Mobile Communications
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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

Overview of the lecture

- Introduction
  - Use-cases, applications
  - Definition of terms
  - Challenges, history
- Wireless Transmission
  - Frequencies & regulations, Cognitive Radio
  - Signals, antennas, signal propagation, MIMO
  - Multiplexing, modulation, spread spectrum, cellular system, SDR
- Medium Access
  - SDMA, FDMA, TDMA, CDMA
  - CSMA/CA, versions of Aloha
  - Collision avoidance, polling
- Wireless Telecommunication Systems
  - GSM, HSCSD, GPRS, DECT, TETRA, UMTS, IMT-2000, LTE
- Satellite Systems
  - GEO, LEO, MEO, routing, handover
- Broadcast Systems
  - DAB, DVB
- Wireless LANs
  - Basic Technology
  - IEEE 802.11a/b/g/…, .15, Bluetooth, ZigBee
- Network Protocols
  - Mobile IP
  - Ad-hoc networking
  - Routing
- Transport Protocols
  - Reliable transmission
  - Flow control
  - Quality of Service
- Support for Mobility
  - File systems, WWW, WAP, i-mode, J2ME, ...
- Outlook

Mobile Communications
Chapter 1: Introduction

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

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 Examples

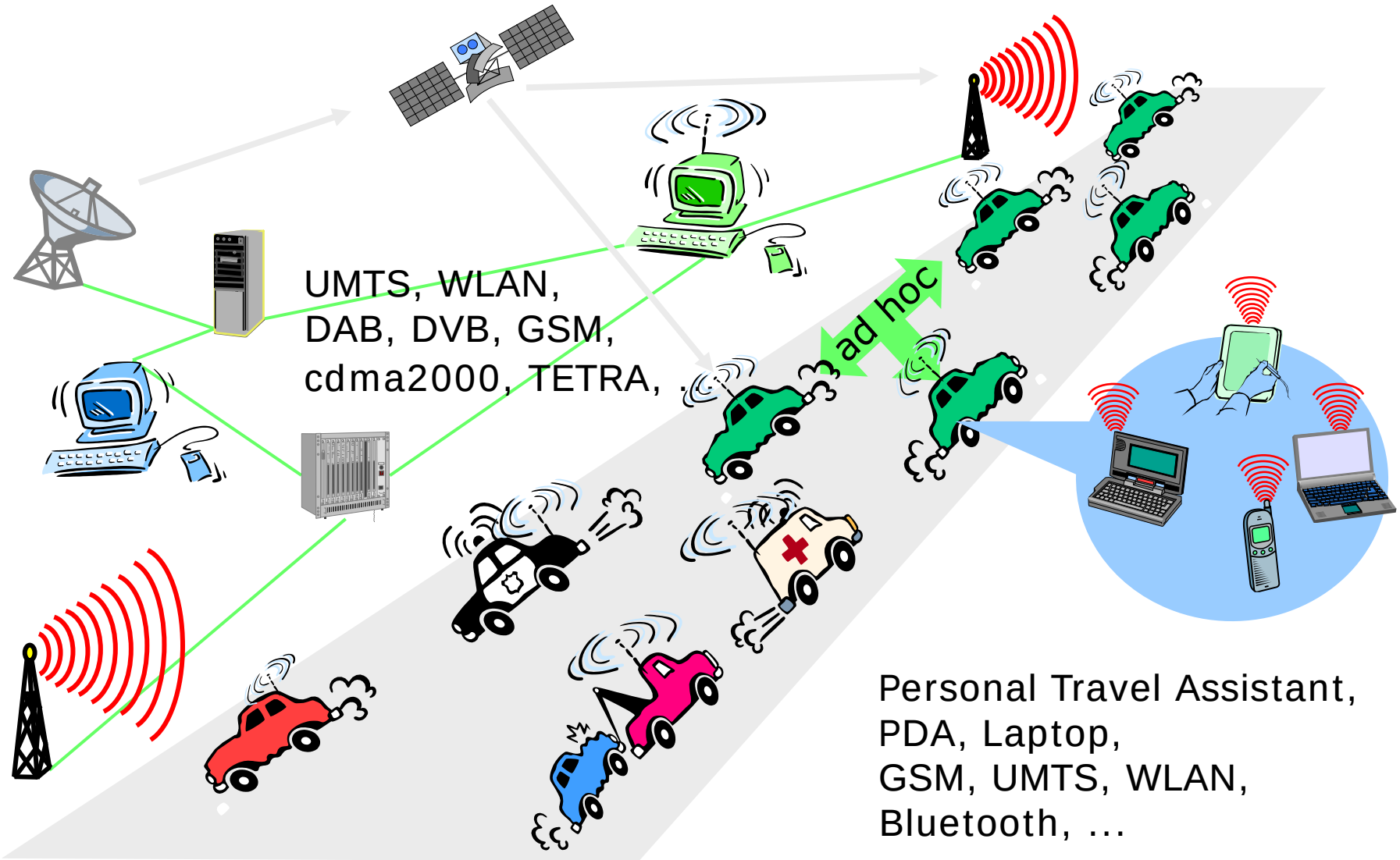
✘	✘	stationary computer
✘	✓	notebook in a hotel
✓	✘	wireless LANs in historic buildings
✓	✓	Personal Digital Assistant (PDA)

