

CS 425 / ECE 428

Distributed Systems

Fall 2026

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Lecture 5: Gossiping

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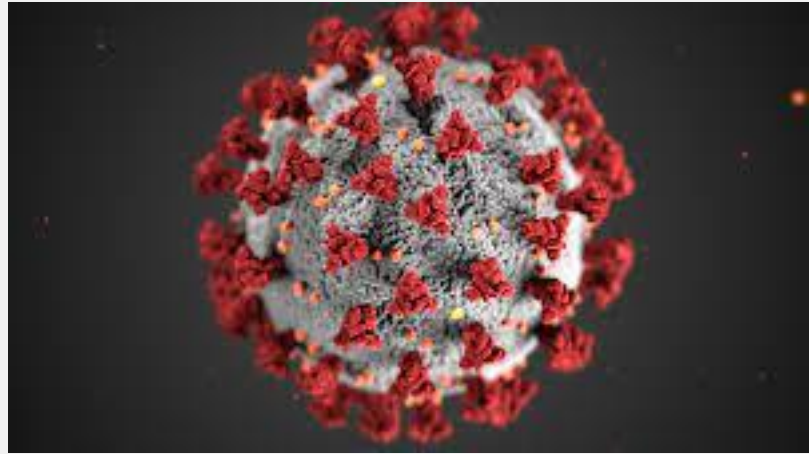
Announcements

- HW1 out; due Sep 20th
 - Solve problems right after lecture covers topic
- Gradescope open for submissions now
- MP1 due Sep 13th
 - VMs will be distributed tomorrow (watch Piazza)
 - GitHub by Monday (use personal to collaborate now)
 - Demos will be Monday Sep 14th
 - Demo signups and instructions will be posted on Sep 9th



Today's Agenda

- Epidemics, or how to use them to your advantage (to do good things)



Multicast

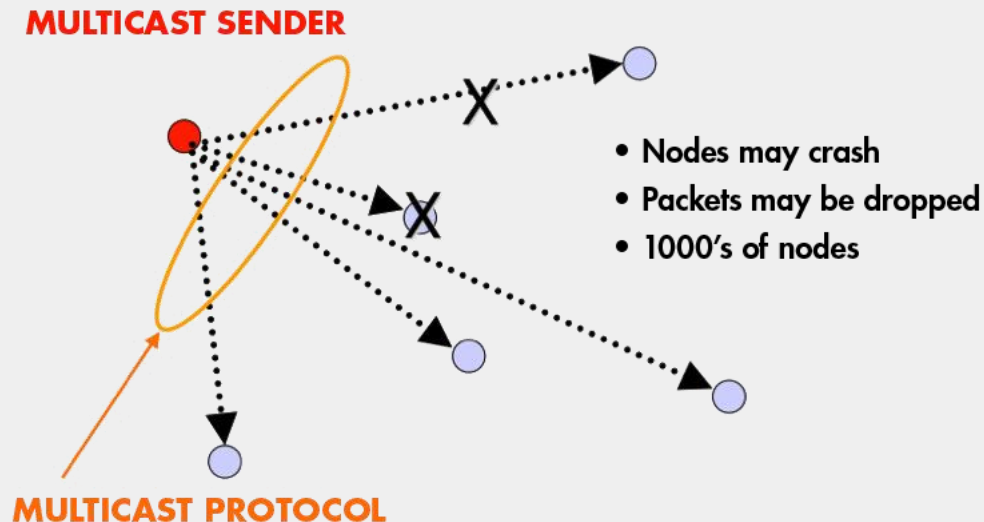
Node with a piece of information
to be communicated to everyone



