HLR (Home Location Register) in GSM a mobile user can find a local towing service

Transaction processing

- “mobile” transactions can not necessarily rely on the same models as transactions over fixed networks (ACID: atomicity, consistency, isolation, durability)
- therefore models for “weak” transaction

World Wide Web and mobility

Protocol (HTTP, Hypertext Transfer Protocol) and language (HTML, Hypertext Markup Language) of the Web have not been designed for mobile applications and mobile devices, thus creating many problems!

Typical transfer sizes

- HTTP request: 100-350 byte
- responses avg. <10 kbyte, header 160 byte, GIF 4.1kByte, JPEG 12.8 kbyte, HTML 5.6 kbyte
- but also many large files that cannot be ignored

The Web is no file system

- Web pages are not simple files to download
- static and dynamic content, interaction with servers via forms, content transformation, push technologies etc.
- many hyperlinks, automatic loading and reloading, redirecting
- a single click might have big consequences!

WWW example

Request to port 80

```
GET / HTTP/1.0
```

Response from server

```
HTTP/1.1 200 OK
Date: Fri, 06 Nov 1998 14:52:12 GMT
Server: Apache/1.3b5
Connection: close
Content-Type: text/html
<HTML>
<HEAD>
<TITLE> Institut f&uuml;r Telematik</TITLE>
</HEAD>
<BODY BGCOLOR="#ffffff">
<img src="icons/uni/faklogo_de.gif"
ALT=" [Universit&auml;t Karlsruhe, Fakult&auml;t
   f&uuml;r Informatik] ">
```

HTTP 1.0 and mobility I

Characteristics

- stateless, client/server, request/response
- needs a connection oriented protocol (TCP), one connection per request (some enhancements in HTTP 1.1)
- primitive caching and security

Problems

- designed for large bandwidth (compared to wireless access) and low delay
- big and redundant protocol headers (readable for humans, stateless, therefore big headers in ASCII)
- uncompressed content transfer
- using TCP
  - huge overhead per request (3-way-handshake) compared with the content, e.g., of a GET request
  - slow-start problematic
- DNS lookup by client causes additional traffic

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HTTP 1.0 and mobility II

Caching

- quite often disabled by information providers to be able to create user profiles, usage statistics etc.
- dynamic objects cannot be cached
  - numerous counters, time, date, personalization, ...
- mobility quite often inhibits caches
- security problems
  - how to use SSL/TLS together with proxies?
- today: many user customized pages, dynamically generated on request via CGI, ASP, ...

POSTing (i.e., sending to a server)

- can typically not be buffered, very problematic if currently disconnected

Many unsolved problems!

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HTML and mobile devices

HTML

- designed for computers with “high” performance, color high-resolution display, mouse, hard disk
- typically, web pages optimized for design, not for communication

Mobile devices

- often only small, low-resolution displays, very limited input interfaces (small touch-pads, soft-keyboards)

Additional “features”

- animated GIF, Java AWT, Frames, ActiveX Controls, Shockwave, movie clips, audio, ...
- many web pages assume true color, multimedia support, high-resolution and many plug-ins

Web pages ignore the heterogeneity of end-systems!

- e.g., without additional mechanisms, large high-resolution pictures would be transferred to a mobile phone with a low-resolution display causing high costs

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Approaches toward WWW for mobile devices

Application gateways, enhanced servers

- simple clients, pre-calculations in the fixed network
- compression, filtering, content extraction
- automatic adaptation to network characteristics

Examples

- picture scaling, color reduction, transformation of the document format (e.g., PS to TXT)
- detail studies, clipping, zoom
- headline extraction, automatic abstract generation
- HDML (handheld device markup language): simple language similar to HTML requiring a special browser
- HDTP (handheld device transport protocol): transport protocol for HDML, developed by Unwired Planet

Problems

- proprietary approaches, require special enhancements for browsers
- heterogeneous devices make approaches more complicated

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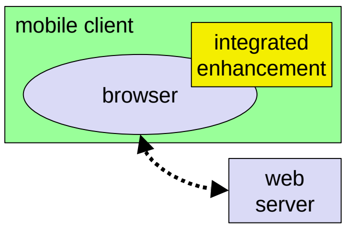
Some new issues that might help mobility?

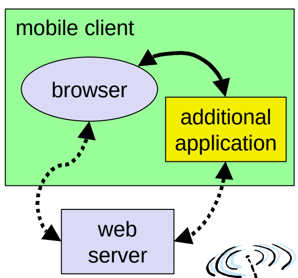
- Push technology
  - real pushing, not a client pull needed, channels etc.
- HTTP/1.1
  - client/server use the same connection for several request/response transactions
  - multiple requests at beginning of session, several responses in same order
  - enhanced caching of responses (useful if equivalent responses!)
  - semantic transparency not always achievable: disconnected, performance, availability -> most up-to-date version...
  - several more tags and options for controlling caching (public/private, max-age, no-cache etc.)
  - relaxing of transparency on app. request or with warning to user
  - encoding/compression mechanism, integrity check, security of proxies, authentication, authorization...
- Cookies: well..., stateful sessions, not really integrated...

