CS647 - Advanced Topics in Wireless Networks

Introduction

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Outline

- A case for mobility – many aspects
- History of mobile communication
- Market
- Wireless Networks
  - Cellular Networks
  - Ad hoc Networks
  - Sensor Networks
- Areas of research
Computers for the next decades?

- Computers are integrated
  - 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

<table>
<thead>
<tr>
<th>Wireless</th>
<th>Mobile</th>
<th>Examples</th>
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<tbody>
<tr>
<td>❌</td>
<td>❌</td>
<td>stationary computer</td>
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<td>❌</td>
<td>✅</td>
<td>notebook in a hotel</td>
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<tr>
<td>✅</td>
<td>❌</td>
<td>wireless LANs in historic buildings</td>
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<td>✅</td>
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<td>Personal Digital Assistant (PDA)</td>
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- 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, ETSI (HIPERLAN)
  - Internet: Mobile IP extension of the internet protocol IP
  - wide area networks: e.g., internetworking of GSM and ISDN
Cell (Mobile) Phone

As soon as the airplane’s door is opened, you can switch on the cell phone and you are connected.

Cell Phone contacts the nearest Base Station and registers itself to get service.
Applications - Cellular

Maintaining the telephone number across geographical areas in a wireless and mobile system.
First Generation Cellular Systems and Services

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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</thead>
<tbody>
<tr>
<td>1970s</td>
<td>Developments of radio and computer technologies for 800/900 MHz mobile communications</td>
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<tr>
<td>1976</td>
<td>WARC (World Administrative Radio Conference) allocates spectrum for cellular radio</td>
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<td>1979</td>
<td>NTT (Nippon Telephone &amp; Telegraph) introduces the first cellular system in Japan</td>
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<td>1981</td>
<td>NMT (Nordic Mobile Telephone) 900 system introduced by Ericsson Radio System AB and deployed in Scandinavia</td>
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<tr>
<td>1984</td>
<td>AMPS (Advanced Mobile Phone Service) introduced by AT&amp;T in North America</td>
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## Second Generation Cellular Systems and Services

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1982</td>
<td>CEPT (Conference Europeenne des Post et Telecommunications) established GSM to define future Pan-European cellular Radio Standards</td>
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<tr>
<td>1990</td>
<td>Interim Standard IS-54 (USDC) adopted by TIA (Telecommunications Industry Association)</td>
</tr>
<tr>
<td>1990</td>
<td>Interim Standard IS-19B (NAMPS) adopted by TIA</td>
</tr>
<tr>
<td>1991</td>
<td>Japanese PDC (Personal Digital Cellular) system standardized by the MPT (Ministry of Posts and Telecommunications)</td>
</tr>
<tr>
<td>1992</td>
<td>Phase I GSM system is operational</td>
</tr>
<tr>
<td>1993</td>
<td>Interim Standard IS-95 (CDMA) adopted by TIA</td>
</tr>
<tr>
<td>1994</td>
<td>Interim Standard IS-136 adopted by TIA</td>
</tr>
<tr>
<td>1995</td>
<td>PCS Licenses issued in North America</td>
</tr>
<tr>
<td>1996</td>
<td>Phase II GSM operational</td>
</tr>
<tr>
<td>1997</td>
<td>North American PCS deploys GSM, IS-54, IS-95</td>
</tr>
<tr>
<td>1999</td>
<td>IS-54: North America</td>
</tr>
<tr>
<td></td>
<td>IS-95: North America, Hong Kong, Israel, Japan, China, etc</td>
</tr>
<tr>
<td></td>
<td>GSM: 110 countries</td>
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</tbody>
</table>
Worldwide wireless subscribers (old prediction 1998)
Mobile phones per 100 people 1999

2005: 70-90% penetration in Western Europe
Worldwide cellular subscriber growth

Note that the curve starts to flatten in 2000 – 2004: 1.5 billion users
Third Generation Cellular Systems and Services (1/2)

  - Fulfill one's dream of anywhere, anytime communications a reality.

