

CS 525M – Mobile and Ubiquitous Computing Class

Emmanuel Agu

A Little about me

- Faculty in WPI CS
- Research interests include graphics, mobile computing/wireless and mobile graphics
- How did I get into wireless?
 - 3 years in wireless LAN lab (*pre 802.11*)
 - Worked on designing, simulating, implementing wireless protocols
 - We actually built working wireless LAN testbed
- Computer Systems/Electrical/Computer Science background

About this class (Administrivia)

- **Class goal:** to give overview, insight into issues in mobile and ubiquitous computing
- Full course name: *Mobile and Ubiquitous Computing*
- Will meet for 14 weeks, break during term break (March 7)
- Seminar class: I will present, **YOU** will present selected papers
- Gain big picture through focussed discussions
- Check for papers on course website:
<http://www.cs.wpi.edu/~emmanuel/courses/cs525m/S06/>
- This area combines lots of other areas: (networking, OS, software, etc): No one has all the background!!

Administrivia: Papers

- Weeks 1, 2 and 13: I will present
- Weeks 2 – 12:
 - First, I will present background material, motivate topic, from **Background Papers** for week
 - Two student presentations from **Required Papers** section for the week
- Each presentation should last about 45 minutes with about 20 minutes of discussion
- 10-min break between talks

Formal Requirements

- *What do you have to do to get a grade?*
- Come to class
- Seminar = Discuss!! Discuss!! Discuss!!
- Select and present 1 paper
- Write summaries and email them for each week's papers
- Do term project, 4-phases
 - Decide project area (3 wks)
 - Propose project (5 wks)
 - Implement, evaluate, experiment (5 wks)
 - Present results (in week 14) (1 wk)
- Grading policy: Presentation(s): 30%, Class participation: 10%, Final project: 50%, Summaries: 10%.

Student Introductions!

- Please introduce yourself
 - Name
 - Status: grad/undergrad, year
 - Relevant background: e.g. coal miner 😊
 - Seriously: systems courses taken.. Networks, OS, etc
 - What you would like to get out of this class?
 - Understanding of a hot field
 - Just a class for masters degree
 - Research interests/publications
 - My spouse told me to 😊

Next... Overview

- Today, quick overview of topics/issues
- Fire-hose section designed to excite you (or discourage you)
- More questions, problems than solutions
- ALL topics will be covered in more detail later
- Most students will only understand part of the topics in today's overview

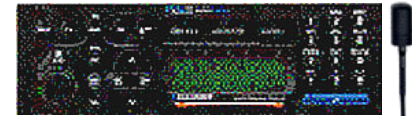
Mobile computing

- Mark Weiser, Xerox PARC CTO
- 1991, articulated vision for ubiquitous mobile computing, outlined issues
- ***Vision:*** *environment saturated with computing and communication capabilities, with humans gracefully integrated*
- Invisible hardware/software that assist human
- Weiser's vision was ahead of its time and available hardware and software
- For example, voice recognition was not available then
- Today, envisioned hardware and software is available

Mobile computing

- Applications:
 - **Vertical:** vehicle dispatching (trucks), package tracking (UPS), point of sale
 - **Horizontal:** collaborative computing, universal data/internet access, messaging systems, streaming multimedia, video conferencing, mobile games, interactive maps
- Mobile devices:
 - PDAs, laptops, cell phones, watches, etc
 - Limited hardware due to regulations, budget constraints (CPU, memory, disk space, battery, screen size)
- Wireless network: 802.11, cellular network (GSM), satellite (VSAT)
- Desirable attributes: convenience, flexibility, portability, productivity
- Favorable trends: more powerful devices, faster digital networks (voice, data, multimedia)

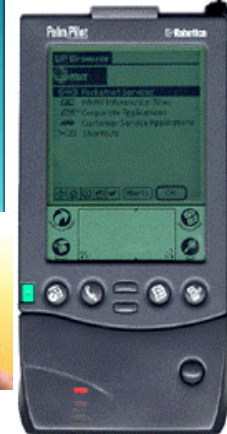
Mobile Devices



Car Stereo-Phone



Subscriber Identification Module (SIM)



CDPD Modem



Portable, mobile & ubiquitous computing

- Mobile users require different levels of connectivity
- Definitions:
 - ***Distributed computing***: system is physically distributed. User can access system/network from various points. E.g. Unix, WWW. (huge 70's revolution)
 - ***Portable (nomadic) computing***: user intermittently changes point of attachment, disrupts or shuts down network activities
 - ***Mobile computing***: continuous access, automatic reconnection
 - ***Ubiquitous (or pervasive) computing***: computing environment including sensors, cameras and integrated active elements that cooperate to help user
- Class concerned with last 3 (nomadic, mobile and ubiquitous)

Distributed Computing

- ***Distributed computing example:*** You, logging in and web surfing from different terminals on campus. Each web page consists of hypertext, pictures, movies and elements anywhere on the internet.
- **Note:** network is fixed, YOU move
- Issues:
 - Remote communication (RPC),
 - Fault tolerance,
 - Availability (mirrored servers, etc)
 - Caching (for performance)
 - Distributed file systems (e.g. Network File System (NFS))
 - Security (Password control, authentication, encryption)

Nomadic computing

- Nomadic computing... Nomads... ?



