This lecture is being recorded

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

Peter Steenkiste
Carnegie Mellon University

Spring 2022

http://www.cs.cmu.edu/~prs/wirelessS22/

Outline

- Goals and structure of the course
- Administrative stuff
- Internet basics
- Course content
- Why an entire course on wireless?
- A bit of history of wireless (context)

- Please ask questions!

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, datalink, and higher layers**
  - » **Physical layer essentials for computer systems types**
  - » **Thefcus 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**

Lectures

- Introduction
  - » What is the course about?
  - » A very quick overview of networking
- Physical layer concepts (~5)
  - » Narrow focus: understanding the impact on higher layers
  - » Conceptual – this is not wireless communications course!
- LANs and WiFi (~6)
- Cellular networks (~4)
- Other technologies; PAN, RFID, NFC, …. (~5)
- GPS, localization, sensing (~3)
- Deployments: sensor networks, ad hoc, …

Projects

Two hands on projects

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?
   - » Individual project this semester
2. **Design, implement and evaluate some wireless protocol, algorithm or system**
   - » Dealwith the unpredictable nature of wireless links, mobility
   - » Multi-phase projects: start small and work your way up to larger networks or systems
   - » Define your own project
   - » Teams of 2 students

Survey Presentations

- **Present a survey of a particular wireless topic to the class**
  - » **Basically a short lecture**
  - » **Done in teams of 2 students**
- **Survey is based on research papers**
  - » **Pick from a list of topics or define your own topic**
  - » **Initial set of papers provided for the topics on 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., more aggressive, evaluation**
- **Final grades are curved separately**
- **The expectation is that students sign up for the course number that matches their status**
  - » **Let the instructor if you are an UG signing up for the grad sections, e.g., as an ECE IMB student**
- **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**
  - **15-513/18-613 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%**

Where to Look for Things

- **Web page is primary source for information**
  - » **Lecture schedule and slides**
  - » **Office hours, contact information, …**
  - » **Deadlines for homeworks, surveys, and projects**
  - » **Handouts**
- **Canvas: recordings lectures, recitations**
- **Gradescope: homeworks, Project 1**
- **Piazza: discussion on homeworks, Project 1**
- **Midterm and final: in-person, depending on the conditions at the time**

Lecture Format

- **The early recitation slots will be used for lectures**
  - » **The number of lectures will remain the same**
- **Moving lectures earlier in the semester has several advantages:**
  - » **Reduced class schedule in the second half of the semester when your workload is often higher, e.g., course projects**
  - » **It helps in picking survey and project topics**
  - » **A tentative lecture schedule is on the web page**
- **Lectures are via zoom for the first week**
  - » **The presentation mode for the rest of the semester is decided by the university**
  - » **Given the uncertain times, we will record all lectures throughout the semester**

More Administrative Stuff

- **Lectures are Mo/Wed 2:30 – 4:20 EST**
  - **But lectures will typically be ~80 minutes, which is the typical lecture duration for a 12 unit course**
- **Recitations are Fr 11:50am -1:10pm EST**
  - **Only 70 minutes**
- **Course admin: Michele Passerrello – HH 1112**
  - **Appointments: Tracy Farbacher (CSD)**
- **Teaching assistant: Jingxian Wang**

- **Syllabus has more details on course policies**

Textbook and Readings

- **Textbook" "Wireless Communication Networks and Systems", Corry Beard and William Stallings, Pearson, 2015**
  - **» Best fit for the course**
- **The course is not 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**
- **The web page has some additional readings**

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**

Delivery Remote Lectures

- I will try to make remote lectures interactive
- I will pause regularly ot ask whether there are questions
- You can use Zoom's chat window to ask questions
  - » I will regularly check the chat window
- I may also use the Zoom poll feature, or ask simple questions to be answered through chat
- I welcome input on how to improve the remote lecture experience at any time

CMU's Disability Services Office and CAPS are Great

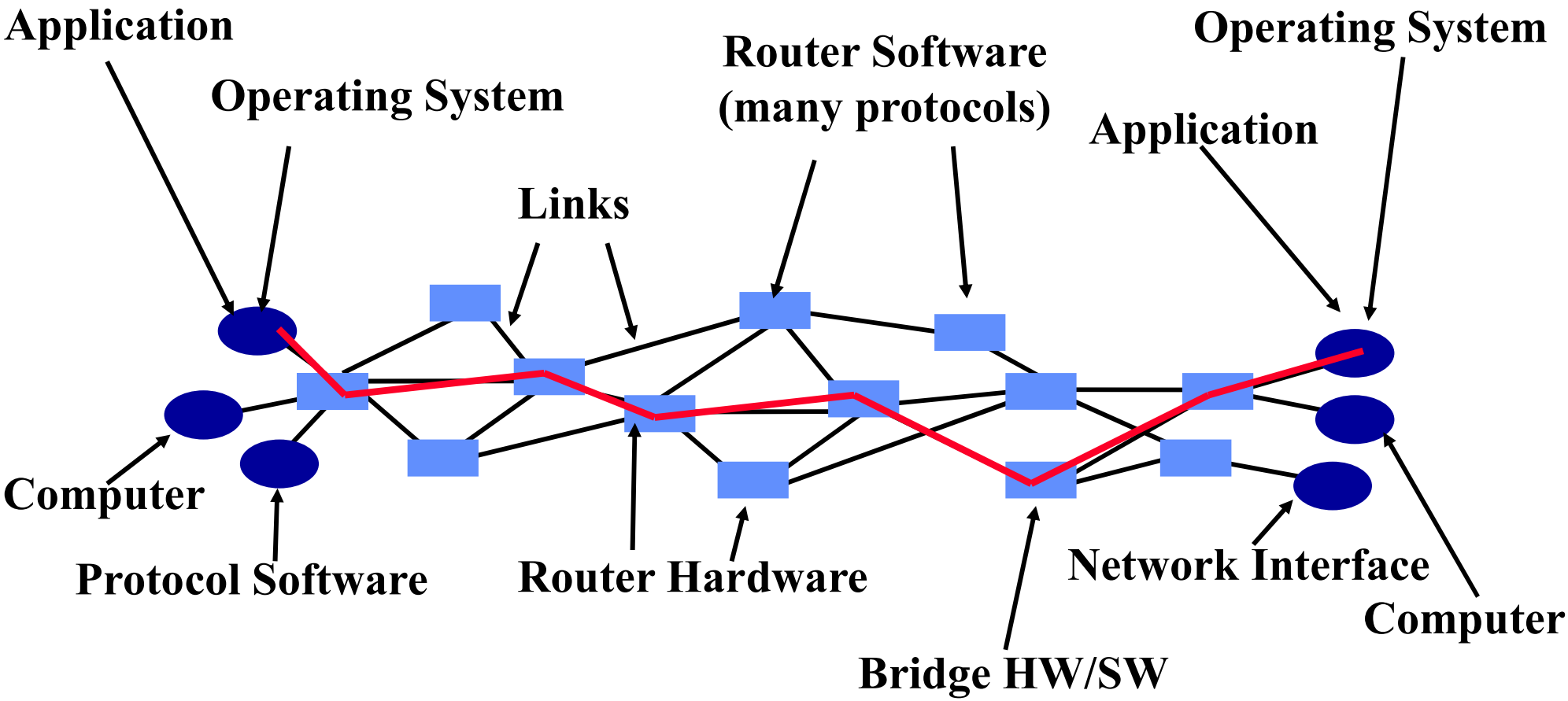
- I follow do what the Disability Services office decides, no questions asked
  - » I don't need to know why you need accommodations
- Please email me a copy of the accommodations sheet for us
  - » I am also notified directly by their office
- CAPS - Counseling and Psychologic Services
  - » They are not just for people with severe mental health troubles
  - » They are a useful resource for anybody who is stressed or needs to talk to someone

