IP ANYCAST AND MULTICAST

READING: SECTION 4.4

COS 461: Computer Networks
Spring 2009 (MW 1:30-2:50 in COS 105)

Mike Freedman
Teaching Assistants: Wyatt Lloyd and Jeff Terrace
http://www.cs.princeton.edu/courses/archive/spring09/cos461/

Outline today

- IP Anycast
- Multicast protocols
  - IP Multicast and IGMP
  - SRM (Scalable Reliable Multicast)
  - PGM (Pragmatic General Multicast)
  - Bimodal multicast
  - Gossiping

Limitations of DNS-based failover

- Failover/load balancing via multiple A records

```
;; ANSWER SECTION:
www.cnn.com.     300   IN    A   157.166.255.19
www.cnn.com.     300   IN    A   157.166.224.25
www.cnn.com.     300   IN    A   157.166.226.26
www.cnn.com.     300   IN    A   157.166.255.18
```

- If server fails, service unavailable for TTL
  - Very low TTL: Extra load on DNS
  - Anyway, browsers cache DNS mappings ☹
- What if root NS fails? All DNS queries take > 3s?

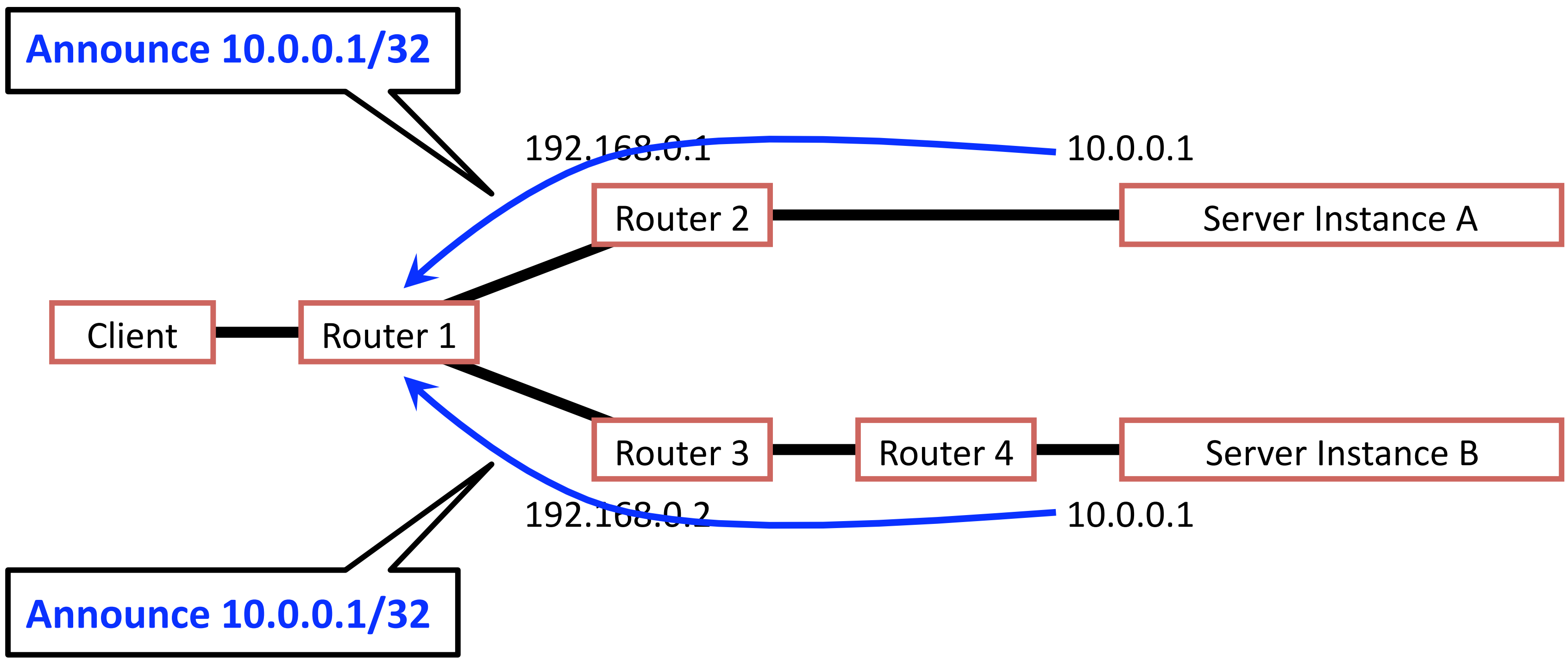
Motivation for IP anycast

- Failure problem: client has resolved IP address
  - What if IP address can represent many servers?

- Load-balancing/failover via IP addr, rather than DNS

- IP anycast is simple reuse of existing protocols
  - Multiple instances of a service share same IP address
  - Each instance announces IP address / prefix in BGP / IGP
  - Routing infrastructure directs packets to nearest instance of the service
    - Can use same selection criteria as installing routes in the FIB
  - No special capabilities in servers, clients, or network

