192620010
Mobile & Wireless Networking

Lecture 1:
Introduction & Wireless Transmission (1/2)

[Schiller, Section 1 & Section 2.1 - 2.5]

Geert Heijenk

Outline of Lecture 1

- Introduction
  - About the course “Mobile & Wireless Networking”
  - History
  - Current Wireless Technologies
  - Important trends

- Wireless Transmission (1/2)
  - Frequencies
  - Signals
  - Antennas
  - Signal Propagation
  - Multiplexing

Why Mobile and Wireless Networking?

- Largest SW/HW/networked system
- Largest number of subscribers
- Mobile devices dominate the Internet
- Mobile applications dominate Internet usage
- New possibilities, new threats
- Technology fully integrated into everybody's life almost 24/7, almost anywhere

Mobile & Wireless Networking

- Mobile
  - user can use network services while moving
    - w.r.t. point of attachment to network
    - Usually user is moving with his/her networking device
- Wireless
  - communications without using a wire
    - directly between two user nodes, or
    - (often) between user node and access point connected to the fixed (wired) network
- Networking
  - roughly, all architectures, protocols, and algorithms at the
    - link layer (mostly medium access control, MAC)
    - network layer, and
    - transport layer
    - (we will briefly address physical layer as well)

What is different in wireless networks?

- Higher loss-rates
- Restrictive spectrum regulations
- Lower transmission rates
- Higher delays, higher jitter
- Lower security
- Shared and unbound medium
- Mobility
  - change of point of attachment to network
  - how to find a user / device
- Limitations of access devices
  - battery power

Course Outline (Mobile & Wireless Networking, M&WN)

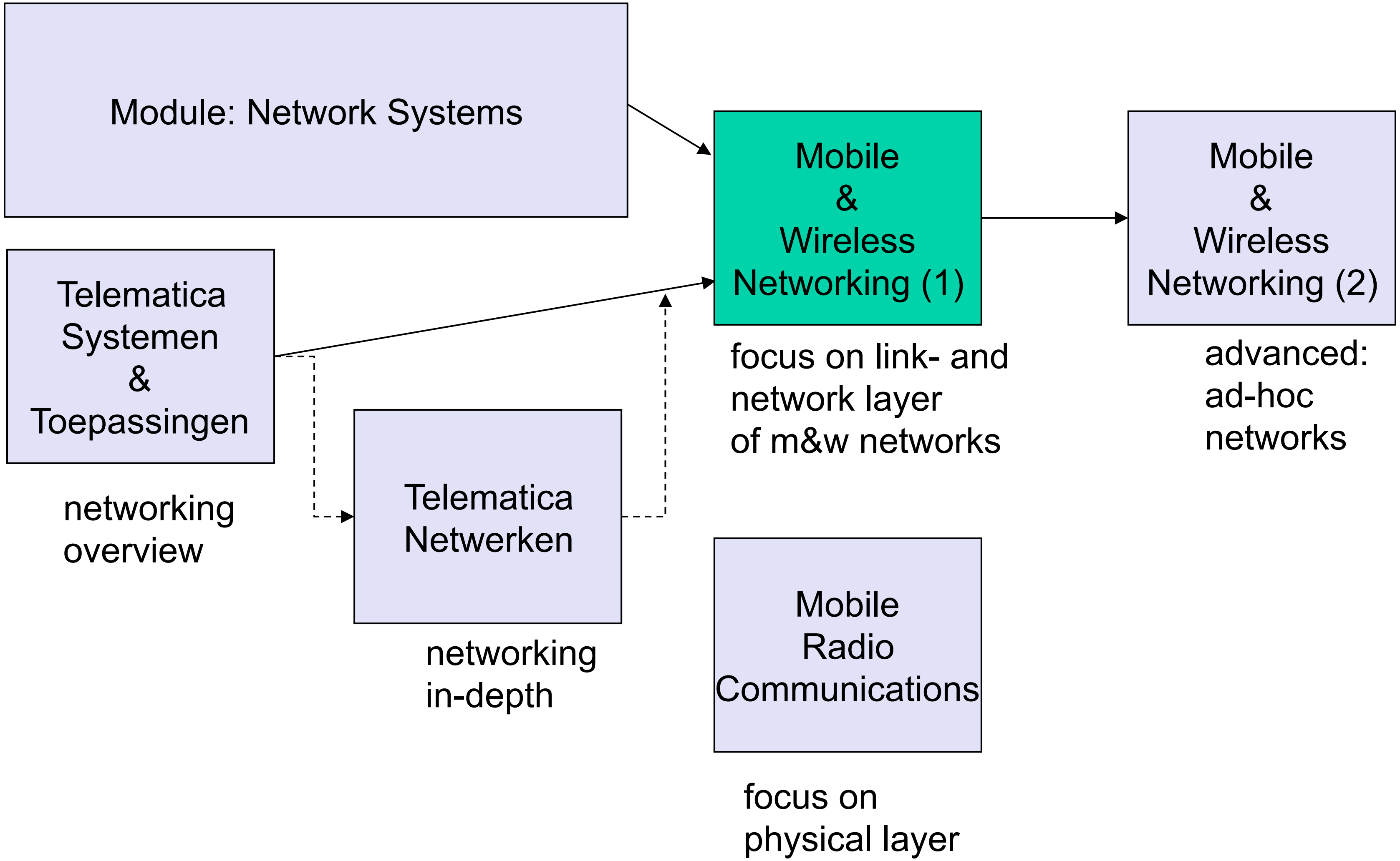
Basic principles:

- Physical layer: propagation, multiplexing, modulation, spread spectrum, OFDM
- MAC layer: hidden terminals, medium access, random access, CDMA, Hybrid ARQ
- Cellular concepts: cell layout, interference
- Dealing with mobility: handover, mobility management
- Transport layer: problems with TCP over wireless
- Ad-hoc networks: problems of ad-hoc routing

Systems:

- Cellular: UMTS, LTE
- Wireless LAN: IEEE 802.11a/b/g/e/n/ac
- Low power / short range systems: Bluetooth, Zigbee
- Mobile IP: + Hierarchical Mobile IP, Fast Handovers for Mobile IP
- Ad-hoc routing: DSDV, DSR, AODV

Positioning Mobile & Wireless Networking



Course organization

See: http://www.cs.utwente.nl/~heijenk/mwn

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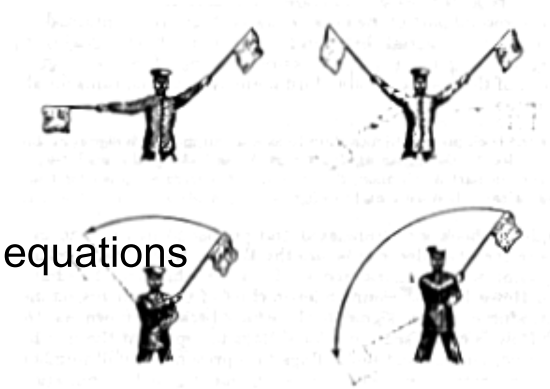
History of wireless communication



Many people in history used light for communication

Discovery of electromagnetic waves

- 1831 Faraday demonstrates electromagnetic induction
- 1864 J. Maxwell theory of electromagnetic fields, wave equations
- 1886 H. Hertz demonstration of the wave character of electrical transmission

Hertz: "*It's of no use whatsoever[...] this is just an experiment that proves Maestro Maxwell was right - we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there.”*

1895	Guglielmo Marconi, first demonstration of wireless telegraphy (long wave)
1907	Commercial transatlantic connections
1915	Wireless voice transmission New York - San Francisco
1920	Marconi, discovery of short waves
1928	many TV broadcast trials (across Atlantic, color TV, TV news)
1933	Frequency modulation (E. H. Armstrong)

History of wireless communication II

1956	First mobile phone system in Sweden
1972	B-Netz in Germany
1979	NMT at 450MHz (Scandinavian countries)
1982	Start of GSM-specification » goal: pan-European digital mobile phone system with roaming
1992	Start of GSM
1997	Wireless LAN - IEEE802.11
1998	Specification of UMTS (Universal Mobile Telecommunication System)
1998	Iridium: portable satellite telephony
1999	IEEE Standard 802.11b, 2.4 GHz, 11 Mbit/s Bluetooth, 2.4 GHz, < 1 Mbit/s

History of wireless communication III

2001	Start of 3G (Japan) UMTS trials in Europe
2002	Start of UMTS in Europe IEEE 802.11g mobile subscribers overtake fixed-line subscribers worldwide 1 billion cellular subscribers
2004	UMTS launch in Netherlands
2007	Introduction of iPhone
2009	IEEE 802.11n standard (December) First LTE Network (Stockholm / Oslo)
2012	6 billion cellular subscribers
2013	LTE launch in Netherlands (KPN, February, Amsterdam)

Current wireless technologies (1/2)

- Telecommunication Systems
  - initial / primary service: mobile voice telephony
  - large coverage per access point
    (100s of meters - 10s of kilometers)
  - low - moderate data rate
    (10s of kbit/s – 10s of Mbits/s)
  - Examples: GSM, UMTS, LTE
- WLAN
  - initial service: wireless ethernet extension
  - moderate coverage per access point
    (10s of meters - 100s of meters)
  - moderate - high data rate
    (Mbits/s - 100s of Mbits/s)
  - Examples: IEEE 802.11b, a, g, n, ac.
- Short-range
- Other systems

Current wireless technologies (2/2)

Short-range
- direct connection between devices (< 10s of meters)
- typical low power usage
- examples: Bluetooth, ZigBee

