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Why Mobile Communications?

- 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

Computers for the next decades?

- Computers are integrated (95% embedded systems!)
  - small, cheap, portable, replaceable - no more separate devices
- Technology is 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, “context awareness”))
- 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

- Two 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

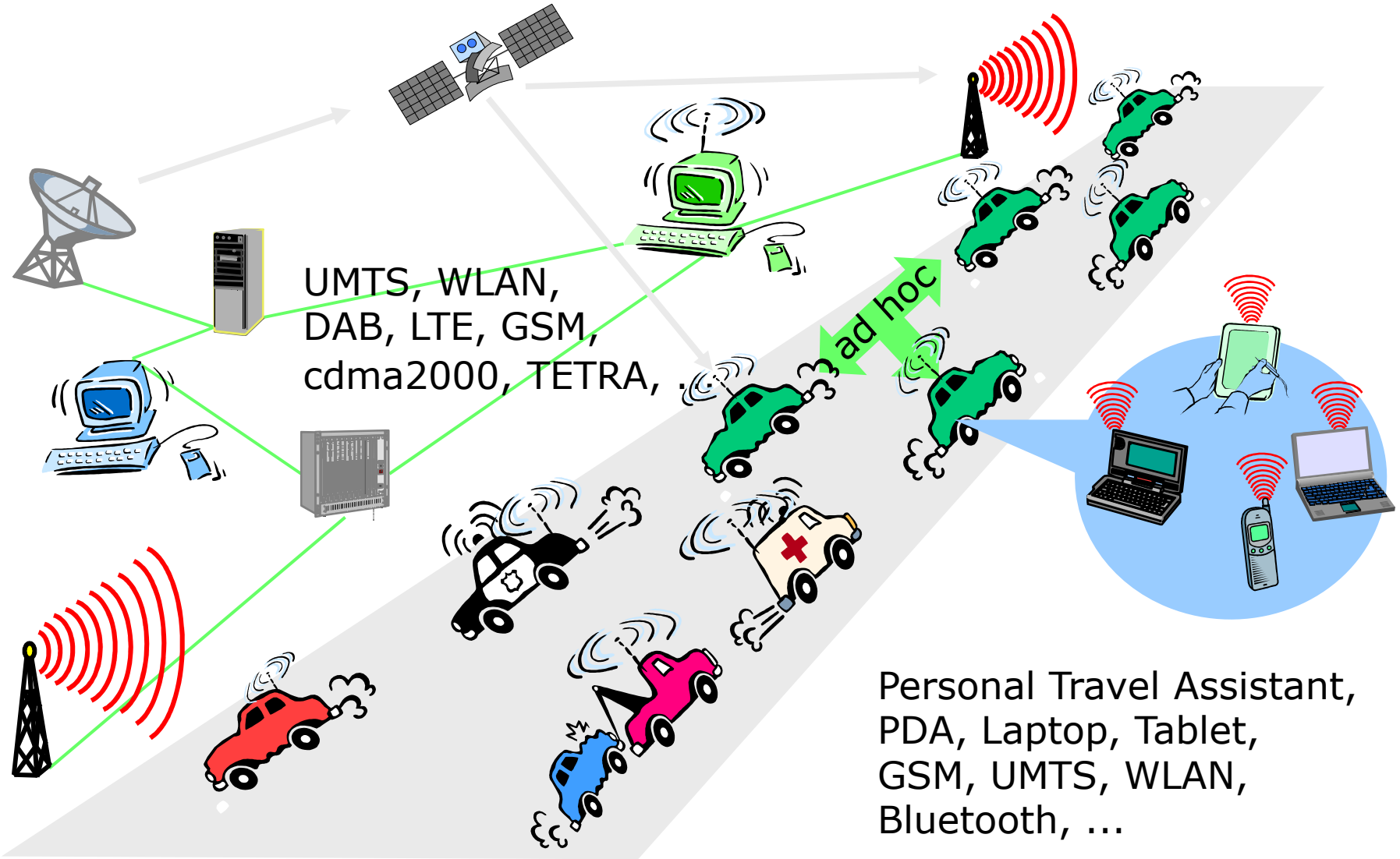
Wireless	Mobile	Examples
✗	✗	stationary computer
✗	✓	notebook in a hotel
✓	✗	wireless LANs in historic buildings
✓	✓	Personal Digital Assistant (PDA)

- 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
  - Internet: Mobile IP extension of the internet protocol IP
  - wide area networks: e.g., internetworking of GSM and ISDN, VoIP over WLAN and POTS

Applications I

- Vehicles
  - transmission of news, road condition, weather, music via DAB/DVB-T
  - personal communication using GSM/UMTS/LTE
  - 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