System support for WWW in a mobile world I

Enhanced browsers
- Pre-fetching, caching, off-line use
- e.g. Internet Explorer



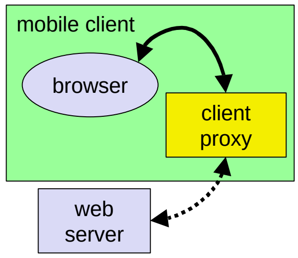
Additional, accompanying application
- Pre-fetching, caching, off-line use
- e.g. original WebWhacker



System support for WWW in a mobile world II

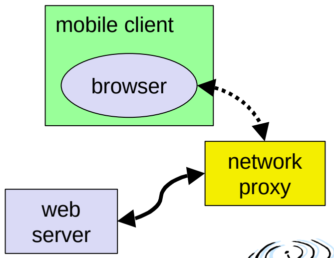
Client Proxy

- Pre-fetching, caching, off-line use
- e.g., Caubweb, TeleWeb, Weblicator, WebWhacker, WebEx, WebMirror, ...



Network Proxy

- adaptive content transformation for bad connections, pre-fetching, caching
- e.g., TranSend, Digestor



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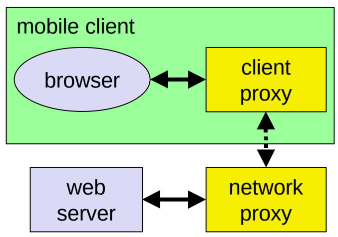
System support for WWW in a mobile world III

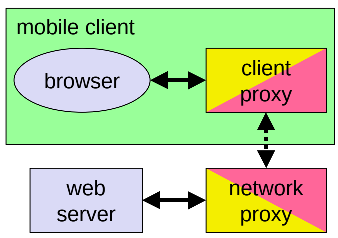
Client and network proxy

- combination of benefits plus simplified protocols
- e.g., MobiScape, WebExpress



Special network subsystem

- adaptive content transformation for bad connections, pre-fetching, caching
- e.g., Mowgli



Additional many proprietary server extensions possible

- “channels”, content negotiation, ...

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WAP - Wireless Application Protocol

Goals

- deliver Internet content and enhanced services to mobile devices and users (mobile phones, PDAs)
- independence from wireless network standards
- open for everyone to participate, protocol specifications will be proposed to standardization bodies
- applications should scale well beyond current transport media and device types and should also be applicable to future developments

Platforms

- e.g., GSM (900, 1800, 1900), CDMA IS-95, TDMA IS-136, 3rd generation systems (IMT-2000, UMTS, W-CDMA)

Forum

- WAP Forum, co-founded by Ericsson, Motorola, Nokia, Unwired Planet
- further information http://www.wapforum.org

WAP - scope of standardization

Browser

- “micro browser”, similar to existing, well-known browsers in the Internet

Script language

- similar to Java script, adapted to the mobile environment

WTA/WTAI

- Wireless Telephony Application (Interface): access to all telephone functions

Content formats

- e.g., business cards (vCard), calendar events (vCalender)

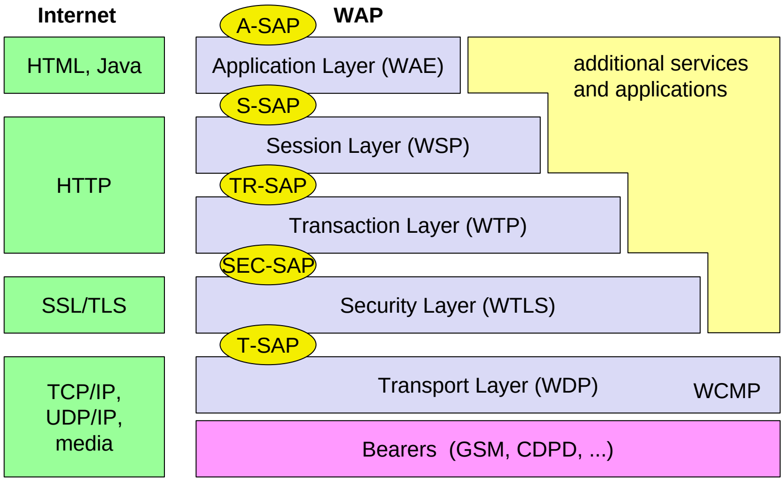
Protocol layers

- transport layer, security layer, session layer etc.

Working Groups

- WAP Architecture Working Group, WAP Wireless Protocol Working Group, WAP Wireless Security Working Group, WAP Wireless Application Working Group

WAP - reference model and protocols



WAE comprises WML (Wireless Markup Language), WML Script, WTAI etc.

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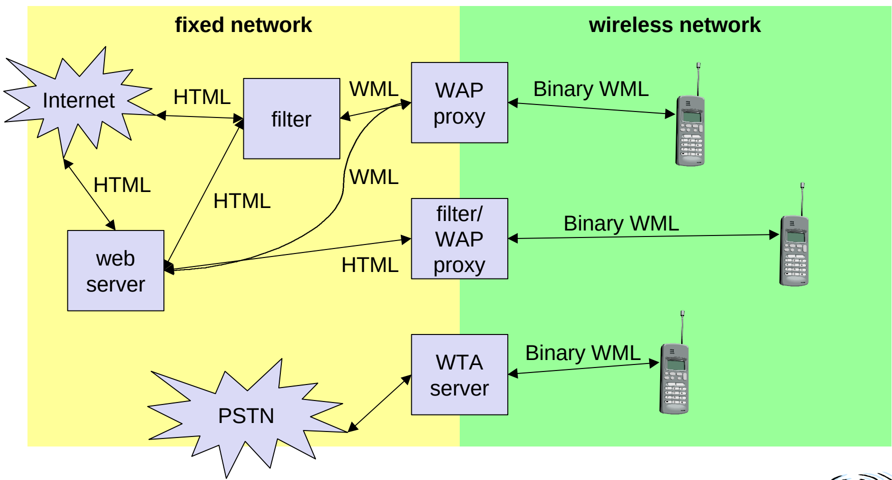
WAP - network elements