Outline

- Goals and structure of the course
- Administrative stuff
- Internet basics
- Course content
- Why an entire course on wireless?
- A bit of history of wireless

The Internet is Big and Has Many, Many Pieces

How do you design something this complex?



What Pieces Do We Need?

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

Module:

Physical

Datalink
Network

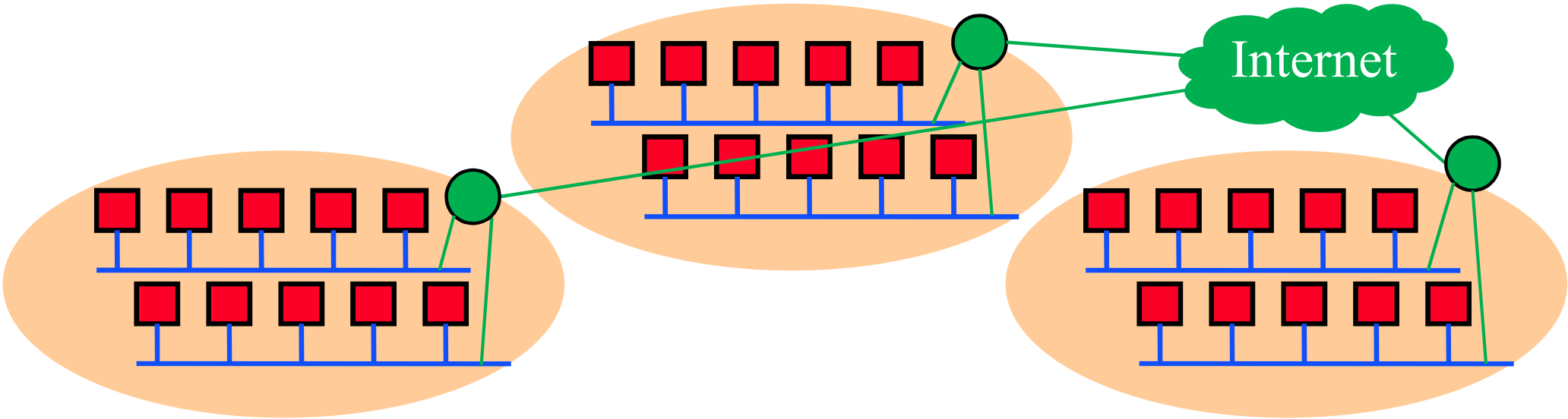
Transport

Application

Hosts Exchanging Packets can be Easy or Hard

Scaling up

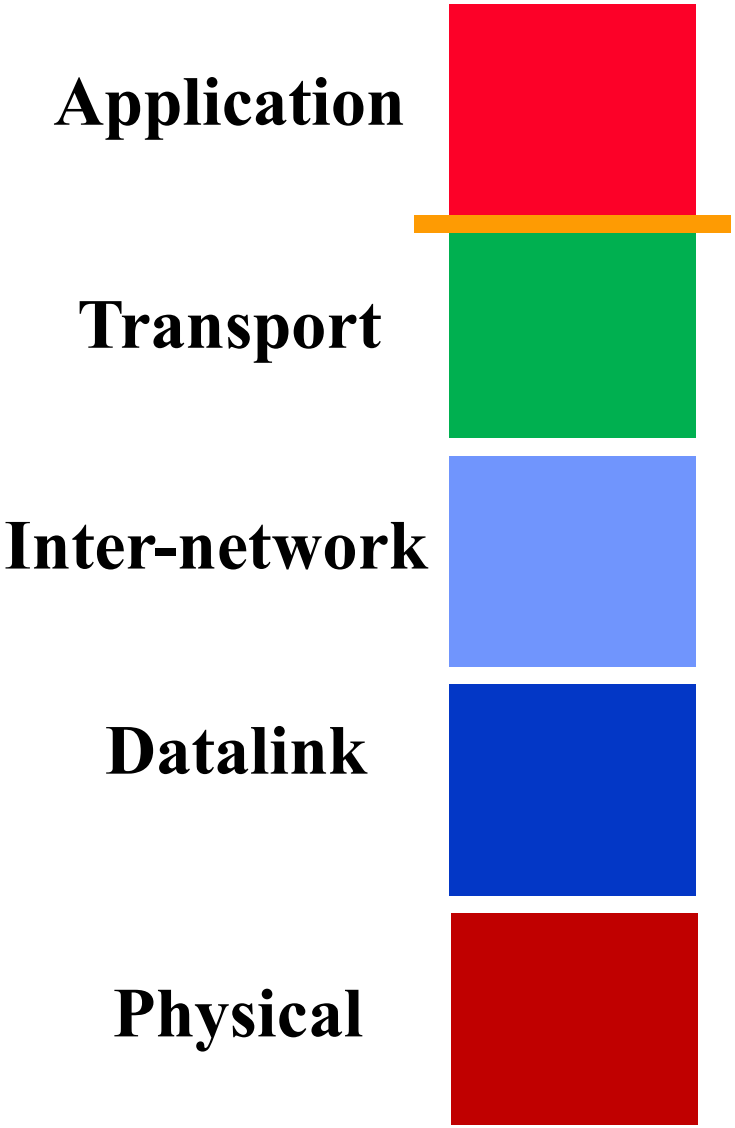
- Two or more hosts talk over a wire (bits) — Physical
- Groups of hosts can talk at two levels — Datalink
  - » Hosts talk in a network is homogeneous in terms of administration and technology
  - » Hosts talk across networks that have different administrators and technologies — Internet
- Differ in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



