CS 425 / ECE 428
Distributed Systems
Fall 2025

Indranil Gupta (Indy)

w/ Aishwarya Ganesan, Ram Kesavan

Lecture 5: Gossiping

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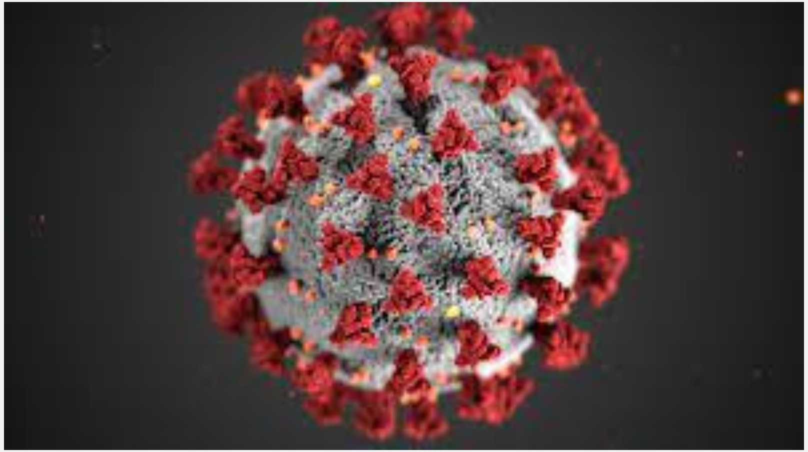
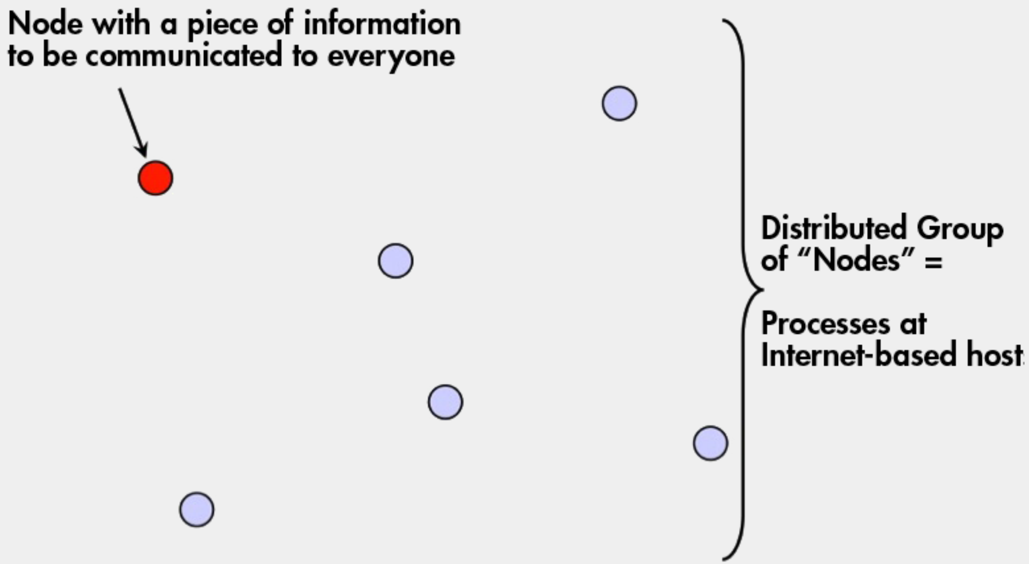
Today's Agenda