- 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

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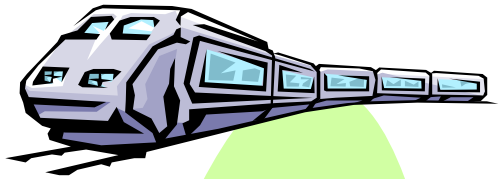
DSL/ WLAN
3 Mbit/s

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

UMTS, GSM
115 kbit/s



LAN
100 Mbit/s
WLAN
54 Mbit/s

UMTS
2 Mbit/s

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

GSM 115 kbit/s,
WLAN 11 Mbit/s

UMTS, GSM
384 kbit/s

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

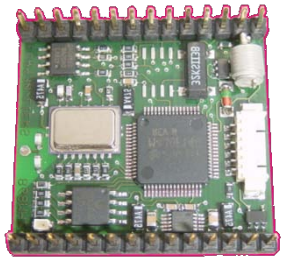
Mobile devices

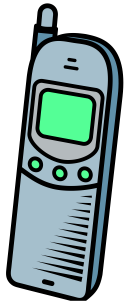
Pager
- receive only
- tiny displays
- simple text messages

PDA
- graphical displays
- character recognition
- simplified WWW

Laptop/Notebook
- fully functional
- standard applications

Sensors, embedded controllers





Mobile phones
- voice, data
- simple graphical displays

Smartphone
- tiny keyboard
- simple versions of standard applications

performance

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

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- 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 (1888, 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