Distributed Group
of "Nodes" =

Processes at
Internet-based host

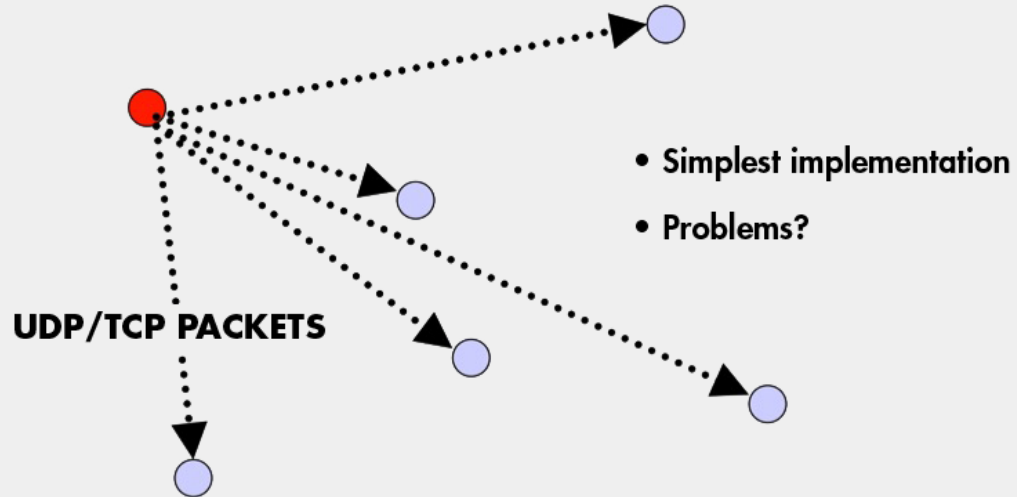
Fault-tolerance and Scalability



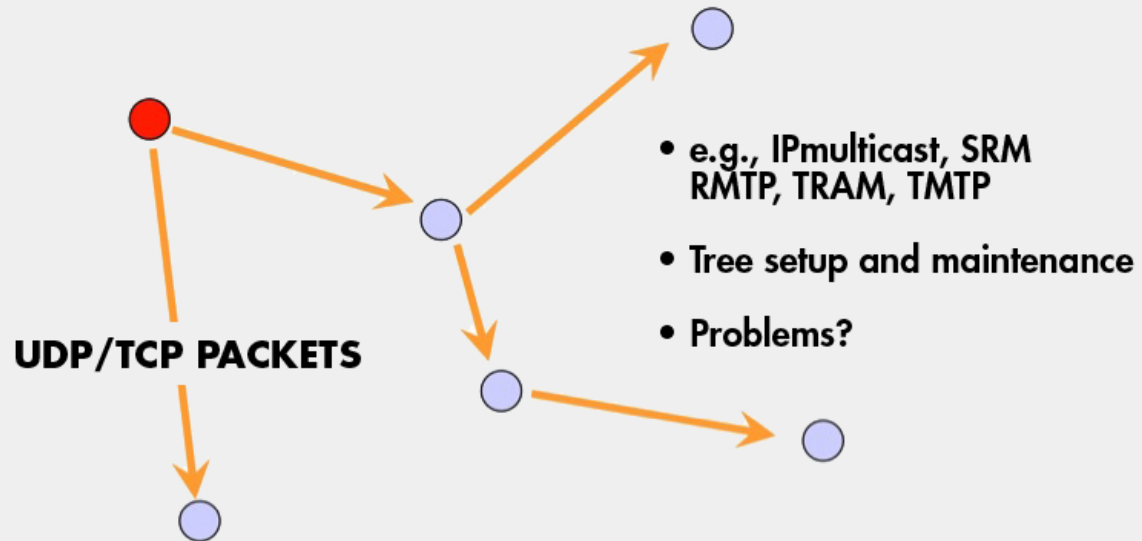
Needs:

1. Reliability (Atomicity)
 - 100% receipt
2. Speed

Centralized



Tree-Based



Tree-based Multicast Protocols

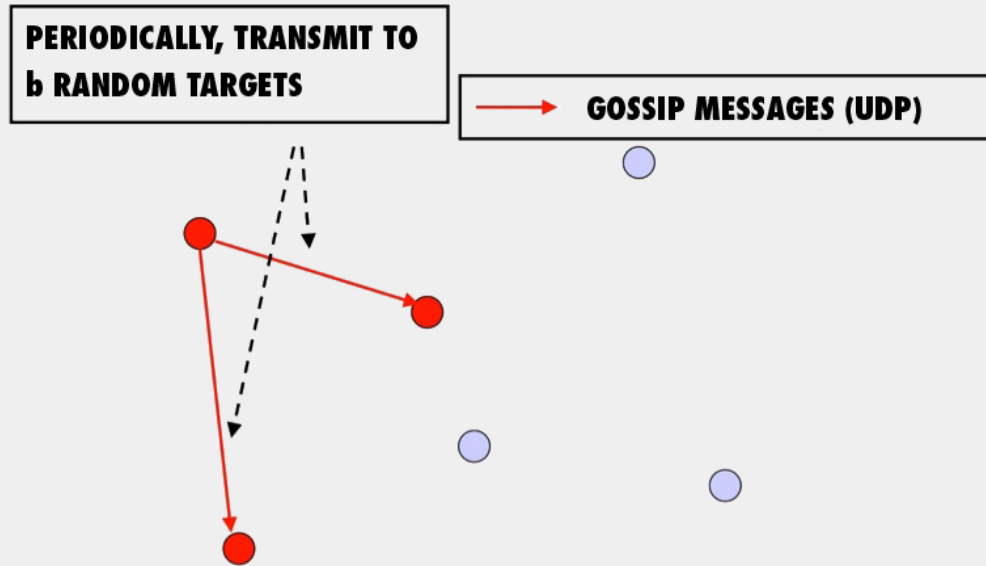
- Build a spanning tree among the processes of the multicast group
- Use spanning tree to disseminate multicasts
- Use either acknowledgments (ACKs) or negative acknowledgements (NAKs) to repair multicasts not received
- SRM (Scalable Reliable Multicast)
 - Uses NAKs
 - But adds random delays, and uses exponential backoff to avoid NAK storms
 - (Do you know why SRM is called a “talented” protocol?)
- RMTP (Reliable Multicast Transport Protocol)
 - Uses ACKs
 - But ACKs only sent to designated receivers, which then re-transmit missing multicasts
- These protocols still cause an $O(N)$ ACK/NAK overhead [Birman99]

