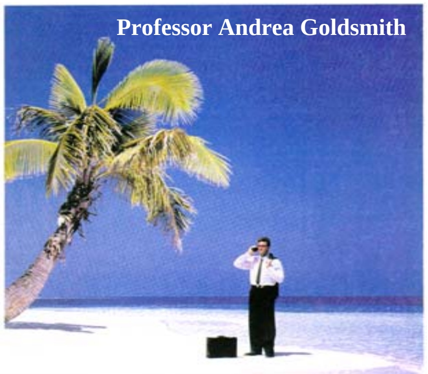
EE 359: Wireless Communications



Outline

- Course Basics
- Course Syllabus
- The Wireless Vision
- Technical Challenges
- Current Wireless Systems
- Emerging Wireless Systems
- Spectrum Regulation
- Standards

Course Information* People

- Instructor: Andrea Goldsmith, andrea@ee, Packard 371, 5-6932, OHs: MW 12:30-1:30 pm and by appt.
- TA: Ritesh Madan, rkmadan@stanford, Discussion: T 5-6, Room TBD, OHs: T after discussion, W 4:30-6:30 pm, Email OHs 10-11am
- Class Administrator: Joice DeBolt, joice@stanford, Packard 365, 3-3164. Homework dropoff: Th 12 pm.

*See web or handout for more details

Course Information Nuts and Bolts

- Prerequisites: EE279 or equivalent (Digital Communications)
- Required Textbook: *Wireless Communications* (by me)
  - Available at bookstore or Amazon
  - Extra credit and prize for finding typos/mistakes/etc.
  - Supplemental texts on 1 day reserve at Terman.
- Class Homepage: www.stanford.edu/class/ee359
  - All handouts, announcements, homeworks, etc. posted to website
  - "Lectures" link continuously updates topics, handouts, and reading
- Class Mailing List: ee359-students (automatic for on-campus registered students).
  - Guest list ee359-guest for SCPD/auditors: send TA email to sign up.
  - Sending mail to ee359-staff reaches me and the TA.

Course Information Policies

- Grading: Two Options
  - Project (4 units): HWs - 20%, 2 Exams - 25%, 30%, Project - 25%
  - No Project (3 units): HWs – 25%, 2 Exams – 35%, 40%.
- HWs: assigned Wednesday, due following Thursday at noon
  - Same deadline for SCPD students
  - Homeworks lose 25% credit per day late, lowest HW dropped
  - Up to 3 students can collaborate and turn in one HW writeup
  - Collaboration means all collaborators work out all problems together
- Exams:
  - Exam 1 tentatively on 11/7 (11-1 pm), Final is 12/14 (9:30-11:30)
  - Exams must be taken at scheduled time, no makeup exams
  - Local SCPD students must take exams on-campus
  - For off-campus exams you must make arrangements well in advance

Course Information Project Option

- Term project on anything related to wireless
- Literature survey, analysis, or simulation
  - Survey is low risk, maximum grade capped at 85%.
  - Analysis/simulation more risky: start early, discuss with me.
  - See link under last year's class for examples (good and bad)
  - 2 can collaborate if project merits collaboration (scope, synergy). Must get collaboration approval prior to proposal deadline.
- Must set up website for your project (for proposal and report)
- Project proposal: due 11/18 at 5 pm
  - ~2 paragraph proposal with detailed description of project plan
  - Should include 2-3 references and their relevance
  - Graded independently of final report (15-20% of grade, ~5-10 hours)
- Final report due 12/9 at 5 pm (~8-10 pages, ~20-40 hours)

Course Syllabus

- Overview of Wireless Communications
- Path Loss, Shadowing, and Fading Models
- Capacity of Wireless Channels
- Digital Modulation and its Performance
- Adaptive Modulation
- Diversity
- MIMO Systems
- Equalization, Multicarrier, and Spread Spectrum
- Multiuser Communications
- Wireless Networks