Nomadic Computing

- **Portable (nomadic) computing example:** I own a laptop. Plugs into my home network, sit on couch, surf web while watching TV. In the morning, wake up, un-plug, shut down, bring laptop to school, plug into WPI network, start up!
- **Note:** Network is fixed, except for your device and its point of attachment. You take your device with you!!
- Issues:
 - File/data pre-fetching
 - Caching (to simulate availability)
 - Update policies
 - Re-integration and consistency models
 - Operation queuing (e.g. emails while disconnected)
 - Mobile databases (fragments, objects may shared)
 - Resource discovery (closest printer while at home is not closest printer while at WPI)
- Note: much of the adaptation in “**middleware**” layer

Mobile/Ubiquitous Computing Examples

- **Mobile computing:** Sarah owns SPRINT PCS phone with web access, voice and short messaging. Remains connected while she drives from Worcester, Massachusetts to Compton, California
- **Note:** Network topology changes, because YOU and mobile users move. Network deals with changing node location
- Issues
 - Mobile networking (mobile IP, TCP performance)
 - Mobile information access (bandwidth adaptive)
 - System-level energy savings (variable CPU speed, hard disk spin-down, voltage scaling)
 - Adaptive applications: (transcoding proxies, adaptive resource management)
 - Location sensing (Using 802.11 signal strength)
 - Resource discovery (e.g. print to closest printer)

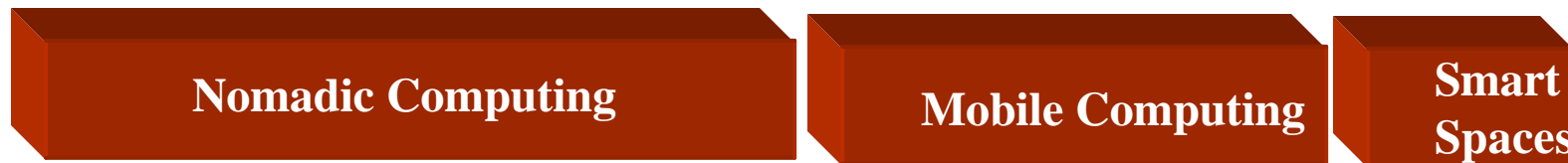
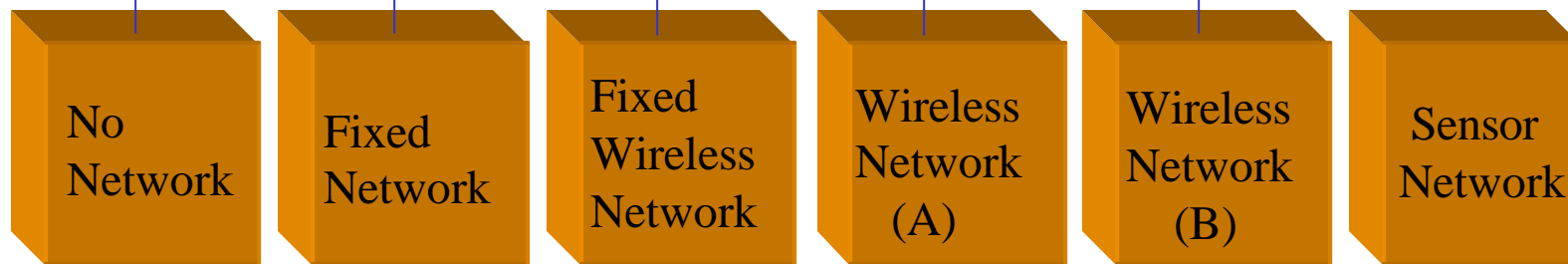
Mobile/Ubiquitous Computing Examples

- **Ubiquitous computing:** John is leaving home to go and meet his friends. While passing the fridge, the fridge sends a message to his shoe that milk is almost finished. When John is passing grocery store, shoe sends message to glasses which displays “BUY milk” message. John buys milk, goes home.
- **Note:** You may need an Aspirin for this one!!
- Issues:
 - Sensor design (miniaturization, low cost)
 - Smart spaces
 - Invisibility (room million sensors, minimal user distraction)
 - Localized scalability (more distant, less communication)
 - Uneven conditioning
 - Context-awareness (assist user based on her current situation)
 - Cyber-foraging (servers augment mobile device)
 - Self-configuring networks

Summary/Relationships

- Systems perspective: nomadic and mobile are *reactive*, ubiquitous is *proactive*
- Distributed systems + mobile computing research issues = mobile computing
- Mobile computing + pervasive computing issues = pervasive computing
- In this class, first part will be mobile/nomadic computing, then ubiquitous computing part