Mobile and wireless services – Always Best Connected

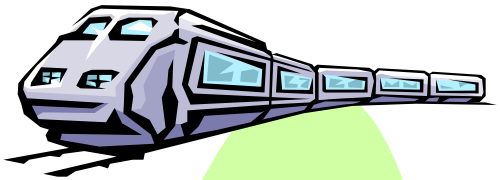
DSL/ WLAN
6 Mbit/s

GSM/EDGE 384 kbit/s,
DSL/WLAN 3 Mbit/s

GSM/GPRS 53 kbit/s
Bluetooth 500 kbit/s

GSM 115 kbit/s,
WLAN 11 Mbit/s

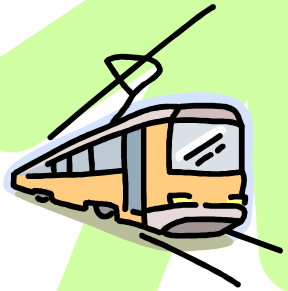
UMTS, GSM
115 kbit/s



UMTS, GSM
384 kbit/s

LAN
100 Mbit/s
WLAN
54 Mbit/s

UMTS
2 Mbit/s




Metering services
Interactive kiosks for virtual shopping
Digital menus for restaurant s
Robot tractors for precision farming
Sensor nets ride rails
Video news goes anywhere
Connecting seafarers with loved ones
Unified threat management for the embedded internet
A smarter way to shop
Robots: Armed with intelligence
Clearing the air over energy
Intelligent transportation is on a roll
Signs of progress
Helping EMTs provide vital care
Ringing up retail savings and services
Smart grids need intelligent substations
Get ready for a great ride
Pedal your way to fitness and energy savings
Wearable brainwave monitor
Converged business communications on a single chip
Medical miracles go mobile
Extending the reach of medial diagnostics
Transforming the home phone
Programmable personalities bring robots to life
Street lights get smart
Solar powered wireless gateway
Sensor fusion helps buildings grow green
Bringing banking services to people everywhere

Applications II

- Traveling 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

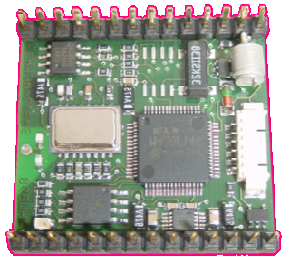
Location dependent services

- 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 Cheese 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

Sensors, embedded controllers

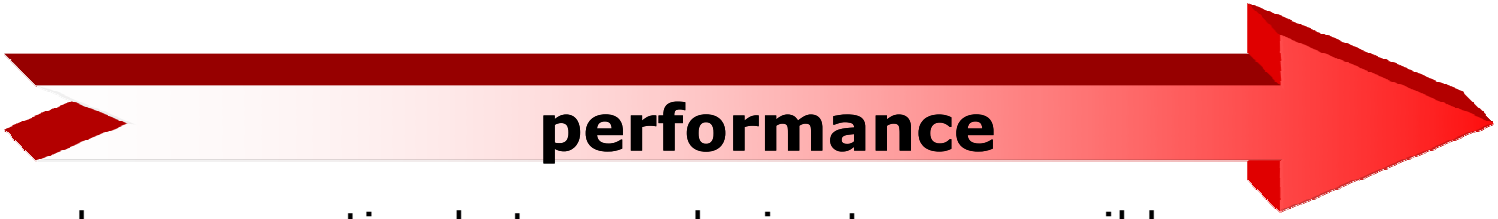


Mobile phones
- voice, data
- simple graphical displays

PDA
- graphical displays
- character recognition
- simplified WWW

Smartphone
- tiny keyboard
- simple versions of standard applications

Laptop/Notebook
- fully functional
- standard applications



No clear separation between device types possible
(e.g. smart phones, embedded PCs, …)

Effects of device portability

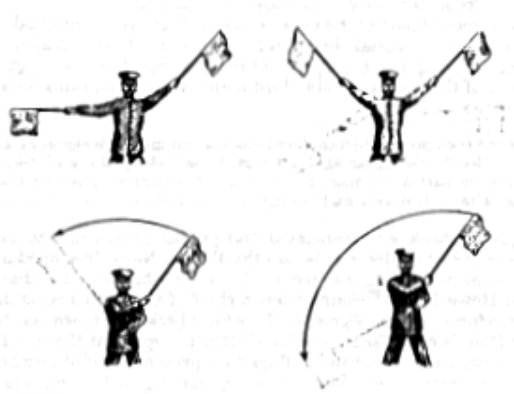
- Power consumption
  - limited computing power, low quality displays, small disks due to limited battery capacity
  - CPU: **power consumption ~ CV^2f**
    - C: internal capacity, reduced by integration
    - V: supply voltage, can be reduced to a certain limit
    - f: clock frequency, can be reduced 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 (always in relation to e.g. PCs)
  - limited usage 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
- Lower transmission rates
  - local some Mbit/s, regional currently, e.g., 53kbit/s with GSM/GPRS or about 150 kbit/s using EDGE – soon Mbit/s with LTE
- Higher delays, higher jitter
  - connection setup time with GSM in the second range, several hundred milliseconds for other wireless systems – soon in ms range with LTE
- 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)

History of wireless communication I

- 1896 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, 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 customers 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
  - was in use until 2000, 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 50 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 200 countries
  - services: data with 9.6kbit/s, FAX, voice, ...

