Wireless Transmission

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These slides are available at:
http://www.csc.lsu.edu/~durresi/csc7702_06/

- Frequencies
- Signals
- Antenna
- Signal propagation
- Multiplexing
- Spread spectrum
- Modulation
- Cellular systems

Why Wireless Mobile Networking ?

- Negroponte's "Switch" : Personal mobile communications go on Ether, Broadcast communications on cable
- Frequency Spectrum probably the most valuable natural resource
- Progress in microelectronic - very smart mobile terminals
- More open for business opportunities
- Mobile phone the only technology with a growth rate higher than Internet. By the year 2003: 700 millions Internet users and 830 millions mobile phone users

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")

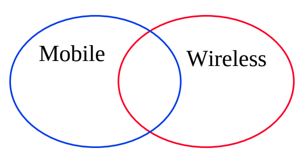
Mobile communication

- 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 Examples

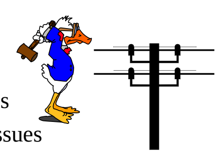
Wireless	Mobile	Examples
✗	✗	stationary computer
✗	✓	notebook in a hotel
✓	✗	wireless LANs in historic buildings
✓	✓	Personal Digital Assistant (PDA)

- 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, ETSI (HIPERLAN)
  - Internet: Mobile IP extension of the internet protocol IP
  - wide area networks: e.g., internetworking of GSM and ISDN

Mobile vs Wireless



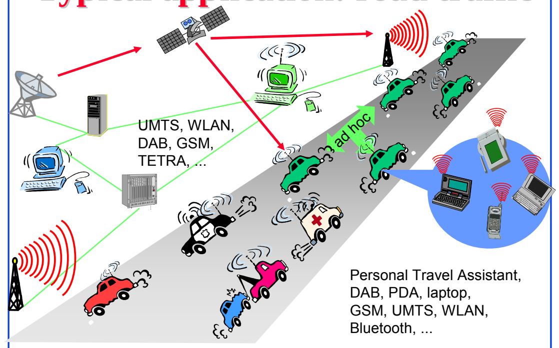
- Mobile vs Stationary
- Wireless vs Wired
- Wireless ⇒ media sharing issues
- Mobile ⇒ routing, addressing issues



Applications

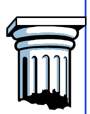
- Vehicles
  - transmission of news, road condition, weather, music
  - personal communication using GSM
  - position via GPS
  - local ad-hoc network with vehicles close-by to prevent accidents, guidance system, redundancy
  - vehicle data (e.g., from busses, high-speed trains) can be transmitted in 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, ...

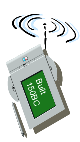
Typical application: road traffic



Applications

- 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

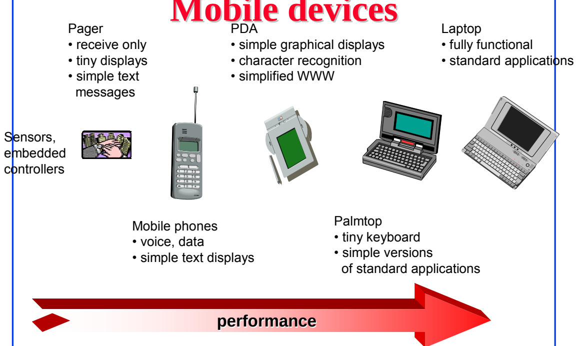




Location dependent services

- 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



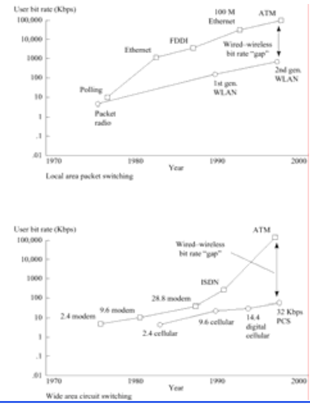
Effects of device portability

- 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
  - 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., 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
- 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

Wireless vs. fixed

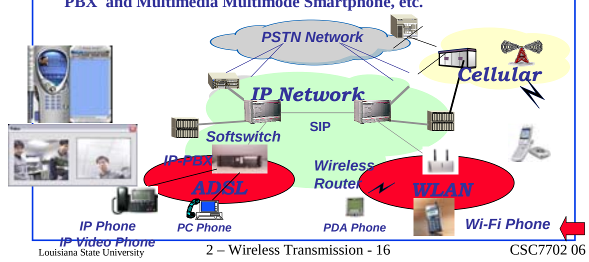


Future Prospects

- **With the integration of fixed line, WLAN, MAN & WAN toward an all-IP networks, multi-network convergence becomes mainstream. People can communicate and exchange information no matter what device, operating system, services or carrier they use.**
- **The demand for broadband service with seamless mobility and ubiquitous connectivity is strong and will create significant economic & social benefits.**
- **Digital Convergence is heralding the emerging markets such as mobile life, wireless digital home (DTV, interactive media center, etc.), car telematics and mobile networks products.**

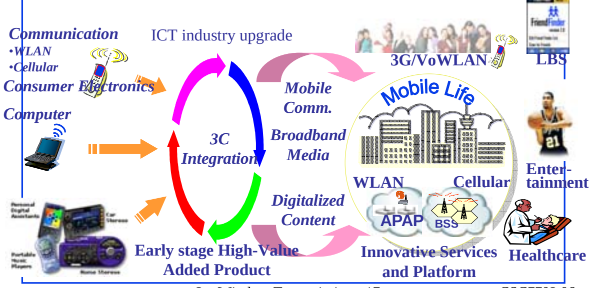
Multi-network Convergence becoming Mainstream

- **Big opportunities for combinational networking terminals & services**
  - **Broadband IP Telephony Getting Momentum - VoIP has the potential to become the killer application of Wi-Fi.**
  - **Other promising products include Wi-Fi Telephony Systems, Wireless IP-PBX and Multimedia Multimode Smartphone, etc.**



Mobile Life on the Rise

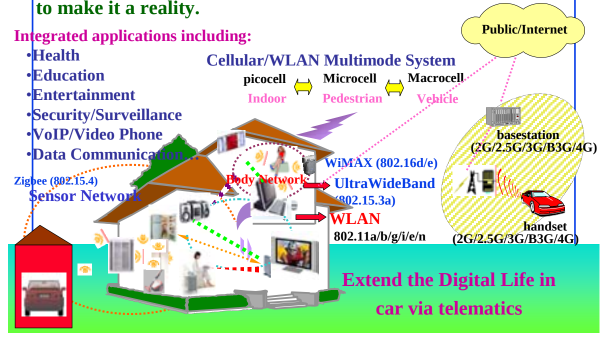
- **People and devices are increasingly mobile, technologies to support this nomadic lifestyle include heterogeneous networks integration, location awareness, resource recovery and session migration.**



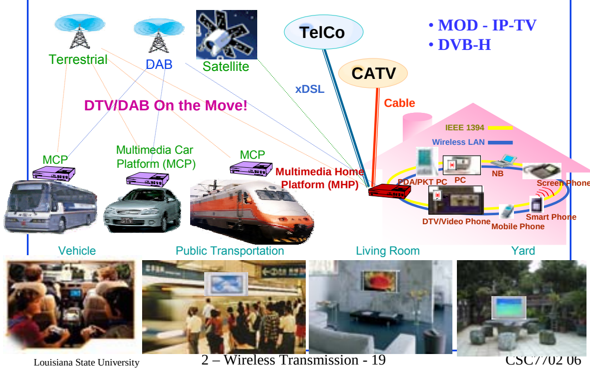
Digital Home and Beyond

- **Global giants have devoted efforts in enabling the digital home to make it a reality.**

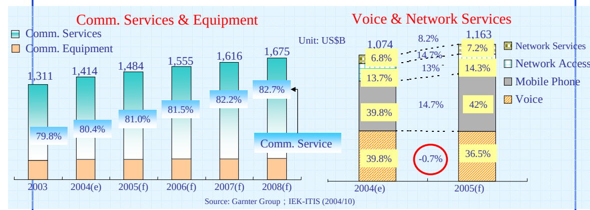
Integrated applications including:
- **Health**
- **Education**
- **Entertainment**
- **Security/Surveillance**
- **VoIP/Video Phone**
- **Data Communication**