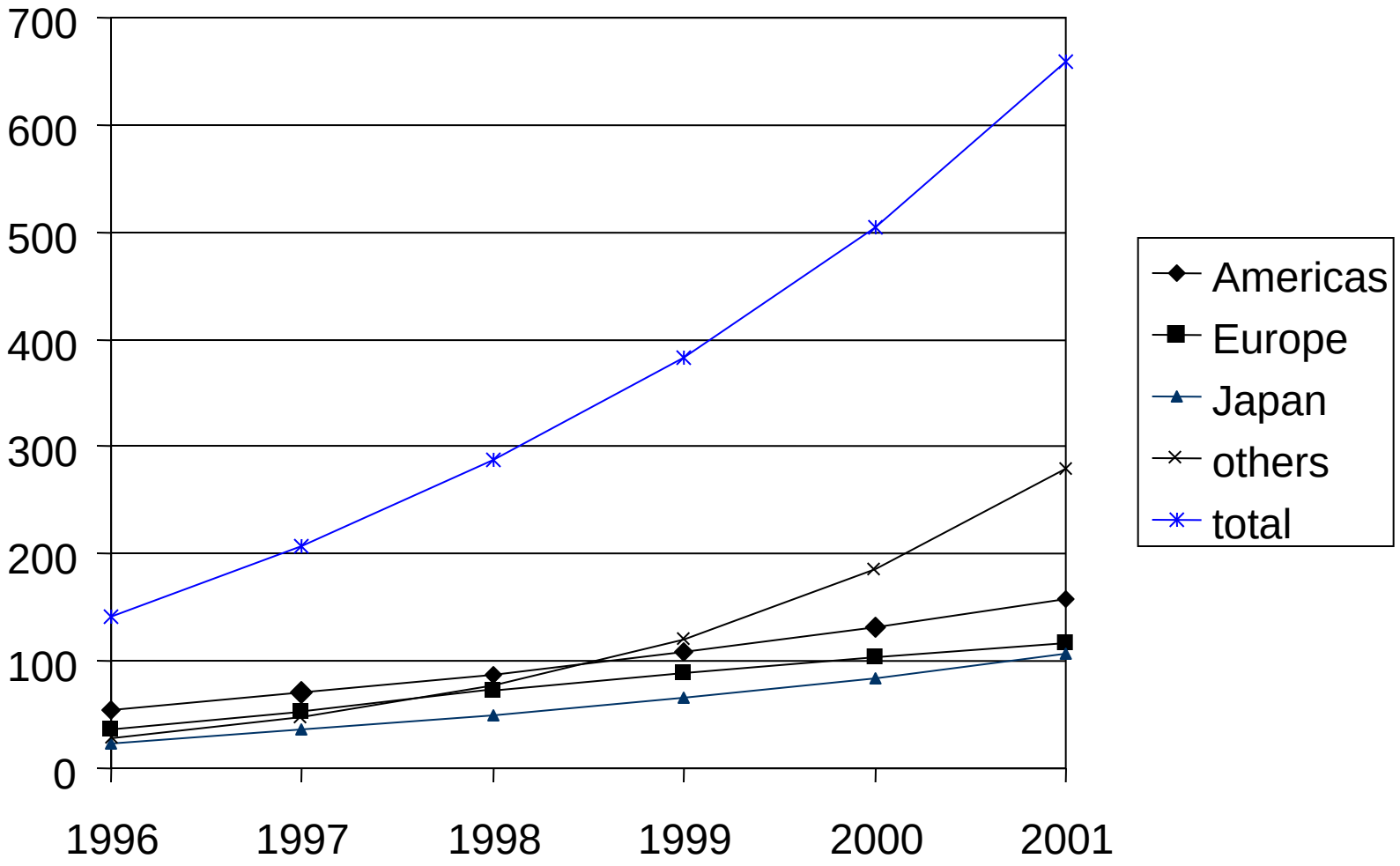
History of wireless communication V

- 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

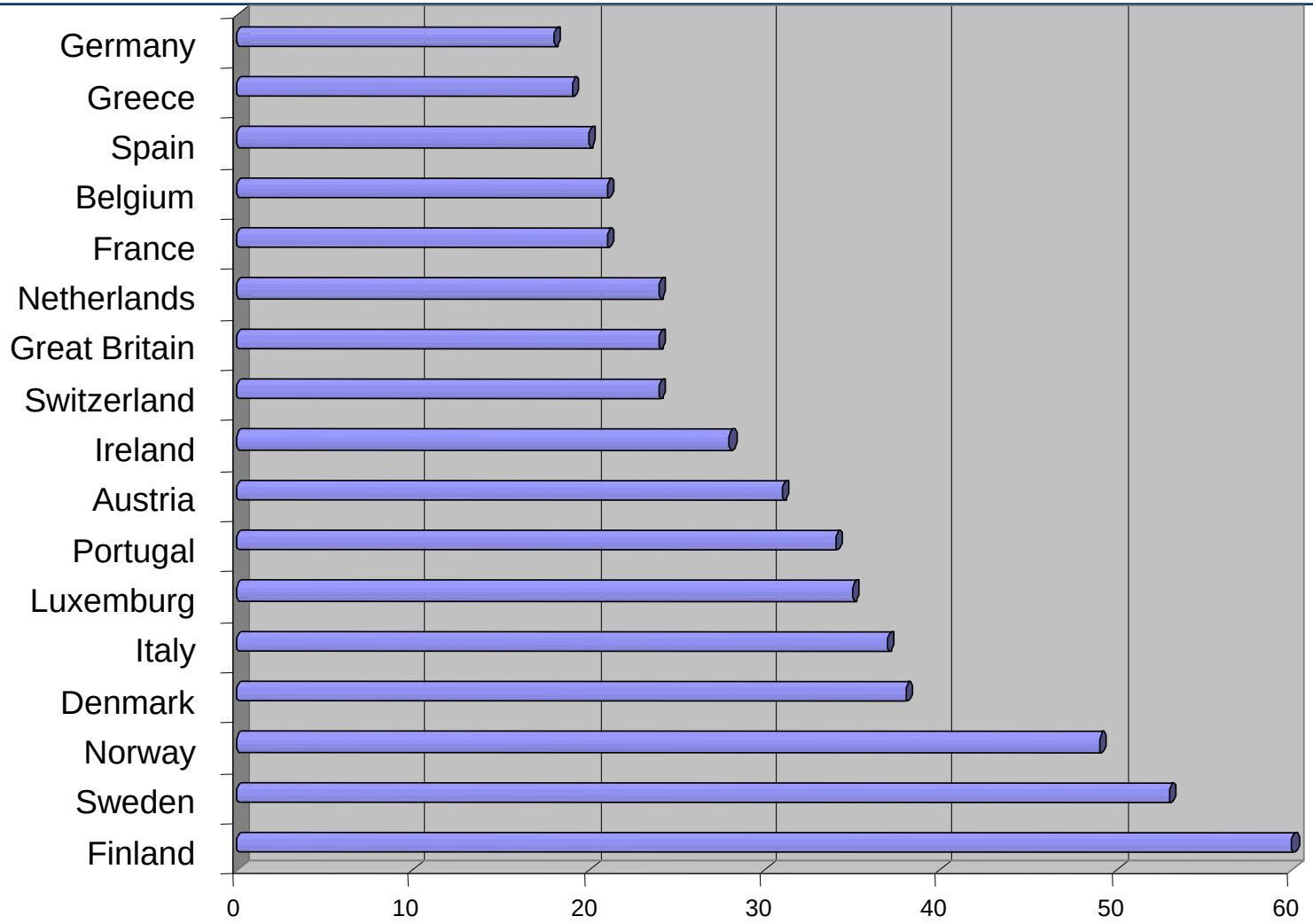
History of wireless communication VI

- 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)

