

ECE 586

Advanced Topics: Wireless Networking

<http://www.ece.rochester.edu/courses/ECE586>

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TR 2-3:15, CSB 523

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Class information (1)

- **Prerequisites:** Permission of instructor

- **Course Description**

This course will cover the latest research in the area of wireless networking, concentrating mainly on mobile ad hoc and sensor networks. Topics will include media access control, routing, flow control and cross-layer architectures. Issues such as quality of service (QoS), energy conservation, reliability and mobility management will be discussed. Students will be required to complete a semester-long research project related to the theme of this course.



Class information (2)

- **Grading**

Grades will be based on a semester-long research project and class participation: Course Project 50%, Class Participation 50%

- **Course Project**

Each student must complete a course research project related to a topic in the wireless networking area. Projects can range from in-depth literature surveys to simulations, analysis, or field experiments. Any topic in the wireless networking field is acceptable, subject to approval. You may work in pairs, but this is not required. At the end of the semester, each group will present their work in class (tentative) and turn in a conference-style paper describing the project.



Class information (3)

■ **Class Participation**

Lectures will only run through March 1 (tentative), so it is expected that you will attend all lectures. Excused absences (e.g., illness, conferences, etc.) are allowed. It is expected that you will have read the relevant material before each class and come to class prepared to participate in the discussion of the day's material.

■ **Discussion leaders**

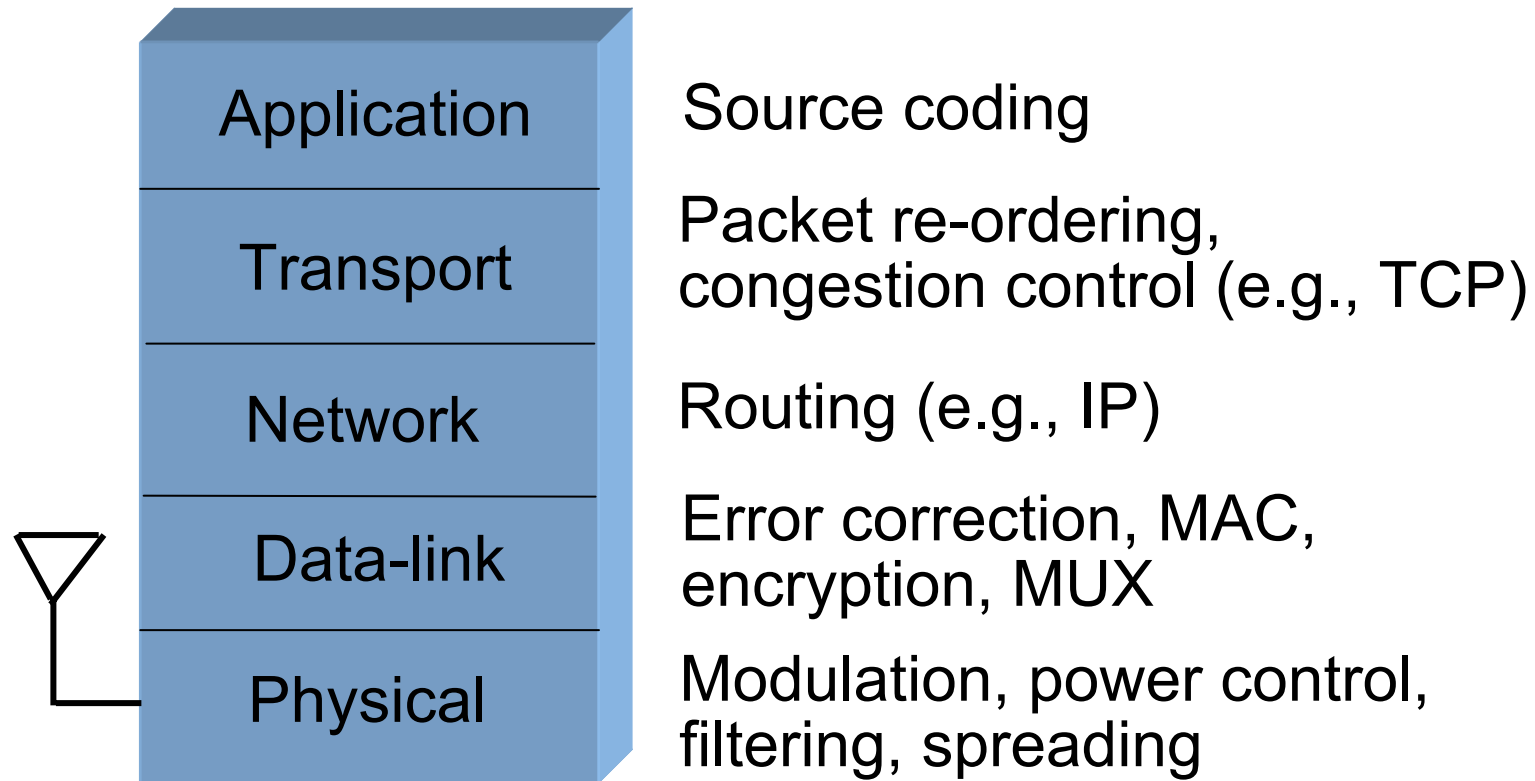
- Everyone must sign up to lead some class discussions
- Sign-up sheet will be passed around at the next class