History of wireless communication IV

- 1994 E-Netz in Germany
  - GSM with 1800MHz, smaller cells
  - 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 (proprietary) products available in the beginning
- 1998 Specification of GSM successors
  - for UMTS (Universal Mobile Telecommunications System) as European proposals for IMT-2000
  - Iridium
    - 66 satellites (+6 spare), 1.6GHz to the mobile phone

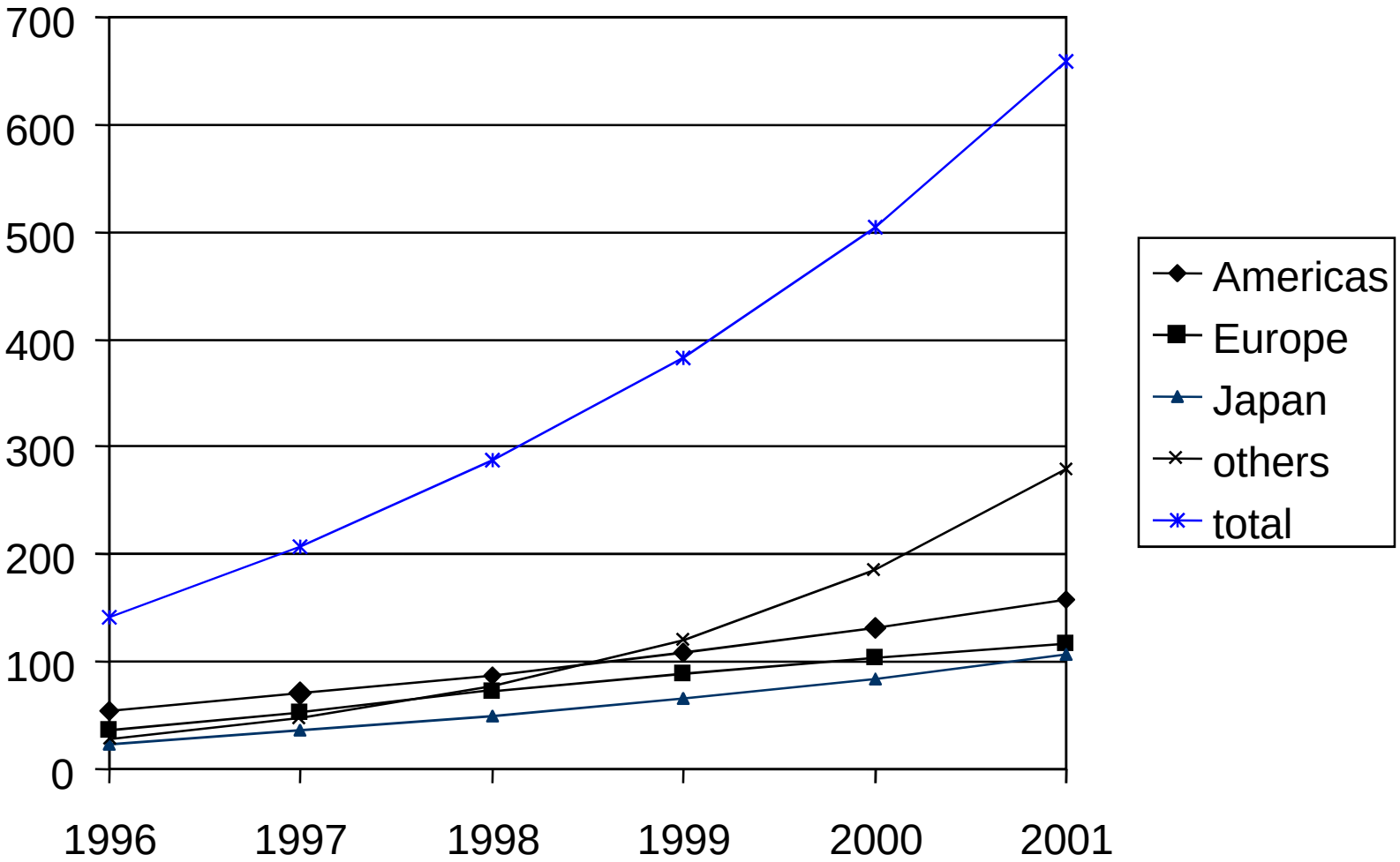
History of wireless communication V

- 1999 Standardization of additional wireless LANs
  - IEEE standard 802.11b, 2.4-2.5GHz, 11Mbit/s
  - Bluetooth for piconets, 2.4GHz, <1Mbit/s
  - decision about IMT-2000
    - several “members” of a “family”: UMTS, cdma2000, DECT, …
  - Start of WAP (Wireless Application Protocol) and i-mode
    - first step towards a unified Internet/mobile communication system
    - access to many services via the mobile phone
- 2000 GSM with higher data rates
  - HSCSD offers up to 57,6kbit/s
  - first GPRS trials with up to 50 kbit/s (packet oriented!)
  - UMTS auctions/beauty contests
    - Hype followed by disillusionment (50 B$ paid in Germany for 6 licenses!)
  - Iridium goes bankrupt
- 2001 Start of 3G systems
  - Cdma2000 in Korea, UMTS tests in Europe, Foma (almost UMTS) in Japan

