Wireless & Mobile Networking

CS 752/852 - Spring 2011

Tamer Nadeem
Dept. of Computer Science
Course Logistics
Welcome to CS 752/852

- **Timings:** M/W 5:45pm to 7:00pm
- **Location:** E&CS 2120
- **Instructor:** Tamer Nadeem
  Ph.D from Univ. of Maryland, 2006
  Research in Networks, Dist Sys, Mobile Comp.
  Email: nadeem@cs.odu.edu
  Office: E&CS Building 3204
- **Office Hours:** M/W 3:00pm to 4:30pm, or by appointment
Welcome to CS 752/852

• Prerequisites: CS 450/550

  Else, see me

• Grading:

  • Class Presentation/Participation: 30%
  • Mid-term exam: 30%
  • Semester-long project: 40%
Welcome to CS 752/852

• Class Webpage:
  • http://www.cs.odu.edu/~cs752/
  • Please check course website frequently

• Make up classes:
  • Will be occasionally necessary due to travel
  • Fixed schedule versus case by case basis?
Course Introduction
Brief history of wireless communications

• In the old days: smoke signals, carrier pigeons, etc
• Radio invented by G. Marconi in the 1880s
• Between then and now:
  • Radio
  • TV
  • Mobile Phones
  • Satellite

• By 1920s Chicago police cars equipped with push-to-talk radios
• In the 1970’s Packet Radio Networks (PRN) used in military applications
• Since 1988 cellular systems have seen exponential growth, with more than 3 billion users worldwide
  ▪ triggered the wireless revolution
  ▪ voice, data and multimedia becoming ubiquitous
  ▪ use in third world countries growing rapidly
Shifting Trends

• The edge of the internet becoming wireless

  • Single hop networks

  • Multi-hop networks
Many Benefits due to Wireless

• **Significantly lower cost**
  - No cable, low labor cost, low maintenance

• **Ease**
  - Minimum infrastructure - scatter and play

• **Unrestricted mobility**
  - Unplugged from power outlet

• **Ubiquity**
  - Available like water/electricity - holy grail
Wireless and Mobile Networking

• Driven by technology and vision
  • wireless communication technology
  • global infrastructure
  • device miniaturization
  • mobile computing platforms

• The field is moving fast

• “People and their machines should be able to access information and communicate with easily and securely, in any medium each other or combination of media – voice, data, image, video, or multimedia – any time, anywhere, in a timely, cost-effective way.”, Dr. G. H. Heilmeier, Oct 1992

• “The mobile device will be the primary connection tool to the Internet for most people in the world in 2020.”, PEW Internet and American Life Project, Dec. 2008
Applications of wireless communications

- Telemedicine
- Distance learning/remote education
- E-911 + Search-and-rescue
- Law-enforcement
- Process/health monitoring
- Location-specific services
- Surveillance
- Combat support
- You name it!
Wireless at Home/Office
Wireless on Move

Source: http://www.ece.uah.edu/~jovanov/whrsms/
Wireless on Road

- GSM/UMTS
- cdmaOne/cdma2000
- WLAN, GPS
- DAB, TETRA, ...

- road condition,
- weather,
- location-based services,
- emergency

Ad hoc connections between vehicles.
Wireless biomedical systems

- In-body wireless devices
  - sensors/monitoring devices
  - drug delivery systems
  - medical robots
  - neural implants

Wireless telemedicine

Recovery from nerve damage

EHR
Telemedicine
Specialist Network
Physician
Diagnostic Station
Patients
Habitat monitoring
Supply chain management
Mobile Social Networking

Microsoft KIN
Why are wireless networks different?

