CSE 574S
Wireless and Mobile Networking

Raj Jain
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@cse.wustl.edu

Audio/Video recordings of this class lecture are available at:
http://www.cse.wustl.edu/~jain/cse574-16/
Overview

- Goal of this Course
- Grading
- Contents of the course
- Tentative Schedule
Mobile vs Wireless

- Mobile vs Stationary
- Wireless vs Wired
- Wireless 🔄 Media sharing issues
- Mobile 🔄 Routing, addressing issues
Wireless Networking

Impact of Wireless on Networking:
1. Not tied to walls/infrastructure
   - Ad-hoc networking
2. Error-prone
   - Traffic Management
3. Frequent Disconnections
   - Resource Management
   - Quality of Service for multimedia
4. Battery operated
   - Media access and networking while sleep
   - Time synchronization
5. Broadcast
   - Security
Mobile Networking

Impact of Mobility on Networking:

- Location
- Addressing
- Handoff
Goal of This Course

- Comprehensive course on wireless and mobile networking
- Broad coverage of current key areas
- Intro to physical layer “Wireless Communication”
- Emphasis on Higher layers: Layers 2, 3
- Emphasize both present (Industry standards and products) and near future (Research)
- Graduate course: (Advanced Topics)
  - Less reliance on one textbook
  - Lot of independent reading and writing
  - Survey paper (Research techniques)
  - Peer-Reviews
Why Wireless Networking?

1. Wireless (WiFi) is ubiquitous (Intel Centrino)
2. Most of the access (end user connectivity) is wireless
   - Smart phones, Tablets, and many laptops (Ultrabooks) have no wired Ethernet connections
3. Most of telecommunication carriers’ revenue is in wireless
4. New Developments:
   - 5G: 1Gbps Metropolitan Area Networks (LTE-Advanced)
   - Vehicular Networking (802.11p)
   - Cognitive networks: Sharing unused spectrum
Mobile Internet

- June 29, 2007: Apple announced iPhone
  - Birth of Mobile Internet, Mobile Apps
  - Almost all services are now mobile apps: Google, Facebook, Bank of America, ...

- 2014 mobile data traffic was $2.5 \times 10^{18}$ B/month.
  - $30 \times$ the size of the entire global Internet in 2000 (75 PB/mth).

- Mobile video traffic was more than 55% of the mobile traffic in 2014.

- Issues: Errors, Disconnection, Limited bandwidth, Limited distance

Washington University in St. Louis http://www.cse.wustl.edu/~jain/cse574-16/ ©2016 Raj Jain
Internet of Things