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

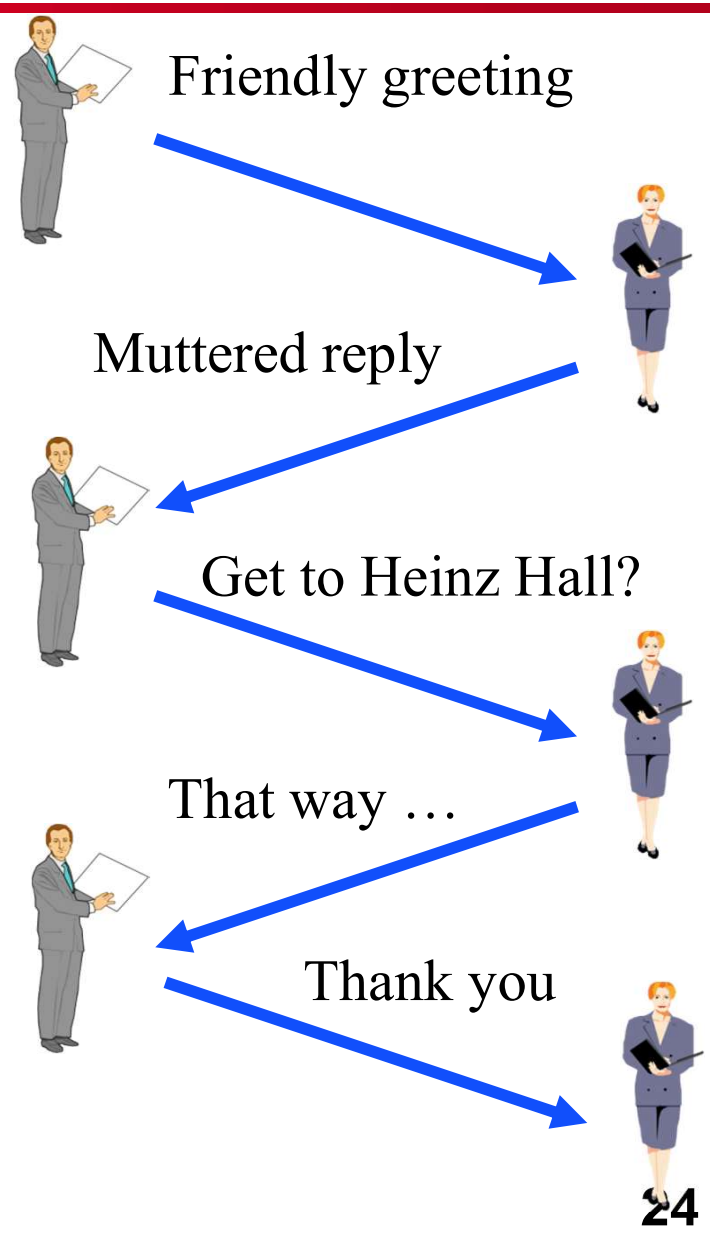
Our Internet So Far



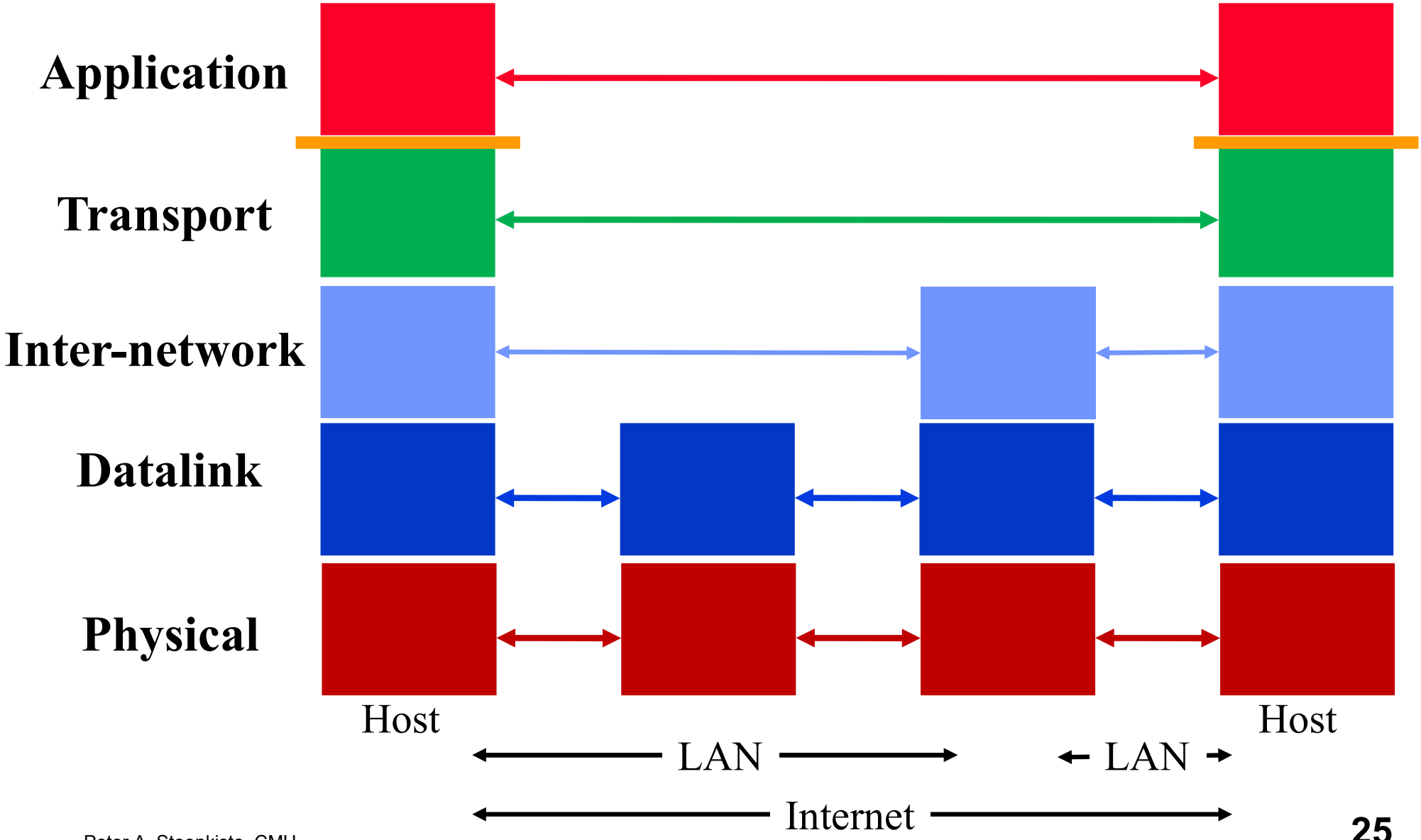
- The Internet as five modules that are stacked as a set of layers
  - More on this later
- Five layers is nice, but …
  - Each module is still huge!
  - What about communication?
- We need protocols!
- Protocol modules within each layer on different devices allow the devices communicate

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"

