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Mobile Communications
- an Overview

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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
Internet of Everything needs mobile/wireless access

Source: https://riot-os.org/

Source: https://www.funktel.international/

Source: https://www.apple.com/

Source: https://www.samsung.com/

Source: https://www.apple.com/

Overview of the lecture

- Introduction
  - Use-cases, applications
  - 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, GPRS, TETRA, UMTS, IMT-2000, LTE
- Wireless LANs/PANs
  - Basic Technology
  - IEEE 802.11a/b/g/…, .15, Bluetooth, ZigBee
- Internet Protocols
  - Mobile IP
  - Locator/Identifier split
  - Ad-hoc networking
  - Routing
  - Transport Protocols
  - IoT
- Outlook
  - Beyond LTE, 5G

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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 (see M. Weiser/invisible computer)

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, message 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: NFC, piconets, wireless LANs, wireless WANs, regional wireless telecommunication networks, VLC etc.

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
✗	✗	high performance cluster
✗	✓	notebook in a hotel, on-board networks
✓	✗	wireless LANs in historic buildings, ad-hoc infrastructure replacement
✓	✓	Smartphone

The demand for mobile communication created already decades ago 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

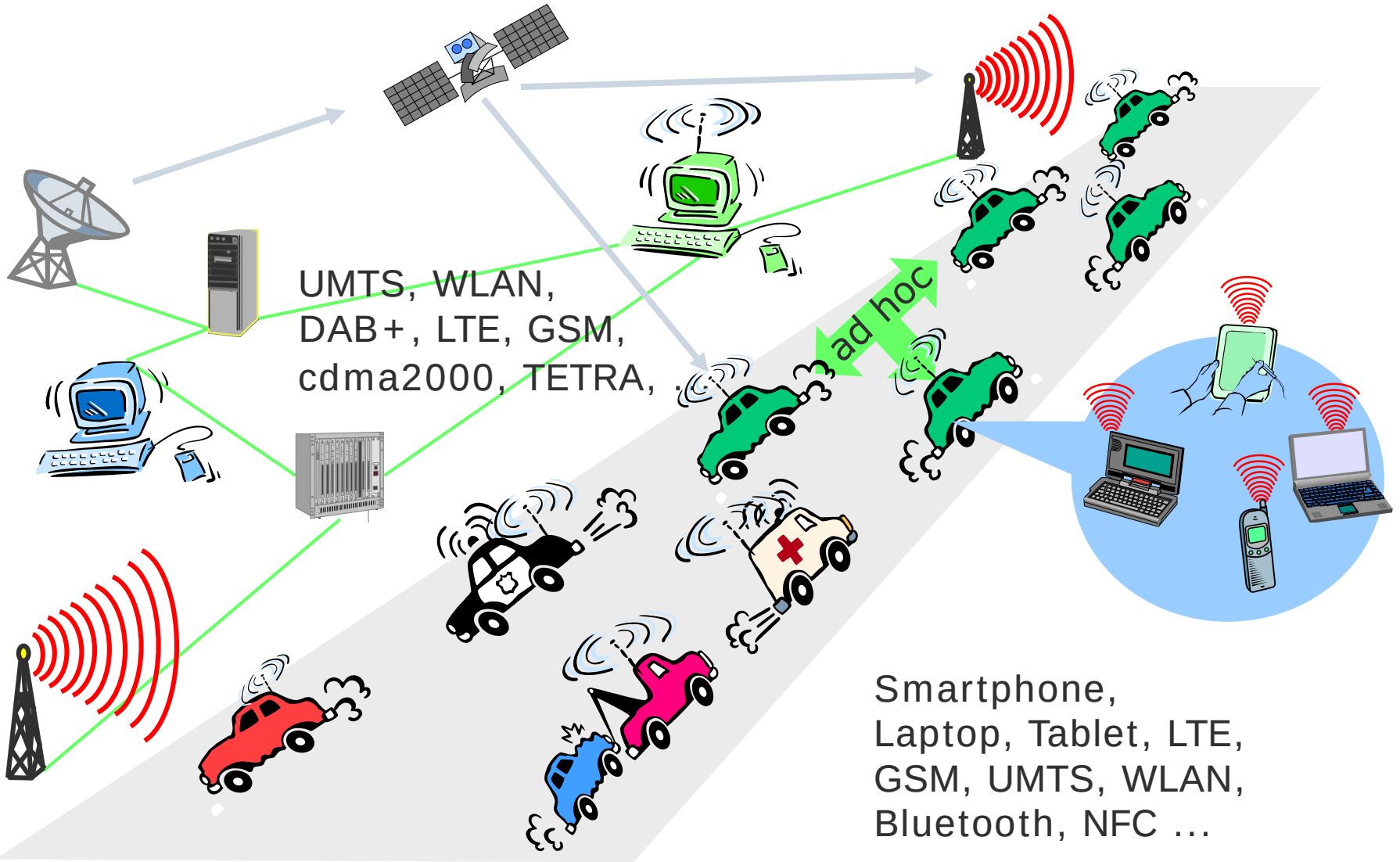
Vehicles

- transmission of news, road condition, weather, music/video via DAB+/DVB-T2/LTE
- personal communication using GSM/UMTS/LTE
- positioning via GPS/Galileo/Glonass/Beidou
- 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