- Smart Watch
- Smart TV
- Smart Car

- Smart Health
- Smart Home
- Smart Kegs

- Smart Space
- Smart Industries
- Smart Cities
## Tentative Schedule

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/20/2016</td>
<td>Course Overview</td>
</tr>
<tr>
<td>3</td>
<td>1/27/2016</td>
<td>Introduction to Wireless Coding and Modulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Project Guidelines</td>
</tr>
<tr>
<td>4</td>
<td>2/1/2016</td>
<td>Introduction to Wireless Signal Propagation</td>
</tr>
<tr>
<td>5</td>
<td>2/3/2016</td>
<td>Introduction to IEEE 802.11 Wireless LANs</td>
</tr>
<tr>
<td>6</td>
<td>2/8/2016</td>
<td>Wireless LANs Part II: 802.11a/b/g/n/ac (Part 1)</td>
</tr>
<tr>
<td>7</td>
<td>2/10/2016</td>
<td>Wireless LANs Part II: 802.11a/b/g/n/ac (Part 2)</td>
</tr>
<tr>
<td>8</td>
<td>2/15/2016</td>
<td>Introduction to 60 GHz Millimeter Wave Gigabit Wireless Networks (Part 1)</td>
</tr>
<tr>
<td>9</td>
<td>2/17/2016</td>
<td>Introduction to 60 GHz Millimeter Wave Gigabit Wireless Networks (Part 2)</td>
</tr>
<tr>
<td>10</td>
<td>2/22/2016</td>
<td>Mid-Term Exam 1</td>
</tr>
<tr>
<td>#</td>
<td>Date</td>
<td>Topic</td>
</tr>
<tr>
<td>---</td>
<td>------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>11</td>
<td>2/24/2016</td>
<td>Introduction to Vehicular Wireless Networks</td>
</tr>
<tr>
<td>12</td>
<td>2/29/2016</td>
<td>Wireless Networking in White Spaces (Part 1)</td>
</tr>
<tr>
<td>13</td>
<td>3/2/2016</td>
<td>Wireless Networking in White Spaces (Part 2)</td>
</tr>
<tr>
<td>14</td>
<td>3/7/2016</td>
<td>IEEE 802.22 Regional Area Network (Part 1)</td>
</tr>
<tr>
<td>15</td>
<td>3/9/2016</td>
<td>IEEE 802.22 Regional Area Network (Part 2)</td>
</tr>
<tr>
<td></td>
<td>3/14/2016</td>
<td>Spring Break (No Class)</td>
</tr>
<tr>
<td></td>
<td>3/16/2016</td>
<td>Spring Break (No Class)</td>
</tr>
<tr>
<td>16</td>
<td>3/21/2016</td>
<td>Bluetooth and Bluetooth Smart</td>
</tr>
<tr>
<td>17</td>
<td>3/23/2016</td>
<td>Wireless Personal Area Networks</td>
</tr>
<tr>
<td>18</td>
<td>3/28/2016</td>
<td>Mid-Term Exam 2</td>
</tr>
</tbody>
</table>
# Tentative Schedule (Cont)

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>3/30/2016</td>
<td>Wireless Protocols for IoT (Part 1)</td>
</tr>
<tr>
<td>21</td>
<td>4/6/2016</td>
<td>Introduction to Cellular Networks: 1G/2G/3G (Part 1)</td>
</tr>
<tr>
<td>22</td>
<td>4/11/2016</td>
<td>Introduction to Cellular Networks: 1G/2G/3G (Part 2)</td>
</tr>
<tr>
<td>23</td>
<td>4/13/2016</td>
<td>Introduction to LTE</td>
</tr>
<tr>
<td>24</td>
<td>4/18/2016</td>
<td>Introduction to LTE-Advanced</td>
</tr>
<tr>
<td>25</td>
<td>4/20/2016</td>
<td>Introduction to 5G (Part 1)</td>
</tr>
<tr>
<td>26</td>
<td>4/25/2016</td>
<td>Introduction to 5G (Part 2)</td>
</tr>
<tr>
<td>27</td>
<td>4/27/2016</td>
<td>Final Exam</td>
</tr>
</tbody>
</table>
Prerequisite: CSE473S

- Protocol Layers: ISO/OSI reference model
- Physical Layer: Nyquist/Shannon theorems, Coding, Manchester
- Transmission Media: UTP, Cat 5, Microwave, Radio
- Data Communication: Asynchronous vs synchronous, Baud, bit, and Hz, Half-Duplex vs Full-duplex, Modulation/Demodulation
- Packet Transmissions: Framing, Bit stuffing, byte stuffing
- Flow Control: On-Off, Window
- Error Detection: Parity, Checksum, Cyclic Redundancy Check
Prerequisites (Cont)

- Error Recovery: Start and Stop, Go back $n$, Selective Reject
- LANs: Aloha, CSMA/CD, Ethernet, IEEE 802.3
- LAN Addressing: Unicast vs multicast, Local vs Global
- LAN wiring: 10Base5, 10Base2, 10Base-T, 100Base-T4, 100Base-TX, 100Base-FX
- Extended LANs: Hubs, Bridges, Routers, Switches
- Routing: Distance Vector vs Link State, Spanning tree, source routing
- Network Layer: Connectionless vs connection oriented
Text Book

