18-759: Wireless Networks
Lecture 2: Wireless Networking Challenges

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http://www.cs.cmu.edu/~prs/wirelessS16/

Motivation: Many many Network Components

What is a Protocol

Schedule for Today

- The OSI model
- Challenges in Wireless Networking
- Evaluation techniques
- Please ask questions!

- An agreement between parties on how communication should take place.
- Protocols may have to 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 "in"
Do We Only Need Protocols?

- Need to also deal with
  - Many, many pieces of functionality
  - Complexity
  - Many parties involved
  - Very long life time

- Key is modularity
  - Natural solution to deal with complexity
  - Independent parties can develop components that will interoperate
  - Different pieces of the system can evolve independently, at a different pace

- Need well-defined interfaces ...

Solution #1

Solution #2?

Solution #3
Let Us Try Again, a Bit More Systematically

- Two or more hosts talk over a wire
- Hosts talk in a homogeneous network (administratively, technology)
- Hosts talk across heterogeneous networks
- We run some applications over that

Protocol and Service Levels

- Can further split up the layers:
  - Application: generic versus application-specific functionality
  - Core: wires versus data delivery

Interfaces

- Each protocol offers an interface to its users, and expects one from the layers on which it builds
  - Syntax and semantics strike again
    - Data formats
    - Interface characteristics, e.g. IP service model
- Protocols build upon each other
  - Add value
    - E.g., a reliable protocol running on top of IP
  - Reuse
    - E.g., OS provides TCP, so apps don’t have to rewrite

Networking 101 Layer Network Model

The Open Systems Interconnection (OSI) Model.
OSI Motivation

- Standard approach of breaking up a system in a set of components, but the components are organized as a set of layers.
  - Only horizontal and vertical communication
  - Components/layers can be implemented and modified in isolation
- 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

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.

Example: Sending a Web Page

A TCP/IP/802.11 Packet
Multiplexing and Demultiplexing

- There may be multiple implementations of each layer.
  - How does the receiver know what version of a layer to use?
- Each header includes a demultiplexing field that is used to identify the next layer.
  - Filled in by the sender
  - Used by the receiver
- Multiplexing occurs at multiple layers.
  - E.g., IP, TCP, ...

Benefits of Layered Architecture

- Significantly reduces the complexity of maintaining the system.
  - Effort is $7 \times n$ 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
- 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

The IP Hourglass

- Optical fiber: very high bandwidth but relatively expensive
  - Multi-mode fiber for campus deployments
  - Single-mode fiber for long distances
- Copper wires: good performance for shorter distances
  - Coax has high capacity but bulky and expensive
  - Twisted pair is cheap but has lower capacity
- Wireless: lowest capacity, very diverse, most difficult technology
  - Performance of a wireless “link” is determined by the physical world (buildings, object, people, other RF, ...)
  - Inter-planetary .. satellite .. WAN .. MAN .. LAN .. PAN
  - Capacity can be increased but gets expensive

Physical Layer Overview

True
For
Wireless?
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Why Use Wireless?

There are no wires!

Has several significant advantages:
- No need to install and maintain wires
  » Reduces cost – important in offices, hotels, ...
  » Simplifies deployment – important in homes, hotspots, ...
- Supports mobile users
  » Move around office, campus, city, ... - users get hooked
  » Remote control devices (TV, garage door, ..)
  » Cordless phones, cell phones, ..
  » WiFi, GPRS, WiMax, ...

What is Hard about Wireless?

There are no wires!

- In wired networks links are constant, reliable and physically isolated
- In wireless networks links are variable, error-prone and share the ether with each other and other external, uncontrolled sources

Attenuation and Errors

Hans — Inge

- In wired networks error rate $10^{-10}$
- Wireless networks are far from that target
- Signal attenuates with distance and is affected by noise
- Probability of a successful reception depends on $\text{SINR} = \frac{S}{I+N}$
- Modulation and coding schemes introduce redundancy to allow for decoding
Throughput vs. distance (WiMAX)

Throughput-Distance 24GHz, 12GHz, 6GHz, 3GHz, 1.5GHz

The Adversity of the Wireless Medium

- Previous hold for line of sight transmissions
  - Attenuation dominates, e.g. in outer space
- In the presence of reflectors signal may experience multipath fading
  - Slow fading when a large obstruction such as a hill or a large building obscures the main signal path
  - Fast fading that could be taken advantage of using error correcting codes and time diversity
- Very hard to predict what the signal strength will be at a given location – models exist for indoors and outdoors spaces (PHY lectures)

Wireless is a shared medium

- Transmitters broadcast
- Devices can operate either in transmit or receive mode
- How do you coordinate access to the medium?

Interference

- Noise is naturally present in the environment from many sources.
- Interference can be from other users or from natural or malicious sources.
- Impacts the throughput users can achieve.
Medium Access Control

- Main goal: avoid collisions while making efficient use of the medium
  - Collision = simultaneous transmissions “nearby” using the same frequency, resulting in packet loss
- Different transmitters/receivers use:
  - Different frequencies (FDMA – Frequency Division Multiple Access)
  - Different time slots (TDMA – Time Division Multiple Access)
  - Different points in space – more on this later
  - Different codes (CDMA – Code Division Multiple Access)
  - Randomly access the medium (e.g., CSMA/CD – Carrier Sense Multiple Access/Collision Detection)

Wireless Losses

- Can be due to:
  - Signal errors that lead to a packet that cannot be decoded
  - OR
  - Corruption of the transmitted information due to collisions, \( \text{SINR} = S/(N+I) \) too low
- Understanding the reason behind a loss requires cross-layer information.
  - Is it PHY?
  - Or MAC-related?
- Information required by more than one layers.