Portable, Mobile & Ubiquitous Computing



Mobile Computing Challenges

- Mobile Computing Issues:
 - Mobile device issues
 - Wireless networking issues
- Mobile device issues
 - Short battery lifetime (Lithium ion battery: 5 hrs max)
 - Limited hardware (display, memory, disk space, etc). E.g. wireless web designers use multiple large screens to design pages for cell phone PDA
 - Prone to theft and destruction
 - Unavailable (frequently powered-off)
 - Few standards (hardware, architecture, etc)

Advances in technology

- Advances in mobile device 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“)

Laptop Improvement

- Most resources increasing exponentially **except** battery energy (ref. Starner, IEEE Pervasive Computing, Dec 2003)

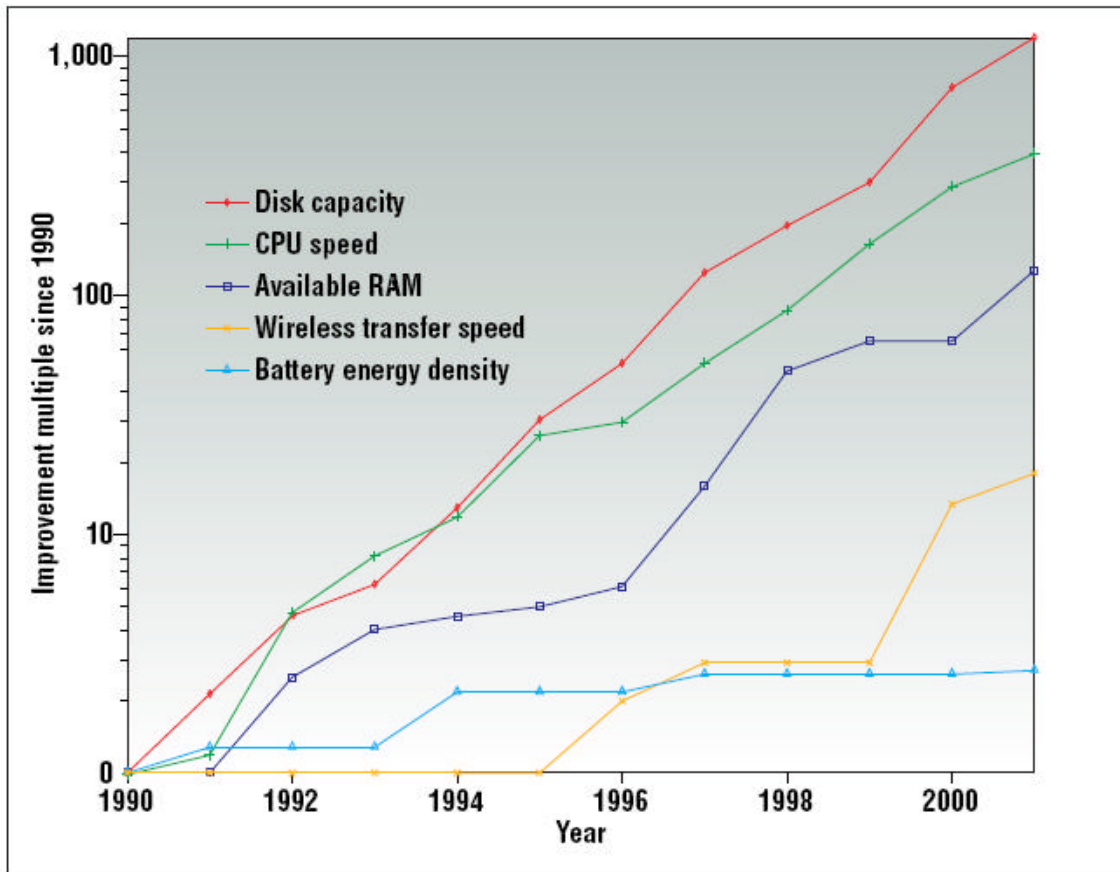


Figure 1. Improvements in laptop technology from 1990–2001.

