

# CSE 574S

# Wireless and Mobile

# Networking



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Audio/Video recordings of this class lecture are available at:

<http://www.cse.wustl.edu/~jain/cse574-18/>



- ❑ Goal of this Course
- ❑ Grading
- ❑ Contents of the course
- ❑ Tentative Schedule

# Networking = “Plumbing”

- ❑ Networking is the “plumbing” of computing
- ❑ Almost all areas of computing are network-based.
  - Distributed computing
  - Big Data
  - Cloud Computing
  - Internet of Things
  - Smart Cities



Networking is the backbone of computing

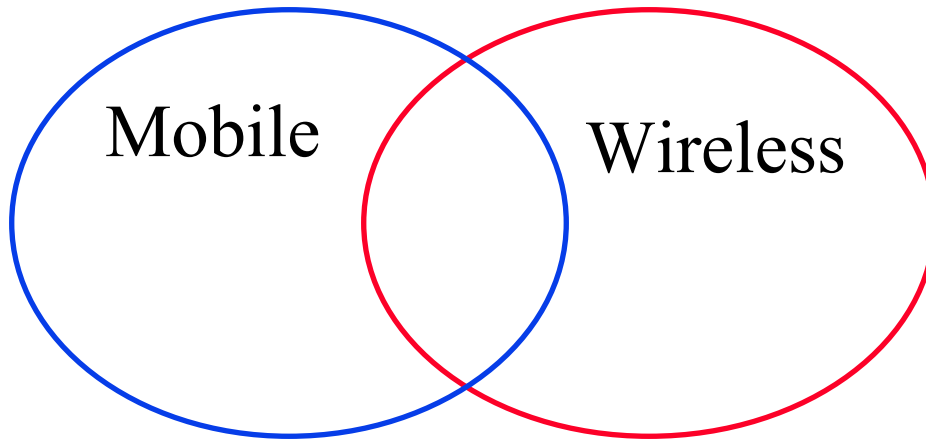
# Networking is Fueling All Sectors of Economy

- ❑ Networking companies are among the most valued companies: Apple, AT&T, Samsung, Verizon, Microsoft, China Mobile, Alphabet, Comcast, NTT, IBM, Intel, Cisco, Amazon, Facebook, ...  
⇒ All tech companies that are hiring currently are networking companies
- ❑ Note: Apple became highly valued only after it switched from computing to communications (iPhone)

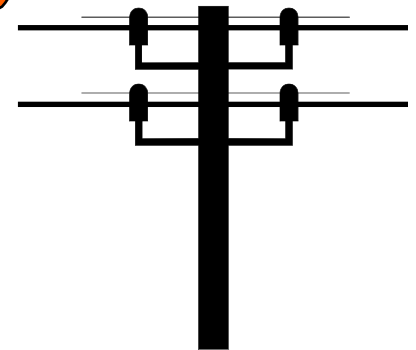


Networking = Economic Indicator

# 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 ManagementQuality 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

# 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: 1 Gbps Metropolitan Area Networks
  - 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× the size of the entire global Internet in 2000 (75 PB/mth).
- ❑ Between 2016-21:
  - PC traffic will be only 1/4<sup>th</sup> compared to 1/2 in 2016.
  - **Smart phone** traffic will be 1/3<sup>rd</sup> compared to 1/8<sup>th</sup> in 2016
  - **Mobile traffic** will grow twice as fast as fixed IP traffic
- ❑ Issues: Errors, Disconnection, Limited bandwidth, Limited distance



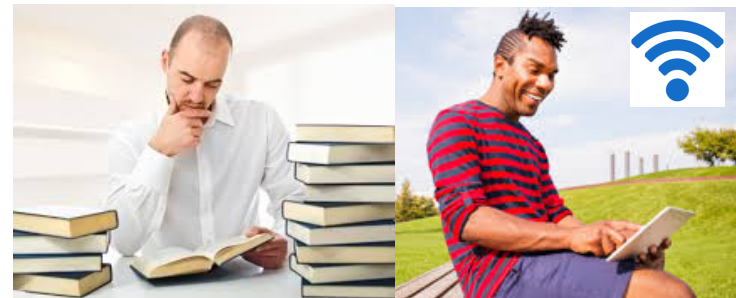
Ref: Cisco, "Cisco Visual Networking Index: Forecast and Methodology, 2016-2021," June 6, 2017,

<https://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.pdf>



# What's Smart?

- ❑ Old: Smart = Can think  $\Rightarrow$  Computation  
= Can Recall  $\Rightarrow$  Storage
- ❑ Now: Smart = Can find quickly, Can Delegate  
 $\Rightarrow$  Communicate = Networking
- ❑ Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, ...