Other systems
- Satellite systems
  - global coverage,
  - applications
    - audio/TV broadcast; positioning
    - personal communications
- Broadcast systems
  - satellite/terrestrial
  - DVB, DAB (Support of high speeds for mobiles)
- Fixed wireless access
  - several technologies (DECT, WLAN, IEEE802.16 (11-60GHz))
- DECT
  - Digital Enhanced Cordless Telecommunication
- TETRA
  - Terrestrial Trunked Radio
  - Netherlands: C2000 system

Standardization

- 3GPP (3G partnership project)
  - GSM
  - UMTS
  - LTE
  - Specifications: http://www.3gpp.org/-specifications-
- IEEE (Institute of Electrical and Electronics Engineers)
  - 802.11 (Wireless LAN: WiFi)
  - 802.15 (Wireless PAN: Bluetooth, Zigbee)
  - 802.16 (Broadband Wireless Access: WiMAX))
  - Standards: http://standards.ieee.org/about/get/802/802.html
- IETF (Internet Engineering Task Force)
  - Mobile IP
  - TCP
  - AODV
  - Requests for Comments (RFCs): http://www.ietf.org/rfc.html

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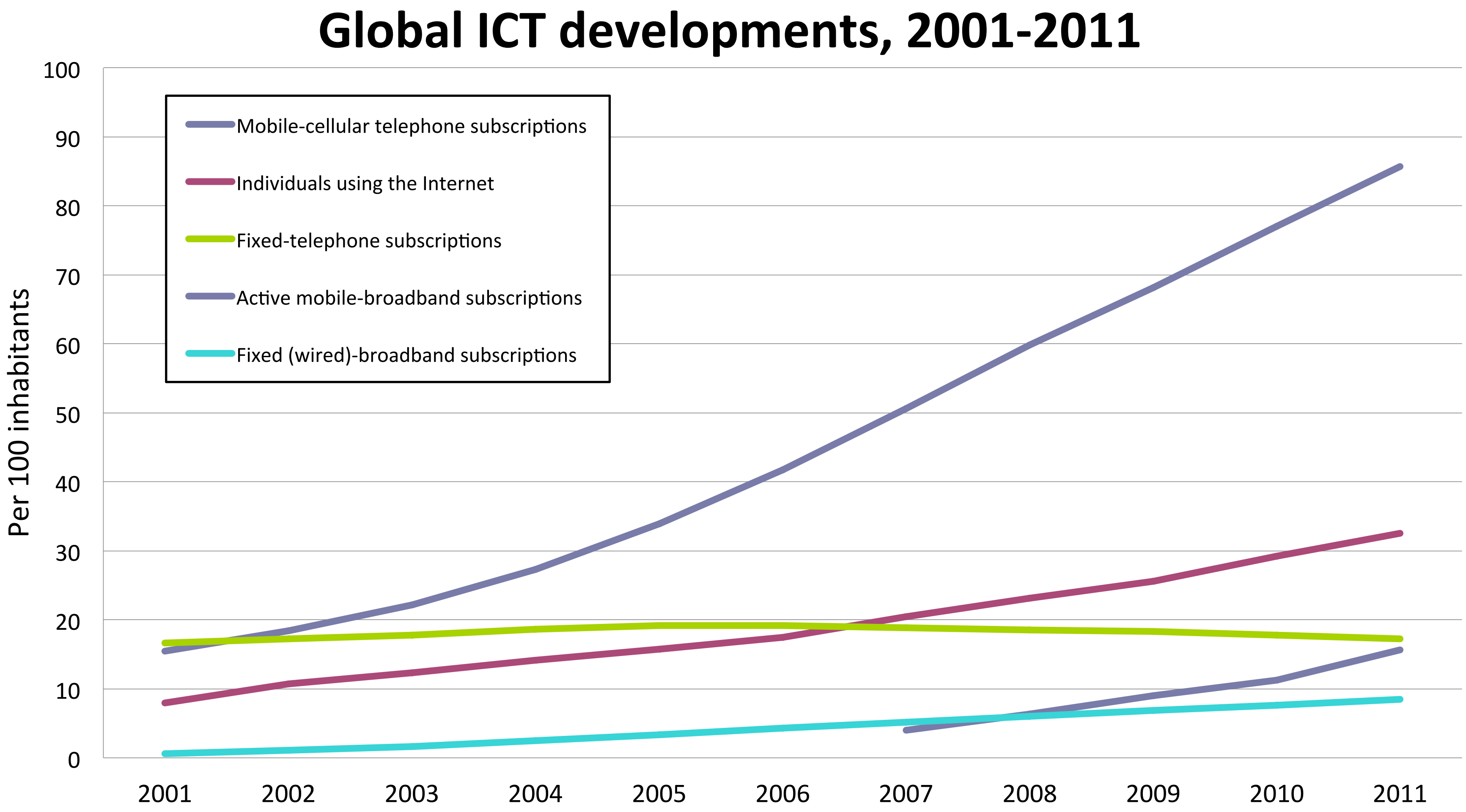
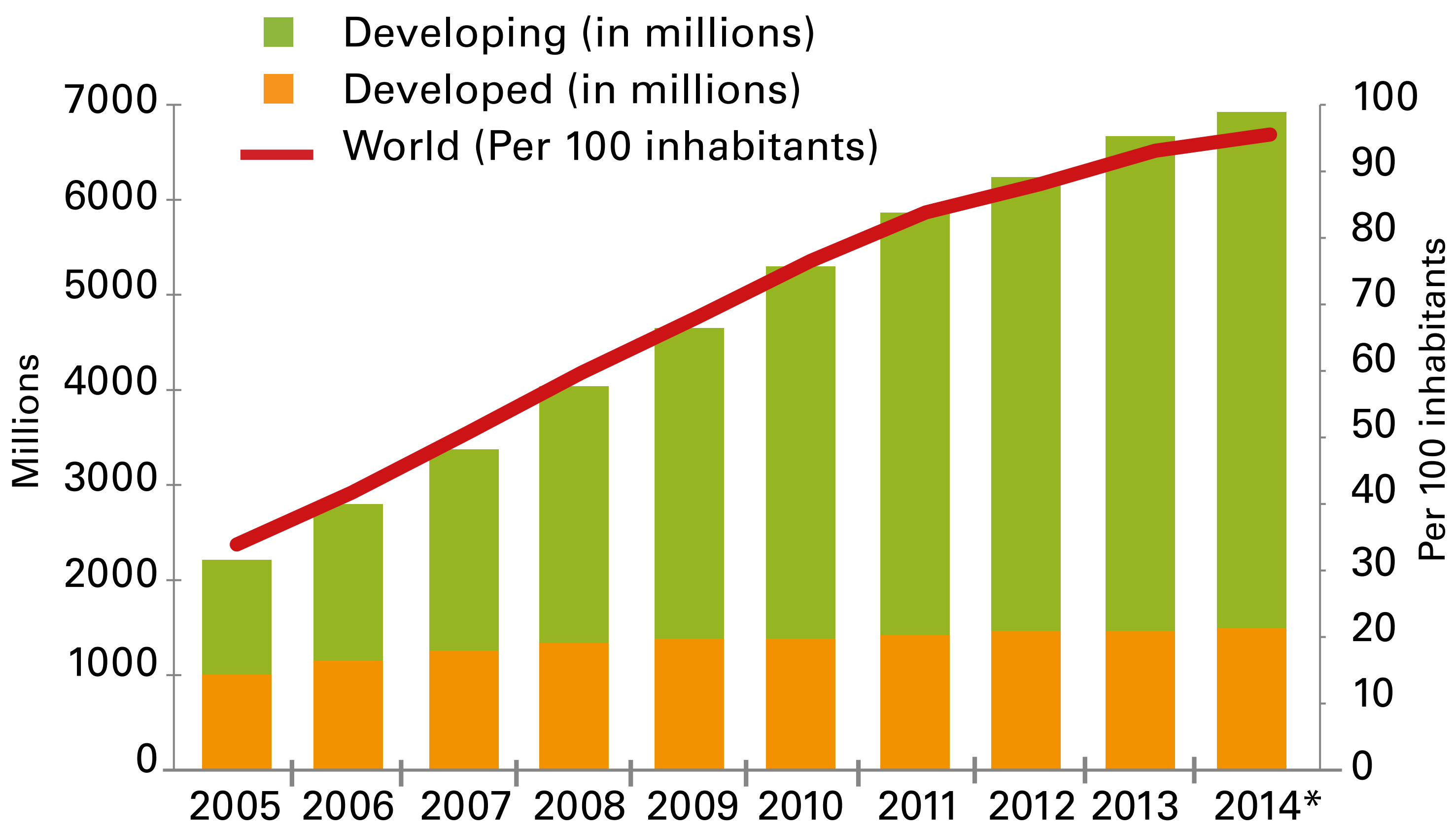
Mobile subscriptions