Wireless History

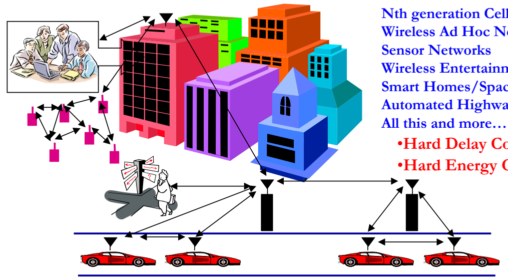
- Ancient Systems: Smoke Signals, Carrier Pigeons, …
- Radio invented in the 1880s by Marconi
- Many sophisticated military radio systems were developed during and after WW2
- Cellular has enjoyed exponential growth since 1988, with almost 1 billion users worldwide today
  - Ignited the recent wireless revolution
  - 3G roll-out disappointing in Europe, nascent in US
  - Asia way ahead of the rest of the world
- Much hype in 1990s, great failures around 2000
  - 1G Wireless LANs/Iridium/Metricom

Exciting Developments

- Internet and laptop use exploding
- 2G/3G wireless LANs growing rapidly
- Huge cell phone popularity worldwide
- Emerging systems such as Bluetooth, UWB, Zigbee, and WiMAX opening new doors
- Military and security wireless needs
- Important interdisciplinary applications

Future Wireless Networks

Ubiquitous Communication Among People and Devices



Wireless Internet access
Nth generation Cellular
Wireless Ad Hoc Networks
Sensor Networks
Wireless Entertainment
Smart Homes/Spaces
Automated Highways
All this and more…
•Hard Delay Constraints
•Hard Energy Constraints

Design Challenges

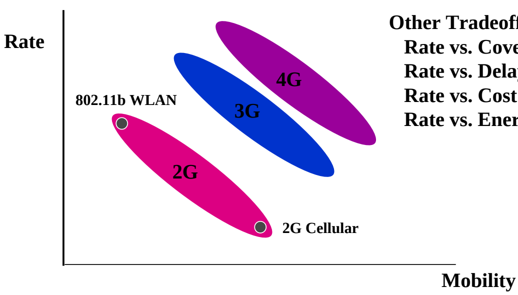
- Wireless channels are a difficult and capacity-limited broadcast communications medium
- Traffic patterns, user locations, and network conditions are constantly changing
- Applications are heterogeneous with hard constraints that must be met by the network
- Energy and delay constraints change design principles across all layers of the protocol stack

Evolution of Current Systems

- Wireless systems today
  - 2G Cellular: ~30-70 Kbps.
  - WLANs: ~10 Mbps.
- Next Generation
  - 3G Cellular: ~300 Kbps.
  - WLANs: ~70 Mbps.
- Technology Enhancements
  - Hardware: Better batteries. Better circuits/processors.
  - Link: Antennas, modulation, coding, adaptivity, DSP, BW.
  - Network: Dynamic resource allocation. Mobility support.
  - Application: Soft and adaptive QoS.

"Current Systems on Steroids"

Future Generations



Other Tradeoffs:
Rate vs. Coverage
Rate vs. Delay
Rate vs. Cost
Rate vs. Energy

Fundamental Design Breakthroughs Needed

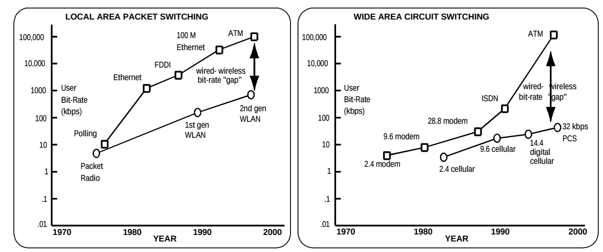
Multimedia Requirements

	Voice	Data	Video
Delay	<100ms	-	<100ms
Packet Loss	<1%	0	<1%
BER	10^{-3}	10^{-6}	10^{-6}
Data Rate	8-32 Kbps	1-100 Mbps	1-20 Mbps
Traffic	Continuous	Bursty	Continuous

One-size-fits-all protocols and design do not work well

Wired networks use this approach, with poor results

Wireless Performance Gap



Quality-of-Service (QoS)

- QoS refers to the requirements associated with a given application, typically rate and delay requirements.
- It is hard to make a one-size-fits all network that supports requirements of different applications.
- Wired networks often use this approach with poor results, and they have much higher data rates and better reliability than wireless.
- QoS for all applications requires a cross-layer design approach.