Not-Smart

Smart

# Goal of This Course

- ❑ Comprehensive course on wireless and mobile networking
- ❑ Broad coverage of current key areas
- ❑ Topics of interest to industry
- ❑ Intro to physical layer “Wireless Communication”
- ❑ Emphasis on lower 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

# What Will You Learn?

1. How is wireless different from wired communication?
2. How does WiFi work?
  1. How is the speed of WiFi increasing from 10 Mbps to 10 Gbps?
  2. What is the difference between a/b/g/n/ac/ad/...
3. How is Bluetooth different from WiFi?
4. How is ZigBee different from WiFi?
5. What are the protocols that are used in IoT?
6. Why do we need new protocols for IoT?
7. What is the basic difference between 1G/2G/3G/4G/5G?
8. What new features came in with 4G?
9. What new techniques enabled 5G?
10. What about 6G? When and how?

# Tentative Schedule

#	Date	Topic
1	8/27	Course Overview
2	8/29	Wireless and Mobile Networking: Facts, Statistics, and Trends
3	9/5	Introduction to Wireless Coding and Modulation
4	9/10	Introduction to Wireless Coding and Modulation
5	9/12	Introduction to Wireless Signal Propagation
6	9/17	Introduction to Wireless Signal Propagation
7	9/19	IEEE 802.11 Wireless LANs. Part I: Basics
8	9/24	Wireless LANs Part II: 802.11a/b/g/n/ac
9	9/26	Introduction to 60 GHz Millimeter Wave Gigabit Wireless Networks
<b>10</b>	<b>10/1</b>	<b>Mid-Term Exam 1</b>

# Tentative Schedule (Cont)

#	Date	Topic
11	10/3	Introduction to 60 GHz Millimeter Wave Gigabit Wireless Networks
12	10/8	Introduction to Vehicular Wireless Networks
13	10/10	Introduction to Vehicular Wireless Networks
14	10/17	Internet of Things
15	10/22	Wireless Protocols for IoT Part I: Bluetooth and Bluetooth Smart
16	10/24	Wireless Protocols for IoT Part II: IEEE 802.15.4 WPAN, ZigBee
17	10/29	Wireless Protocols for IoT Part III: ZigBee
18	10/31	Low Power WAN Protocols for IoT
<b>19</b>	<b>11/5</b>	<b>Mid-Term Exam 2</b>

# Tentative Schedule (Cont)

#	Date	Topic
20	11/7	Low Power WAN Protocols for IoT
21	11/12	Introduction to Cellular Networks: 1G/2G/3G
22	11/14	Introduction to Cellular Networks: 1G/2G/3G
23	11/19	Introduction to LTE
24	11/26	Introduction to 4G/LTE-Advanced
25	11/28	Introduction to 4G/LTE-Advanced
26	12/3	Introduction to 5G
<b>27</b>	<b>12/5</b>	<b>Final Exam</b>



# Prerequisite: CSE473S

- ❑ Protocol Layers: ISO/OSI reference model
- ❑ TCP/IP protocol stack
- ❑ LAN Addressing: Unicast vs. multicast, Local vs. Global
- ❑ Extended LANs: Hubs vs. Bridges vs. Routers vs. Switches
- ❑ IPv4 and IPv6 Address: Public vs. Private Addresses
- ❑ Subnets
- ❑ Address Resolution Protocol (ARP)
- ❑ Internet Control Message Protocol (ICMP)
- ❑ TCP connection setup, Checksum (pseudo-header), Slow start
- ❑ TCP vs. UDP

# 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
  - Reading
  - Writing
- ❑ Average 6 Hrs/week/person on project
- ❑ Average 9 Hrs/week/person on class

# Examples of Projects

## 2016:

- ❑ Implementation of a Mobile Aerial Wireless Network
- ❑ A Survey of Bio-Inspired Wireless Communication
- ❑ Cloud RAN: Basics, Advances and Challenges
- ❑ A Survey of Distributed Radio Systems
- ❑ Energy Efficient Wireless Communication Survey
- ❑ Long Range Low Power (LRLP) Wireless Network
- ❑ LTE-A for Device to Device and Machine-to-Machine Comm
- ❑ M2M Communication Scheduling using LTE/LTE-A
- ❑ Emerging MIMO Technologies
- ❑ Network Coding for Wireless Applications: A review
- ❑ A Survey of Self-Organizing Networks

Ref: Raj Jain, "Wireless and Mobile Networking (Spring 2016)," <http://www.cse.wustl.edu/~jain/cse574-16/index.html>

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<http://www.cse.wustl.edu/~jain/cse574-18/>

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# 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

Ref: Raj Jain, “Wireless and Mobile Networking (Spring 2014),” <http://www.cse.wustl.edu/~jain/cse574-14/index.html>

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# 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.

