CSE 461: Introduction to Computer Communications Networks
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Module 1.5
Introduction – Reliable Multicast

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Context

- We can all name examples of distributed applications
- It turns out that what's going on inside networks are distributed applications as well
- Understanding distributed applications requires thinking in new ways
- Here's an example that exposes that (and that considers a key issue in any distributed app: ordering)

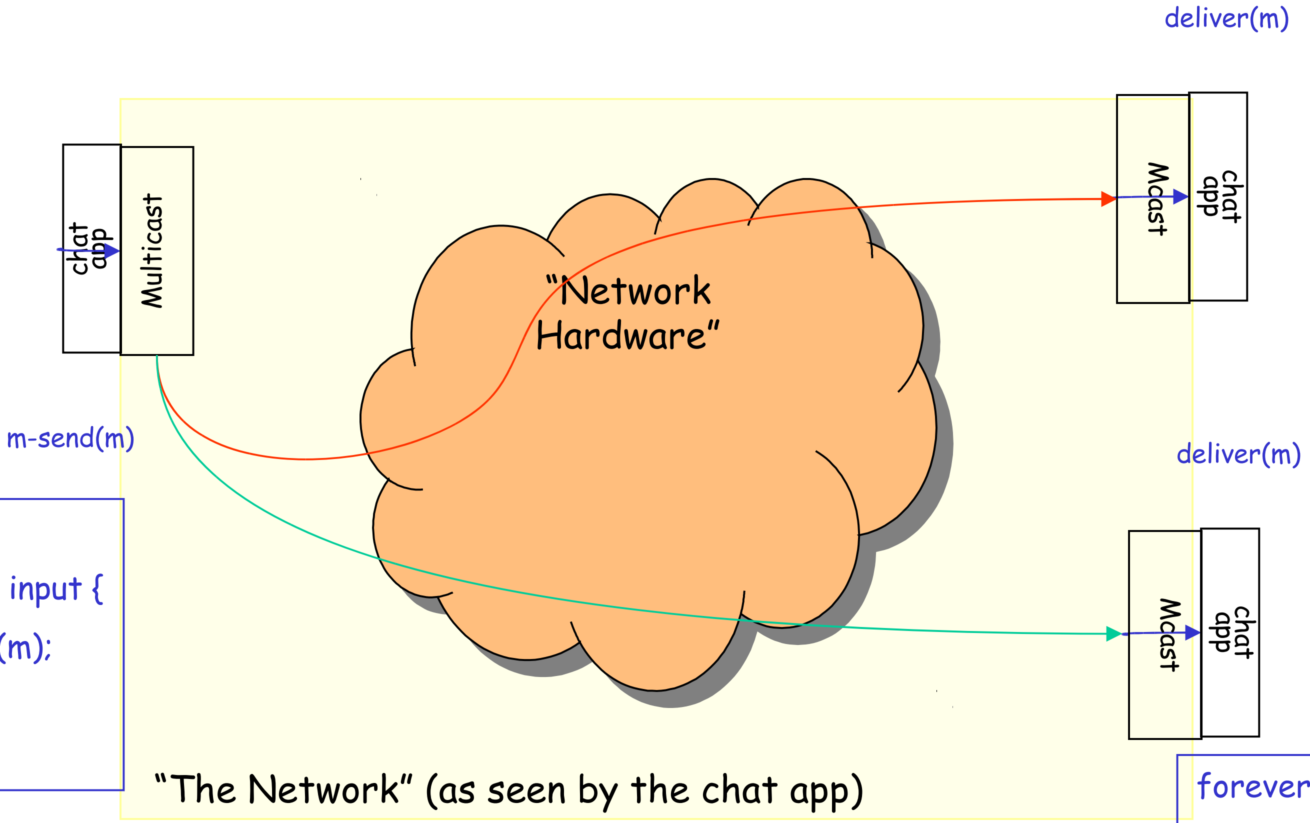
The Example Application

- Suppose you want to build chat room software

- You want all messages typed by all participants to show up on everyone’s screen in the same order

- Division of responsibilities:
  - Chat room application software: most everything, except for…
  - Multicast
    - a single send(m) call causes message m to be delivered to multiple destinations