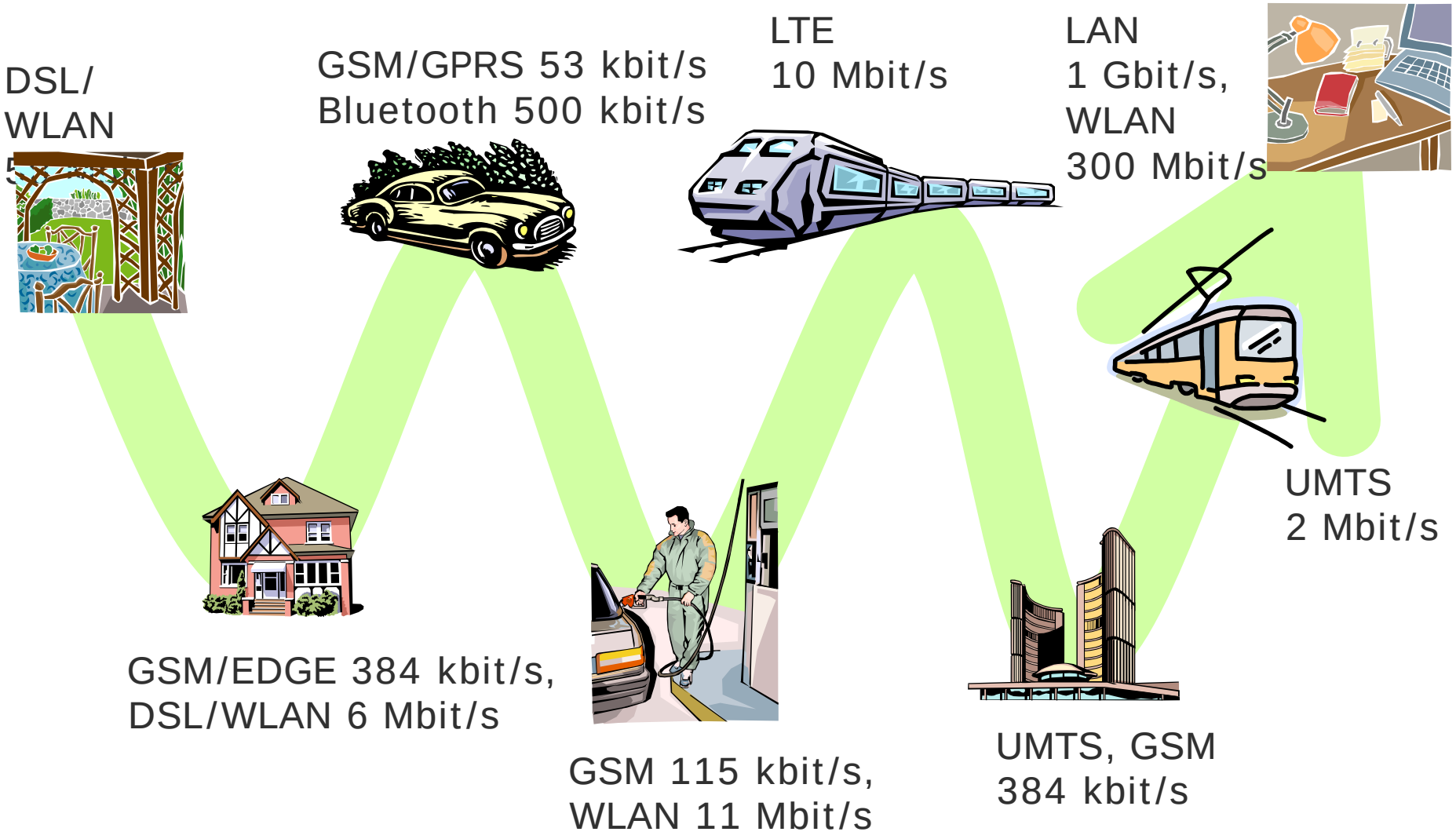
Emergencies

- 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



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, phone, server etc. exist in the local environment

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

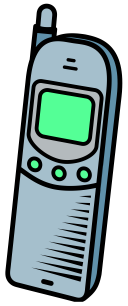
Information services
- “push”: e.g., current special offers in the supermarket
- “pull”: e.g., where is the Black Forrest Cheese Cake?

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

Specialized PDAs
- graphical displays
- character recognition
- application specific
- ruggedized



Laptop/Notebook/Convertible
- fully functional
- standard applications

Sensors, embedded controllers

Smart dust

Classical mobile phones
- voice, data
- simple graphical displays
- robust, water proof

Smartphone/Tablet
- tiny virtual keyboard
- voice recognition
- simple(r) 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

Source: https://www.welectron.com/

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

Source: https://www.catphones.com/

Limited fast memory (always in relation to e.g. PCs)
- Limited/no 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 sometimes only, e.g., 53kbit/s with GSM/GPRS or about 150 kbit/s using EDGE – some Mbit/s with LTE (shared!) – compare country side vs. downtown

Higher delays, higher jitter
- connection setup time with GSM in the second range, several hundred milliseconds for other wireless systems – 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

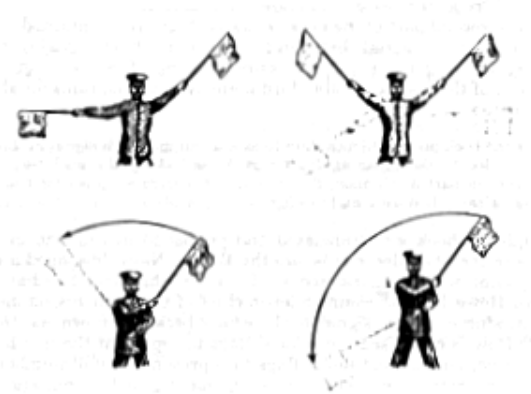
Questions & Tasks

- Compare theoretical (and often announced) values for transmission data rates with realistic data rates. What could be reasons for the sometimes big difference?
  - How do fixed and wireless systems differ in this context?
- Compare advances in CPU power, displays, batteries, applications, data rates. What are limiting factors of today?
- Go to the web sites of the three big organizations that push forward standardization of mobile and wireless communication (among many other organizations): for LANs http://grouper.ieee.org/groups/802/index.shtml, for the Internet https://www.ietf.org/ and for WANs https://www.3gpp.org/. Find out how they do their standardization!
- What are pros and cons regarding push or pull services?

