EEC173B/ECS152C, Winter 2006

Introduction to Wireless/Mobile Networking

- Motivation
- Design Constraints & Challenges
- Taxonomy & Class Roadmap
- History & Evolution
- Areas of Research

Acknowledgment: Selected slides from Prof. Schiller & Prof. Goldsmith

Computers for the next decades?

- Computers are integrated
  - Small, cheap, portable, replaceable - no more separate devices
- 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

Wireless vs. Mobile Communication

- Two aspects of mobility:
  - *User mobility*: users communicate "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 (Ethernet)
✓	✗	wireless LANs in historic buildings
✓	✓	Personal Digital Assistant (PDA)

Mobile Communication

- 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

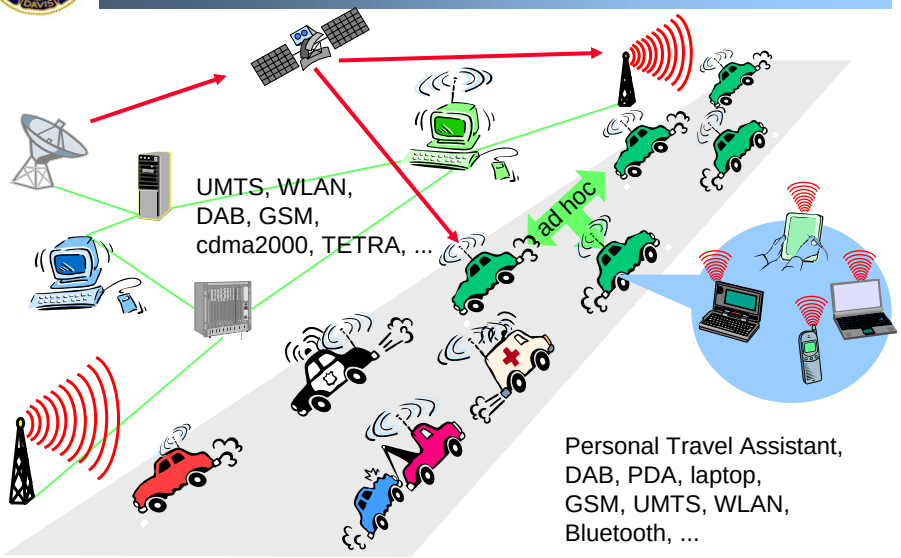
Principles of Mobile Computing

- Accessibility
  - Interface should be simple and intuitive to allow for quick, on-the-spot information access.
- Location Awareness
  - Information should always be relevant to the user's current location. Computer are aware of their environment and adapt
- Context Awareness
  - Computer recognize the location of the user and react appropriately (e.g., call forwarding, fax forwarding)
- Mobility
  - Device should be efficient in both space and weight freeing the users from physical burdens.
- Security
  - Device should be secure enough for users to store personal data and respect user's privacy.

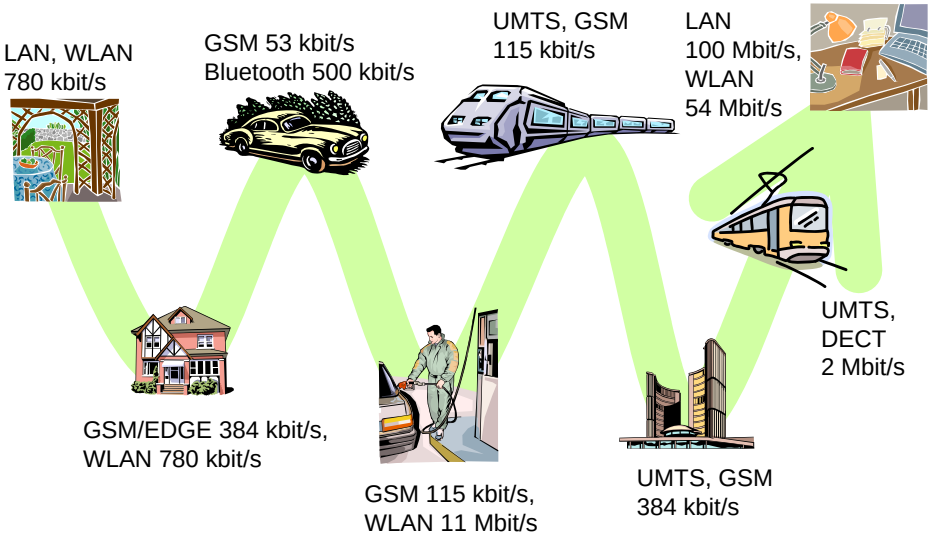
Applications - I

- 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, ...