Source: ITU World Telecommunication /ICT Indicators database

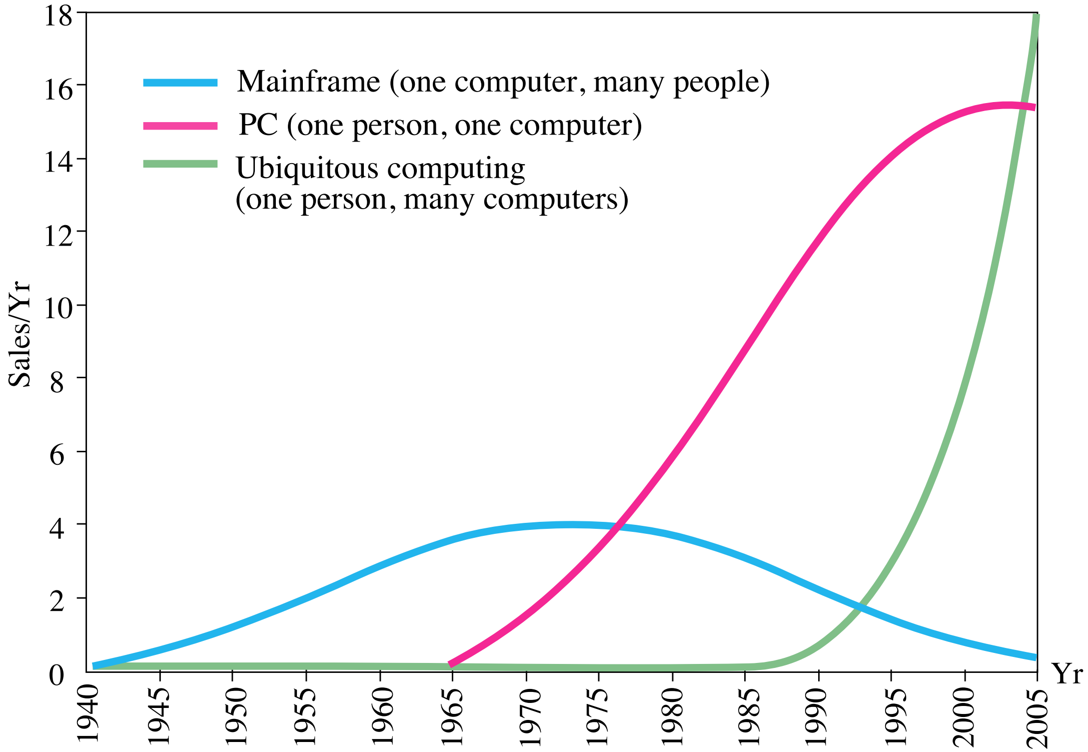
Mobile-cellular subscriptions total and per 100 inhabitants



Note: * Estimate

Source: ITU World Telecommunication/ICT Indicators database

Trends in computing

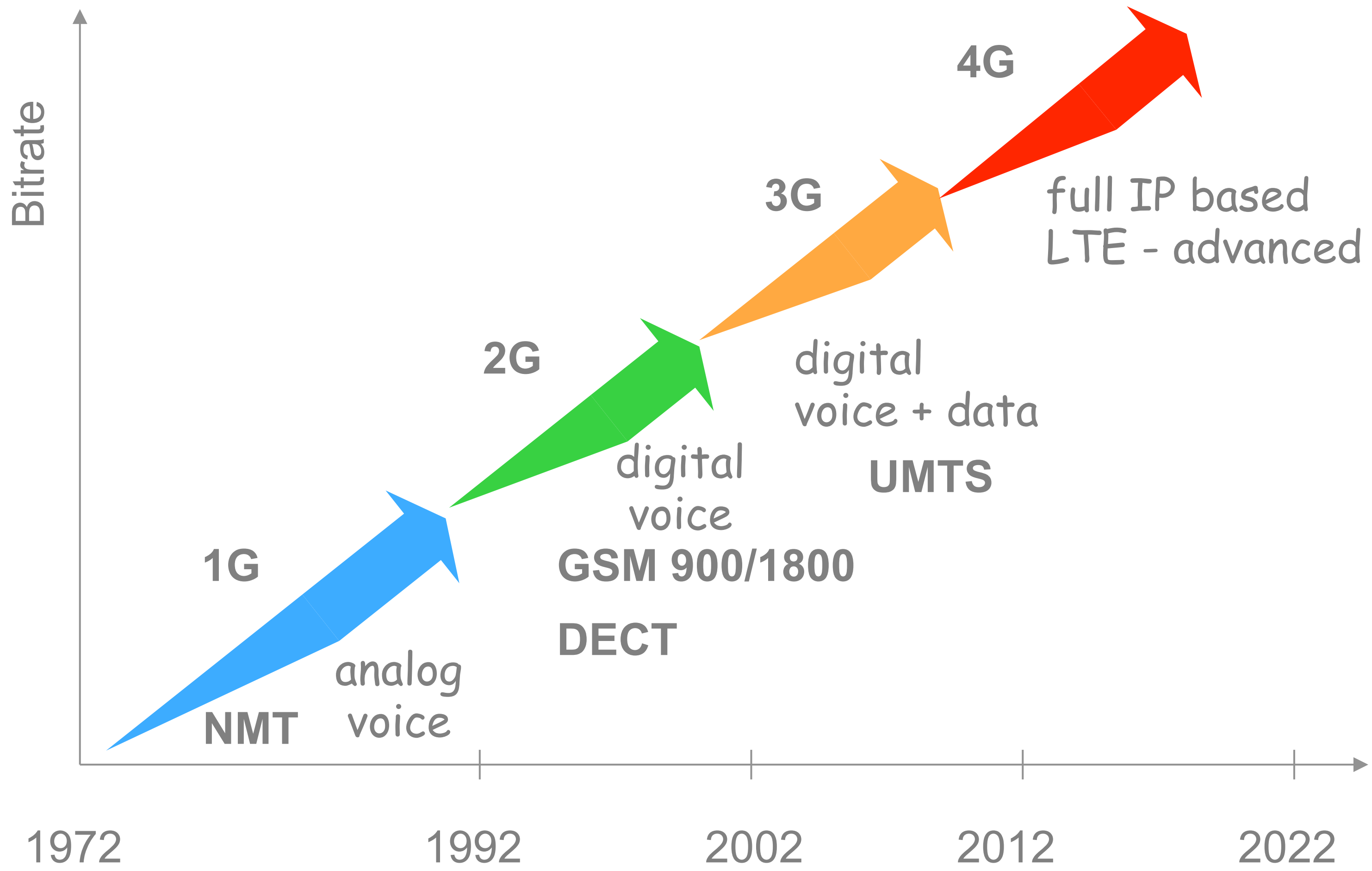


Source: Presentation by Marc Weiser "Nomadic issues in Ubiquitous computing", Xerox, Palo Alto. Research Center, 1996.

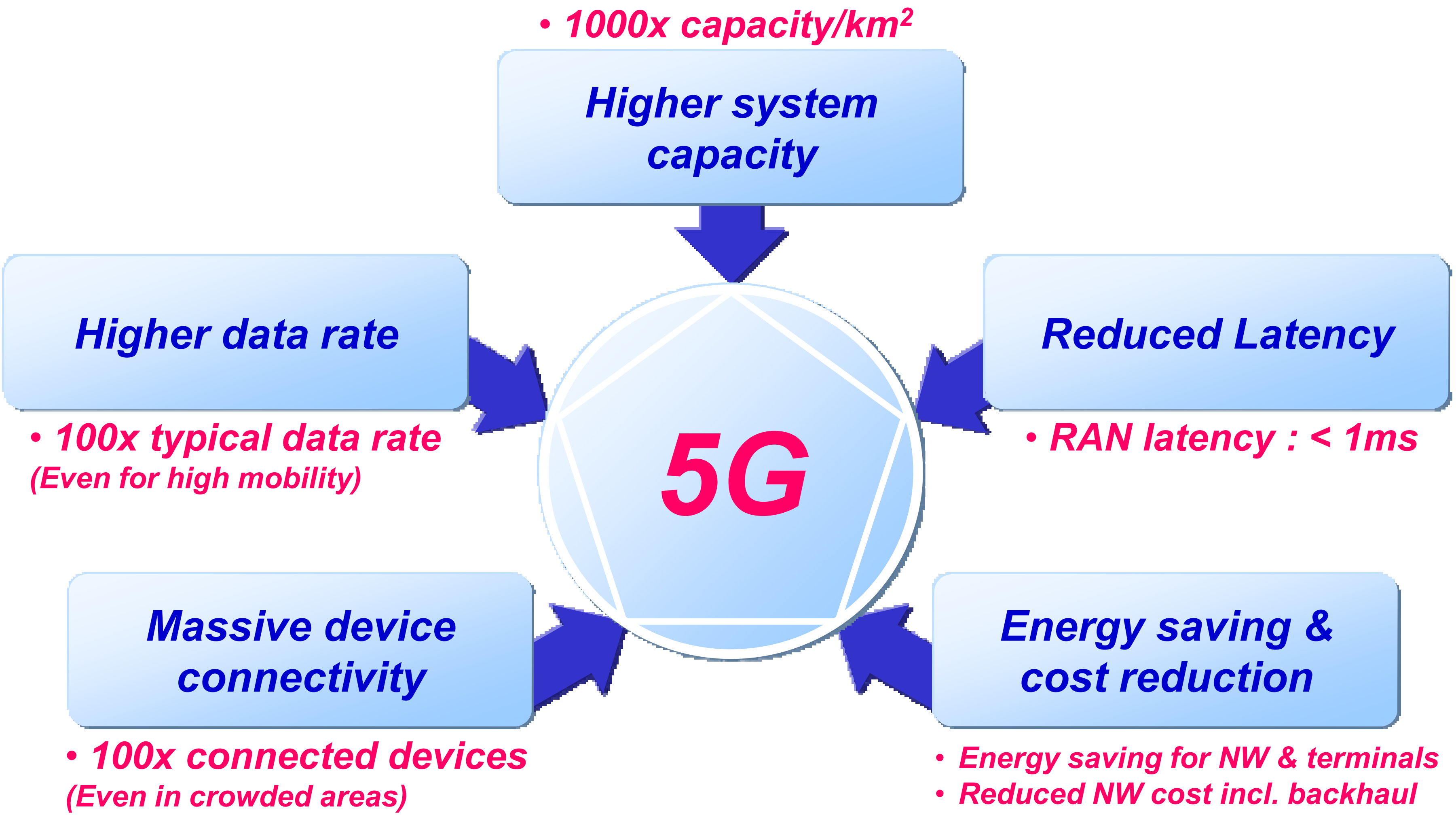
A proliferation of small, low-cost, embedded devices incorporating computing and communication capabilities