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/km2, 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 50kbit/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, iPhone, VoIPoWLAN…

2010 – LTE available in some cities, new frequencies allocated
- Reuse of old analog TV bands, LTE as DSL replacement for rural areas

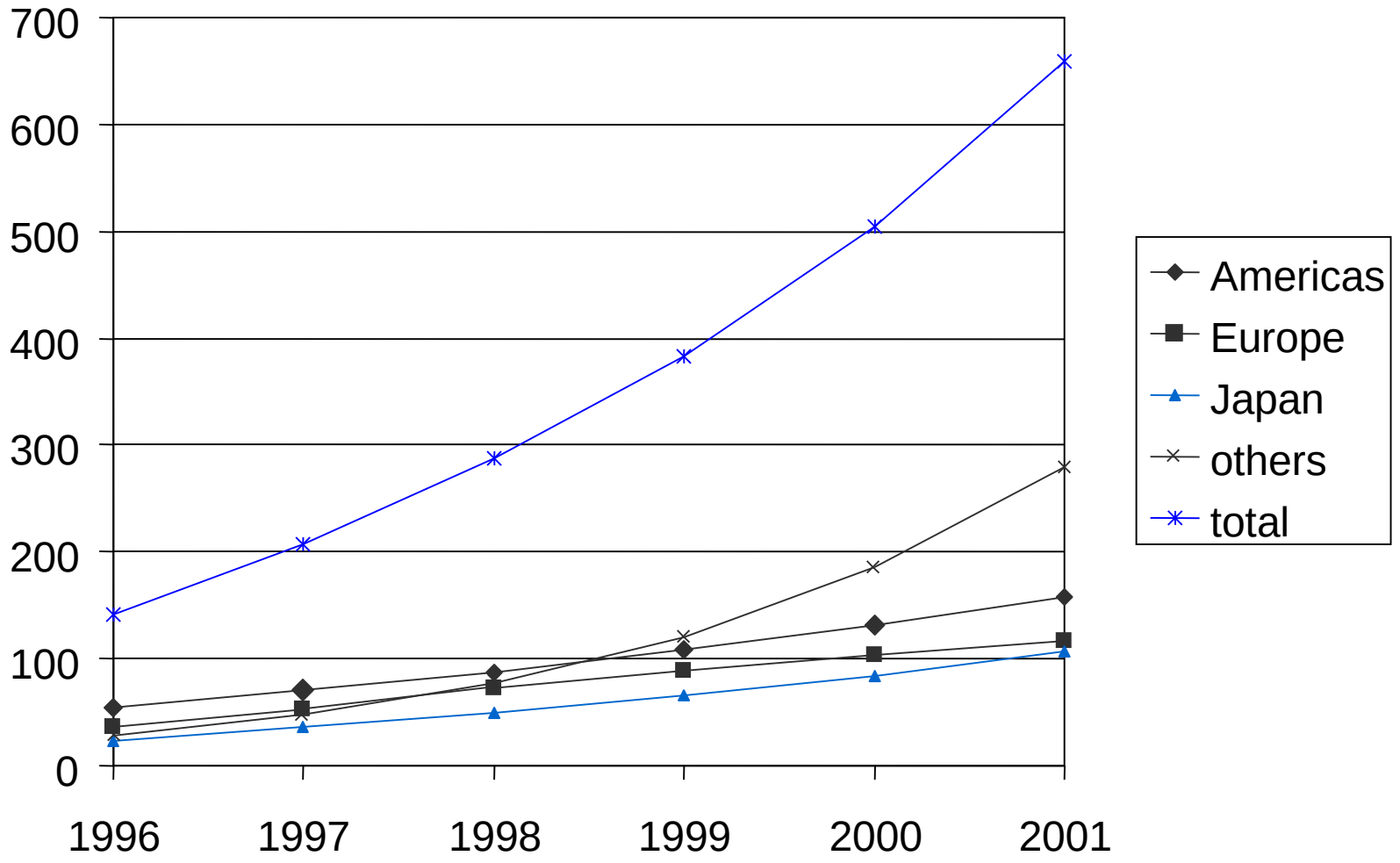
2015 – VoLTE, LTE@700MHz, LTE advanced

2020 – Start of 5G

Questions & Tasks

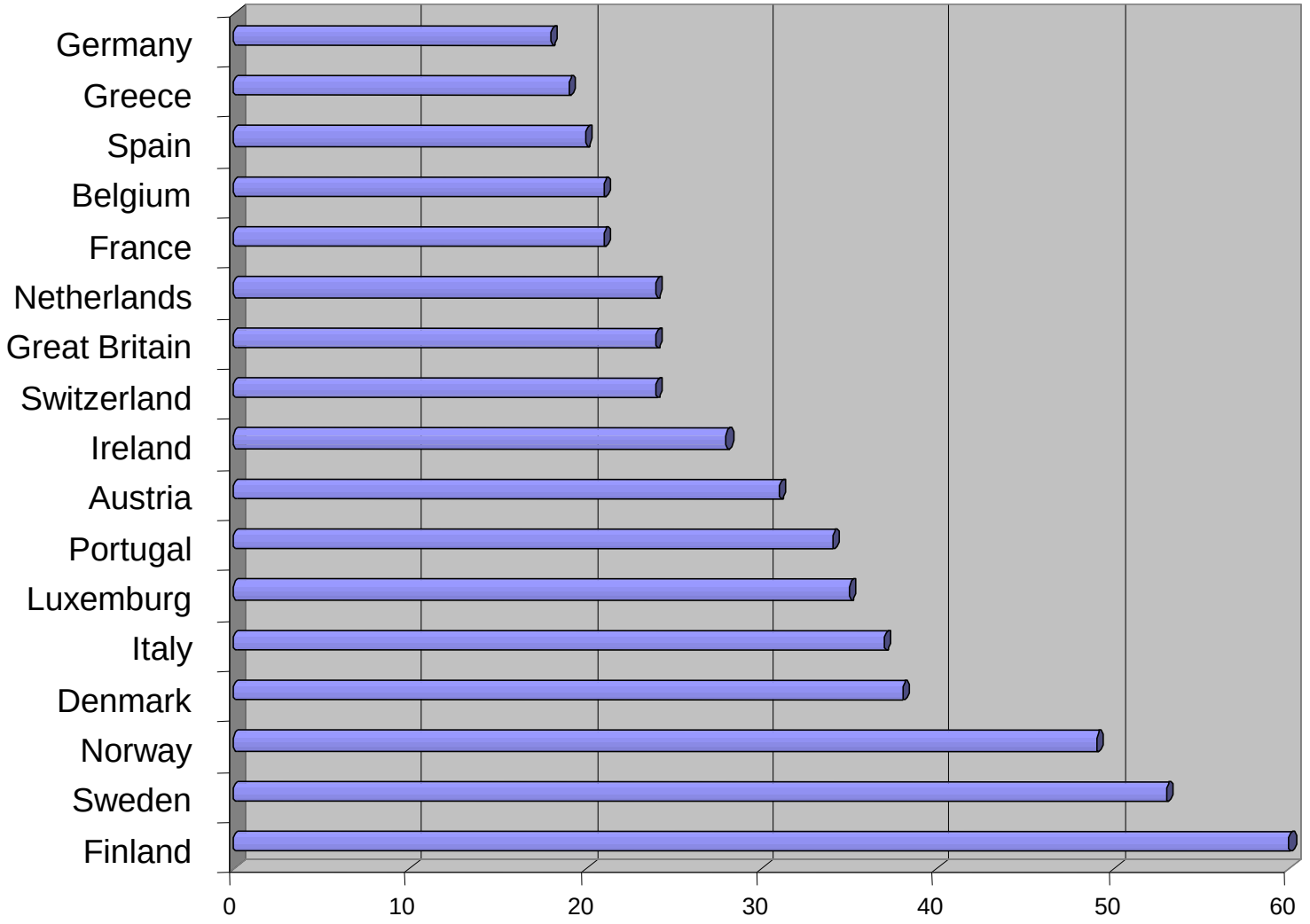