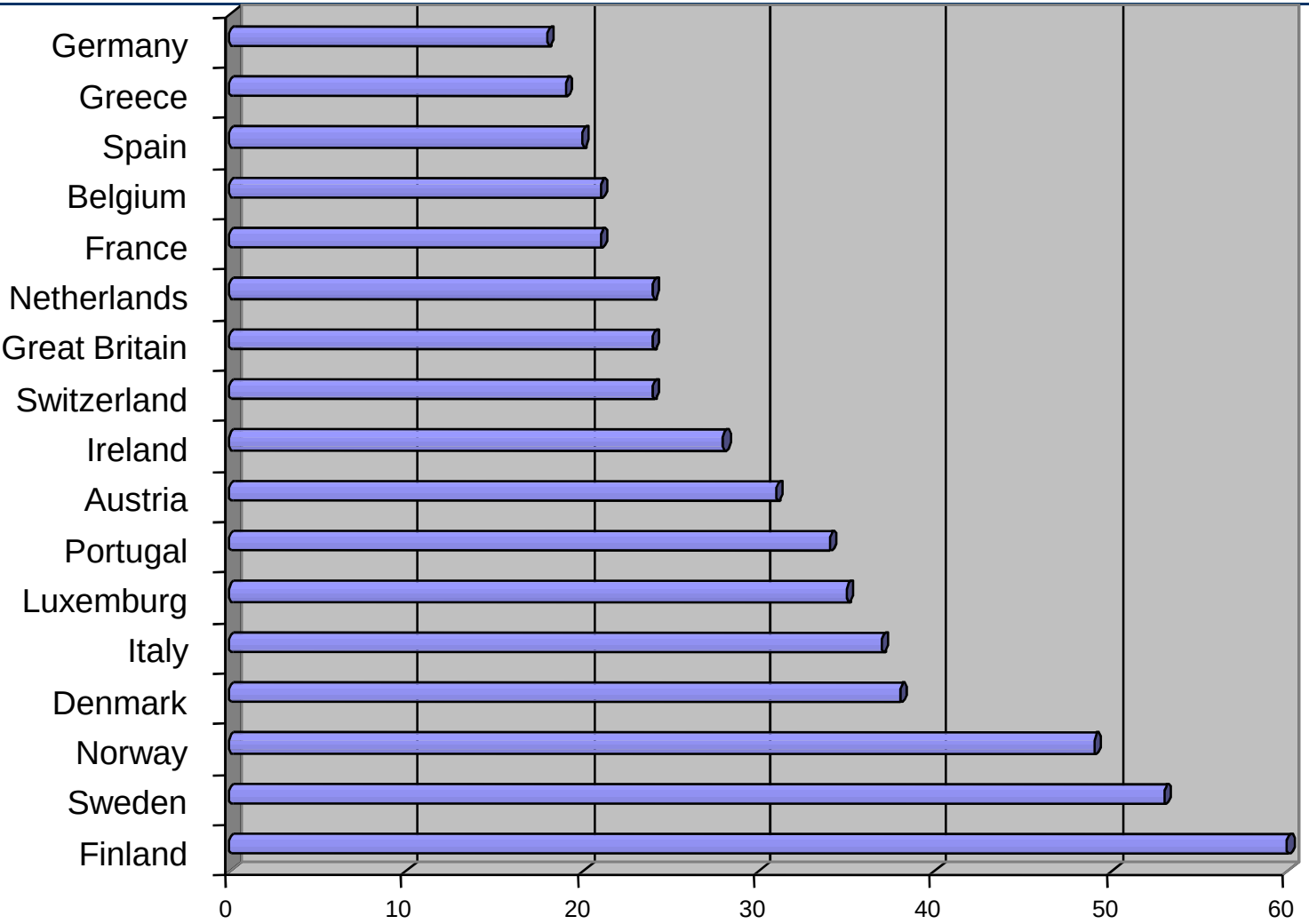
History of wireless communication VI

- 2002
  - WLAN hot-spots start to spread
- 2003
  - UMTS starts in Germany
  - Start of DVB-T in Germany replacing analog TV
- 2005
  - WiMax starts as DSL alternative (not mobile)
  - first ZigBee products
- 2006
  - HSDPA starts in Germany as fast UMTS download version offering > 3 Mbit/s
  - WLAN draft for 250 Mbit/s (802.11n) using MIMO
  - WPA2 mandatory for Wi-Fi WLAN devices
- 2007
  - over 3.3 billion subscribers for mobile phones (NOT 3 bn people!)
- 2008
  - "real" Internet widely available on mobile phones (standard browsers, decent data rates)
  - 7.2 Mbit/s HSDPA, 1.4 Mbit/s HSUPA available in Germany, more than 100 operators support HSPA worldwide, first LTE tests (>100 Mbit/s)
- 2009 – the story continues with netbooks, iphones, VoIPoWLAN…
- 2010 – LTE available in some cities, new frequencies allocated
  - Reuse of old analog TV bands, LTE as DSL replacement for rural areas

