CS 356: Computer Network Architectures
Lecture 6: Multi-access links

Chapter 2.5.3, 2.6, 2.7

Xiaowei Yang
xwy@cs.duke.edu
Overview

• Reliable transmission
  – Sliding window
  – Concurrent multiple logical channels

• Multiple access links
  – Ethernet: CSMA/CD
  – 802.11 (WiFi): RTS/CTS
  – Bluetooth
  – Cell phone
  – Note: understand the concepts
Sequence number space and SWS/RWS

• n-bit sequence number space
• SWS=RWS < $2^{n-1}$
• Why?
Exercise

- Delay: 100ms; Bandwidth: 1Mbps; Packet Size: 1000 Bytes; Ack: 40 Bytes
- Q: the smallest window size to keep the pipe full?
Concurrent logical channels

- A link has multiple logical channels
- Each channel runs an independent stop-and-wait protocol
- + keeps the pipe full
- - no relationship among the frames sent in different channels: out-of-order
Today

• Multiple access links
  – Ethernet
  – 802.11 (WiFi)
  – Bluetooth
  – Cell phone
  – Note: understand the concepts
Original design

- 802.3 standard defines both MAC and physical layer details
  - No switches

Robert Metcalfe’s original Ethernet Sketch
He identified the day Ethernet was born as 05/22/1973
Multiple-access links

- Many nodes attached to the same link
  - Ethernet
  - Token rings
  - Wireless network (WiFi)

- Problem: who gets to send a frame?
  - Multiple senders lead to collision

- Solution: a general technique
  - Multiple access with collision detect (CSMA/CD)
Ethernet

- Developed in mid-1970s at Xerox PARC
- Speed: 10Mbps -- 10 Gbps
- Standard: 802.3, Ethernet II (DIX, stands for Digital-Intel-Xerox)

Most popular physical layers for Ethernet
- Last digital shows segment length
  - 10Base5 **Thick Ethernet**: 10 Mbps coax cable. A segment < 500m
  - 10Base2 **Thin Ethernet**: 10 Mbps coax cable. < 200 m
  - 10Base-T 10 Mbps T: Twisted Pair < 100m
  - 100Base-TX 100 Mbps over Category 5 twisted pair, duplex
  - 100Base-FX 100 Mbps over Fiber Optics, duplex
  - 1000Base-FX 1Gbps over Fiber Optics, duplex
  - 10000Base-FX 10Gbps over Fiber Optics (for wide area links), duplex
Bus Topology

- 10Base5 (thick) and 10Base2 (thin) Ethernets have a bus topology
- 10Base5 as our case study

10BASE2 cable  T-connector  Terminator
Physical properties

Sensing the line; if idle, sends signals

- **Transceiver**
  - A small device directly attached to the tap
  - It detects when the line is idle and drives the signal when the host is transmitting
  - It also receives incoming signals.

10Base5
How to expand an Ethernet segment

• A repeater is a device that forwards digital signals
  – Multiple segments can be joined together by repeaters

• No more than four repeaters between any host
  – <2500 meters

• < 1024 hosts

• Terminators are attached to each end of the segment

• Manchester encoding
How to expand an Ethernet segment (II)

- Starting with 10Base-T, stations are connected to a hub (or a switch) in a star configuration
- 100Mbps, 1000Mbps

10 Base-T cable and jack

A hub is a multiway repeater
Collision Domain

• Any host hears any other host
  – A single segment
  – Multiple segments connected by repeaters
  – Multiple segments connected by a hub

☐ All these hosts are competing for access to the same link, and as a consequence, they are said to be in the same collision domain.
**Access control**

- Bit-oriented framing
- In a host’s memory, Ethernet header is 14 bytes
- The adaptor adds the preamble and CRC
- The type field is the de-multiplexor

- 46-1500 bytes of data
  - Pad to minimum length
  - Minimum length is for collision detection
- 802.3 has the same header format, but substitutes type with length field
  - How to tell whether the field indicates type or length?
    - All types > 1500B
A prettier picture

- You’ll need to know this for Lab 2
Ethernet addresses

- A flat unique 6-byte address per adaptor
  - 00-13-E8-6D-8C-3D
- Each manufacture is given a unique prefix
  - e.g: 8:0:20::??:??:?? - Advanced Micro Devices (AMD)
- An all 1s address is a broadcast address (FF:FF:FF:FF:FF:FF)
- An address with first bit 1 but not broadcast is multicast

An adaptor receives

- Frames with its address as a destination address
- In promiscuous mode, delivers all frames
- Broadcast frames
- Multicast frames if configured to
Transmitter Algorithm (1)

1. The adaptor receives datagram from network layer, creates frame
2. If the adaptor senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.
3. If NIC transmits an entire frame without detecting another transmission, NIC is done with frame!
4. If NIC detects another transmission while transmitting, aborts and sends jam signal (collision!!)