- There is no one book that covers the breadth of the material in this course.
- There will be a reading list with each lecture. The list will include some books, web sites, and Wikipedia links.
- Mostly books available as “Safari Books” will be used.
- WUSTL has a subscription to Safari Books.
  - All WUSTL students and faculty have free online access.
Project

- A survey paper on a recent topic. A list of topics will be provided in the class.
- A hands-on (implementation or measurement) project of your choice approved by the instructor.
- Teams of 2 allowed for hands-on project.
- Stages:
  - Literature search
    - CD ROMs: Compendex, Books in Print, WWW
  - Reading
  - Writing
- Average 6 Hrs/week/person on project
- Average 9 Hrs/week/person on class
Examples of Projects

2014:
- Voice over LTE: Status and Migration Trends
- A Survey of Software-Defined Wireless Networks
- Virtualization in Wireless Networks
- Energy Efficiency in Wireless Networking Protocols
- Wireless Power Transfer – Concepts and Applications
- Survey of Low Altitude Unmanned Aerial Vehicles
- Security and Privacy Issues in the Internet of Things
- Wireless Networks for Disaster Relief
- Survey of Wireless Based Indoor Localization Technologies
- Recent Advances in Broadband Wireless Access Networks
- Recent Advances in Cognitive Radios
- Constrained Application Protocol for Internet of Things
Examples of Projects (Cont)

2010:

- 802.16m and WiMAX Release 2.0
- Current Status and Overview of the CAPWAP Protocol
- Femtocell: Indoor Cellular Communication Redefined
- Long Term Evolution (LTE)
- An Overview of Long Term Evolution Advanced (LTE-Advanced)
- Mobile Based Augmented Reality
- Mobile Cloud Computing
- Smart Grid
- Smart Grid: Trends in Power Market
- The Future of Networking: The Green Movement
Examples of Project (Cont)

2008:

- Body Area Networks (BAN)
- OSPF Extensions for Mobile Ad-hoc Networks
- 4G Wireless and International Mobile Telecommunication (IMT) - Advanced
- The 700 MHz Band: Recent Developments and Future Plans
- Wireless Options for Providing Internet Services to Rural America
- Long Term Evolution (LTE) & Ultra-Mobile Broadband (UMB) Technologies for Broadband Wireless Access
- Medical Applications of Ultra-Wideband (UWB)
- Medical Applications of Wireless Networks
- New and Emerging Energy Efficient Wireless Protocols
- Applications of Recent Wireless Standards in Satellite Networking
Examples of Projects (Cont)

2006:

- Metropolitan and Regional Wireless Networks: 802.16, 802.20 and 802.22
- Wireless Personal Area Networks
- RFID
- Recent Advances in the Wireless Physical Layer
- Location Management in Wireless Data Networks
- Location Management in Wireless Cellular Networks
- Time Synchronization in Wireless Networks
- Power Management in Wireless Networks
- Energy Efficient Routing in Wireless Networks
- Mobile IP
- Network Mobility
- Network Architectures for Mobility
Project Requirements

- Recent Developments: Last 3 to 5 years
  - Generally not in books
- Comprehensive Survey:
  Technical Papers, Industry Standards, Products
- Will be published on my website,
  Better ones may be submitted to magazines or journals
- No copyright violations:
  - You need to re-draw all figures
  - You need to summarize all ideas in your *own* words
  - Cannot copy any part of text or figure unmodified
  - Short quotes ok
  - Any unmodified figures need permissions
Any infringement will result in forfeiture of grades even after graduation.
# Project Schedule