Example 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, 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
- simpler graphical displays
- character recognition
- simplified WWW

Laptop
- fully functional
- standard applications

Sensors, embedded controllers

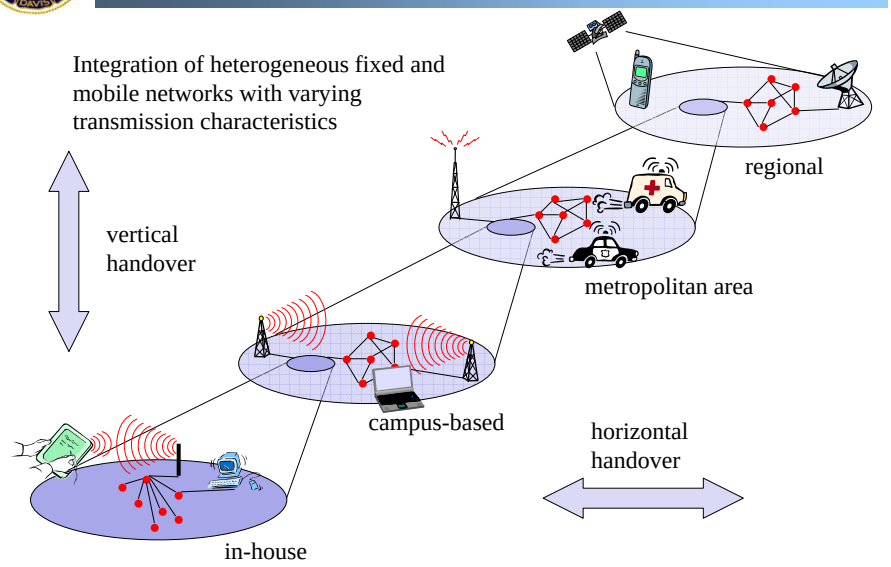
Mobile phones
- voice, data
- simple graphical displays

Palmtop
- tiny keyboard
- simple versions of standard applications

Performance

Wireless Data Vision

Integration of heterogeneous fixed and mobile networks with varying transmission characteristics

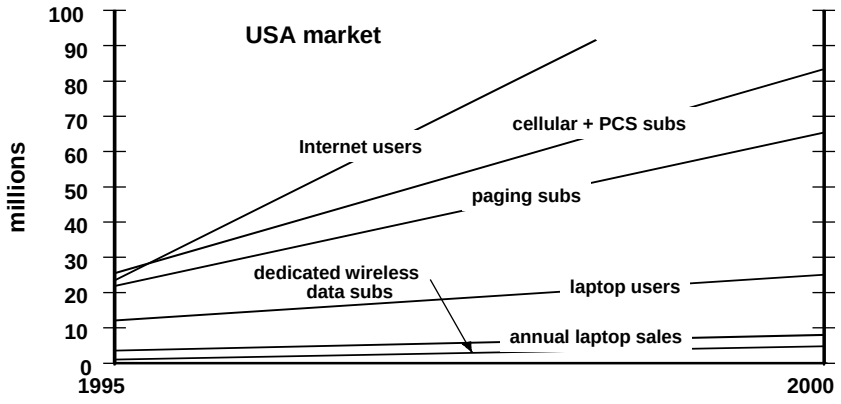


Voice versus Data versus Video

	Voice	Data	Video
Delay	< 100 ms	–	< 100 ms
Packet Loss	< 1%	0	<1%
BER	10^{-2} - 10^{-3}	< 10^{-5}	< 10^{-7}
Data Rate	8-32 kbps	1-100 Mbps	1-20 Mbps
Traffic	Continuous	Bursty	Continuous

Wired Networks Trying to Integrate (ATM, SONET, Multimedia Services)

What Is the Future of Wireless Data?