- Key Features of IMT-2000 include:
  - High degree of commonality of design worldwide;
  - Compatibility of services within IMT-2000 and with the fixed networks;
    - High quality;
    - Small terminal for worldwide use;
    - Worldwide roaming capability;
    - Capability for multimedia applications, and a wide range of services and terminals.
Third Generation Cellular Systems and Services (2/2)

- Important Component of IMT-2000 is its ability to provide high bearer rate capabilities:
  - 2 Mbps for fixed environment;
  - 384 Kbps for indoor/outdoor and pedestrian environment;
  - 144 kbps for vehicular environment.

- Standardization Work:
  - In progress

- Scheduled Service:
  - Started in October 2001 in Japan (W-CDMA)

- M.687-2
  - IMT-2000 concepts and goals
- M.816-1
  - framework for services
- M.817
  - IMT-2000 network architectures
- M.818-1
  - satellites in IMT-2000
- M.819-2
  - IMT-2000 for developing countries
- M.1034-1
  - requirements for the radio interface(s)
- M.1035
  - framework for radio interface(s) and radio sub-system functions
- M.1036
  - spectrum considerations
- M.1078
  - security in IMT-2000
- M.1079
  - speech/voiceband data performance
- M.1167
  - framework for satellites
- M.1168
  - framework for management
- M.1223
  - evaluation of security mechanisms
- M.1224
  - vocabulary for IMT-2000
- M.1225
  - evaluation of transmission technologies
- . . .

http://www.itu.int/imt
Coverage Aspect of Next Generation Mobile Communication Systems

- Satellite
- Picocell
- Microcell
- Macrocell
- In-building
- Urban
- Suburban
- Global
Transmission capacity as a function of mobility in some radio access systems:

- Broadband radio
- Universal Mobile Telecommunications System
- Mobile Broadband System
- Local Multipoint Distribution System
- Satellite Universal Mobile Telecommunications System
- Broadband Satellite Multimedia
Medical and Healthcare Applications

Possibility for Remote consulting (including Audio Visual communication)
Applications I

- **Vehicles**
  - transmission of news, road condition, weather, music via DAB
  - personal communication using GSM
  - 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

UMTS, WLAN, DAB, DVB, GSM, cdma2000, TETRA, ...

Personal Travel Assistant, PDA, Laptop, GSM, UMTS, WLAN, Bluetooth, ...
Mobile and wireless services – Always Best Connected

- DSL/ WLAN: 3 Mbit/s
- GSM/GPRS: 53 kbit/s, Bluetooth: 500 kbit/s
- GSM/EDGE: 384 kbit/s, DSL/WLAN: 3 Mbit/s
- GSM: 115 kbit/s, WLAN: 11 Mbit/s
- UMTS, GSM: 115 kbit/s
- LAN: 100 Mbit/s, WLAN: 54 Mbit/s
- UMTS: 2 Mbit/s
- UMTS, GSM: 384 kbit/s
- DSL/WLAN: 3 Mbit/s
Applications II

- Travelling 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 Cherry 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

Mobile phones
• voice, data
• simple graphical displays

Palmtop
• tiny keyboard
• simple versions of standard applications

Sensors, embedded controllers

www.scatterweb.net
Effects of device portability

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

- **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**
  - limited value 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

- Low transmission rates
  - local some Mbit/s, regional currently, e.g., 53kbit/s with GSM/GPRS

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

- 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, at the location of today’s University of Karlsruhe)
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, 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 Austria, Netherland and Luxembourg, 1979 13000 customer 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

- **1986C-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 Telecommunication 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$ payed in Germany for 6 licenses!)
- 2001 Start of 3G systems
  - Cdma2000 in Korea, UMTS tests in Europe, Foma (almost UMTS) in Japan
Wireless systems: overview of the development