Course outline (tentative)

Lecture #	Day	Date	Topic
1	Thurs	1/13	Intro to wireless networking: network architectures
2	Tues	1/18	MAC protocols
3	Thurs	1/20	MAC protocols (cont.)
4	Tues	1/25	802.11
5	Thurs	1/27	Ad hoc networks: intro
6	Tues	2/1	Routing
7	Thurs	2/3	MAC
8	Tues	2/8	QoS
9	Thurs	2/10	Sensor networks: intro
10	Tues	2/15	Architectures
11	Thurs	2/17	Routing
12	Tues	2/22	MAC
13	Thurs	2/24	Sensor management
14	Tues	3/1	Localization

Network protocol stack



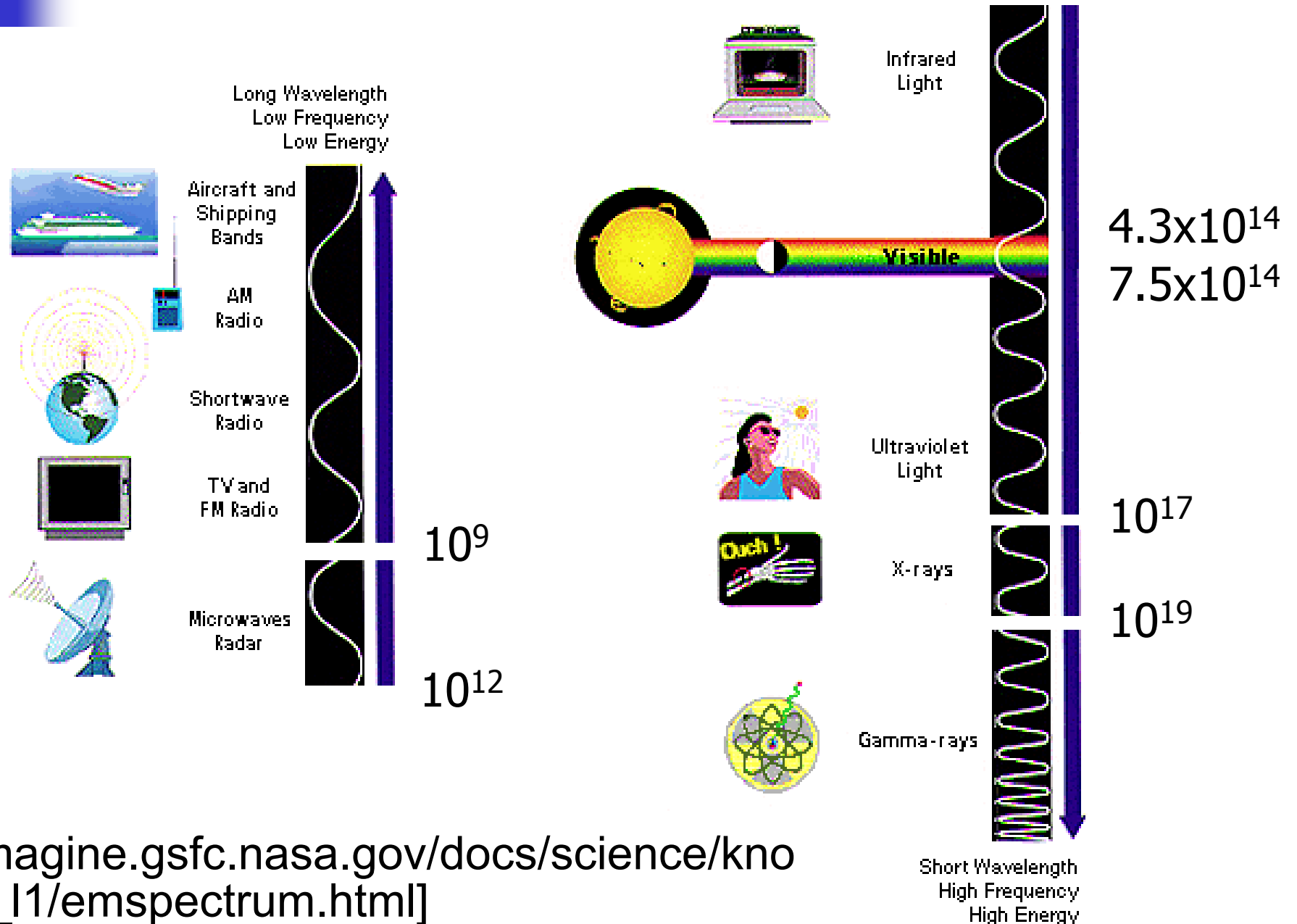
- Provides abstraction when designing layers
- We'll focus on MAC, Network, Transport and Cross-layer designs