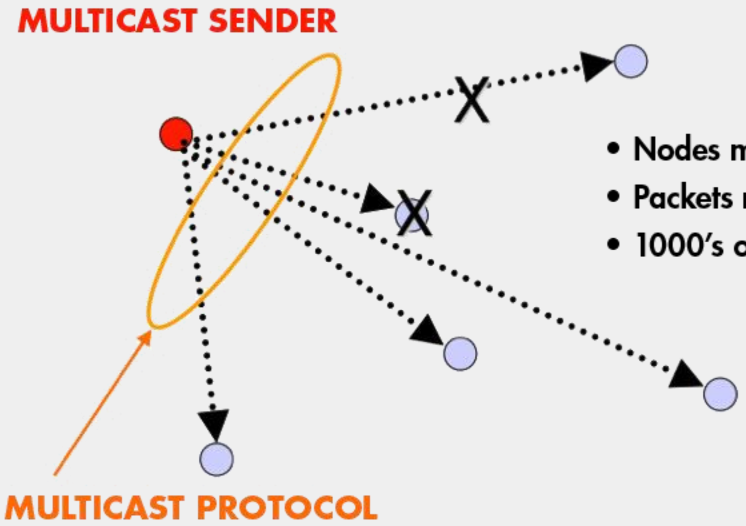
- Epidemics, or how to use them to your advantage (to do good things)



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

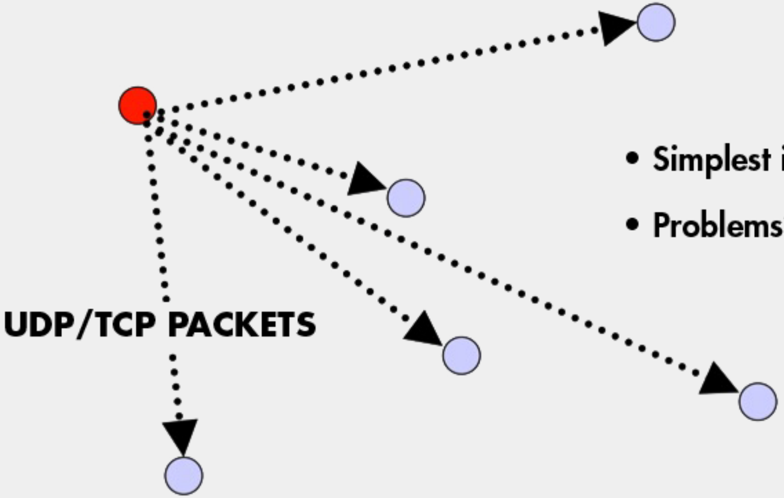


- Nodes may crash
- Packets may be dropped
- 1000's of nodes

Needs:

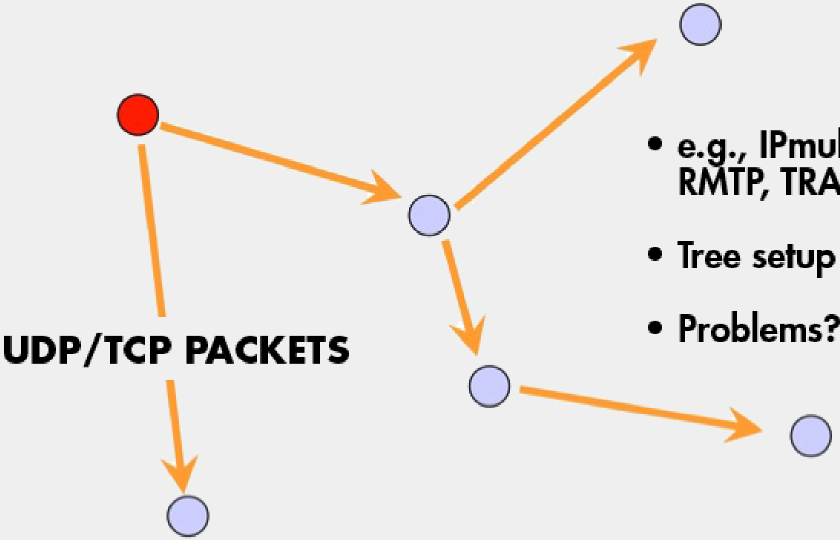
1. Reliability (Atomicity)
   - 100% receipt
2. Speed

Centralized



- Simplest implementation
- Problems?