• Here are a few reasons
  • open communication medium
  • radio signals spread through the environment in contrast with wired communications
  • user mobility – changing topology
  • lack of centralized control
  • mobile users are easily compromised
  • cooperative/distributed algorithms and protocols

• Protocols developed for wired networks often do not apply to wireless
  • Unreliable and Unpredictable Wireless Coverage - vary over time and space
  • Open Wireless Medium – Interference, Hidden Node, Exposed Nodes, Security
  • Mobility - poor-quality wireless links, intermittent connection, changes context
  • Portability - Limited battery power, Limited processing, display and storage
So, what does it take for that mobile/wireless future to become feasible?
Research Challenges

Applications that exploit ubiquity and mobility. Challenges underlying such applications

- Ubiquitous Services
- Incentives
- Loss Discrimination
- Energy Savings
- Spatial Reuse
- Application
  - Security
  - Transport
  - Network
  - MAC / Link
  - PHY
- Privacy
- Eavesdropping
- Mobility
- Interference Mgmt.
- Channel fluctuations

Enabling wireless ubiquity. Showing what is feasible, and what is not …
Course Overview
This Course

• Introduces fundamentals and applications of wireless and mobile networking

• Exposes implications on protocol design
  • At MAC, Network, Transport, Security
  • Investigates gap between idea and actual system
  • Considers theoretical aspects

• Envisions new mobile computing applications
  • Identifies challenges underlying them
  • Resolves these challenges into a full system solution
At the End of this Course …

• You understand
  • Physical layer (radios, rate, antennas, channels)
  • MAC protocols (who gets the chance to talk)
  • Routing (path selection algorithms and issues)
  • Reliability (wireless congestion control, rate control)
  • Applications (social networks, personal networks, P2P)
  • Human sensing, Urban sensing
    • Localization (extracting the location of a device)
    • Mobility (how it helps and disrupts communication)
    • Interfaces (phones are more than communication devices)
    • Privacy (how to protect a user from being tracked)
  • Energy-awareness (how it percolates various network functions)
  • Emerging Topics (interference cancellation, multicast, rural nets)
  • Capacity (what is feasible, what are performance bounds)
What this Course Does Not Cover

• Not a wireless communications course

• Does not cover
  • Modulation schemes
  • Transmitter/Receiver design
  • Signal processing and antenna design
  • Source coding / channel coding
  • Etc.

• This is course on
  • Design, analysis, and implementation of protocols and algorithms in (mobile) wireless network systems
Course Responsibilities

• I will present most lectures and papers
  • You present 1-2 in entire semester (30 minutes)
  • 2 students present in one class

• For every class, read assigned papers
  • Write reviews for each and email me before class
  • Bring printed copy to class

• Several recommended readings
  • Make an effort to read them
  • I understand that you cannot do so always
Course Structure

• 1 mid term, No Final Exam
  • Tentative date of mid-term: Mid march after Spring break

• Semester-long class project
  • In groups of 2 (max 3).
    • Individual projects are allowed by permission
  • Focus on this from early on

• Class ends with a final project poster/demo
  • Submit conference-style paper
Class Participation / Presentation, Reading Assignment, and Course Project
Participation / Presentation

• Ask lots of questions. Period.
  • I strongly encourage you to ask, disagree, debate

• Class presentation
  • You present 1-2 paper (30 minutes)
  • Check class schedule by next week for reading papers
  • Pick an open slot (check class schedule)
    • Earlier you pick, more options you have to choose from
    • Deadline is Jan 28, 2011

• Email me your choice of paper (and date)
  • Don’t worry about not knowing the topic of paper
    • By that time, you will know enough
Reading Assignment

• **Read the papers assigned for reading**
  • Critic / Review them carefully
  • Reviews should not be more than a page
  • Hints on how to review a paper on class webpage

• **Email me your reviews before the beginning of the class.**
  • Bring a hardcopy with you to the class.
Thoughts on Reading Papers

• Know why you are reading the paper
  • Reading for absorbing concepts (class assignment)
    • Read fully, think, reread, ask, challenge
  • Reading for excitement (deciding project topic)
    • Read initial parts, don’t try to understand everything, get a feel
  • Reading for problem identification
    • Read the problem carefully
  • Reading to discriminate (before finalizing project)
    • Read solution, ensure your ideas different, analyse performance
Course Research Projects