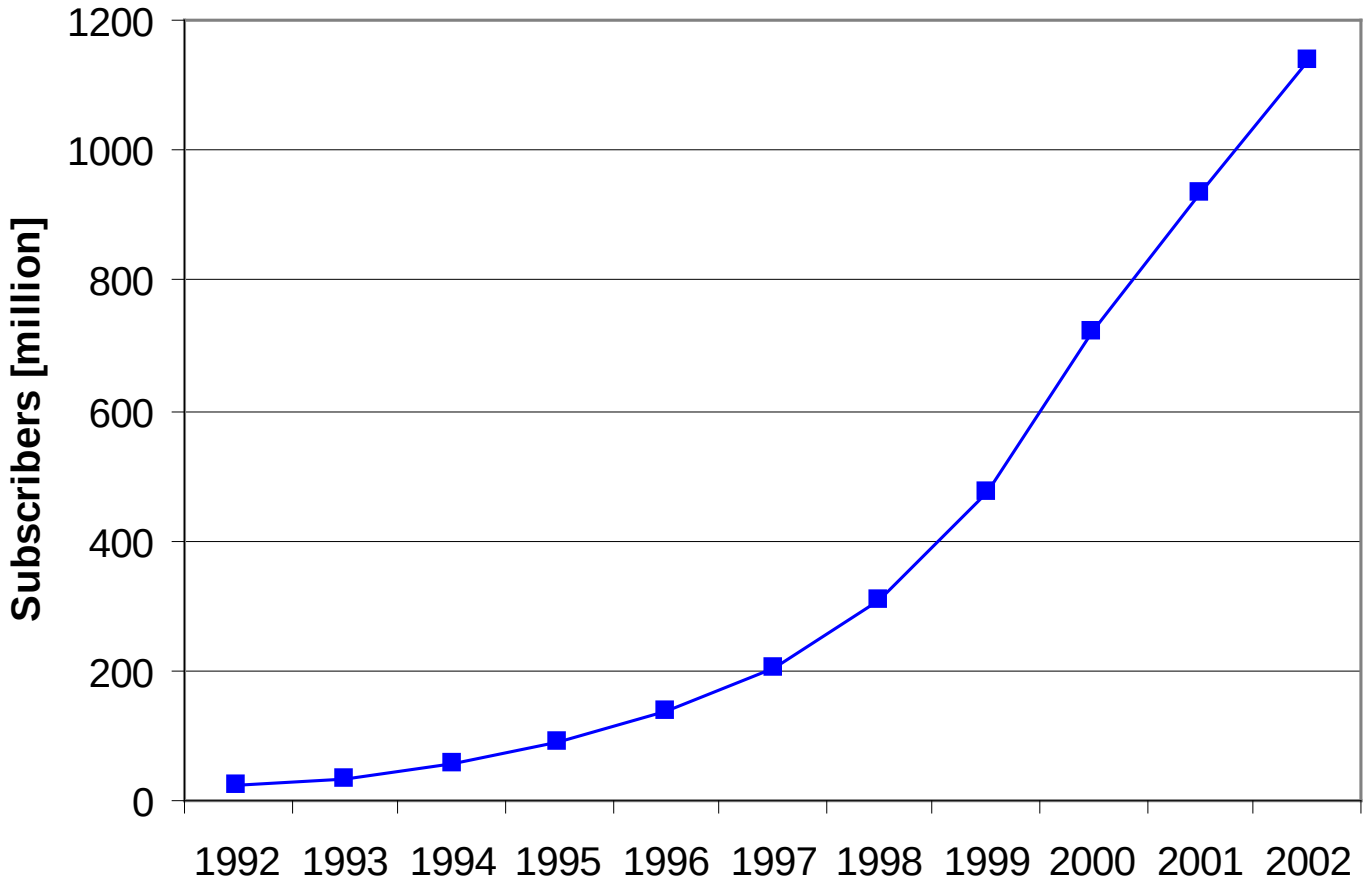


Mobile phones per 100 people 1999



