CS4220
Computer Networks

Lecture 4 Medium Access Control

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Medium Access Control Sublayer
Chapter 4

• Channel Allocation Problem
• Multiple Access Protocols
• Ethernet
• Wireless LANs
• Broadband Wireless
• Bluetooth
• RFID
• Data Link Layer Switching
The MAC Sublayer

- Responsible for deciding who sends next on a multi-access link
  - An important part of the link layer, especially for LANs

Chapter Overview

- Broadcast Networks
  - All information sent to all users
  - No routing
  - Shared media
  - Radio
    - Cellular telephony
    - Wireless LANs
  - Copper & Optical
    - Ethernet LANs
    - Cable Modem Access

- Medium Access Control
  - To coordinate access to shared medium
  - Data link layer since direct transfer of frames

- Local Area Networks
  - High-speed, low-cost communications between co-located computers
  - Typically based on broadcast networks
  - Simple & cheap
  - Limited number of users
Multiple Access Communications

° Shared media basis for broadcast networks
  • Inexpensive: radio over air; copper or coaxial cable
  • M users communicate by broadcasting into medium

° Key issue: How to share the medium (multi-access) when there is a competition for it?
  • The control protocols are in MAC sublayer

Approaches to Media Sharing

Medium sharing techniques

° Static channelization
° Dynamic medium access control

Partition medium
° Dedicated allocation to users
° Satellite transmission
° Cellular Telephone

Scheduling
° Polling: take turns
° Request for slot in transmission schedule
° Token ring
° Wireless LANs

Random access
° Loose coordination
° Send, wait, retry if necessary
° Aloha
° Ethernet
Channelization: Satellite

Satellite Channel

*uplink* $f_{in}$  
*downlink* $f_{out}$

What we can learn from the foundations of queueing theory?

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Static Channel Allocation in LANs and MANs

- Frequency Division Multiplexing (FDM): for $N$ users, divide the bandwidth of the channel into $N$ equal-sized portions
- Given a multi-access channel with capacity $C$ bps, the average arrival rate of $N$ users $\lambda$ frames/sec (Poisson), average frame size $1/\mu$ bits/frame (exponential).

What is the service rate?

What is the average response time ($= 1 / (\text{service rate} - \text{arrival rate})$) of frames in a single channel (queue) system?

What is the average response time ($= 1 / (\text{service rate} - \text{arrival rate})$) of frames in a multi-channel (multiple queues) system?

When they are the same?

What is the problem of FDM?
**Dynamic Channel Allocation in LANs and MANs**

**Assumptions**

- Station Model: $N$ independent stations generating frames at a constant rate, one-by-one transmission
- Single Channel: only one for all stations equivalently
- Collision: if two frames are transmitted simultaneously, the resulting signal is garbled
  - (a) Continuous Time: transmission begins at any instant.
  - (b) Slotted Time: transmission begins at the start of a slot.
- (a) Carrier Sense: stations can sense the channel busy or idle.
  - (b) No Carrier Sense: just go ahead transmission

LANs generally have carrier sense, how about wireless networks?

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**Random Access**

**Multi-tapped (mulit-access) Bus**

Transmit when ready

Transmissions can occur; need retransmission strategy
Scheduling: Polling

Multiple Access Protocols

- ALOHA
- Carrier Sense Multiple Access Protocols
- Collision-Free Protocols
- Limited-Contention Protocols
- Wavelength Division Multiple Access Protocols
- Wireless LAN Protocols
In pure ALOHA, frames are transmitted at completely arbitrary times.

How a station knows its frame was destroyed due to collision?

Feedback property of broadcasting.

What is the efficiency of an ALOHA channel?

\[ S = G \times P_0 \]

Pure ALOHA (2)

- \( G \) per frame time be the mean number of transmission attempts per frame time, and \( P_0 \) is the probability of a transmission does not suffer a collision, throughput \( S = G \times P_0 \)
**Slotted ALOHA**

- A station is required to wait for the beginning of the next slot, one time slot corresponding to one frame time

  What is the vulnerable period for a frame?
  What is required to turn a pure ALOHA to a slotted ALOHA?
  What benefit received by slotted ALOHA?
  What is the price for the benefit? And how much?