- The history of wireless and mobile communication is not only a history of successes, but also failures. Iridium, HiperLAN, WAP, WiMax are examples. Find reasons for their failure (or at least limited success)!
- Check the current, newest standards for mobile communications (3gpp), WLAN (IEEE), PANs (Zigbee, Bluetooth)

Worldwide wireless subscribers (old prediction 1998)



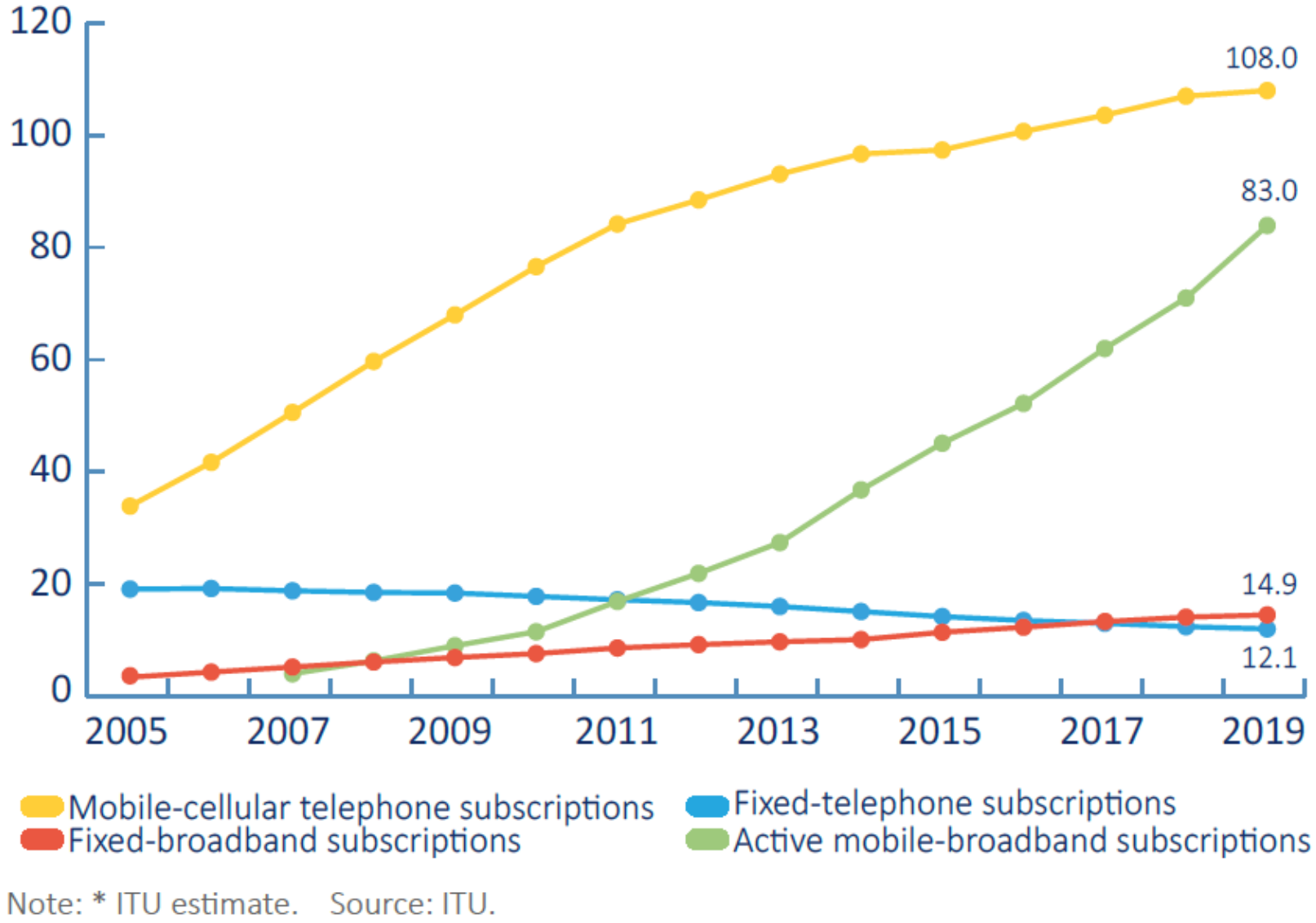
2014 more than 7 billion subscriptions – be aware: this includes many devices!