DTV Market Ready to Take Off

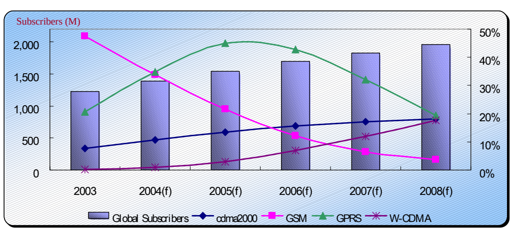


Global Telecom & Networking Market



- Voice services decline and network services keep growing
- Future Trends:
  - **Multi-services:** broadband mobile, broadband access, VoIP, digital video services through heterogeneous, All-IP networks
  - Growth of equipment market is driven by various services
  - Product trend towards 4C (Communication, Computer, Consumer Electronics, Content) integration

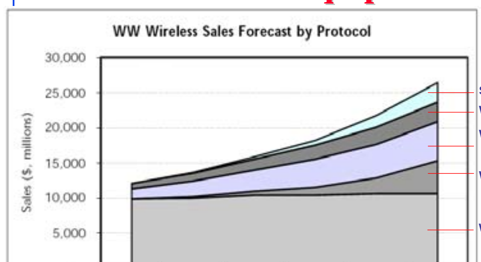
Global Mobile Services Market



- Number of global mobile phone subscribers reached 1.4B in 2004 with worldwide penetration rate over 20%; will grow to 2B by 2008
- 3G Services will take off in 2006, cdma2000 subscribers grow steadily; W-CDMA subscribers are expected to increase substantially during 2006-2007
- Revenue from data services is increased due to high bandwidth, innovative applications, and lower tariff.
- Mobile data revenue in N. America increased considerably.

source：SA；IEK (2004/11)

Global Wireless Equipment Sales



	2004	2005	2006	2007	2008	2009
Sensor	$23.7	$96.7	$284	$693	$1,621	$2,837
PAN	$702	$1,114	$1,623	$2,082	$2,474	$2,823
LAN	$1,488	$2,324	$3,015	$3,936	$4,827	$5,492
MAN	$8.1	$227	$607	$1,122	$2,211	$4,670
WAN	$9,831	$9,897	$10,332	$10,418	$10,576	$10,657

UWB/ZigBee/Bluetooth
802.11a/b/g，UWB WLAN
WiMax
3G/Others

April 2004, WTRS (West Technology Research Solution)

Mobile phone: Four Generations

- 1G - First Generation: Analog, 70’-80’, Access FDMA
  - Good basic service, good territorial coverage, only voice
  - Continue to operate profitably. Will survive for some time
  - At the begin 0f 2002: 30% of mobile US subscribers – 1G
- 2G - Second Generation, Digital Technology
  - Mostly for voice, data less than 10kbps
  - Capacity: The old systems were almost saturated
  - More services, specially value added
  - Analog system more vulnerable to physical influences and disturbances
- 2.5 G – Most operators are upgrading their 2G networks to higher speed
  - Data rate 40-100kbps
  - Packet switching – more efficient way to share connections and easier integration with Internet

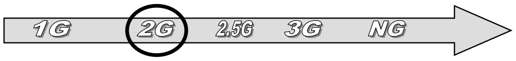
Evolution of Mobile Wireless (1)

Advance Mobile Phone Service (AMPS)
- FDMA
- 824-849 MHz (UL), 869-894 MHz (DL)
- U.S. (1983), So. America, Australia, China

European Total Access Communication System (E-TACS)
- FDMA
- 872-905 MHz (UL), 917-950 MHz (DL)
- Deployed throughout Europe

Evolution of Mobile Wireless (2)

Global System for Mobile communications (GSM)
• TDMA
• Different frequency bands for cellular and PCS
• Developed in 1990, expected >1B subscriber by end of 2003



IS-95
• CDMA
• 800/1900 MHz – Cellular/PCS
• U.S., Europe, Asia

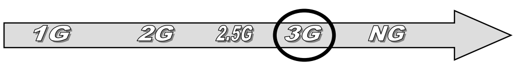
Evolution of Mobile Wireless (3)

General Packet Radio Services (GPRS)
• Introduces packet switched data services for GSM
• Transmission rate up to 170 kbps
• Some support for QoS

Enhanced Data rates for GSM Evolution (EDGE)
• Circuit-switched voice (at up to 43.5 kbps/slot)
• Packet-switched data (at up to 59.2 kbps/slot)
• Can achieve on the order of 475 kbps on the downlink, by combining multiple slots

Evolution of Mobile Wireless (4)

Universal Mobile Telecommunication Systems (UMTS)
• Wideband DS-CDMA
• Bandwidth-on-demand, up to 2 Mbps
• Supports handoff from GSM/GPRS

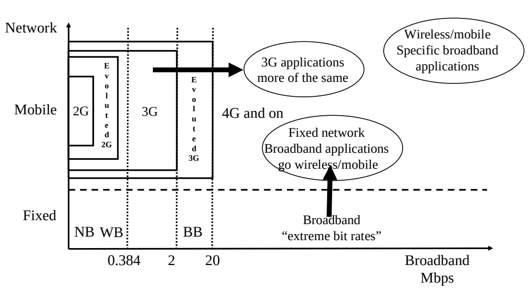


IS2000
• CDMA2000: Multicarrier DS-CDMA
• Bandwidth on demand (different flavors, up to a few Mbps)
• Supports handoff from/to IS-95

Mobile phone: Four Generations

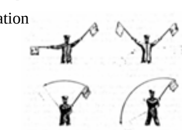
- 3G - Third Generation in development: 2.5 G will seamlessly evolve to provide high-speed data and support for multimedia application
  - Data rate up to 2Mbps, advanced applications – videoconferencing
  - Wireless home networks
- 4G - Fourth Generation are already in labs
  - Data rate as much as 100 Mbps
  - All packet switching
  - New services to be invented
  - Many wireless LANs are already close to 4G

Evolution of Applications



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

History of wireless communication

- 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

History of wireless communication

- 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
- 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

- 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, ...

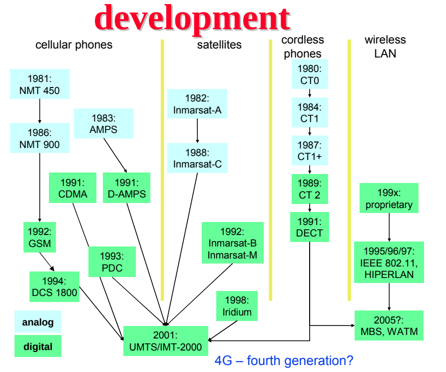
History of wireless communication

- 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

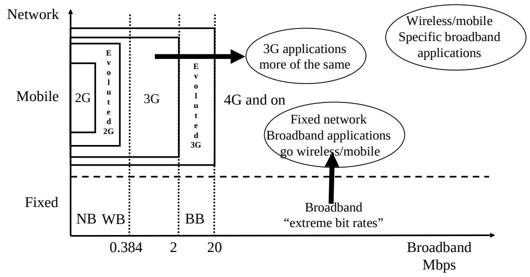
History of wireless communication

- 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 communicaiton 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 (approx. 50 B$ payed in Germany for 6 UMTS licences!)
- 2001 Start of 3G systems
  - Cdma2000 in Korea, UMTS in Europe, Foma (almost UMTS) in Japan

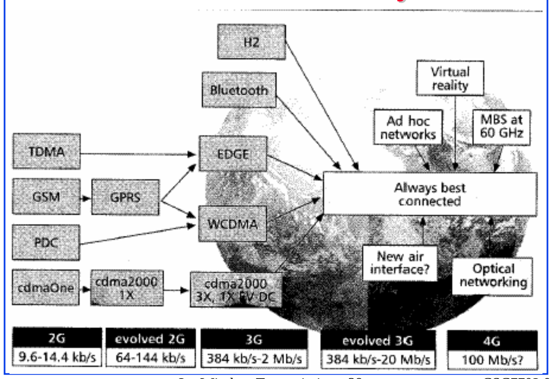
Wireless systems: overview of the development