Transmitter Algorithm (2)

• If collision…
  – jam for 32 bits, then stop transmitting frame
  – Wait and try again
    • exponential backoff (doubling the delay interval of each collision)
    • After the $n$th collision: the adaptor waits for $k \times 51.2$us, for randomly selected $k=0, \ldots, 2^n - 1$
      – 1st time: 0 or 51.2us
      – 2nd time: 0, 51.2, 102.4, or 153.6us
      – …
    • give up after several tries (usually 16)
Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

• An adaptor senses the signals on the line and compares it with its own
  – If same, no collision; otherwise, collision
  – Sends 32-bit jamming sequence after collision

• In the worst case, a sender needs to send 512 bits (46+14+4 = 64B) to detect collision
  – Why?
A and B are at opposite ends of the network

One way delay is d

A needs to send for 2d (round-trip delay) to detect collision

2d = 51.2 μs. On a 10Mps Ethernet, corresponds to 512 bits

Related to maximum Ethernet length ~ 2500 m

Has some margin for errors

(a) A sends a frame at time t;

(b) A’s frame arrives at B at time t + d;

(c) B begins transmitting at time t + d and immediately collides with A’s frame;

(d) B’s runt (32-bit) frame arrives at A at time t + 2d.
• Propagation delay for this maximum-extent Ethernet network is 25.6us
• \(2d = 51.2us\)
• Minimum Ethernet packet frame is 512 bits (64B)
  – Header 14B, payload 46B, CRC 4B
Ethernet experience

• 30% utilization is heavy
• Most Ethernets are not light loaded
• Very successful
  – Easy to maintain
  – Price: does not require a switch which used to be expensive
Wireless links

- Most common
  - Asymmetric
- Point-to-multipoint
Wireless access control

- Can’t use Ethernet protocol
  - Hidden terminal
    - A and C can’t hear each other’s collision at B
  - Exposed terminal
    - B can send to A; C can send to D
802.11 (WiFi) Multiple access with collision avoidance (CSMA/CA)

- Sender and receiver exchange control
  - Sender → receiver: Request to send (RTS)
    - Specifies the length of frame
  - Receiver → sender: Clear to send (CTS)
    - Echoes length of frame
  - Sender → receiver: frame
  - Receiver → sender: ack
  - Other nodes can send after hearing ACK

- Node sees CTS
  - Too close to receiver, can’t transmit
  - Addressing hidden terminals

- Node only sees RTS
  - Okay to transmit
  - Addressing exposed terminals
How to resolve collision

• Sender cannot do collision detection
  – Single antenna can’t send and receive at the same time

• If no CTS, then RTS collide
• Exponential backoff to retransmit
Distribution system

- Hosts associate with APs
- APs connect via the distribution system
  - A layer-2 system
    - Ethernet, token ring, etc.
  - Host IP addresses do not need to change
AP association

• Active scanning
  – Node: Probe
  – APs: Probe response
  – Node selects one of APs, send Association request
  – AP replies Association Response

• Passive scanning
  – AP sends Beacon to announce itself
  – Node sends Association Request
Frame format

- Same AP
  - Addr1: dst
  - Addr2: src

- Different Aps
  - ToDS and FromDS in control field set
  - Addr1: dst, Addr2: AP_dst
  - Addr3: AP_src, Add4: src
Bluetooth

- Connecting devices: mobile phones, headsets, keyboards
  - Very short range communication
  - Low power
- License exempt band 2.45 Ghz
- 1~3Mpbs
- Specified by Bluetooth Special Interest Group
A Bluetooth piconet

- A master device and up to seven slave devices
- Communication is between the master and a slave
Cell phone technologies

- Using licensed spectrum
- Different bands using different frequencies
- **Base stations** form a wired network
- Geographic area served by a base station’s antenna is called a **cell**
  - Similar to wifi
- Phone is associated with one base station
- Leaving a cell entering a cell causes a **handoff**
Cellular technologies