Moving towards pervasive computing

Evolution of mobile cellular systems

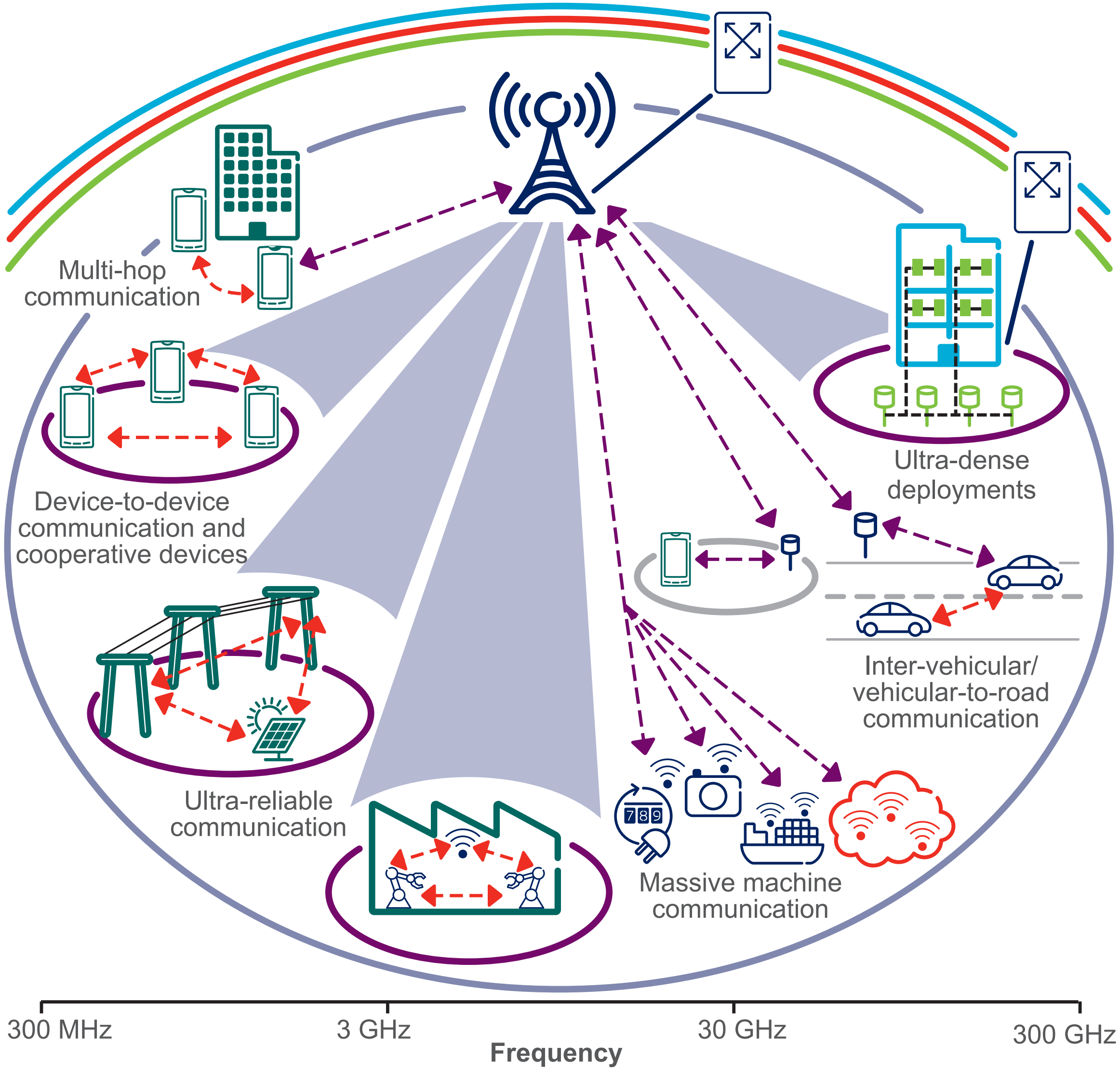


Towards 5G (1/2)



Source: 5G Radio Access: Requirements, Concept and Technologies, NTT DoCoMo, 2014.

Towards 5G (2/2)



Source: 5G Radio Access, Whitepaper, Ericsson, 2013.

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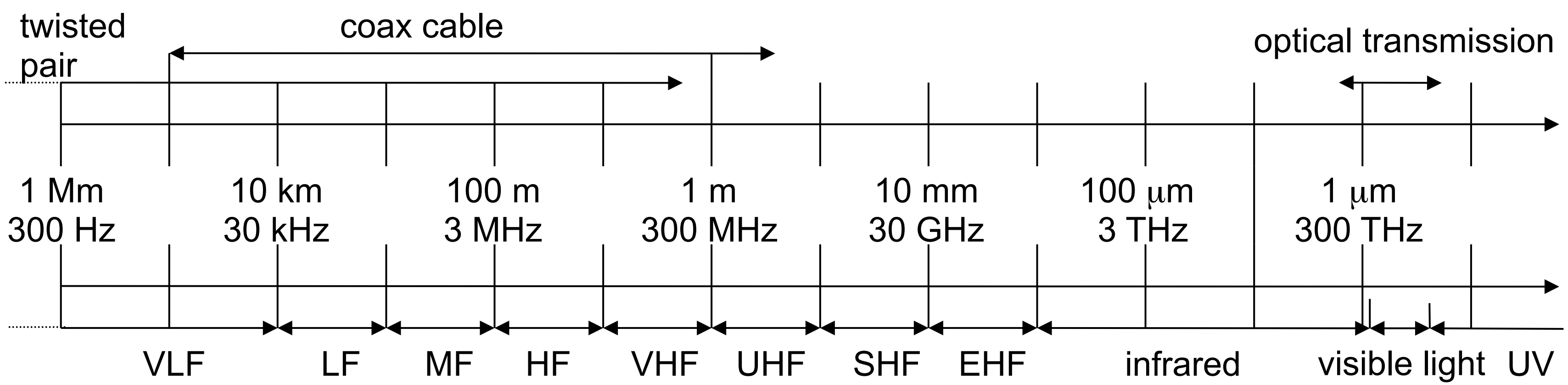
Frequencies for communication



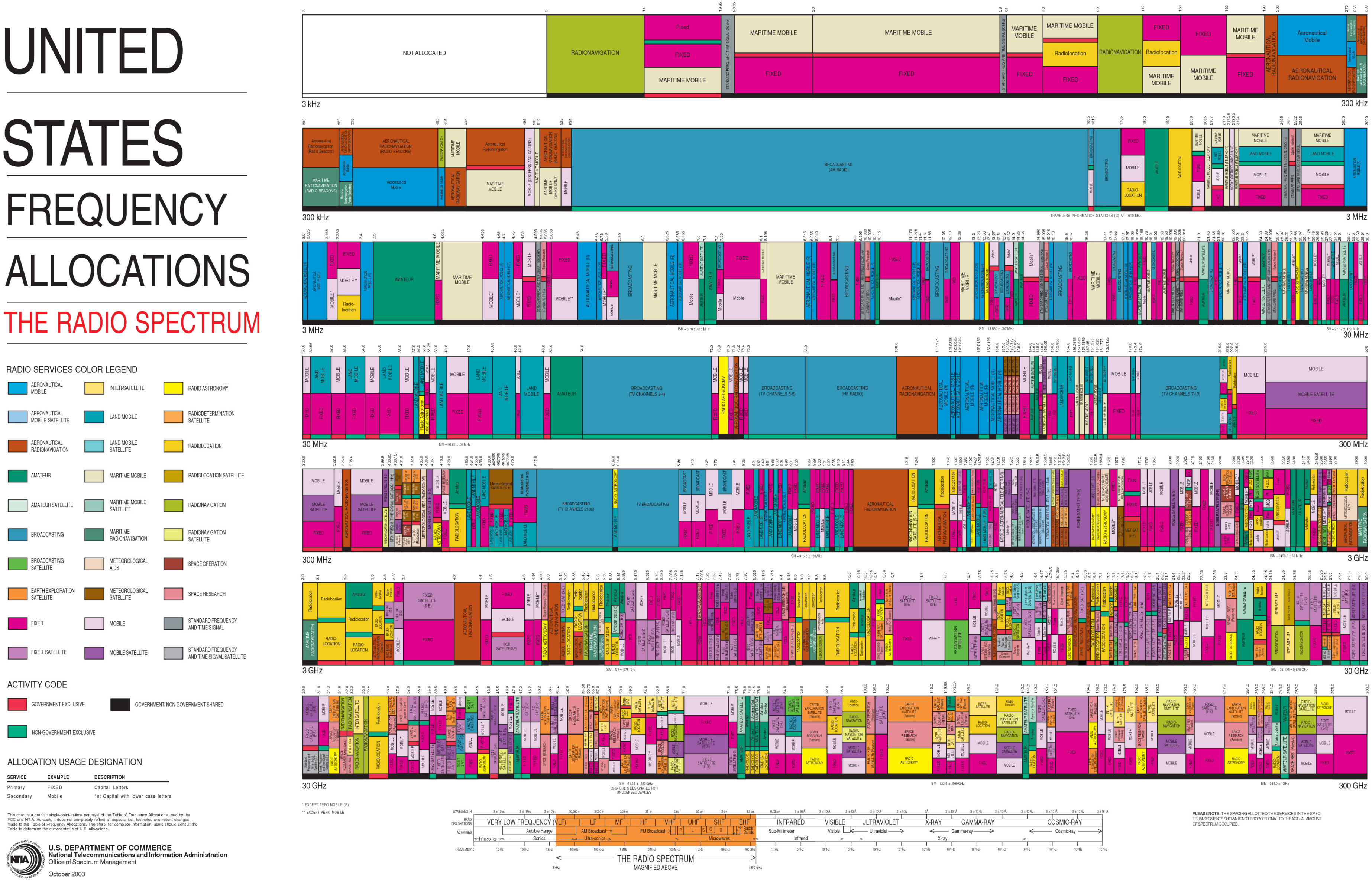
VLF = Very Low Frequency
LF = Low Frequency
MF = Medium Frequency
HF = High Frequency
VHF = Very High Frequency