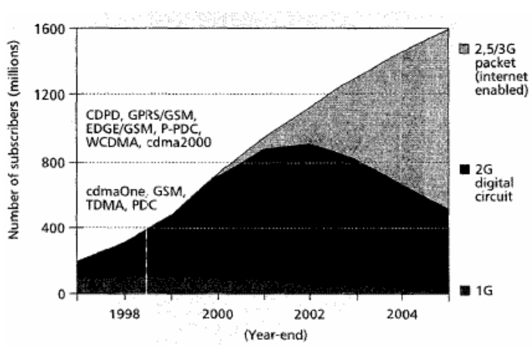
Evolution of Applications



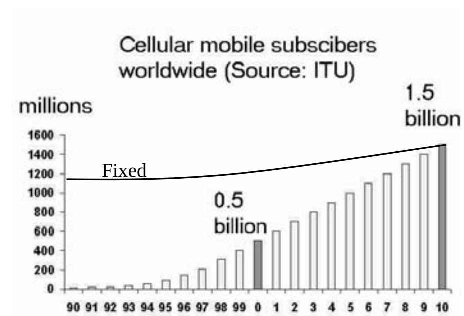
Generations Mobile Systems



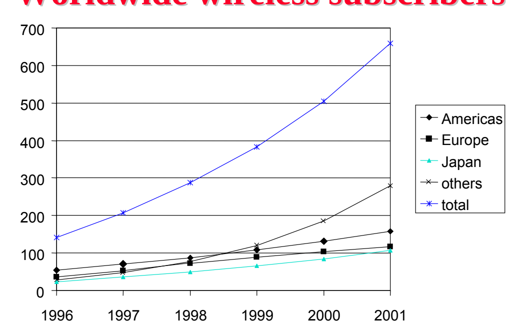
Cellular Subscribers



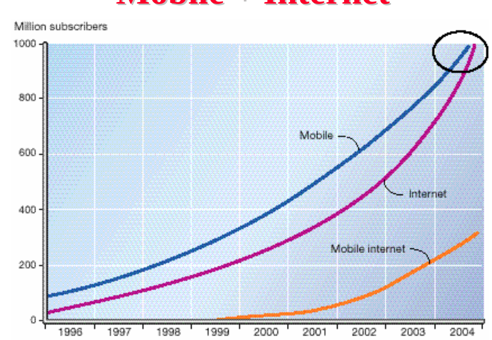
Growth of Cellular Market



Worldwide wireless subscribers

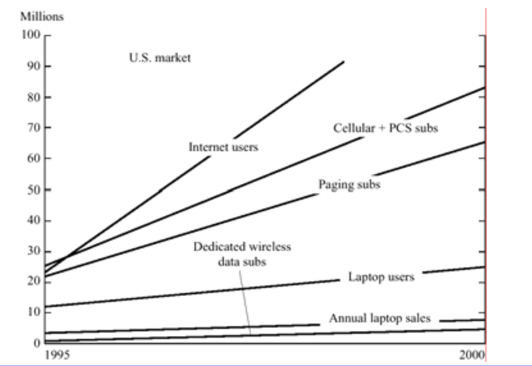


Mobile + Internet

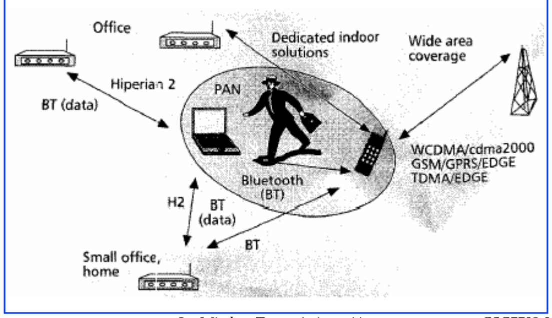


[IPWRLSS]

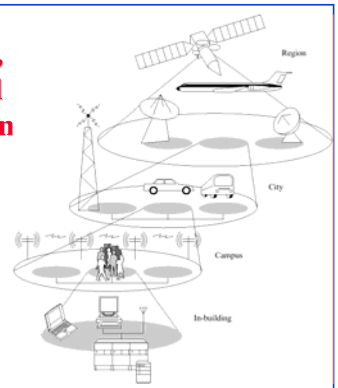
Growth of Wireless



Personal Area Network

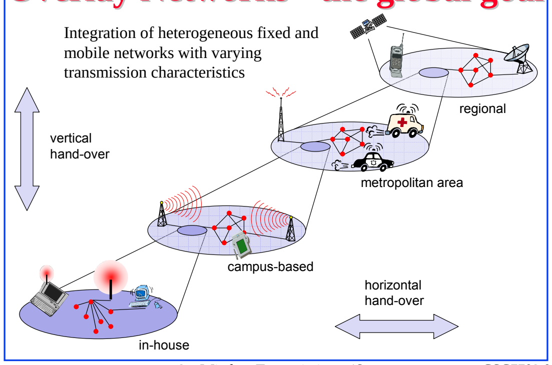


Wireless Applications, Systems, and coverage region

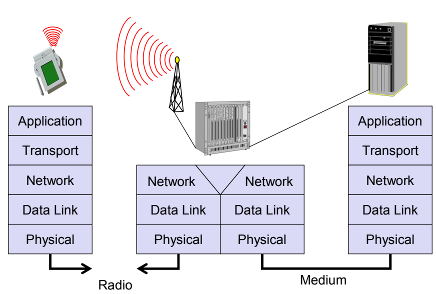


Overlay Networks - the global goal

Integration of heterogeneous fixed and mobile networks with varying transmission characteristics



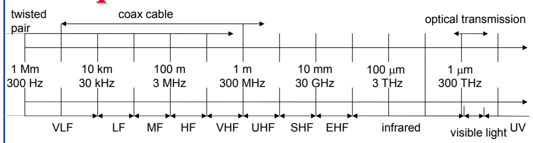
Simple reference model used here



Influence of mobile communication to the layer model

- Application layer
  - service location
  - new applications, multimedia
  - 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
  - media access control
- Physical layer
  - encryption
  - modulation
  - interference
  - attenuation
  - frequency

Frequencies for communication



- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

- Frequency and wave length:
- $\lambda = c/f$
- wave length λ, speed of light $c \cong 3\mathrm{x}10^8$m/s, frequency f

Frequencies for mobile communication

- VHF-/UHF-ranges for mobile radio
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antenna, focusing
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF spectrum
  - some systems planned up to EHF
  - limitations due to absorption by water and oxygen molecules (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.

Frequencies and regulations

- ITU-R holds auctions for new frequencies, manages frequency bands worldwide (WRC, World Radio Conferences)

	Europe	USA	Japan
Cellular Phones	**GSM** 450-457, 479-486/460-467,489-496, 890-915/935-960, 1710-1785/1805-1880 **UMTS** (FDD) 1920-1980, 2110-2190 **UMTS** (TDD) 1900-1920, 2020-2025	**AMPS**, **TDMA**, **CDMA** 824-849, 869-894 **TDMA**, **CDMA**, **GSM** 1850-1910, 1930-1990	**PDC** 810-826, 940-956, 1429-1465, 1477-1513
Cordless Phones	**CT1+** 885-887, 930-932 **CT2** 864-868 **DECT** 1880-1900	**PACS** 1850-1910, 1930-1990 **PACS-UB** 1910-1930	**PHS** 1895-1918 **JCT** 254-380
Wireless LANs	**IEEE 802.11** 2400-2483 **HIPERLAN 2** 5150-5350, 5470-5725	902-928 **IEEE 802.11** 2400-2483 5150-5350, 5725-5825	**IEEE 802.11** 2471-2497 5150-5250
Others	**RF-Control** 27, 128, 418, 433, 868	**RF-Control** 315, 915	**RF-Control** 426, 868

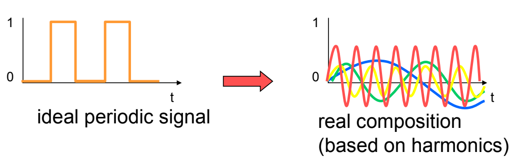
Signals I

- physical representation of data
- function of time and location
- signal parameters: parameters representing the value of data
- classification
  - continuous time/discrete time
  - continuous values/discrete values
  - analog signal = continuous time and continuous values
  - digital signal = discrete time and discrete values
- signal parameters of periodic signals: period T, frequency f=1/T, amplitude A, phase shift φ
  - sine wave as special periodic signal for a carrier:

$$s(t) = A_t \sin(2\,\pi\,f_t\,t + \varphi_t)$$

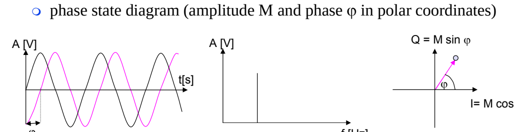
Fourier representation of periodic signals

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



Signals II

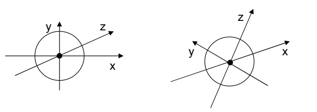
- Different representations of signals
  - amplitude (amplitude domain)
  - frequency spectrum (frequency domain)
  - phase state diagram (amplitude M and phase φ in polar coordinates)



- Composed signals transferred into frequency domain using Fourier transformation
- Digital signals need
  - infinite frequencies for perfect transmission
  - modulation with a carrier frequency for transmission (analog signal!)