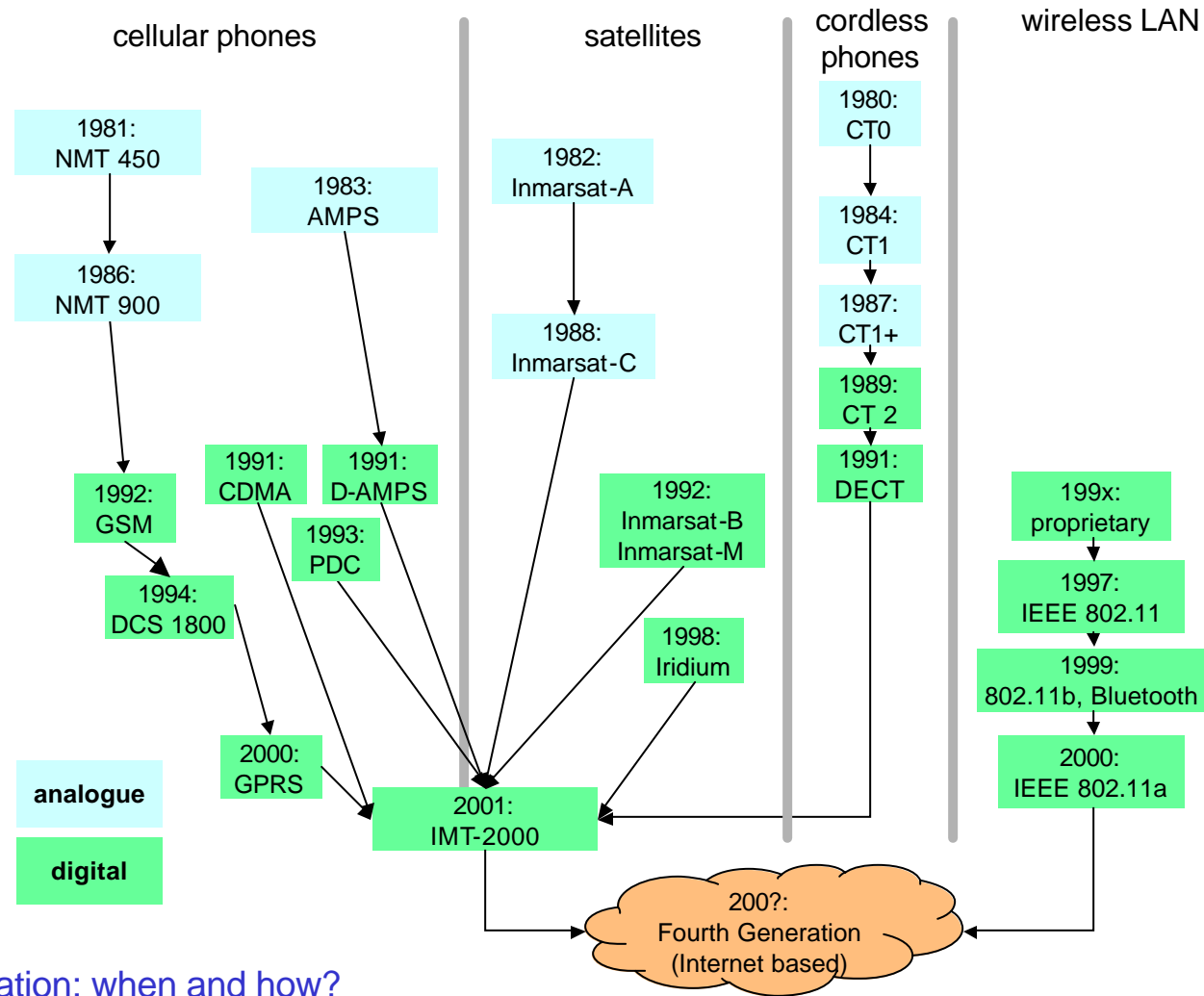
Network Backbones

- Developed countries (e.g. US, UK) have 4 main wide area telecommunications networks (or backbones)
 - Internet
 - Telephone
 - Cable television
 - Cellular phone
- Most are hierarchical: divided into **backbone** and **local loop**
- Only some of 4 exist in developing nations?
- Internet is main computing backbone
- Major companies/universities directly on Internet
- Small companies/residential use other local loops to access internet (currently analog)
- Result: huge trend towards making making other local loops digital, carry data (e.g. ADSL, cable modem, wireless local loop)

Wireless Networks Types

- **Cellular Network:** Wide area wireless network operated by Sprint, Verizon, AT&T, etc. 1G (analog), 2G today's network, 3G coming, 4G (in some labs)
- **WLANs:**
 - **Infrastructure networks:** wired backbone (Internet), wireless last hop. E.g WPI wireless LAN, **New:** mesh networks
 - **Ad hoc networks:** all wireless, no backbone, no order known in advance. E.g. few deployed examples..
.futuristic
- **Sensor networks:** self-organizing network of large numbers of cooperating sensors deployed inside phenomenon. E.g. even more futuristic. Many research projects