<table>
<thead>
<tr>
<th>#</th>
<th>Day</th>
<th>Date</th>
<th>Project</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Monday</td>
<td>1/25/2016</td>
<td>Search Sample Due</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Monday</td>
<td>2/1/2016</td>
<td>HTML Sample Due</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Monday</td>
<td>2/8/2016</td>
<td>Topic Selection Due</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Monday</td>
<td>2/15/2016</td>
<td>References Due</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Monday</td>
<td>3/7/2016</td>
<td>Outline Due</td>
<td>2</td>
</tr>
<tr>
<td>22</td>
<td>Monday</td>
<td>4/11/2016</td>
<td>Reviews Due</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>Monday</td>
<td>4/18/2016</td>
<td>Revised Report Due</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HTML</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>20</td>
</tr>
</tbody>
</table>
Grading

- Exams (Best of 2 mid terms + Final) 60%
- Class participation 5%
- Homeworks 15%
- Project 20%
Frequently Asked Questions

- Yes, I do use “curve”. Your grade depends upon the performance of the rest of the class.
- One 8.4x11 sheet allowed in the exam. Class handouts, books not allowed. Time limited.
- Exams consist of numerical as well as multiple-choice (true-false) questions.
- There is negative grading on incorrect multiple-choice questions. Grade: +1 for correct. -1/(n-1) for incorrect.
- Everyone including the graduating students are graded the same way.
Homework Submission

- All homeworks are due on the following Monday at the beginning of the class unless specified otherwise.
- Any late submissions, if allowed, will *always* have a penalty.
- All homeworks should be submitted in hardcopy unless specified otherwise.
- All homeworks are identified by the class handout number.
- All homeworks should be on a separate sheet. Your name should be on every page.
- Please write CSE574 in the subject field of all emails related to this course.
- Use word “Homework” in the subject field on emails related homework. Also indicate the homework number.
Homework Grading

- Grading basis: Method + Correct answer
- Show how you got your answer
  - Show intermediate calculations.
  - Show equations or formulas used.
  - If you use a spreadsheet, a statistical package, or write a program, print it out and turn it in with the homework.
  - For Excel, set the print area and scale the page accordingly to fit to a page. (See Page Setup)
There may be a short 5-minute quiz at the beginning of each class to check if you have read the topics covered in the last class.
Office Hours

- Monday: 11:00 to 12:00 noon
  Wednesday: 11:00 to 12:00 noon

- Office: Bryan 523

- **Teaching Assistant**: Siddhant Sirohi, Bryan 516, s.sirohi (at) wustl.edu
  Office Hours: Friday 1:00-2:00PM
  Sunday 1:00-2:00PM
Summary

- Goal: To prepare you for the current job market in networking
- Teach you how to keep up with the latest in networking
- There will be a significant amount of self-reading and writing
- Get ready to work hard
Google Search Modifiers

- filetype:pdf, doc, ppt, pptx
- site:wustl.com
- intitle:trend
- inurl:trend
- allintitle:Networking Trends
- Allinurl:
- “ “ Exact Phrase
- OR
- AND
- + Must include
- - Not include
- ~X X or similar
- * Wildcard
Project Homework 1

Search web pages, books, and journal articles from IEEE XPlorer, ACM Digital Library, MOBIUS, Safari books, ILLIAD at Olin Library for one of the following topics:
1. Wireless Networking Trends
2. Mobile Networking Trends
3. Internet of Things

On the web try the following search points:
- [http://library.wustl.edu/findart.html](http://library.wustl.edu/findart.html)
- [http://library.wustl.edu/fulltext/](http://library.wustl.edu/fulltext/)
- [http://scholar.google.com](http://scholar.google.com)
- [http://books.google.com](http://books.google.com)
- [http://dl.acm.org/](http://dl.acm.org/)
- [http://ieeexplore.ieee.org/Xplore/home.jsp](http://ieeexplore.ieee.org/Xplore/home.jsp)
Project Homework 1 (Cont)

- Ignore all entries dated 2011 or before. Also ignore all entries that do not indicate topic or similar words in the title. List others in the following format (5 each):
  - Author, “Title,” publisher, year, ISBN. (for 5 books)
  - “Title,” URL [One line description] (for 5 web pages)
  - Author, “Title,” source (for 5 technical/magazine articles)

- For the books, include whether the book is available at WUSTL, MOBIUS, Safari, or ILLiad

- Serially number the references and submit electronically to jain@wustl.edu. The mail should have a subject field of “CSE 574 Project Homework 1” (Please note the subject carefully. Do not any other characters in the subject). Your answers should be the content of the message and not in an attachment.