• Goal: obtain hands-on experience

• Initial proposal due 1 before Spring break + 1-page progress report every 2 weeks (due Friday night) + final report + [presentation]

• Projects consist of 3 parts:
  • Problem identification
  • Solution design
  • Performance evaluation

• Each paper you read is someone’s project
  • Many papers are actually student’s class projects
  • Read them critically
  • Ask yourself
    • Is the problem really important? Should you care?
    • Is the solution sound? Under what assumptions? Do you have other (better) ideas?
    • Is evaluation biased? Are results shown only in good light?
More on Projects

• Discuss your thoughts, ideas with me
  • They need not be cooked, and can have many flaws
  • Statistically, every 18 ideas lead to one decent idea

• If you like an area / direction
  • Read many many related papers

• Don’t try to come up with a quick solution
  • Ensure your problem is a new, real problem
  • Finding the solution is typically easy
More on Projects

- Protocol evaluation typically requires coding
  - Think what you would like to do
  - Options are:
    - Coding on real devices (like sensors, phones, routers)
    - Coding in existing network simulators (ns2, Qualnet, etc.)
    - Coding your own simulator
    - Theoretical projects involve MATLAB, CPLEX, etc.

- Project ideas take time … think now and then
  - Spending 3 hours for 10 days better than 10 hours for 3 days
More on Projects

• Find a project partner early
  • Discuss reviews, papers (e.g., Mobicom, Mobihoc, Mobisys, INFOCOM), potential project themes

• Class project often bottlenecked by platform
  • Think of the evaluation platform during project selection
  • If you are not familiar with the Linux OS, it’s a bad idea to do a project involving router-programming
Some Closing Thoughts

• This class is about research
  • Be active, ask questions, debate, and disagree

• Don’t worry too much about grades
  • It does not matter as much as you think

• Read a lot - this is a hot research area
  • If you are hunting for MS/PhD area, read even more

• Interact with me
  • Even if you have ZERO clue of what’s going on
Questions?
INTRODUCTION
The OSI Communication Model
The OSI Communication Model

**Application Layer**
- Facilitates communication between software applications like Outlook, IE

**Presentation Layer**
- Data Representation and Encryption

**Session Layer**
- Interhost Communication

**Transport Layer**
- End-to-End connection and reliability

**Network Layer**
- Path determination and logical addressing

**Data Link Layer**
- MAC and LLC – Physical Addressing

**Physical Layer**
- Media, signal and binary transmission

**OSI MODEL**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Type of communication: E-mail, file transfer,</td>
</tr>
<tr>
<td></td>
<td>client/server.</td>
</tr>
<tr>
<td>Presentation</td>
<td>Encryption, data conversion: ASCII to EBCDIC,</td>
</tr>
<tr>
<td></td>
<td>BCD to binary, etc.</td>
</tr>
<tr>
<td>Session</td>
<td>Starts, stops session. Maintains order.</td>
</tr>
<tr>
<td>Transport</td>
<td>Ensures delivery of entire file or message.</td>
</tr>
<tr>
<td>Network</td>
<td>Routes data to different LANs and WANS based on</td>
</tr>
<tr>
<td></td>
<td>network address.</td>
</tr>
<tr>
<td>Data Link</td>
<td>Transmits packets from node to node based on</td>
</tr>
<tr>
<td>(MAC) Layer</td>
<td>station address.</td>
</tr>
<tr>
<td>Physical Layer</td>
<td>Electrical signals and cabling.</td>
</tr>
</tbody>
</table>
The OSI Communication Model

Node A → Node B

1: Physical Layer
2: Data Link Layer
3: Network Layer
4: Transport Layer
5: Session Layer
6: Presentation Layer
7: Application Layer

Data Transmission

System 1 to System 2

Logical Connection in each Layer

Realisation of the communication
The OSI Communication Model

Diagram showing the layers of the OSI model with icons for Application, Presentation, Session, Transport, Network, Data Link, Physical, and Network layer communication.
Overview of Current Wireless Technologies
Current wireless systems

