CS 525M – Mobile and Ubiquitous Computing Class

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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/](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

- Subscriber Identification Module (SIM)
- CDMA Modem
- Car Stereo-Phone
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 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
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 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 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

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, 2\textsuperscript{nd} edition
Cellular subscribers per region (June 2002)

- Asia Pacific: 36.9
- Europe: 36.4
- Americas (incl. USA/Canada): 22
- Africa: 3.1
- Middle East: 1.6

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)
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 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
(a) Hidden station problem. 

(b) Exposed station problem.

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 provides 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.