Binary WML: binary file format for clients

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WDP - Wireless Datagram Protocol

Protocol of the transport layer within the WAP architecture

- uses directly transports mechanisms of different network technologies
- offers a common interface for higher layer protocols
- allows for transparent communication using different transport technologies

Goals of WDP

- create a worldwide interoperable transport system with the help of WDP adapted to the different underlying technologies
- transmission services such as SMS in GSM might change, new services can replace the old ones

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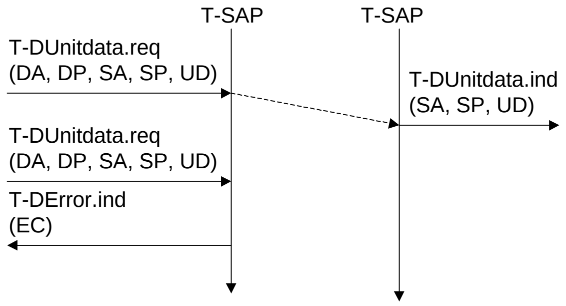
WDP - Service Primitives



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WTLS - Wireless Transport Layer Security

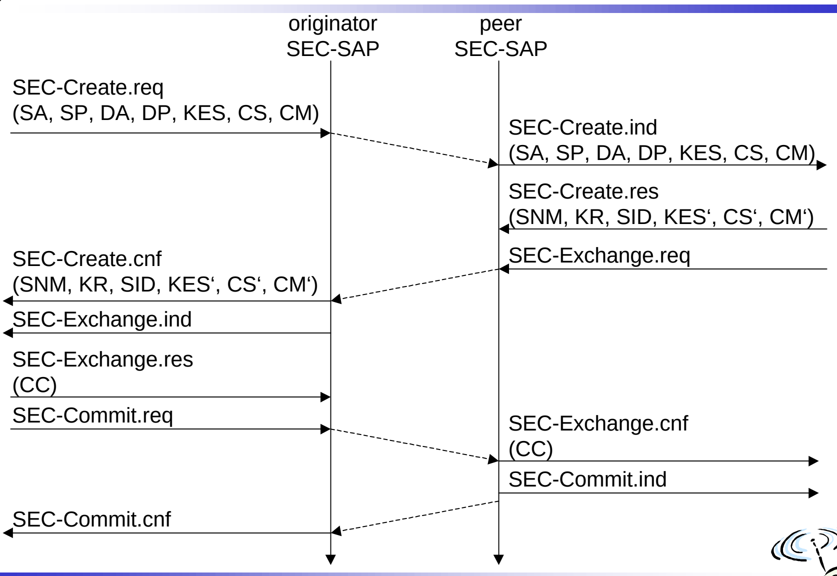
Goals

- data integrity
  - prevention of changes in data
- privacy
  - prevention of tapping
- authentication
  - creation of authenticated relations between a mobile device and a server
- protection against denial-of-service attacks
  - protection against repetition of data and unverified data

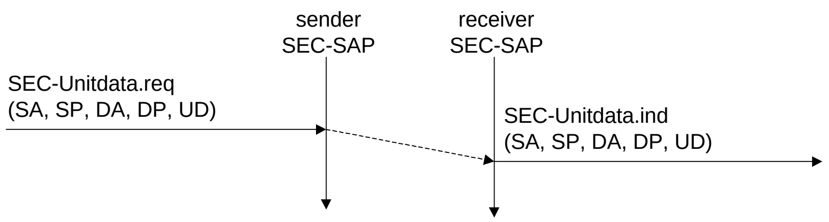
WTLS

- is based on the TLS (Transport Layer Security) protocol (former SSL, Secure Sockets Layer)
- optimized for low-bandwidth communication channels

Secure session, full handshake



SEC-Unitdata - transferring datagrams



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WTP - Wireless Transaction Protocol

Goals

- different transaction services, offloads applications
  - application can select reliability, efficiency
- support of different communication scenarios
  - *class 0:* unreliable message transfer
  - *class 1:* reliable message transfer without result message
  - *class 2:* reliable message transfer with exactly one reliable result message
- supports peer-to-peer, client/server and multicast applications
- low memory requirements, suited to simple devices (< 10kbyte)
- efficient for wireless transmission
  - segmentation/reassembly
  - selective retransmission
  - header compression
  - optimized connection setup (setup with data transfer)

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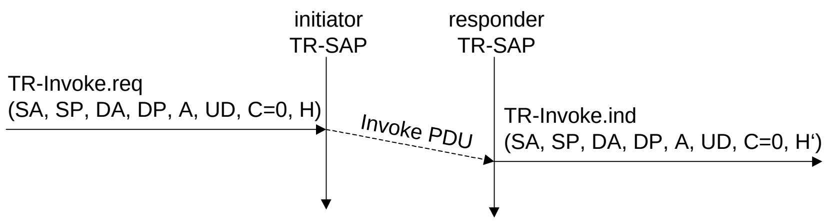
WTP Class 0 transaction



