CSE 445: Mobile and Wireless Communication

Lecture 1: Introduction

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Prerequisite for this course

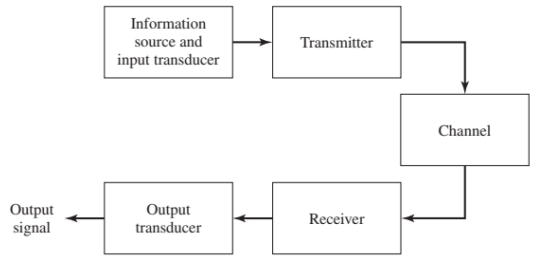
- Basic Understandings of statistics
- Basic understanding of Fourier Series and Fourier Transform
- Basic Understanding of Electronics

Communication Basics

Communication??

- In simplest sense communication is exchange or transfer of information from one entity to another through the use of mutually understood signs and semiotic rules.
- The simplest form of communication can be though as a signal sent to a distant person using a light to inform about any situation. (Fire signal, etc)
- Using of Morse code is another example of simple communication.
- For this course we will study mainly electronic communication system.
  - Electronic communication can be simple classified into 2 types, Wireline and wireless

Functional Block diagram of a Communication System



Elements of Communication System

- The heart of the communication system consists of three basic parts, namely,
  - the *transmitter,*
  - the *channel,* and
  - the *receiver*.

Elements of Communication System

- The Transmitter
  - The transmitter converts the electrical signal into a form that is suitable for transmission through physical channel or transmission medium
- The Receiver
  - The function of the receiver is to recover the message signal contained in the received signal.
  - If the message signal is transmitted by carrier modulation, the receiver performs *carrier demodulation* in order to extract the message from the sinusoidal carrier.

Elements of Communication System

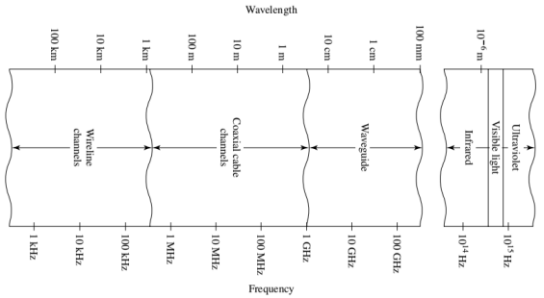
- The Channel
  - The communications channel is the physical medium that is used to send the signal from the transmitter to the receiver.
  - Communication channel provides the connection between transmitter and receiver. The physical channel may be a pair of wires that carry electrical signals or an optical fiber that carries the information on a modulated light beam.
  - In wireless transmission, the channel is usually the atmosphere (free space).
  - On the other hand, telephone channels usually employ a variety of physical media, including
    - wirelines,
    - optical fiber cables,and
    - wireless (microwave radio)

Common Communication Channel

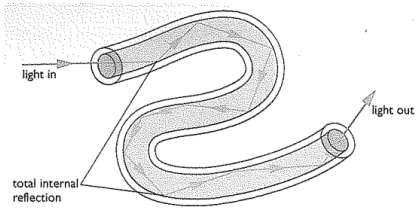
- Wireline Channel
- Fiber Optic Channel
- Wireless Electromagnetic Channel
- Wireless Optical Channel
- Underwater Acoustic Channel
- Storage Channel

Wireline Channel

- One of the early physical channel used.
- Generally Uses Electrical signaling.
- Most common is the use in telephone networking.



Fiber Optic Channel



- Optical fibers offer the communications system designer a channel bandwidth that is several orders of magnitude larger than coaxial cable channels.
- The transmitter or modulator in a fiber optic communication system is a light source, either a light-emitting diode (LED) or a laser
- Information is transmitted by varying (modulating) the intensity of the light source with the message signal.

Wireless Electromagnetic Channel

- The medium is free space.
- Electromagnetic waves are modulated to send signal.
- Electromagnetic signals can be of different frequencies.
- The chosen frequency defines the engineering of full system like transduce design, antenna design.
- Main focus of this course.

Wireless Optical Channel

- A special version of wireless electromagnetic channel.
- Similar to wireless Electromagnetic channel and Optical fiber channel.
- The medium is free space.
- Signal is send via modulated lights.

Underwater Acoustic Channel

- Medium is water.
- Signal sent using modulated sound wave.
- Electromagnetic is bad choice because of their propagation loss in water.
- Ambient ocean acoustic noise is caused by shrimp, fish, and various mammals.
- Near harbors, there is also man-made acoustic noise in addition to the ambient noise.
- In spite of this hostile environment, it is possible to design and implement efficient and highly reliable underwater acoustic communication systems for transmitting digital signals over large distances.

