18-452/18-750
Wireless Networks and Applications
Lecture 1: Course Organization and Overview

Peter Steenkiste
Carnegie Mellon University

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http://www.cs.cmu.edu/~prs/wirelessS20/

1

Outline

- **Goals and structure of the course**
- **Administrative stuff**
- **A bit of history**
- **Wireless technologies**
- **Building a network**

- **Please ask questions!**

2

Goals of the Course

- **Learn about the unique challenges in wireless networking**
  - » Starting point is "regular" wired networks
  - » But the physical layer is very different!
- **Gain an understanding of wireless technologies at the physical, MAC, and higher layers**
  - » Physical layer essentials for computer systems types
  - » Focus of course is on the wireless protocol layer
  - » Implications for the higher layers of the protocol stack
- **Get some hands-on experience in working with wireless networks and devices**
  - » Measurements of a wireless network
  - » Implementing wireless protocols, algorithms

3

Lectures

- **Introduction**
  - » Why are wireless networks so interesting?
  - » A very quick overview of networking
- **Physical layer concepts (~5)**
  - » Narrow focus: understanding the impact on higher layers
  - » Not an in-depth course on wireless communications!
- **LANs and WiFi (~6)**
- **Cellular networks (~3)**
- **Other technologies; PAN, RFID, NFC, …. (~5)**
- **GPS, localization, sensing (~3)**
- **Deployments: sensor networks, ad hoc, …**

4

Page 1

Projects

Projects are hands-on, team-based

1. **Measurement project to improve your understanding of wireless link properties**
   - » Measure signal strength and other signal properties
   - » How do they relate to the physical context?
2. **Design, implement and evaluate some wireless protocol, algorithm or system**
   - » Needs to deal with the unpredictable nature of wireless links and with mobility
   - » Multi-phase projects: start small and work your way up to larger networks
   - » Define your own project or set project

Survey Presentations

- **Present a survey of a particular wireless topic to the class**
  - » Basically a short lecture
- **Done in small teams**
- **Survey is based on research papers**
  - » Pick from a list of topics or define your own topic
  - » Initial set of papers provided for the list
- **Goals are:**
  - » Learn about a specific topic in depth
  - » Develop critical thinking skills
  - » Improve your presentation skills

Graduate versus Undergraduate Course Numbers

The course content is the same, but they are separate courses:

- **Some different questions on the tests**
- **Different levels of expectation for projects and surveys, e.g., original versus set project**
- **Final grades are assigned as separate pools**
- **The expectation is that students sign up for the course number that matches their status**
  - » Talk to the instructor if you want to sign up for the "wrong" course number, e.g., ECE IMB students
- **18-452 is a Software Systems area course**
- **18-750 part of Wireless Systems concentration**

Prerequisites

- **The course assumes you have taken an "Introduction to Computer Systems" course**
  - » For example based on the O'Hallaron and Bryant book
- **We will also build on basic networking and signals concepts but the course includes introductory material on these topics**
- **Programming experience needed for project**
  - » Often: C/C++ or other language, depending on project

- **Course should be accessible to students with a broad range of backgrounds, but …**
- **I don't know you, so please ask questions when something is not clear!**

More Specifically …

- **For undergraduates – 18-452**
  - » **18-213 or 15-213: Introduction to Computer Systems**

- **For graduates – 18-750**
  - » **15-513/18-600 or …**
  - » **Equivalent: a basic understanding of how computer systems work both inside the box (CMU, memory, IO, ..) and across boxes (familiarity with networking)**
  - » **If you have a degree in computer science or computer engineering, you should generally be ok**
  - » **Please talk to me if you have concerns**

Grading

Grade distribution:
- **Homeworks: 10%**
- **Project 1: 5%**
- **Project 2: 25%**
- **Survey: 10%**
- **Midterm: 20%**
- **Final: 30%**