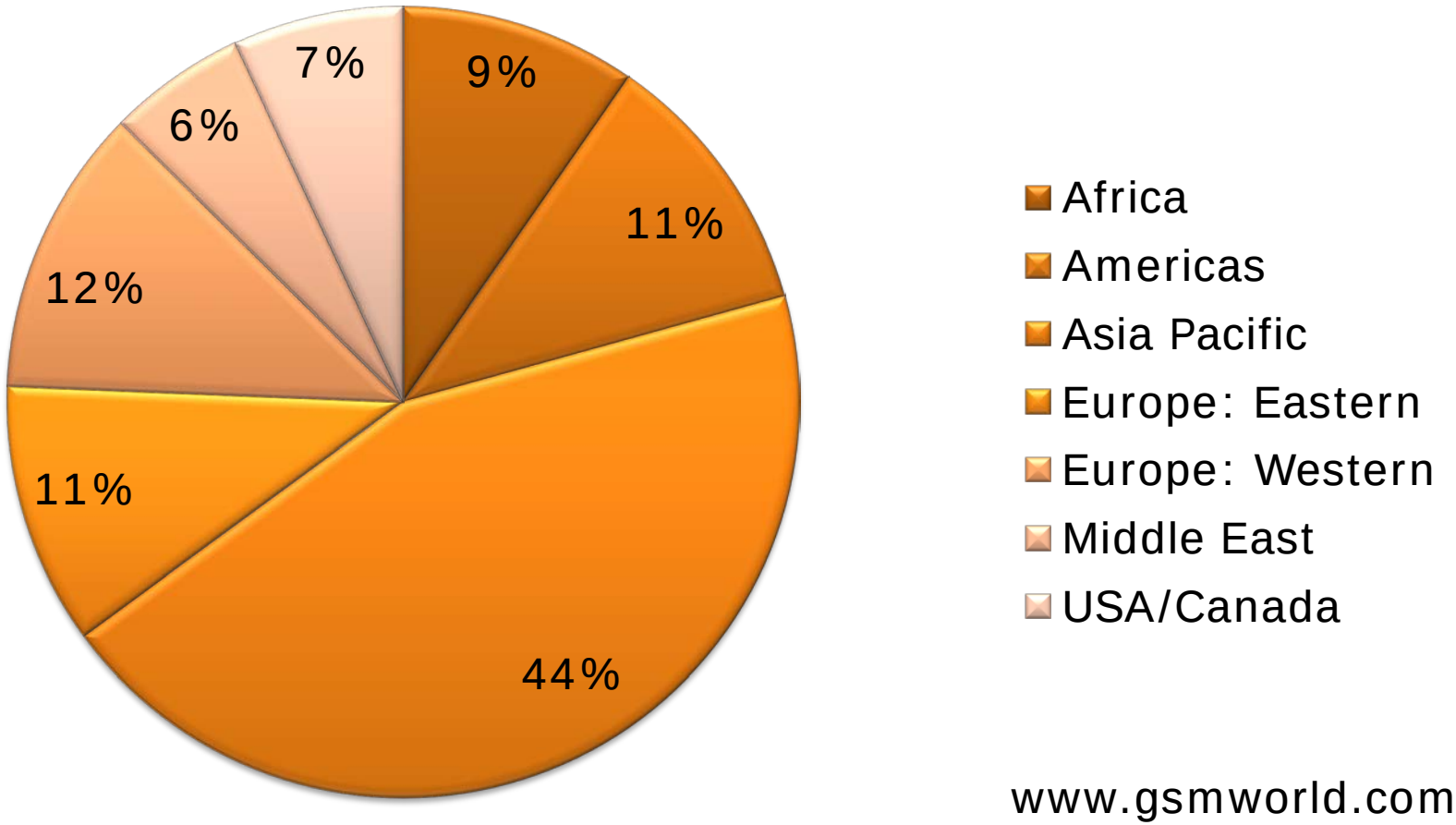
2005: 70-90% penetration in Western Europe, 2009 (ten years later): > 100%!