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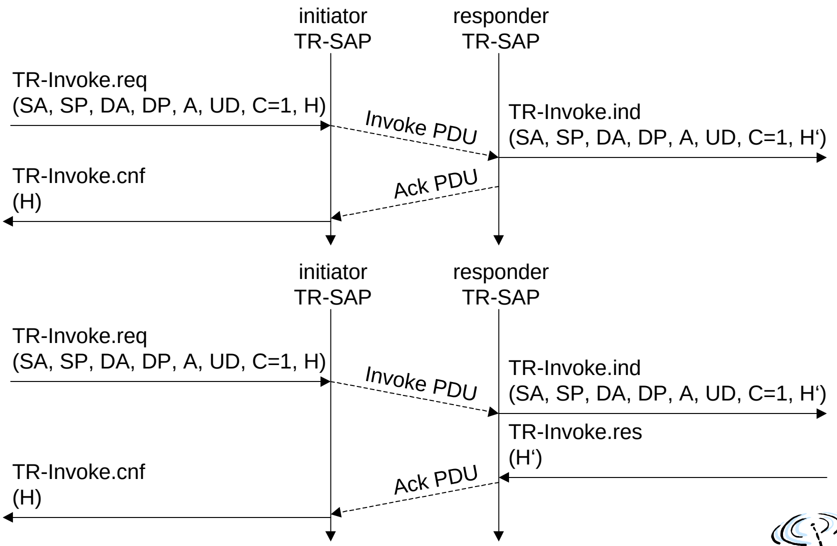
WTP Class 1 transaction, no user ack & user ack



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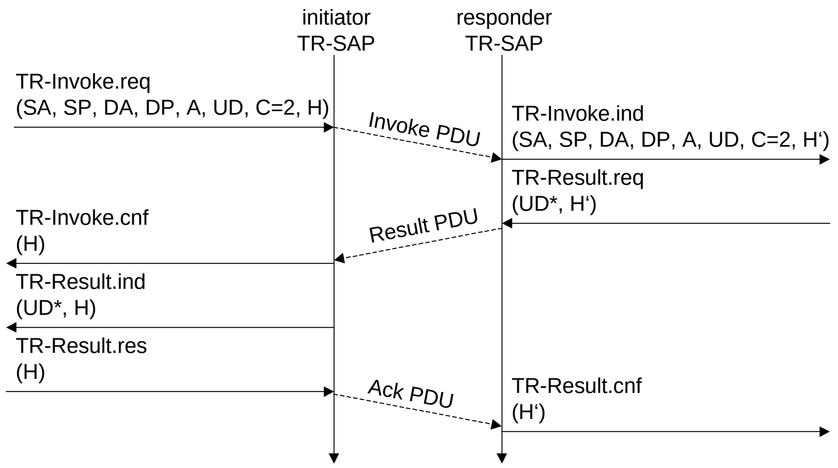
WTP Class 2 transaction, no user ack, no hold on



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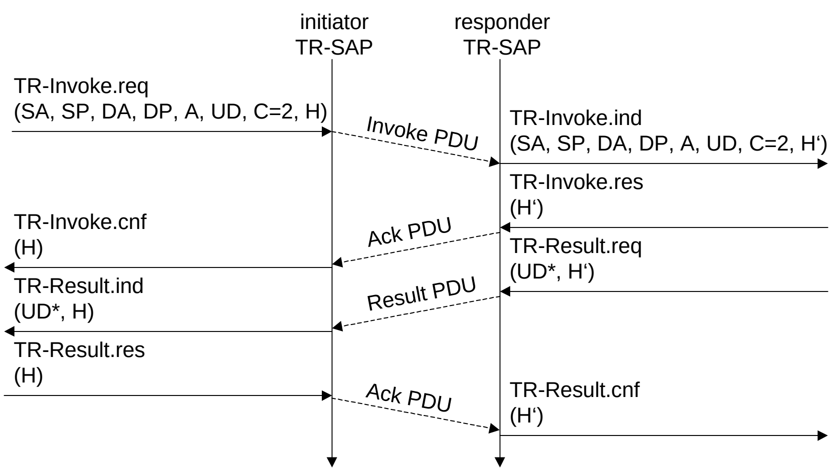
WTP Class 2 transaction, user ack



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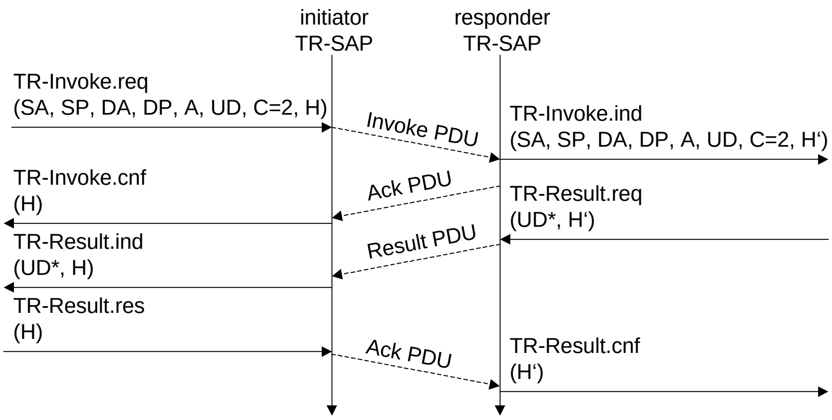
WTP Class 2 transaction, hold on, no user ack



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WSP - Wireless Session Protocol

Goals
- HTTP 1.1 functionality
  - Request/reply, content type negotiation, ...
- support of client/server, transactions, push technology
- key management, authentication, Internet security services
- session management (interruption, resume,...)