Mobile phones per 100 people 1999



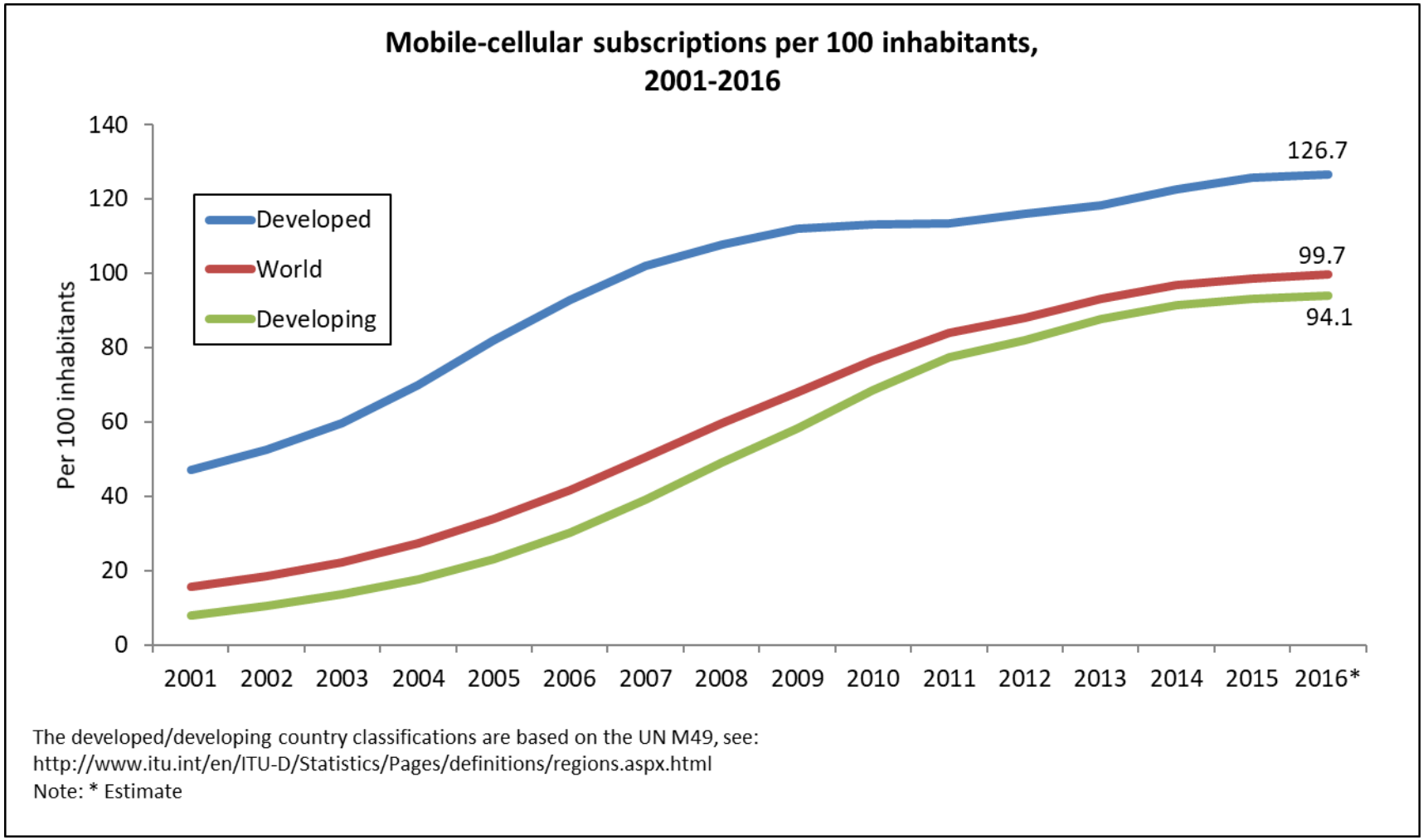
2005: 70-90% penetration in Western Europe, 2009 (ten years later): > 100% – 2016: 96% worldwide!