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 $c \cong 3 \times 10^8$ m/s, frequency f


UNITED STATES FREQUENCY ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
AERONAUTICAL MOBILE
AERONAUTICAL MOBILE SATELLITE
AERONAUTICAL RADIONAVIGATION
AMATEUR
AMATEUR SATELLITE
BROADCASTING
BROADCASTING SATELLITE
EARTH EXPLORATION SATELLITE
FIXED
FIXED SATELLITE
INTER-SATELLITE
LAND MOBILE
LAND MOBILE SATELLITE
MARITIME MOBILE
MARITIME MOBILE SATELLITE
MARITIME RADIONAVIGATION
METEOROLOGICAL AIDS
METEOROLOGICAL SATELLITE
MOBILE
MOBILE SATELLITE
RADIO ASTRONOMY
RADIODETERMINATION SATELLITE
RADIOLOCATION
RADIOLOCATION SATELLITE
RADIONAVIGATION
RADIONAVIGATION SATELLITE
SPACE OPERATION
SPACE RESEARCH
STANDARD FREQUENCY AND TIME SIGNAL
STANDARD FREQUENCY AND TIME SIGNAL SATELLITE
ACTIVITY CODE
GOVERNMENT EXCLUSIVE
GOVERNMENT/NON-GOVERNMENT SHARED
NON-GOVERNMENT EXCLUSIVE
ALLOCATION USAGE DESIGNATION
SERVICE EXAMPLE DESCRIPTION
Primary FIXED Capital Letters
Secondary Mobile 1st Capital with lower case letters
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
October 2003
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz
NOT ALLOCATED
RADIONAVIGATION
BROADCASTING (AM RADIO)
BROADCASTING (TV CHANNELS 2-4)
BROADCASTING (FM RADIO)
BROADCASTING (TV CHANNELS 7-13)
BROADCASTING (TV CHANNELS 21-36)
TV BROADCASTING
THE RADIO SPECTRUM
MAGNIFIED ABOVE
VERY LOW FREQUENCY (VLF)
LF
MF
HF
VHF
UHF
SHF
EHF
INFRARED
VISIBLE
ULTRAVIOLET
X-RAY
GAMMA-RAY
COSMIC-RAY

Frequencies for mobile communication

- UHF-ranges for mobile cellular systems
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antenna, focusing
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF spectrum
  - some systems planned up to EHF
  - limitations due to absorption by water (>5 GHz) and oxygen (60 GHz) molecules (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.

Licensed vs Unlicensed bands

- Mobile cellular typically uses licensed bands
  - Spectrum licensed to operator
  - GSM:
    - 900 MHz, 1800 MHz (Europe)
    - 850 Mhz, 1900 MHz (US)
    - other bands
  - UMTS, LTE
  - See e.g., http://www.frequentieland.nl/wie.htm
- WLAN typically uses unlicensed bands
  - 2.4 GHz Industrial, Scientific, and Medical (ISM) band:
    - IEEE 802.11b/g
    - Bluetooth
    - Zigbee
    - microwave oven
  - 5.8 GHz ISM band:
    - IEEE 802.11a

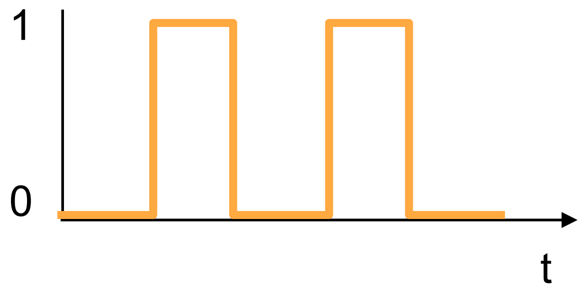
Signals I

- 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:

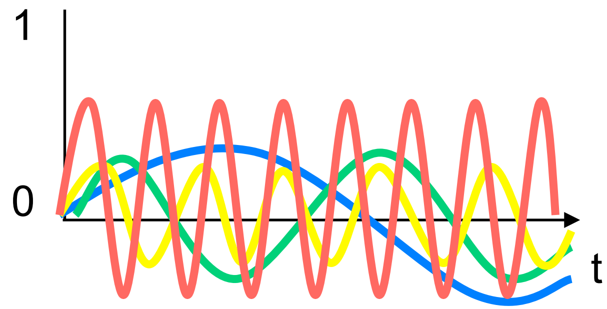
$$s(t) = A_t \sin(2 \pi f_t t + \varphi_t)$$

Fourier representation of periodic signals

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



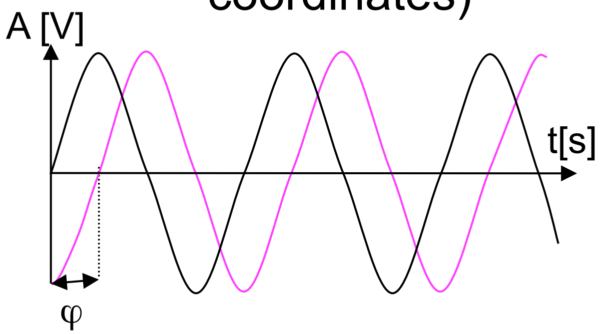
ideal periodic signal

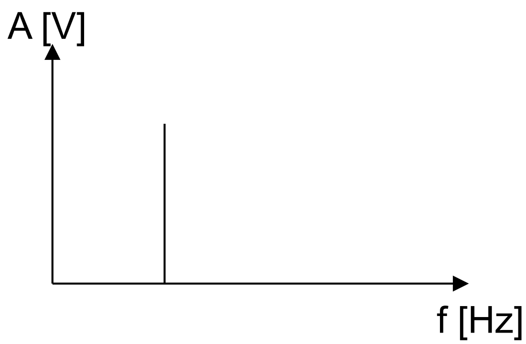


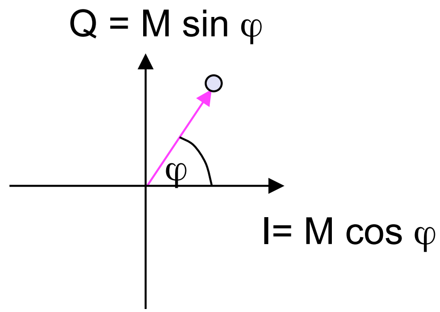
real composition
(based on harmonics)

Signals II

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



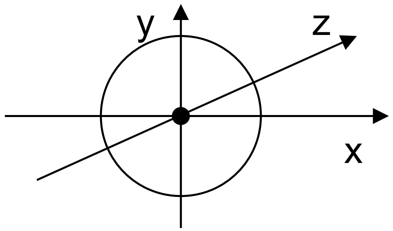


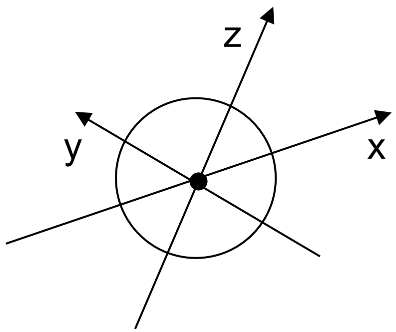


- Composed signals transferred into frequency domain using Fourier transformation
- Digital signals need
  - infinite frequencies for perfect transmission
  - modulation with a carrier frequency for transmission (analog signal!)

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

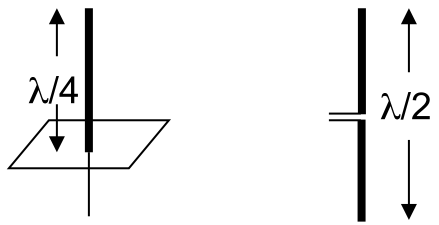




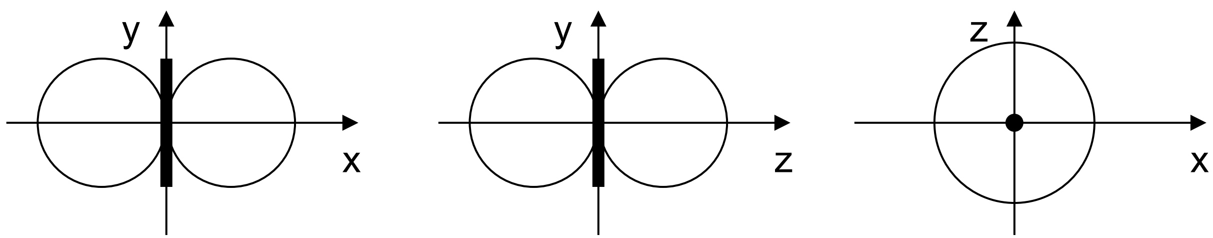
ideal isotropic radiator

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



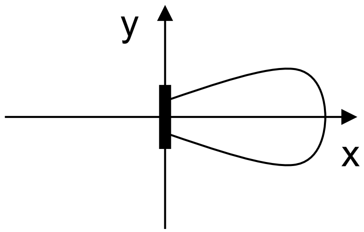
side view (xy-plane) side view (yz-plane) top view (xz-plane)

simple dipole

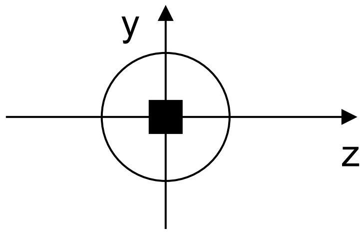
Gain: maximum power in the direction of the main lobe compared to the power of an isotropic radiator (with the same average power)