IP anycast in action



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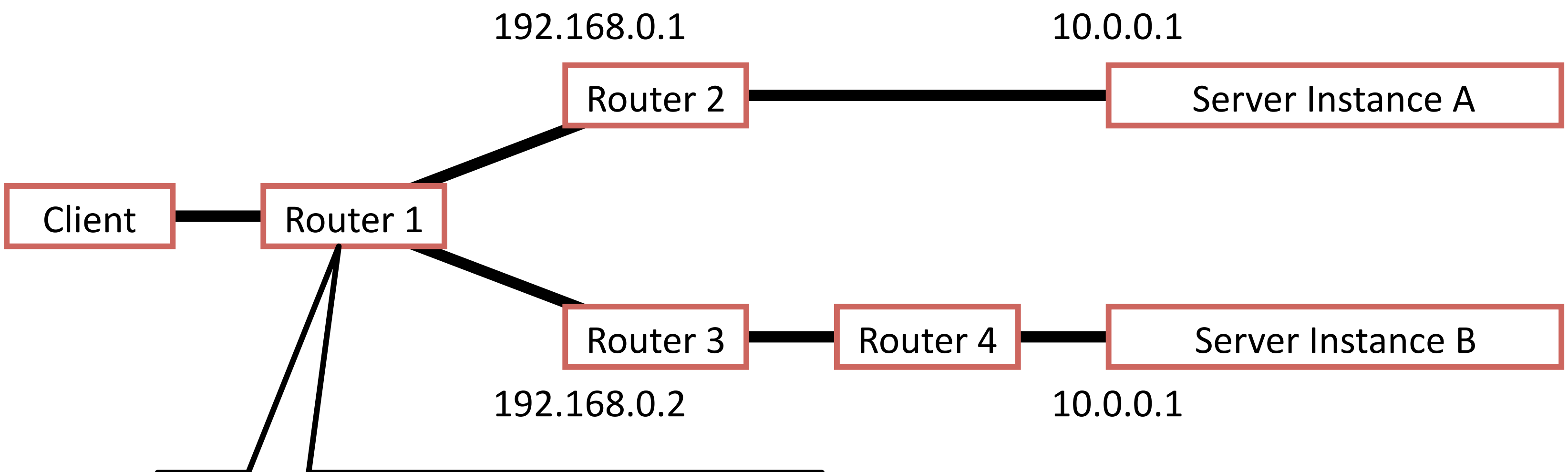

Routing Table from Router 1:

Destination	Mask	Next-Hop	Distance
192.168.0.0	/29	127.0.0.1	0
10.0.0.1	/32	192.168.0.1	1
10.0.0.1	/32	192.168.0.2	2

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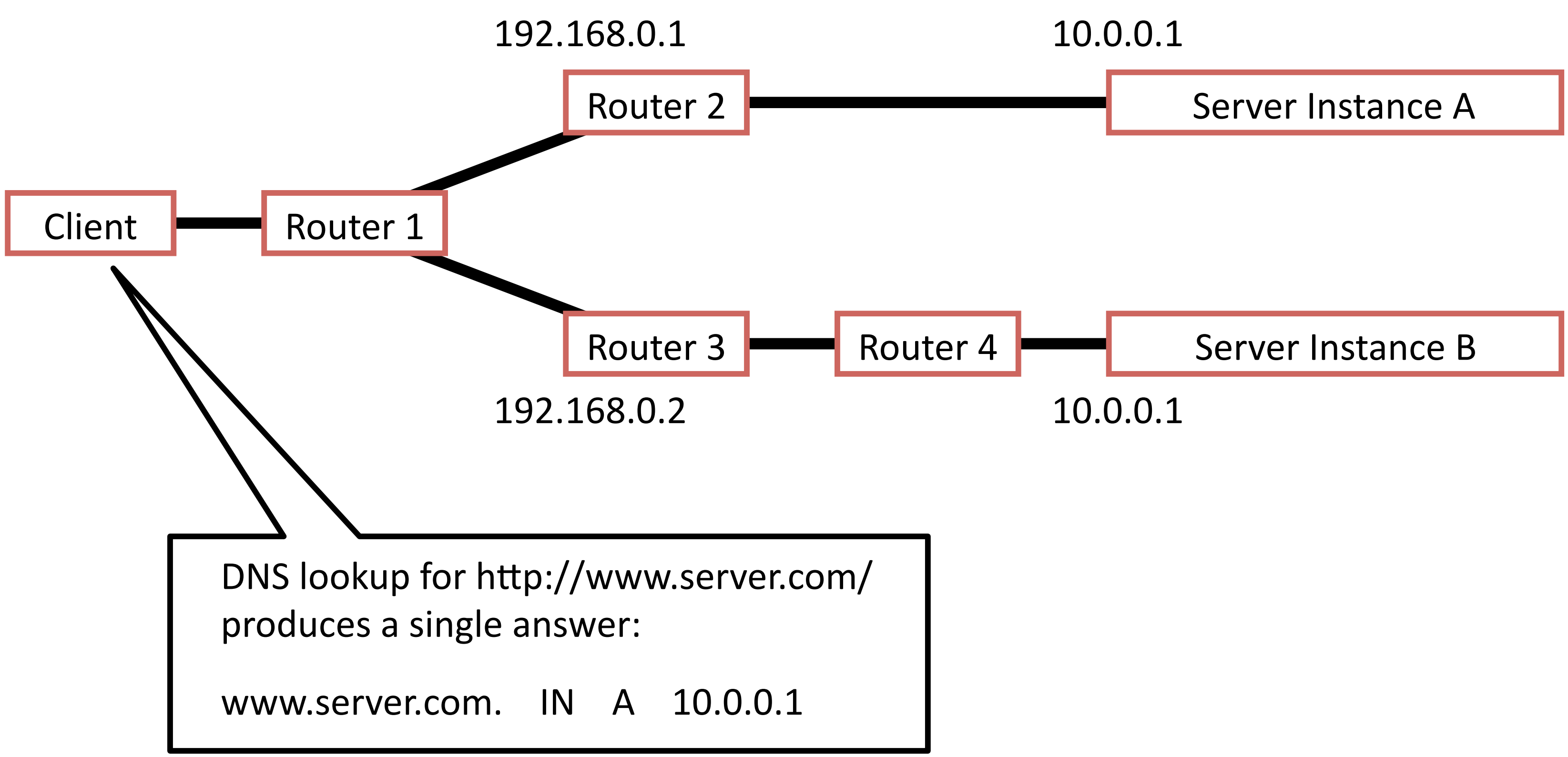