How Do We Increase Network Capacity?

- Easy to do in wired networks: simply add wires.
  - Fiber is especially attractive
- Adding wireless “links” increases interference.
  - Frequency reuse can help ... subject to spatial limitations
  - Or use different frequencies ... subject to frequency limitations
- The capacity of the wireless network is fundamentally limited.

Cellular architecture

- Deployment comprising cells – can reuse frequencies in different areas
  - Non-adjacent
- Challenge to provide consistent service even at the edge of the cell – be able to deal with intensity given the capacity of the cell
WiFi architecture

- Could be chaotic or managed
- Limited spectrum – service guarantees hard to make
- Channel assignment, power control

Mobility Affects the Link Throughput

- Quality of the transmission depends on distance and other factors.
  - Covered later in the course
- Affects the throughput mobile users achieve.
- Worst case is periods with no connectivity!

Mobility is an Issue even for Stationary Users

- Mobile people and devices affect the transmission channel of stationary nodes.

And It Gets Worse ...

- The impact of mobility on transmission can be complex.
  - Multi-path effects – more on this later
- Mobility also affects addressing and routing.
Back to the Applications

WiFi applications:
- GoogleWifi: provide sufficient coverage given that installation is on light posts – ensure adequate quality
- Meraki: ensure mesh works and there is enough coverage to connect more customers at appropriate levels of quality
- Developing regions: Make WiFi work across links that cover Kms – changes in the MAC
- Home security: Ensure that interference will not adversely impact readings
- Vehicle-to-vehicle: deal with fast moving vehicles, ensure that information is propagated to the relevant region
- Key challenges tend to be different for various application domains, but almost all challenges must be considered everywhere

How Well Does the Layered Architecture Work for Wireless?

- Works pretty well:
  - We all use WiFi and it usually works well
  - Our cell phones usually work
- But getting it to work is a lot more work than for a wired network!
  - PHY layer impacts other layers in the stack
- And a lot of solutions are kind of ugly!
- Some example ...

Examples

- How do you multiplex at the physical layer?
  - Not an issue for wired communication!
- Physical layer solutions to deal with signal propagation challenges
  - Use of redundancy, rate adaptation, dealing with multi-path, etc.
- MAC layer solutions to deal with challenges
  - ACKs and retransmissions, hidden terminals, etc.
- Higher layer challenges
  - TCP congestion control issues, highly variable bandwidth links, dealing with disconnected operation
  - IP address used by applications as an identifier

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- Challenges in Wireless Networking
- Evaluation techniques
Evaluation: Challenges and Tradeoffs

- Wireless testbeds are hard to manage
  - Interference, production networks, control node movement, ..
- Wireless network research has largely been simulation based
  - Questionable accuracy
  - Difficult to evaluate real hardware and applications

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<thead>
<tr>
<th>Simulator</th>
<th>Emulator</th>
<th>Testbed</th>
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<tbody>
<tr>
<td>Control &amp; Repeatability</td>
<td>Realism</td>
<td></td>
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- Emulator provides an attractive middle ground between simulation and testbeds

Why these Differences?

<table>
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<tr>
<th>Reality</th>
<th>Simulation</th>
<th>Physical Emulation</th>
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<tbody>
<tr>
<td>Applications</td>
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<td>OS</td>
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<td>Networking Stack</td>
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<td>Host Device</td>
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<td>MAC</td>
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<td>Signal Propagation</td>
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Gives Control

Emulator Architecture

Simulation Accuracy

- Several papers show major differences in results for wireless experiments on different simulators, or compared with the real world
- Shows that standalone simulations are not enough
  - OPNET, NS-2, GloMoSim
  - NS-3 is already much more realistic
- Hybrid approach of simulation and real testbed is more appropriate
Example of Result

Max node speed = 10 m/s, Pause time = 100 s, Broadcast rate = 4 pk/s

Power range = 200 m, Pause time = 100 s, Broadcast rate = 4 pk/s

Figure 3: Success rate vs Power range
Figure 4: Success rate vs Mobility

More Examples

- Proofs used for criticism:

Some Improvements

- Two ray ground model
  - Still very simple – too static and regular
- Models that include a “grey” region
  - Packet delivery rate still depends on distance
  - But model includes a region where PDR is probabilistic
  - Possible to “fit” to different environments
- Modeling of interference
  - Very relevant for both PHY and MAC layer effects
- Advanced models also model fading, impact of transmit rate, terrain factors, etc.
Testbeds

- Fully realistic, but:
  » Hard to control and repeat experiments
  » Representative for one particular location
- A number of testbeds available over the internet
  » Emulab in Utah
  » Indoor and outdoor Orbit
  » Vehicular testbed at CMU
  » Or use a “production” network

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- Evaluation techniques
- Starting on Monday: the physical layer