Tree-Based

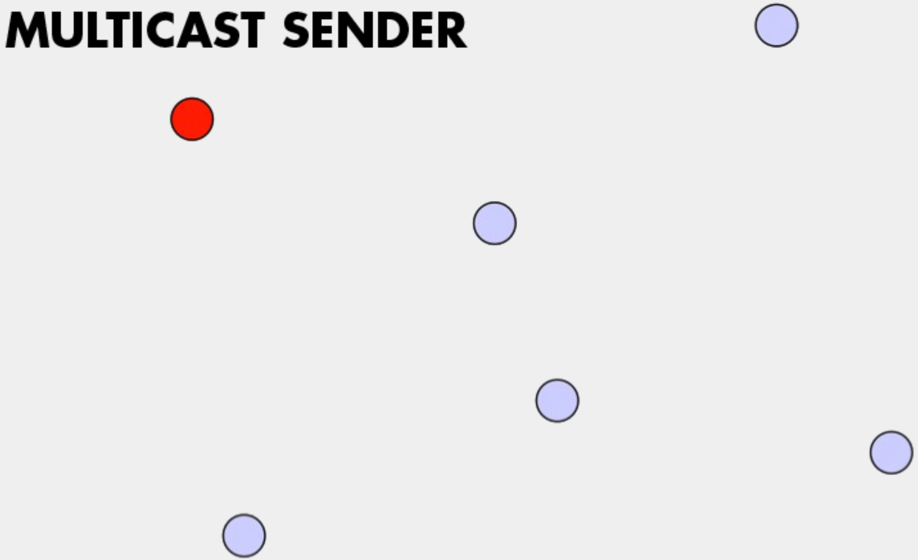


- e.g., IPmulticast, SRM RMTP, TRAM, TMTP
- Tree setup and maintenance
- Problems?

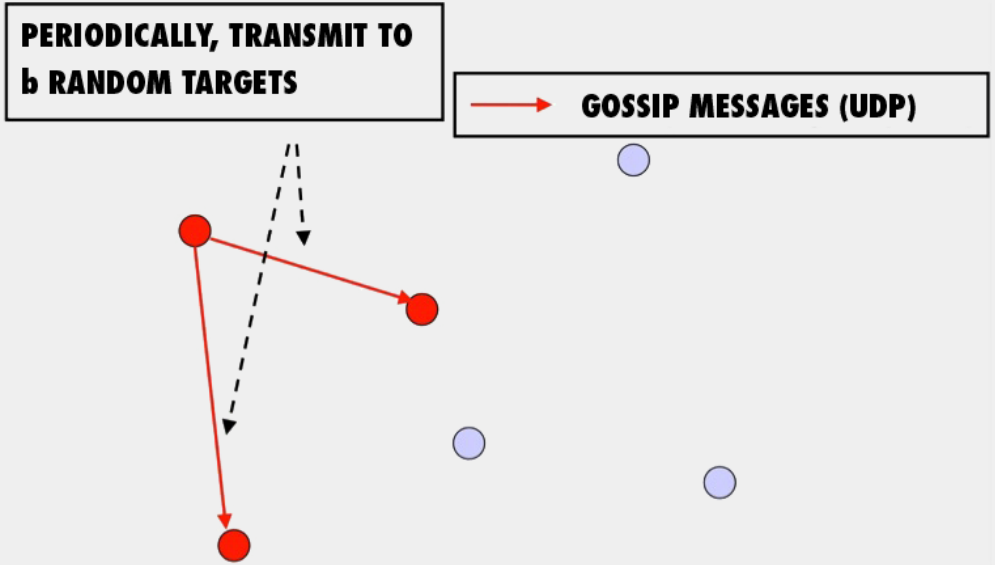
Tree-based Multicast Protocols

- 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]