Antennas: directed and sectorized

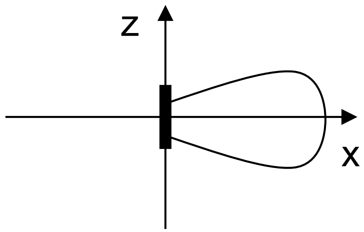
Often used for microwave connections or base stations for mobile phones (e.g., radio coverage of a valley)



side view (xy-plane)

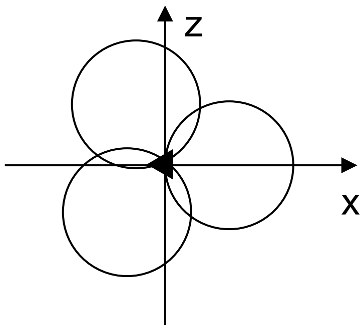


side view (yz-plane)

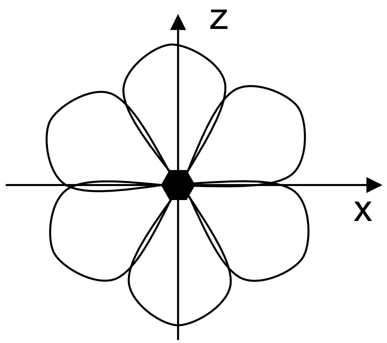


top view (xz-plane)

directed antenna



top view, 3 sector



top view, 6 sector

sectorized antenna

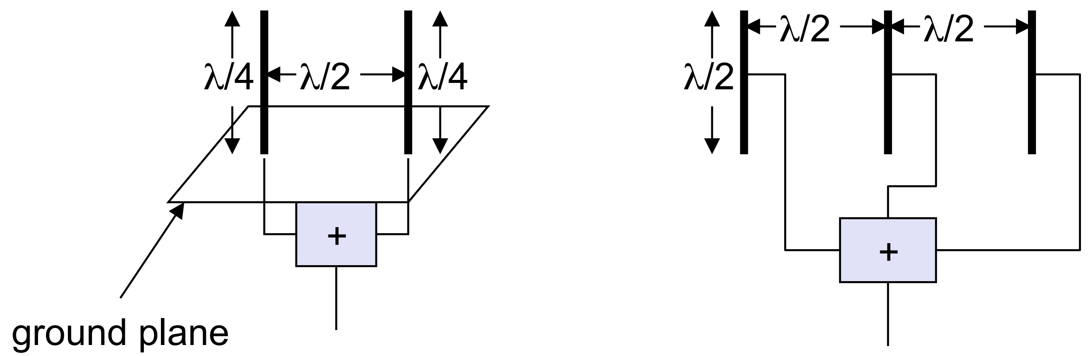
Antennas: diversity

Grouping of 2 or more antennas

- multi-element antenna arrays

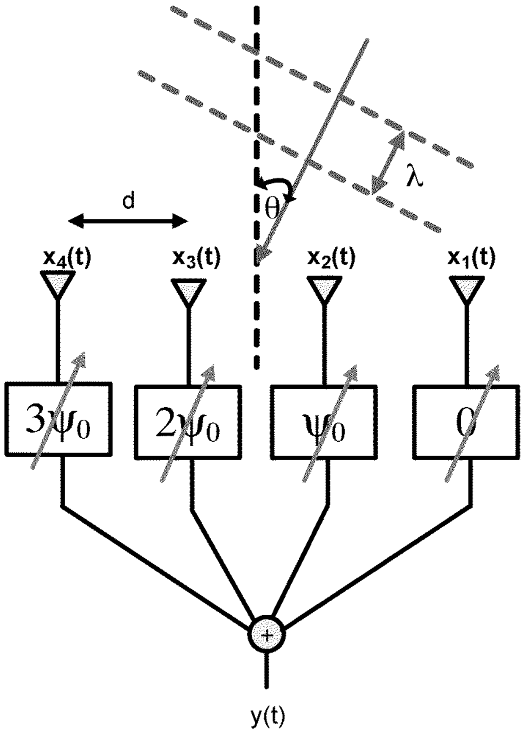
Antenna diversity

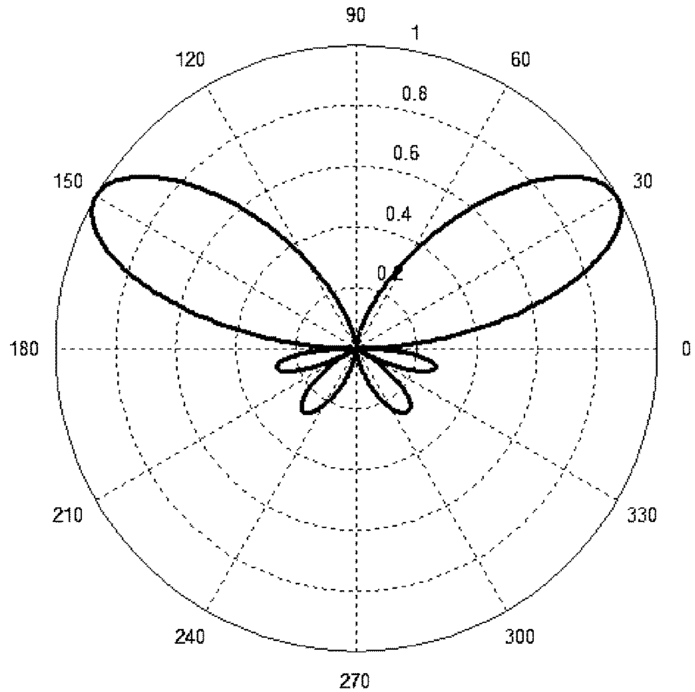
- switched diversity, selection diversity
  - receiver chooses antenna with largest output
- diversity combining
  - combine output power to produce gain
  - cophasing needed to avoid cancellation



- Smart antennas
  - beam forming

Beamforming example





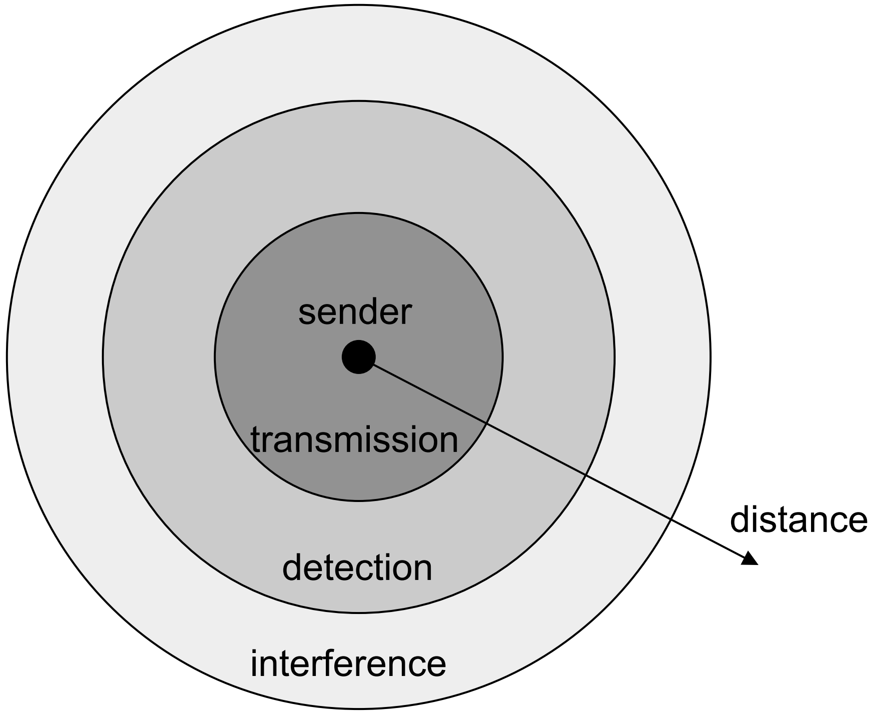
[Paramesh, J.; Bishop, R.; Soumyanath, K.; Allstot, D.J.,
"A four-antenna receiver in 90-nm CMOS for beamforming and spatial diversity",
Solid-State Circuits, IEEE Journal of , vol.40, no.12, Dec. 2005]

Signal propagation ranges

Transmission range
- communication possible
- low error rate

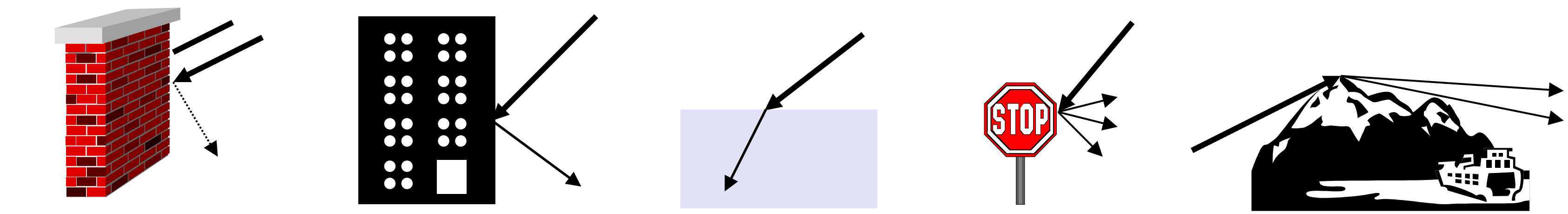
Detection range
- detection of the signal possible
- no communication possible