- Make a list of other interesting search points and share in class.
Common Mistakes in Project Homework #1

- Not indicating where the book can be found in WUSTL
- Listing books/Magazines/journals that have little to do with the topic – may show up in search engines because of a minor mention of the topic or words
- Web Pages – No one line descriptions
- Missing journals. Need names of journals dealing with the topic chosen.
Quiz 0: Prerequisites

True or False?

T F

1. □ □ Datalink refers to the 2nd layer in the ISO/OSI reference model
2. □ □ Cat 5 unshielded twisted pair cable is better than Cat 3 cable.
3. □ □ Finding path from one node to another in a large network is a transport layer function.
4. □ □ It is impossible to send 3000 bits/second through a wire which has a bandwidth of 1000 Hz.
5. □ □ Bit stuffing is used so that characters used for framing do not occur in the data part of the frame.
6. □ □ For long delay paths, on-off flow control is better than window flow control.
7. □ □ Ethernet uses a CSMA/CD access method.
8. □ □ 10Base2 runs at 2 Mbps.
9. □ □ The packets sent in a connection-oriented network are called datagrams.
10. □ □ Spanning tree algorithm is used to find a loop free path in a network.

Marks = Correct Answers ___ - Incorrect Answers __ = ______
Acronyms

- **BAN**  Body Area Networks
- **CAPWAP**  Protocol
- **CSMA/CD**  Carrier Sense Multiple Access with Collision Detection
- **IEEE**  Institution of Electrical and Electronic Engineers
- **ILLIAD**  Inter-Library Loan
- **IMT**  International Mobile Telecommunication
- **IPv4**  Internet Protocol Version 4
- **IPv6**  Internet Protocol Version 6
- **ISO**  International Standards Organization
- **LAN**  Local Area Network
- **LTE**  Long-Term Evolution
- **MAC**  Media Access Control
- **MHz**  Mega Hertz
- **OSI**  Open System Interconnection
- **OSPF**  Open Shortest Path First
- **QoS**  Quality of Service
Acronyms (Cont)

- RF       Radio Frequency
- RFID     Radio Frequency Identification
- TCP      Transmission Control Protocol
- UMB      Ultra-Mobile Broadband
- URL      Uniform Resource Locator
- UTP      Unshielded Twisted Pair
- UWB      Ultra-Wideband
- VoIP     Voice over IP
- WAP      Wireless Access Protocol
- WiFi     Wireless Fidelity
- WiMAX    Wireless Micro-wawe Access
- WUSTL    Washington University in Saint Louis
- WWW      World-Wide Web
Student Questionnaire

- Name: ____________________________________________
- Email: ____________________________________________
- Phone: ____________________________________________
- Degree: ________ Expected Date: ________________
- Technical Interest Areas:
  ____________________________________________
  ____________________________________________
- Prior networking related courses/activities:
  ____________________________________________
  ____________________________________________
- Prior wireless networking related courses/activities:
  ____________________________________________
Scan This to Get These Slides
Related Modules

Introduction to 5G,
http://www.cse.wustl.edu/~jain/cse574-16/j_195g.htm

Low Power WAN Protocols for IoT,
http://www.cse.wustl.edu/~jain/cse574-16/j_14ahl.htm

Introduction to Vehicular Wireless Networks,
http://www.cse.wustl.edu/~jain/cse574-16/j_08vwn.htm

Internet of Things,
http://www.cse.wustl.edu/~jain/cse574-16/j_10iot.htm

Audio/Video Recordings and Podcasts of Professor Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw