CS514: Intermediate Course in Computer Systems

Lecture 17: October 24, 2003

Reliable Multicast

Reliable multicast is a key component

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- It is a core element of pub/sub architectures
  - Even when not requiring ordering guarantees
  - Pub/sub is a nice paradigm, but ultimately it is about multicast
- It is a core element of the group communications systems we looked at
  - Every data message is multicast
- So lets spend some time looking at multicast issues

First, what is multicast?

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- One-to-many (1-M) or many-to-many (M-M) communications
  - But so are cache-based CDNs, so…
- *Pushed* 1-M or M-M communications
  - Paradigm is like pub/sub: Receivers *join* (or *subscribe)* to a multicast group, senders send (or *publish*) to the multicast group
- Often it is real-time and "simultaneous", but this is not actually central to our definition

What is reliable multicast?

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- *Pushed* 1-M or M-M communications where all members eventually receive every message with high probability
  - TIB uses the word "*guaranteed*" when the sender gets acknowledged
  - Even then, though, reception is not 100% (i.e. partitions can cause eventual delivery failure)
- This is the definition we will work with

What makes reliable multicast hard?

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- In a word, IP multicast makes reliable multicast hard!!!

A little IP multicast history…

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- Early 80's, people started playing with IP multicast over a single LAN
  - David Cheriton, Stanford, V distributed file system
- This had very nice properties… efficient use of media, simple, …
- Decided to extend this to small networks of routers
- And decided to model it after IPv4
  - Connectionless, unreliable
- And even decided to use the IPv4 header
  - I'm not sure why…

A little IP multicast history…

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- The TCP/IP guys were enamored with the end-to-end paradigm
  - Which at first only said that you have to do things at the end
  - But later came to mean you should never do things in the middle
- After all, reliable unicast streams (TCP) over an unreliable middle (IP) worked great!
  - Well, eventually, more-or-less
- So, why not the same thing for reliable multicast?

What makes reliable IP multicast hard?

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- Three things:
  1. Dealing with the “implosion” of ACKs or NAKs
  2. Avoiding receiver overrun
  3. Avoiding network congestion
- Note that TCP deals with the last two only through constant feedback
  - (and, for congestion avoidance, much difficulty)

IP multicast doesn't deal well with feedback

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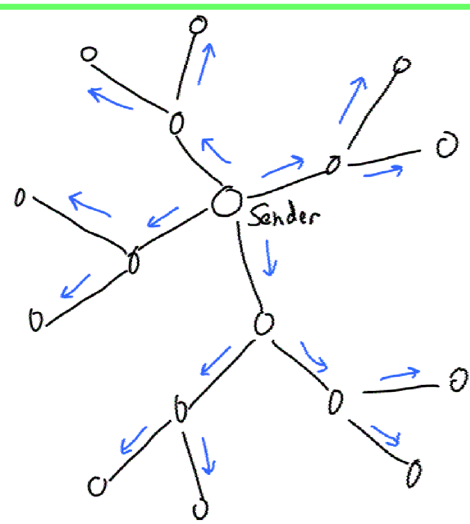

- Easy enough to transmit packets
  - Each router does only a little work

Implosion of ACKs will kill you

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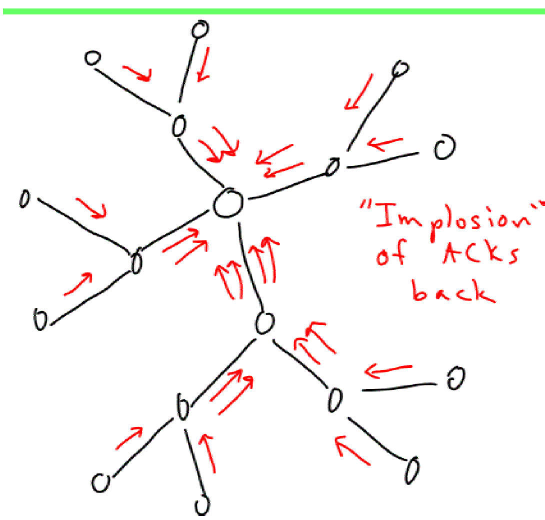

- Same goes for implosion of receive windows or congestion notifications

Can try NAKs instead, but…

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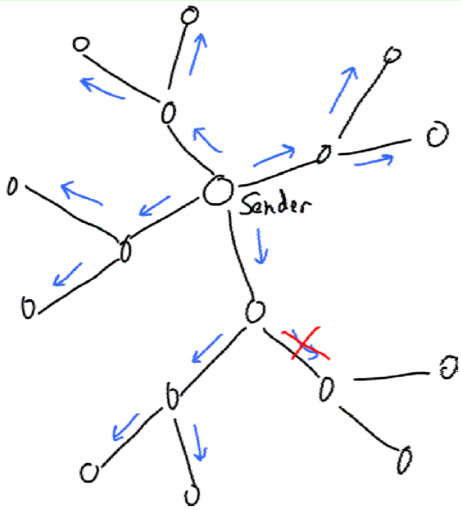

That can kill you too

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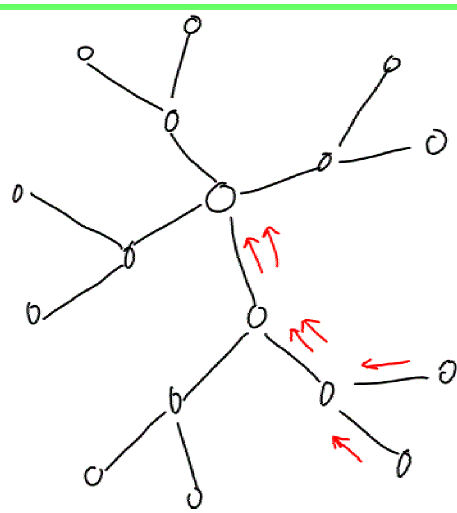

- If packet loss near source
- And lots of receivers
- Then lots of NAKs…

And the retransmit is inefficient too…

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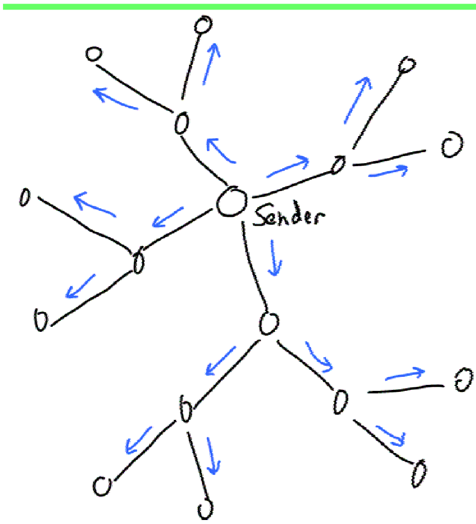

- Retransmit goes to all nodes

Dealing with the implosion

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- It certainly is possible to aggregate feedback messages uptree, but…
- There will usually be some nodes that slow everything down
  - Say 1000 receivers, chances are high that at any time, one or more will exhibit high drop rate, congestion, or small receive window

Dealing with the implosion

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- Fundamentally, the simultaneity of IP multicast generates a “weakest link” effect
  - In small, well engineered environments, this can be avoided to an extent
- Ultimately, you need a strategy of dropping the slow guys
  - I.e., you place a floor on your send rate, and anyone who can’t keep up should drop out

Ok, so what are the alternatives?

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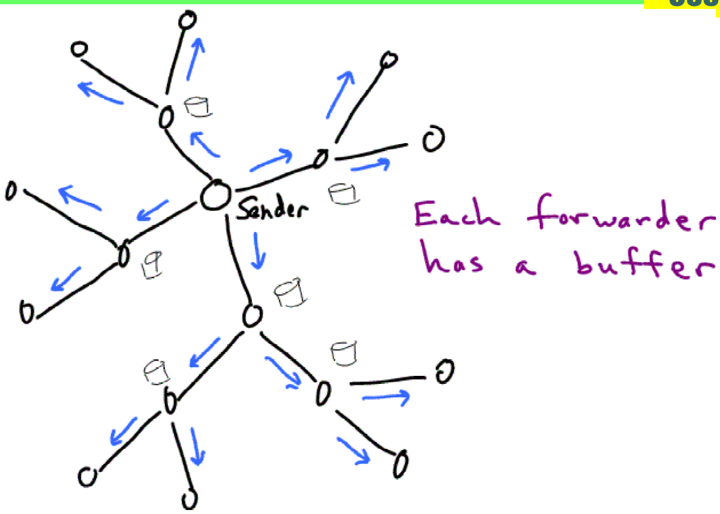
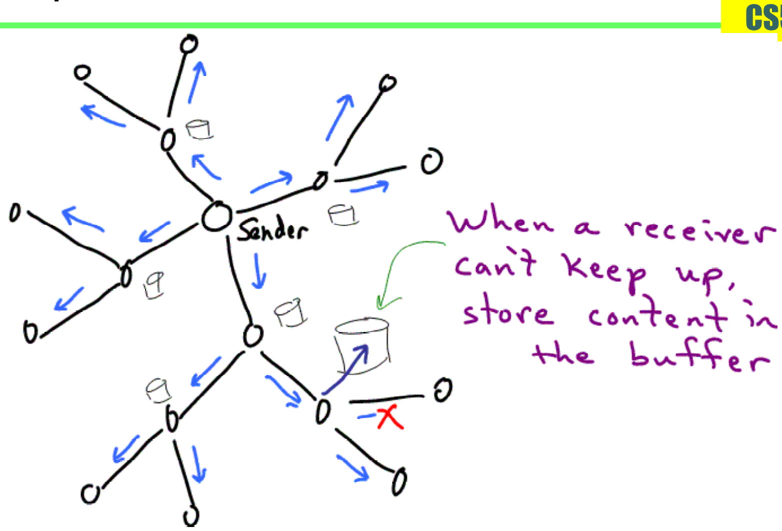
- The simultaneity effect must be broken…receivers must be decoupled from each other
- Two ways:
  1. Buffering in the forwarders (or other receivers!)
  2. Erasure (a.k.a. forward error correction) coding
- The latter actually works with IP multicast, so there is hope!

Buffering in forwarders



Buffering in forwarders



Buffering in forwarders

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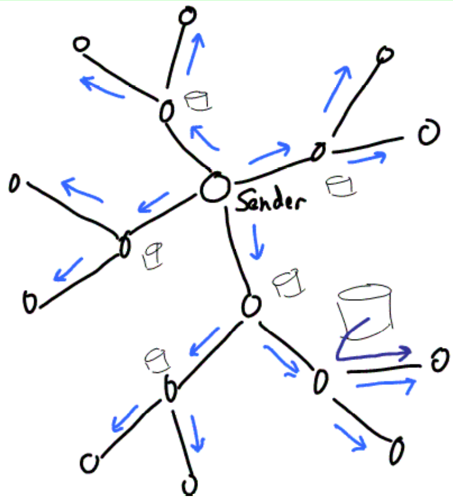

Later, when the problem goes away, feed the receiver from the buffer

Implies that the average receiver rate is good enough

Erasure codes

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- Mainly for multicasting files (not live streams)
- File with M blocks is encoded as N blocks (N > M)
- If any M+K blocks are received, then file can be reconstructed

- Sender cycles through N blocks over and over
- Slower or more lossy receivers simply listen longer
- Also, receivers can start listening at different times

What we'll look at more closely:

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- SRM (Scalable Reliable Multicast)
- PGM (algorithm formerly known as Pretty Good Multicast)
- pbcast (Ken's gossip-supported multicast)
- Digital Fountain (erasure code style)
- Overlay Multicast

SRM (Scalable Reliable Multicast)

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- Developed in the true IP multicast, E2E model spirit
- In other words, IP multicast completely stateless, end hosts do all the work
- Recall IP multicast model:
  - Any host can send to the group
    - (Even if not a receiver, though SRM doesn't use this fact)
  - Also, IP multicast packets have a "scoping" mechanism" (using IP's TTL field)
    - Larger TTL, packet goes further, but not precisely defined as one hop per TTL value

SRM basic idea

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- Packets have per-sender sequence number
- Receivers can tell when a packet was missed when they receive a later packet
  - Or when they receive a periodic "session message"
- Receivers multicast a "repair request" for missing packets
  - With limited scope, so that not all other members see it

SRM basic idea

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- Packets have per-sender sequence number
- Receivers can tell when a packet was missed when they receive a later packet
  - Or when they receive a periodic "session message"
- Receivers multicast a "repair request" for missing packets
  - But *randomly timed*, so that not all other members with missing packet send a repair request
  - And with *limited TTL scope*, so that not all other members see it

SRM basic idea

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- Upon receiving a repair request, if the member has the packet, it multicasts the repair packet
  - Also randomly timed and with limited TTL scope
- If receiver with missing packet doesn't hear a repair after a while, it retransmits repair request with larger TTL
- Etc.

SRM Example

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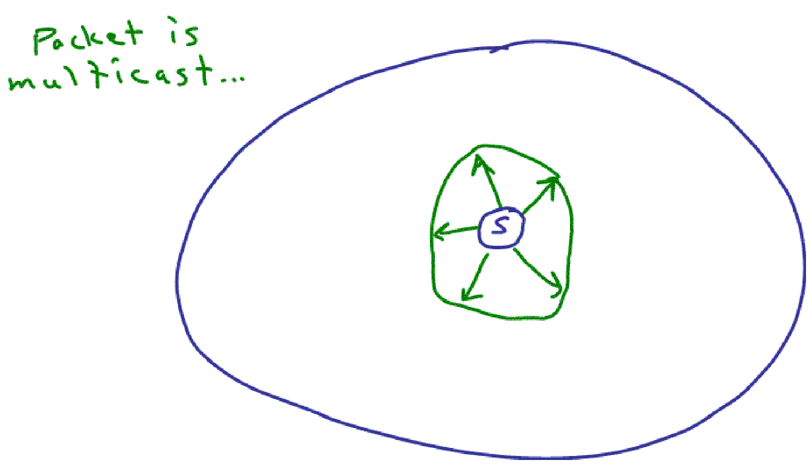
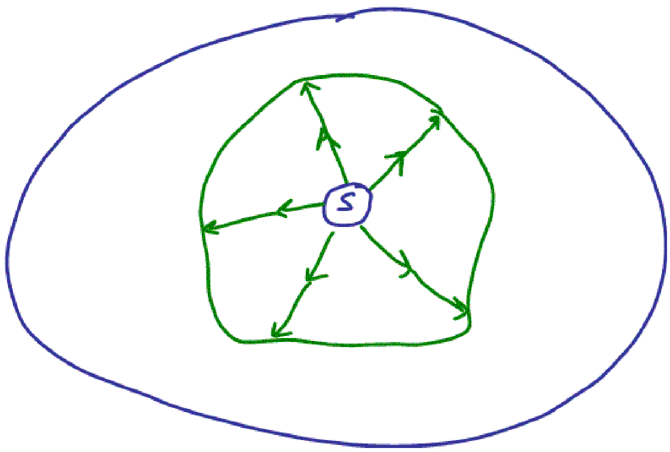
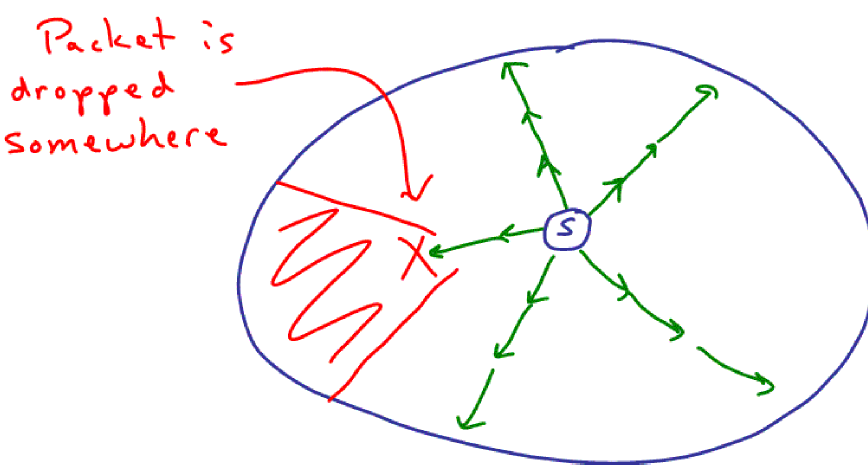


SRM Example



SRM Example



SRM Example

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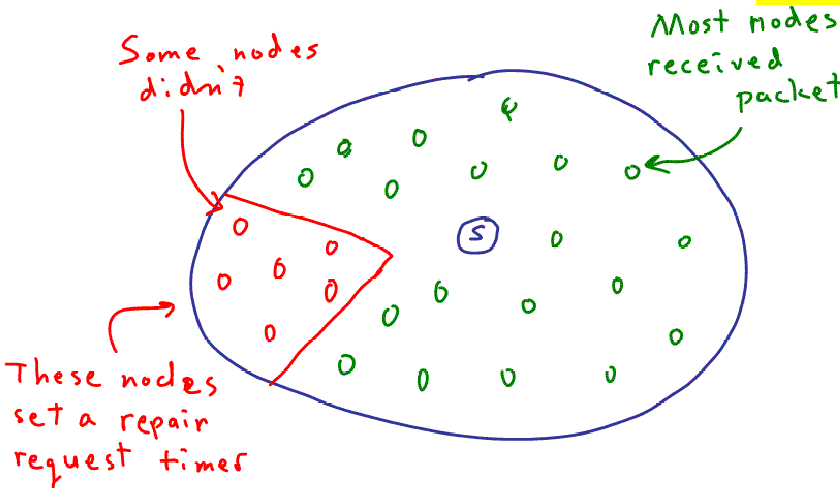

SRM Example

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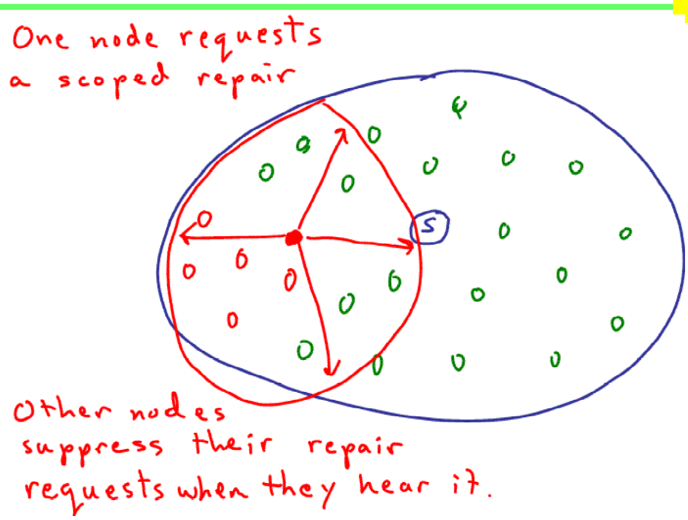

SRM Example

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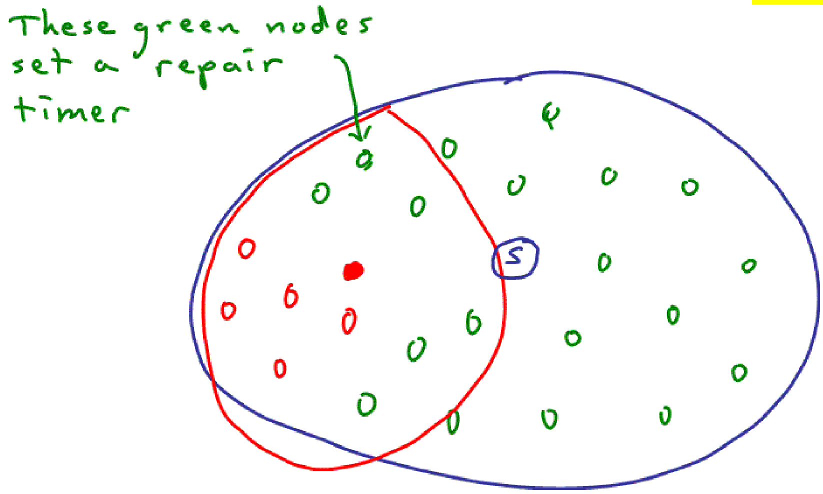

SRM Example

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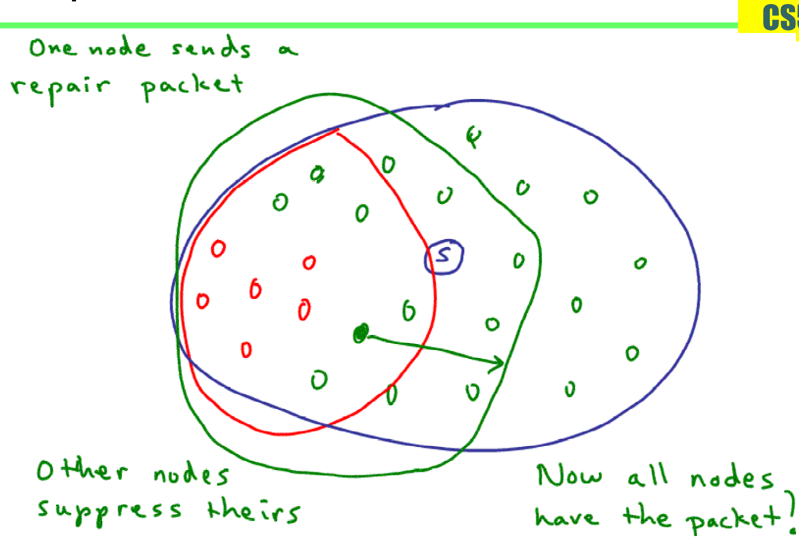

SRM timers

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- Set to a value proportional to distance from sender
  - The closer to the sender, the smaller the value
- This way, nodes nearer to the sender tend to respond first
- True for both nodes requesting repairs, and node providing repairs
- Ideal: One repair request, one repair!

SRM excitement

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- Initially there was lots of excitement about SRM
  - And, early results looked promising
- But . . .

Turns out it was hard to make SRM scale

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- Tension between size of scope and value of timers
  - Exacerbated by vague definition of TTL
- Increase in dropped packets with size of multicast group
- Congested links tended to cause dropped repair requests and repairs
  - Causing yet more repair requests, which caused still more congestion, etc.

SRM difficulties

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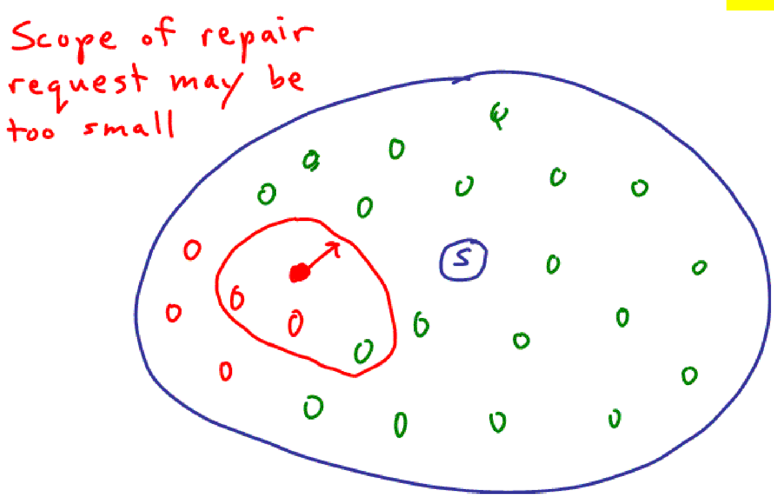

SRM difficulties

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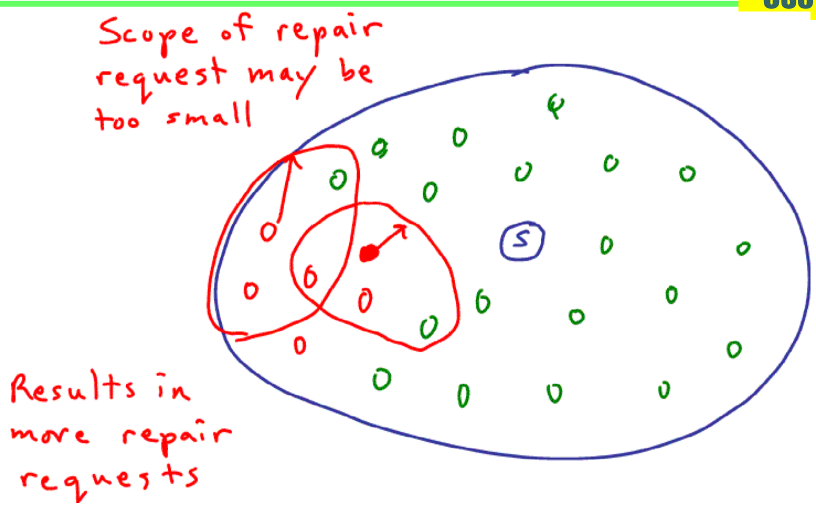