Antennas: isotropic radiator

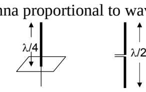
- Radiation and reception of electromagnetic waves, coupling of wires to space for radio transmission
- Isotropic radiator: equal radiation in all directions (three dimensional) - only a theoretical reference antenna
- Real antennas always have directive effects (vertically and/or horizontally)
- Radiation pattern: measurement of radiation around an antenna



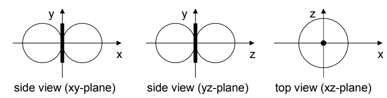
ideal isotropic radiator

Antennas: simple dipoles

- Real antennas are not isotropic radiators but, e.g., dipoles with lengths λ/4 on car roofs or λ/2 as Hertzian dipole
  ➔ shape of antenna proportional to wavelength



- Example: Radiation pattern of a simple Hertzian dipole

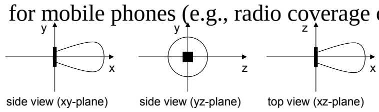


simple dipole

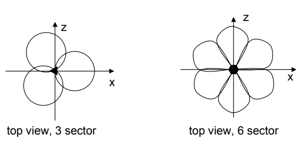
- Gain: maximum power in the direction of the main lobe compared to the power of an isotropic radiator (with the same average power)

Antennas: directed and sectorized

- Often used for microwave connections or base stations for mobile phones (e.g., radio coverage of a valley)



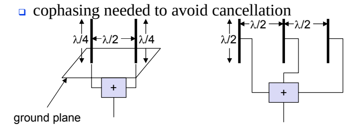
directed antenna



sectorized antenna

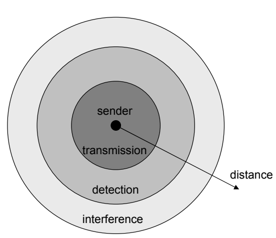
Antennas: diversity

- Grouping of 2 or more antennas
  - multi-element antenna arrays
- Antenna diversity
  - switched diversity, selection diversity
    - receiver chooses antenna with largest output
  - diversity combining
    - combine output power to produce gain
    - cophasing needed to avoid cancellation

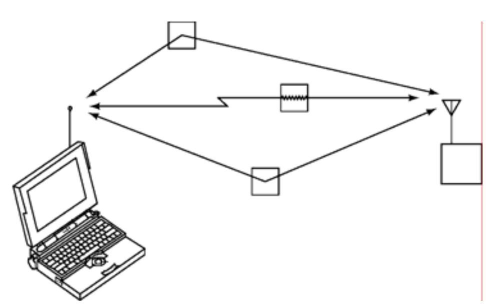


Signal propagation ranges

- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise

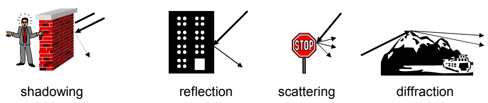


Propagation Scenario



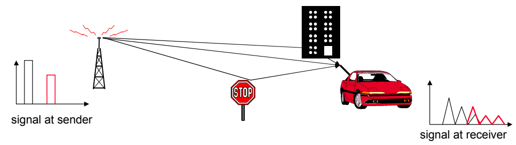
Signal propagation

- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$
  (d = distance between sender and receiver)
- Receiving power additionally influenced by
- fading (frequency dependent)
- shadowing
- reflection at large obstacles
- scattering at small obstacles
- diffraction at edges



Multipath propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



- Time dispersion: signal is dispersed over time
- ➔ interference with “neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
- ➔ distorted signal depending on the phases of the different parts

Physical Impairments: Noise

- Unwanted signals added to the message signal
- May be due to signals generated by natural phenomena such as lightning or man-made sources, including transmitting and receiving equipment as well as spark plugs in passing cars, wiring in thermostats, etc.
- Sometimes modeled in the aggregate as a random signal in which power is distributed uniformly across all frequencies (white noise)
- Signal-to-noise ratio (SNR) often used as a metric in the assessment of channel quality

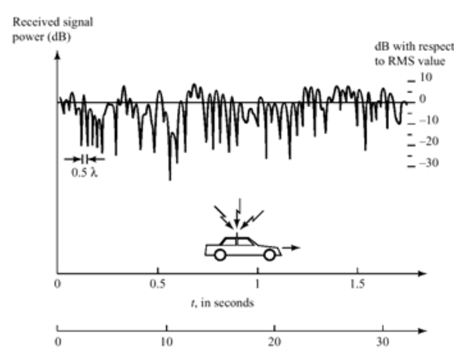
Physical Impairments: Interference

- Signals generated by communications devices operating at roughly the same frequencies may interfere with one another
  - Example: IEEE 802.11b and Bluetooth devices, microwave ovens, some cordless phones
  - CDMA systems (many of today’s mobile wireless systems) are typically interference-constrained
- Signal to interference and noise ratio (SINR) is another metric used in assessment of channel quality

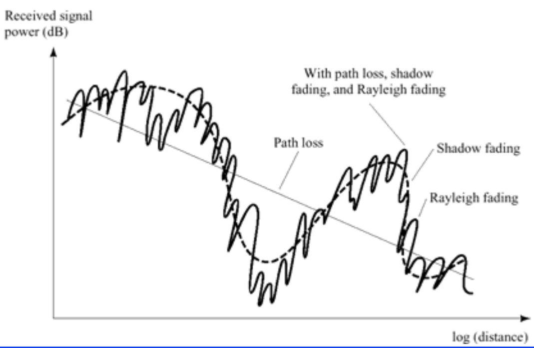
Physical impairments: Fading (2)

- Strength of the signal decreases with distance between transmitter and receiver: path loss
  - Usually assumed inversely proportional to distance to the power of 2.5 to 5
- Slow fading (shadowing) is caused by large obstructions between transmitter and receiver
- Fast fading is caused by scatterers in the vicinity of the transmitter

Fading

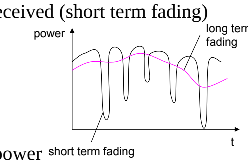


Fading + loss



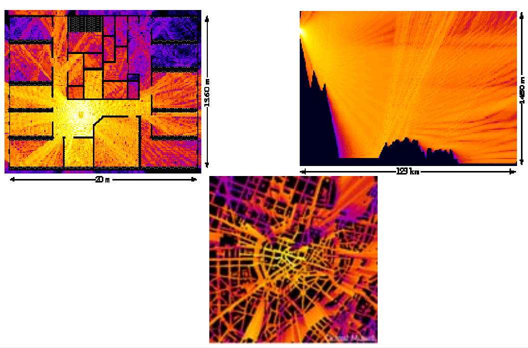
Effects of mobility

- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
- ➔ quick changes in the power received (short term fading)



- Additional changes in
  - distance to sender
  - obstacles further away
- ➔ slow changes in the average power received (long term fading)

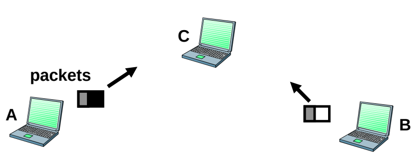
Real world example



Diversity

- A diversity scheme extracts information from multiple signals transmitted over different fading paths
- Appropriate combining of these signals will reduce severity of fading and improve reliability of transmission
- In space diversity, antennas are separated by at least half a wavelength
  - Other forms of diversity also possil
  - Polarization, frequency, time diver

Contention for the Medium



- If A and B simultaneously transmit to C over the same channel, C will not be able to correctly decode received information: a collision will occur
- Need for medium access control mechanisms to establish what to do in this case (also, to maximize aggregate utilization of available capacity)

Effects of Mobility

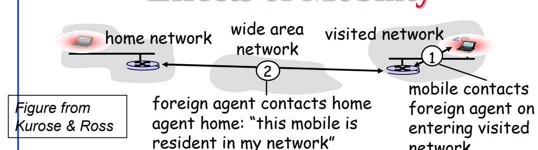


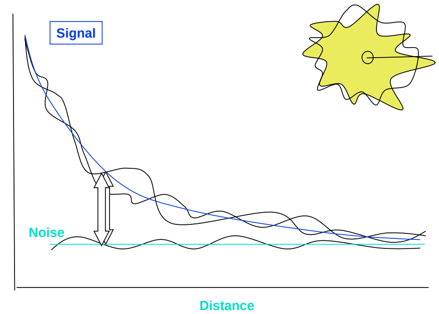
Figure from Kurose & Ross

- Destination address not equal to destination location
- Addressing and routing must be taken care of to enable mobility
- Can be done automatically through handoff or may require explicit registration by the mobile in the visited network
- Resource management and QoS are directly affected by route changes

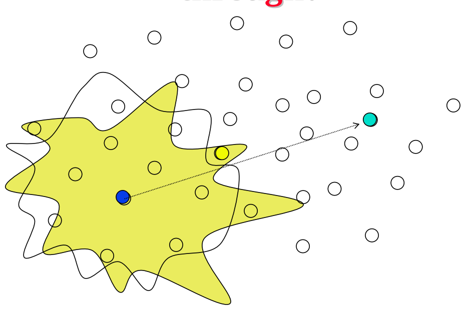
What is connectivity?