The Chat Room Application



```
forever {
  when user input {
     m-send(m);
  }
}
```

```
forever {
  when deliver(m) {
     print m;
  }
}
```

Reliable, Totally Ordered Multicast

- multicast: a single send(m) call causes message m to be delivered to multiple destinations
- totally ordered: roughly, there is a unique sorted order to the messages (less roughly, the ordering is determined by an antisymmetric, transitive, and total relation)
- reliable: if a correctly operating client displays message m before displaying message m’, then any other correctly operating client that displays m’ will first display m

RTOM

- We actually want more than this, in a practical setting
  - Liveness: all messages are eventually displayed
  - “Reasonableness”: in normal operation, each message should be displayed promptly at all clients
- Some unreasonable (and possibly not-live) solutions:
  - Never show any messages
  - Choose a single client and show only its messages
  - We cycle in a fixed order among the clients
    - Show msg from A, then B, then ...Z, then A,....
  - Wait until all clients quit the chat, then sort the messages lexicographically and print them.

We're Going to Solve This Twice

- Method A:
  - Implement something
  - run to find bugs
  - change to fix bugs
  - repeat

- Method B:
  - Let's consider the problem carefully
  - Then let's implement

First Try: The Straightforward Implementation

- When m-send(m) is invoked, immediately send it to each client (including yourself):

```
foreach client c {
    net-send(c,m);
}
```

- When a message m is received from the network, hand it up to the app (to display):

```
deliver(m);
```

- What can (will) go wrong?
- Observation: receiver side timestamps are useless in solving this problem

Second Try: Sender timestamps

- Assume net-send() is reliable, and that no client crashes or has bugs

- On m-send(m) :

```
t = localClockTime();
foreach client c {
    net-send(c,m,t);
}
```

- When a message (m,t) is received from client s:

```
put (m,t) in a sorted queue;
while (there is a message in the queue) {
   deliver(the message with the lowest timestamp);
   remove the delivered message from the queue;
}
```

- Does it work?

Third Try

- Assume net-send() is reliable, and that no client crashes or has bugs
- On m-send(m) :

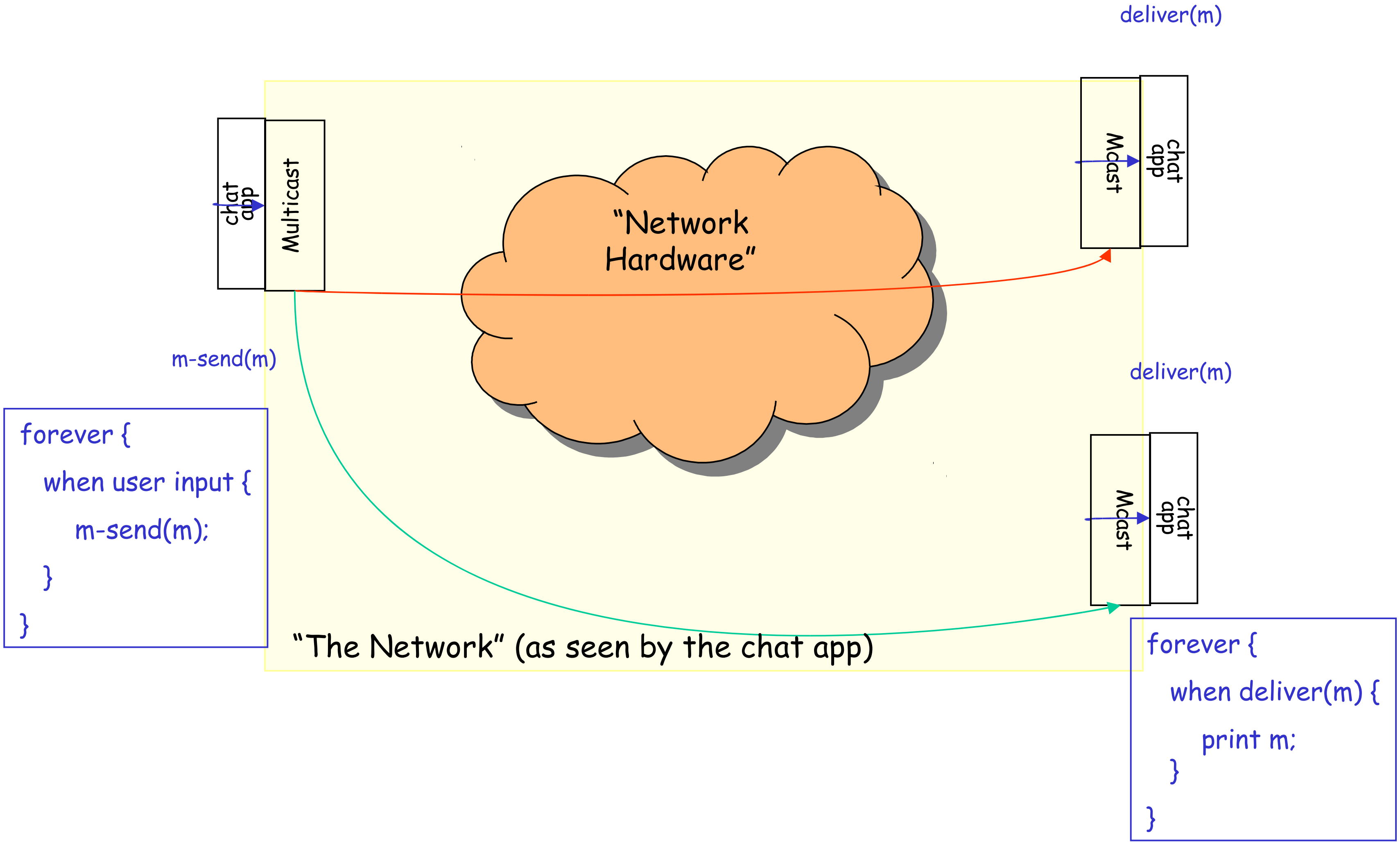
```
t = localClockTime();
foreach client c {
    net-send(c,m,t);
}
```