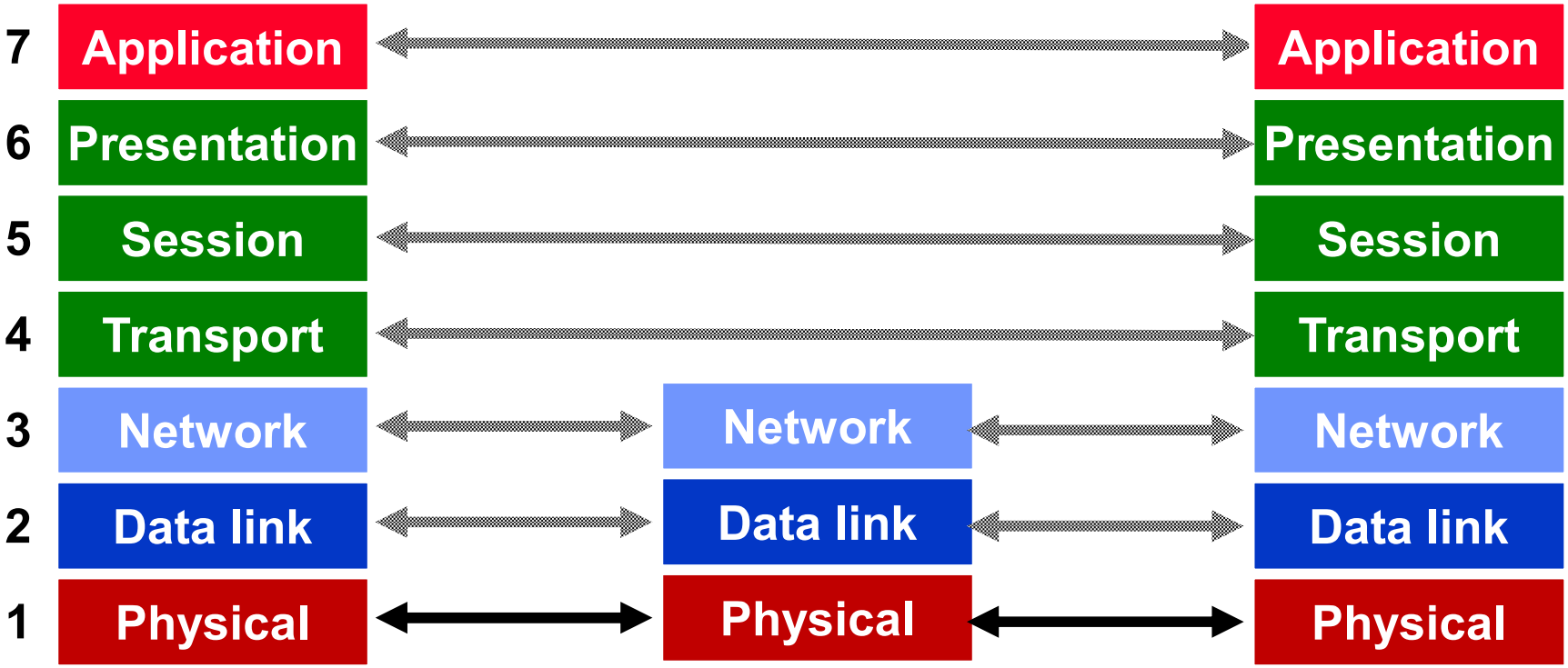


Protocol and Service Levels



The ISO Layered Network Model

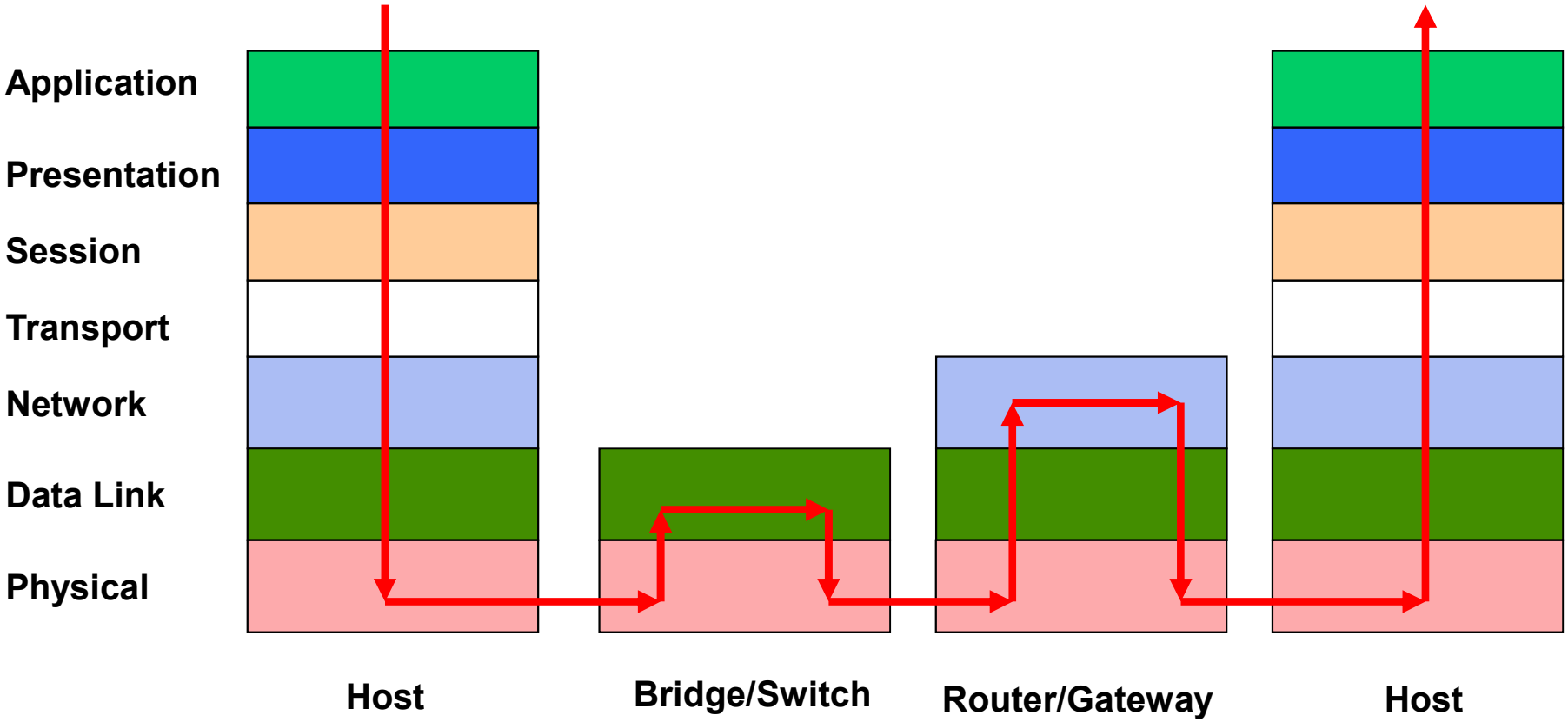
The Open Systems Interconnection (OSI) Model.