- CS: Ability to correctly receive a large fraction of transmitted packets
- EE: Signal-to-noise ratio exceeds some threshold

The Amoeboed "cell"



Which node do you route through?

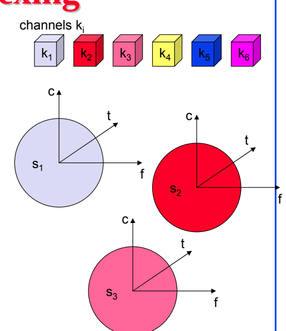


Access methods SDMA/FDMA/TDMA

- SDMA (Space Division Multiple Access)
  - segment space into sectors, use directed antennas
  - cell structure
- FDMA (Frequency Division Multiple Access)
  - assign a certain frequency to a transmission channel between a sender and a receiver
  - permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
- TDMA (Time Division Multiple Access)
  - assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time

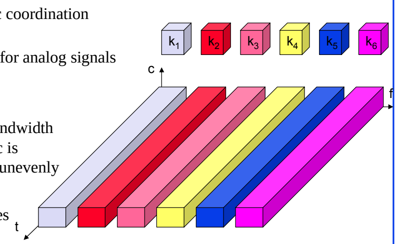
Multiplexing

- Multiplexing in 4 dimensions
  - space (s_i)
  - time (t)
  - frequency (f)
  - code (c)
- Goal: multiple use of a shared medium
- Important: guard spaces needed!



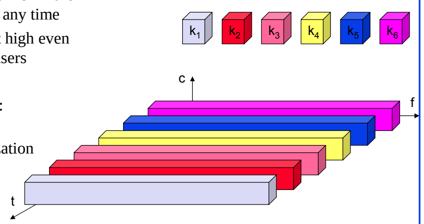
Frequency multiplex

- Separation of the whole spectrum into smaller frequency bands
- A channel gets a certain band of the spectrum for the whole time
- Advantages:
  - no dynamic coordination necessary
  - works also for analog signals
- Disadvantages:
  - waste of bandwidth if the traffic is distributed unevenly
  - inflexible
  - guard spaces



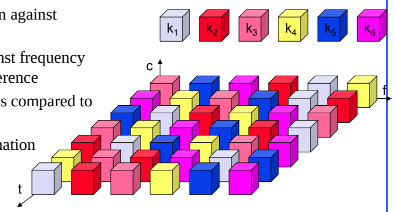
Time multiplex

- A channel gets the whole spectrum for a certain amount of time
- Advantages:
  - only one carrier in the medium at any time
  - throughput high even for many users
- Disadvantages:
  - precise synchronization necessary

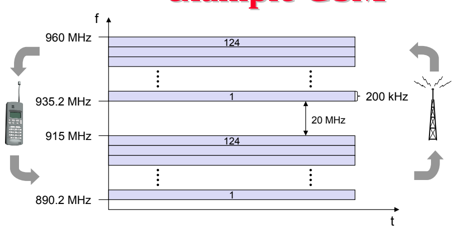


Time and frequency multiplex

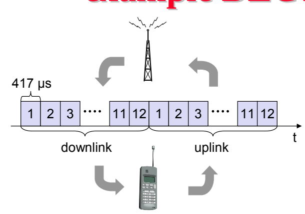
- Combination of both methods
- A channel gets a certain frequency band for a certain amount of time
- Example: GSM
- Advantages:
  - better protection against tapping
  - protection against frequency selective interference
  - higher data rates compared to code multiplex
- but: precise coordination required



FDD/FDMA - general scheme, example GSM

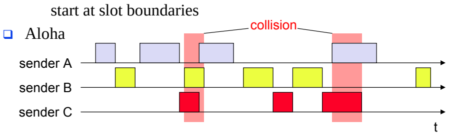


TDD/TDMA - general scheme, example DECT

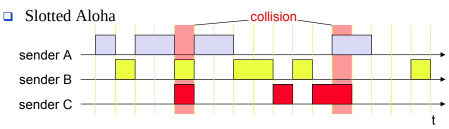


Aloha/slotted aloha

- Mechanism
  - random, distributed (no central arbiter), time-multiplex
  - Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- Aloha



- Slotted Aloha

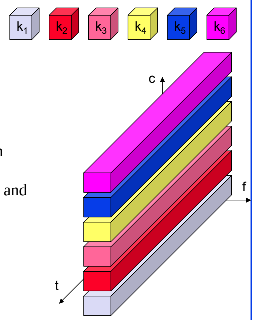


DAMA - Demand Assigned Multiple Access

- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length)
- Reservation can increase efficiency to 80%
  - a sender *reserves* a future time-slot
  - sending within this reserved time-slot is possible without collision
  - reservation also causes higher delays
  - typical scheme for satellite links
- Examples for reservation algorithms:
  - *Explicit Reservation according to Roberts (Reservation-ALOHA)*
  - *Implicit Reservation (PRMA)*
  - *Reservation-TDMA*

Code multiplex

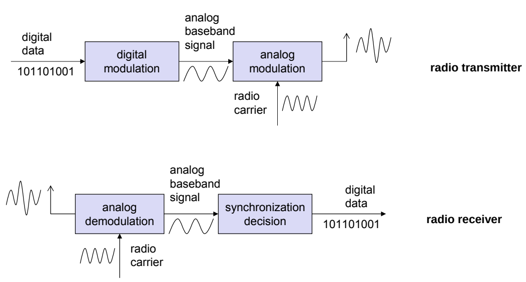
- Each channel has a unique code
- All channels use the same spectrum at the same time
- Advantages:
  - bandwidth efficient
  - no coordination and synchronization necessary
  - good protection against interference and tapping
- Disadvantages:
  - lower user data rates
  - more complex signal regeneration
- Implemented using spread spectrum technology



Modulation

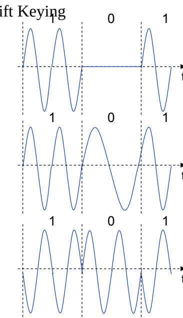
- Digital modulation
  - digital data is translated into an analog signal (baseband)
  - ASK, FSK, PSK
  - differences in spectral efficiency, power efficiency, robustness
- Analog modulation
  - shifts center frequency of baseband signal up to the radio carrier
- Motivation
  - smaller antennas (e.g., $\lambda/4$)
  - Frequency Division Multiplexing
  - medium characteristics
- Basic schemes
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)

Modulation and demodulation



Digital modulation

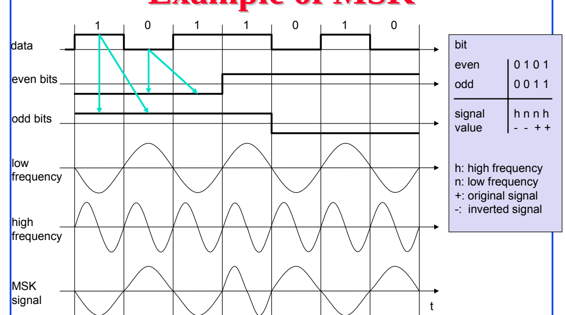
- Modulation of digital signals known as Shift Keying
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- Frequency Shift Keying (FSK):
  - needs larger bandwidth
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference



Advanced Frequency Shift Keying

- bandwidth needed for FSK depends on the distance between the carrier frequencies
- special pre-computation avoids sudden phase shifts
  ➔ MSK (Minimum Shift Keying)
- bit separated into even and odd bits, the duration of each bit is doubled
- depending on the bit values (even, odd) the higher or lower frequency, original or inverted is chosen
- the frequency of one carrier is twice the frequency of the other
- Equivalent to offset QPSK
- even higher bandwidth efficiency using a Gaussian low-pass filter ➔ GMSK (Gaussian MSK), used in GSM

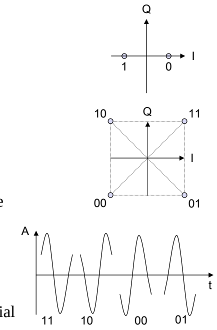
Example of MSK



No phase shifts!