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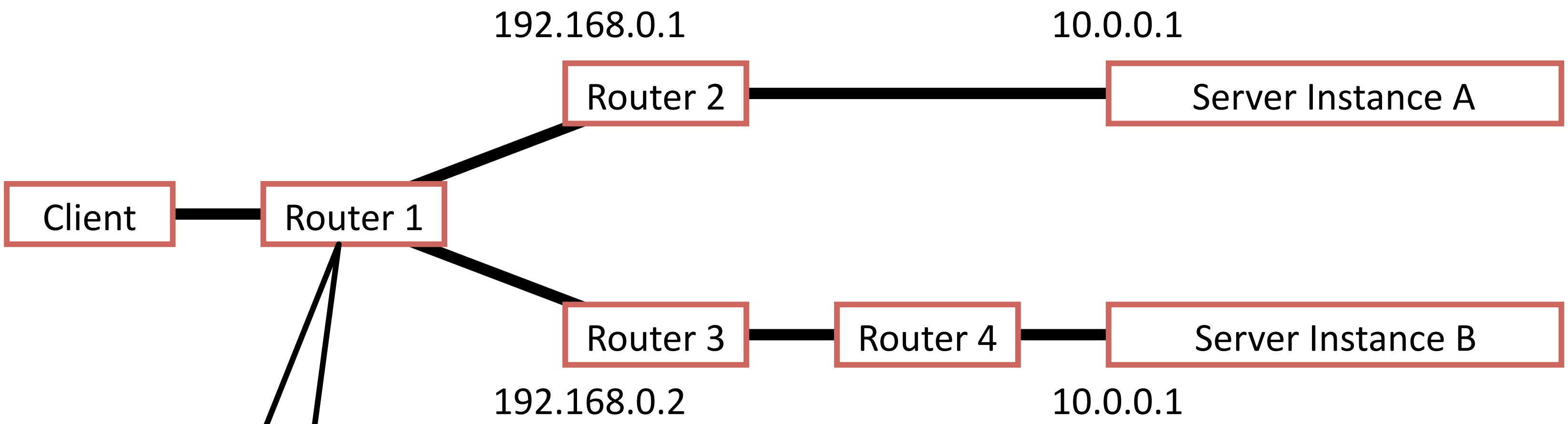

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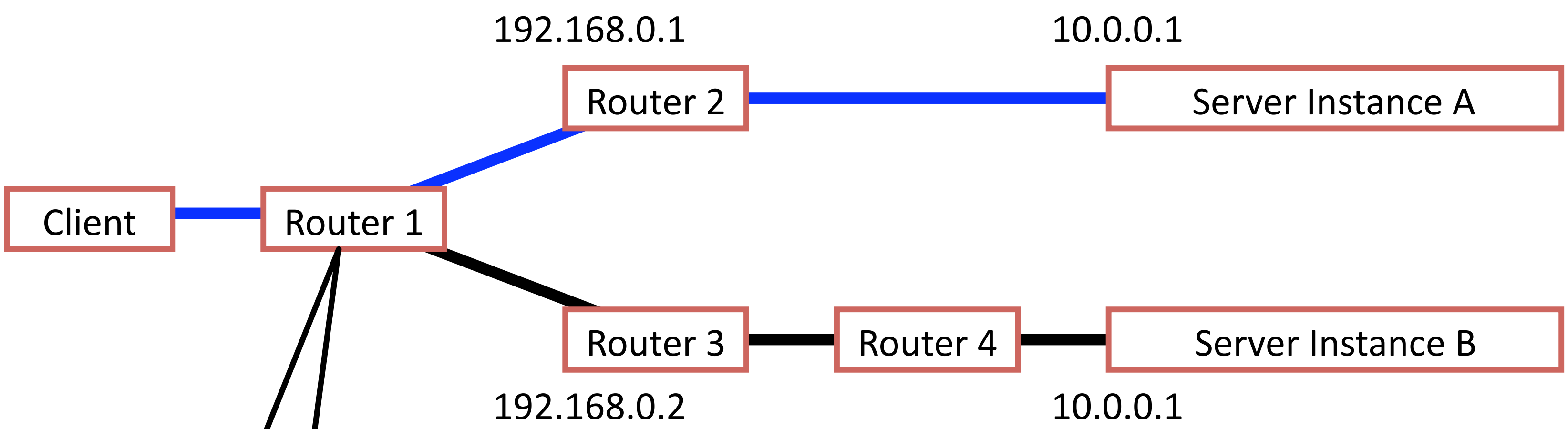

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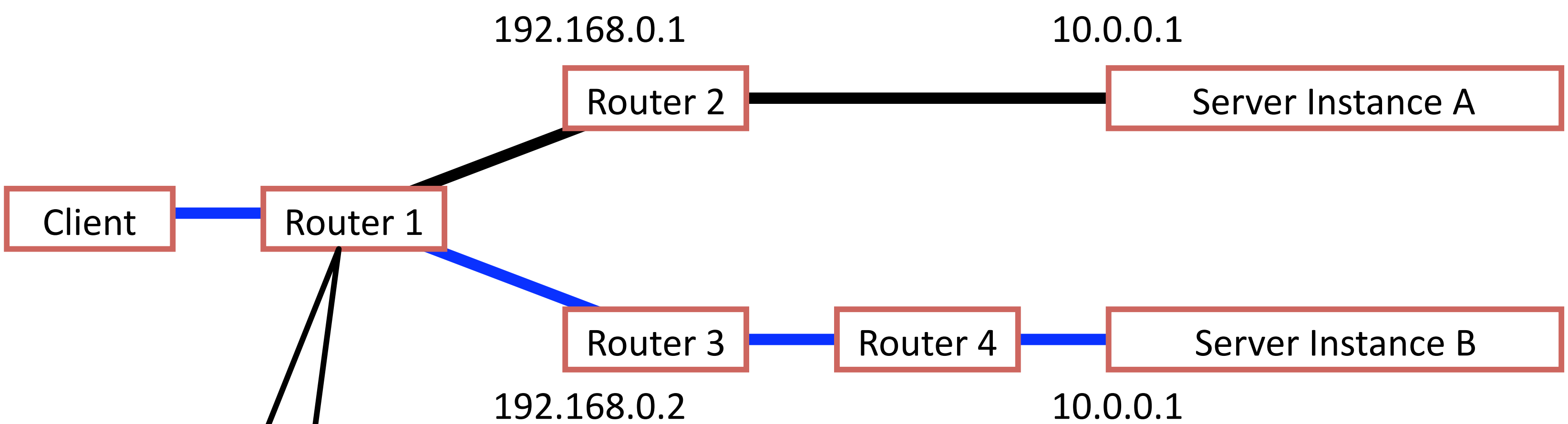

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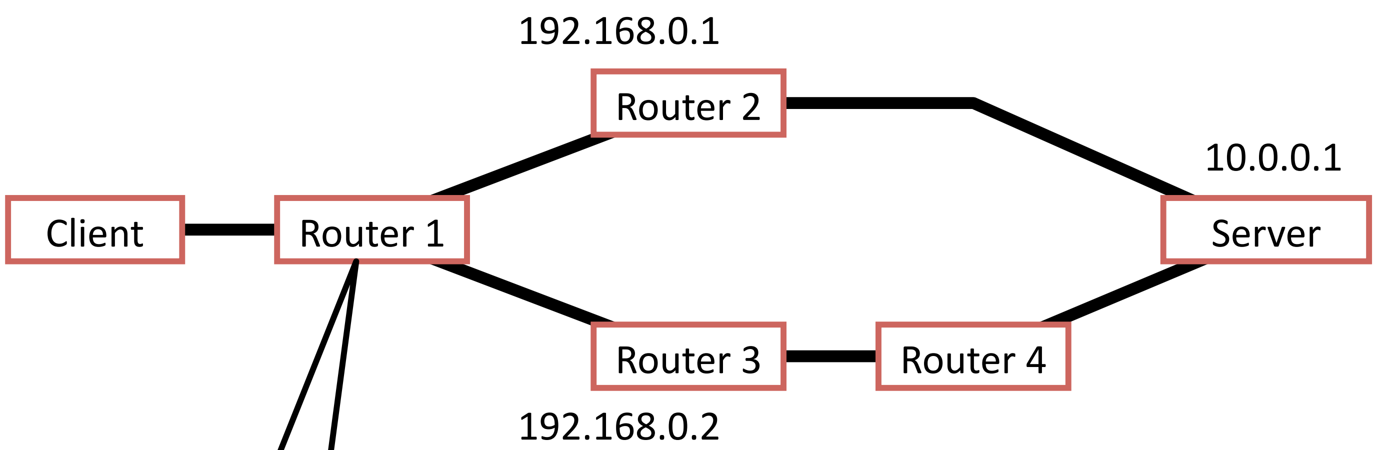
IP anycast in action

From client/router perspective, topology could as well be:



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Downsides of IP anycast

- Many Tier-1 ISPs ingress filter prefixes > /24
  - Publish a /24 to get a "single" anycasted address: Poor utilization
- Scales poorly with the # anycast groups
  - Each group needs entry in global routing table
- Not trivial to deploy
  - Obtain an IP prefix and AS number; speak BGP
- Subject to the limitations of IP routing
  - No notion of load or other application-layer metrics
  - Convergence time can be slow (as BGP or IGP convergence)
- Failover doesn't really work with TCP
  - TCP is stateful; other server instances will just respond with RSTs
  - Anycast may react to network changes, even though server online
- Root name servers (UDP) are anycasted, little else

Multicast protocols

Multicasting messages

- Simple application multicast: Iterated unicast
  - Client simply unicasts message to every recipient
  - Pros: simple to implement, no network modifications
  - Cons: O(n) work on sender, network
- Advanced overlay multicast
  - Build receiver-driven tree
  - Pros: Scalable, no network modifications
  - Cons: O(log n) work on sender, network; complex to implement
- IP multicast
  - Embed receiver-driven tree in network layer
  - Pros: O(1) work on client, O(# receivers) on network
  - Cons: requires network modifications; scalability concerns?

Another way to slice it

	Best effort	Reliable
Iterated Unicast	UDP-based communication	TCP-based communication; Atomic broadcast
Application "Trees"	UDP-based trees (P2P)	TCP-based trees; Gossiping; Bimodal multicast *
IP-layer multicast	IP multicast	SRM; PGM; NORM; Bimodal multicast *

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IP Multicast

- Simple to use in applications
  - Multicast "group" defined by IP multicast address
    - IP multicast addresses look similar to IP unicast addrs
    - 224.0.0.0 to 239.255.255.255 (RPC 3171)
      - 265 M multicast groups at most
  - Best effort delivery only
    - Sender issues single datagram to IP multicast address
    - Routers delivery packets to all subnetworks that have a receiver "belonging" to the group
- Receiver-driven membership
  - Receivers join groups by informing upstream routers
  - Internet Group Management Protocol (v3: RFC 3376)

IGMP v1

- Two types of IGMP msgs (both have IP TTL of 1)
  - Host membership query: Routers query local networks to discover which groups have members
  - Host membership report: Hosts report each group (e.g., multicast addr) to which belong, by broadcast on net interface from which query was received
- Routers maintain group membership
  - Host senders an IGMP "report" to join a group
  - Multicast routers periodically issue host membership query to determine liveness of group members
  - Note: No explicit "leave" message from clients

IGMP

- IGMP v2 added:
  - If multiple routers, one with lowest IP elected querier
  - Explicit leave messages for faster pruning
  - Group-specific query messages

- IGMP v3 added:
  - Source filtering: Join specifies multicast “only from” or “all but from” specific source addresses

IGMP

- Parameters
  - Maximum report delay: 10 sec
  - Query internal default: 125 sec
  - Time-out interval: 270 sec
    - 2 * (query interval + max delay)

- Questions
  - Is a router tracking each attached peer?
  - Should clients respond immediately to membership queries?
  - What if local networks are layer-two switched?

So far, we've been best-effort IP multicast…

Challenges for reliable multicast

- Ack-implosion if all destinations ack at once
- Source does not know # of destinations
- How to retransmit?
  - To all? One bad link effects entire group
  - Only where losses? Loss near sender makes retransmission as inefficient as replicated unicast
- Once size fits all?
  - Heterogeneity: receivers, links, group sizes
  - Not all multicast applications need reliability of the type provided by TCP. Some can tolerate reordering, delay, etc.

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Scalable Reliable Multicast

- Receives all packets or unrecoverable data loss
- Data packets sent via IP multicast
  - ODATA includes sequence numbers
- Upon packet failure:
  - Receiver multicasts a NAK
    - … or sends NAK to sender, who multicasts a NAK confirmation (NCF)
  - Scale through NAK suppression
    - … if received a NAK or NCF, don't NAK yourself
    - What do we need to do to get adequate suppression?
      - Add random delays before NAK'ing
      - But what if the multicast group grows big?
  - Repair through packet retransmission (RDATA)
    - From initial sender
    - From designated local repairer (DLR – IETF loves acronyms!)

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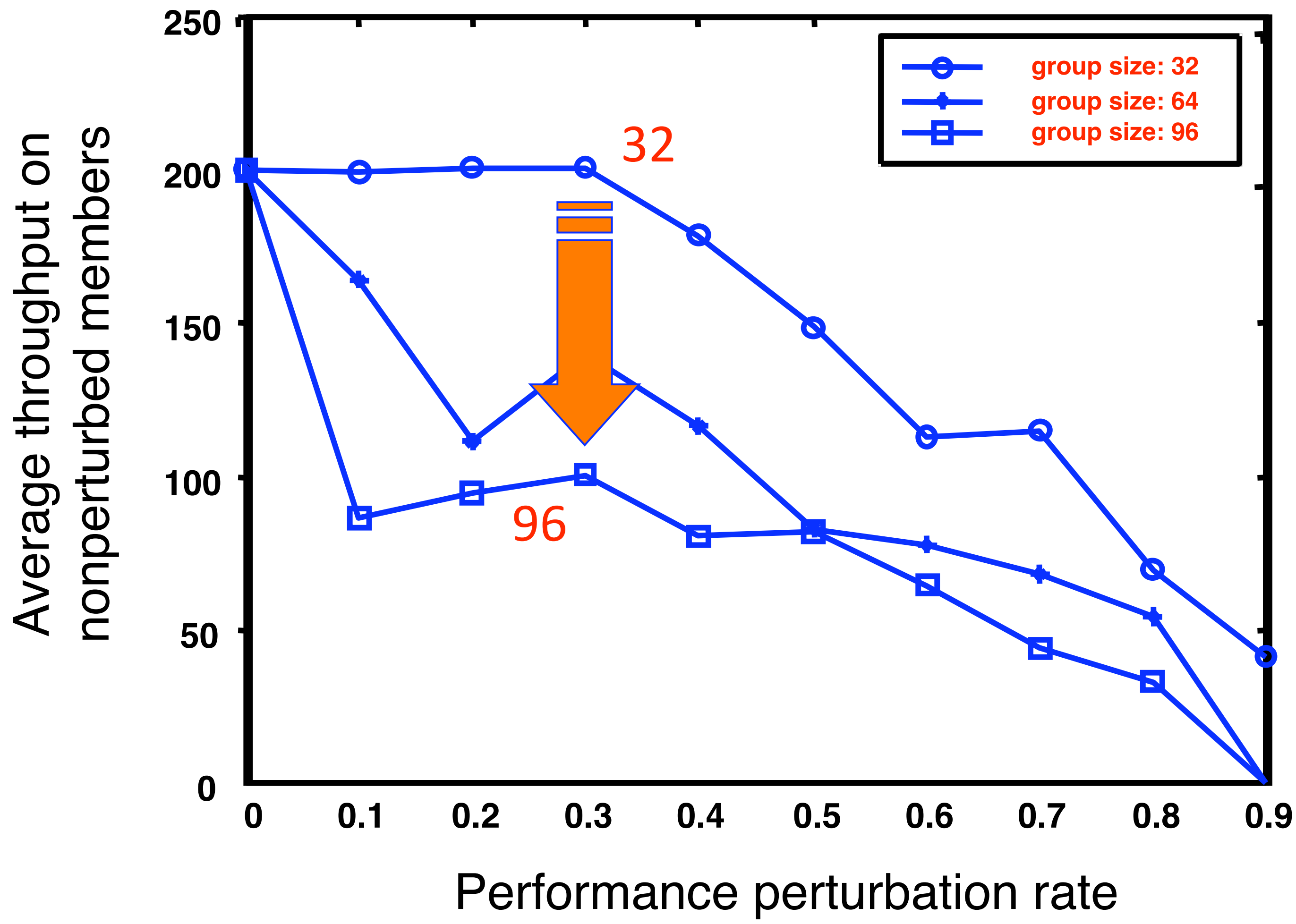
Pragmatic General Multicast (RFC 3208)

- Similar approach as SRM: IP multicast + NAKs
  - … but more techniques for scalability
- Hierarchy of PGM-aware network elements
  - NAK suppression: Similar to SRM
  - NAK elimination: Send at most one NAK upstream
    - Or completely handle with local repair!
  - Constrained forwarding: Repair data can be suppressed downstream if no NAK seen on that port
  - Forward-error correction: Reduce need to NAK
- Works when only sender is multicast-able

A stronger "reliability"?