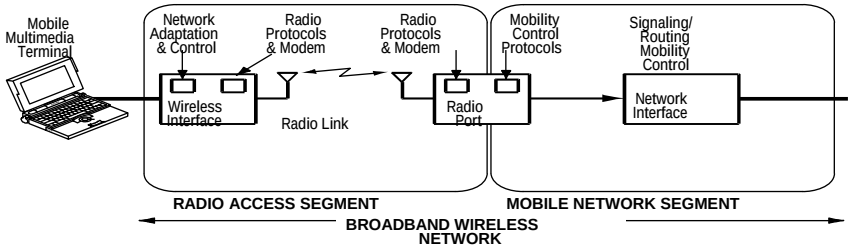


*Estimates as of 1996

The Issue Is Performance !!!

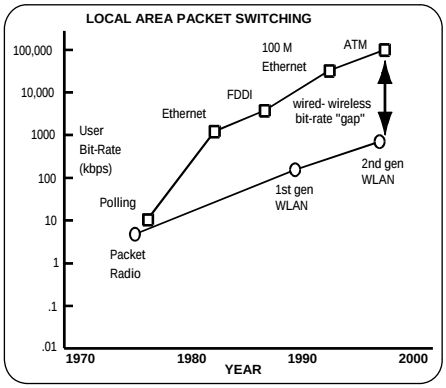
"The mobile data market has been slow to take off, but progress is being made. The most formidable obstacle to user acceptance remains performance."

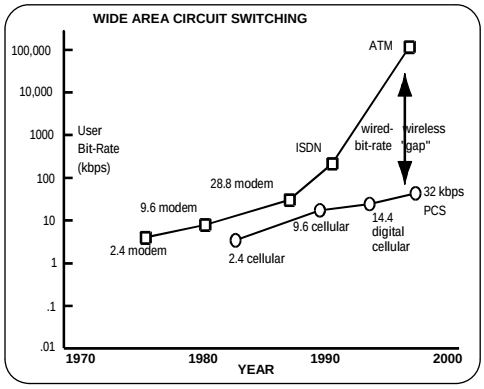
I. Brodsky, "Countdown to Mobile Blast Off", Network World, February 19, 1996



- **Link Performance: Data Rate and Quality**
- **Network Performance: Access, Coverage, Reliability, QoS, and Internetworking**

Gap between Wired and Wireless Network Capabilities





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- **Design Constraints & Challenges**
- Taxonomy & Class Roadmap
- History & Evolution
- Areas of Research

Technical Challenges

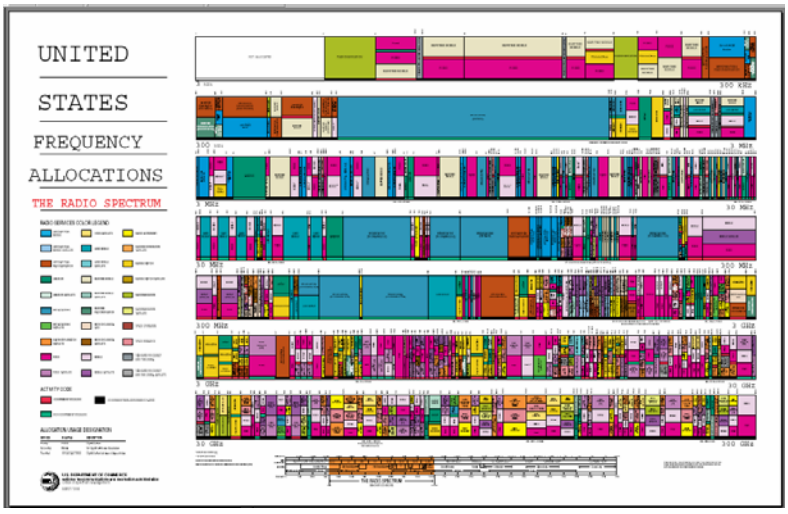
1. Scarce Radio Spectrum
2. Radio Channel Characteristics
   - Time-varying and location dependent
   - Limits on signal coverage and data rates
3. Low power, low cost implementation
4. Mobility: Seamless Internetworking
5. Shared medium
   - Authentication, security, and privacy issues