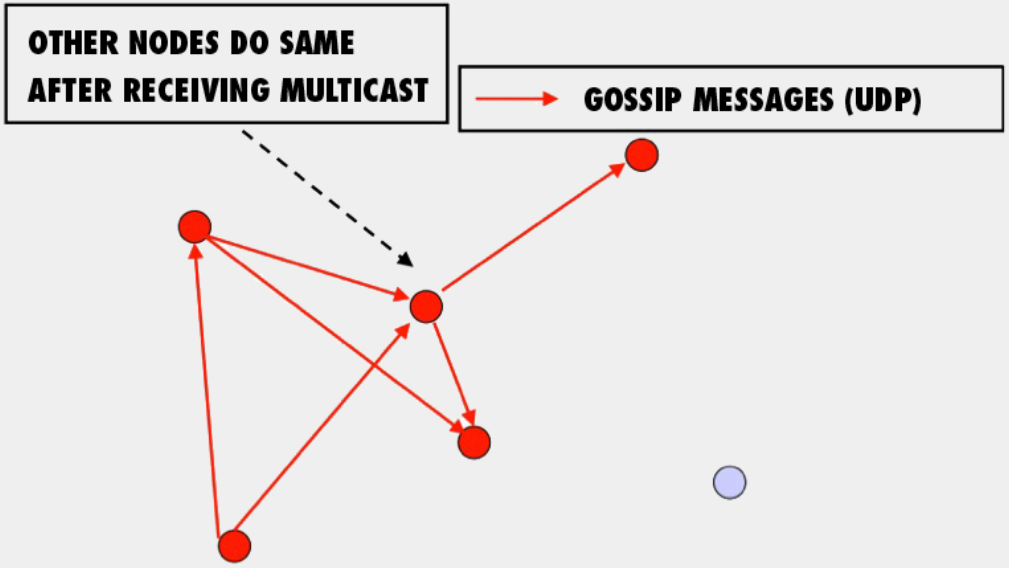
A Third Approach



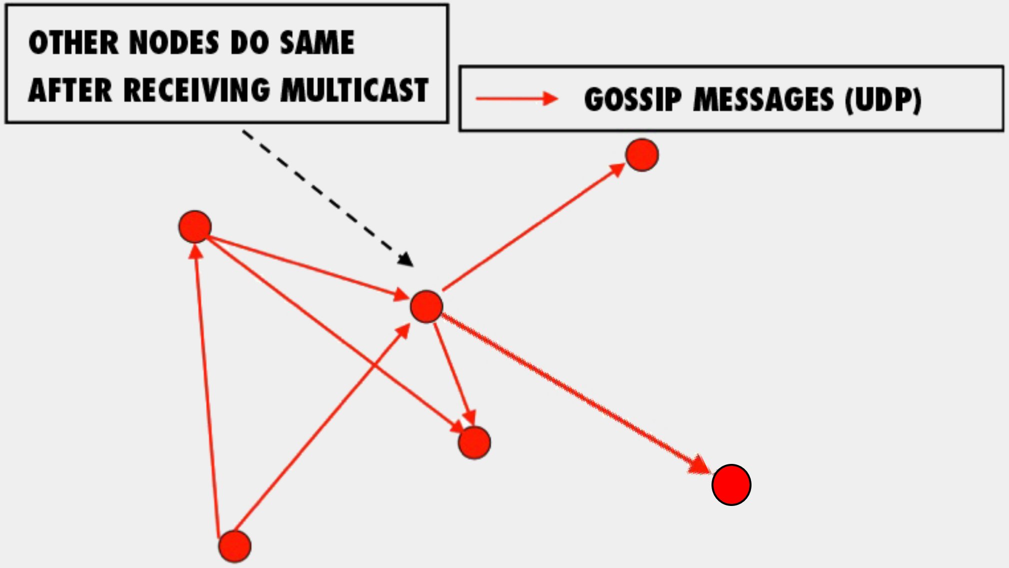
A Third Approach



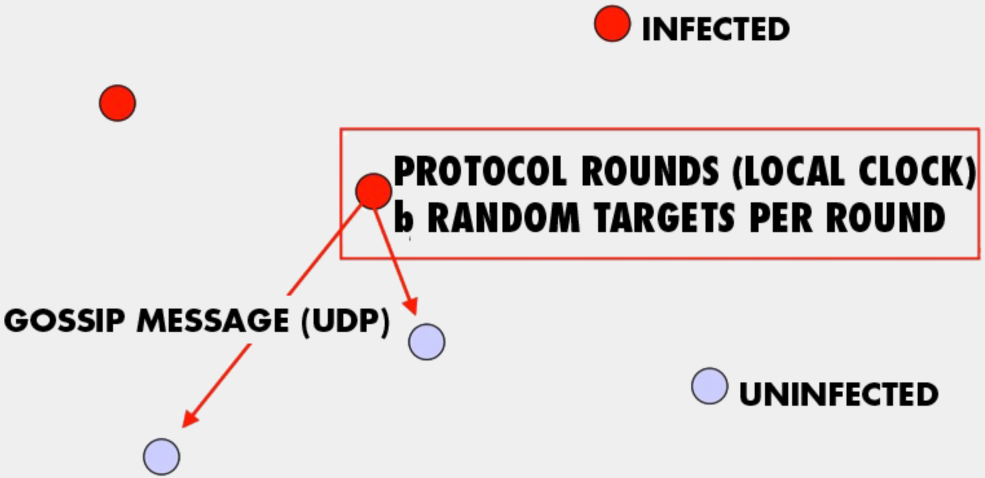
A Third Approach



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

Announcements

- MP1: Due coming Sunday 9/14, demos Monday 9/15
  - VMs distributed: see Piazza
  - Demo signup sheet: now on Piazza (sign up by Friday!)
  - Demo details: will be posted tomorrow on Piazza
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- HW1 due soon, Thu 9/18!
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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

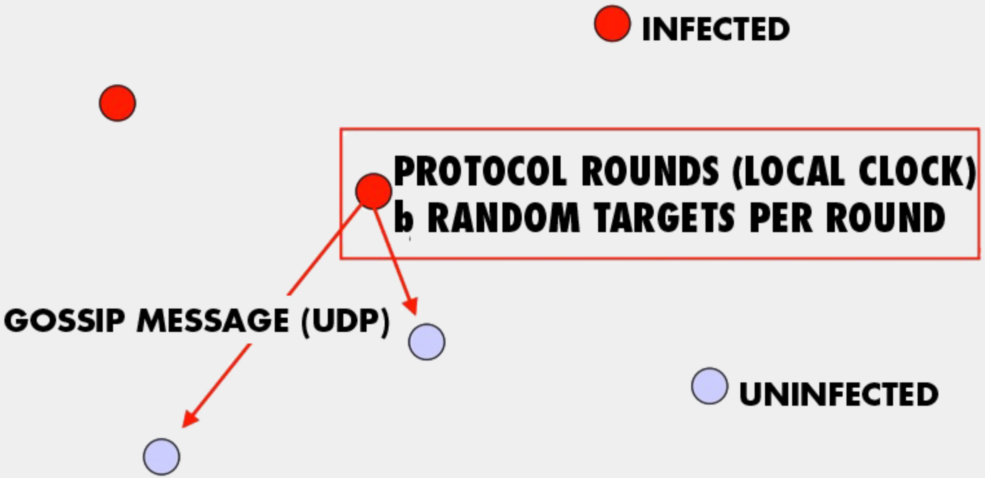
$$\frac{dx}{dt} = -\beta xy \qquad \text{(why?)}$$

with solution:

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

(can you derive it?)