- Wireless LANs
- Cellular systems
- **WiMAX**: Worldwide Interoperability for Microwave Access
- Satellite systems
- Zigbee
- Bluetooth
- Ultra-wideband radios
Wireless LAN

- WLANs connect local nodes (≈100m range)
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
- Poor performance in some apps (e.g. video)
Wireless LAN Standards

- **IEEE 802.11**: The WLAN standard was originally 1 Mbit/s and 2 Mbit/s, 2.4 GHz RF and infrared [IR] standard (1997), all the others listed below are Amendments to this standard, except for Recommended Practices 802.11F and 802.11T.
  - **IEEE 802.11a**: 54 Mbit/s, 5 GHz standard (1999, shipping products in 2001)
  - **IEEE 802.11b**: Enhancements to 802.11 to support 5.5 and 11 Mbit/s (1999)
  - **IEEE 802.11c**: Bridge operation procedures; included in the IEEE 802.1D standard (2001)
  - **IEEE 802.11d**: International (country-to-country) roaming extensions (2001)
  - **IEEE 802.11e**: Enhancements: **QoS**, including packet bursting (2005)
  - **IEEE 802.11g**: 54 Mbit/s, 2.4 GHz standard (backwards compatible with b) (2003)
  - **IEEE 802.11h**: Spectrum Managed 802.11a (5 GHz) for European compatibility (2004)
  - **IEEE 802.11i**: Enhanced security (2004)
  - **IEEE 802.11j**: Extensions for Japan (2004)
  - **IEEE 802.11k**: Radio resource measurement enhancements (2008)
  - **IEEE 802.11n**: Higher throughput improvements using MIMO (multiple input, multiple output antennas)(2009)
  - **IEEE 802.11p**: WAVE—Wireless Access for the Vehicular Environment (e.g, ambulances and passenger cars) (2010)
Wireless LAN Standards

- **IEEE 802.11r**: Fast BSS transition (FT) (2008)
- **IEEE 802.11s**: Mesh Networking, Extended Service Set (ESS) (~ June 2011)
- IEEE 802.11T: Wireless Performance Prediction (WPP)—test methods and metrics Recommendation cancelled
- **IEEE 802.11u**: Interworking with non-802 networks (for example, cellular) (~ Dec 2010)
- **IEEE 802.11v**: Wireless network management (~ Dec 2010)
- **IEEE 802.11w**: Protected Management Frames (2009)
- **IEEE 802.11y**: 3650–3700 MHz Operation in the U.S. (2008)
- **IEEE 802.11z**: Extensions to Direct Link Setup (DLS) (September 2010)
- IEEE 802.11mb: Maintenance of the standard. Will become 802.11-2011. (~ Dec 2011)
- **IEEE 802.11aa**: Robust streaming of Audio Video Transport Streams (~ Mar 2012)
- **IEEE 802.11ac**: Very High Throughput <6 GHz; potential improvements over 802.11n: better modulation scheme (expected ~10% throughput increase); wider channels (80 or even 160 MHz), multi user MIMO; (~ Dec 2012)
- **IEEE 802.11ad**: Very High Throughput 60 GHz (~ Dec 2012)
- **IEEE 802.11ae**: QoS Management (~ Dec 2011)
- **IEEE 802.11af**: TVWhitespace (~ Mar 2012)
- **IEEE 802.11ah**: Sub 1Ghz (~ July 2013)
- **IEEE 802.11ai**: Fast Initial Link Setup
- ????????
Wireless LAN standards

- **802.11b**
  - standard for 2.4GHz ISM band (80 MHz)
  - direct sequence spread spectrum (DSSS)
  - speed up to 11 Mbps ≈ 100 meters range

- **802.11a/g**
  - standard for 5GHz NII band (300 MHz)
  - OFDM in 20 MHz with adaptive rate/codes
  - speed up to 54 Mbps, ≈ 100-200 ft range