1980: CT0
1982: Inmarsat-A
1988: Inmarsat-B
1988: Inmarsat-M
1991: D-AMPS
1991: CDMA
1991: DECT
1991: PDC
1998: Iridium
2000: GPRS
2000: IEEE 802.11
2000: IEEE 802.11a
2001: IMT-2000
2001: GPRS
2007: Fourth Generation (Internet based)

4G – fourth generation: when and how?
Cellular subscribers per region (June 2002)

- Asia Pacific: 36,9
- Europe: 36,4
- Americas (incl. USA/Canada): 22
- Africa: 3,1
- Middle East: 1,6

2004: 715 million mobile phones delivered
Mobile statistics snapshot (09/2002 / 12/2004)

- Total Global Mobile Users: 869M / 1.52bn
- Total Analogue Users: 71M / 34m
- Total US Mobile users: 145M / 140m
- Total Global GSM users: 680M / 1.25T
- Total Global CDMA Users: 127M / 202m
- Total TDMA users: 84M / 120m
- Total European users: 283M / 343m
- Total African users: 18.5M / 53m
- Total 3G users: 130M / 130m(?)
- Total South African users: 13.2m / 19m
- European Prepaid Penetration: 63%
- European Mobile Penetration: 70.2%
- Global Phone Shipments 2001: 393m
- Global Phone Sales 2Q02: 96.7m

#1 Mobile Country: China (139M / 300m)
#1 GSM Country: China (99m)
#1 SMS Country: Philippines
#1 Handset Vendor 2Q02: Nokia (37.2%)
#1 Network In Africa: Vodacom (6.6m)
#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 1Q02: 60T / 135bn
SMS sent in UK 6/02: 1.3T / 2.1bn
SMS sent Germany 1Q02: 5.7T
GSM Countries on Air: 171 / 210
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.!
Simple reference model used here
## Influence of mobile communication to the layer model

<table>
<thead>
<tr>
<th>Layer</th>
<th>Key Concepts</th>
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<tbody>
<tr>
<td><strong>Application layer</strong></td>
<td>- service location</td>
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<tr>
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<td>- new applications, multimedia</td>
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<td>- adaptive applications</td>
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<td><strong>Transport layer</strong></td>
<td>- congestion and flow control</td>
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<td>- quality of service</td>
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<tr>
<td><strong>Network layer</strong></td>
<td>- addressing, routing, device location</td>
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<td>- hand-over</td>
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<td><strong>Data link layer</strong></td>
<td>- authentication</td>
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<td>- media access</td>
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<tr>
<td></td>
<td>- multiplexing</td>
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<tr>
<td></td>
<td>- media access control</td>
</tr>
<tr>
<td><strong>Physical layer</strong></td>
<td>- encryption</td>
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<tr>
<td></td>
<td>- modulation</td>
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<td></td>
<td>- interference</td>
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<td></td>
<td>- attenuation</td>
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<td>- frequency</td>
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Scope of Wireless technologies

**RAN < 100Km**
- 802.22 (proposed)
- 18 – 24 Mbps

**WAN < 15Km**
- 802.20 (proposed)
- GSM, GPRS, CDMA, 2.5G, 3G
- 10 Kbps – 2.4 Mbps

**MAN < 5Km**
- 802.16 a/d/e – 70 Mbps
- LMDS – 38 Mbps

**LAN < 150 m**
- 11-54 Mbps
- 802.11 a/b/e/g
- HiperLAN/2
- 802.11n (proposed) > 100 Mbps

**PAN < 10m**
- 802.15.1 (Bluetooth) < 1Mbps
- 802.15.3 > 20Mbps
- 802.15.3a (UWB) < 480 Mbps
- 802.15.4 (Zigbee) < 250 Kbps
The envisioned communication puzzle of beyond 4G
Overlay Networks - the global goal

integration of heterogeneous fixed and mobile networks with varying transmission characteristics

vertical handover

horizontal handover

metropolitan area

regional

in-house

campus-based
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)
  - Routing
  - ...

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

- **Security**