A Third Approach

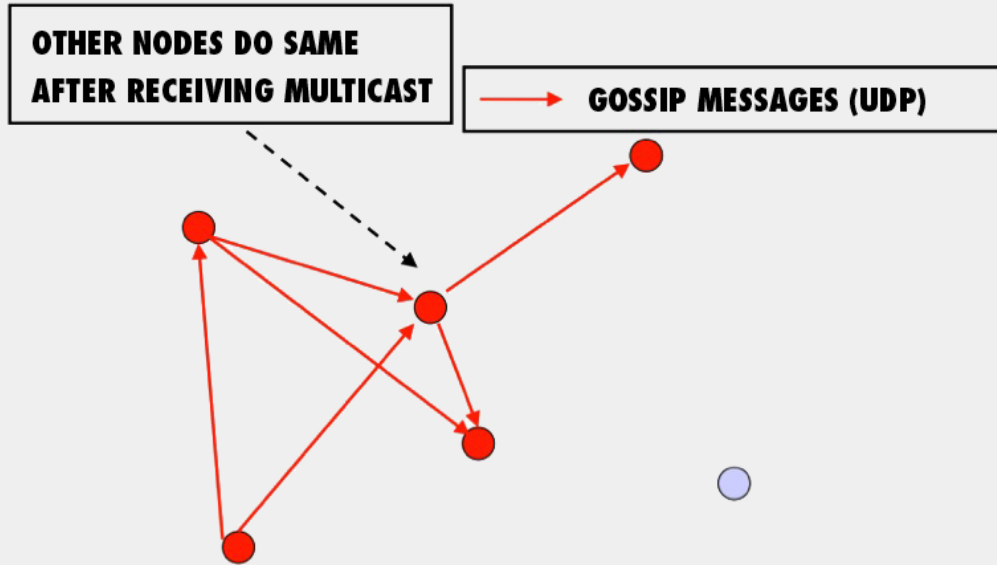
MULTICAST SENDER



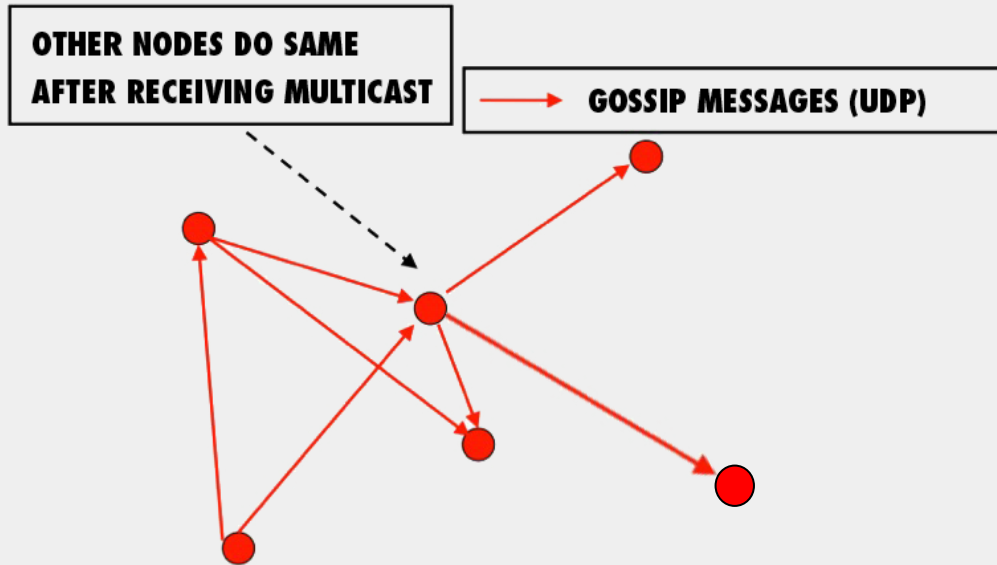
A Third Approach



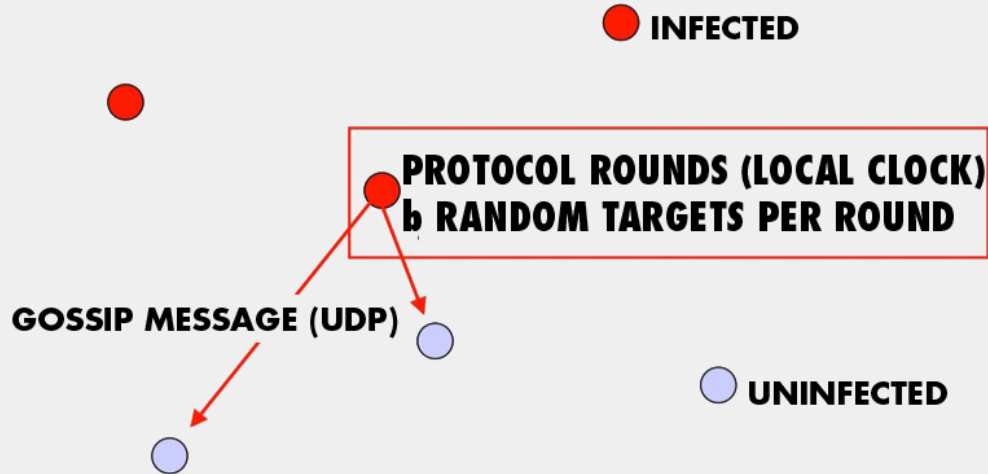
A Third Approach



A Third Approach



“Epidemic” Multicast (or “Gossip”)



Push vs. Pull

- So that was “Push” gossip
 - Once you have a multicast message, you start gossiping about it
 - Multiple messages? Gossip a random subset of them, or recently-received ones, or higher priority ones
- There’s also “Pull” gossip
 - Periodically poll a few randomly selected processes for new multicast messages that you haven’t received
 - Get those messages
- Hybrid variant: Push-Pull
 - As the name suggests

Properties

Claim that the simple Push protocol

- Is lightweight in large groups
- Spreads a multicast quickly
- Is highly fault-tolerant

Analysis

From old mathematical branch of *Epidemiology* [Bailey 75]

- Population of $(n+1)$ individuals mixing homogeneously
- Contact rate between any individual pair is β
- At any time, each individual is either uninfected (numbering x) or infected (numbering y)
- Then, $x_0 = n, y_0 = 1$
and at all times $x + y = n + 1$
- Infected–uninfected contact turns latter infected, and it stays infected

Analysis (contd.)