What is wireless communication?

- Any form of communication that does not require the transmitter and receiver to be in physical contact
- Electromagnetic wave propagated through free-space
 - Radar, RF, Microwave, IR, Optical
- Simplex: one-way communication (e.g., radio, TV)
- Half-duplex: two-way communication but not simultaneous (e.g., push-to-talk radios)
- Full-duplex: two-way communication (e.g., cellular phones)
 - Frequency-division duplex (FDD)
 - Time-division duplex (TDD): simulated full-duplex

EM spectrum



[imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html]



Why use wireless communication?

- Provides mobility
 - A user can send or receive a message no matter where he or she is located
- Added convenience/reduced cost
 - Enables communication without installing an expensive infrastructure
 - Can easily set-up temporary LANs
 - Disaster situations
 - Office moves
 - Developing nations utilize cellular telephony rather than laying twisted-pair wires to each home
- Only use resources when sending or receiving a signal



How does mobility affect...

- Hardware
 - Lighter
 - More robust
 - Lower power (battery operation)
- Wireless communication
 - Time-varying channels
- Network protocols
 - Name/address/location changes
 - Delay changes
 - Error rate changes
- Fidelity
 - High fidelity may not be possible



How does mobility affect...

- Security
 - Lighter-weight algorithms
 - Endpoint authentication harder
 - Devices more vulnerable
- Performance
 - Network, CPU all constrained
 - Delay and delay variability
- Operating systems
 - New resources to track and manage: energy
- Applications
 - Name changes
 - Changes in connectivity
 - Changes in quality of resources
- People
 - Introduces new complexities, failures, devices



Example changes

- Addresses
 - Phone numbers, IP addresses
- Network performance
 - Bandwidth, delay, bit error rates, cost, connectivity
- Network interfaces
 - WiFi, Ethernet
- Between applications
 - Different interfaces over phone & laptop
- Within applications
 - Loss of bandwidth triggers change from color to B&W
- Available resources
 - Files, printers, displays, power, even routing



Summary

Generally, mobility stresses all resources further:

- CPU
- Power
- Bandwidth
- Delay tolerance
- Radio spectrum
- Human attention
- Physical size
- Constraints on peripherals and GUIs (modality of interaction)



Wireless environments

■ Differ in

- Mobility
- Type of application
- Type of environment
- Media characteristics
- Pervasiveness of hosts
- Level of infrastructure
- Visibility of infrastructure
- Coverage
- Cost

■ Examples

- Cellular telephony
- Satellite
- Metropolitan-area data networks
- Local-area networks
- Personal-area networks
- Ubiquitous computing environments
- Ad hoc networks
- Sensor networks



Why is wireless different than wired?