Administrative Stuff

- **Textbook" "Wireless Communication Networks and Systems", Corry Beard and William Stallings, Pearson, 2015**
  - » **Best fit for the course**
- **The course is <u>not</u> based on the book**
  - » **The book should be used to read about the topics covered in class, e.g., to clarify points or get more depth**
  - » **Book does not cover all material, but slides are detailed**
- **Web page is primary source for information**
  - » **Lecture material**
  - » **Office hours, contact information, …**
  - » **Dates for homeworks, exams and project deadlines**
- **We will use Canvas for assignments**

More Administrative Stuff

- **Lectures are Mo/Wed 2:30-4:20 EST**
  - » **But lectures will typically be 80 minutes**
- **Recitations are Fr 12:30-1:50pm EST**
  - » **Some recitation slots will be used for the project (next slide)**
- **Uses video conferencing for SV students**
  - » **Video is available for offline viewing for all students, e.g., in case you miss a lecture**
- **Course admin is Ms. Malloy – Gates 9006**
  - » **Pick up assignments, make appointment, …**
- **Teaching assistant: Justin Niweteto**

Lecture Schedule

- **I plan is to use the recitation slot for some lectures**
- **Make up lectures for travel conflicts**
- **Move lectures earlier in the semester**
  - » Reduced class schedule in the second half of the semester when load is high, e.g., course projects
  - » Also helps in picking survey and project topics
  - » Current plan: Friday lectures in weeks 1, 3, 4, and 5
- **The total number of lectures will be the same as with a regular schedule**

Collaboration

- **Traditional rules of collaboration apply**
  - » **https://www.cmu.edu/policies/student-and-student-life/academic-integrity.html**
- **You must complete individual assignments and tests by yourself**
- **You are expected to collaborate with your partner in the team-based projects**
- **It is acceptable and encouraged to help fellow students with generic problems**
  - » **E.g. where to find documentation, use of tools, ..**
- **You must give proper credit when reusing material**
  - » **But check with the instructors first**

Course Material

- **Most slides were prepared by the course instructor**
- **Some slides contain material from other sources**
  - » **Previous co-instructors have contributed slides**
  - » **Some figures are taken from the textbook**
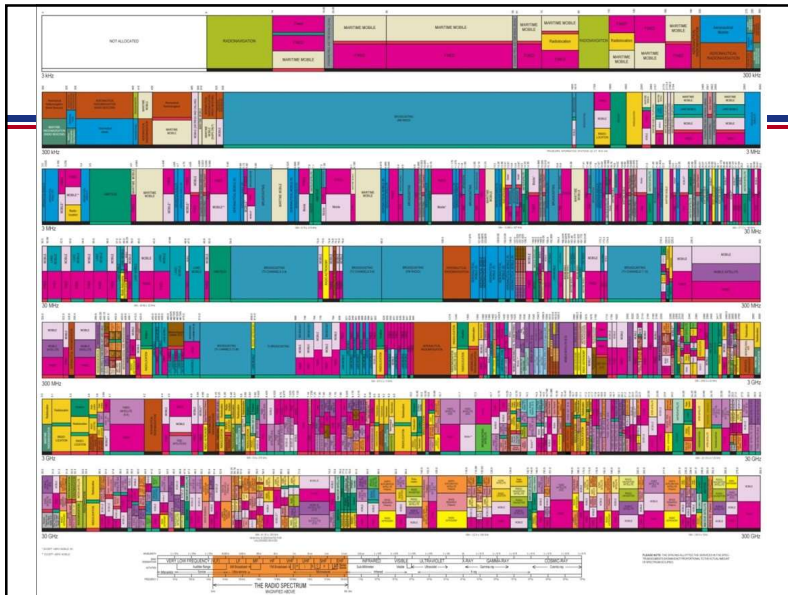 - » **Some lectures contain material from other sources**

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Spectrum Shared by Many Users