- **802.11n**
  - standard in 2.4 GHz and 5 GHz band
  - adaptive OFDM /MIMO in 20/40 MHz
  - speed up to 600Mbps, ≈ 200 ft range

<table>
<thead>
<tr>
<th></th>
<th>802.11a</th>
<th>802.11b</th>
<th>802.11g</th>
<th>802.11n</th>
</tr>
</thead>
<tbody>
<tr>
<td>approved by</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEEE</td>
<td>October 2000</td>
<td>December 1999</td>
<td>June 2003</td>
<td></td>
</tr>
<tr>
<td>Maximum data</td>
<td>54 Mbps</td>
<td>11 Mbps</td>
<td>54 Mbps</td>
<td>600 Mbps</td>
</tr>
<tr>
<td>rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different data</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td>576</td>
</tr>
<tr>
<td>rate configurations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical range</td>
<td>75 feet</td>
<td>100 feet</td>
<td>150 feet</td>
<td>150 feet</td>
</tr>
<tr>
<td>Modulation</td>
<td>OFDM</td>
<td>DSSS, CCK</td>
<td>DSSS, CCK, OFDM</td>
<td>DSSS, CCK, OFDM+</td>
</tr>
<tr>
<td>technologies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RF band</td>
<td>5 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz and 5 GHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Up to 4</td>
</tr>
<tr>
<td>spatial streams</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and antennas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel width</td>
<td>20 MHz</td>
<td>20 MHz</td>
<td>20 MHz</td>
<td>20 MHz or 40 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of</td>
<td>23</td>
<td>3</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>channels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cellular Systems

Trend: everything wireless in one small device
Basic Cellular Architecture

- **Mobile Station (MS)**: the user terminal is that is made up of a SIM (Subscriber Identity Module) card allowing the user to be uniquely identified, and a mobile terminal, in other words the user device (normally a portable telephone).

- **Base Station (BS/BTS)**: a fixed station in a cellular system used for radio communication with the mobile stations. Base stations are located at the center of a coverage region. They consist of radio channels and transmitter and receiver antennas mounted on top of a tower.

- **Base Station Controller (BSC)**: all BS are connected to a BSC, which is responsible for managing distribution of the resources. The system consisting of BSC and its connected BSs is called the **Base Station Subsystem (BSS)**.

- **Mobile Switching Center (MSC)**: coordinates the routing of calls in a large service area. The MSC connects the base stations and the mobiles to the telephone network.
Cellular System Definitions

- **Control channel:** radio channel used for transmission of call setup, call request, call initiation and other beacon and control purposes
- **Forward channel:** frequency channel used for transmission of information from the base station to the mobile
- **Reverse channel:** frequency channel used for transmission of information from mobile to base station
- **Simplex systems:** communication systems that provide only one-way communication
- **Half-duplex systems:** communication systems that allow two-way communication by using the same radio channel for both transmission and reception. At any given time, the user can either transmit or receive information
- **Full-duplex systems:** communication systems that allow simultaneous two-way communication. Transmission and reception is typically on two different channels
- **Handoff:** the process of transferring a mobile station from one channel or base station to another.
- **Roaming:** a mobile station which operates in a service area (market) other than that from which service has been subscribed
- **Page:** brief message which is broadcast over the entire service area, usually in simulcast fashion by many base stations at the same time
Cellular Challenges

• Key idea: reuse channels to maximize capacity
• Geographic region divided into cells
• Frequency/timeslots/codes/ reused at spatially-separated locations
• Co-channel interference between same color cells
• Base stations/MSCs coordinate handoff and control functions
• Shrinking cell size increases capacity, as well as networking burden
Generations of cellular networks

• **First Generation**
  • Analog Systems
  • Analog Modulation, mostly FM
  • AMPS
  • Voice Traffic
  • FDMA/FDD multiple access

• **Second Generation (2G)**
  • Digital Systems
  • Digital Modulation
  • Voice Traffic
  • TDMA/FDD and CDMA/FDD multiple access

• **2.5G**
  • Digital Systems
  • Voice + Low-datarate Data

• **Third Generation (3G)**
  • Digital
  • Voice + High-datarate Data (384 Kbps)
  • Multimedia Transmission also
4G Cellular: what can you expect?