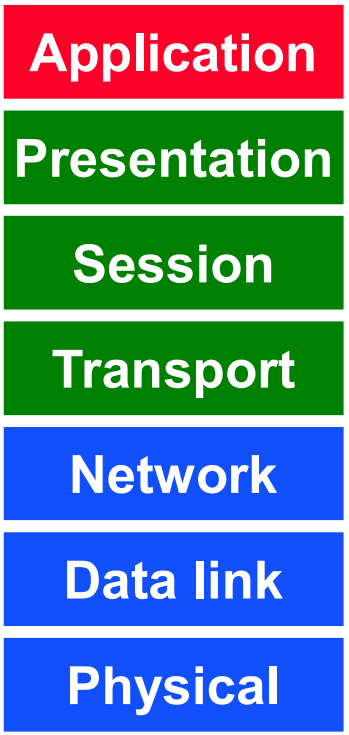
OSI Functions

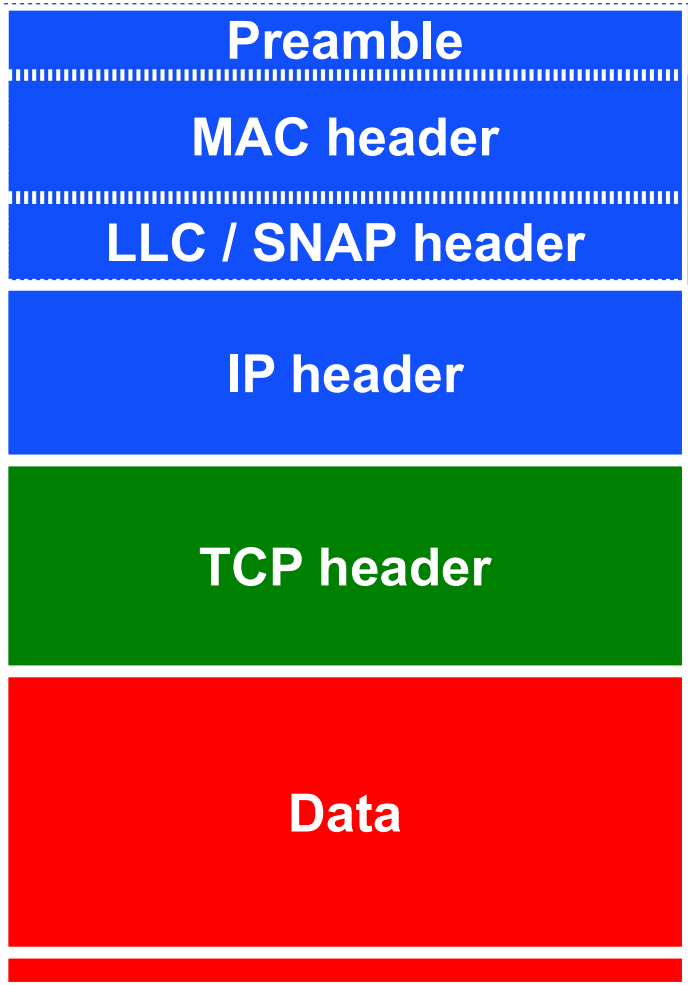
- (1) Physical: transmission of a bit stream.
- (2) Data link: flow control, framing, error detection.
- (3) Network: switching and routing.
- (4) Transport: reliable end to end delivery.
- (5) Session: managing logical connections.
- (6) Presentation: data transformations.
- (7) Application: specific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

