Multiple Access and Spanning Tree

EE122 Fall 2012

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Give it up for Gautam!

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…And to Jamie!

• “Also, shout-out to Jamie for being so generous with his test-cases yet again, and being so awesome about working out the problems that arose.”
Today is Panda’s Birthday!
Good News!

• Only half of you will flunk this course!

• Participation count now at roughly half the class

• Simple question:
  – *What the hell are the other half of you thinking?*

• The facts:
  – Not enough time for all of you to ask questions in class
  – Cannot just pop your head in OH and have that count.
  – So start participating now….
Upcoming lectures

• Congestion Control
• Advanced Topics in Congestion Control
• Wireless (Yahel Ben-David)
• Multicast/QoS/ReverseTR (Scott and Colin)
• Security
• SDN I
• SDN II
• Alternate Architectures
• Summing up
Clarification from last time

• Routing tables in “Routing Along DAGs” are per-destination

• Each link has a direction for each destination
  – The direction of the link needed to reach A may be different than the direction of the link needed to reach B

• This is no different than distance vector routing
  – DV has a distance for each destination

• RAD has a vector of directions for each link
Some History

- Ethernet was invented as a broadcast technology
  - Each packet received by all attached hosts

- Easy to set up, cheap to build
  - But hosts had to share channel (multiple access)

- Current Ethernets are “switched”
  - No sharing

- But need spanning tree to route on switches
  - Everyone hates spanning tree, trying to eliminate it
Today

• Study two algorithms that are dying out
  – But both important conceptually!

• Spanning Tree (endangered algorithms list)
  – Still used, but alternatives being developed

• Multiple Access in wired media (extinct)
  – Not used at all, but useful background for wireless
Routing in Switched Ethernets
Shuttling Data at Different Layers

- Different devices switch different things
  - Physical layer: electrical signals or bits (hubs)
  - Link layer: frames (switches)
  - Network layer: packets (routers)
Switches Enable Concurrent Comm.

• Host A can talk to C, while B talks to D

• Completely avoids collisions (if hosts directly attached)
  • No need for all material we discuss later in lecture
  • Change in nature of multiple access, but same framing
    • **Key to the success of ethernet!**
Self Learning

• Maps destination MAC to outgoing interface
• Construct switch table automatically
• Floods when does not have entry in table
Flooding Can Lead to Loops

• Flooding can lead to forwarding loops
  – E.g., if the network contains a cycle of switches
  – “Broadcast storm”
Solution: Spanning Trees

• Ensure the forwarding **topology** has no loops
  – Avoid using some of the links when flooding
  – … to prevent loop from forming

• **Spanning tree**
  – **Sub-graph** that covers all vertices but contains no cycles
  – Links not in the spanning tree do not forward frames
You: Design a Spanning Tree Algorithm

- Distributed
- No global information
- Neighbors can exchange information
- Must adapt when failures occur
  - But don’t worry about that on first try…
- Take 5 minutes, break into groups, report back
What Do We Know?

• Shortest paths to (or from) a node form a tree
  – No shortest path can have a cycle

• But we must limit each node to one outgoing port towards destination
  – Why?

• Because this is not a directed graph!
Two Shortest Paths Create Cycle!
Must only choose one
Algorithm Has Two Aspects

• Pick a root:
  – This will be the destination to which all shortest paths go
  – **Pick the one with the smallest identifier (MAC add.)**

• Compute shortest paths to the root
  – Only keep the links on shortest-paths
  – Break ties in some way, so only keep one shortest path from each node
Breaking Ties

• When there are multiple shortest paths to the root, choose the path that uses the neighbor switch with the lower ID.

• One could use any tiebreaking system, but this is an easy one to remember and implement

• In homeworks and test, remember this.
Constructing a Spanning Tree

• Switches need to **elect a root**
  – The switch w/ smallest identifier (MAC addr)

• Each switch determines if each interface is on the **shortest path** from the root
  – Excludes it from the tree if not

• **Messages** (Y, d, X)
  – From node X
  – Proposing Y as the root
  – And the distance is d
Steps in Spanning Tree Algorithm

• Initially, each switch proposes itself as the root
  – Switch sends a message out every interface
  – … proposing itself as the root with distance 0
  – Example: switch X announces (X, 0, X)

• Switches update their view of the root
  – Upon receiving message (Y, d, Z) from Z, check Y’s id
  – If new id smaller, start viewing that switch as root

• Switches compute their distance from the root
  – Add 1 to the distance received from a neighbor
  – Identify interfaces not on shortest path to the root
  – … and exclude them from the spanning tree

• If root or shortest distance to it changed, “flood” updated message (Y, d+1, X)
Example From Switch #4’s Viewpoint

• Switch #4 thinks it is the root
  – Sends (4, 0, 4) message to 2 and 7

• Then, switch #4 hears from #2
  – Receives (2, 0, 2) message from 2
  – … and thinks that #2 is the root
  – And realizes it is just one hop away

• Then, switch #4 hears from #7
  – Receives (2, 1, 7) from 7
  – And realizes this is a longer path
  – So, prefers its own one-hop path
  – And removes 4-7 link from the tree
Example From Switch #4’s Viewpoint

- Switch #2 hears about switch #1
  - Switch 2 hears (1, 1, 3) from 3
  - Switch 2 starts treating 1 as root
  - And sends (1, 2, 2) to neighbors

- Switch #4 hears from switch #2
  - Switch 4 starts treating 1 as root
  - And sends (1, 3, 4) to neighbors

- Switch #4 hears from switch #7
  - Switch 4 receives (1, 3, 7) from 7
  - And realizes this is a longer path
  - So, prefers its own three-hop path
  - And removes 4-7 link from the tree
Which links are on spanning tree?

• Take a few minutes, work this out
• 3-1?
• 5-1?
• 6-1?
• 2-6?
• 2-3?
Links on spanning tree

• 3-1
• 5-1
• 6-1
• 2-3
• 4-2
• 7-2
Now which ones are on the spanning tree?

- 2 is new root
- 3-2
- 6-2
- 4-2
- 7-2
- 5-6
Robust Spanning Tree Algorithm

- Algorithm must react to failures
  - Failure of the root node
    o Need to elect a new root, with the next lowest identifier
  - Failure of other switches and links
    o Need to recompute the spanning tree

- Root switch continues sending messages
  - Periodically reannouncing itself as the root (1, 0, 1)
  - Other switches continue forwarding messages

- Detecting failures through timeout (soft state)
  - If no word from root, *time out and claim to be the root!*
Why do people hate spanning tree?

• Delay in reestablishing spanning tree
  – Network is “down” until spanning tree rebuilt
  – Work on rapid spanning tree algorithms…
    o And multiple spanning trees

• Much of the network bandwidth goes unused
  – Forwarding is only over the spanning tree
  – Why did you bother with all those other links?
Broadcast vs Point-to-Point
Point-to-Point vs. Broadcast Media

• Point-to-point: dedicated pairwise communication
  – Long-distance fiber link
  – Point-to-point link between Ethernet switch and host

• Broadcast: shared wire or medium
  – Traditional Ethernet
  – 802.11 wireless LAN
Multiple Access Algorithm

• Single shared broadcast channel
  – Must avoid having multiple nodes speaking at once
  – Otherwise, collisions lead to garbled data
  – Need distributed algorithm for sharing the channel
  – Algorithm determines which node can transmit

• Classes of techniques
  – **Channel partitioning**: divide channel into pieces
  – **Taking turns**: scheme for trading off who gets to transmit
  – **Random access**: allow collisions, and then recover
Channel Partitioning: TDMA

TDMA: Time Division Multiple Access

- Access to channel in "rounds"
  - Each station gets fixed length slot in each round

- Time-slot length is packet transmission time
  - *Unused slots go idle*

- Example: 6-station LAN with slots 0, 3, and 4
Channel Partitioning: FDMA

FDMA: Frequency Division Multiple Access

- Channel spectrum divided into frequency bands
- Each station assigned fixed frequency band
- Unused transmission time in frequency bands go idle
- Example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle
“Taking Turns” MAC protocols

Polling

- Master node “invites” slave nodes to transmit in turn

- Concerns:
  - Polling overhead
  - Latency
  - Single point of failure (master)

Token passing

- Control token passed from one node to next sequentially

- Node must have token to send

- Concerns:
  - Token overhead
  - Latency
  - At mercy of any node
None of these are the “Internet way”…

• Why not?

• What’s wrong with
  – TDMA
  – FDMA
  – Polling
  – Token passing

• Turn to random access
  – Optimize for the common case (no collision)
  – Don’t avoid collisions, just recover from them….
  – Sound familiar?
Random Access MAC Protocols
Random Access MAC Protocols

• When node has packet to send
  – Transmit at full channel data rate
  – No \textit{a priori} coordination among nodes

• Two or more transmitting nodes $\Rightarrow$ collision
  – Data lost

• Random access MAC protocol specifies:
  – How to detect collisions
  – How to recover from collisions

• Examples
  – ALOHA and \textbf{Slotted ALOHA}
  – \textbf{CSMA, CSMA/CD, CSMA/CA} (wireless, covered later)
Key Ideas of Random Access

- **Carrier sense**
  - *Listen before speaking, and don’t interrupt*
  - Checking if someone else is already sending data
  - … and waiting till the other node is done

- **Collision detection**
  - *If someone else starts talking at the same time, stop*
    - *But make sure everyone knows there was a collision!*
  - Realizing when two nodes are transmitting at once
  - …by detecting that the data on the wire is garbled

- **Randomness**
  - *Don’t start talking again right away*
  - Waiting for a random time before trying again
Where it all Started: AlohaNet

- Norm Abramson left Stanford in 1970
- *So he could surf!*
- Set up first data communication system for Hawaiian islands
- Hub at U. Hawaii, Oahu
- Had two radio channels:
  - Random access:
    - Sites sending data
  - Broadcast:
    - Hub rebroadcasting data
Aloha Signaling

• Two channels: random access, broadcast

• Sites send packets to hub (random)
  – If received, hub sends ACK (random)
  – If not received (due to collision), site resends

• Hub sends packets to all sites (broadcast)
  – Sites can receive even if they are also sending

• Questions:
  – When do you resend? Resend with probability $p$
  – How does this perform? Need a clean model….
Slotted ALOHA

**Assumptions**
- All frames same size
- Time divided into equal slots (time to transmit a frame)
- Nodes are synchronized
- Nodes begin to transmit frames only at start of slots
- If multiple nodes transmit, nodes detect collision

**Operation**
- When node gets fresh data, transmits in next slot
- No collision: success!
- Collision: node retransmits with probability $p$ until success
Slot-by-Slot Example

node 1
node 2
node 3

→ slota
Efficiency of Slotted Aloha

• Suppose N stations have packets to send
  – Each transmits in slot with probability \( p \)

• Probability of successful transmission:
  by a particular node \( i \):
  \[
  S_i = p (1-p)^{(N-1)}
  \]
  by any of N nodes:
  \[
  S = N p (1-p)^{(N-1)}
  \]

• What value of \( p \) maximizes prob. of success:
  – For fixed \( p \), \( S \rightarrow 0 \) as \( N \) increases
  – But if \( p = 1/N \), then \( S \rightarrow 1/e = 0.37 \) as \( N \) increases

• Max efficiency is only slightly greater than \( 1/3 \)!
Pros and Cons of Slotted Aloha

**Pros**

- Single active node can continuously transmit at full rate of channel
- Highly decentralized: only need slot synchronization
- Simple

**Cons**

- Wasted slots:
  - Idle
  - Collisions
- Collisions consume entire slot
- Clock synchronization
Improving on Slotted Aloha

• Fewer wasted slots
  – Need to decrease collisions and empty slots

• Don’t waste full slots on collisions
  – Need to decrease time to detect collisions

• Avoid need for synchronization
  – Synchronization is hard to achieve
  – And Aloha performance drops if you don’t have slots
CSMA (Carrier Sense Multiple Access)

- CSMA: **listen** before transmit
  - If channel sensed idle: transmit entire frame
  - If channel sensed busy, defer transmission

- Human analogy: don’t interrupt others!

- Does this eliminate all collisions?
  - No, because of nonzero propagation delay
CSMA Collisions

Propagation delay: two nodes may not hear each other’s before sending.

*Would slots hurt or help?*

CSMA reduces but does not eliminate collisions

*Biggest remaining problem?*

Collisions still take full slot! How do you fix that?
CSMA/CD (Collision Detection)

- CSMA/CD: carrier sensing, deferral as in CSMA
  - **Collisions detected within short time**
  - Colliding transmissions aborted, reducing wastage

- Collision detection easy in wired LANs:
  - Compare transmitted, received signals

- Collision detection difficult in wireless LANs:
  - Reception shut off while transmitting (well, perhaps not)
  - Not perfect broadcast (limited range) so collisions local
  - Leads to use of *collision avoidance* instead
    - *Will discuss in wireless lecture*
CSMA/CD Collision Detection

B and D can tell that collision occurred.

Note: for this to work, need restrictions on minimum frame size and maximum distance.

Why?
Limits on CSMA/CD Network Length

- Latency depends on physical length of link
  - Time to propagate a packet from one end to the other

- Suppose $A$ sends a packet at time $t$
  - And $B$ sees an idle line at a time just before $t+d$
  - … so $B$ happily starts transmitting a packet

- $B$ detects a collision, and sends jamming signal
  - But $A$ can’t see collision until $t+2d$
Limits on CSMA/CD Network Length

• A needs to wait for time \(2d\) to detect collision
  – So, A should keep transmitting during this period
  – … and keep an eye out for a possible collision

• Imposes restrictions. E.g., for 10 Mbps Ethernet:
  – Maximum length of the wire: 2,500 meters
  – Minimum length of a frame: 512 bits (64 bytes)
    o 512 bits = 51.2 \(\mu\)sec (at 10 Mbit/sec)
    o For light in vacuum, 51.2 \(\mu\)sec \(\approx\) 15,000 meters vs. 5,000 meters “round trip” to wait for collision
  – What about 10Gbps Ethernet?
Performance of CSMA/CD

- Time wasted in collisions
  - Proportional to distance \( d \)

- Time spend transmitting a packet
  - Packet length \( p \) divided by bandwidth \( b \)

- Rough estimate for efficiency (\( K \) some constant)

\[
E \sim \frac{p}{b} + Kd
\]

- Note:
  - For large packets, small distances, \( E \sim 1 \)
  - As bandwidth increases, \( E \) decreases
  - That is why high-speed LANs are all switched
Ethernet Multiple Access

First widely deployed multiple access
Benefits of Ethernet

• Easy to administer and maintain
• Inexpensive
• Increasingly higher speed
• Evolvable!
Evolution of Ethernet

• Changed everything except the frame format
  – From single coaxial cable to hub-based star
  – From shared media to switches
  – From electrical signaling to optical

• Lesson #1
  – The right interface can accommodate many changes
  – Implementation is hidden behind interface

• Lesson #2
  – Really hard to displace the dominant technology
  – Slight performance improvements are not enough
Ethernet: CSMA/CD Protocol

- **Carrier sense:** wait for link to be idle

- **Collision detection:** listen while transmitting
  - No collision: transmission is complete
  - Collision: abort transmission & send *jam* signal

- **Random access:** *binary exponential back-off*
  - After collision, wait a random time before trying again
  - After $m^{th}$ collision, choose $K$ randomly from $\{0, \ldots, 2^m-1\}$
  - … and wait for $K*512$ bit times before trying again
    - Using min packet size as “slot”
    - If transmission occurring when ready to send, wait until end of transmission (CSMA)
Binary Exponential Backoff (BEB)

• Think of time as divided in slots

• After each collision, pick a slot randomly within next $2^m$ slots
  – Where $m$ is the number of collisions since last successful transmission

• Questions:
  – Why backoff?
  – Why random?
  – Why $2^m$?
  – Why not listen while waiting?
Behavior of BEB Under Light Load

Look at collisions between two nodes

• First collision: pick one of the next two slots
  – Chance of success after first collision: 50%
  – Average delay 1.5 slots

• Second collision: pick one of the next four slots
  – Chance of success after second collision: 75%
  – Average delay 2.5 slots

• In general: after $m^{th}$ collision
  – Chance of success: $1 - 2^{-m}$
  – Average delay (in slots): $\frac{1}{2} + 2^{(m-1)}$
In theory, there is no difference between theory and practice. But, in practice, there is.
BEB Reality

• Performs well (far from optimal, but no one cares)
  – *Large packets are ~23 times as large as minimal slot*

• Is mostly irrelevant
  – *Almost all current ethernets are switched*
BEB Theory

• A very interesting algorithm

• Stability for finite N only proved in 1985
  – Ethernet can handle nonzero traffic load without collapse
    o Greenberg et al. (AT&T)

• All backoff algorithms unstable for infinite N (1985)
  – Poisson model: infinite user pool, total demand is finite
    o David Aldous (UCB Statistics)

• Not of practical interest, but gives important insight
  – Multiple access should be in your “bag of tricks”
Question

• Two hosts, each with infinite packets to send
  
• What happens under BEB?
  
• Throughput high or low?
  
• Bandwidth shared equally or not?
The BEB Game Show!

• Starring two enthusiastic volunteers
MAC “Channel Capture” in BEB

• Finite chance that first one to have a successful transmission will never relinquish the channel
  – The other host will *never* send a packet

• Therefore, asymptotically channel is fully utilized and completely allocated to one host
Example

- Two hosts, each with infinite packets to send
  - Slot 1: collision
  - Slot 2: each resends with prob $\frac{1}{2}$
    - Assume host A sends, host B does not
  - Slot 3: A and B both send (collision)
  - Slot 4: A sends with probability $\frac{1}{2}$, B with prob. $\frac{1}{4}$
    - Assume A sends, B does not
  - Slot 5: A definitely sends, B sends with prob. $\frac{1}{4}$
    - Assume collision
  - Slot 6: A sends with probability $\frac{1}{2}$, B with prob. $\frac{1}{8}$

- Conclusion: if A gets through first, the prob. of B sending successfully halves with each collision.
Another Question

• Hosts now have large but finite # packets to send

• What happens under BEB?

• Throughput high or low?
Answer

• Efficiency less than one, no matter how many packets

• Time you wait for loser to start is proportional to time winner was sending…. 
Different Backoff Functions

• Exponential: backoff $\sim a^i$
  – Channel capture?
  – Efficiency?

• Superlinear polynomial: backoff $\sim i^p \; p>1$
  – Channel capture?
  – Efficiency?

• Sublinear polynomial: backoff $\sim i^p \; p\leq1$
  – Channel capture?
  – Efficiency?
Different Backoff Functions

• Exponential: backoff $\sim a^i$
  – Channel capture *(loser might not send until winner idle)*
  – Efficiency less than 1 *(time wasted waiting for loser to start)*

• Superlinear polynomial: backoff $\sim i^p \ p>1$
  – Channel capture
  – Efficiency is 1 (for any finite # of hosts N)

• Sublinear polynomial: backoff $\sim i^p \ p\leq1$
  – No channel capture *(loser not shut out)*
  – Efficiency is less than 1 (and goes to zero for large N)
    0 *Time wasted resolving collisions*
Why Do I Care?

• Why do you like music?

• It makes me happy….

• But also, until this work was done, no one knew about capture, or what properties of the backoff enabled it.

• You don’t understand something until you’ve played with it. Just getting it to work isn’t enough.
That’s All for Today!

- Next week, congestion control