- Atomic broadcast
  - "Everybody or nobody" receives a packet
  - Clearly not guaranteed with SRM/PGM:
    - Requires consensus between receivers
    - Performance problem: One slow node hurts everybody
- Performance problems with SRM/PGM?
  - Sender spends lots of time on retransmissions as heterogenous group increases in size
    - Local repair makes this better

“Virtual synchrony” multicast performance



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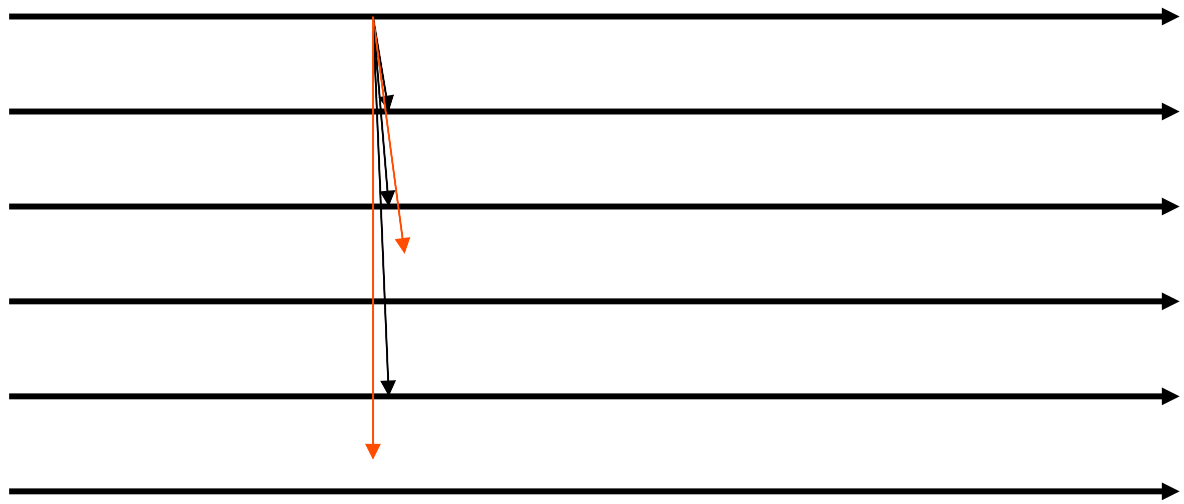
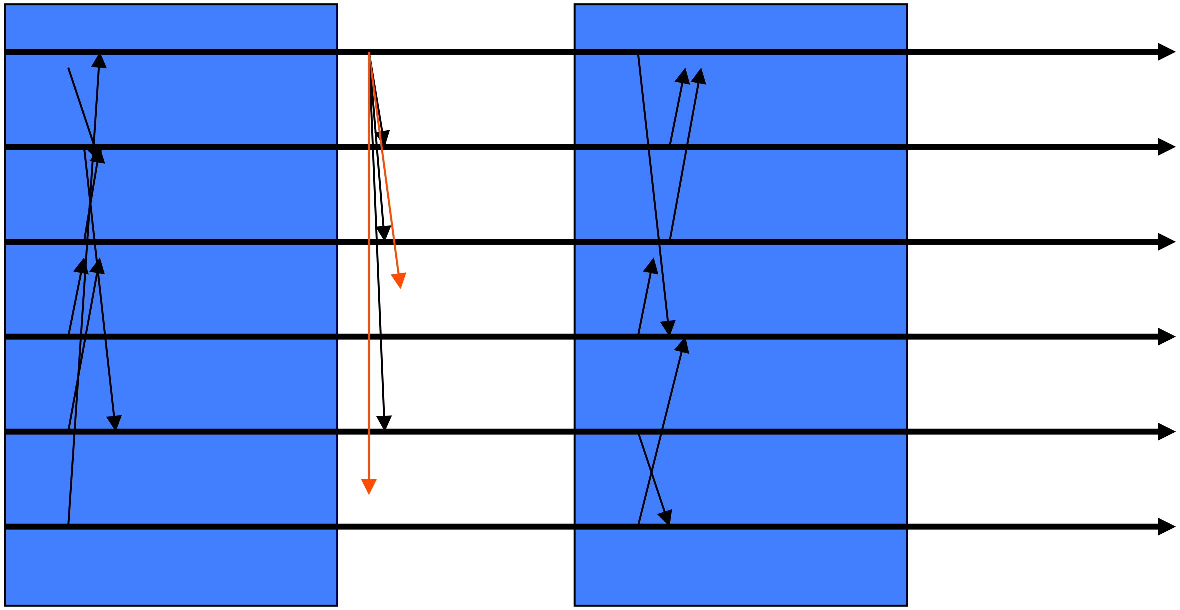
Bimodal multicast



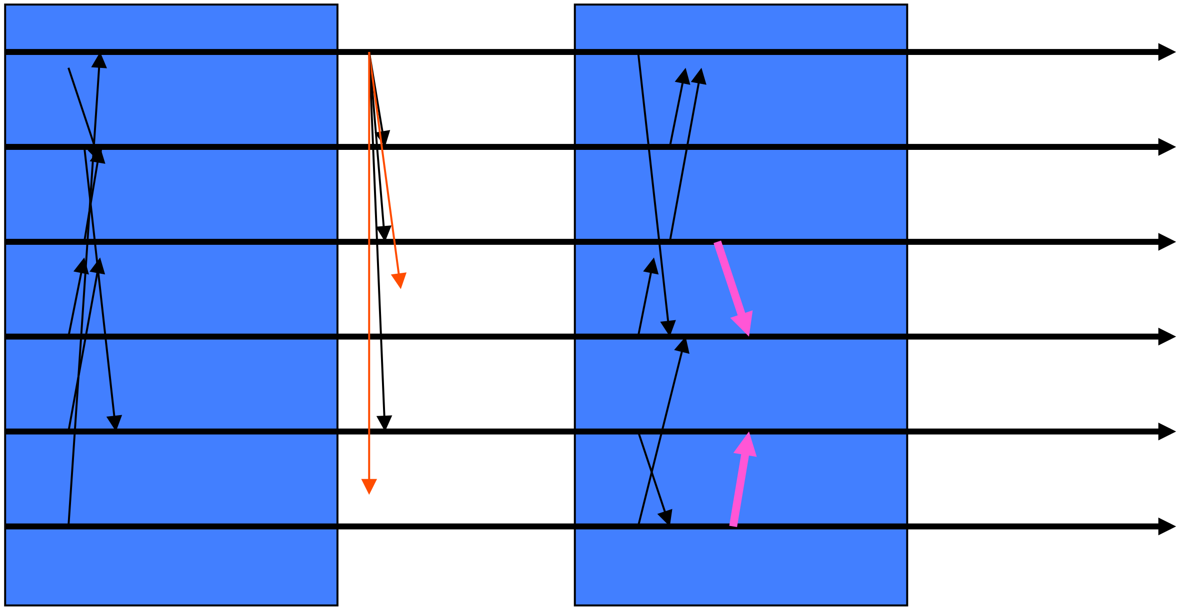
- Initially use UDP / IP multicast

Bimodal multicast



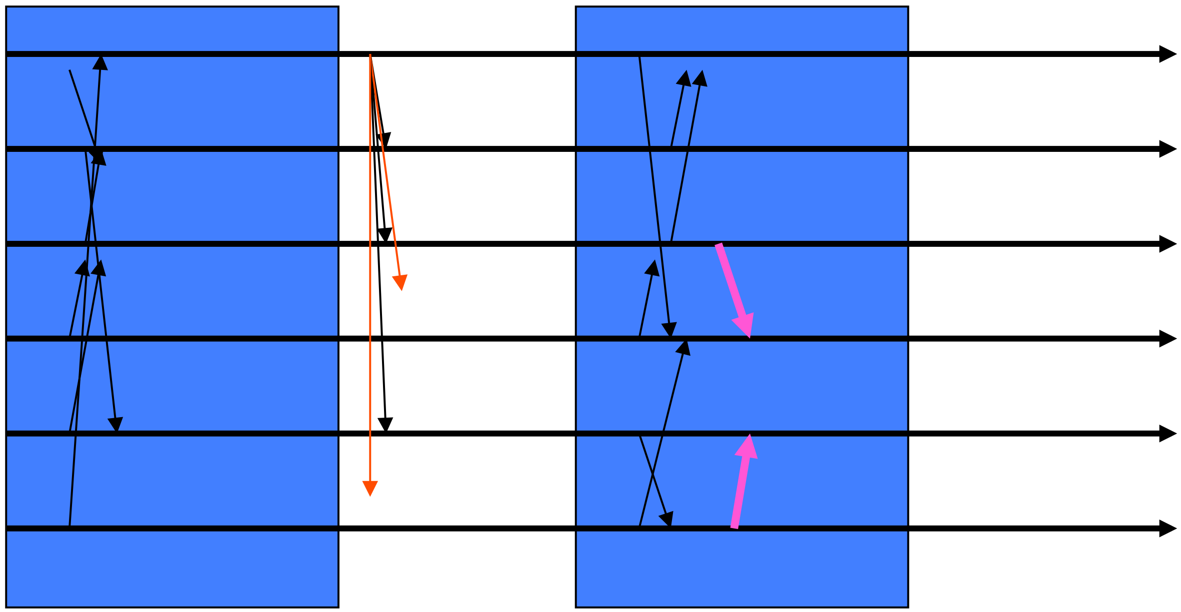
- Periodically (e.g. 100ms) each node sends *digest* describing its state to randomly-selected peer.
- The digest identifies messages; it doesn't include them.

Bimodal multicast



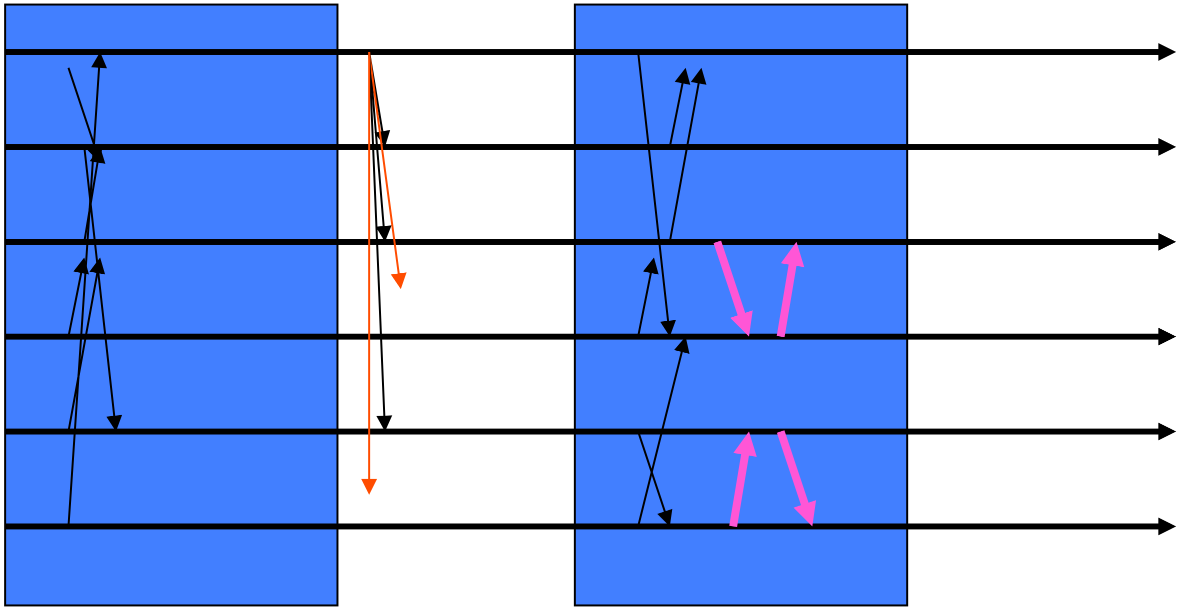
- Recipient checks gossip digest against own history
- Solicits any missing message from node that sent gossip

Bimodal multicast



- Recipient checks gossip digest against own history
- Solicits any missing message from node that sent gossip
- Processes respond to solicitations received during a round of gossip by retransmitting the requested message.

Bimodal multicast



- Respond to solicitations by retransmitted requested msg

Delivery? Garbage Collection?