Life of Packet

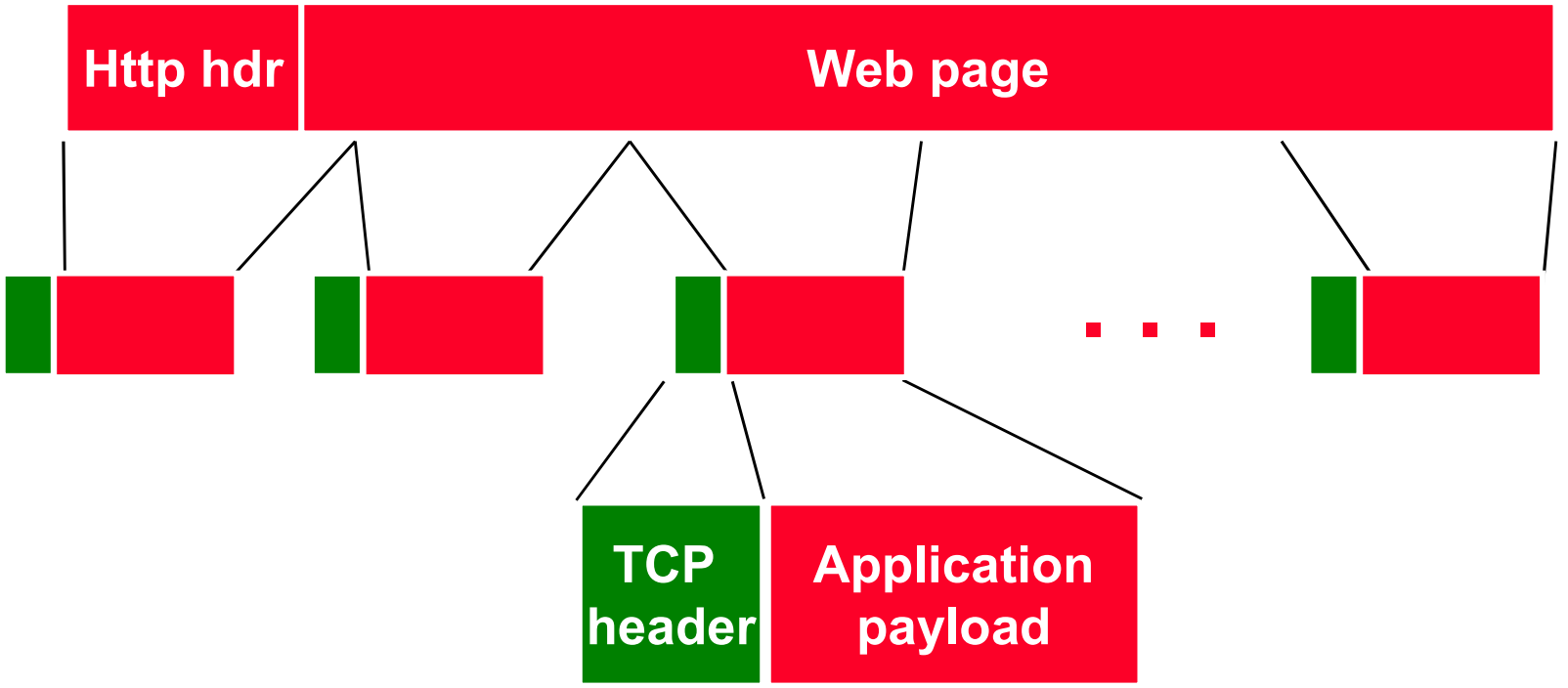


A TCP / IP / 802.11 Packet





Example: Sending a Web Page



Application
Presentation
Session
Transport
Network
Data link
Physical

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

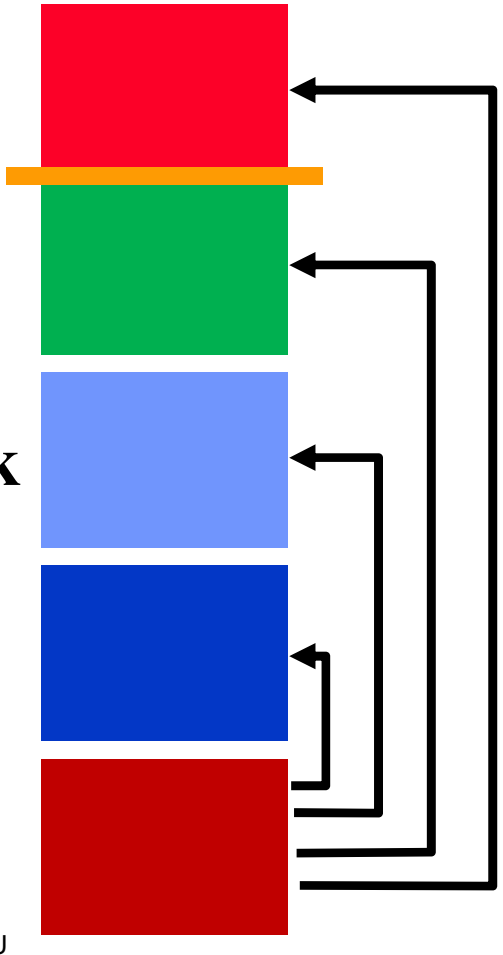
- **Significantly reduces the complexity of building and maintaining the system.**
  - » **Effort is 7 x N instead of N^7 for N versions per layer**
- **The implementation of a layer can be replaced easily as long as its interfaces are respected**
  - » **Does not impact the other components in the system**
  - » **Different implementation versus different protocols**

True For Wireless?

- **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



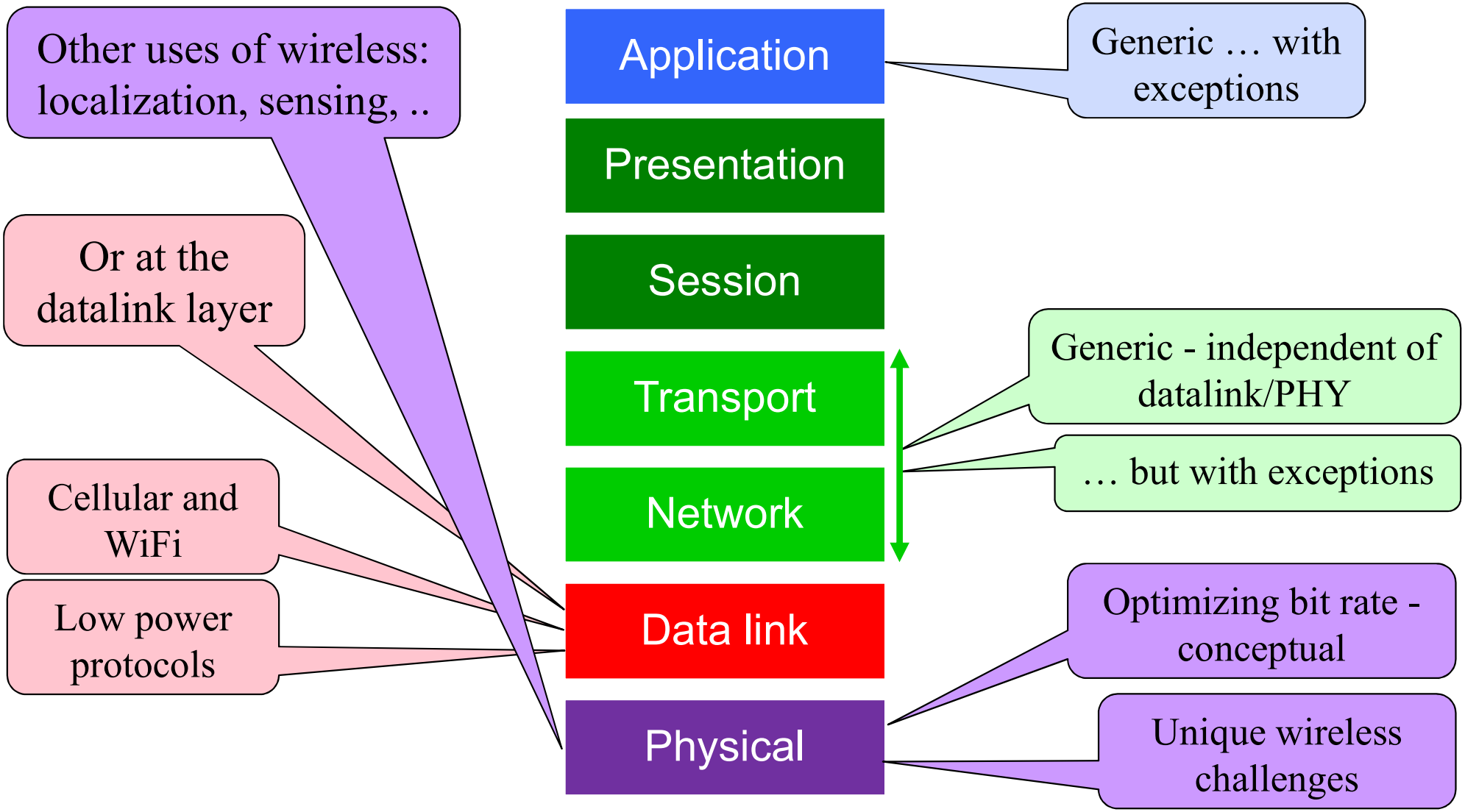
Wireless:
error prone and variable

- **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**

Outline

- Goals and structure of the course
- Administrative stuff
- Internet basics
- Course content
- Why an entire course on wireless?
- A bit of history of wireless

What is Covered?



Scope of Wireless Covered in the Course

- **Significant depth on two technologies**
  - » WiFi (unlicensed spectrum) and cellular (licensed spectrum)
  - » Optimize performance with high spectrum efficiency
  - » Sophisticated protocols to fight physical layer challenges
- **Other wireless communication technologies**
  - » RFID/NFC, low-power, sensor networks, …
- **Wireless deployments**
  - » Infrastructure WiFi, ad hoc, sensor networks, vehicular, ..
- **Other applications of wireless**
  - » GPS, Wifi for localization, dynamic spectrum access, …
  - » Diverse set of topics covered in the surveys

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**

Outline

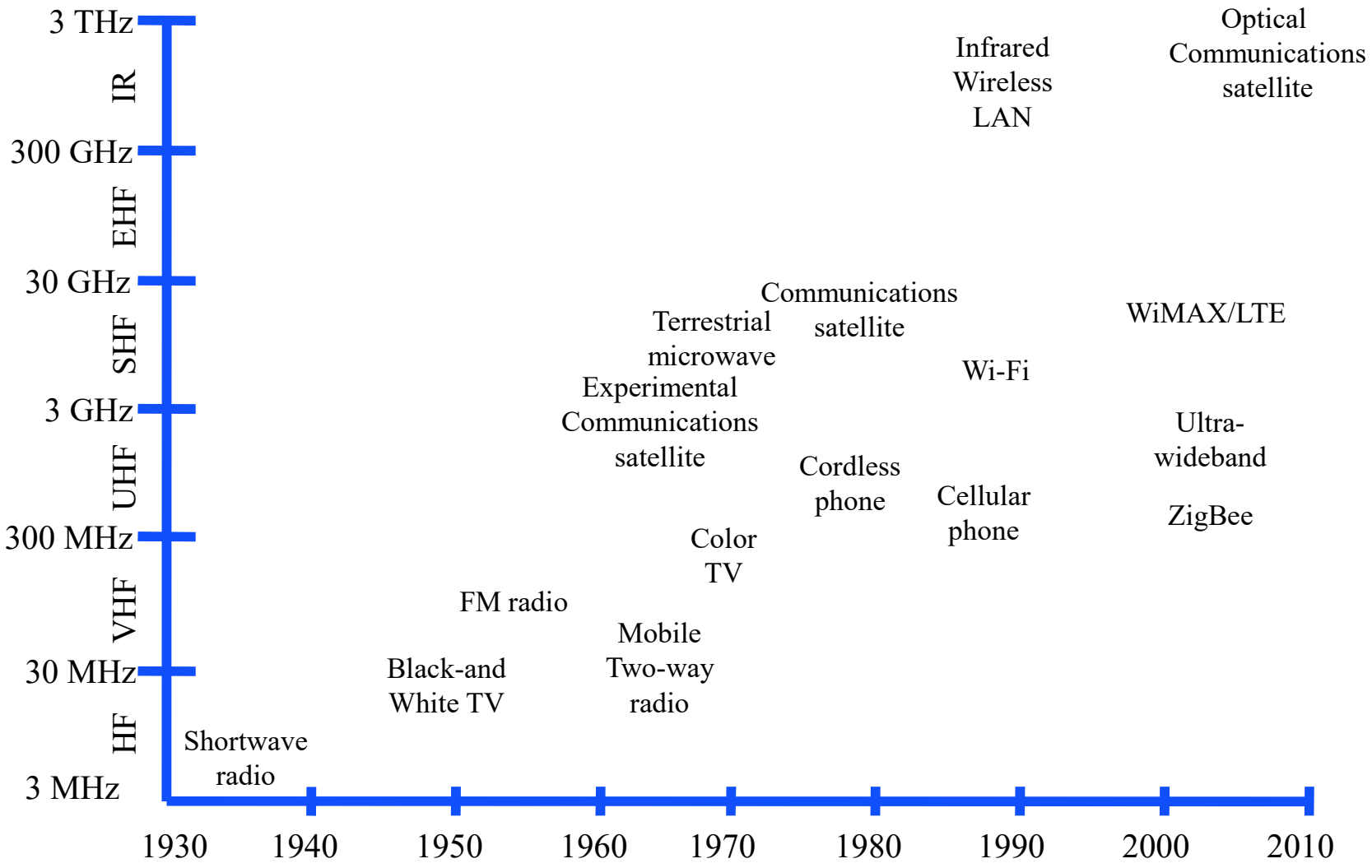
- Goals and structure of the course
- Administrative stuff
- Internet basics
- Course content
- Why an entire course on wireless?
- A bit of history of wireless


NOT ALLOCATED
RADIONAVIGATION
MARITIME MOBILE
FIXED
Radiolocation
AERONAUTICAL RADIONAVIGATION
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
THE RADIO SPECTRUM
MAGNIFIED ABOVE

Spectrum Shared by Many Users

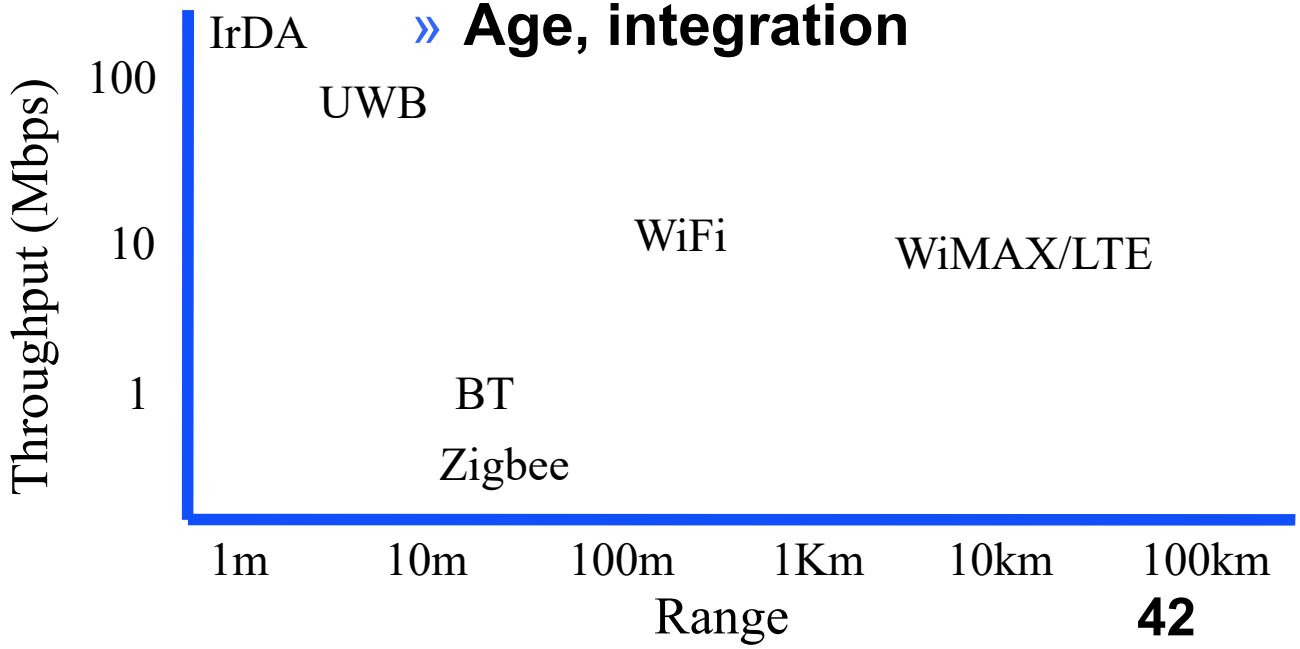
- **Spectrum allocated by FCC and NTIA**
- **Two types of spectrum bands:**
  1. **Licensed spectrum: exclusive access to an organization**
     - **Federal agencies, broadcast TV, first responders, …**
     - **Commercial, e.g., cellular operators**
  2. **Unlicensed spectrum: everyone can use it with 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**