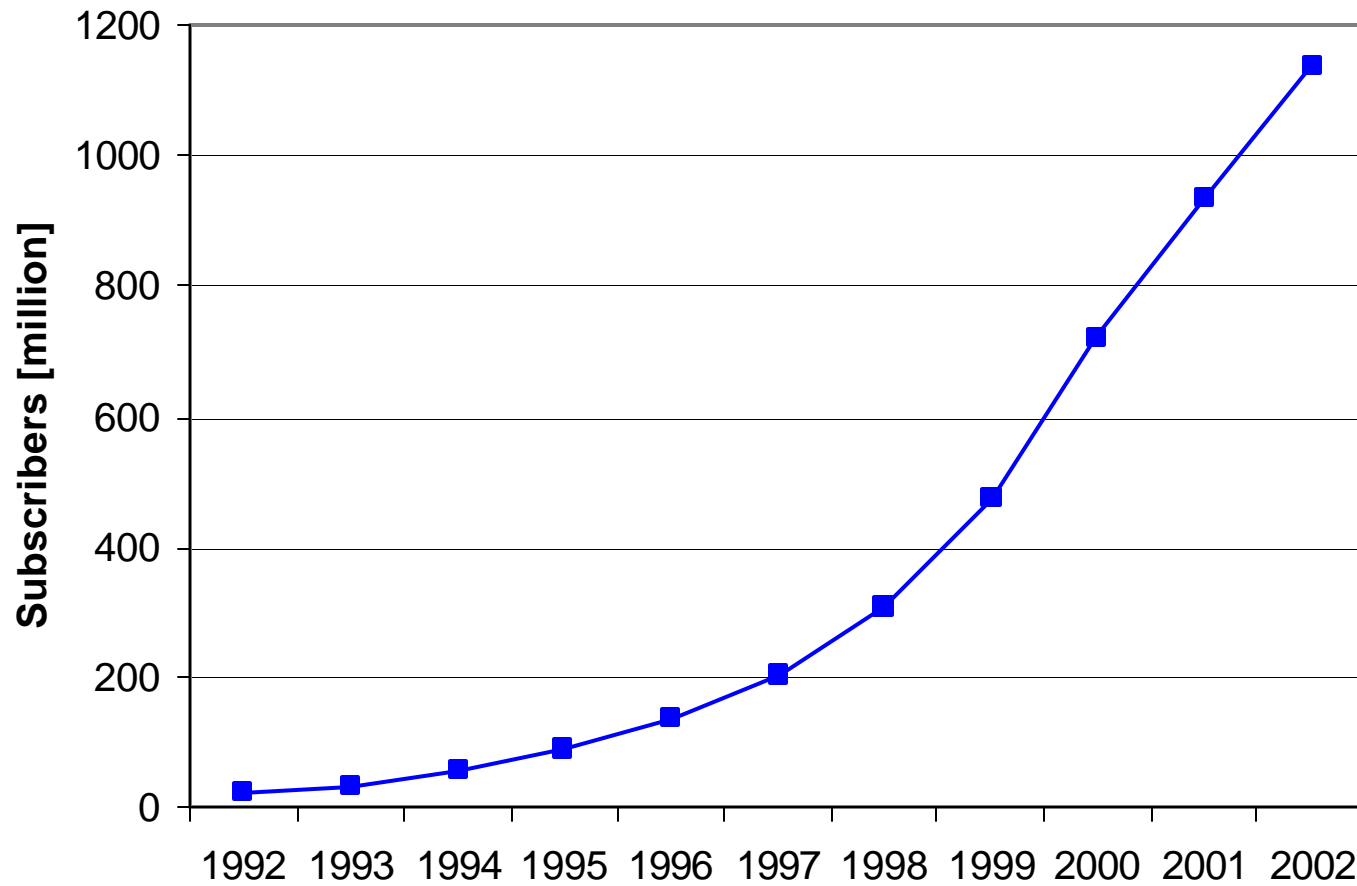
Wireless systems: evolution



4G – fourth generation: when and how?

Ref: Mobile Communications, 2nd edition

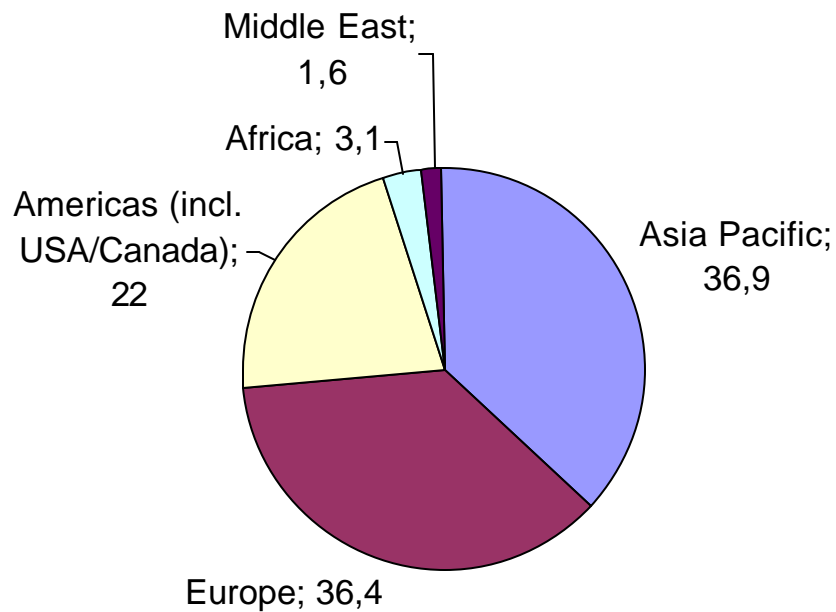
Worldwide cellular subscriber growth



Note that the curve starts to flatten in 2000 – 2004: 1.5 billion users

Ref: Mobile Communications, 2nd edition

Cellular subscribers per region (June 2002)