• 1G: analog
• 2G: digital and data
• 3G: higher bandwidth and simultaneous voice and data
• 4G: even higher. Top around 2.6Ghz
• 5G: 15Ghz
<table>
<thead>
<tr>
<th>List of mobile phone generations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0G (radio telephones)</strong></td>
</tr>
<tr>
<td><strong>1G (1985)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>2G (1992)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>2G transitional (2.5G, 2.75G)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>3G (2003)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>3G transitional (3.5G, 3.75G, 3.9G)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>4G (2013)</strong></td>
</tr>
<tr>
<td>(IMT Advanced)</td>
</tr>
<tr>
<td><strong>5G (2020)</strong></td>
</tr>
<tr>
<td>(IMT-2020) (Under development)</td>
</tr>
</tbody>
</table>
Summary

• A new reliable transmission mechanism
  – Current logical channels

• Multiple access links
  – Ethernet
  – 802.11 (WiFi)
  – Bluetooth
  – Cell phone
  – Note: understand the concepts
Backup
Token rings

- A token circulates the ring

- If a node has something to send, take the token off the ring, and send the frame
  - Node 1

- Each node along the way simply forwards the frame

- Receiver copies the frame
  - Node 4

- Frame comes back to sender
  - Sender removes the packet and puts the token back
Token ring standard

- IBM Token Ring
- A nearly identical IEEE standard
  - 802.5: not widely used
- Fiber Distributed Data Interface (FDDI)
  - Derived from the IEEE 802.4
- Resilient Packet Ring (RPR)
  - 802.17
Challenges must be addressed

• Fault tolerance

• Media access control
  – How long each node can hold the token?

• Reliability
  – How does the sender know the frame is received

• Resource utilization
Adding fault tolerance

- Problem: single node powers off disconnects the ring
- Solution: relay that closes when host’ss powered off

an electromechanical relay

(a) Host

From previous host

To next host

Relay

(b) Host

From previous host

To next host

Relay
Token ring media access control

- An adaptor has a receiver and a transmitter
- Problem: how long can a node hold a token?
  - Token holding time (THT), default 10ms in 802.5
  - Short: waste bandwidth
  - Long: starve others
  - What if you have an important short message?
802.5 Token Access Protocol

- A token has a 3-bit priority field
- A frame has three reservation bits
  - A device seizes the token if its packet is at least as the token
  - Reservation
    - A sender X sets priority n in the three reservation bits in a frame if
      - The bits are not set to a higher value
    - The station that holds the token set priority to n
  - Sender X lowers the token priority after releasing it so other senders can send
  - Drawback: may starve lower priority traffic
Token ring reliability

• No sliding window!

• Two trailing bits (A, C) after each frame
  – A recipient sets A bit when it sees the frame
  – Sets C bit after it copies the frame back to its adaptor
  – If a sender does not see both bits set, retransmits

- A=0, C=0: the intended recipient is not functioning or absent
- A=1, C=0: for some reason (e.g., lack of buffer space), the destination could not accept the frame
- A=1, C=1: frame received
When to release a token

- Early release:
  Sender inserts the token back onto the ring immediately following its frame

- Late release:
  Sender inserts the token after the frame it transmits has gone all the way around the ring and been removed

Which one is better?
- 802.5 originally used (b), and adds (a) later
A monitor makes sure the token is not lost
  – Periodically announces itself

If the monitor fails
  – A station elects itself by sending a claim token
  – If the token comes back, it’s the monitor
  – If competition, highest address wins
Monitor’s job

• If it does not see a token for a long time, it creates a new one
  – # of stations * token holding time + ringLatency

• Detect and remove orphaned frames (whose “parent” died)
  – Monitor sets a head bit to 1 after seeing a frame
  – If it sees the bit already set, remove the packet
Similar to the Ethernet, 802.5 addresses are 48 bits long.
The frame also includes a 32-bit CRC.
Frame status byte includes the A and C bits for reliable delivery.
Transmitter Algorithm

Begin: Wait until the line is idle and has data to send, the adaptor sends it, and listens to collision

– If no, go back to Begin
– else exponentially backoff
  • randomly selects a k between \([0,2^n-1]\), waits for \(k \times 51.2 \, \mu s\) to try Begin again

• Gives up after \(n\) reaches 16
• One way delay is $d$
• A needs to send for $2d$ duration to detect collision
• $2d = 512 \mu s$. On a 10Mps Ethernet, corresponds to 512 bits
Token rings

- A token circulates the ring

- If a node has something to send, take the token off the ring, and send the frame

- Receiver copies the frame

- Frame comes back to sender

- Sender removes the packet and puts the token back
When to release a token

- A) early; b) late
- Which one is better?
  - 802.5 has a,b