Epidemic Multicast



Epidemic Multicast Analysis

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

Substituting, at time *t=clog(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 *clog(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 *cblog(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) ~ 10
  - log(1M) ~ 20
  - log (1B) ~ 30
  - log(all IPv4 addresses) = 32
  - log(all IPv6 addresses) = 128

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)
- 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

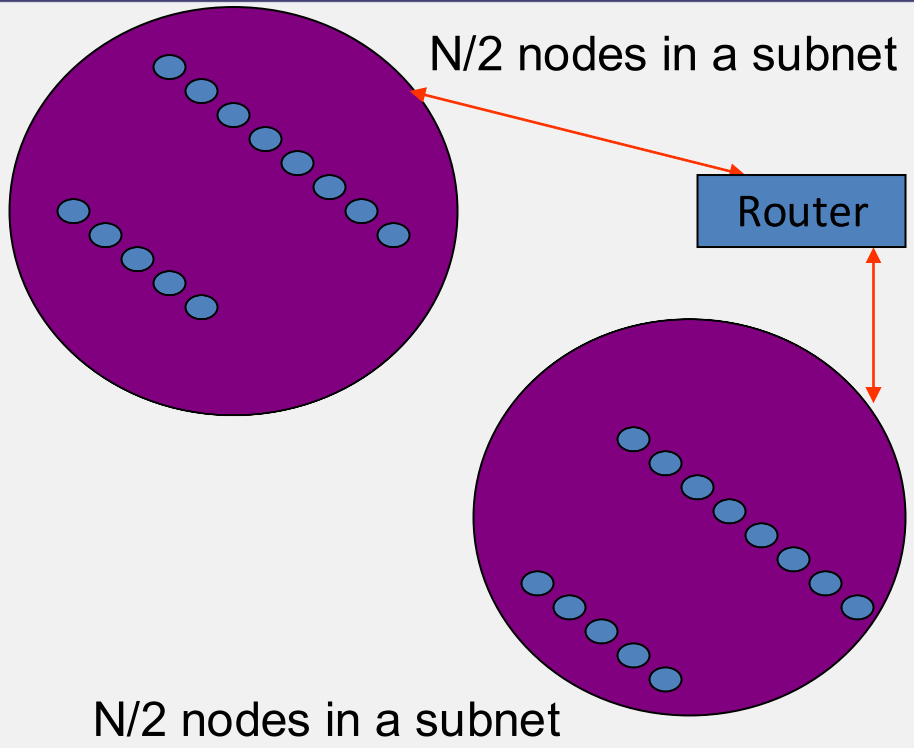
$$p_{i+1} = \left(p_i\right)^{k+1}$$

- 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 => 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))



Answer – Push Analysis (contd.)

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

Substituting, at time *t=clog(n)*

$$y = \frac{n+1}{1+ne^{-\frac{b}{n}(n+1)c\log(n)}} \approx \frac{n+1}{1+\frac{1}{n^{cb-1}}}$$

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

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

SO,…

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

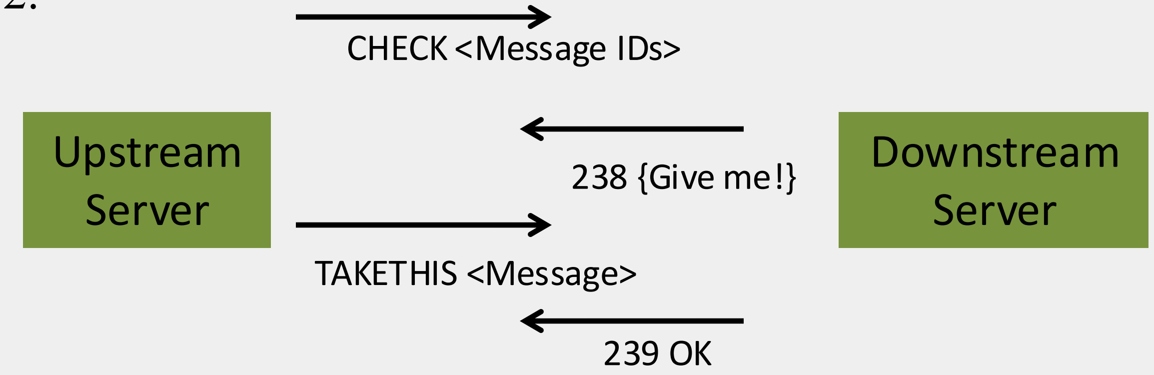
Some implementations

- 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

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