1. Scarce Radio Spectrum

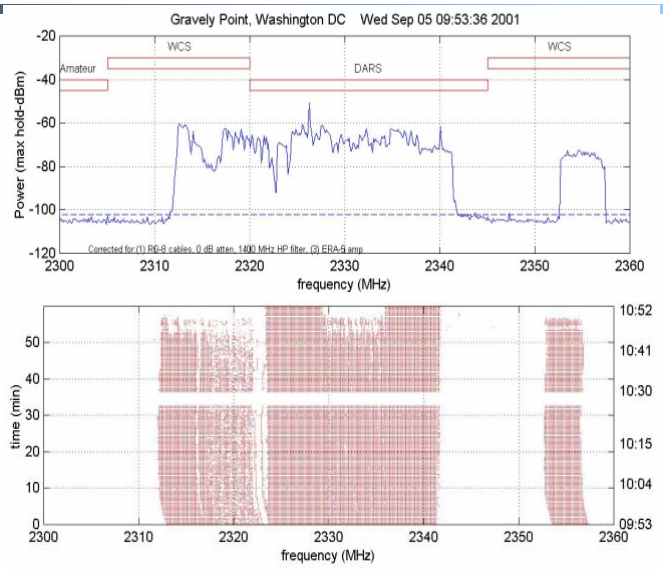
- Spectrum is expensive and heavily regulated
- Frequencies have to be coordinated, useful frequencies are almost all occupied
- 3G spectrum auction in EU
  - $35 billion in England, $46 billion in Germany

Q: Is spectrum really that scarce and expensive?

Spectrum Allocation

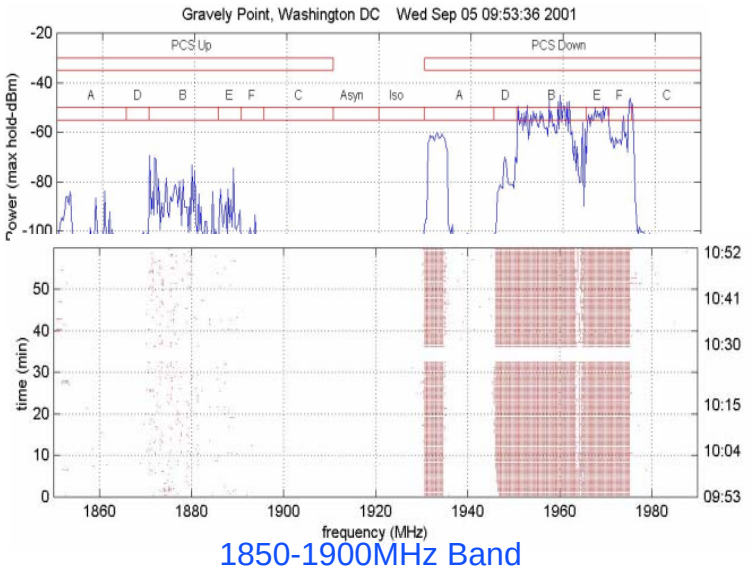


Spectrum Usage: high



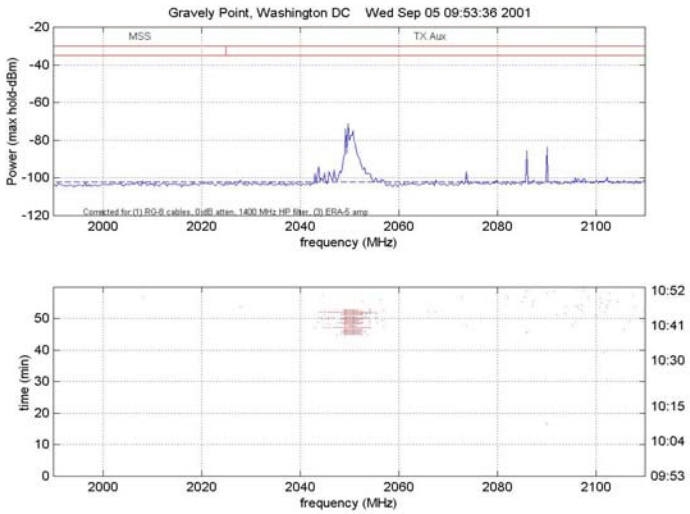
2300-2360MHz band

Spectrum Usage: medium



1850-1900MHz Band

Spectrum Usage: Low



1990-2100MHz band

Spectrum Occupancy Is Low

- Shared Spectrum's measurements indicate
  - Low occupancy bands
  - High occupancy bands
  - Under 3GHz, over 62% of white space
    - White space: more than 1MHz wide 10 minutes long
- FCC Spectrum Policy Task Force Report
  - The limiting factor: spectrum access instead of physical scarcity of spectrum
  - Due to legacy command-and-control regulation
  - More flexible regulations needed