- **Spectrum allocated by FCC and NTIA**
- **Two types of spectrum bands:**
  1. **Licensed spectrum: exclusive access to an organization**
     - **Federal agencies, broadcast TV, first responders, …**
     - **Commercial, e.g., cellular operators**
  2. **Unlicensed spectrum: everyone can use it with appropriate equipment, e.g., WiFi, zigbee, …**
- **Other trends:**
  » **Technology improvements have allowed us to use higher frequency bands over time**
  » **Many bands have low utilization**
  » **Older bands often use very inefficient technologies**
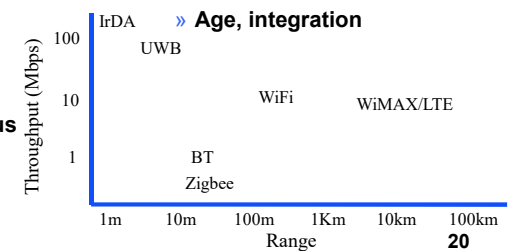
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18

Wireless Technologies
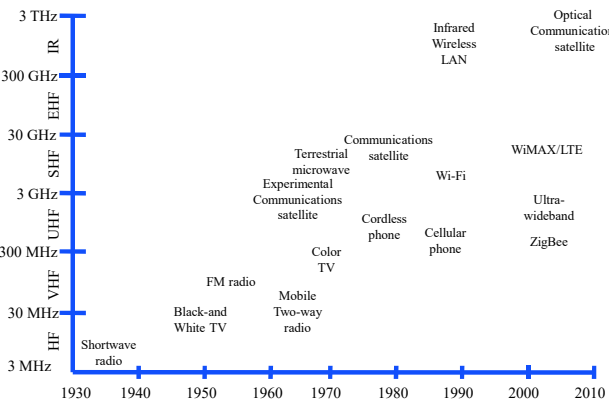
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19

Why so many Technologies?

- **Diverse application requirements**
  » **Energy consumption**
  » **Range**
  » **Bandwidth**
  » **Mobility**
  » **Cost**
- **Diverse deployments**
  » **Licensed versus unlicensed**
  » **Provisioned or not**

- **Technologies have different**
  » **Signal penetration**
  » **Frequency use**
  » **Cost**
  » **Market size**
  » **Age, integration**

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20

Page 5

Application Trends in Wireless

- **Early days: specialized applications**
  - » Broadcast TV and radio, voice calls, data, ..
  - » Holds for wireless and wired
- **Today: flexible wireless platforms**
  - » Phones, tables, and laptops all run similar applications
  - » Same trend as for wired networks: everything runs over the Internet
- **Wireless is expanding in new domains**
  - » Sensor networks, body area networks, …
  - » Edge of the internet is increasingly wireless
  - » Many of these applications are unique to wireless
- **Future?**

Scope of Wireless Covered in the Course

- **Significant depth on two technologies:**
  - » Wireless in unlicensed band: WiFi
  - » Wireless in licensed spectrum: cellular
  - » Focus is on optimizing performance with limited spectrum
  - » Sophisticated protocols to fight challenging physical layer
- **Other wireless communication technologies**
  - » RFID/NFC, low-power, satellite, UWB, visible light, …
- **Localization and sensing**
  - » GPS, Wifi for localization and sensing, …
- **Wireless deployments**
  - » Infrastructure WiFi, ad hoc, sensor networks, vehicular, DTN, visible light, ..
 - » Some topics covered in the surveys

Some History…

- **Tesla credited with first radio communication in 1893**
- **Wireless telegraph invented by Guglielmo Marconi in 1896**
- **First telegraphic signal traveled across the Atlantic ocean in 1901**
- **First "cell phone" concept developed in 1946**
  - » FCC allocated spectrum in the 70s; commercial service in the early 80s
  - » Data started only in the 90s
- **GPS project started in 1973, complete in 1995**
- **WiFi technology developed in the mid-1990s**