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**Throughput of ALOHA Systems**

Throughput versus offered traffic for ALOHA systems.

Are ALOHA protocols carrier sense?
Example

- Five thousand banking stations are competing for the use of a single slotted ALOHA channel. The average station makes 72 requests/hour. A slot is 125 $\mu$sec. What is the average total channel load? And what is the throughput $S$?

$$G = 5000 \times 0.02 \times 0.00125 = 1/80$$

Carrier Sensing Multiple Access (CSMA)

- A station senses the channel before it starts transmission
  - If busy, either wait or schedule backoff (different options)
  - If idle, start transmission
  - Vulnerable period is reduced to $t_{prop}$ (channel capture effect)
  - When collisions occur they involve entire frame transmission times
  - Always better than ALOHA?
CSMA Options

Transmitter behavior when busy channel is sensed

- 1-persistent CSMA (most greedy)
  - Start transmission as soon as the channel becomes idle
  - Possible simultaneously transmission in a propagation delay
  - Low delay and low efficiency

- Non-persistent CSMA (least greedy)
  - If busy, wait a backoff period, then sense carrier again
  - High delay and high efficiency

- p-persistent CSMA (adjustable greedy)
  - Wait till channel becomes idle, transmit with prob. p; or wait one mini-slot time & re-sense with probability 1-\( p \)
  - Delay and efficiency can be balanced

CSMA Performance

Comparison of the channel utilization versus load.

What is the price of non-persistent and p-persistent protocols?

Longer delay

UC. Colorado Springs
CSMA with Collision Detection

- CSMA/CD: a station aborts its transmission as soon as it detects a collision – quickly terminating a damaged frame saves T & BW
- Widely used on LANs in the MAC sublayer

CSMA/CD can be in one of three states: contention, transmission, or idle.

Can collision occur with CSMA/CD? If so, when does it occur and when does it not occur?

When a station can seize the channel for transmission (how long is the contention)?

Why CSMA/CD More Efficient?

- Monitor for collisions & abort transmission
  - Stations with frames to send, first do carrier sensing
  - After beginning transmissions, stations continue listening to the medium to detect collisions
  - If collisions detected, all stations involved stop transmission, reschedule random backoff times, and try again at scheduled times
- In CSMA collisions result in wastage of X seconds spent transmitting an entire frame
- CSMA-CD reduces wastage to time to detect collision and abort transmission
Delay-Bandwidth Product

- **Delay-bandwidth** product key parameter
  - Coordination in sharing medium involves using bandwidth (explicitly or implicitly)
  - Difficulty of coordination commensurate with delay-bandwidth product

- **Simple two-station example**
  - Station with frame to send listens to medium and transmits if medium found idle
  - Station monitors medium to detect collision
  - If collision occurs, station that begin transmitting earlier retransmits (propagation time is known)

When a station can know it has seized the channel for transmission successfully?

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Two-Station MAC Example

Two stations are trying to share a common medium

A transmits at \( t = 0 \)

Distance \( d \) meters

\( t_{prop} = \frac{d}{v} \) seconds

A detects collision at \( t = 2t_{prop} \)

Case 1

Station listens to medium and transmits if medium found idle

B does not transmit before \( t = t_{prop} \) & A captures channel

Case 2

A detects collision before \( t = t_{prop} \) & detects collision soon thereafter

B transmits before \( t = t_{prop} \) and detects collision soon thereafter

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**Efficiency of Two-Station Example**

- Each frame transmission requires $2t_{\text{prop}}$ of quiet time
  - Station B needs to be quiet $t_{\text{prop}}$ before and after time when Station A transmits
  - $R$ transmission bit rate
  - $L$ bits/frame