Services
- session management (establish, release, suspend, resume)
- capability negotiation
- content encoding

WSP/B (Browsing)
- HTTP/1.1 functionality - but binary encoded
- exchange of session headers
- push and pull data transfer
- asynchronous requests

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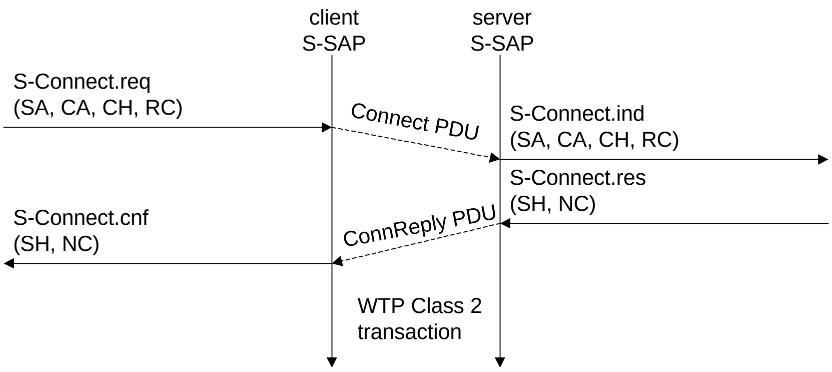
WSP/B session establishment



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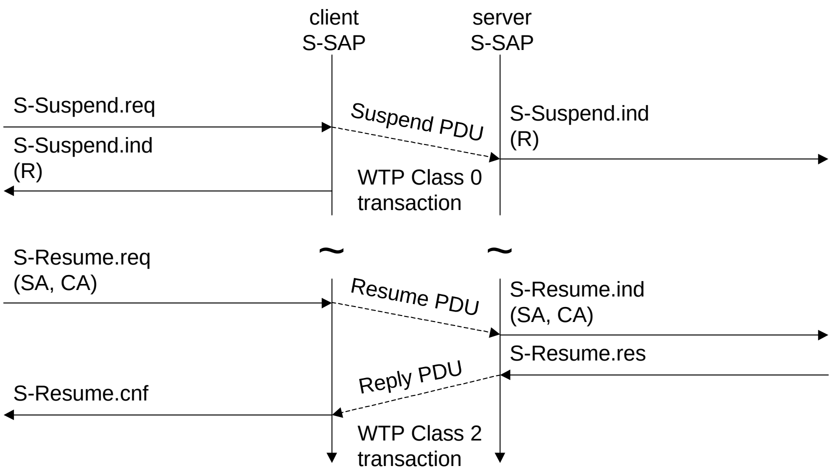
WSP/B session suspend/resume



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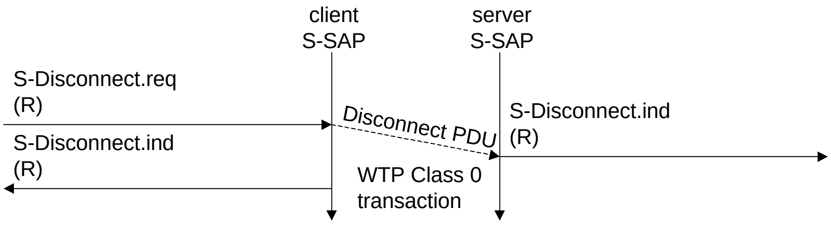
WSP/B session termination



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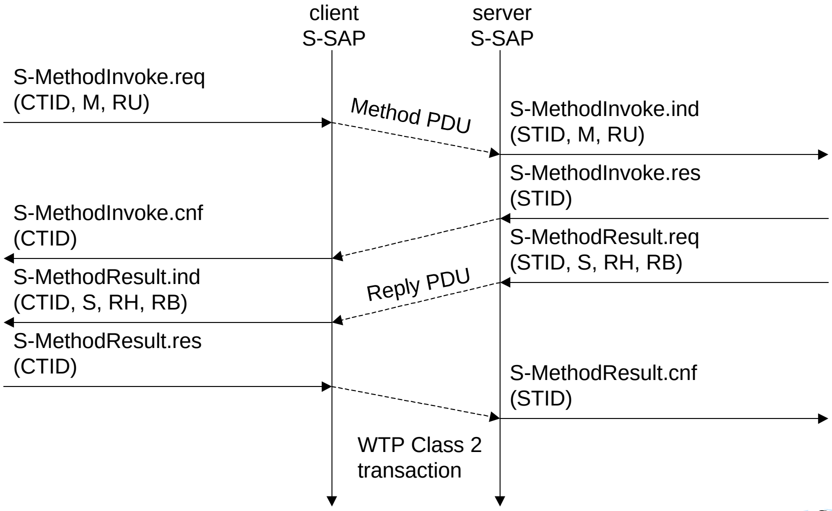
WSP/B method invoke