The MTS network

http://www.privateline.com/PCS/images/SaintLouis2.gif
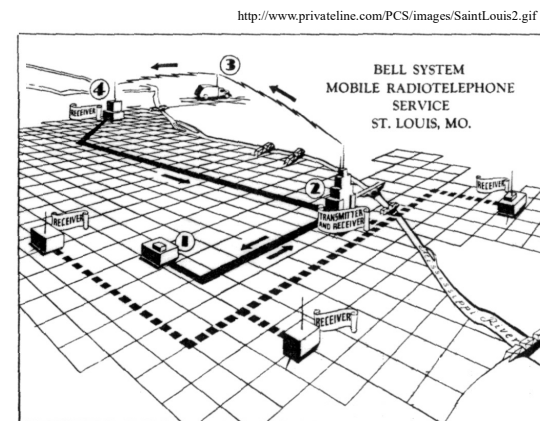
The origin of mobile phone

- **America's mobile phone age started in 1946 with MTS**
- **First mobile phones bulky, expensive and hardly portable, let alone mobile**
  - » **Phones weighed 40 Kg~**
- **Operator assisted with 250 maximum users**

25

Short History of WiFi

- **In 1985, the FCC opened up the 900 Mhz, 2.4 GHz and 5.8 Ghz bands for unlicensed devices**
- **NCR and AT&T developed a WiFi predecessor called "Wavelan" starting in 1988**
  - » **NCR wanted to connect cashier registers wirelessly**
  - » **Originally used the 900 MHz band and ran at 1 Mbps**
- **Standardization started in early 90s and led to 802.11b (1999) and 802.11a (2000)**
  - » **Pre-standard products were available earlier**
- **Today –many standards!**
  - » **Working on 802.11ba - rates up to several Gps**
  - » **Very sophisticated technology: OFDM, MIMO, multi-user MIMO, ..**

27

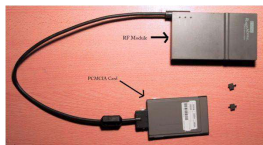## Early WiFi Interfaces

PCMCIA form factor made Wavelan more portable

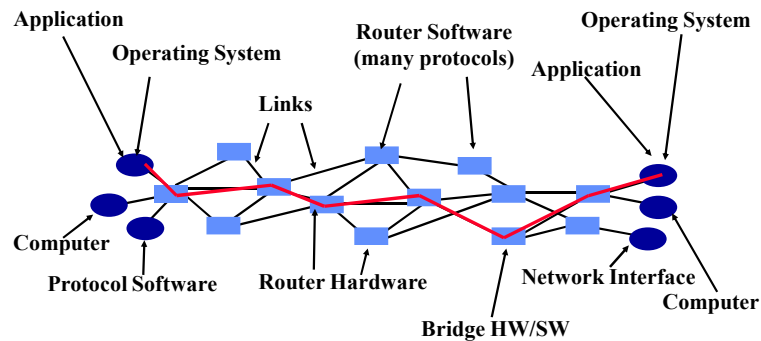**Wavelan at 900MHz 1 Mbps throughput**

28

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- **Goals and structure of the course**
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- **Wireless technologies**
- **Building a network**
  - » **What pieces do we need**
  - » **The OSI model**
  - » **Packet-based communication**
  - » **Challenges in Wireless Networking**

29

The Internet is Big and Has Many, Many Pieces

How do you design something this complex?

Application
Operating System
Router Software (many protocols)
Operating System
Application
Links
Computer
Protocol Software
Router Hardware
Network Interface
Computer
Bridge HW/SW

What Pieces Do We Need?