Efficiency

$$\rho_{\text{max}} = \frac{L}{L + 2t_{\text{prop}} R} = \frac{1}{1 + 2t_{\text{prop}} R / L} = \frac{1}{1 + 2a}$$

MaxThroughput

$$R_{\text{eff}} = \frac{L}{L / R} = \frac{1}{1 + 2a} \text{bits/second}$$

Normalized Delay-Bandwidth Product

$$a = \frac{t_{\text{prop}}}{L / R}$$

- Propagation delay
- Time to transmit a frame

**Typical MAC Efficiencies**

Two-Station Example:

$$\text{Efficiency} = \frac{1}{1 + 2a}$$

- If $a<<1$, then efficiency close to 100%
- As $a$ approaches 1, the efficiency becomes low

CSMA-CD (Ethernet) protocol:

$$\text{Efficiency} = \frac{1}{1 + 5.44a}$$

Token-ring network

$$\text{Efficiency} = \frac{1}{1 + a'}$$

$a'$ = latency of the ring (bits)/average frame length
Typical Delay-Bandwidth Products

<table>
<thead>
<tr>
<th>Distance</th>
<th>10 Mbps</th>
<th>100 Mbps</th>
<th>1 Gbps</th>
<th>Network Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td>3.33 x 10^{-2}</td>
<td>3.33 x 10^{-1}</td>
<td>3.33 x 10^0</td>
<td>Desk area network</td>
</tr>
<tr>
<td>100 m</td>
<td>3.33 x 10^{-1}</td>
<td>3.33 x 10^{0}</td>
<td>3.33 x 10^3</td>
<td>Local area network</td>
</tr>
<tr>
<td>10 km</td>
<td>3.33 x 10^{0}</td>
<td>3.33 x 10^{3}</td>
<td>3.33 x 10^{4}</td>
<td>Metropolitan area network</td>
</tr>
<tr>
<td>1000 km</td>
<td>3.33 x 10^{4}</td>
<td>3.33 x 10^{5}</td>
<td>3.33 x 10^{6}</td>
<td>Wide area network</td>
</tr>
<tr>
<td>100000 km</td>
<td>3.33 x 10^{6}</td>
<td>3.33 x 10^{5}</td>
<td>3.33 x 10^{8}</td>
<td>Global area network</td>
</tr>
</tbody>
</table>

° Max size Ethernet frame (payload): 1500 bytes = 12000 bits

° Long and/or fat pipes give large $\alpha$

Carrier Sensing and Priority Transmission

° Certain applications require faster response than others, e.g. ACK messages

° Impose different inter-frame times
  • High priority traffic sense channel for time $\tau_1$
  • Low priority traffic sense channel for time $\tau_2 > \tau_1$
  • High priority traffic, if present, seizes channel first

° This priority mechanism is used in IEEE 802.11 wireless LAN
Next: Scheduling for Medium Access Control

- Schedule frame transmissions to avoid collision in shared medium
  - More efficient channel utilization
  - Less variability in delays
  - Can provide fairness to stations
    - Increased computational or procedural complexity
- Two main approaches
  - Reservation
  - Polling

Reservation System Options

- Centralized or distributed system
  - Centralized systems: A central controller listens to reservation information, decides order of transmission, issues grants
  - Distributed systems: Each station determines its slot for transmission from the reservation information
- Single or Multiple Frames
  - Single frame reservation: Only one frame transmission can be reserved within a reservation cycle
  - Multiple frame reservation: More than one frame transmission can be reserved within a frame
- Channelized or Random Access Reservations
  - Channelized (typically TDMA) reservation: Reservation messages from different stations are multiplexed without any risk of collision
  - Random access reservation: Each station transmits its reservation message randomly until the message goes through
Collision-Free (1): A Bit-Map Reservation Protocol

- Assumptions: \( N \) stations have unique addresses 0 to \( N - 1 \)
  - Which station gets the channel after a successful transmission?