- When a message (m,t) is received from client s:

```
put (m,t) in a sorted queue;
while (there is a message in the queue from each client) {
   deliver(the message with the lowest timestamp);
   remove the delivered message from the queue;
}
```

- Does it work?
  - Are you sure?
  - What assumption about what net-send() guarantees are required?
  - What other assumption is it making?
  - Why isn’t it an acceptable solution in practice?

2nd Try: Develop a Solution Carefully



```
forever {
   when user input {
      m-send(m);
   }
}
```

```
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   }
}
```
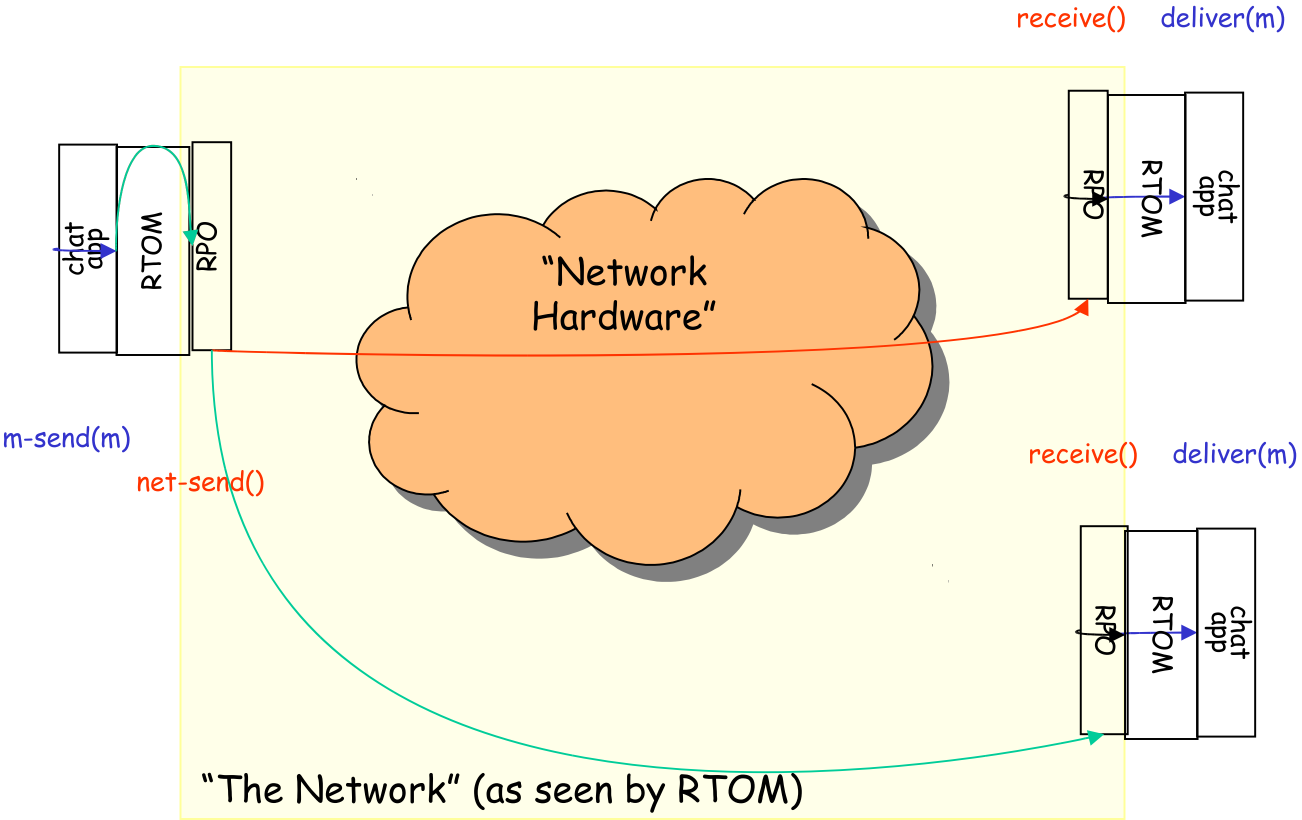

Implementing RTOM

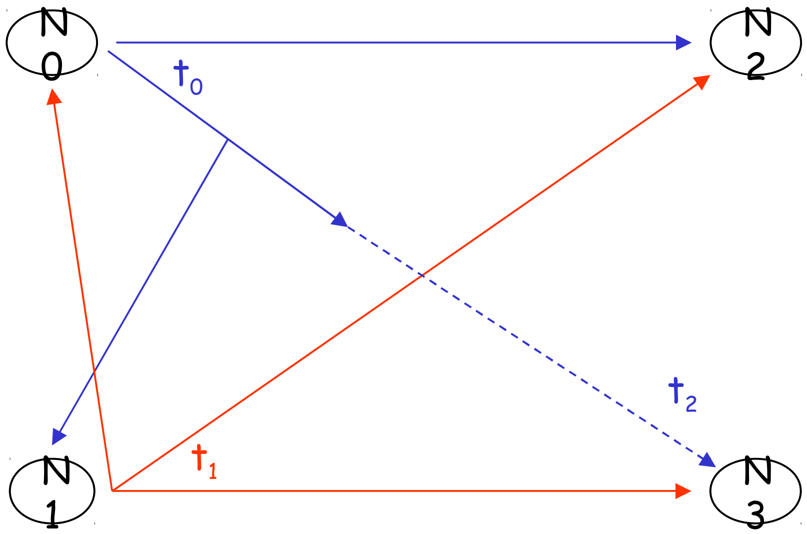
- RTOM has its own view of what the network is
  - The interface provided by lower layer networking software and/or hardware
- Assumed properties of that interface (RPO):
  - Reliability Assumption: Reliable
    - If A does a net-send(m,B), B will eventually receive m
      - Note: The delivery delay is finite but unpredictable
  - Ordering Assumption: *Pair-wise ordered*
    - If A does net-send(m,B) and later net-send(m',B), m will be deliver()'ed to B before m'
      - Note: this property holds only "pairwise." If A does net-send(m,B) then net-send(m',C), there is no guarantee about the order of delivery of m and m'

The Layer Below RTOM



Why Is This Not Trivial?

- Unpredictable delays in the network is enough



t_0 : N0 sends; N1,N2 receive

t_1 : N1 sends; all receive

t_2: N3 receives N0’s message

Essence of the Solution

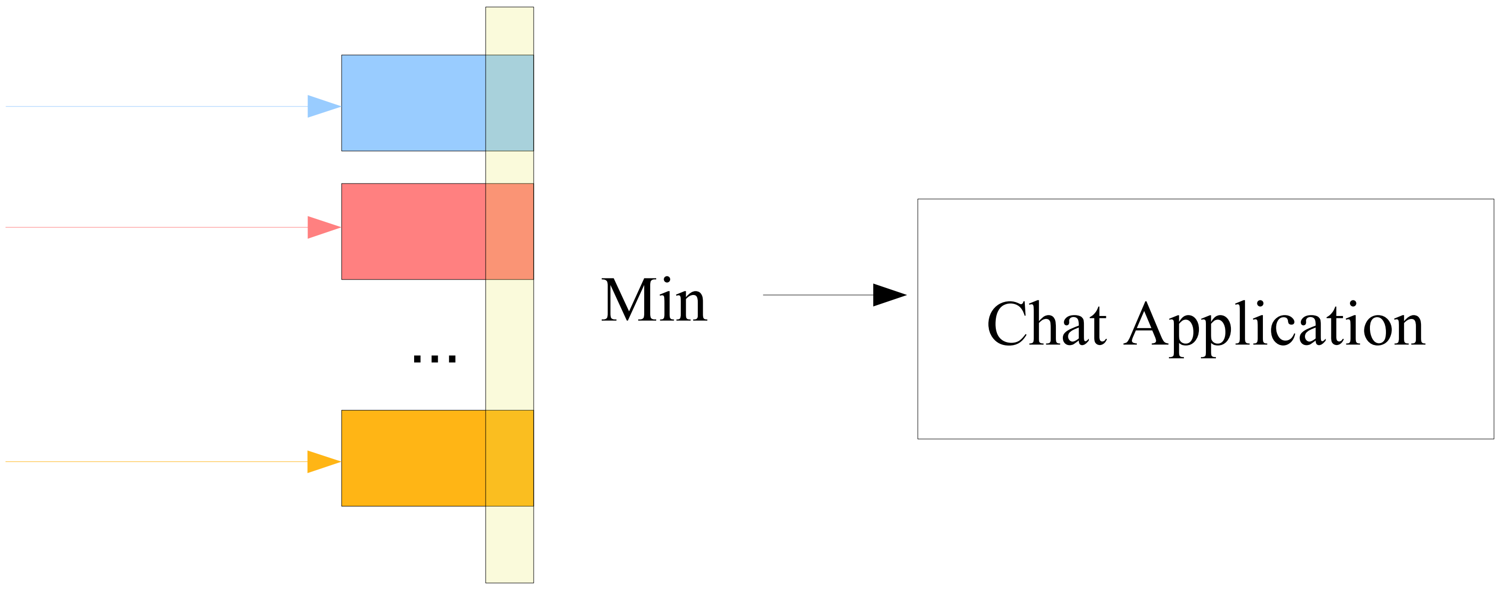
- The problem is distributed
- Each node is going to make a decision, based entirely on information it has itself
    - It knows what it sent and what is has received
    - It doesn't know (with complete accuracy) what any other node has sent or received
- The key property we need is that all nodes make consistent decisions
- To do that, we want them to:
    - Apply a deterministic function to...
    - Data that is enough alike that they get the same answer

The Function: Min({timestamps})

- If all nodes had the same set S of timestamps, and all made a decision, they'd make the same decision
  - That's good
- There's no way to know what set other nodes have
  - That's bad
- In fact, the set of timestamps at node A may not be a subset of the set at B, nor vice-versa

One Important Aspect of the Solution

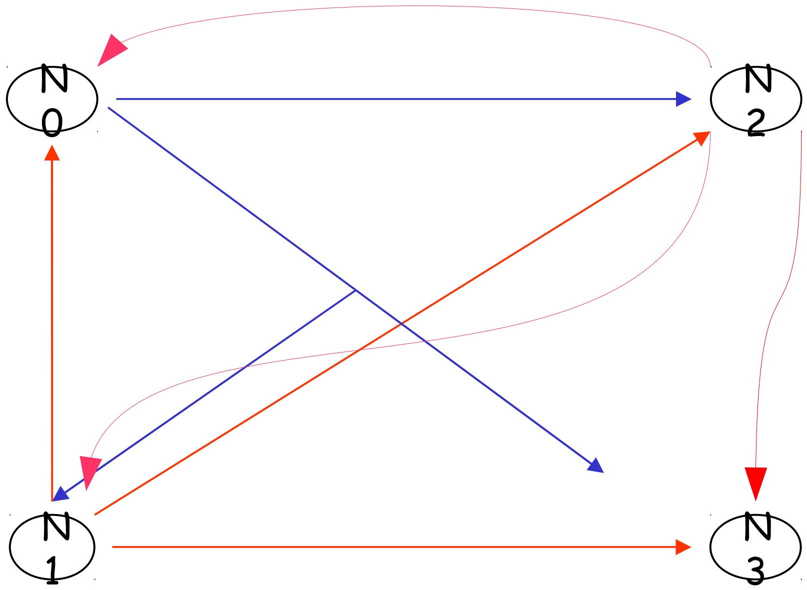
- Exploit (assumed) pairwise-ordered property of underlying network