Crosslayer Design

- Application
- Network
- Access
- Link
- Hardware

Delay Constraints
Rate Constraints
Energy Constraints

Adapt across design layers
Reduce uncertainty through scheduling
Provide robustness via diversity

Crosslayer Techniques

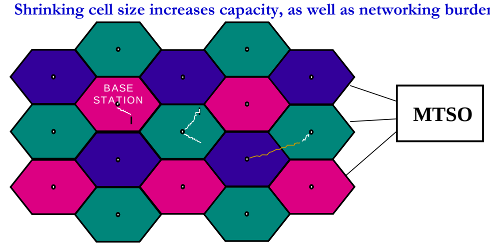
- Adaptive techniques
  - Link, MAC, network, and application adaptation
  - Resource management and allocation (power control)
- Diversity techniques
  - Link diversity (antennas, channels, etc.)
  - Access diversity
  - Route diversity
  - Application diversity
  - Content location/server diversity
- Scheduling
  - Application scheduling/data prioritization
  - Resource reservation
  - Access scheduling

Current Wireless Systems

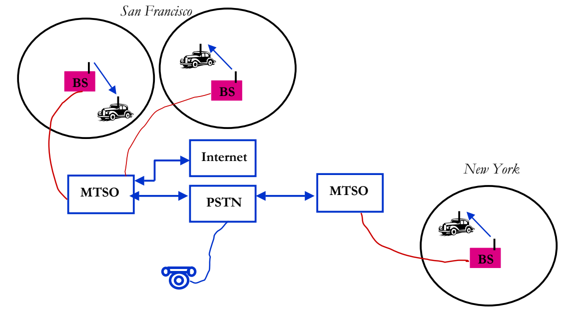
- Cellular Systems
- Wireless LANs
- Satellite Systems
- Paging Systems
- Bluetooth
- Ultrawideband radios
- Zigbee radios

Cellular Systems: Reuse channels to maximize capacity

- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations/MTSOs coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden



Cellular Phone Networks

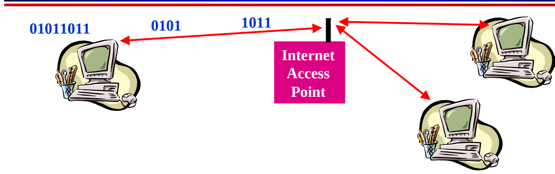


3G Cellular Design:
Voice and Data

- Data is bursty, whereas voice is continuous
  - Typically require different access and routing strategies
- 3G "widens the data pipe":
  - 384 Kbps.
  - Standard based on wideband CDMA
  - Packet-based switching for both voice and data
- 3G cellular struggling in Europe and Asia
- Evolution of existing systems (2.5G,2.6798G):
  - GSM+EDGE
  - IS-95(CDMA)+HDR
  - 100 Kbps may be enough
- What is beyond 3G?

The trillion dollar question

Wireless Local Area Networks (WLANs)



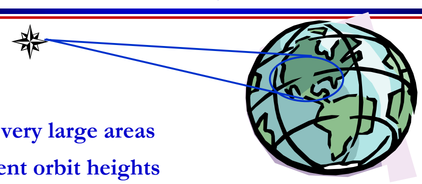
- WLANs connect "local" computers (100m range)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
  - Poor performance in some apps (e.g. video)

Wireless LAN Standards

- 802.11b (Current Generation)
  - Standard for 2.4GHz ISM band (80 MHz)
  - Frequency hopped spread spectrum
  - 1.6-10 Mbps, 500 ft range
- 802.11a (Emerging Generation)
  - Standard for 5GHz NII band (300 MHz)
  - OFDM with time division
  - 20-70 Mbps, variable range
  - Similar to HiperLAN in Europe
- 802.11g (New Standard)
  - Standard in 2.4 GHz and 5 GHz bands
  - OFDM
  - Speeds up to 54 Mbps