- A bit-map protocol:
  - a contention period has exactly \( N \) slots and a station \( j \) announces it has a frame to send by inserting a bit of 1 into slot \( j \)

![Diagram showing the bit-map protocol]

The basic bit-map protocol.

How long should be one contention slot?
Is it fair to stations with different addresses?

Analysis of a Bit-Map Protocol

- How long does a station have to wait in the worst case before it can start transmitting its frame over a LAN that uses the basic bit-map protocol?

![Diagram showing the analysis of the bit-map protocol]

The basic bit-map protocol.

What is the overhead per frame and the efficiency at high and low load? (if propagation delay is negligible) how about delay?

- Low load: \( d/(N+d) \)
- High load: \( 1/(d+1) \)
Collision-Free (2) – Token Ring

- Token sent round ring defines the sending order
  - Station with token may send a frame before passing
  - Idea can be used without ring too, e.g., token bus

Collision-Free (3) – Countdown

- Binary countdown improves on the bitmap protocol
  - Stations send their address in contention slot (log N bits instead of N bits)
  - Medium ORs bits; stations give up when they send a “0” but see a “1”
  - Station that sees its full address is next to send

<table>
<thead>
<tr>
<th>Bit time</th>
<th>0 1 2 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 1 0</td>
<td>0 -- --</td>
</tr>
<tr>
<td>0 1 0 0</td>
<td>0 -- --</td>
</tr>
<tr>
<td>1 0 0 1</td>
<td>1 0 0 --</td>
</tr>
<tr>
<td>1 0 1 0</td>
<td>1 0 1 0</td>
</tr>
</tbody>
</table>

A dash indicates silence.
Limited-Contention Protocols (1)

- Idea is to divide stations into groups within which only a very small number are likely to want to send
  - Avoids wastage due to idle periods and collisions

![Probability of success graph](image)

Already too many contenders for a good chance of one winner

Limited Contention (2) – Adaptive Tree Walk

- Tree divides stations into groups (nodes) to poll
  - Depth first search under nodes with poll collisions
  - Start search at lower levels if >1 station expected

![Tree diagram](image)
Wireless LAN Protocols (1)

- Wireless has complications compared to wired.
- Nodes may have different but fixed coverage regions
  - If a receiver is within the range of two active transmitter, the resulting signal will be garbled and useless
  - Leads to hidden and exposed terminals
- Nodes can’t detect collisions, i.e., sense while sending
  - Makes collisions expensive and to be avoided

Wireless LANs (2) – Hidden terminals

- Hidden terminals are senders that cannot sense each other but nonetheless collide at intended receiver
  - Want to prevent; loss of efficiency
  - A and C are hidden terminals when sending to B

![Diagram showing radio range and hidden terminals](image)
Wireless LANs (3) – Exposed terminals

- **Exposed terminals** are senders who can sense each other but still transmit safely (to different receivers)
  - Desirably concurrency; improves performance
  - B $\rightarrow$ A and C $\rightarrow$ D are exposed terminals

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CSMA with Collision Avoidance (MACA)

(a) A requests to send

(b) B announces A ok to send

(c) A sends Data Frame

How C knows how long to set NAV (network allocation vector)?
**Wireless LAN Protocols - MACA**

- Multiple access with collision avoidance: the sender stimulates the receiver into outputting a short frame so stations nearly can detect the transmission and avoid transmitting for the duration of the upcoming data frame.

![Diagram of MACA](image)

A sending an RTS to B.

B responding with a CTS to A.

Can C transmit the data somewhere simultaneously? Can D? Can E?

Can a collision still occur?