# Grading

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

# Project Schedule

<b>Day</b>	<b>Date</b>	<b>Due</b>	<b>Points</b>
Wednesday	9/5/2018	Search	1
Monday	9/20/2018	HTML Sample	1
Monday	9/17/2018	Topic	
Monday	9/24/2018	References	1
Monday	10/10/2018	Outline	1
Monday	11/12/2018	Draft Paper	5
Monday	11/19/2018	Reviews	1
Monday	11/26/2018	HTML	2
		Final Paper	8
		Total	20



# Exams

- ❑ Exams consist of numerical, fill-in-the-blank and multiple-choice (true-false) questions.
- ❑ There is negative grading on incorrect multiple-choice questions. Grade: +1 for correct.  $-1/(n-1)$  for incorrect.  
➔ For True-False: +1 for Correct, -1 for Incorrect  
This ensures that random marking will produce an average of 0.
- ❑ Everyone including the graduating students are graded the same way.
- ❑ Highest score achieved becomes 100% for that exam.

# Exams (Cont)

- ❑ All exams are closed book.  
One 8.5”X11” cheat sheet with your notes on both sides is allowed.
- ❑ No smart phones allowed.  
Only simple TI-30 or equivalent calculator allowed for calculations.
- ❑ Exam dates are fixed and there are no substitute exams  
→ Plan your travel accordingly.
- ❑ Best of the two mid-terms is used.

# 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
- ❑ 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.
- ❑ **The first page of all homeworks submitted should be blank with only your name on the top-right corner**

# 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)

# Quizzes

- 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.

# Academic Integrity

- ❑ Academic integrity is expected in homeworks
- ❑ All solutions submitted are expected to be yours and not copied from others or from solution manuals or from Internet
- ❑ All integrity violations will be reported to the department and action taken

# Class Discussions

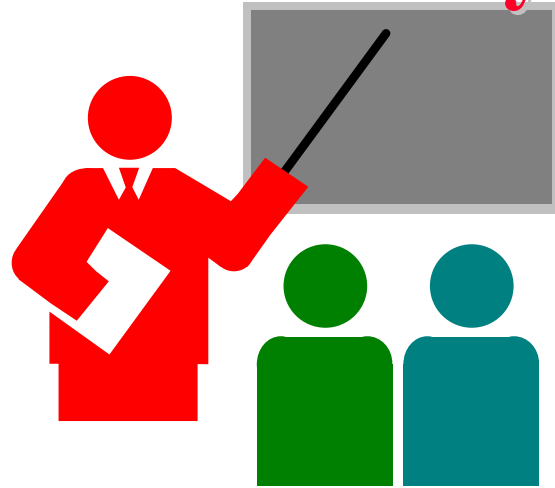
- ❑ We will use Piazza for class discussion.
- ❑ Find our class page at:
- ❑ <https://piazza.com/wustl/fall2018/cse574/home>

# Office Hours

- ❑ Office Hours: By appointment
- ❑ Office: Jolley 208
  
- ❑ **Teaching Assistant:** Ria Das, ria.das at wustl.edu
  - Office Hours: Friday 1:30-2:30PM  
Sunday 1:30-2:30PM



# Summary



- ❑ Goal: To prepare you for the current job market in networking
- ❑ Teach you how to keep up with the latest in wireless and mobile 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> (Classic, MOBIUS, WorldCat)
  - <https://library.wustl.edu/research-instruction/ejournals-ebooks/>
  - <https://libguides.wustl.edu/hathitrust>
  - <http://ieeexplore.ieee.org/Xplore/home.jsp>
  - <http://scholar.google.com>
  - <http://books.google.com>
  - <http://proquest.safaribooksonline.com/>

# Project Homework 1 (Cont)

- ❑ Ignore all entries dated 2013 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](mailto: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
- ❑ Incomplete bibliographic data for journal articles. Need volume, issue, year, pages.
- ❑ 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.   HTTP is an example of an application layer protocol
3.   Finding path from one node to another in a large network is a transport layer function.
4.   CRC is used for error detection
5.   MAC address of a node changes as it changes its location.
6.   For long delay paths, on-off flow control is better than window flow control.
7.   Ethernet uses a CSMA/CD access method.
8.   All Ethernet packets are acknowledged.
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
- ❑ 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
- ❑ LRLP        Long Range Low Power
- ❑ LTE         Long-Term Evolution
- ❑ MAC         Media Access Control
- ❑ OSI         Open System Interconnection
- ❑ OSPF        Open Shortest Path First

# Acronyms (Cont)

- ❑ RFID Radio Frequency Identification
- ❑ TCP Transmission Control Protocol
- ❑ TV Television
- ❑ UMB Ultra-Mobile Broadband
- ❑ URL Uniform Resource Locator
- ❑ UWB Ultra-Wideband
- ❑ VoIP Voice over IP
- ❑ WiFi Wireless Fidelity
- ❑ WUSTL Washington University in Saint Louis
- ❑ WWW World-Wide Web



# Scan This to Download These Slides



Raj Jain

<http://rajjain.com>

# Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),  
[https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n\\_1X0bWWNyZcof](https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof)

CSE473S: Introduction to Computer Networks (Fall 2011),  
[https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e\\_10TiDw](https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e_10TiDw)



Recent Advances in Networking (Spring 2013),  
<https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5>

CSE571S: Network Security (Fall 2011),  
<https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u>



Video Podcasts of Prof. Raj Jain's Lectures,  
<https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw>