CS 268: Lecture 12 (Multicast)

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History

- Multicast and QoS dominated research literature in the 90's
- Both failed in their attempt to become pervasively available
  - Both now available in enterprises, but not in public Internet
- Both now scorned as research topics

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Irony

- The biggest critics of QoS were the multicast partisans
  - And the QoS advocates envied the hipness of mcast…
- They complained about QoS being unscalable
  - Among other complaints….
- Irony #1: multicast is no more scalable than QoS
- Irony #2: scaling did not cause either of their downfalls
- Many now think economics was the problem
  - Revenue model did not fit delivery model

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Lectures

- Today: multicast
  - Focus on multicast as a state of mind, not on details
- Wednesday: QoS
  - More “why” than “what”

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Agenda

- Preliminaries
- Multicast routing
- Using multicast
- Reliable multicast
- Multicast's philosophical legacy

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Motivation

- Often want to send data to many machines at once
  - Video distribution (TV broadcast)
  - Teleconferences, etc.
  - News updates
- Using unicast to reach each individual is hard and wasteful
  - Sender state: ~O(n) and highly dynamic
  - Total load: ~O(nd) where d is net diameter
  - Hotspot load: load ~O(n) on host and first link
- Multicast:
  - Sender state: O(1), total load O(d log n), hotspot load O(1)

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Multicast Service Model

- Send to logical group address
  - Location-independent
- Delivery limited by specified scope
  - Can reach “nearby” members
- Best effort delivery

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Open Membership Model

- Anyone, anywhere, can join
- Dynamic membership
  - join and leave at will
- Anyone can send at any time
  - Even nonmembers

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Division of Responsibilities

- Host's responsibility to register interest with networks
  - IGMP
- Network's responsibility to deliver packets to host
  - Multicast routing protocol
- Left unspecified:
  - Address assignment (random, MASC, etc.)
  - Application-to-group mapping (session directory, etc.)

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Target Environment

- LANs connected in arbitrary topology
- LANs support local multicast
- Host network cards filter multicast traffic

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Multicast Routing Algorithms

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Routing Performance Goals

- Roughly equivalent to unicast best-effort service in terms of drops/delays
  - Efficient tree
  - No complicated forwarding machinery, etc.
- Low join/leave latency

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Two Basic Routing Approaches

- Source-based trees: (e.g., DVMRP, PIM-DM)
  - A tree from each source to group
  - State: O(G*S)
  - Good for dense groups (all routers involved)
- Shared trees: (e.g., CBT, PIM-SM)
  - A single tree for group, shared by sources
  - State: O(G)
  - Better for sparse groups (only routers on path involved)

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DVMRP

- Developed as a sequence of protocols:
  - Reverse Path Flooding (RPF)
  - Reverse Path Broadcast (RPB)
  - Truncated Reverse Path Broadcasting (TRPB)
  - Reverse Path Multicast (RPM)
- General Philosophy: multicast = pruned broadcast
  - Don’t construct new tree, merely prune old one
- Observation:
  - Unicast routing state tells router shortest path to S
  - Reversing direction sends packets from S without forming loops

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Basic Forwarding Rule

- Routing state:
  - To reach S, send along link L
- Flooding Rule:
  - If a packet from S is *received* along link L, forward on all other links
- This works fine for symmetric links
  - Ignore asymmetry today
- This works fine for point-to-point links
  - Can result in multiple packets sent on LANs

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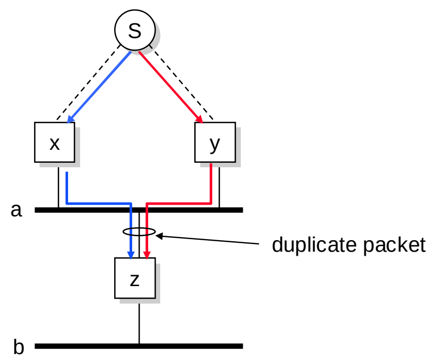
Example

- Flooding can cause a given packet to be sent multiple times over the same link



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Broadcasting Extension

- For each link, and each source S, define *parent* and *child*
  - Parent: shortest path to S (ties broken arbitrarily)
  - All other routers on link are children
- Broadcasting rule: only parent forwards packet to L
- Problem fixed
- But this is still broadcast, not multicast!

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Multicast = Pruned Broadcast

- Start with full broadcast (RPB)
- If leaf has no members, prune state
  - Send non-membership report (NMR)
- If all children of a router R prune, then router R sends NMR to parent
- New joins send graft to undo pruning

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Problems with Approach

- Starting with broadcast means that all first packets go everywhere
- If group has members on most networks, this is ok
- But if group is sparse, this is lots of wasted traffic
- What about a different approach:
  - Source-specific tree vs shared tree
  - Pruned broadcast vs explicitly constructed tree

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Core Based Trees (CBT)

- Ballardie, Francis, and Crowcroft,
  - "Core Based Trees (CBT): An Architecture for Scalable Inter-Domain Multicast Routing", SIGCOMM 93
- Similar to Deering's Single-Spanning Tree
- Unicast packet to core, but forwarded to multicast group
- Tree construction by receiver-based "grafts"
  - One tree per group, only nodes on tree involved
- Reduce routing table state from O(S x G) to O(G)

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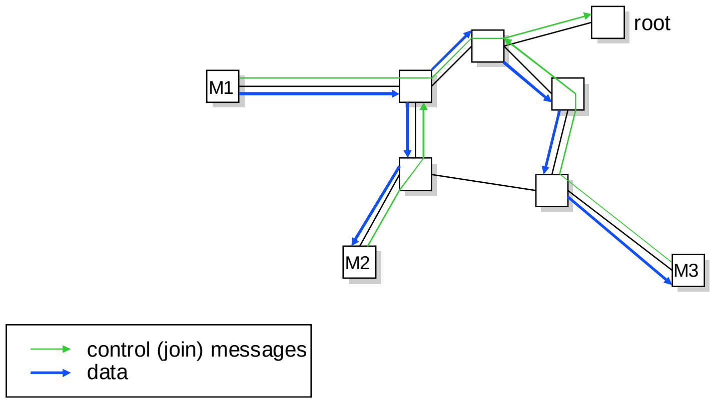
Example

- Group members: M1, M2, M3
- M1 sends data



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Disadvantages

- Sub-optimal delay
- Small, local groups with non-local core
  - Need good core selection
  - Optimal choice (computing topological center) is NP complete

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Why Isn't Multicast Pervasive?

- Sound technology
- Implemented in most routers
- Used by many enterprises
- But not available on public Internet

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Possible Explanation [Holbrook & Cheriton '99]

- Violates ISP input-rate-based billing model
  - No incentive for ISPs to enable multicast!
- No indication of group size (needed for billing)
- Hard to implement sender control
  - Any mcast app can be subject to simple DoS attack!!
- Multicast address scarcity
  - Global allocation required
- Awkward interdomain issues with "cores"

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Solution: Single-Source Multicast

- Each group has only one source
- Use both source and destination IP fields to define a group
  - Each source can allocate 16 millions “channels”
  - Use RPM algorithm
- Add a counting mechanism
  - Use a recursive CountQuery message
- Use app-level relays to for multiple sources

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Discussion

- Does multicast belong in the network layer?
  - Why not implemented by end hosts?
- How important is economic analysis in protocol design?
  - Should the design drive economics, or the other way around?
- Multicast addresses are “flat”
  - Doesn’t that make it hard for routers to scale?
  - Address allocation and aggregation?
- Should everything be multicast?
- What other delivery models are needed?

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Reliable Multicast

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How to Make Multicast Reliable?

- FEC can help, but isn't perfect
- Must have retransmissions
- But sender can't keep state about each receiver
  - Has to be told when someone needs a packet

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SRM Design Approach

- Let receivers detect lost packets
  - By holes in sequence numbers
- They send NACK when loss is detected
- Any node can respond to NACK
- NACK/Response implosion averted through suppression
  - Send NACKs at random times
  - If hear NACK for same data, reset NACK timer
  - If node has data, it resends it, using similar randomized algorithm

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Repair Request Timer Randomization

- Chosen from the uniform distribution on

$$2^i[C_1 d_{S,A}, (C_1 + C_2) d_{S,A}]$$

  - A: node that lost the packet
  - S: source
  - C_1, C_2 : algorithm parameters
  - $d_{S,A}$: latency between S and A
  - i : iteration of repair request tries seen
- Algorithm
  - Detect loss $\rightarrow$ set timer
  - Receive request for same data $\rightarrow$ cancel timer, set new timer
  - Timer expires $\rightarrow$ send repair request

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Timer Randomization

- Repair timer similar
  - Every node that receives repair request sets repair timer
  - Latency estimate is between node and node requesting repair
- Timer properties – minimize probability of duplicate packets
  - Reduce likelihood of implosion (duplicates still possible)
    - Poor timer, randomized granularity
    - High latency between nodes
  - Reduce delay to repair
    - Nodes with low latency to sender will send repair request more quickly
    - Nodes with low latency to requester will send repair more quickly
    - When is this sub-optimal?

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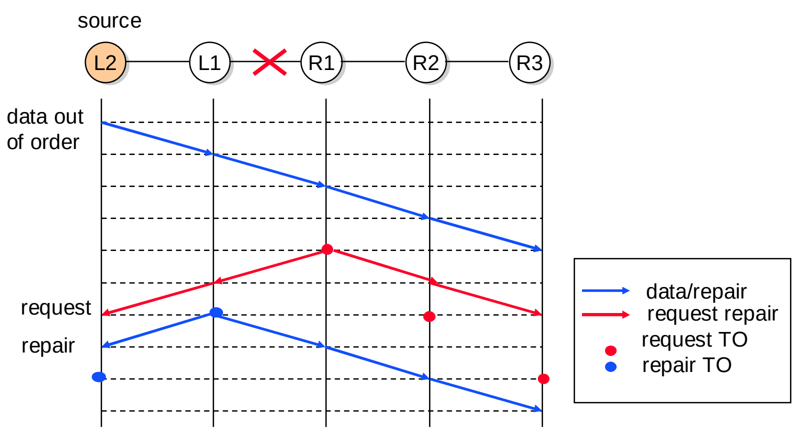
Chain Topology

- $C_1 = D_1 = 1, C_2 = D_2 = 0$
- All link distances are 1



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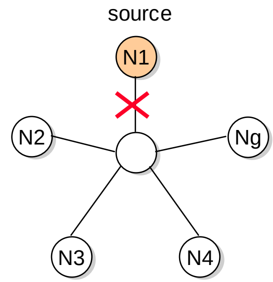
Star Topology

- $C_1 = D_1 = 0$,
- Tradeoff between (1) number of requests and (2) time to receive the repair
- $C_2 <= 1$
  - E(# of requests) = $g - 1$
- $C_2 > 1$
  - E(# of requests) = $1 + (g-2)/C_2$
  - E(time until first timer expires) = $2C_2/g$
- $C_2 = \sqrt{g}$
  - E(# of requests) = $\sqrt{g}$
  - E(time until first timer expires) = $1/\sqrt{g}$



Bounded Degree Tree

- Use both
  - Deterministic suppression (chain topology)
  - Probabilistic suppression (star topology)
- Large C_2/C_1 → fewer duplicate requests, but larger repair time
- Large C_1 → fewer duplicate requests
- Small C_1 → smaller repair time

Adaptive Timers

- *C* and *D* parameters depends on topology and congestion → choose adaptively
- After sending a request:
  - Decrease start of request timer interval
- Before each new request timer is set:
  - If requests sent in previous rounds, and any dup requests were from further away:
    - Decrease request timer interval
  - Else if average dup requests high:
    - Increase request timer interval
  - Else if average dup requests low and average request delay too high:
    - Decrease request timer interval

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Local Recovery

- Some groups are very large with low loss correlation between nodes
  - Multicasting requests and repairs to entire group wastes bandwidth
- Separate recovery multicast groups
  - e.g. hash sequence number to multicast group address
  - only nodes experiencing loss join group
  - recovery delay sensitive to join latency
- TTL-based scoping
  - send request/repair with a limited TTL
  - how to set TTL to get to a host that can retransmit
  - how to make sure retransmission reaches every host that heard request

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Suppression

- Two kinds:
  - Deterministic suppression
  - Randomized suppression
- Subject of extensive but incomplete scaling analysis

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Application Layer Framing (ALF)

- Application should define Application Data Unit (ADU)
- ADU is unit of error recovery
  - app can recover from whole ADU loss
  - app treats partial ADU loss/corruption as whole loss
- App can process ADUs out of order

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Multicast's True Legacy

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Benefits of Multicast

- Efficient delivery to multiple hosts (initial focus)
  - Addressed by SSM and other simple mechanisms
- Logical addressing (pleasant byproduct)
  - Provides layer of indirection
  - Now focus of much architecture research
  - Provided by DHTs and other kinds of name resolution mechanisms

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