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**What is a LAN?**

Local area means:

- Private ownership
  - freedom from regulatory constraints of WANs
- Short distance (~1km) between computers
  - low cost
  - very high-speed, relatively error-free communication
  - complex error control unnecessary
- Machines are constantly moved
  - Keeping track of location of computers a chore
  - Simply give each machine a unique address
  - *Broadcast all messages to all machines in the LAN*
- Need a *medium access control protocol*
**Typical LAN Structure**

- Transmission Medium
- Network Interface Card (NIC)

**Unique MAC “physical” address**

**Ethernet**

- Ethernet Cabling
- Manchester Encoding
- The Ethernet MAC Sublayer Protocol
- The Binary Exponential Backoff Algorithm
- Ethernet Performance
- Switched Ethernet
- Fast Ethernet
- Gigabit Ethernet
- IEEE 802.2: Logical Link Control
A bit of history…

- 1970  ALOHA network deployed in Hawaiian islands
- 1973  Metcalf and Boggs invent Ethernet, random access in wired net
- 1979  DIX Ethernet II Standard
- 1985  IEEE 802.3 LAN Standard (10 Mbps)
- 1995  Fast Ethernet (100 Mbps)
- 1998  Gigabit Ethernet
- 2002  10 Gigabit Ethernet
- Ethernet is the dominant LAN standard

Metcalf’s Sketch

<table>
<thead>
<tr>
<th>Name</th>
<th>Cable</th>
<th>Max. seg.</th>
<th>Nodes/seg.</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>10Base5</td>
<td>Thick coax</td>
<td>500 m</td>
<td>100</td>
<td>Original cable; now obsolete</td>
</tr>
<tr>
<td>10Base2</td>
<td>Thin coax</td>
<td>185 m</td>
<td>30</td>
<td>No hub needed</td>
</tr>
<tr>
<td>10Base-T</td>
<td>Twisted pair</td>
<td>100 m</td>
<td>1024</td>
<td>Cheapest system</td>
</tr>
<tr>
<td>10Base-F</td>
<td>Fiber optics</td>
<td>2000 m</td>
<td>1024</td>
<td>Best between buildings</td>
</tr>
</tbody>
</table>

The most common kinds of Ethernet cabling.
IEEE 802.3 MAC: Ethernet

MAC Protocol:

- CSMA/CD

- Slot Time is the critical system parameter
  - upper bound on time to detect collision
  - upper bound on time to acquire channel
  - upper bound on length of frame generated by collision
  - quantum for retransmission scheduling
  - At least round-trip propagation

- Truncated binary exponential backoff
  - for nth retransmission: $0 < r < 2^k$, where $k = \min(n, 10)$
  - Give up after 16 retransmissions

Ethernet MAC Sublayer Protocol

Frame formats. (a) DIX Ethernet, (b) IEEE 802.3.

<table>
<thead>
<tr>
<th>Bytes</th>
<th>8</th>
<th>6</th>
<th>2</th>
<th>0-1500</th>
<th>0-46</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Preamble</td>
<td>Destination address</td>
<td>Source address</td>
<td>Type</td>
<td>Data</td>
<td>Pad</td>
</tr>
<tr>
<td>(b)</td>
<td>Preamble</td>
<td>Source address</td>
<td>Length</td>
<td>Data</td>
<td>Pad</td>
<td>Check-sum</td>
</tr>
</tbody>
</table>

Multicast, broadcast, and group management

What is the maximum and minimum size of an Ethernet frame?
Why Pad is 0-46? Can we say the maximum is 1518?
### Ethernet MAC Sublayer Protocol (2)

- Why there is a minimum length (64B) for a frame?
  - All frames must take more than $2\tau$ to send so that the transmission is still taking place when the noise burst gets back to the sender.

Collision detection can take as long as $2\tau$ (50 µsec in 10 Mbps 2500m).

### The Binary Exponential Backoff Algorithm

- CSMA/CD: a station aborts its transmission ASAP a detection collision – quickly terminating a damaged frame saves T & BW
  - If there is a collision, a station waits a random amount of time to try again, how randomization is done?
  - Binary exponential backoff: after $i$ collisions, a random number between 0 to $2^i - 1$ is chosen, that number of slots is skipped

CSMA/CD can be in one of three states: contention, transmission, or idle.

What is a time slot used in Ethernet?
**Ethernet Performance**

- How long does it take to resolve contention?
- Contention is resolved (“success”) if exactly 1 station transmits in a slot:
  \[ P_{\text{success}} = kp(1 - p)^{k-1} \]
- By taking derivative of \( P_{\text{success}} \) we find max occurs at \( p = 1/k \)
  \[ P_{\text{success}}^{\max} = k \left( 1 - \frac{1}{k} \right)^{k-1} = \left( 1 - \frac{1}{k} \right)^{k-1} \rightarrow \frac{1}{e} \]
- On average, \( 1/P_{\text{max}} = e = 2.718 \) time slots to resolve contention

**Average Contention Period** = \( 2t_{\text{prop}} e \) seconds

**Efficiency** = \( \frac{1}{1 + 5.44a} \)

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**Switched Ethernet**

A simple example of switched Ethernet.

How about collision domain (and buffering)?
Fast Ethernet

The original fast Ethernet cabling.

<table>
<thead>
<tr>
<th>Name</th>
<th>Cable</th>
<th>Max. segment</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>100Base-T4</td>
<td>Twisted pair</td>
<td>100 m</td>
<td>Uses category 3 UTP</td>
</tr>
<tr>
<td>100Base-TX</td>
<td>Twisted pair</td>
<td>100 m</td>
<td>Full duplex at 100 Mbps</td>
</tr>
<tr>
<td>100Base-FX</td>
<td>Fiber optics</td>
<td>2000 m</td>
<td>Full duplex at 100 Mbps; long runs</td>
</tr>
</tbody>
</table>

Fast Ethernet (2)

- Ethernet frames must be at least 64 bytes long to ensure that the transmitter is still going in the event of a collision at the far end of the cable. Fast Ethernet has the same 64-byte minimum frame size but can get the bits out ten times faster. How is it possible to maintain the same minimum frame size?

![Diagram of packet transmission and collision detection](image)

Collision detection can take as long as $2\tau (50 \rightarrow 5 \mu\text{sec})$. 

Collision at time $\tau$.
### Medium Access Control Sublayer

In IEEE 802.2, Data Link Layer divided into:

1. **Medium Access Control Sub-layer**
   - Coordinate access to medium
   - Connectionless frame transfer service
   - Machines identified by MAC/physical address
   - Broadcast frames with MAC addresses

2. **Logical Link Control Sub-layer**
   - Between Network layer & MAC sublayer
   - Hides the difference between the various 802 networks
   - Can provide reliable communication – enhance services provided by MAC sub-layer
   - Closely based on the HDLC protocol
IEEE 802.2: Logical Link Control

- LLC: an error-controlled flow-controlled data link protocol
- also hides the differences between various kinds of 802 networks by providing a single format and interface to the network layer.

(a) Position of LLC.  (b) Protocol formats.

MAC Sub-layer

IEEE 802

OSI

Network layer

Data link layer

Physical layer
Logical Link Control Services

° Type 1: Unacknowledged connectionless service
  • Unnumbered frame mode of HDLC

° Type 2: Reliable connection-oriented service
  • Asynchronous balanced mode of HDLC

° Type 3: Acknowledged connectionless service

° Additional addressing
  • A workstation (NIC) has a single MAC physical address
  • Can handle several logical connections, distinguished by their SAP (service access points).

Wireless LANs

• The 802.11 Protocol Stack
• The 802.11 Physical Layer
• The 802.11 MAC Sublayer Protocol
• The 802.11 Frame Structure
• Services
The 802.11 Protocol Stack

Part of the 802.11 protocol stack.

802.11 physical layer

- NICs are compatible with multiple physical layers
  - E.g., 802.11 a/b/g

<table>
<thead>
<tr>
<th>Name</th>
<th>Technique</th>
<th>Max. Bit Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b</td>
<td>Spread spectrum, 2.4 GHz</td>
<td>11 Mbps</td>
</tr>
<tr>
<td>802.11g</td>
<td>OFDM, 2.4 GHz</td>
<td>54 Mbps</td>
</tr>
<tr>
<td>802.11a</td>
<td>OFDM, 5 GHz</td>
<td>54 Mbps</td>
</tr>
<tr>
<td>802.11n</td>
<td>OFDM with MIMO, 2.4/5 GHz</td>
<td>600 Mbps</td>
</tr>
</tbody>
</table>
The 802.11 MAC Sublayer Protocol

- **DCF**: distributed coordination function
- **PCF**: point coordination function

(a) The hidden station problem.  
(b) The exposed station problem.