Global ICT developments, 2005-2019



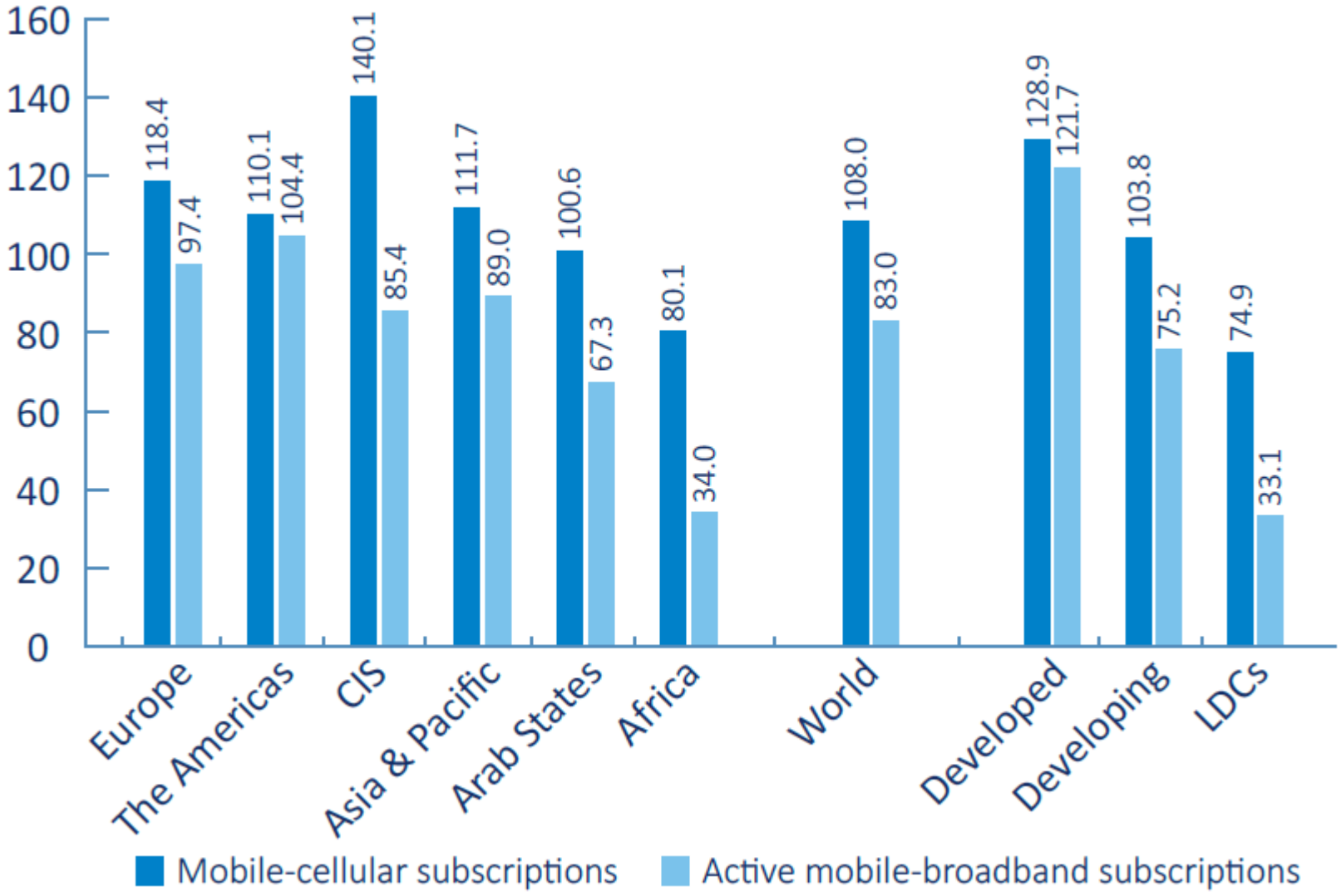
Note: * ITU estimate. Source: ITU.