Wireless Technologies



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



Application Trends in Wireless

- **Early days: specialized wireless networks**
  - » Broadcast TV and radio, voice calls, data, ..
  - » The same was true for wired networks
- **Today: single network for diverse apps**
  - » Phones, tables, and laptops all run similar applications
  - » Everything runs over the Internet (= data)
  - » The edge of the Internet is increasingly wireless
- **Wireless is expanding in new domains**
  - » Originally: support nomadic and mobile users
  - » Sensor networks, body area networks, RFID, …
  - » Emerging: sensing, backscatter, energy harvesting, ...
- **Future?**

Outline

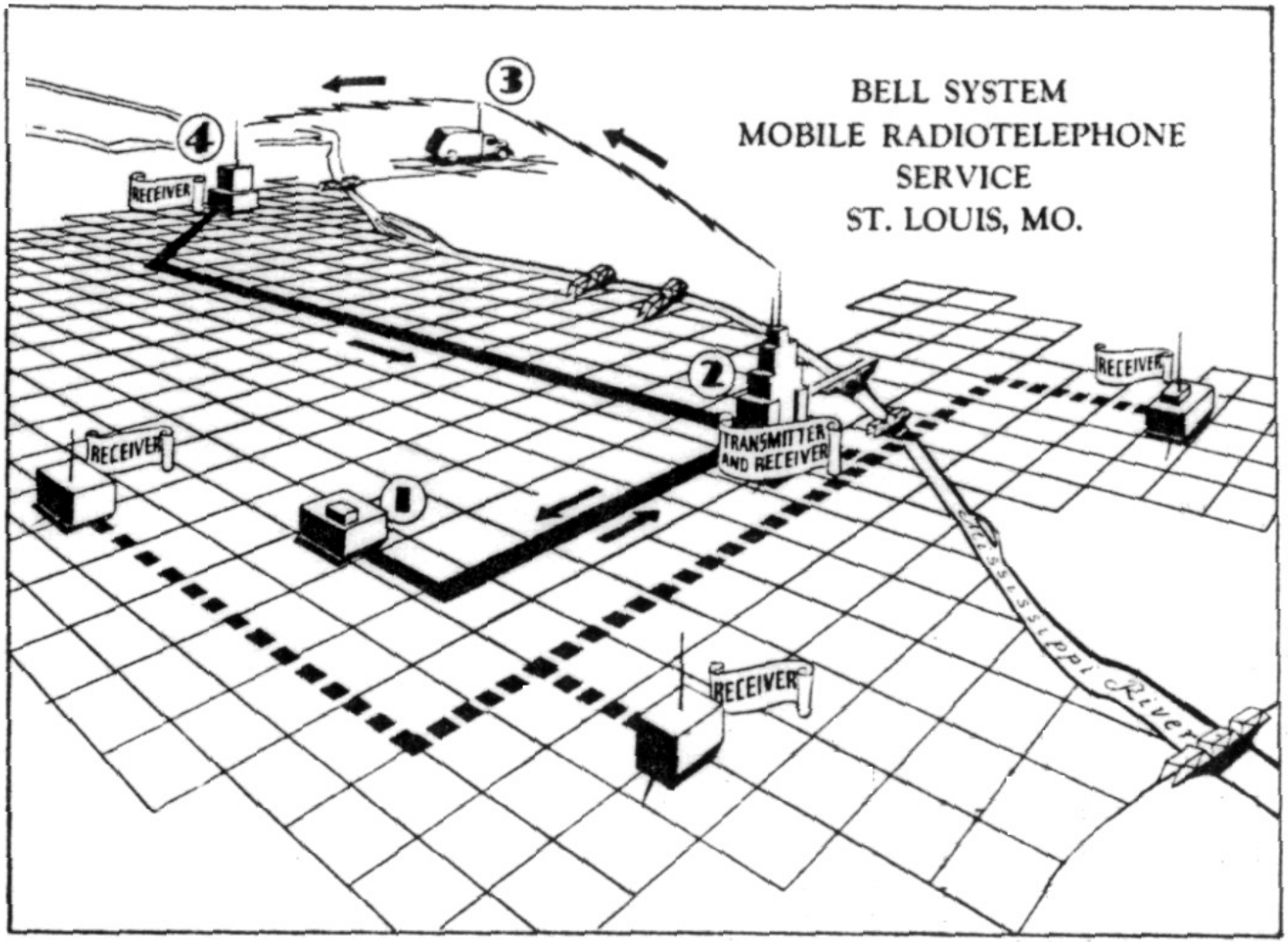
- Goals and structure of the course
- Administrative stuff
- Internet basics
- Course content
- Why an entire course on wireless?
- A bit of history of wireless

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

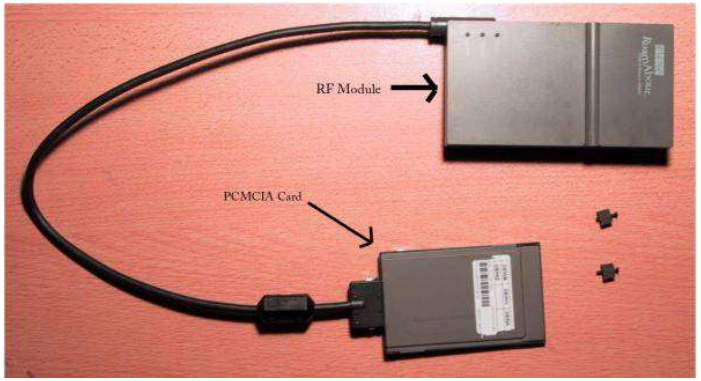
- America's mobile phone age started in 1946 with MTS
- First mobile phones bulky, expensive and hardly portable, let alone mobile
  - » Phones weighed 40 Kg~
- Operator assisted with 250 maximum users

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 802.11ax and ay - rates up to several Gps
  - » Very sophisticated: OFDM, MIMO, multi-user MIMO, ..
  - » Multiple frequency bands: 2.4 GHz, 5 GHz, 60 GHz

Early WiFi Interfaces

Wavelan at 900MHz
1 Mbps throughput



PCMCIA form factor made Wavelan more portable