SRM difficulties

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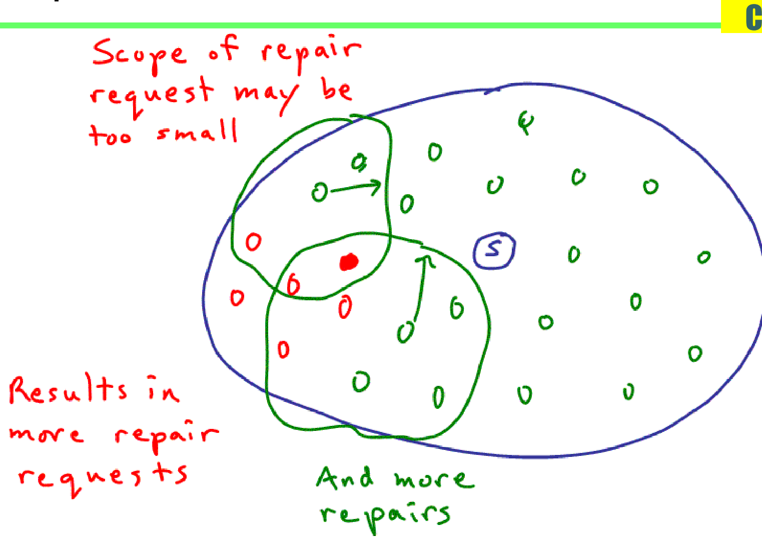

SRM difficulties

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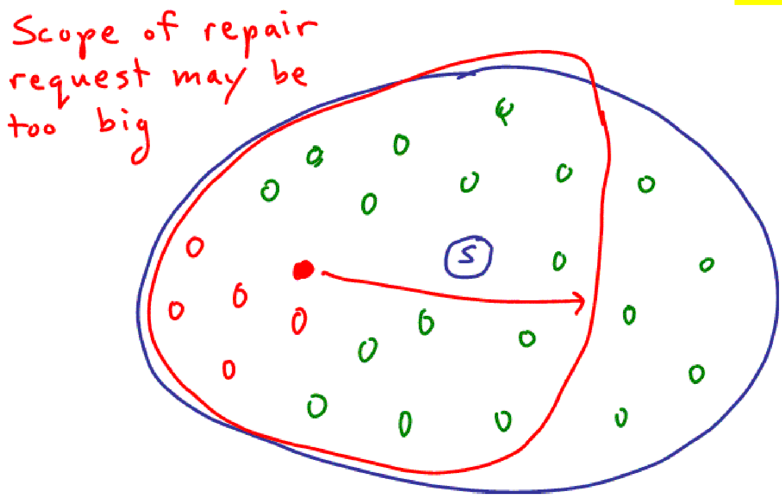

SRM difficulties

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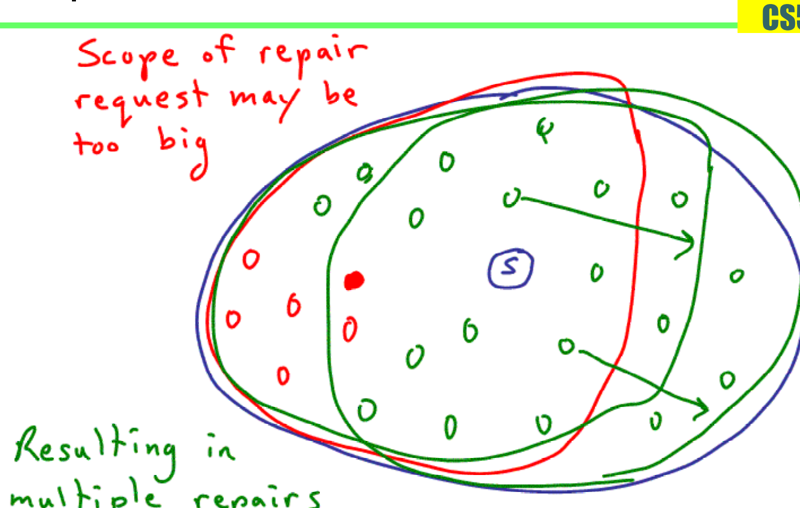