Storage Channel

- Information storage and retrieval systems constitute a very significant part of our data handling activities on a daily basis.
- Magnetic tape, including digital audio tape and video tape, magnetic disks used for storing large amounts of computer data, and optical disks used for computer data storage, music (compact disks), and video are examples of data storage systems that can be characterized as communication channels.

Analog Vs Digital Communication

- Communication system can be digital or analog
- Messages are digital or analog.
  - Digital messages are constructed with a finite number of symbols. For example, a text file is a digital message constructed from 50 symbols, consists of 26 letters, 10 numbers, a space and several punctuation marks. Similarly, a Morse-coded telegraph is a binary message, implying only two symbols – mark and space.
  - Analog messages are characterized by data whose values vary over a continuous range. For example, a speech waveform has amplitudes that vary over a continuous range. A picture is also an analog message.

Analog Vs Digital Communication

- **Noise immunity of digital signals** – digital data can be recovered without any error as long as the distortion and noise are within limits. On the other hand, for an analog message, even a slight distortion or interference in the waveform will cause an error in the received signal.
- **Regenerative repeaters**—Based on this "noise immunity", when transporting a bit stream over a long distance, regenerative repeaters or repeater stations are placed along the path of a digital system at distances short enough to ensure that noise and distortion remain within a limit. The viability of regenerative repeaters is the main reason for the superiority of digital systems over analog ones.
- **Every possible communication can be carried on with a minimum of two symbols**, i.e., by using a proper binary sequence. In the last 20 years, digital communication gradually replace its analog competitors, and the revolution is now nearly complete.

Noise immunity of digital signals

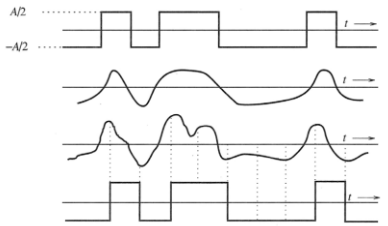


Figure 1.3 (a) Transmitted signal. (b) Received distorted signal (without noise). (c) Received distorted signal (with noise). (d) Regenerated signal (delayed).

Interface of Analog and Digital Systems -- A/D and D/A Conversion

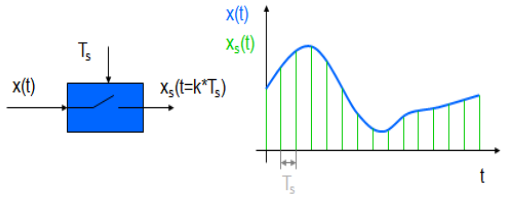
- Analog to Digital Converter (ADC) converts Analog signal to digital signal for interfacing Digital and Analog systems
- Digital to Analog Converter (DAC) converts Analog signal to digital signal for interfacing Digital and Analog systems
- There are

There are three steps in ADC process:

- Sampling
- Quantification
- Coding

Conversion Process: Sampling

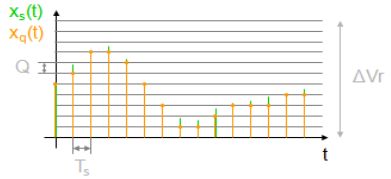
- Digital system works with discrete states
- The signal is only defined at determined times
- The sampling times are proportional to the sampling period (T_s)



Conversion Process: Quantification

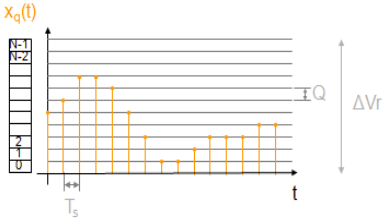
The signal can only take determined values
Belonging to a range of conversion (ΔV_r)

- Based on number of bit combinations that the converter can output
- Number of possible states: $N=2^n$ where n is number of bits
- Resolution: $Q= \Delta V_r/N$



Conversion Process: Coding

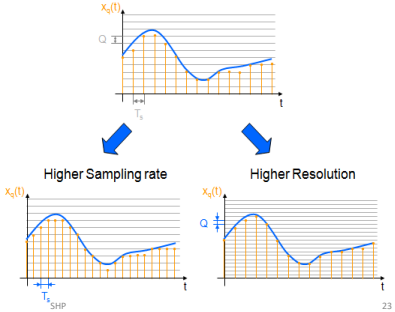
- Assigning a unique digital word to each sample
- Matching the digital word to the input signal



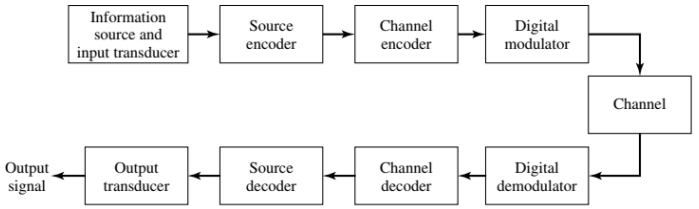
Increasing the accuracy of ADC

The accuracy of an ADC can be improved by increasing:

- The sampling rate (T_s)
- The resolution (Q)



Basic elements of a digital communication system



Wireless and Mobile Communication

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, almos.. anywhere
- Internet of Everything needs mobile/wireless access

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

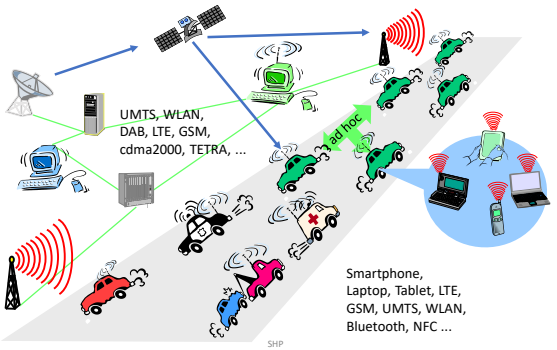
✗	✗	high performance cluster
✗	✓	notebook in a hotel, on-board networks
✓	✗	wireless LANs in historic buildings,
✓	✓	Smartphone

- 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

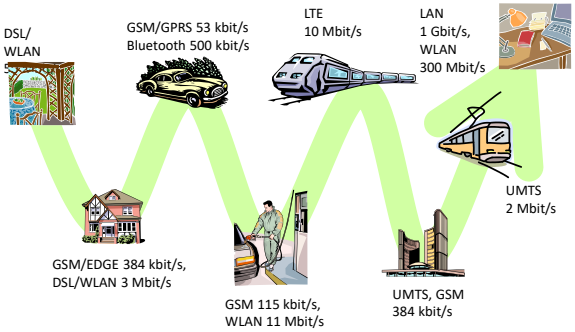
Applications I

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



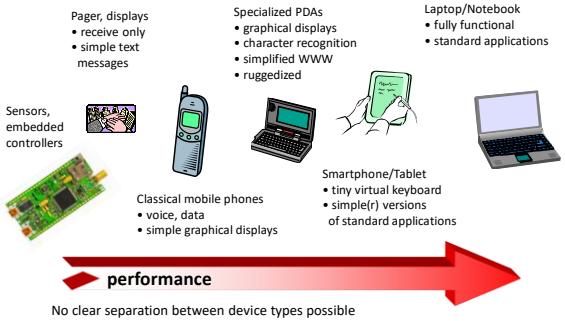
Applications II

- 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



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

Effects of device portability

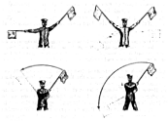
- Power consumption
  - limited computing power, low quality displays, small disks due to limited battery capacity
  - CPU: power consumption ~ CV^2f
    - C: internal capacity, reduced by integration
    - V: supply voltage, can be reduced to a certain limit
    - f: clock frequency, can be reduced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

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

- 1893, Nikola Tesla
  - made the first public demonstration of wireless (radio) telegraphy
- 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

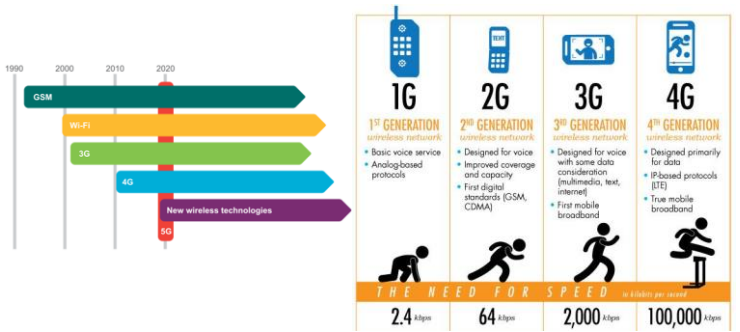
History of wireless communication V

- 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 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

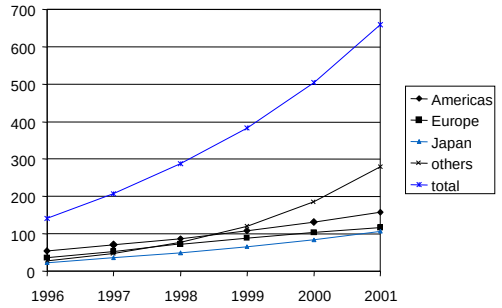
History of wireless communication VI

- 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, 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 planned

Cellular Systems Evolution

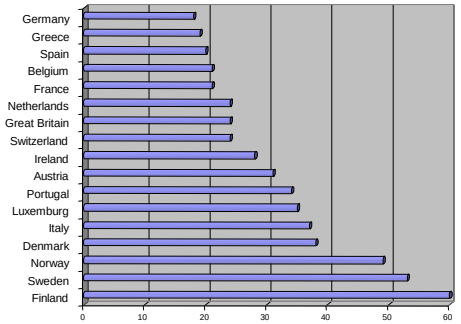


Worldwide wireless subscribers (old prediction 1998)