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



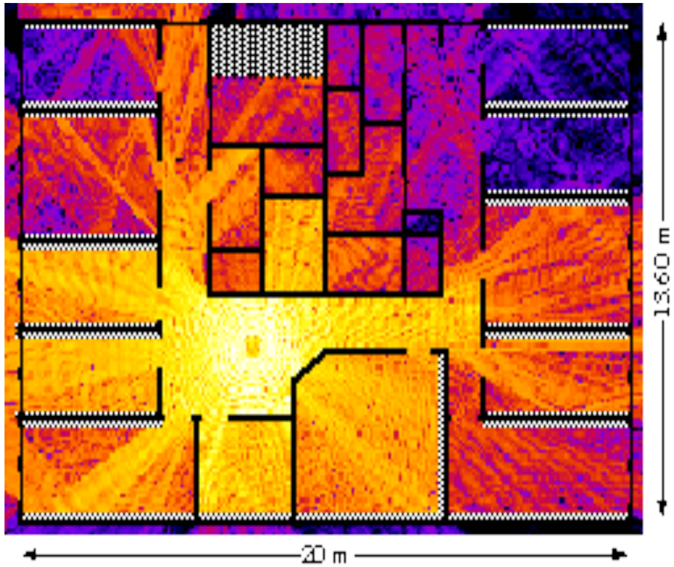
Signal propagation

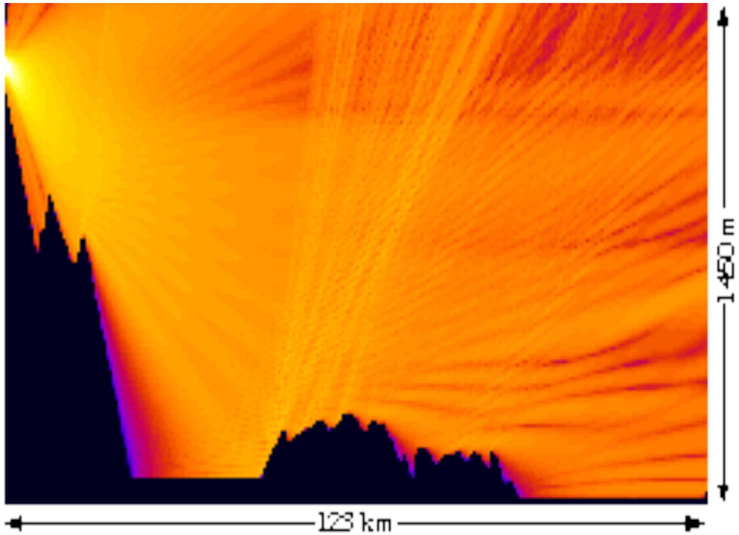
- Propagation in free space always like light (straight line)
- Path loss
  - Receiving power proportional to $1/d^2$ (free space)
    (d = distance between sender and receiver)
  - In reality (e.g., due to atmospheric absorption, and effects below): $1/d^{\alpha}$, with α between 2 and 5
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges

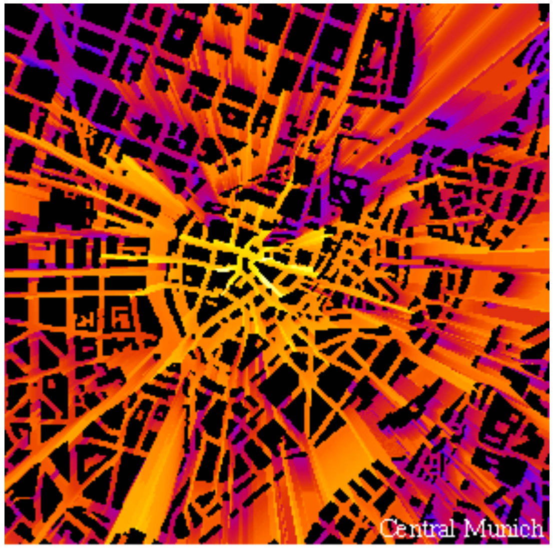


shadowing reflection refraction scattering diffraction

Real world example

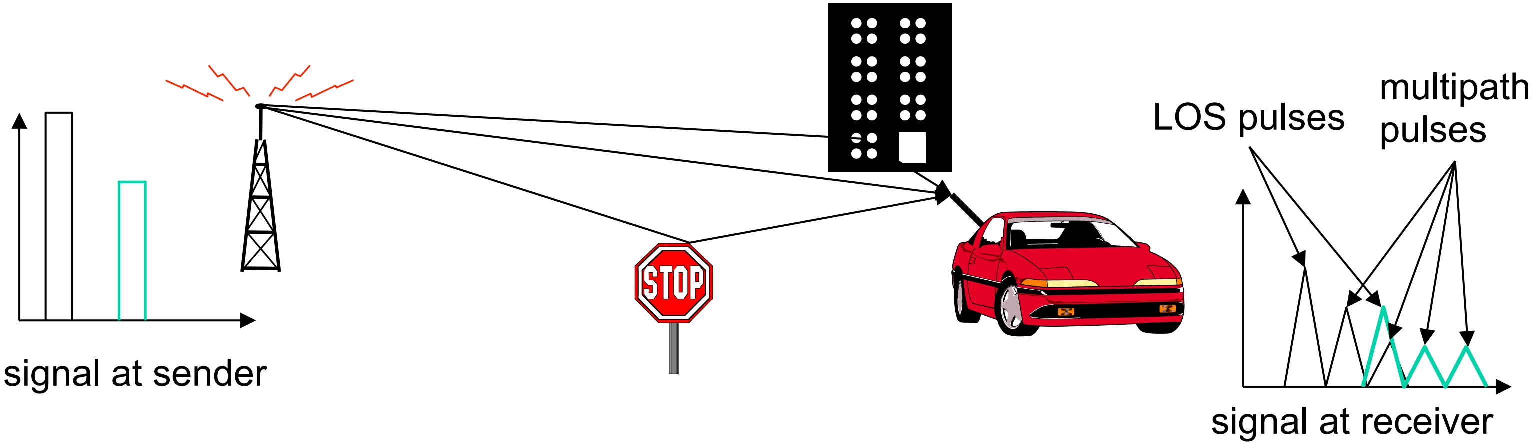






Multipath propagation

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

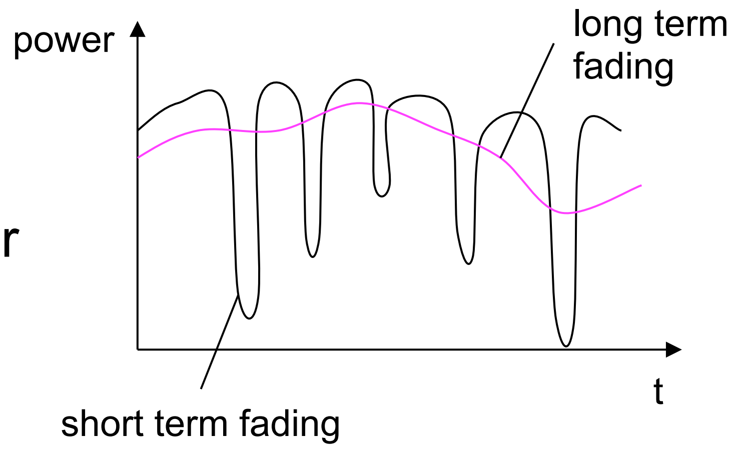
- signal paths change
- different delay variations of different signal parts
- different phases of signal parts

➔ 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)



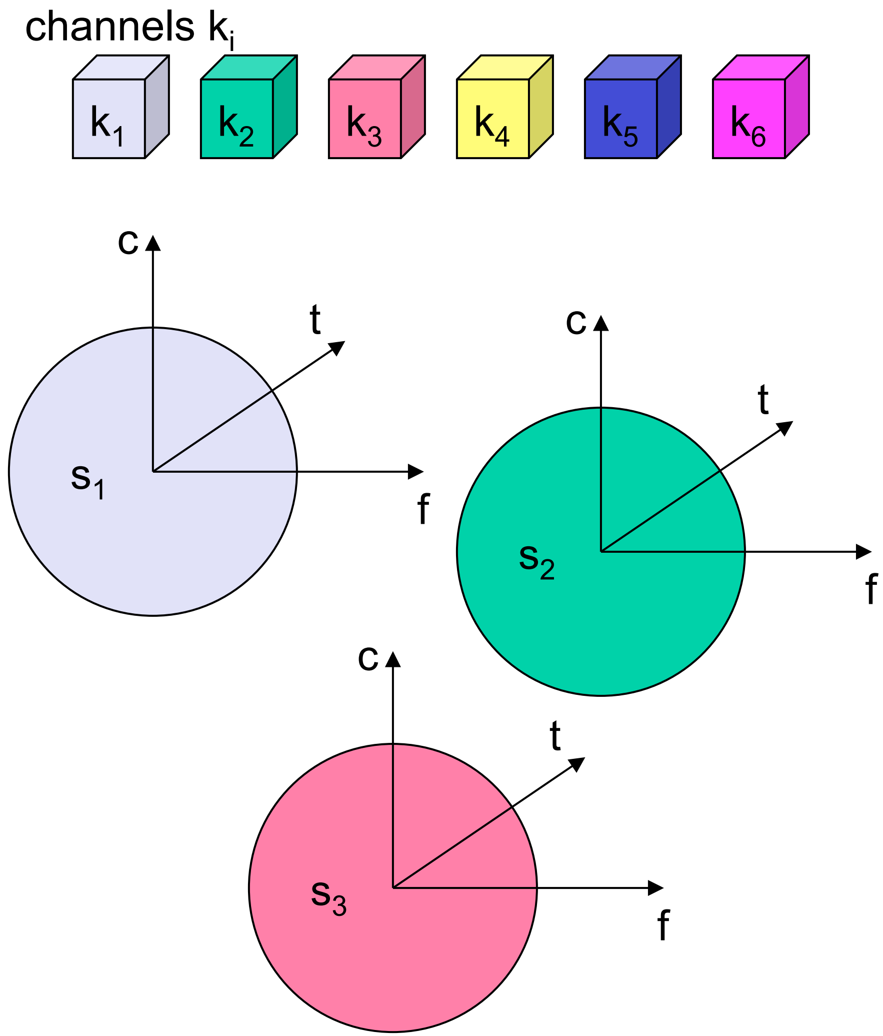
Multiplexing

Multiplexing in 4 dimensions

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

Goal: multiple use
of a shared medium

Important: guard spaces needed!