In 200?, all WLAN cards will have all 3 standards

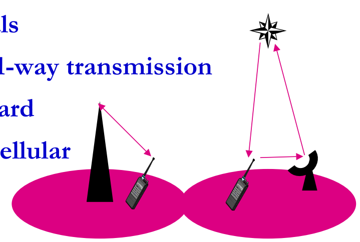
Satellite Systems



- Cover very large areas
- Different orbit heights
  - GEOs (39000 Km) versus LEOs (2000 Km)
- Optimized for one-way transmission
  - Radio (XM, DAB) and movie (SatTV) broadcasting
- Most two-way systems struggling or bankrupt
  - Expensive alternative to terrestrial system
  - A few ambitious systems on the horizon

Paging Systems

- Broad coverage for short messaging
- Message broadcast from all base stations
- Simple terminals
- Optimized for 1-way transmission
- Answer-back hard
- Overtaken by cellular



Bluetooth

- Cable replacement RF technology (low cost)
- Short range (10m, extendable to 100m)
- 2.4 GHz band (crowded)
- 1 Data (700 Kbps) and 3 voice channels
- Widely supported by telecommunications, PC, and consumer electronics companies
- Few applications beyond cable replacement

Ultrawideband Radio (UWB)

- UWB is an impulse radio: sends pulses of tens of picoseconds(10^{-12}) to nanoseconds (10^{-9})
- Duty cycle of only a fraction of a percent
- A carrier is not necessarily needed
- Uses a lot of bandwidth (GHz)
- Low probability of detection
- Excellent ranging capability
- Multipath highly resolvable: good and bad
  - Can use OFDM to get around multipath problem.

Why is UWB Interesting?

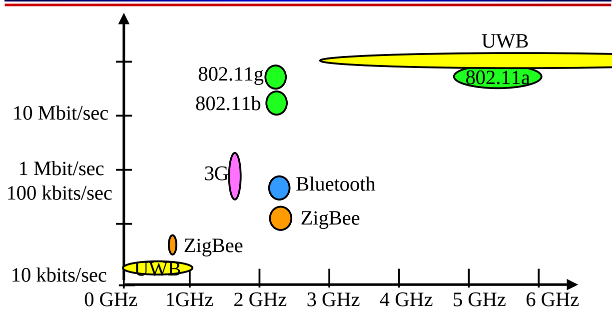
- Unique Location and Positioning properties
  - 1 cm accuracy possible
- Low Power CMOS transmitters
  - 100 times lower than Bluetooth for same range/data rate
- Very high data rates possible
  - 500 Mbps at ~10 feet under current regulations
- 7.5 Ghz of "free spectrum" in the U.S.
  - FCC recently legalized UWB for commercial use
  - Spectrum allocation overlays existing users, but its allowed power level is very low to minimize interference
- "Moore's Law Radio"
  - Data rate scales with the shorter pulse widths made possible with ever faster CMOS circuits

IEEE 802.15.4 / ZigBee Radios

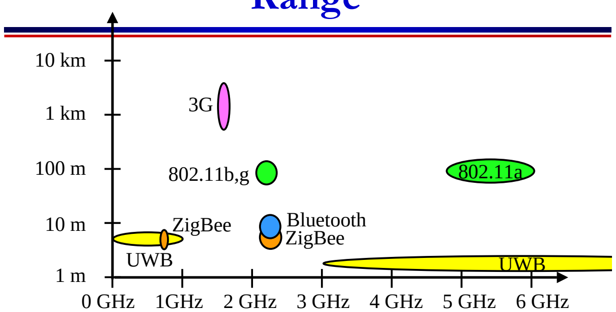
- Low-Rate WPAN
- Data rates of 20, 40, 250 kbps
- Star clusters or peer-to-peer operation
- Support for low latency devices
- CSMA-CA channel access
- Very low power consumption
- Frequency of operation in ISM bands