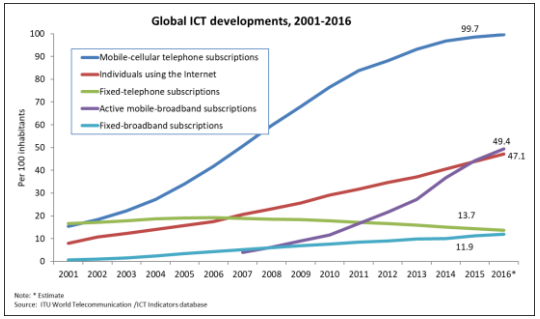
2014 more than 7 billion subscriptions – be aware: this includes many devices!

Mobile phones per 100 people 1999

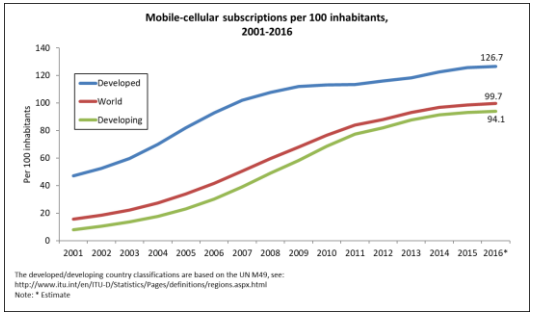


2005: 70-90% penetration in Western Europe, 2009 (ten years later): > 100% – 2016: 96% worldwide!

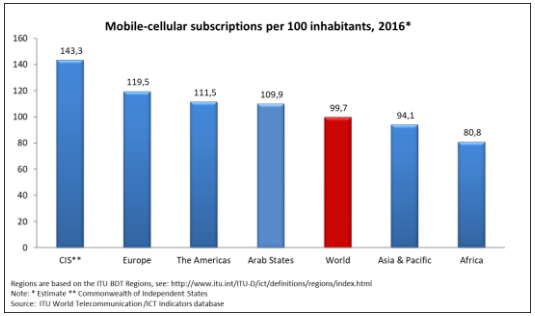
Global ICT developments, 2001-2016



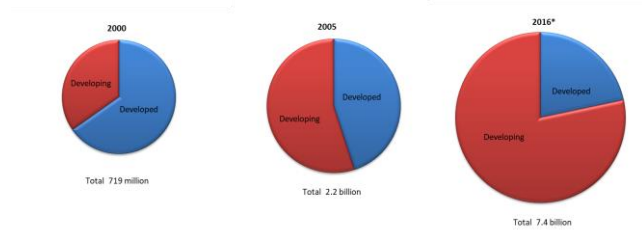
Mobile-cellular subscriptions, 2001-2016



Mobile-cellular subscriptions per region 2016



Mobile-cellular share



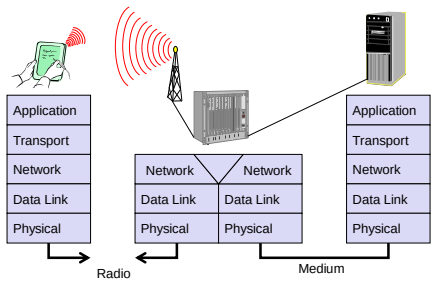
See https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx for up-to-date data
See https://www.itu.int/en/ITU-D/Statistics/Pages/definitions/regions.aspx for the definition of regions etc.

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
  - ...

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

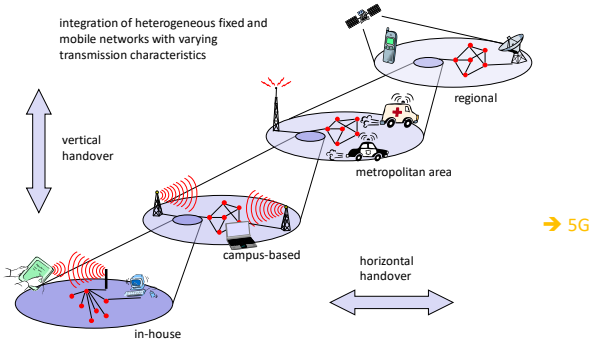
Simple reference model used here



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
Physical layer	encryption modulation interference attenuation frequency

Seamless Overlay Networks – (still) the global goal



Recommended Text for this lecture

- Communication Systems Engineering by John G. Proakis
  - Chapter 1
- Mobile Communications by Jochen Schiller
  - Chapter 1
- Modern Digital and Analog Communication System by B.P. Lathi

Disclaimer

- This Presentation contains some edited version of slides provided by Jochen Schiller writer of the book Mobile Communications.
- There is also some screenshots from different books.
- Some online images are also used.

*I have tried to cite any source. But if any citation is missed, kindly contact me to add your citation.

END