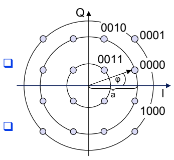
Advanced Phase Shift Keying

- BPSK (Binary Phase Shift Keying):
  - bit value 0: sine wave
  - bit value 1: inverted sine wave
  - very simple PSK
  - low spectral efficiency
  - robust, used e.g. in satellite systems
- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - symbol determines shift of sine wave
  - needs less bandwidth compared to BPSK
  - more complex
- Often also transmission of relative, not absolute phase shift: DQPSK - Differential QPSK (IS-136, PHS)



Quadrature Amplitude Modulation

- Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation
- it is possible to code n bits using one symbol
- 2^n discrete levels, n=2 identical to QPSK
- bit error rate increases with n, but less errors compared to comparable PSK schemes



Example: 16-QAM (4 bits = 1 symbol)

- Symbols 0011 and 0001 have the same phase φ, but different amplitude *a*. 0000 and 1000 have different phase, but same amplitude.
- ➔ used in standard 9600 bit/s modems

Spread Spectrum

- Introduction
- Frequency Hopping Spread Spectrum
- Direct Sequence Spread Spectrum

Why Spread Spectrum?

- Spread spectrum signals are distributed over a wide range of frequencies and then collected back at the receiver
  - These wideband signals are noise-like and hence difficult to detect or interfere with
- Initially adopted in military applications, for its resistance to jamming and difficulty of interception
- More recently, adopted in commercial wireless communications

Access method CDMA

- CDMA (Code Division Multiple Access)
  - all terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
  - each sender has a unique random number, the sender XORs the signal with this random number
  - the receiver can "tune" into this signal if it knows the pseudo random number, tuning is done via a correlation function
- Disadvantages:
  - higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
  - all signals should have the same strength at a receiver
- Advantages:
  - all terminals can use the same frequency, no planning needed
  - huge code space (e.g. 2^{32}) compared to frequency space
  - interferences (e.g. white noise) is not coded
  - forward error correction and encryption can be easily integrated

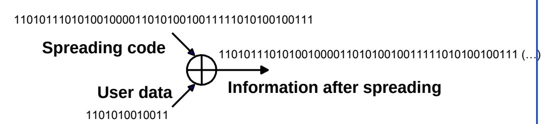
CDMA in theory

- Sender A
  - sends $A_d = 1$, key $A_k = 010011$ (assign: „0"= -1, „1"= +1)
  - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - sends $B_d = 0$, key $B_k = 110101$ (assign: „0"= -1, „1"= +1)
  - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose in space
  - interference neglected (noise etc.)
  - $A_s + B_s = (-2, 0, 0, -2, +2, 0)$
- Receiver wants to receive signal from sender A
  - apply key A_k bitwise (inner product)
    - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
    - result greater than 0, therefore, original bit was „1"
  - receiving B
    - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. „0"

Frequency Hopping Spread Spectrum (FHSS)

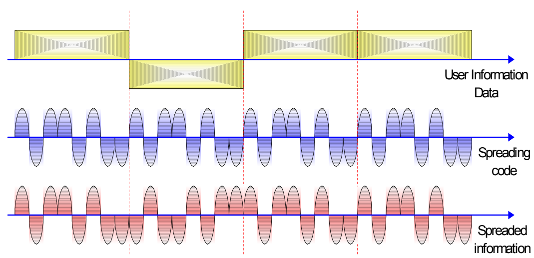
- Data signal is modulated with a narrowband signal that *hops* from frequency band to frequency band, over time
- The transmission frequencies are determined by a spreading, or hopping code (a pseudo-random sequence)

Direct Sequence Spread Spectrum (DSSS)

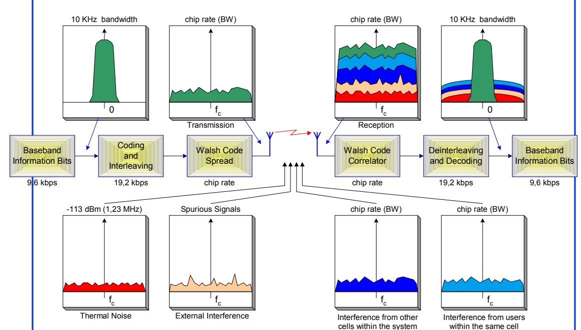


- Data signal is multiplied by a spreading code, and resulting signal occupies a much higher frequency band
- Spreading code is a pseudo-random sequence

DSSS Example

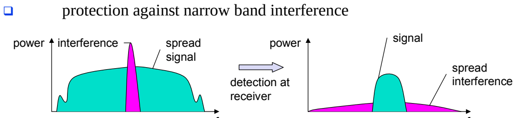


Spreading and De-spreading DSSS



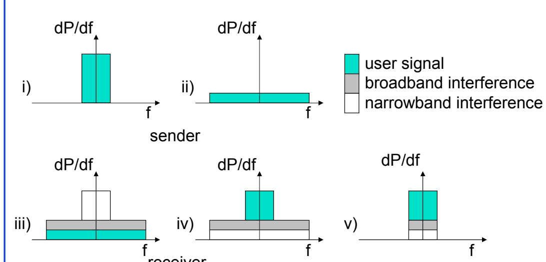
Spread spectrum technology

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal into a broad band signal using a special code
- protection against narrow band interference

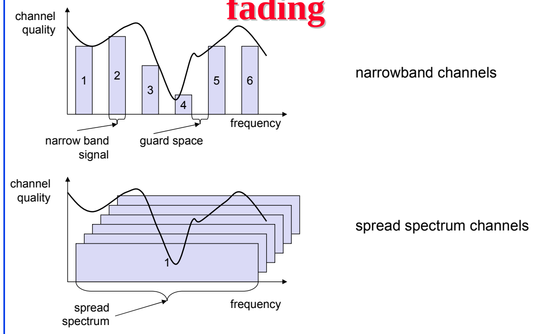


- protection against narrowband interference
- Side effects:
  - coexistence of several signals without dynamic coordination
  - tap-proof
- Alternatives: Direct Sequence, Frequency Hopping

Effects of spreading and interference

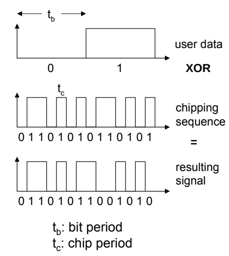


Spreading and frequency selective fading

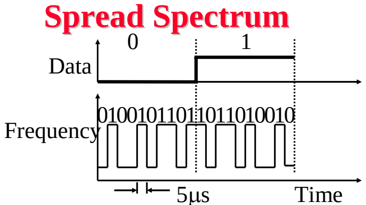


DSSS (Direct Sequence Spread Spectrum) I

- XOR of the signal with pseudo-random number (chipping sequence)
  - many chips per bit (e.g., 128) result in higher bandwidth of the signal
- Advantages
  - reduces frequency selective fading
  - in cellular networks
    - base stations can use the same frequency range
    - several base stations can detect and recover the signal
    - soft handover
- Disadvantages
  - precise power control necessary

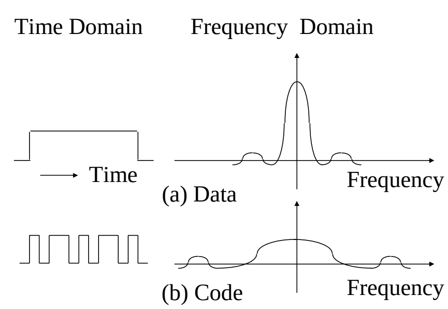


Direct-Sequence Spread Spectrum

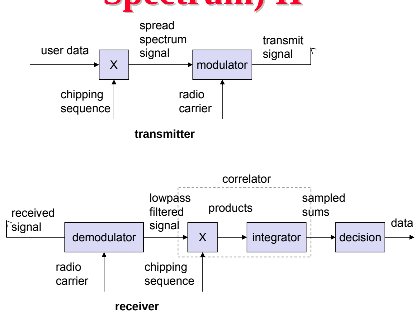


- Spreading factor = Code bits/data bit, 10-100 commercial (Min 10 by FCC), 10,000 for military
- Signal bandwidth >10 × data bandwidth
- Code sequence synchronization
- Correlation between codes ⇒Interference⇒ Orthogonal