Module:

- **We need to be able to send bits**
  - » Over wired and wireless links
  - » Based on analog signals — **Physical**
- **We really want to send packets**
  - » Statistical multiplexing: users can share link
  - » Need addresses to deliver packets correctly — **Datalink Network**
- **But network may not be reliable**
  - » Bit errors, lost packets, …
  - » Must recover from these errors end-to-end — **Transport**
- **You need applications and services**
  - » Otherwise: who cares? — **Application**

Hosts Exchanging Packets can be Easy or Hard

Scaling up →

- **Two or more hosts talk over a wire (bits)** — Physical
- **Groups of hosts can talk at two levels**
  - » Hosts talk in a network is homogeneous in terms of administration and technology — Datalink
  - » Hosts talk across networks that have different administrators and technologies — Internet
- **Differ in physical and admin properties, scale**

Internet
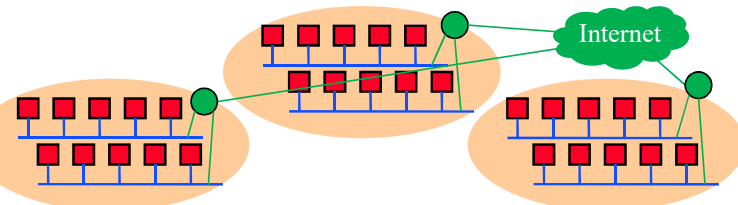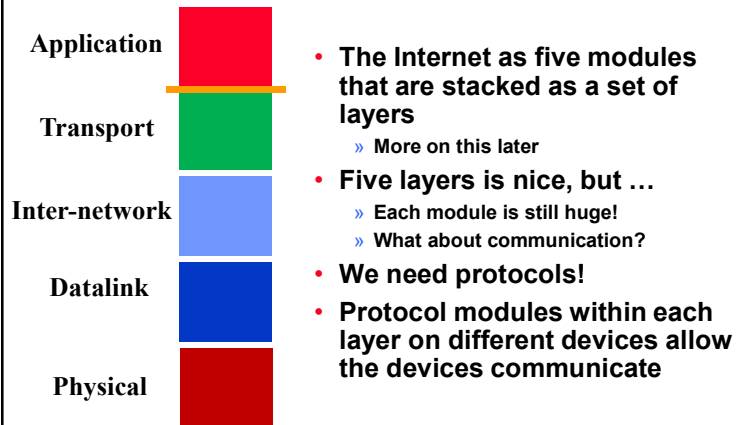
A Bit More Detail

- **Physical layer delivers bits between the two endpoints of a "link"**
  - » Copper, fiber, wireless, visible light, …
- **Datalink layer delivers packets between two hosts in a local area network**
  - » Ethernet, WiFi, cellular, …
  - » Best effort service: should expect a modest loss rate
  - » "Boxes" that connect links are called bridges or switches
- **Network layer connects multiple networks**
  - » The Inter-net protocol (IP)
  - » Also offers best effort service
  - » Boxes that forward packets are called routers
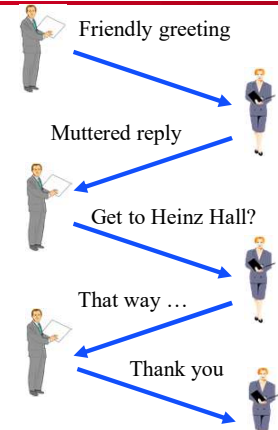
Scaling up the network →

Our Internet So Far

Application

Transport

Inter-network

Datalink

Physical

- **The Internet as five modules that are stacked as a set of layers**
  - » **More on this later**
- **Five layers is nice, but …**
  - » **Each module is still huge!**
  - » **What about communication?**
- **We need protocols!**
- **Protocol modules within each layer on different devices allow the devices communicate**