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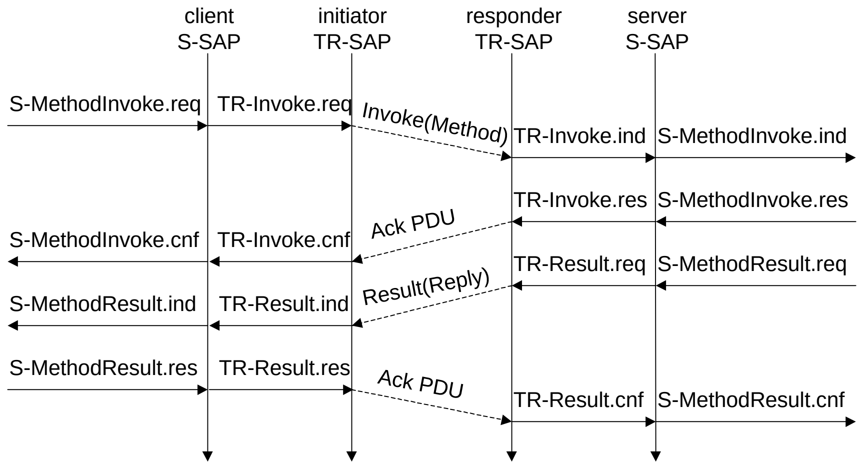
WSP/B over WTP - method invocation



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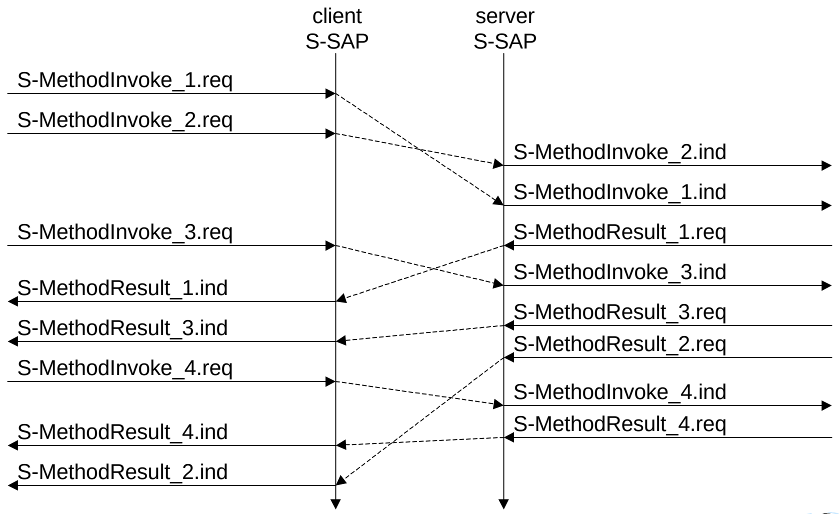
WSP/B over WTP - asynchronous, unordered requests



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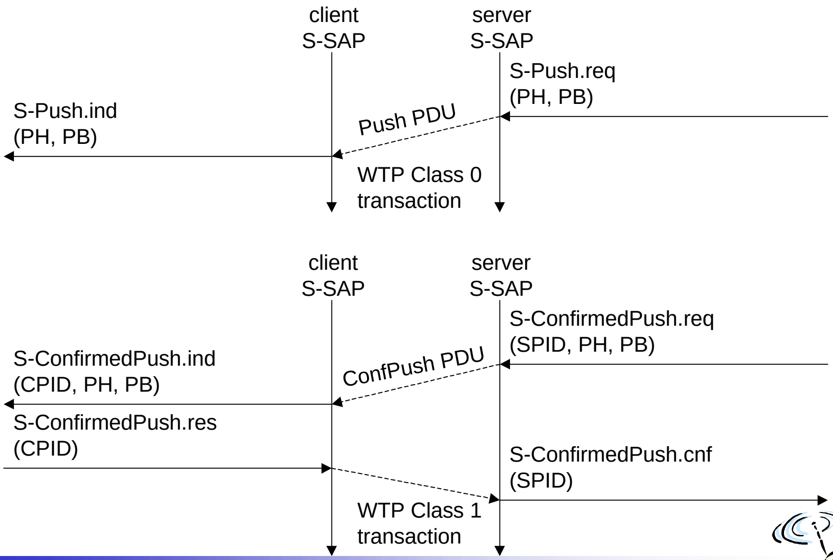
WSP/B - confirmend/non-confirmed push



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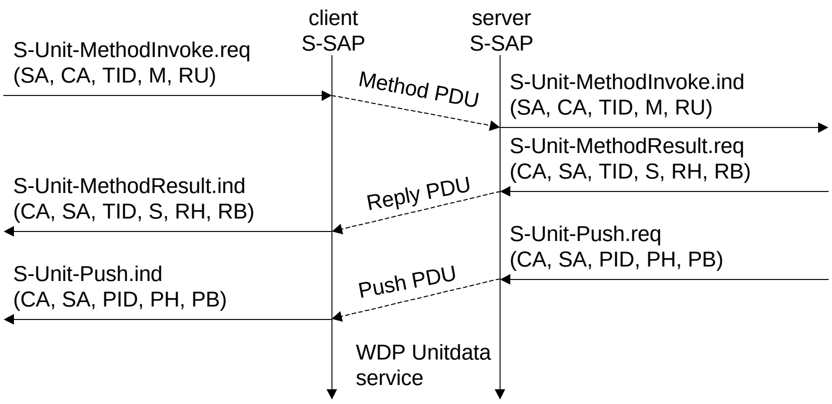
WSP/B over WDP