DS Spectrum



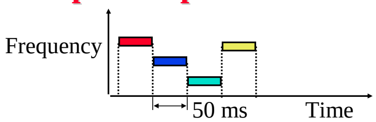
DSSS (Direct Sequence Spread Spectrum) II



FHSS (Frequency Hopping Spread Spectrum) I

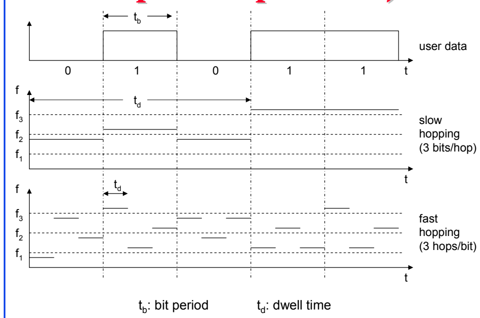
- Discrete changes of carrier frequency
  - sequence of frequency changes determined via pseudo random number sequence
- Two versions
  - Fast Hopping:
    several frequencies per user bit
  - Slow Hopping:
    several user bits per frequency
- Advantages
  - frequency selective fading and interference limited to short period
  - simple implementation
  - uses only small portion of spectrum at any time
- Disadvantages
  - not as robust as DSSS
  - simpler to detect

Frequency Hopping Spread Spectrum

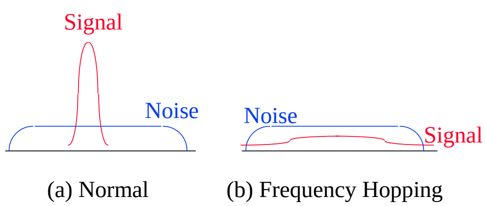


- Pseudo-random frequency hopping
- Spreads the power over a wide spectrum
  ⇒ Spread Spectrum
- Developed initially for military
- Patented by actress Hedy Lamarr
- Narrowband interference can't jam

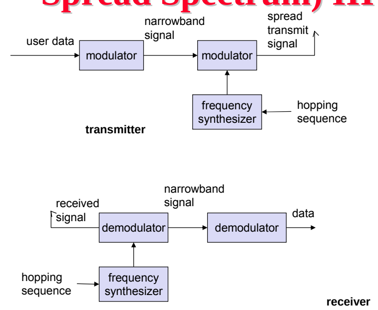
FHSS (Frequency Hopping Spread Spectrum) II



Spectrum



FHSS (Frequency Hopping Spread Spectrum) III



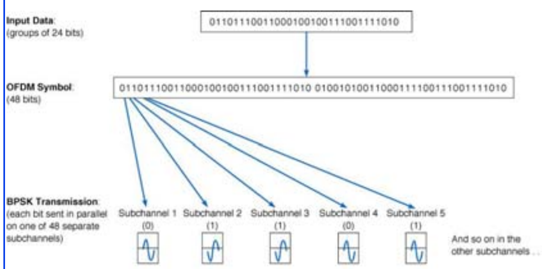
TDMA vs. CDMA

- Spectrum Efficiency: Which multiple access scheme has better bps/Hz.cell ?
- Flexibility: Which access scheme offers better flexibility to handle multi-rate, -cell, -load, and -services ?
- TDMA: some flexibility advantages, but has a spectrum efficiency disadvantage
- CDMA: Less flexibility but has better spectrum efficiency Has
- Actual results depend on standards details

Ortogonal Frequency Division Multiplexing - OFDM

- OFDM is designed to reduce multipath effects
- The multipath effect is increased with the frequency
- OFDM reduces the bit rate by splitting high speed data into several lower speed streams
- OFDM shares a user between many frequencies
  - Some wireless LANs split a signal into 104 channels
- The waste of bandwidth is obtained by using orthogonal carrier waves
- Is OFDM really spread spectrum?
  - They share some characteristics: Both use orthogonal frequencies and use wide bandwidth spectrum

OFDM



How 6 Mbps 802.11a uses OFDM and BPSK to transmit data

Comparison SDMA/TDMA/FDMA/CDMA

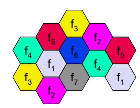
Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time-slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantages	very simple, increases capacity per km²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantages	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

Cell structure

- Implements space division multiplex: base station covers a certain transmission area (cell)
- Mobile stations communicate only via the base station
- Advantages of cell structures:
  - higher capacity, higher number of users
  - less transmission power needed
  - more robust, decentralized
  - base station deals with interference, transmission area etc. locally
- Problems:
  - fixed network needed for the base stations
  - handover (changing from one cell to another) necessary
  - interference with other cells
- Cell sizes from some 100 m in cities to, e.g., 35 km on the country side (GSM) - even less for higher frequencies

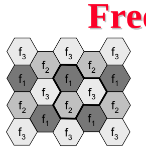
Frequency planning I

- Frequency reuse only with a certain distance between the base stations
- Standard model using 7 frequencies:

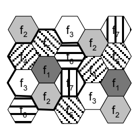


- Fixed frequency assignment:
  - certain frequencies are assigned to a certain cell
  - problem: different traffic load in different cells
- Dynamic frequency assignment:
  - base station chooses frequencies depending on the frequencies already used in neighbor cells
  - more capacity in cells with more traffic
  - assignment can also be based on interference measurements

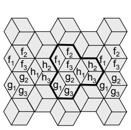
Frequency planning II



3 cell cluster



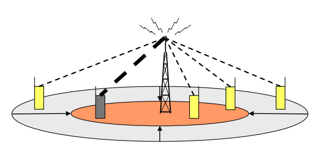
7 cell cluster



3 cell cluster
with 3 sector antennas

Cell breathing

- CDM systems: cell size depends on current load
- Additional traffic appears as noise to other users
- If the noise level is too high users drop out of cells



Wireless Networks

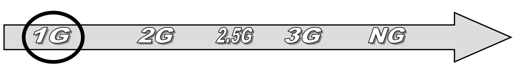
- Mobile wireless WANs
- Fixed wireless WANs
- WLANs: the 802.11 family
- WLANs/WPANs: Bluetooth

Generations in Mobile Wireless Service

- First Generation (1G)
  - Mobile voice services
- Second Generation (2G)
  - Primarily voice, some low-speed data (circuit switched)
- Generation 2½ (2.5G)
  - Higher data rates than 2G
  - A bridge (for GSM) to 3G
- Third Generation (3G)
  - Seamless integration of voice and data
  - High data rates, full support for packet switched data

Evolution of Mobile Wireless (1)

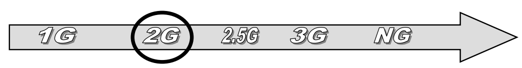
Advance Mobile Phone Service (AMPS)
- FDMA
- 824-849 MHz (UL), 869-894 MHz (DL)
- U.S. (1983), So. America, Australia, China



European Total Access Communication System (E-TACS)
- FDMA
- 872-905 MHz (UL), 917-950 MHz (DL)
- Deployed throughout Europe

Evolution of Mobile Wireless (2)

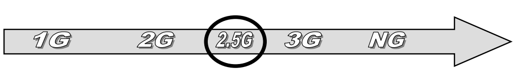
Global System for Mobile communications (GSM)
- TDMA
- Different frequency bands for cellular and PCS
- Developed in 1990, expected >1B subscriber by end of 2003



IS-95
- CDMA
- 800/1900 MHz – Cellular/PCS
- U.S., Europe, Asia

Evolution of Mobile Wireless (3)

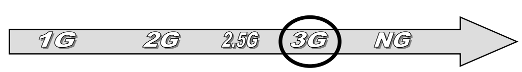
General Packet Radio Services (GPRS)
- Introduces packet switched data services for GSM
- Transmission rate up to 170 kbps
- Some support for QoS



Enhanced Data rates for GSM Evolution (EDGE)
- Circuit-switched voice (at up to 43.5 kbps/slot)
- Packet-switched data (at up to 59.2 kbps/slot)
- Can achieve on the order of 475 kbps on the downlink, by combining multiple slots

Evolution of Mobile Wireless (4)

Universal Mobile Telecommunication Systems (UMTS)
- Wideband DS-CDMA
- Bandwidth-on-demand, up to 2 Mbps
- Supports handoff from GSM/GPRS



IS2000
- CDMA2000: Multicarrier DS-CDMA
- Bandwidth on demand (different flavors, up to a few Mbps)
- Supports handoff from/to IS-95