Worldwide wireless subscribers (old prediction 1998)

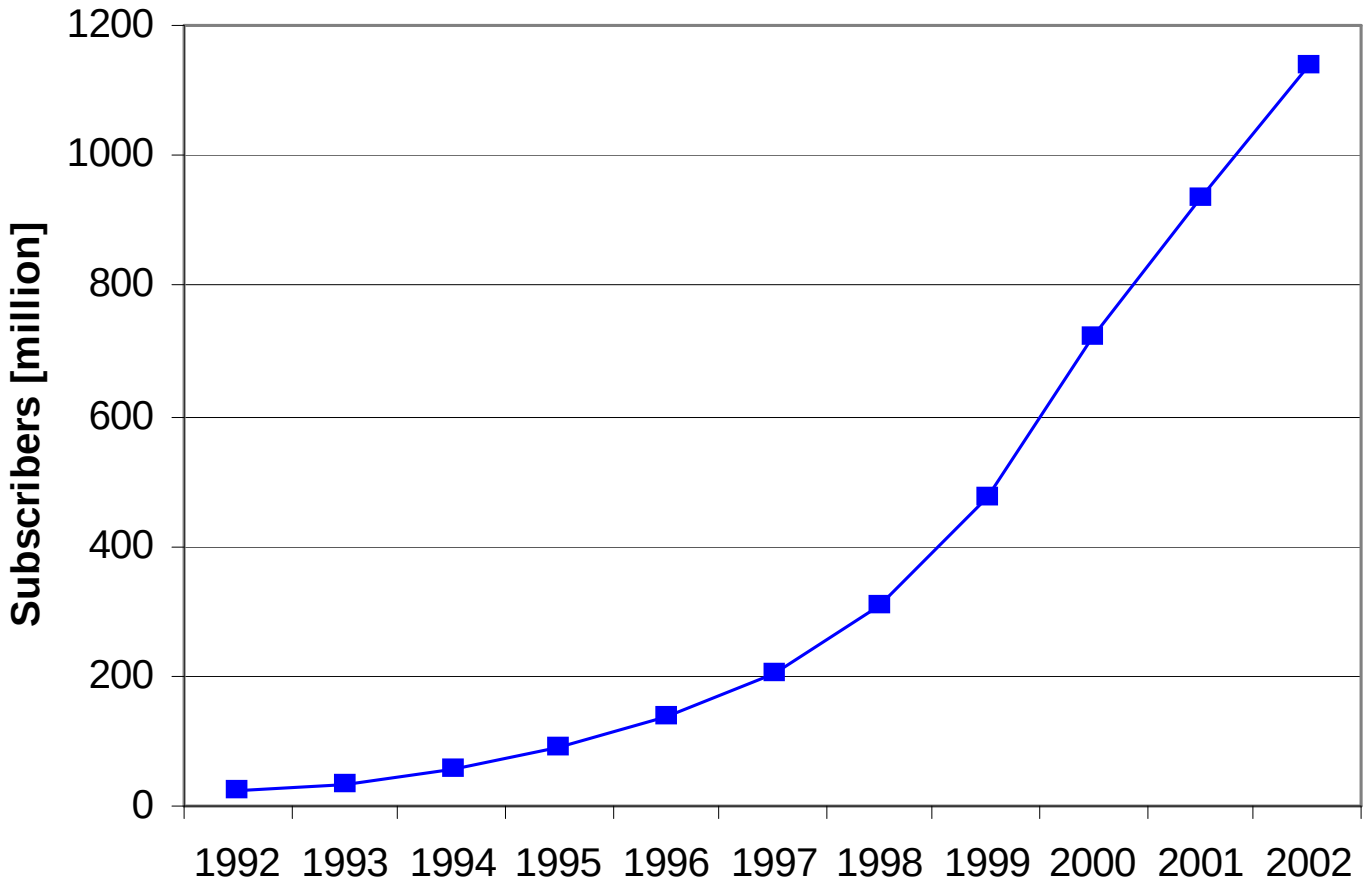


Mobile phones per 100 people 1999



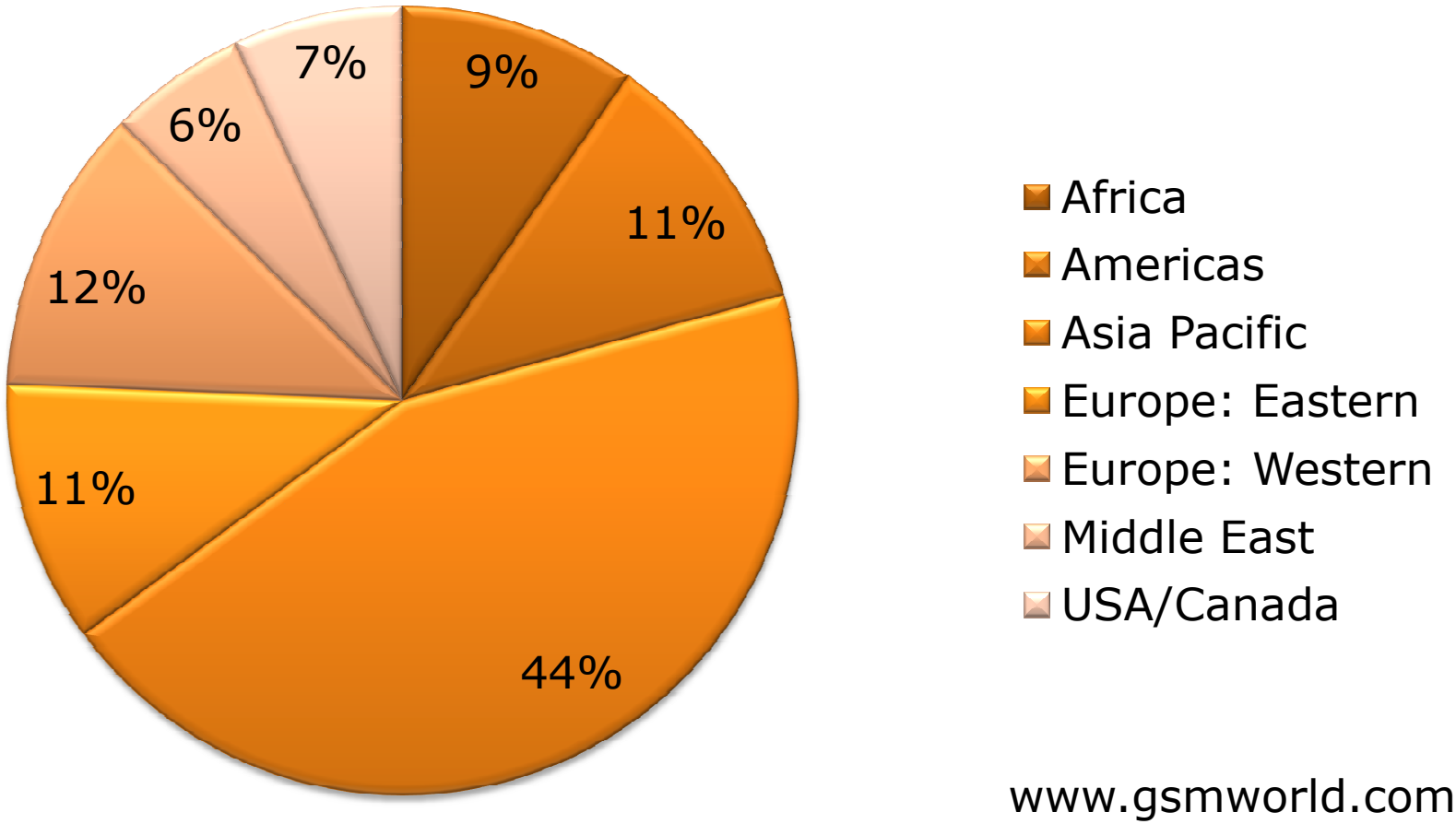
2005: 70-90% penetration in Western Europe, 2009 (ten years later): > 100%!

Worldwide cellular subscriber growth



Note that the curve starts to flatten in 2000 – 2011: over 5.5 billion subscribers!

Cellular subscribers per region (September 2009)