2. Channel Conditions

Compared to fixed networks, wireless networks have

- Time-varying and location-dependent transmission performance
  - Higher loss-rates due to interference, e.g., emissions of engines, microwaves, lightning
  - Depends on strength of desired signals vs. noise and/or interference
- Low transmission rates
  - Local some Mbit/s, regional currently, e.g., 9.6kbit/s with GSM
- Higher delays, higher jitter
  - Connection setup time with GSM in the second range, several hundred milliseconds for other wireless systems

3. Low-Power/Low-Cost Devices for Portability

- 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
- 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

4. Mobility/Seamless Inter-Networking

- Interconnectivity between fixed network and heterogeneous wireless networks
  - Wireless Wide-Area Networks (WWANs): Cellular networks
  - Wireless Local Area Networks (WLANs): WiFi, IEEE 802.11x
  - Wireless Metropolitan Area Network (WMANs): WiMAX
  - Wireless ad hoc networks, mobile ad hoc network
  - Mesh/community networks
  - Wireless sensor networks
  - … *Wearable motes?*
- Need efficient architecture and protocols

5. Shared Medium

- Always shared medium
  - Secure access mechanisms important
- Lower security, simpler active attacking
  - Radio interface accessible for everyone, base station can be simulated, thus attracting calls from mobile phones

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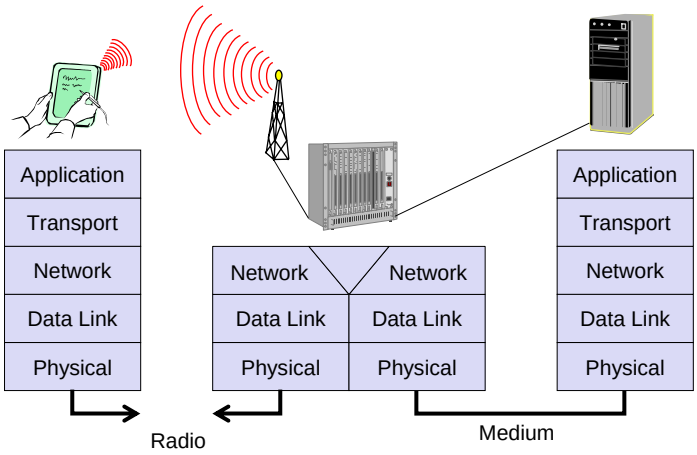
Simple Reference Model



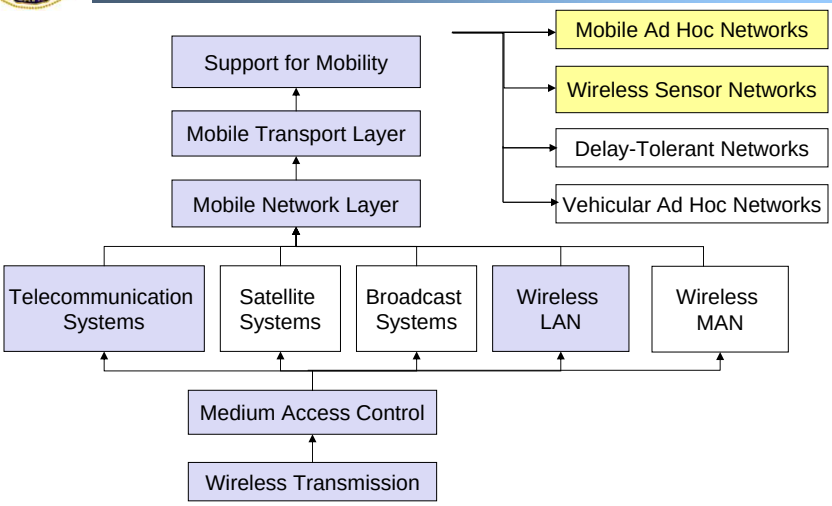
Influence of Mobile Communication to the Layer Model