- OFDM/MIMO
- Much higher data rates (50-100 Mbps)
- Greater spectral efficiency (bits/s/Hz)
- Flexible use of up to 100 MHz of spectrum
- Low packet latency (<5ms).
- Increased system capacity
- Reduced cost-per-bit
- Support for multimedia
WiMAX (802.16)

- Wide area wireless network standard
  - system architecture similar to cellular
  - hopes to compete with cellular
- OFDM/MIMO is core link technology
- Operates in 2.5 and 3.5 MHz bands
  - different for different countries, 5.8 MHz also used
  - bandwidth is 3.5-10 MHz
- Fixed (802.16d) vs. Mobile (802.16e) WiMAX
  - fixed: 75 Mbps max, up to 50 mile cell radius
  - mobile: 15 Mbps max, up to 1-2 mile cell radius
# WiMAX Standards

<table>
<thead>
<tr>
<th></th>
<th>IEEE 802.16</th>
<th>IEEE 802.16a/REVd</th>
<th>IEEE 802.16e</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Completed</strong></td>
<td>Dec. 2001</td>
<td>802.16a: Jan 2003</td>
<td>Estimate: 2nd half of 2005</td>
</tr>
<tr>
<td><strong>Spectrum</strong></td>
<td>10 to 66 GHz</td>
<td>&lt; 11 GHz</td>
<td>&lt; 6 GHz</td>
</tr>
<tr>
<td><strong>Channel Conditions</strong></td>
<td>Line-of-sight only</td>
<td>Non line-of-sight</td>
<td>Non line-of-sight</td>
</tr>
<tr>
<td><strong>Bit Rate</strong></td>
<td>32 to 134 Mb/s at 28 MHz channellization</td>
<td>Up to 75 Mb/s at 20 MHz channellization</td>
<td>Up to 15 Mb/s at 5 MHz channellization</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>QPSK, 16 QAM and 64 QAM</td>
<td>OFDM 256, OFDMA 64 QAM, 16 QAM, QPSK, BPSK</td>
<td>Same as REVd</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Fixed</td>
<td>Fixed and Portable</td>
<td>Mobility, Regional Roaming</td>
</tr>
<tr>
<td><strong>Channel Bandwidths</strong></td>
<td>20, 25 and 28 MHz</td>
<td>Selectable channel bandwidths between 1.25 and 20 MHz, with up to 16 logical sub-channels</td>
<td>Same as REVd</td>
</tr>
<tr>
<td><strong>Typical Cell Radius</strong></td>
<td>1 to 3 miles</td>
<td>3 to 5 miles: Maximum range 30 miles based on tower height, antenna gain and transmit power (among other parameters)</td>
<td>1 to 3 miles</td>
</tr>
</tbody>
</table>
Satellite systems

- Intended to cover very large areas
- Different orbit heights
- Optimized for one-way transmission
  - radio (XM, Sirius) and movie (SatTV) broadcasts
  - most two-way systems struggling or bankrupt
- Global Positioning System (GPS) use growing
  - satellite signals used to pinpoint location
  - popular in cell phones, PDAs, and navigational devices
LEO Satellites

**Description:**
- low Earth Orbit: 500km-2000km
- high, constant, velocity
- deployed in constellations of multiple satellites

**Benefits**
- low power requirements at the user
- low signal propagation delay
- global coverage

**Satellite footprint** (coverage area on the Earth) is divided into “spotbeams”, forming a pattern of overlapping circles.
## LEO Examples