34

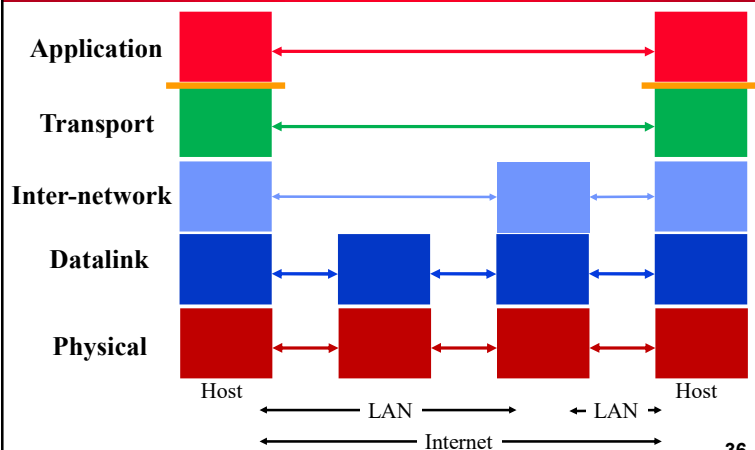## Protocol Enable Communication

- **An agreement between parties on how communication should take place.**
- **Protocols must define many aspects of the communication.**
- **Syntax:**
  - » **Data encoding, language, etc.**
- **Semantics:**
  - » **Error handling, termination, ordering of requests, etc.**
- **Protocols at hardware, software, *all* levels!**
- **Example: Buying airline ticket by typing.**
- **Syntax: English, ascii, lines delimited by "\n"**

Friendly greeting

Muttered reply

Get to Heinz Hall?

That way …

Thank you

35

Protocol and Service Levels

Application

Transport

Inter-network

Datalink

Physical

Host   Host

← LAN →   ← LAN →

Internet

36

The ISO Layered Network Model

The Open Systems Interconnection (OSI) Model.

| 7	Application				Application
6	Presentation				Presentation
5	Session				Session
4	Transport				Transport
3	Network		Network		Network
2	Data link		Data link		Data link
1	Physical		Physical		Physical

37

Page 9
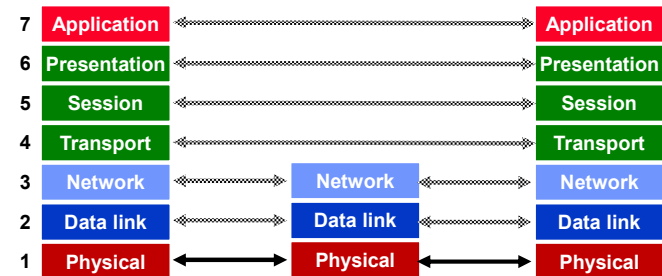
OSI Functions

- **(1) Physical: transmission of a bit stream.**
- **(2) Data link: flow control, framing, error detection.**
- **(3) Network: switching and routing.**
- **(4) Transport: reliable end to end delivery.**
- **(5) Session: managing logical connections.**
- **(6) Presentation: data transformations.**
- **(7) Application: specific uses, e.g. mail, file transfer, telnet, network management.**