- Deliver a message when it is in FIFO order
  - Report an unrecoverable loss if a gap persists for so long that recovery is deemed "impractical"

- Garbage collect a message when no "healthy" process could still need a copy

- Match parameters to intended environment

Optimizations

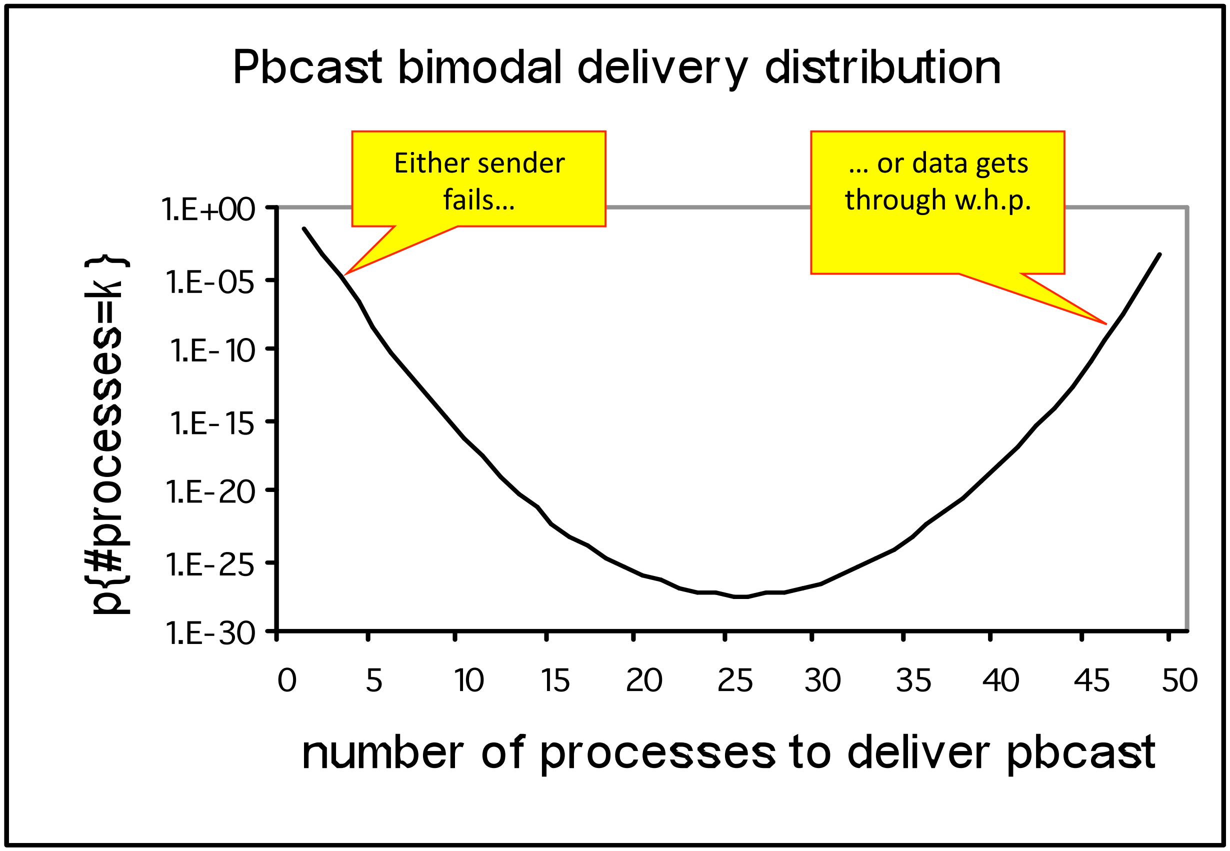
- Retransmission for most recent multicast first
  - "Catch up quickly" to leave at most one gap in sequence
- Participants bound the amount of data they will retransmit during any given round of gossip.
  - If too much is solicited they ignore the excess requests
- Label gossip msgs with sender's gossip round #
  - Ignore if expired round #; node probably no longer correct
- Don't retransmit same msg twice in row to same dest
  - Retransmission may still be in transit

Optimizations

- Use UDP multicast when retransmitting a message if several processes lack a copy
  - For example, if solicited twice
  - Also, if a retransmission is received from "far away"
  - Tradeoff: excess messages versus low latency
- Use regional TTL to restrict multicast scope

Why "bimodal"?

- There are two phases?
- Nope; description of duals "modes" of result



Idea behind analysis

- Can use the mathematics of epidemic theory to predict reliability of the protocol
  - Assume an initial state
  - Now look at result of running B rounds of gossip: Converges exponentially quickly to atomic delivery

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Epidemic algorithms via gossiping

- Assume a fixed population of size *n*
- For simplicity, assume epidemic spreads homogenously through popularly
  - Simple randomized epidemic: any one can infect any one with equal probability
- Assume that *k* members are already infected
- Infection occurs in rounds

Probability of Infection

- Probability $P_{infect}(k,n)$ that a uninfected member is infected in a round if k are already infected?

$$P_{infect}(k,n) = 1 - P\ (\text{nobody infects})$$
$$= 1 - (1 - 1/n)^k$$

$$E\ (\#\text{newly infected}) = (n-k) \bullet P_{infect}(k,n)$$

- Basically it's a Binomial Distribution
- # rounds to infect entire population is O(log n)

Two prevailing styles

- Gossip push ("rumor mongering"):
  - A tells B something B doesn't know
  - Gossip for multicasting
    - Keep sending for bounded period of time*:* *O (log n)*
  - Also used to compute aggregates
    - Max, min, avg easy. Sum and count more difficult.

- Gossip pull ("anti-entropy")
  - A asks B for something it is trying to "find"
  - Commonly used for management replicated data
    - Resolve differences between DBs by comparing digests
    - Amazon S3 !

Still several research questions

- Gossip with bandwidth control
  - Constant rate?
  - Tunable with flow control?
  - Prefer to send oldest data? Newest data?
- Gossip with heterogenous bandwidth
  - Topology / bandwidth-aware gossip
- …

Summary

- IP Anycast
  - Failover and load balancing between IP addresses
  - Uses existing routing protocols, no mods anywhere
  - But problems: scalability, coarse control, TCP stickiness
  - Primarily used for DNS, now being introduced inside ISPs
- Multicast protocols
  - Unrealiable: IP Multicast and IGMP
  - Realiable: SRM, PGM, Bimodal multicast
  - Gossiping