Worldwide cellular subscriber growth



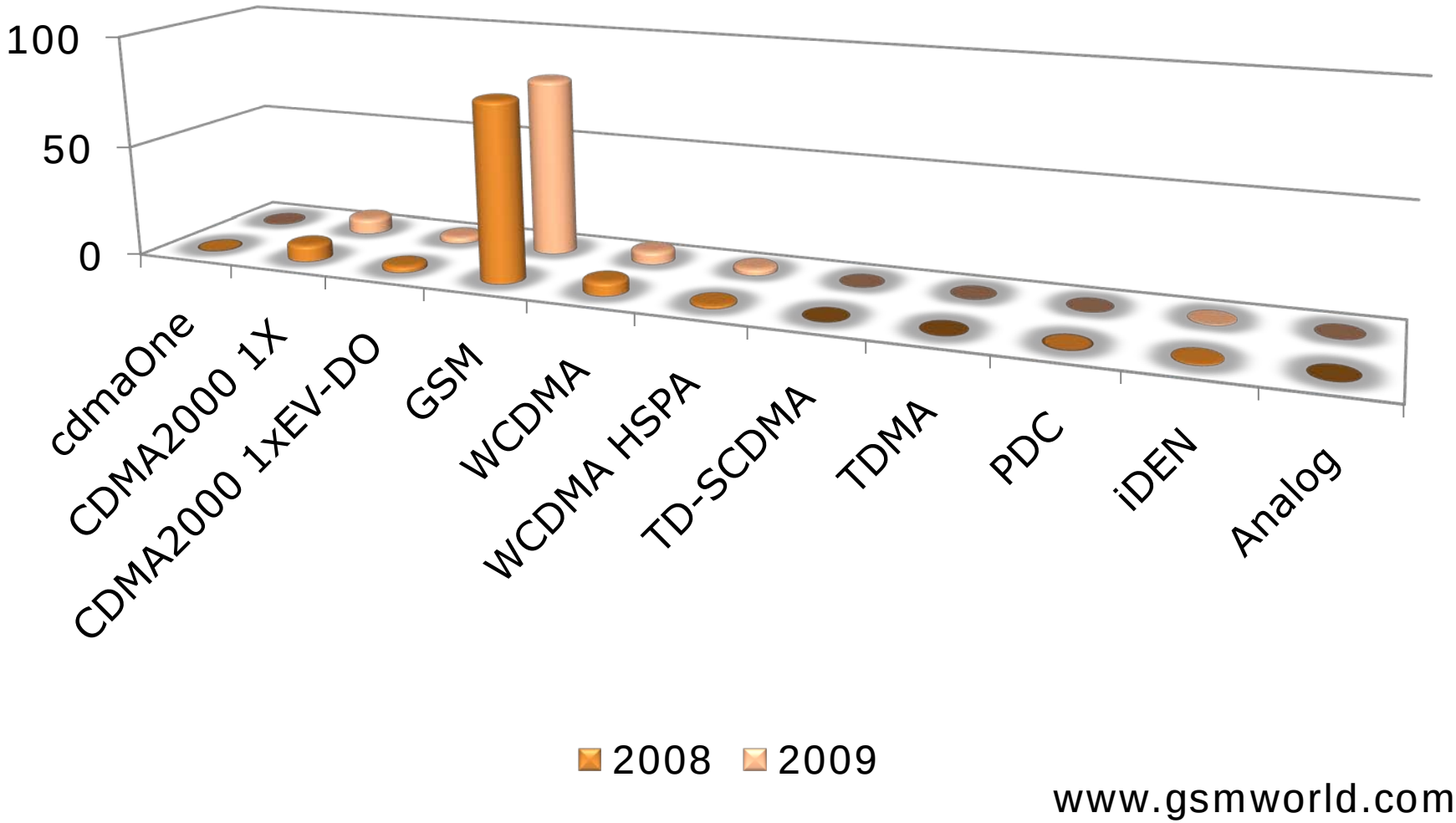
Note that the curve starts to flatten in 2000 – 2010: over 4.5 billion subscribers!

Cellular subscribers per region (September 2009)



www.gsmworld.com

Cellular subscribers in % per technology



www.gsmworld.com

Mobile statistics snapshots (09/2002 / 12/2004 / 04/2006 / Q4/2007

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- Total Global Mobile Users
- 869M / 1.52G / 2G / 3.3G
- Total Analogue Users 71M / 34M / 1M
- Total US Mobile users 145M / 140M
- Total Global GSM users 680M / 1.25G 1.5G / 2.7G
- Total Global CDMA Users 127M / 202M
- Total TDMA users 84M / 120M
- Total European users 283M / 343M
- Total African users 18.5M / 53M / 83M
- Total 3G users 130M / 130M
- Total South African users 13.2M / 19M / 30M
- European Prepaid Penetration 63%
- European Mobile Penetration 70.2%
- Global Phone Shipments 2001 393M / 1G 2008
- Global Phone Sales 2Q02 96.7M