The 802.11 MAC Sublayer Protocol (1)

- CSMA/CA inserts backoff slots to avoid collisions
- MAC uses ACKs/retransmissions for wireless errors
The 802.11 MAC Sublayer Protocol (2):

° Virtual channel sensing with the NAV and optional RTS/CTS (often not used) avoids hidden terminals

The use of virtual channel sensing using CSMA/CA (MACA).

How C and D knows how long to set NAV (network allocation vector)?

<table>
<thead>
<tr>
<th>Time</th>
<th>NAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

The 802.11 MAC Sublayer Protocol (3)

• What is the problem with the reliability of sending a long frame in wireless networks?

• Example: probability of any bit being in error is \( p \), what is the probability of an \( n \)-bit frame being received entirely correct?

  • \((1 - p)^n \approx 30\% \) for \( p = 10^{-4} \) for a full-size Ethernet frame

  • \((1 - p)^n \approx 11\% \) for \( p = 10^{-5} \) for a full-size Ethernet frame

Main benefit?
The 802.11 MAC Sublayer Protocol (4)

- If a frame is too long, very little of chance getting through undamaged and will probably have to be retransmitted
  - 802.11 allows frames to be fragmented to smaller pieces, each individually sequenced and acked with Stop&Wait
  - A fragment burst after a RTS/CTS

![Fragment burst diagram]

Main benefit?

The 802.11 MAC Sublayer Protocol (5)

- Different backoff slot times add quality of service
  - SIFS: receiver sends CTS, receiver sends ACK, sender sends a fragment without sending an RTS again
  - PIFS: base station send a beacon frame or poll frame
  - DIFS: any station can attempt to acquire a channel
  - EIFS: receiver to recover a bad frame

![Quality of service diagram]
Broadband Wireless

- 802.16 Architecture / Protocol Stack
- 802.16 Physical Layer
- 802.16 MAC
- 802.16 Frames

802.16 Architecture/Protocol Stack (1)

- Wireless clients connect to a wired base-station (like 4G)
**802.16 Architecture/Protocol Stack (2)**

- MAC is connection-oriented; IP is connectionless
  - Convergence sublayer maps between the two

**802.16 Physical Layer**

- Based on OFDM; base station gives mobiles bursts (subcarrier/time frame slots) for uplink and downlink
802.16 MAC

- Connection-oriented with base station in control
  - Clients request the bandwidth they need

- Different kinds of service can be requested:
  - Constant bit rate, e.g., uncompressed voice
  - Real-time variable bit rate, e.g., video, Web
  - Non-real-time variable bit rate, e.g., file download
  - Best-effort for everything else

802.16 Frames

- Frames vary depending on their type
- Connection ID instead of source/destination addresses

(a) A generic frame. (b) A bandwidth request frame
Bluetooth

- Bluetooth Architecture
- Bluetooth Applications
- The Bluetooth Protocol Stack
- The Bluetooth Radio Layer
- The Bluetooth Basaband Layer
- The Bluetooth L2CAP Layer
- The Bluetooth Frame Structure

Data Link Layer Switching

- Bridges from 802.x to 802.y
- Local Internetworking
- Spanning Tree Bridges
- Remote Bridges
- Repeaters, Hubs, Bridges, Switches, Routers, Gateways
- Virtual LANs
Data Link Layer Switching

Multiple LANs connected by a backbone to handle a total load higher than the capacity of a single LAN.