- Noisy, time-varying channel
 - BER varies by orders of magnitude
 - Environmental conditions affect transmission
- Shared medium
 - Other users create interference
 - Must develop ways to share the channel
- Bandwidth is limited
 - FCC determines how spectrum is allocated
 - ISM band for unlicensed use (902-928 MHz, 2.4-2.5 GHz and 5.725-5.875 GHz)
- Requires intelligent SP and comm. to make efficient use of limited bandwidth in error-prone environment



Why is wireless different than wired?

- Major differences due to broadcast nature of wireless communication
 - Transmitted signals can be received by an arbitrary (and perhaps unknown) number of other users
 - Cannot guarantee a link from every transmitting node to every intended receiving node
 - Each transmitted message utilizes scarce resources (BW)
 - Need to provide means for fair and efficient utilization of available bandwidth among transmitting nodes
 - Transmitted signal power important parameter
 - Require enough signal power to reach destination node
 - Want to limit signal power to minimize interference and max battery life



Network topologies

- Types of network topologies
 - Centralized
 - De-centralized (peer-to-peer)
 - Hybrid
- Centralized (hub-and-spoke) topology
 - Communication from one node to another goes through hub (base station)
 - Hub station controls nodes and monitors transmissions from each node
 - Hub manages access by nodes to network's allocated bandwidth
 - Configuration for cellular systems and many WLAN networks



Decentralized topologies

- Decentralized (peer-to-peer) topology
- Fully-connected network
 - All nodes can communicate directly
 - Requires nodes to be co-located
- Multi-hop network
 - If nodes cannot directly reach destination, intermediate nodes must relay messages to destination
 - Widely used in ad-hoc networks where cannot guarantee connectivity of all nodes



Centralized topology

■ Advantages

- Efficient use of transmit power
 - Compared with fully-connected peer-to-peer, nodes can reach other nodes twice the distance with same signal power (since BS high power)
- Hub/BS can be appropriately placed to minimize obstruction
- Hub/BS provides connection to backbone network → reason many WLANs have centralized topology
- Nodes can be made simple and BS complex
- Helpful for power control → a central point can determine required power for nodes to minimize interference and conserve battery
- Hub can provide common timing reference



Centralized topology (cont.)

■ Disadvantages

- Single point of failure
- Delay due to multiple transmit/receive operations
- Cannot deal with unpredictable propagation environments
- Cannot cover wide areas where connections exceed range of single link
- Not suitable for ad-hoc networks
- Requires significant infrastructure setup



Fully connected peer-to-peer

■ Advantages

- No single point of failure
- No store-and-forward delay
- No routing so complexity of nodes reduced
- Can provide a node that is a gateway to backbone network

■ Disadvantages

- Performance degradation in large networks
- Near-far problem
- Transmitters operating at high power levels (to reach far station) will interfere with unintended receivers in close proximity



Multi-hop peer-to-peer

■ Advantages

- Power efficiency if Tx power dominates over Rx power
- Only solution if no infrastructure available
- Widely used in military applications
- Gaining popularity in other types of wireless networks
 - Ad hoc networks
 - Sensor networks

■ Disadvantages

- Complex algorithms for efficient message routing and control
- Multiple store-and-forwards → increase delay for users separated by multiple hops
- Overhead to set up efficient routes
- No central timing or power control authority



Types of networks

- WiFi / 802.11
 - Two modes
 - Centralized: wireless local area data network
 - Peer-to-peer: MAC/PHY for ad hoc networks
- Ad hoc networks
 - Multi-hop peer-to-peer networks
 - Hybrid networks
 - Unicast, multicast and broadcast networks
- Wireless sensor networks
 - Different applications uses different network topologies
 - Converge-cast, unicast, broadcast and multicast networks



Mobile ad hoc networks

- Definition
 - A collection of wireless mobile hosts forming a temporary network without the aid of any centralized administration or standard support services
- Often ad-hoc network topology is dynamic—nodes enter and leave the network continuously
- No centralized control or fixed infrastructure to support network configuration or reconfiguration
- Example scenarios for MANETs
 - Meetings
 - Emergency or disaster relief situations
 - Military communications
 - Wearable computers
 - Sensor networks



MANETs (cont.)