www.cellular.co.za/stats/stats-main.htm

www.gsmworld.com

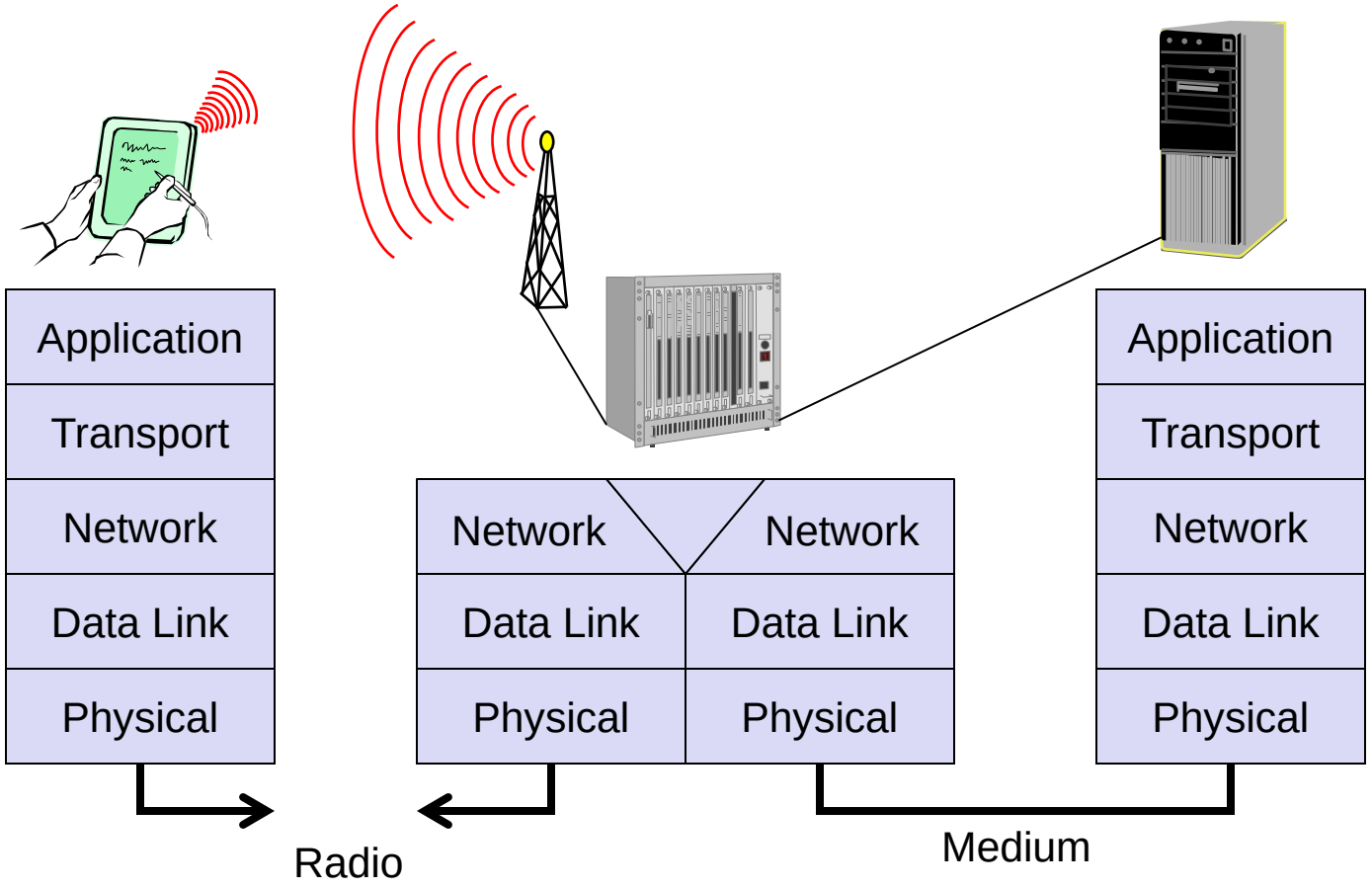
- #1 Mobile Country China (139M / 300M)
- #1 GSM Country China (99M / 282M / 483M)
- #1 SMS Country Philipines
- #1 Handset Vendor 2Q02 Nokia (37.2%)
- #1 Network In Africa Vodacom (6.6M / 11M)
- #1 Network In Asia Unicom (153M)
- #1 Network In Japan DoCoMo
- #1 Network In Europe T-Mobile (22M / 28M)
- #1 In Infrastructure Ericsson
- SMS Sent Globally 1Q 60T / 135G / 235G / 650 G
- SMS sent in UK 6/02 1.3T / 2.1G
- SMS sent Germany 1Q02 5.7T
- GSM Countries on Air 171 / 210 / 220
- GSM Association members 574 / 839
- Total Cost of 3G Licenses in Europe 110T€
- SMS/month/user 36

The figures vary a lot depending on the statistic, creator of the statistic etc.!