2004: 715 million mobile phones delivered

Ref: Mobile Communications, 2nd edition

Wireless Networking Challenges

- Wireless networking issues
 - Wireless spectrum scarcity (regulated)
 - Low bandwidth, asymmetric, heterogeneous
 - Higher error rates (10^{-3}):
 - multipath fading, noise (engines, microwaves), echos...
 - **Note:** indoor channel is different from outdoor
 - Higher delays, higher jitter
 - Connection time: secs for GSM, $> 0.1s$ other wireless
 - Moving users:
 - Uncontrolled cell population, variable link quality
 - Different points of attachment to network
 - Frequent network disconnections (cell phone)

Wireless Networking Challenges

- Wireless networking issues (contd)
 - Less secure and less robust
 - (e.g. signal leakage)
 - More easily stolen, tampered with (drunk employees)
 - Shared medium
 - Who's turn to transmit, etc
 - Tough to guarantee Quality of Service (QoS)

Our Assumed Networking Model

- Adopt 5-layer (not 7 OSI):
 - application : WAP, email, etc
 - Transport
 - Network
 - data link
 - physical layer: wireless
- CS approach
 - Start with applications
 - Initially only minimalist PHY abstraction
 - Later (at end), we will talk about PHY in detail (encoding, modulation, antennas, radio propagation models, etc)

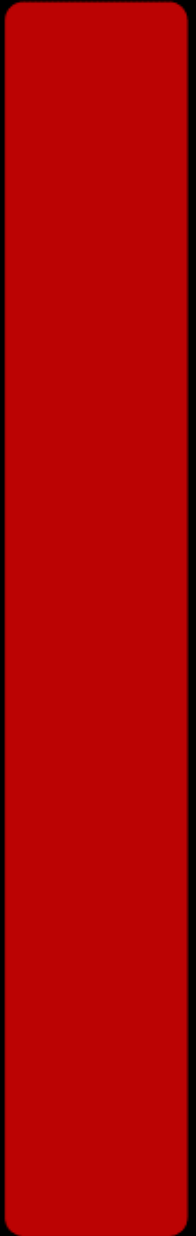
Application

Transport

Network

Data Link

Physical



Wireless Application

- Applications: emergencies, vehicles, traveling salesman, entertainment, education, etc.
- Mobile data (Broadcast disks):
 - Wireless channel is broadcast in nature
 - 1 person talks, everyone hears
 - Take advantage for streaming data (e.g. stock quotes)
- Wireless/mobile standards
 - Wireless web: iMode, Wireless Access Protocol (WAP)
 - Wireless messaging: e.g. SMS: cheaper, new standards
 - MPEG-4 has wireless features in encoding
 - Scalable Vector Graphics (SVG): bit-mapped to vector graphics move
 - J2ME: Reduce Java Virtual Machine (JVM) to essentials

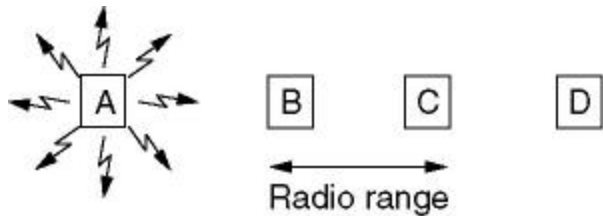
Physical Layer

- Too many gadgets want wireless spectrum: garage openers, radio stations, WLAN, etc
- FCC allocates wireless spectrum: some licensed, some unlicensed. E.g Radio 94.5FM licensed
- Industrial, Scientific and Medical (ISM) Bands:
 - FCC solves demand problems by lumping many users into ISM bands (900MHz, 2.4GHz, 5.5GHz)
 - Each country decides its ISM bands. Only 2.4GHz worldwide
 - WLANs use ISM bands
 - Interference between devices can be a problem: use spread spectrum
 - FCC previously mandated spread spectrum in ISM bands, dropped this in 2002
 - Result? My home phone now interferes with WLAN

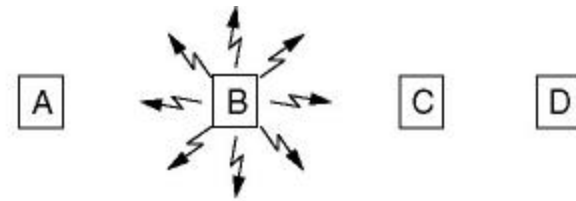
MAC Sub-Layer Issues

- Medium Access Control (MAC) layer is first protocol layer above unreliable wireless medium
- Need to perform medium access function while compensating for wireless channel
- PHY layer effects on MAC:
 - Channel: slow, asymmetric, time-varying (fading)
 - Errors: random and burst
 - Location-dependent carrier sensing
 - Hidden Terminal
 - Exposed Terminal
 - Capture effect

Hidden/Exposed Terminal



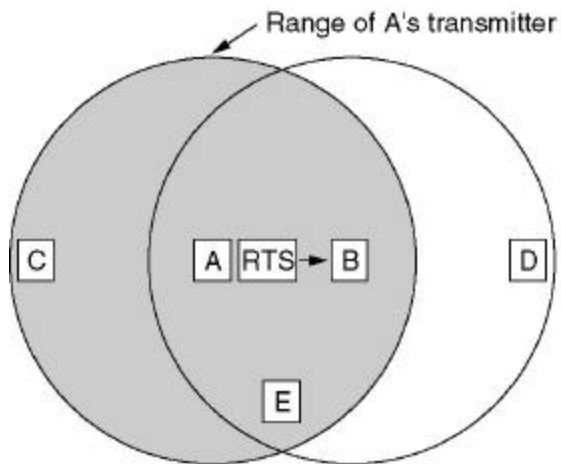
(a)



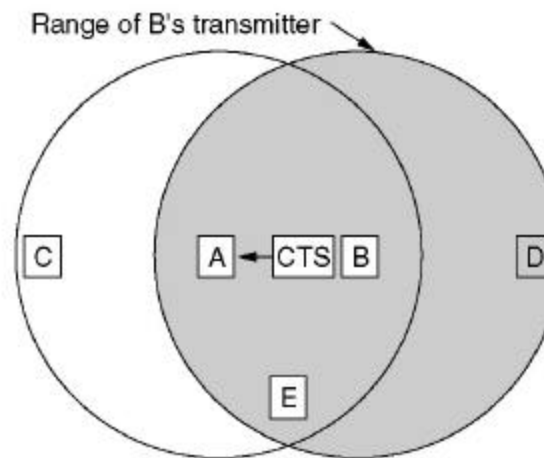
(b)

(a) Hidden station problem.

(b) Exposed station problem.



(a)



(b)

RTS-CTS handshake before starting transmission solves hidden terminal, called **Collision Avoidance**

MAC Sub-Layer

- Why not use old MAC standards like Ethernet?
 - Ethernet (**CSMA/CD**) detects collision by measuring voltage levels. Wireless MAC cannot rely on this because of presence of high atmospheric noise
 - Token-based protocols are bad idea because token easily lost
 - Centralized protocols like polling mean arbiter is always on, preferably wired, one point of failure (battery, jamming, etc)

802.11 MAC Sub-Layer

- What techniques are used in wireless MACs?
- 2 main standards:
 - IEEE 802.11
 - European HiperLAN-2
- 802.11:
 - Infrastructure: uses Access Points (AP), or ad hoc
 - Distributed MAC protocol (CSMA/CA)
 - RTS-CTS-DATA-ACK packet sequence (ACKs each pkt)
 - Retransmit if error occurs
 - If collisions: exponential backoff algorithm like Ethernet
 - Priority scheme: different wait periods for different types of packets, traffic called **Interframe Space (IFS)**. E.g. ongoing conversation (CTS, DATA, fragment) < new multimedia traffic < non-multimedia new traffic
- ***New area: Mesh networks***

Network Layer Issues

- Routing is key issue in network layer
- Original IPv4 did not consider mobile nodes
- Would like mobile nodes to roam without service disruption
- Mobile IP (RFC 2002) fixes IP problems with mobile nodes in infrastructure networks including:
 - Addressing
 - Security
 - Route inefficiencies
- Addressing:
 - Each IP address associated with fixed network location. E.g. 130.215.36.150 is *ccc.wpi.edu*.
 - What if mobile user with IP address 130.215.36.90 took laptop to Apple conference in California?

Mobile IP

- Mobile IP assigns mobile host 2 addresses: ***fixed home address*** and ***care-of-address*** which changes with new networks
- Analogy? PO or friend forwards mail
- TCP uses ***fixed home address***
- IP needs IP of new mobile host network, uses ***care-of-address***
- ***Home agent*** in home network
 - a. receives packets addressed to *fixed home address*,
 - b. encapsulates it in new packet with care-of-address and
 - c. forwards it to *foreign network (tunneling)*
- Mobile host does ***reverse encapsulation*** in foreign network so that its TCP connections still work well
- Mobile host has to *register* new care-of-address anytime it moves

Ad Hoc Routing

- Fixed networks use shortest path routing metric
- Shortest path has different meaning in ad hoc networks. Why?
 - Nodes are constantly moving
 - Link quality and node availability vary quickly
 - In general, highly mobile node should be avoided as intermediate node
- New ad hoc routing metrics: link delay, signal strength, power life, route relaying load
- Research issues: QoS, power, multicast awareness

Transport Layer Issues

- Transport layer concerned with end-to-end data transmission
- TCP assumes all timeouts caused by congestion
- Why? Before wireless congestion more likely
- Philosophically, congestion action is to ***decrease transmission***, wait longer (increase congestion window)
- Wireless errors, MAC collisions require opposite = ***increase transmission***
- TCP will work unmodified for wireless, however huge ***performance*** penalties

Transport Layer

- Wireless transport layer strategies:
 - Link layer strategies: FEC, base station agent that caches quickly retransmits packets, inform TCP of wireless loss
 - Split connections: 1 TCP connection for wireless (short RTT timer), 1 TCP for wired (longer RTT timer), violates semantics
 - Receiver/Sender discrimination: try to infer congestion/wireless loss from packet inter-arrival time pattern
- ***New area: Delay-tolerant networks***

Wireless Security

- Wireless signals leak beyond building confines
- Mobile devices designed to be carried around=> more prone to theft or misplacement
- Mobility: tracking perpetrators is hard
- Security standards like Wireless Encryption Protocol (WEP) have significant demonstrated flaws
- Anderson: over 90% of security breaches caused by lapses in physical security:
- **Example:** drunk employee at bar with laptop

Wireless Security Areas

- Cryptography (low power, strong enough, etc)
- Enforcing confidentiality (preventing traffic analysis, etc)
- Key Management
- Authentication mechanisms
- Intrusion detection
- Tamper-proof hardware
- Protocol (e.g 802.11) vulnerabilities:
 - **Rogue APs:** Attacker inserts access point, hijacks mobile nodes
 - **Jamming:** ISM bands prone to that, microwaves, etc
 - **Induce congestions, collisions:** Induce collisions, congestion, disobey protocol. Delay bad for multimedia
 - **Exhaustion:** Keep sending packets to wireless node, prevent sleep modes, drain battery, DoS
 - **Packet header manipulation:** e.g sequence/ACK Nos.

Ubiquitous Computing

- Mobile computing deals mostly with passive network components
- Human simply provided universal, seamless network connectivity
- Human does all the work, initiates all network traffic!!
- Ubiquitous computing introduces collection of specialized assistants to assist human in simple defined tasks
- Networked array of active elements, sensors, software agents, artificial intelligence
- Ubiquitous computing builds on *distributed systems* and *mobile computing*

Sensors and Smart Spaces

- Sense what?
 - **Human:** motion, mood, identity, gesture
 - **Environmental:** temperature, sound, light/vision, humidity
 - Location
- Environmental is easy, simply integrate
- Human is a little harder
 - **Where:** location (easiest):
 - **Who:** Identification
 - **How:** (Mood) happy, sad, bored (gesture recognition)
 - **What:** eating, cooking (meta task)
 - **Why:** reason for actions (extremely hard!)
 - **Note:** Human-related (gesture, mood, etc) easier with cameras than sensors
- Work in smart office, smart kindergarten, smart office, etc

Sensor Node

- 1000s per room
- low power, multifunctional, low cost (\$1 per sensor?)
- Sensing, data processing, communication
- Senses specific phenomenon, minimal processing and sends results to a sink node
- Small OS, programmable
- Also: new RFID tag push



(courtesy of MANTIS project, U. of Colorado)

Sensor Networking

- Sensor network is similar to ad hoc network with few differences:
 - Many more network nodes
 - Sensor nodes are densely deployed
 - Deployment? Throw a bunch into phenomenon
 - Sensors are prone to failure
 - Many nodes => topology change likely
 - Sensor nodes use broadcast, ad hoc networks tend to be point-to-point
 - Sensor nodes more limited power, CPU, etc
 - Globally distinct ID (IP address) not feasible because of number of nodes

Sensor Protocol Stack

- Sensor network impacts different layers
- Some issues such as power management permeate multiple layers
- Sensor PHY layer
 - similar to ad hoc network
 - sensor hardware design getting more mature
- Sensor MAC layer
 - Still perform media access
 - Add self-organizing: Initially (throwing) and if nodes go down
 - Even better resource management (power, bandwidth)

Sensor Network Layer

- Distinguish between your traffic and other (routing) traffic
- If you are already committed to helping, good sensor node may drop its own packets!!
- Multiple optimal routes:
 - Maximum power available route
 - Minimum energy route
 - Minimum hop route, etc
- Sensor router may do minimal processing to aggregate packets from multiple nodes
- Attribute-based naming instead of IP address. E.g. “***all nodes in region with temp over 70 degrees***” better than temp reading or IP address

Sensor Transport Layer

- Almost no work on sensor transport layer
- Split connections may be promising
- ACKs too expensive for sensor network
- Attribute-based naming replaces IP addresses
- Dynamic/self set-up, currently human configures all network nodes

Homework

- Go home
- Scan papers for each week
- Decide which ones you would like to present
- Next week, we will sign up for talks
- Procedure: we will pass around paper, simply sign
- Project? Never too early to start thinking about project, talking to me.