Mobile-cellular subscriptions, 2001-2016

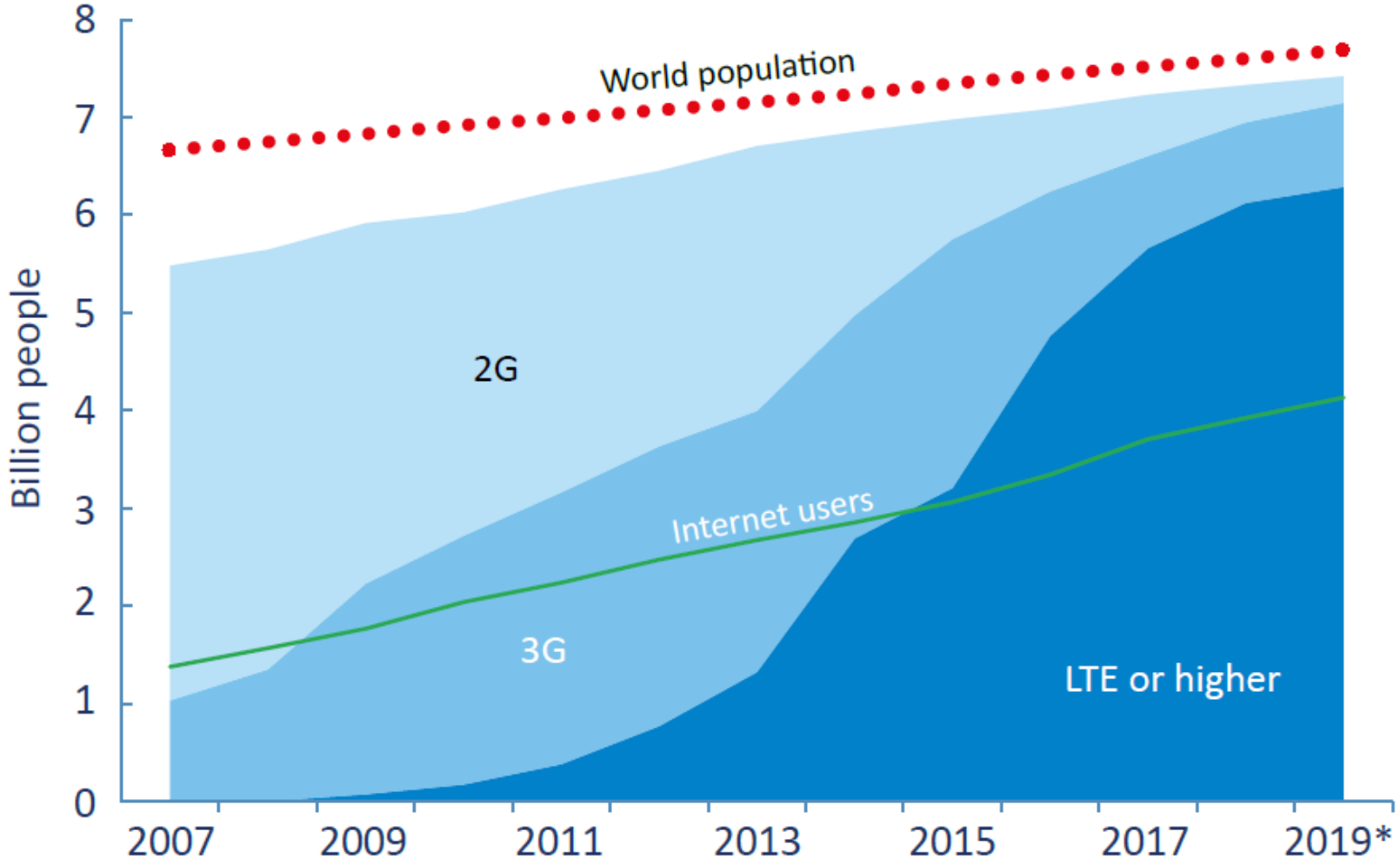


The developed/developing country classifications are based on the UN M49, see:
http://www.itu.int/en/ITU-D/Statistics/Pages/definitions/regions.aspx.html
Note: * Estimate

Mobile-cellular subscriptions per region per 100 inhabitants 2019



Mobile population coverage by type of network 2007-2019



Note: * ITU estimate. Source: ITU.

Questions & Tasks

- Check https://www.itu.int for up-to-date figures
  - Additionally, look at https://www.3gpp.org/
- Currently, network operators roll-out 5G technology (covered later in this course). Figure out the strategies of the different network operators while migrating towards 5G systems. Can you find reasons why a single common system is not in sight?
- 4G or higher coverage is flattening way before reaching the world population. Give reasons!

Areas of research in mobile and wireless communication

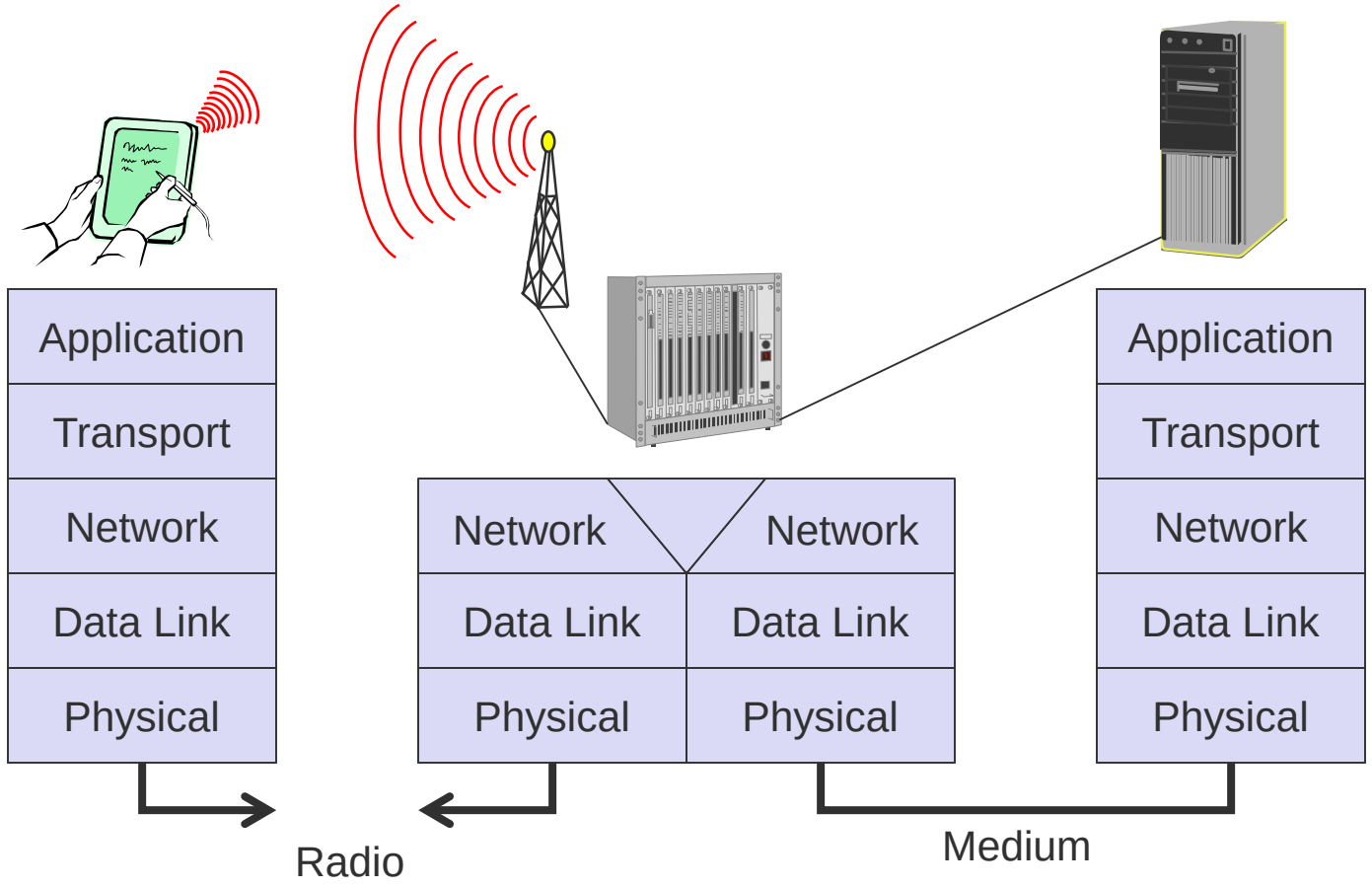
Wireless Communication
- transmission quality (bandwidth, error rate, delay)
- modulation, coding, interference
- medium access, regulations
- ...