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WAE - Wireless Application Environment

Goals

- network independent application environment for low-bandwidth, wireless devices
- integrated Internet/WWW programming model with high interoperability

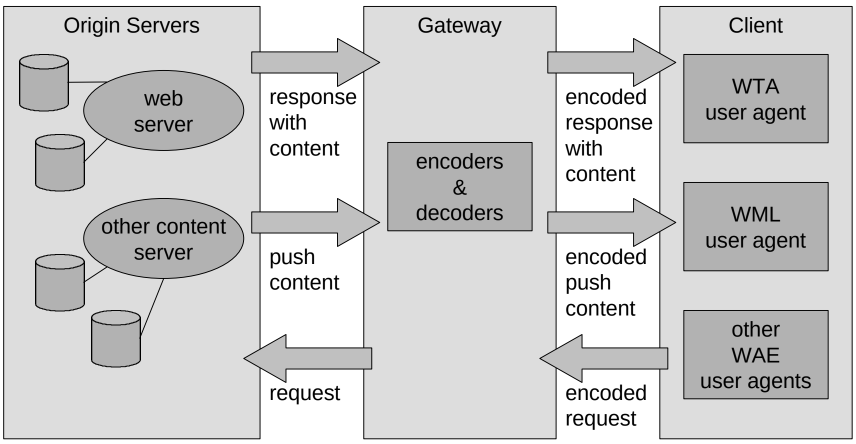
Requirements

- device and network independent, international support
- manufacturers can determine look-and-feel, user interface
- considerations of slow links, limited memory, low computing power, small display, simple user interface (compared to desktop computers)

Components

- architecture: application model, browser, gateway, server
- WML: XML-Syntax, based on card stacks, variables, ...
- WMLScript: procedural, loops, conditions, ... (similar to JavaScript)
- WTA: telephone services, such as call control, text messages, phone book, ... (accessible from WML/WMLScript)
- content formats: vCard, vCalendar, Wireless Bitmap, WML, ...

WAE logical model



Wireless Markup Language (WML)

WML follows deck and card metaphor

- WML document consists of many cards, cards are grouped to decks
- a deck is similar to an HTML page, unit of content transmission
- WML describes only intent of interaction in an abstract manner
- presentation depends on device capabilities

Features

- text and images
- user interaction
- navigation
- context management

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WML - example

```
<WML>
   <CARD>
        <DO TYPE="ACCEPT">
                <GO URL="#card_two"/>
        </DO>
        This is a simple first card!
        On the next you can choose ...
   </CARD>
   <CARD NAME="card_two">
        ... your favorite pizza:
        <SELECT KEY="PIZZA">
                <OPTION VALUE=”M”>Margherita</OPTION>
                <OPTION VALUE=”F”>Funghi</OPTION>
                <OPTION VALUE=”V”>Vulcano</OPTION>
        </SELECT>
   </CARD>
</WML>
```

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WMLScript

Complement to WML

Provides general scripting capabilities

Features

- validity check of user input
  - check input before sent to server
- access to device facilities
  - hardware and software (phone call, address book etc.)
- local user interaction
  - interaction without round-trip delay
- extensions to the device software
  - configure device, download new functionality after deployment

WMLScript - example

```
function pizza_test(pizza_type) {
   var taste = "unknown";
   if (pizza_type = "Margherita") {
        taste = "well... ";
   }
   else {
        if (pizza_type = "Vulcano") {
                taste = "quite hot";
        };
   };
   return taste;
};
```

Wireless Telephony Application (WTA)

Collection of telephony specific extensions

Extension of basic WAE application model

- content push
  - server can push content to the client
  - client may now be able to handle unknown events
- handling of network events
  - table indicating how to react on certain events from the network
- access to telephony functions
  - any application on the client may access telephony functions

Example

- calling a number (WML)
  `wtai://wp/mc;07216086415`
- calling a number (WMLScript)
  `WTAPublic.makeCall("07216086415");`

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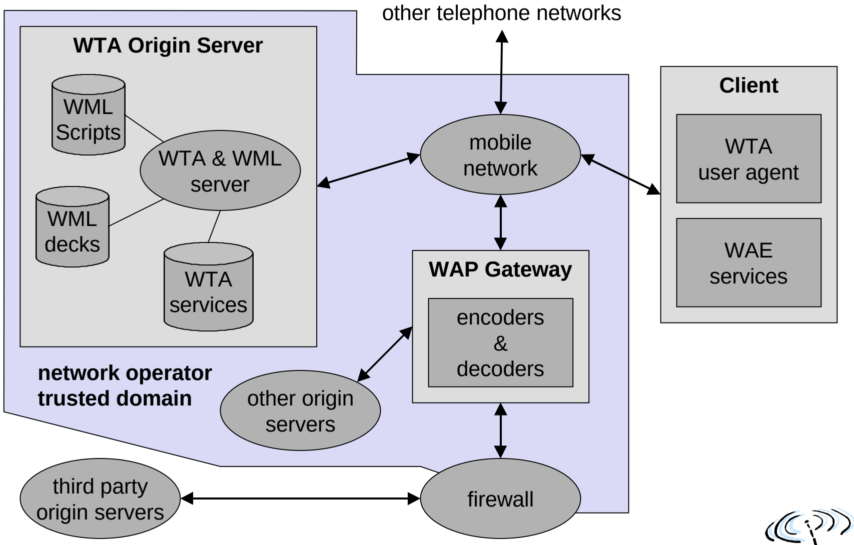
WTA logical architecture