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
  - ...

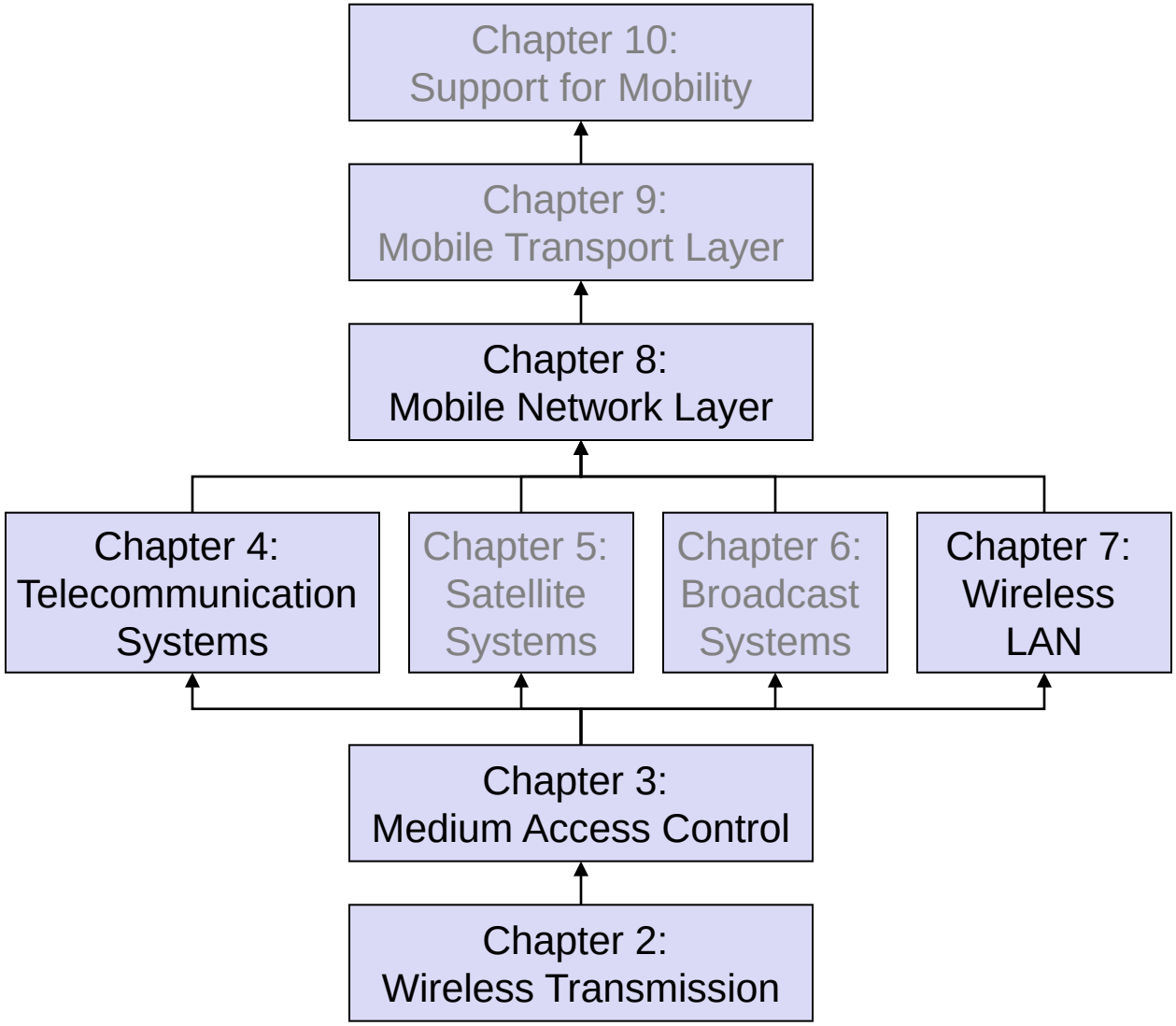
Simple reference model used here



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

Overview of the main chapters



Overlay Networks - the global goal