PGM

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- Originally “Pretty Good Multicast”
  - From cisco
- But they were sued by the PGP (pretty good privacy) folks
- So changed to “Pragmatic General Multicast”

Router support for reliability

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- Not surprising that it was driven by Cisco
- Idea is that routers would have “transport layer” intelligence
- NAKs travel uptree through routers towards source
- Routers remember NAKs, and transmit resends only on interfaces that received NAKs
- Later, routers could even store packets, retransmit from local store

PGM example

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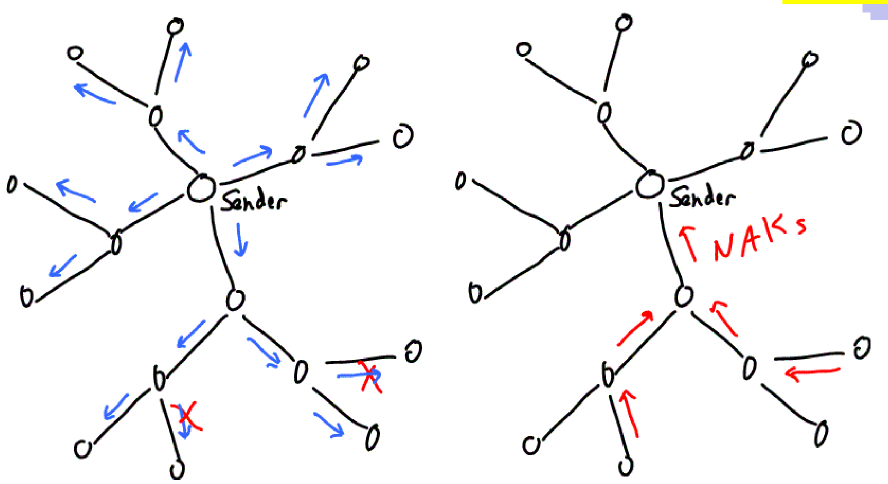

PGM example

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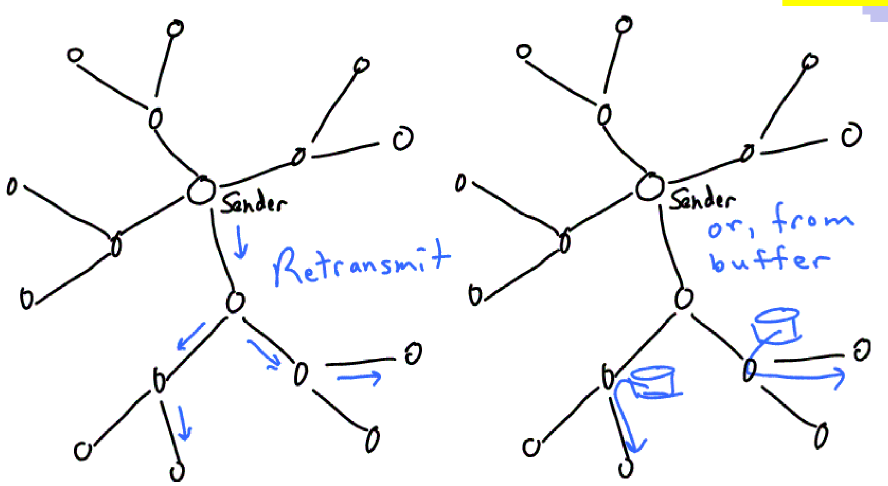

PGM never really took off

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- Hard to say why, but…
- Turned out to be pretty complex
  - Hosts had to be modified
  - Had to work with mix of PGM and non-PGM routers…lots of tricky corner cases
- Didn't really decouple receivers
  - Still "weakest link" problem

PGM never really took off

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- Possibly more to the point, PGM was not really general
- Different reliable multicasts have different needs
  - Guarantees, prioritization, even ordering
  - PGM didn't really do this
- Ultimately, it made more sense to build reliability into middleware hosts (like pub/sub), and really customize it to application needs