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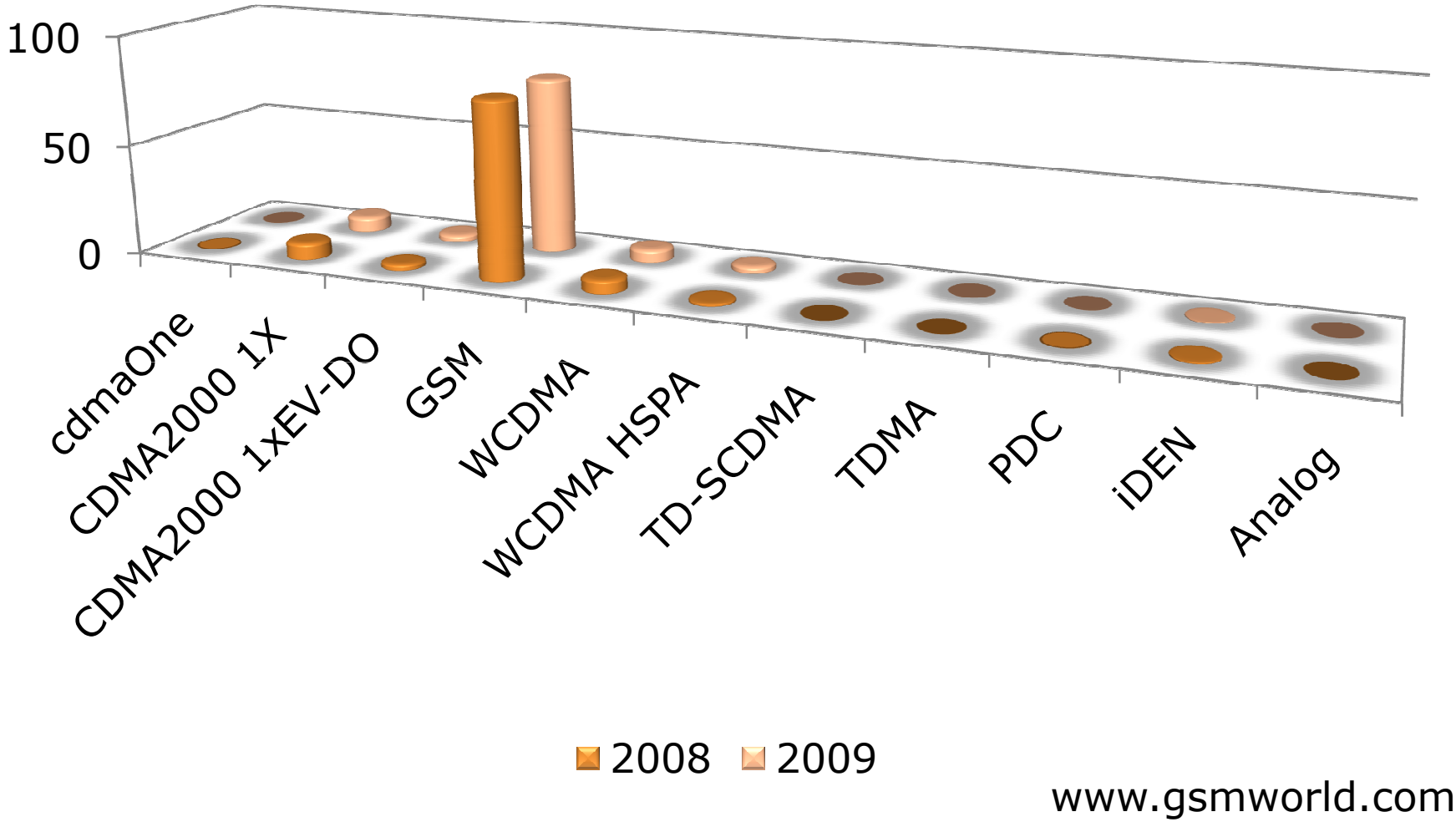
Cellular subscribers in % per technology