Autonomy, cost, load sharing, collision domain, distance, reliability, security

Local Internetworking: Hubs, Bridges & Routers

- Interconnecting LANs
  - Repeater/hub: Signal regeneration
    - All traffic appears in both LANs
  - Bridge: MAC address filtering
    - Local traffic stays in own LAN
  - Routers: Internet routing
    - All traffic stays in own LAN

Higher Scalability Efficiency?
Uses of Bridges

- Common setup is a building with centralized wiring
  - Bridges (switches) are placed in or near wiring closets

Local Internetworking

A configuration with four LANs and two bridges.
Operation at data link level implies capability to work with multiple MAC sub-layers

However, must deal with
- Difference in MAC formats
- Difference in data rates; buffering; timers; security
- Difference in maximum frame length

Common case involves LANs of same type
Bridging is done at MAC level
### Transparent Bridges

- Interconnection of IEEE LANs with complete transparency
- Use table lookup, and
  - discard frame, if source & destination in same LAN
  - forward frame, if source & destination in different LAN
  - use *flooding*, if destination unknown
- Use *backward learning* to build table
  - observe source address of arriving LANs
  - handle topology changes by removing old entries

---

### Backward Learning

- Use backward learning to build table
  - observe source address of arriving LANs
  - handle topology changes by removing old entries
S1 → S5

Address | Port
--- | ---
S1 | 1
S3 | 1

S3 → S2

Address | Port
--- | ---
S1 | 1
S3 | 2
Adaptive Learning

- In a static network, tables eventually store all addresses & learning stops
- In practice, stations are added & moved all the time
  - Introduce timer (minutes) to age each entry & force it to be relearned periodically
  - If frame arrives on port that differs from frame address & port in table, update immediately

Why not bridging the Internet?

Receivers, Hubs, Bridges, Switches, Routers and Gateways (2)

(a) A hub. (b) A bridge. (c) A switch.

Cut-through switches vs. store-and-forward switches
Different collision domains
Receivers, Hubs, Bridges, Switches, Routers and Gateways

(a) Which device is in which layer.

(b) Frames, packets, and headers.

Summary

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDM</td>
<td>Dedicate a frequency band to each station</td>
</tr>
<tr>
<td>WDM</td>
<td>A dynamic FDM scheme for fiber</td>
</tr>
<tr>
<td>TDM</td>
<td>Dedicate a time slot to each station</td>
</tr>
<tr>
<td>Pure ALOHA</td>
<td>Unsynchronized transmission at any instant</td>
</tr>
<tr>
<td>Slotted ALOHA</td>
<td>Random transmission in well-defined time slots</td>
</tr>
<tr>
<td>1-persistent CSMA</td>
<td>Standard carrier sense multiple access</td>
</tr>
<tr>
<td>Nonpersistent CSMA</td>
<td>Random delay when channel is sensed busy</td>
</tr>
<tr>
<td>P-persistent CSMA</td>
<td>CSMA, but with a probability of p of persisting</td>
</tr>
<tr>
<td>CSMA/CD</td>
<td>CSMA, but abort on detecting a collision</td>
</tr>
<tr>
<td>Bit map</td>
<td>Round robin scheduling using a bit map</td>
</tr>
<tr>
<td>Binary countdown</td>
<td>Highest numbered ready station goes next</td>
</tr>
<tr>
<td>Tree walk</td>
<td>Reduced contention by selective enabling</td>
</tr>
<tr>
<td>MACA, MACAW</td>
<td>Wireless LAN protocols</td>
</tr>
<tr>
<td>Ethernet</td>
<td>CSMA/CD with binary exponential backoff</td>
</tr>
<tr>
<td>FHSS</td>
<td>Frequency hopping spread spectrum</td>
</tr>
<tr>
<td>DSSS</td>
<td>Direct sequence spread spectrum</td>
</tr>
<tr>
<td>CSMA/CA</td>
<td>Carrier sense multiple access with collision avoidance</td>
</tr>
</tbody>
</table>

Channel allocation methods and systems for a common channel.
Reading

- Chapter 4 of the textbook
- Homework: see website