Frequency multiplex

Separation of the whole spectrum into smaller frequency bands

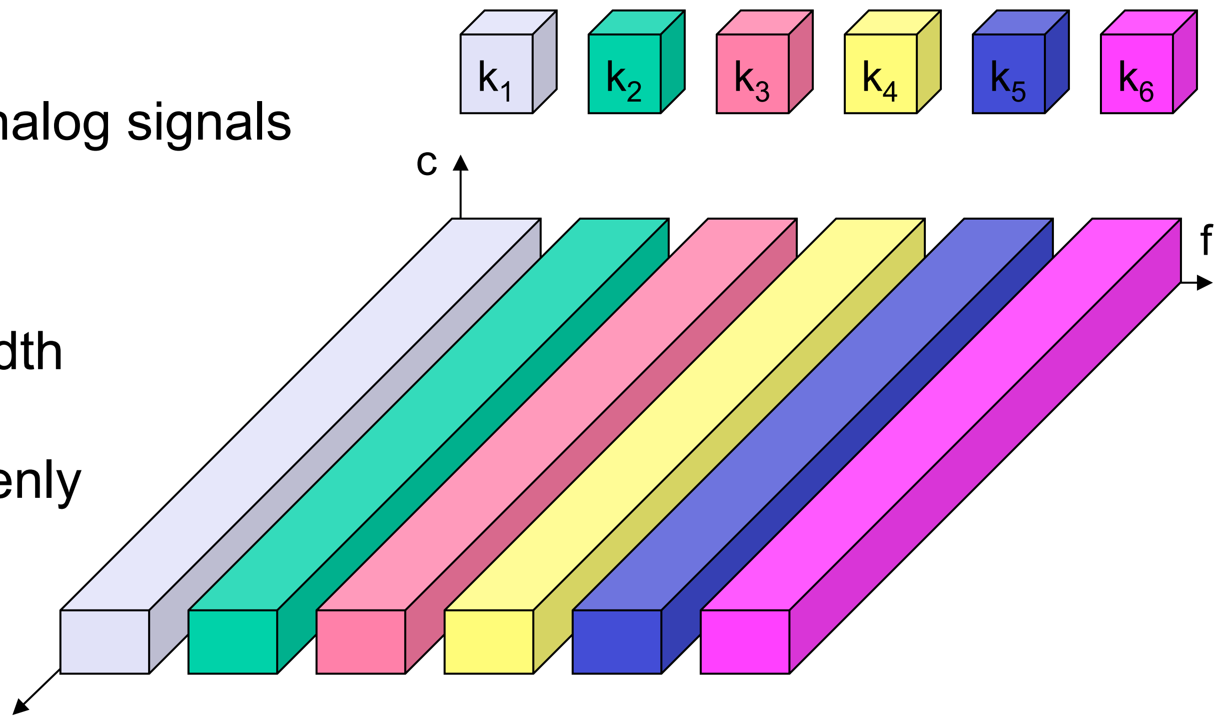
A channel gets a certain band of the spectrum for the whole time

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

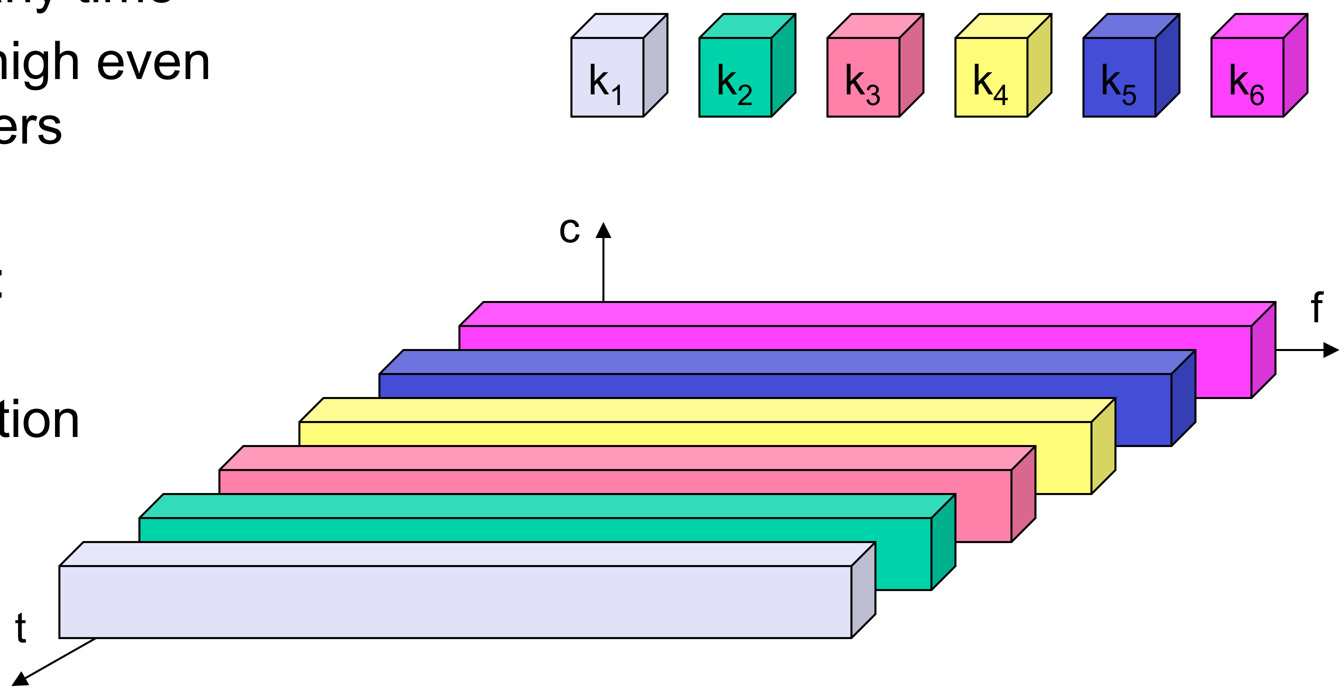
A channel gets the whole spectrum for a certain amount of time

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

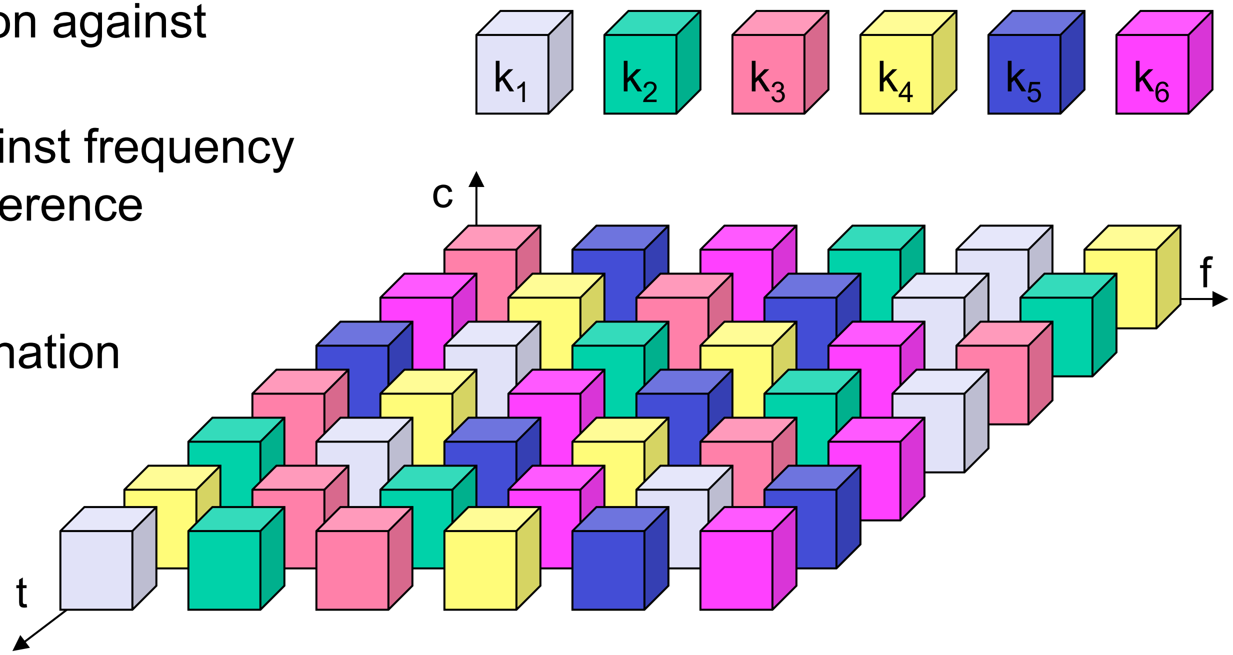
Example: GSM

Advantages:

- better protection against tapping
- protection against frequency selective interference

but:

- precise coordination required



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:

- more complex signal regeneration

Implemented using spread spectrum technology