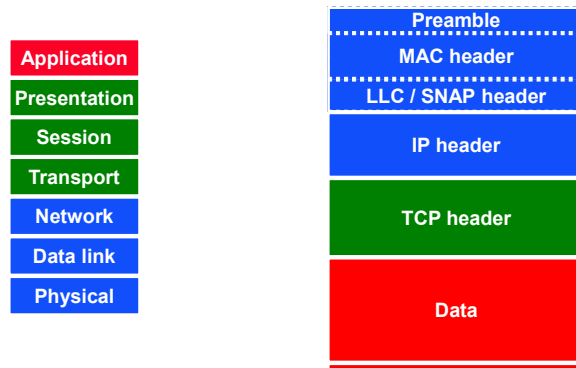Peter A. Steenkiste. CMU

38
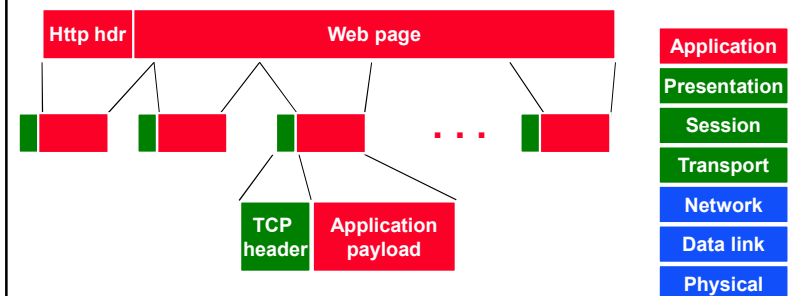
Life of Packet
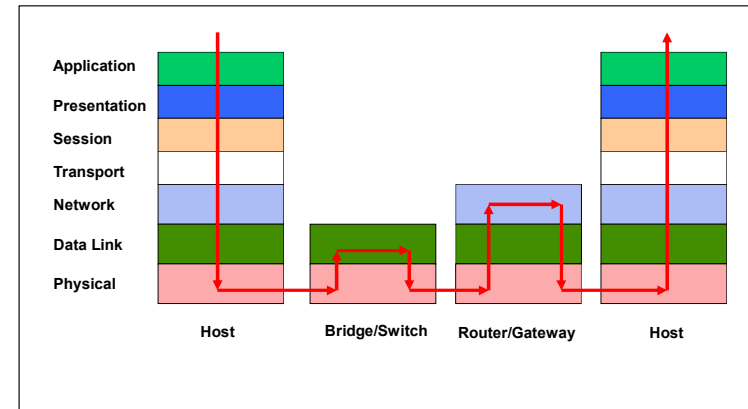
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39

39

A TCP / IP / 802.11 Packet

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40

Example: Sending a Web Page

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41

OSI Motivation

- **Standard approach of breaking up a system in a set of components with well defined interfaces, but components are organized as a set of layers.**
  - » Only horizontal and vertical communication
  - » Components/layers can be implemented and modified in isolation without affecting the other components
- **Each layer offers a service to the higher layer, using the services of the lower layer.**
- **"Peer" layers on different systems communicate via a protocol.**
  - » higher level protocols (e.g. TCP/IP, Appletalk) can run on multiple lower layers
  - » multiple higher level protocols can share a single physical network
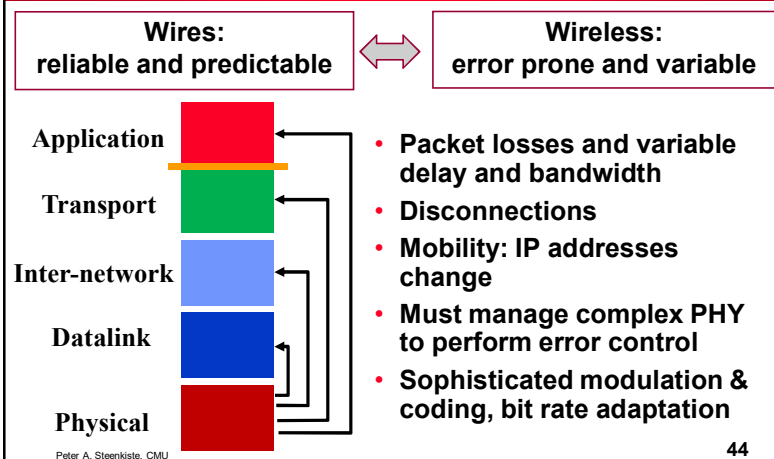
Benefits of Layered Architecture

- **Significantly reduces the complexity of building and maintaining the system.**
  - » Effort is 7 x N instead of N^7 for N versions per layer
- **The implementation of a layer can be replaced easily as long as its interfaces are respected** **True For Wireless?**
  - » Does not impact the other components in the system
  - » Different implementation versus different protocols
- **In practice: most significant evolution and diversity at the top and bottom:**
  - » Applications: web, peer-to-peer, video streaming, ..
  - » Physical layers: optical, wireless, new types of copper
  - » Only the Internet Protocol in the "middle" layer

Impact of the Physical Layer

Wires: reliable and predictable	⟷	Wireless: error prone and variable

- Application
- Transport
- Inter-network
- Datalink
- Physical

- **Packet losses and variable delay and bandwidth**
- **Disconnections**
- **Mobility: IP addresses change**
- **Must manage complex PHY to perform error control**
- **Sophisticated modulation & coding, bit rate adaptation**