- Continuous time process
- Then

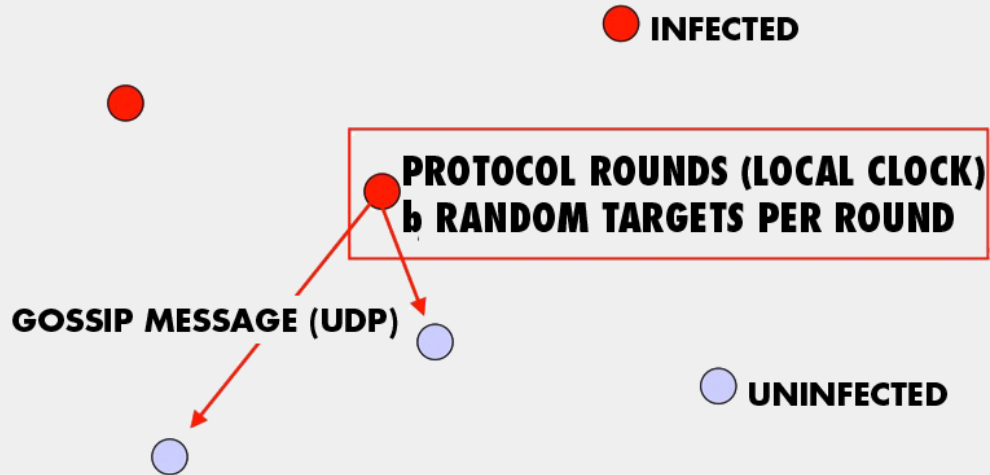
$$\frac{dx}{dt} = -\beta xy \quad (\text{why?})$$

with solution:

$$x = \frac{n(n+1)}{n + e^{\beta(n+1)t}}, \quad y = \frac{(n+1)}{1 + ne^{-\beta(n+1)t}}$$

(can you derive it?)

Epidemic Multicast



Epidemic Multicast Analysis

$$\beta = \frac{b}{n} \quad (\text{why?})$$

Substituting, at time $t=c\log(n)$, the number of infected is

$$y \approx (n+1) - \frac{1}{n^{cb-2}}$$

(correct? can you derive it?)

Analysis (contd.)

- Set c, b to be small numbers independent of n
- Within $c \log(n)$ rounds, [**low latency**]
 - all but $\frac{1}{n^{cb-2}}$ number of nodes receive the multicast
[**reliability**]
 - each node has transmitted no more than $cb \log(n)$ gossip messages
[**lightweight**]

Why is $\log(N)$ low?

- $\log(N)$ is not constant in theory
- But pragmatically, it is a very slowly growing number
- Base 2
 - $\log(1000) \sim 10$
 - $\log(1\text{M}) \sim 20$
 - $\log(1\text{B}) \sim 30$
 - $\log(\text{all IPv4 addresses}) = 32$
 - $\log(\text{all IPv6 addresses}) = 128$

Fault-tolerance

- Packet loss
 - 50% packet loss: analyze with b replaced with $b/2$
 - How many rounds to achieve the same reliability?

Fault-tolerance

- Packet loss
 - 50% packet loss: analyze with b replaced with $b/2$
 - To achieve same reliability as 0% packet loss, takes twice as many rounds

Fault-tolerance

- Packet loss
 - 50% packet loss: analyze with b replaced with $b/2$
 - To achieve same reliability as 0% packet loss, takes twice as many rounds
- Node failure
 - 50% of nodes fail: analyze with n replaced with $n/2$ and b replaced with $b/2$
 - Same as above

Fault-tolerance

- With failures, is it possible that the epidemic might die out quickly?
- Possible, but improbable:
 - Once a few nodes are infected, with high probability, the epidemic will not die out
 - So the analysis we saw in the previous slides is actually behavior *with high probability*
- [Galey and Dani 98]
- Think: why do rumors spread so fast? why do infectious diseases cascade quickly into epidemics? why does a virus or worm spread rapidly?

Pull Gossip: Analysis

- In all forms of gossip, it takes $O(\log(N))$ rounds before about $N/2$ processes get the gossip
 - Why? Because that's the fastest you can spread a message – a spanning tree with fanout (degree) of constant degree has $O(\log(N))$ total nodes (**height of tree**)
- Which should be faster thereafter, push or pull?

Pull Gossip: Analysis

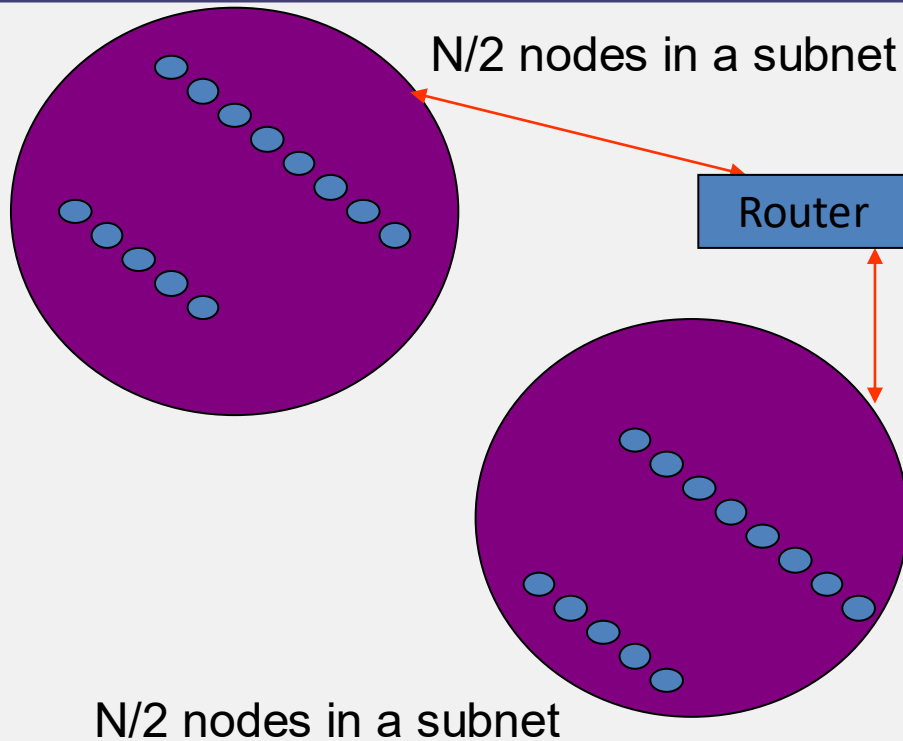
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- Thereafter, pull gossip is faster than push gossip
- After the i th, round let p_i be the fraction of non-infected processes. Let each round have k pulls. Then

$$p_{i+1} = (p_i)^{k+1}$$

- This is super-exponential
- Second half of pull gossip finishes in time $O(\log(\log(N)))$

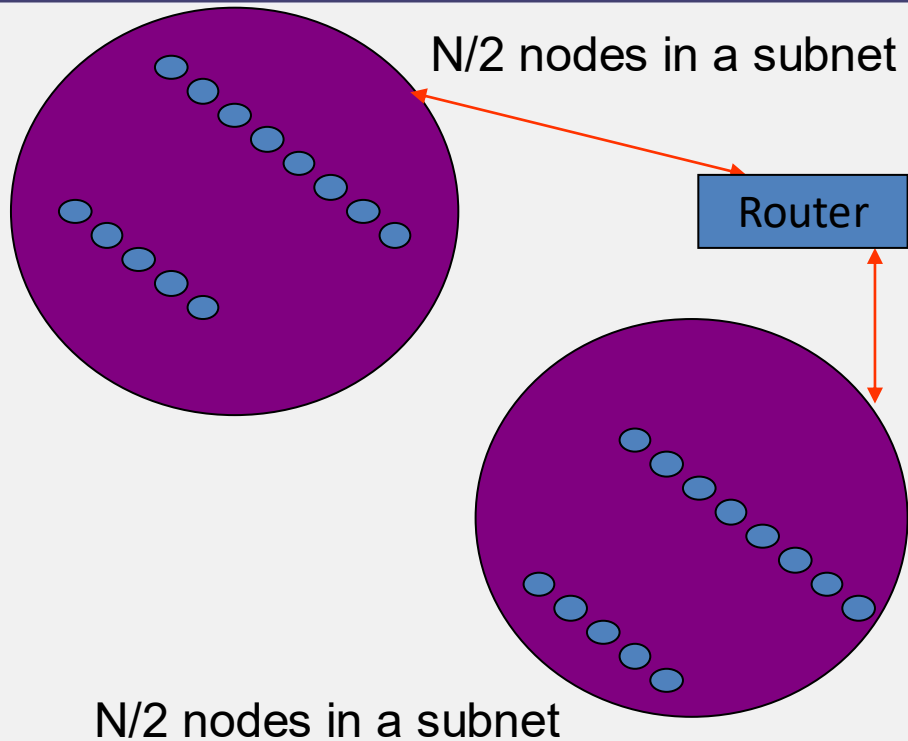
Topology-Aware Gossip

- Network topology is hierarchical
- Random gossip target selection => What is the load on the router in big O?



Topology-Aware Gossip

- Network topology is hierarchical
- Random gossip target selection $\Rightarrow$ core routers face $O(N)$ load (Why?)
- **Fix:** In subnet i , which contains n_i nodes, pick gossip target in your subnet with probability $(1 - 1/n_i)$
- Router load $= O(1)$
- Dissemination time $= O(\log(N))$



SO,...

- Is this all theory and a bunch of equations?
- Or are there implementations yet?

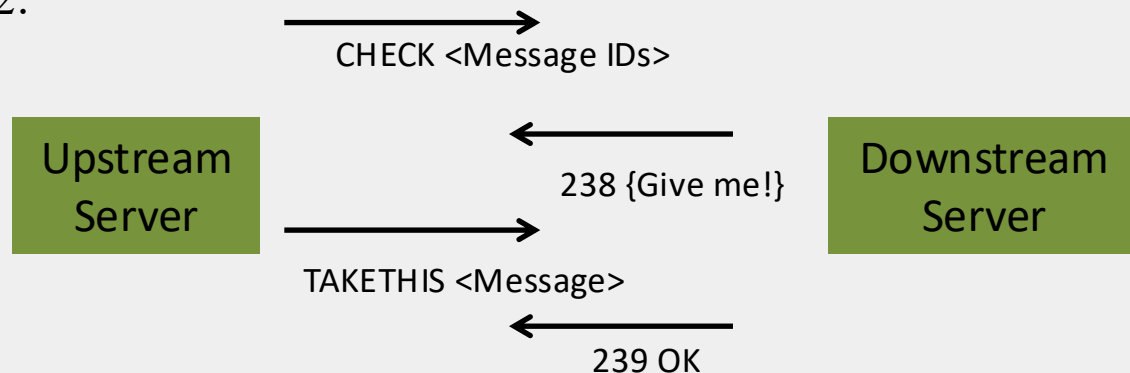
Some implementations

- Clearinghouse and Bayou projects: email and database transactions [PODC '87]
- refDBMS system [Usenix '94]
- Bimodal Multicast [ACM TOCS '99]
- Sensor networks [Li Li et al, Infocom '02, and PBBF, ICDCS '05]
- AWS EC2 and S3 Cloud (rumored). ['00s]
- Cassandra key-value store (and others) use gossip for maintaining membership lists
- Usenet NNTP (Network News Transport Protocol) ['79]

NNTP Inter-server Protocol

1. Each client uploads and downloads news posts from a news server

2.



Server retains news posts for a while,
transmits them lazily, deletes them after a while.

Summary

- Multicast is an important problem
- Tree-based multicast protocols
- When concerned about scale and fault-tolerance, gossip is an attractive solution
- Also known as epidemics
- Fast, reliable, fault-tolerant, scalable, topology-aware

Answer – Push Analysis (contd.)

Using: $\beta = \frac{b}{n}$

Substituting, at time $t=c\log(n)$

$$\begin{aligned} y &= \frac{n+1}{1 + ne^{-\frac{b}{n}(n+1)c\log(n)}} \approx \frac{n+1}{1 + \frac{1}{n^{cb-1}}} \\ &\approx (n+1)\left(1 - \frac{1}{n^{cb-1}}\right) \\ &\approx (n+1) - \frac{1}{n^{cb-2}} \end{aligned}$$