Application layer	- Service location - New applications (multimedia, gaming) - Adaptive applications
Transport layer	- Congestion and flow control - Quality of service
Network layer	- Addressing, routing, device location - Hand-over
Data link layer	- Authentication - Media access - Multiplexing
Physical layer	- Encryption - Modulation - Interference - Attenuation - Frequency

Taxonomy

- Wireless Communications: Physical Layer
  - IR vs. RF
- Wireless Networks:
  - Infrastructure: Cellular (Base Station), WLANs/WMANs
  - Ad Hoc: peer-to-peer wireless connectivity
- Medium Access Control
  - Random vs. Controlled Access

Course Roadmap



http://www.ece.ucdavis.edu/~chuah/classes/EEC173B/lecture.html

Illustration

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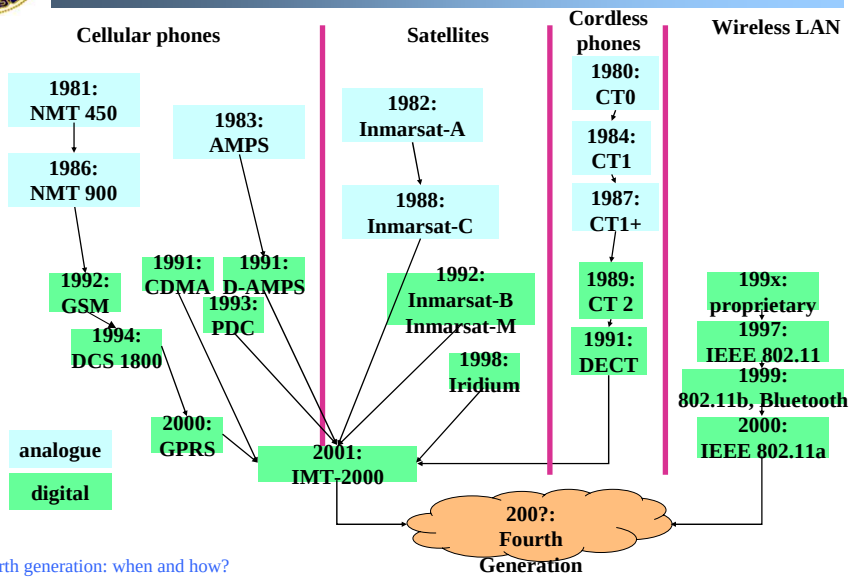
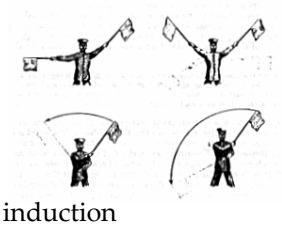
Evolution of Wireless Systems



4G – fourth generation: when and how?

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

- 1895 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 A, NL and LUX, 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

- 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 170 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
- 1998 Iridium
  - 66 satellites (+6 spare), 1.6GHz to the mobile phone

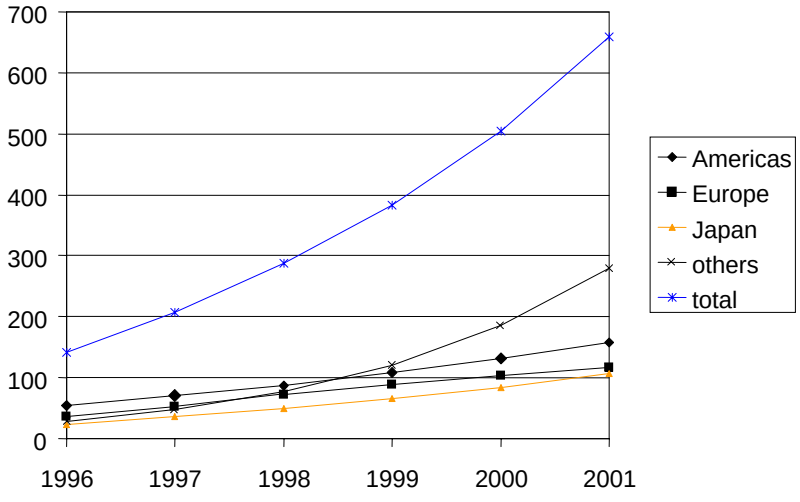
History of wireless communication - V

- 1999 Standardization of additional wireless LANs
  - IEEE standard 802.11b, 2.4-2.5GHz, 11Mbit/s
  - Bluetooth for piconets, 2.4Ghz, <1Mbit/s
- 1999 Decision about IMT-2000
  - Several "members" of a "family": UMTS, cdma2000, DECT, …
- 1999 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!)
- 2000 UMTS auctions/beauty contests
  - Hype followed by disillusionment (approx. 50 B$ paid in Germany for 6 UMTS licenses!)
- 2001 Start of 3G systems
  - Cdma2000 in Korea, UMTS in Europe, Foma (almost UMTS) in Japan