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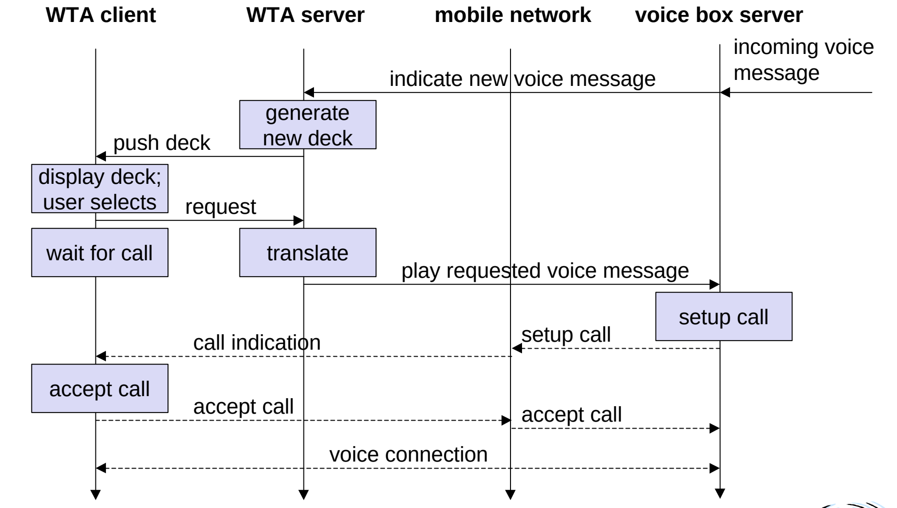
Voice box example



WTAI - example with WML only

```
<WML>
   <CARD>
        <DO TYPE="ACCEPT" TASK="GO" URL="#voteChamp"/>
        Please vote for your champion!
   </CARD>

   <CARD NAME="voteChamp">
        <DO TYPE="ACCEPT" TASK="GO" URL="wtai://cc/sc;$voteNo;1"/>
        Please choose:
        <SELECT KEY="voteNo">
               <OPTION VALUE="6086415">Mickey</OPTION>
               <OPTION VALUE="6086416">Donald</OPTION>
               <OPTION VALUE="6086417">Pluto</OPTION>
        </SELECT>
   </CARD>
</WML>
```

WTAI - example with WML and WMLScript I

```
function voteCall(Nr) {
   var j = WTACallControl.setup(Nr,1);
   if (j>=0) {
        WMLBrowser.setVar("Message", "Called");
        WMLBrowser.setVar("No", Nr);
   }
   else {
        WMLBrowser.setVar("Message", "Error!");
        WMLBrowser.setVar("No", j);
   }
   WMLBrowser.go("showResult");
}
```

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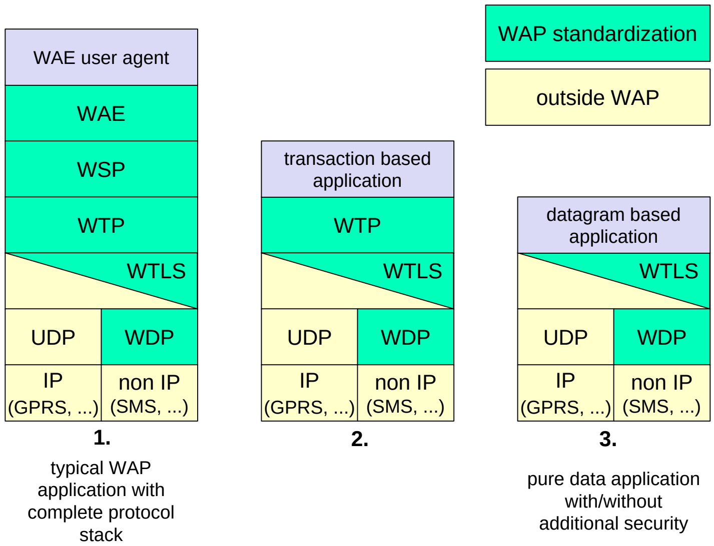
WTAI - example with WML and WMLScript II

```
<WML>
   <CARD>
        <DO TYPE="ACCEPT" TASK="GO" URL="#voteChamp"/>
   Please vote for your champion!
   </CARD>
   <CARD NAME="voteChamp">
        <DO TYPE="ACCEPT" TASK="GO" URL="/script#voteCall($voteNo)"/>
        Please choose:
        <SELECT KEY="voteNo">
                <OPTION VALUE="6086415">Mickey</OPTION>
                <OPTION VALUE="6086416">Donald</OPTION>
                <OPTION VALUE="6086417">Pluto</OPTION>
        </SELECT>
   </CARD>
   <CARD NAME="showResult">
        Status of your call: $Message $No
   </CARD>
</WML>
```

Mobile Communications: Support for Mobility 11.55.1

Examples for WAP protocol stacks



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