Focus is primarily on radio and access techniques

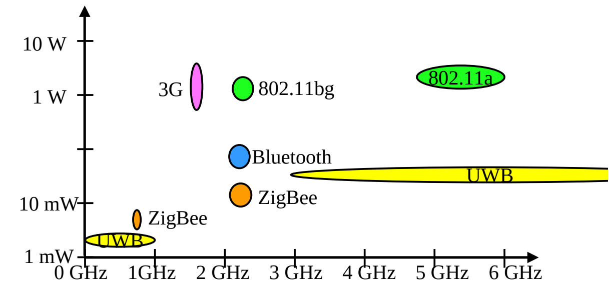
Data rate



Range



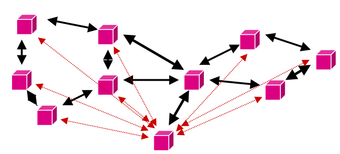
Power Dissipation



Emerging Systems

- Ad hoc wireless networks
- Sensor networks
- Distributed control networks

Ad-Hoc Networks



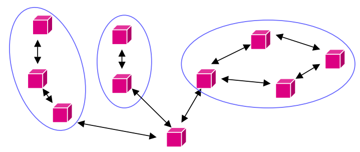
- Peer-to-peer communications.
- No backbone infrastructure.
- Routing can be multihop.
- Topology is dynamic.
- Fully connected with different link SINRs

Design Issues

- Ad-hoc networks provide a flexible network infrastructure for many emerging applications.
- The capacity of such networks is generally unknown.
- Transmission, access, and routing strategies for ad-hoc networks are generally ad-hoc.
- Crosslayer design critical and very challenging.
- Energy constraints impose interesting design tradeoffs for communication and networking.

Sensor Networks

Energy is the driving constraint

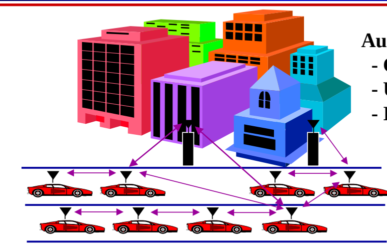


- Nodes powered by nonrechargeable batteries
- Data flows to centralized location.
- Low per-node rates but up to 100,000 nodes.
- Data highly correlated in time and space.
- Nodes can cooperate in transmission, reception, compression, and signal processing.

Energy-Constrained Nodes

- Each node can only send a finite number of bits.
  - Transmit energy minimized by maximizing bit time
  - Circuit energy consumption increases with bit time
  - Introduces a delay versus energy tradeoff for each bit
- Short-range networks must consider transmit, circuit, and processing energy.
  - Sophisticated techniques not necessarily energy-efficient.
  - Sleep modes save energy but complicate networking.
- Changes everything about the network design:
  - Bit allocation must be optimized across all protocols.
  - Delay vs. throughput vs. node/network lifetime tradeoffs.
  - Optimization of node cooperation.

Distributed Control over Wireless Links

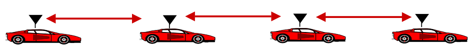


Automated Vehicles
- Cars
- UAVs
- Insect flyers

- Packet loss and/or delays impacts controller performance.
- Controller design should be robust to network faults.
- Joint application and communication network design.

Joint Design Challenges

- There is no methodology to incorporate random delays or packet losses into control system designs.
- The best rate/delay tradeoff for a communication system in distributed control cannot be determined.
- Current autonomous vehicle platoon controllers are not string stable with *any* communication delay



Can we make distributed control robust to the network?

Yes, by a radical redesign of the controller and the network.

Spectrum Regulation

- Spectral Allocation in US controlled by FCC (commercial) or OSM (defense)
- FCC auctions spectral blocks for set applications.
- Some spectrum set aside for universal use
- Worldwide spectrum controlled by ITU-R

Regulation can stunt innovation, cause economic disasters, and delay system rollout

Standards

- Interacting systems require standardization
- Companies want their systems adopted as standard
  - Alternatively try for de-facto standards
- Standards determined by TIA/CTIA in US
  - IEEE standards often adopted
  - Process fraught with inefficiencies and conflicts
- Worldwide standards determined by ITU-T
  - In Europe, ETSI is equivalent of IEEE

Standards for current systems are summarized in Appendix D.

Main Points

- The wireless vision encompasses many exciting systems and applications
- Technical challenges transcend across all layers of the system design.
- Cross-layer design emerging as a key theme in wireless.
- Existing and emerging systems provide excellent quality for certain applications but poor interoperability.
- Standards and spectral allocation heavily impact the evolution of wireless technology