Fixed Wireless

- Microwave
  - Traditionally used in point-to-point communications
  - Initially, 1 GHz range, more recently in the 40 GHz region
- Local Multipoint Distribution Service (LMDS)
  - Operates around 30 GHz
  - Point-to-multipoint, with applications including Internet access and telephony
  - Virginia Tech owns spectrum in SW VA and surroundings
- Multichannel Multipoint Distribution Service (MMDS)
  - Operates around 2.5 GHz
  - Initially, for TV distribution
  - More recently, wireless residential Internet service

WLANs: IEEE 802.11 Family

- 802.11 working group
  - Specify an open-air interface between a wireless client and a base station or access point, as well as among wireless clients
- IEEE 802.11a
  - Up to 54 Mbps in the 5 GHz band
  - Uses orthogonal frequency division multiplexing (OFDM)
- IEEE 802.11b (Wi-Fi)
  - 11 Mbps (with fallback to 5.5, 2 and 1 Mbps) in the 2.4 GHz band
  - Uses DSSS
- IEEE 802.11g
  - 20+ Mbps in the 2.4 GHz band

WLANs/WPANs: Bluetooth

- Cable replacement technology
- Short-range radio links
- Small, inexpensive radio chip to be plugged into computers, phones, palmtops, printers, etc.
- Bluetooth was invented in 1994
- Bluetooth Special Interest Group (SIG) founded in 1998 by Ericsson, IBM, Intel, Nokia and Toshiba to develop an open specification
  - Now joined by > 2500 companies

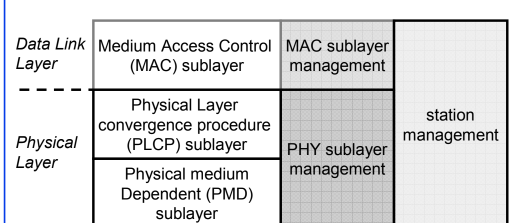
IEEE 802.11

- Characteristics
- Modes of operation
- Association, authentication and privacy

IEEE 802.11 Standard

- Final draft approved in 1997
- Operates in the 2.4 GHz industrial, scientific and medical (ISM) band
- Standard defines the physical (PHY) and medium access control (MAC) layers
  - Note that the 802.11 MAC layer also performs functions that we usually associated with higher layers (e.g., fragmentation, error recovery, mobility management)
- Initially defined for operation at 1 and 2 Mbps
  - DSSS, FHSS or infrared
  - Extensions (IEEE 802.11b, IEEE 802.11a, etc.) allow for operation at higher data rates and (in the case of 802.11a) different frequency bands

Reference Model (1)



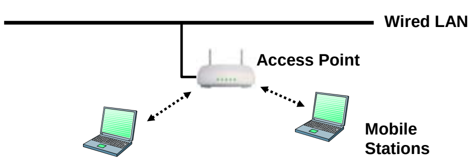
Reference Model (2)

- Physical Medium Dependent (PMD) sublayer
  - Defines a method for transmitting and receiving data through the medium, including modulation and coding
  - Dependent on whether DSSS, FHSS or IR is used
- Physical Layer Convergence Procedure (PLCP) sublayer
  - Maps MAC layer PDUs into a packet suitable for transmission by the PMD sublayer
  - Performs carrier sensing
- MAC sublayer
  - Defines access mechanism, based on CSMA

IEEE 802.11b

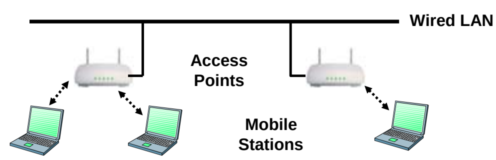
- Standard released in 1999
- 2.4 – 2.483 GHz band
- Uses DSSS
- Data rates of up to 11 Mbps
  - Data rates are automatically adjusted for noisy conditions, so can operate at 1, 2, 5.5 or 11 Mbps
- Modes of operation
  - Infrastructure-based
  - Ad-hoc
- Most widely implemented to date

Infrastructure Mode (1)



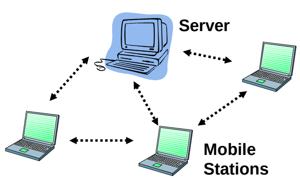
- Basic Service Set (BSS)
- Access point serves as a local bridge
- Stations communicate through the access point, which relays frames to/from mobile stations

Infrastructure Mode (2)



- Extended Service Set (ESS)
- A set of infrastructure BSSs
- Access points communicate among themselves to forward frames between BSSs and to facilitate movement of stations between BSSs

Ad Hoc Mode

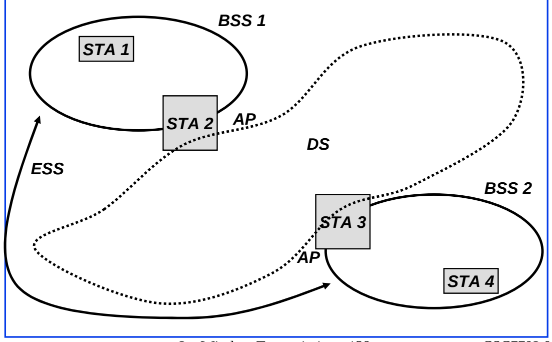


- Independent Basic Service Set (IBSS) or Peer to Peer
- Stations communicate directly with each other
- When no direct link is feasible between two station, a third station may act as a relay (multi-hop communications)

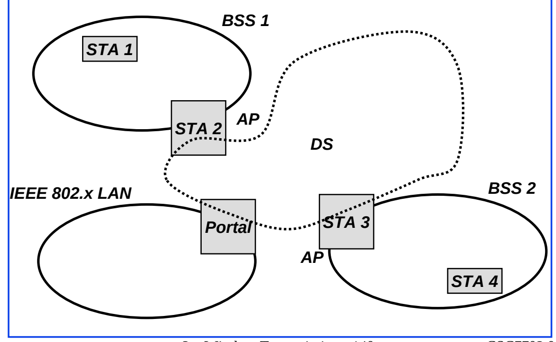
Distribution Systems

- The architectural component used to interconnect BSSs is the distribution system (DS)
- DS enable mobile device support
  - Address-to-destination mapping
  - Seamless integration of several BSSs
- In practice, an access point implements DS services

Distribution Systems and Access Points



Integration with Wired LANs



Association

- To deliver a message within the DS, must know which AP to access for a given mobile station
- Before a station is allowed to send a message through an AP, it must associate itself with that AP
  - At any given time, a station must be associated with no more than one AP
  - An AP may be associated with multiple stations
- As it moves between BSSs, a mobile station may reassociate itself with a different AP

Authentication

- 802.11 provides link-level authentication between stations
- 802.11 also supports shared key authentication
  - Requires that wired equivalent privacy (WEP) be enabled
  - Identity is demonstrated by knowledge of a shared, secret, WEP encryption key
- Typically, authentication is performed at association with an AP

Privacy

- Default state is "in the clear" – messages are *not* encrypted
- Optional privacy mechanism, WEP, is provided
  - Goal is to achieve a level of security at least as good as in a wired LAN
- Note that encryption provided by WEP is relatively easy to break

Bluetooth

- Characteristics
- Comparison with IEEE 802.11

Introduction

- Motivation: cable replacement in peripherals and embedded devices
- Named after Harald Blaatand "Bluetooth" II, king of Denmark 940-981 A.D.
- Estimated > 800 M Bluetooth-enabled devices by 2006

Requirements

Bluetooth phone and headset

Bluetooth printer module

- Universal framework to integrate a diverse set of devices in a seamless, user-friendly, efficient manner
- Devices must be able to establish ad hoc connections
- Support for data and voice
- Similar security as cables
- Simple, small, power-efficient implementation
- Inexpensive!

Characteristics

- Operates in the ISM band (like 802.11b)
- Frequency hopping spread spectrum
- Up to 720 kbps data transfer with a range of 10 m
  - Transmission rate decreases if interference from other devices is present
- Master/slave architecture
  - A collection of master + slaves is called a piconet
  - Up to 7 slave devices may communicate with a master
  - Piconets can be linked together to form a scatternet

Comparison with 802.11

Characteristic	Bluetooth	IEEE 802.11b	IEEE 802.11a
Spectrum	**2.4 GHz**	**2.4 GHz**	**5 GHz**
Max Data Rate	**725 kbps**	**11 Mbps**	**54 Mbps**
Connections	**Point-to-Multipoint**	**Point-to-Point**	**Point-to-Point**
Frequency Selection	**FHSS**	**DSSS**	**OFDM**
Circuit cost (est. 2001)	**$ 11.00**	**$ 46.00**	**N/A**

Summary

- Applications
- Modulation TDMA, FDMA, CDMA
- Cellular systems