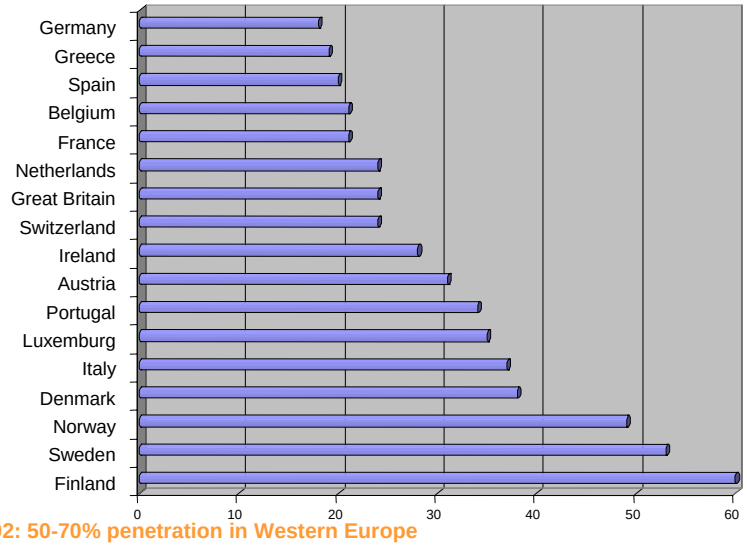
Foundation: ITU-R - Recommendations for IMT-2000

- International Telecommunication Union (ITU), International Mobile Telecommunications (IMT) -2000
  - http://www.itu.int/home/imt.html
  - Global standard for third generation (3G) wireless communications

Worldwide Wireless Subscribers (old prediction 1998)

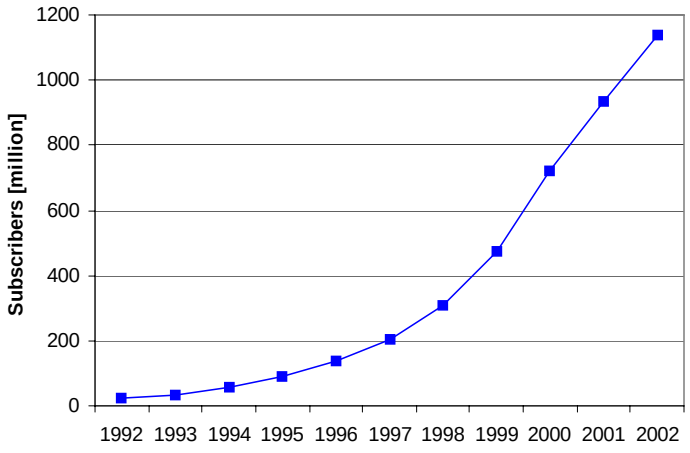


Mobile phones per 100 people 1999



2002: 50-70% penetration in Western Europe

Worldwide Cellular Subscriber Growth



Note that the curve starts to flatten in 2000

Mobile Statistics Snapshot (12/2004)

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

Total Global Mobile Users 1.52 billion
Total Analogue Users 34m
Total US Mobile users 140m
Total Global GSM users 1.25 billion
Total Global CDMA Users 202m
Total TDMA users 120m
Total European users 342.43m
Total African users 53m
Total 3G users 130m
Total South African users 19m

#1 Mobile Country China (300m)
#1 GSM Country China (282m)
#1 Handset Vendor 2Q02 Nokia (34.5%)
#1 Network In Africa Vodacom (11m)
#1 Network In Asia Unicom (153m)
#1 Network In Japan DoCoMo
#1 Network In Europe T-Mobil (28m)
#1 In Infrastructure Ericsson
Global monthly SMSs 36/user
SMS Sent Globally 1Q04 135 billion
SMS sent in UK 3/04 2.1 billion

Areas of Research

- 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