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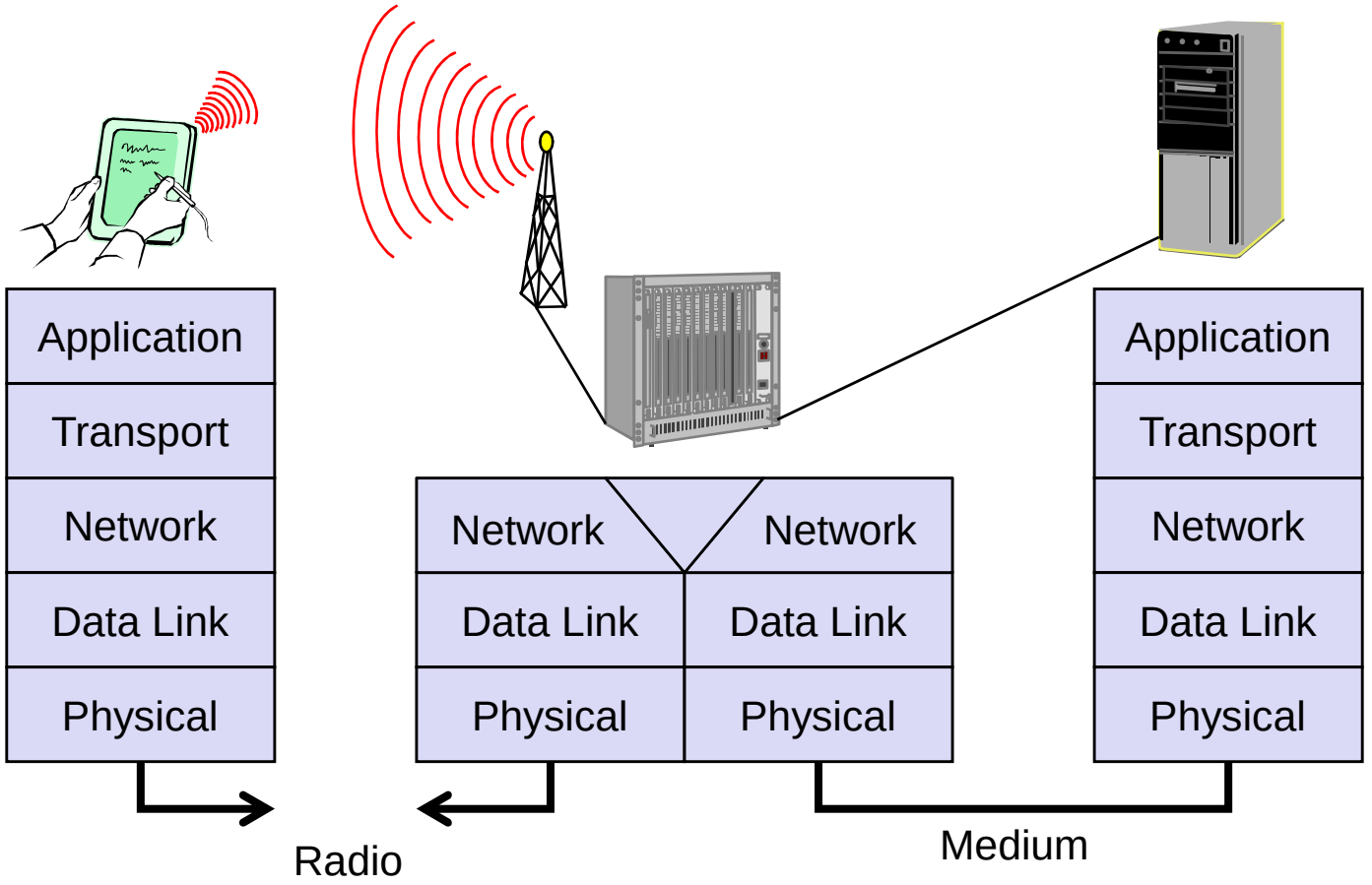
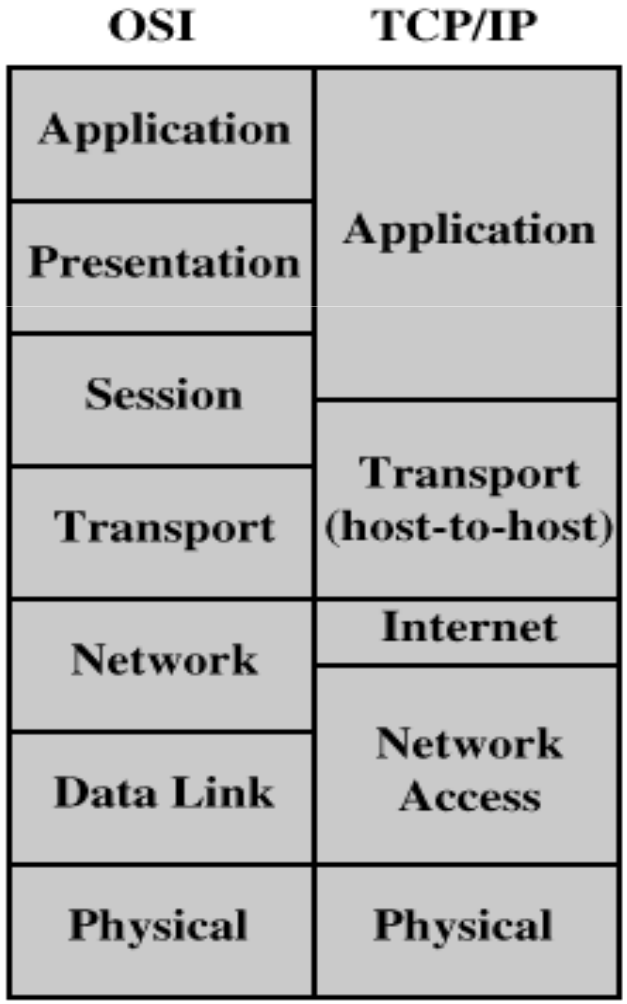
Areas of research in mobile communication

- 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
  - ...

Simple reference model used here



Comparison of OSI and TCP/IP



Functions of a Router

- Provide a link between networks
- Provide for the routing and delivery of data between processes on end systems attached to different networks
- Provide these functions in such a way as not to require modifications of the networking architecture of any of the attached subnetworks

Network Differences Routers Must Accommodate

- Addressing schemes
  - Different schemes for assigning addresses
- Maximum packet sizes
  - Different maximum packet sizes requires segmentation
- Interfaces
  - Differing hardware and software interfaces
- Reliability
  - Network may provide unreliable service

Influence of mobile communication to the layer model

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

Overlay Networks – (still) the global goal

integration of heterogeneous fixed and mobile networks with varying transmission characteristics