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

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

… and as always: security (privacy, data integrity, tracking, encryption, law enforcement…)!

Simple reference model used here

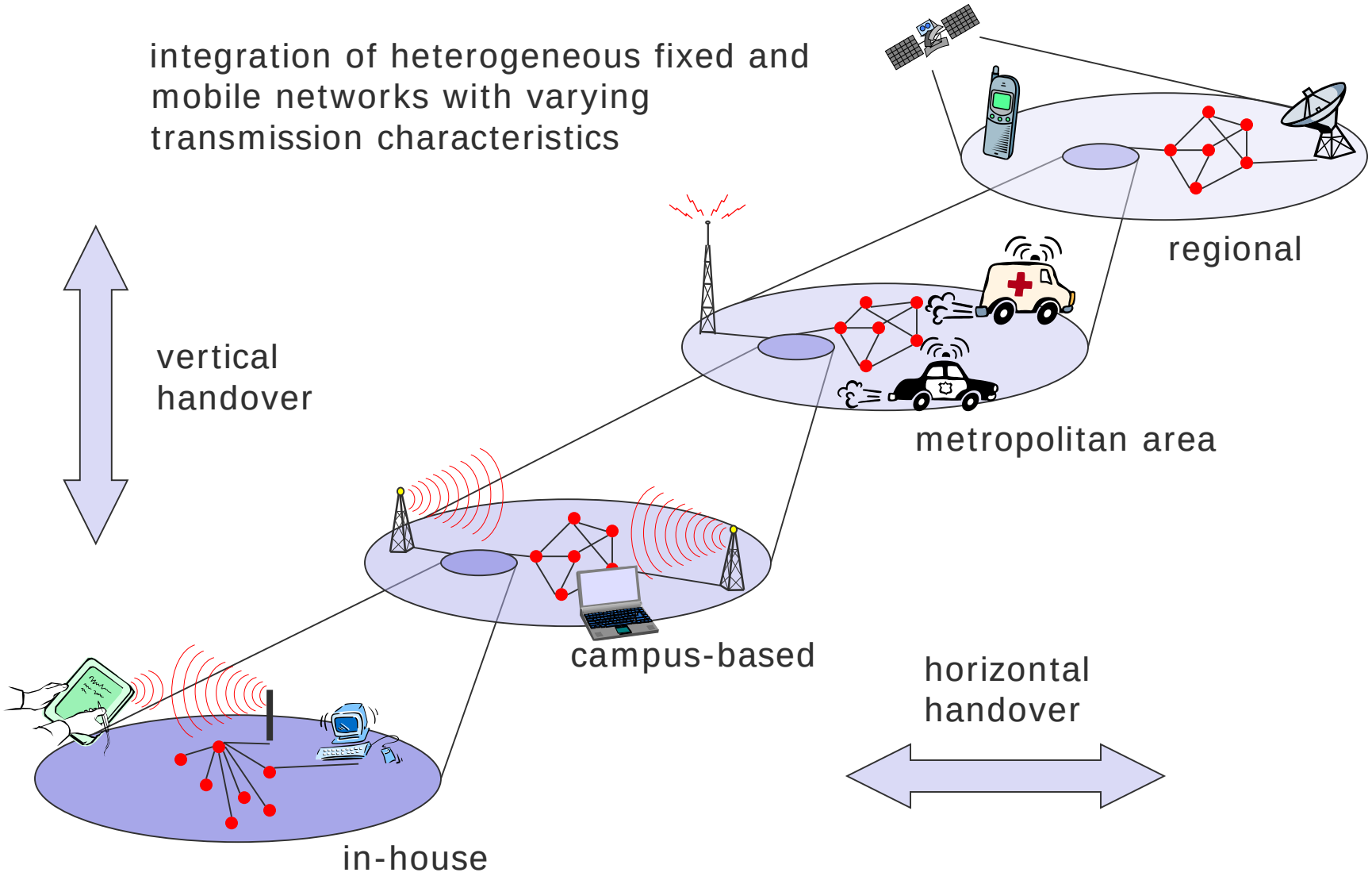


Influence of mobile communication to the layer model

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

Seamless Overlay Networks – (still) the global goal

integration of heterogeneous fixed and mobile networks with varying transmission characteristics



➔ 5G

Questions & Tasks

- This course requires sound knowledge in fixed computer networks, layering, protocols etc. So please refresh your knowledge with our Computer Networks lecture, books, tutorial …
  - The principle of layering, the task of the layers, the Internet protocol family should be familiar!
- Where do you use horizontal handover since many years?
- What about vertical handovers? Give examples where they already exist!
  - What are problems for vertical handovers?
- The data rate of LTE is already higher than many DSL connections (> 100Mbit/s) – so why doing more research? Can’t we just replace all DSL connections by LTE – problem solved?