- Mobile nodes have limited communication range
 - Reduces battery drain
 - Enables spatial reuse of limited bandwidth → increased network capacity
- To connect all nodes in the network, each node is a
 - Packet source
 - Packet sink
 - Router
- Nodes must route packets for other nodes to keep the network fully connected
- In MANETs, a big problem is how to determine where a destination node is located relative to a sending node



MANETs (cont.)

- Route-finding is a current area of much research
 - Want to determine an “optimal” way to find “optimal” routes
- Dynamic links
 - Broken links must be updated when a node moves out of communication range with another node
 - New links must be formed when a node moves into communication range with another node
 - Based on this new information, routes must be modified
- Frequency of route changes a function of node mobility



Issues in MANETs

- Routing performance

- Routes change over time due to node mobility
- Would like to avoid long delays when sending packets
- But would like to avoid lots of route maintenance overhead
- Want as many participating nodes as possible for greater aggregate throughput, shorter paths, and smaller chance of partition

- MAC

- Broadcast communication channel
- Neighbor nodes change over time
- Nodes sleep to reduce energy drain
- No coordination/cooperation among nodes



Issues in MANETs

- Quality of service
 - Link variability → route variability
 - Collisions
 - Congestion
- Security - interesting new vulnerabilities and complexities
 - Routing denial of service
 - Nodes may agree to route packets
 - Nodes may then fail to do so
 - Broken, malicious, selfish nodes
 - Key distribution and trust issues



Wireless sensor networks

- Microsensors
 - Low power, cheap sensors
 - Sensor module (e.g., acoustic, seismic, image)
 - A digital processor for sig. proc. and network protocol functions
 - Radio for communication
 - Battery-operated
- Sensors monitor environment
 - Cameras, microphones, physiological sensors, etc.
 - Gather data for some purpose
- Microsensor data limited in range and accuracy
 - Each node can only gather data from a limited physical area
 - Data may be noisy
 - Data aggregation enables higher quality (less noisy) data, gives information about larger physical area than individual data



WSNs (cont.)

- Hundreds or thousands of nodes scattered throughout an environment
- New wireless networking paradigm
 - Requires autonomous operation
 - Highly dynamic environments
 - Sensor nodes added/fail
 - Events in the environment
 - Distributed computation and communication protocols required
- Microsensor network applications
 - Home security
 - Machine failure diagnosis
 - Chemical/biological detection
 - Medical monitoring
 - Surveillance and reconnaissance
 - Animal/plant monitoring (e.g., for research)



WSNs (cont.)

- Networking sensors enables
 - Extended range of sensing → improved quality
 - Fault tolerance due to redundancy in data from different sensors
 - Distributed processing of large amounts of sensor data
 - Scalability: quality can be traded for system lifetime
 - “Team-work”: nodes can help each perform a larger sensing task



MANETs vs. WSNs

MANETs	WSNs
Unreliable communication	Unreliable communication
Require self-configuration	Require self-configuration
Constrained energy and bandwidth	Very constrained energy and bandwidth
Small-scale	Large-scale
Typically mobile	Typically immobile
Competitive	Cooperative
Address-centric	Data-centric
QoS: delay, etc	Application-specific QoS



Discussion

- What potential do you see for wireless networks?
- What do you see as the hardest things for us to address?
- If you could wish for one key piece of technology to come true, what would it be?
- What applications can you envision if we had pervasive ad hoc networks?
- What everyday uses can you think of for wireless sensor networks?
- What are user-level issues in wireless communication that need to be addressed?



Discussion

- What is your biggest complaint about current wireless technology?
- In what application areas do you see wireless networks succeeding?
- In what application areas do you see wireless networks failing?
- What do you see as the motivating factors for using wireless as opposed to wired networks?
- What do you see as the most pressing research need to improve wireless networking?