<table>
<thead>
<tr>
<th>System</th>
<th>Orbcomm</th>
<th>LEO One</th>
<th>Final Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
<td>Orbcomm, Orbital Sciences</td>
<td>LEO One</td>
<td>Final Analysis, General Dynamics Info Systems</td>
</tr>
<tr>
<td>Service Types</td>
<td>messaging, paging, e-mail</td>
<td>messaging, paging, e-mail</td>
<td>messaging, e-mail, file transfer</td>
</tr>
<tr>
<td>Voice (kbps)</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Data Rate</td>
<td>2.4 kbps uplink</td>
<td>2.4-9.6 kbps uplink</td>
<td>TBD</td>
</tr>
<tr>
<td></td>
<td>4.8 kbps downlink</td>
<td>24 kbps downlink</td>
<td></td>
</tr>
<tr>
<td>Orbit Altitude (km)</td>
<td>825</td>
<td>950</td>
<td>1000</td>
</tr>
<tr>
<td>No. of Satellites</td>
<td>48</td>
<td>48</td>
<td>38</td>
</tr>
<tr>
<td>No. of Orbit Planes</td>
<td>3</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Earth Stations</td>
<td>10</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>Mobile Uplink</td>
<td>148-150 MHz</td>
<td>148-150 MHz</td>
<td>VHF/UHF</td>
</tr>
<tr>
<td>Mobile Downlink</td>
<td>137-138 MHz, 400 MHz</td>
<td>137-138 MHz</td>
<td>137-138 MHz</td>
</tr>
<tr>
<td>Feeder Uplink</td>
<td>148-150 MHz</td>
<td>148-150.5 MHz</td>
<td>VHF/UHF</td>
</tr>
<tr>
<td>Feeder Downlink</td>
<td>137-138 MHz, 400 MHz</td>
<td>400.15-401 MHz</td>
<td>VHF/UHF</td>
</tr>
<tr>
<td>ISL</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Service Date</td>
<td>1996</td>
<td>2002</td>
<td>2001</td>
</tr>
</tbody>
</table>
The High Altitude Long Operation (HALO) network

To satellites

1-15 HALO™ Gateway beams

50 Gb/s throughput capacity

100-1000 subscriber beams

Coverage cells

Frequency options: 28 or 38 GHz service availability

Urban area

Suburban and rural areas

50–75 miles
IEEE 802.15.4 / ZigBee Radios

- Low-rate WPAN (Wireless Personal Area Networks)
- Data rates of 20, 40, 250 Kbps
- Support for large mesh networking or star clusters
- Support for low latency devices
- CSMA-CA channel access
- Very low power consumption
- Frequency of operation in ISM bands
Bluetooth

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

- High data rates, up to 500 Mbps

- 7.5 Ghz of “free spectrum” in the U.S.

- Multipath highly resolvable: good and bad

- Limited commercial success to date
Questions?
Warming UP

• Read posted materials about: How to read, write, and present papers:
  • http://www.crhc.uiuc.edu/wireless/talks/howto.ppt
  • http://www.biochem.arizona.edu/classes/bioc568/papers.htm
  • http://www2.cs.uregina.ca/~pwlfong/CS499/reading-paper.pdf
  • http://www.cs.columbia.edu/~hgs/netbib/efficientReading.pdf

• Pick 5 conferences:
  • ACM Mobicom, MobiHoc, MobiSys, Sigcomm, NSDI, Hotnets, HotMobile
  • IEEE ICNP, ICDCS, SECON, WoWMoM

• Get the “Program” lists for last three years (2008, 2009, 2010) of each of your conference.
Warming UP

• For each paper in a program list, estimate weights (0%-100%) to the corresponding OSI Network layers. Sum of all weights is 100%.
  - DO NOT read the whole paper
  - In most cases, title w/o paper abstract is enough.
  - Utilize your instincts.

• Draw a corresponding histogram for each program list.

• Email me one page table with 15 histograms.

• Send me an ordered list of only 5 papers you mostly liked!
  - Again use instincts/guts
  - Your presentation paper(s) could be among this list

• **Deadline:** Jan 13\(^{th}\), 5:45pm.
Questions?