What if someone doesn't send for while?

- If any of the incoming queues is empty, we can't deliver anything
- If there are messages in some queues, we'd like to be sure there will “soon” be messages in all
- One way:
  - If a client hasn't sent a message in the least T milliseconds, it must send a “I have no message” message
  - Problem with that?
- Another way:
  - Make sure that for each actual message sent by any client c, every other client sends a message shortly thereafter
    - We're goint to call these *acknowledgments*, but they're have an additional purpose beyond the ACKs we'll see throughout t he course after this

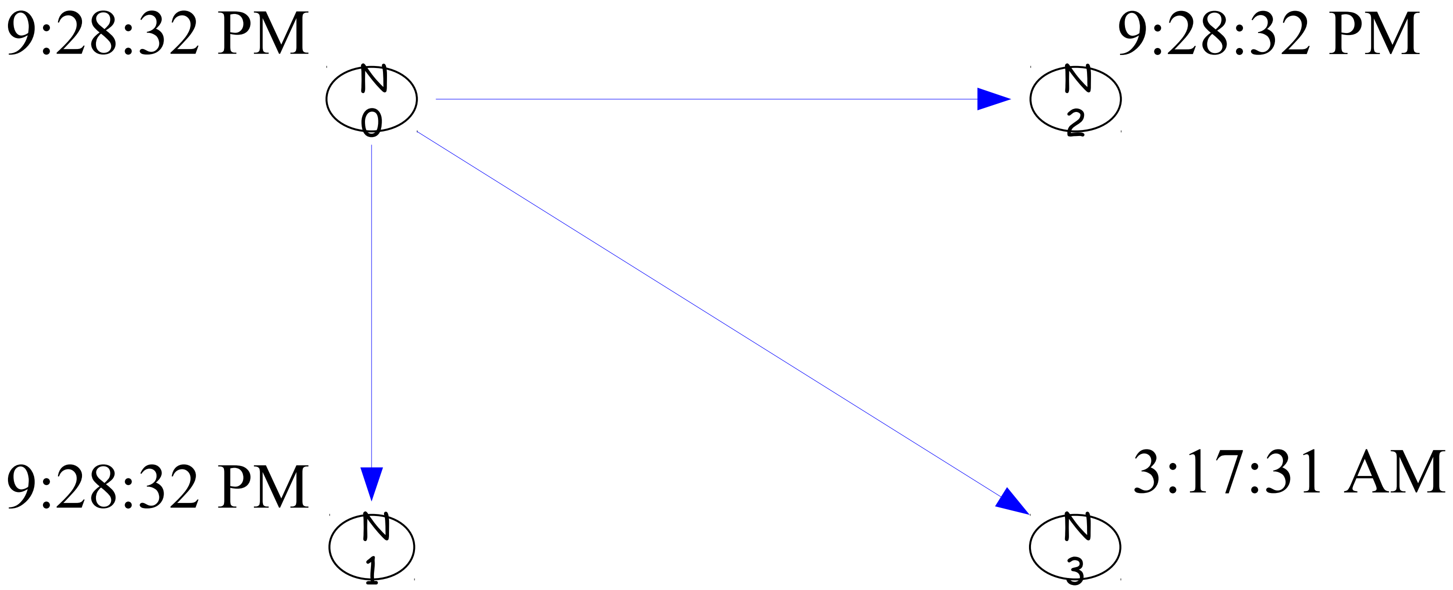
Acknowledgments



Blue: data mcast

Red: ACK mcast

One Remaining Problem...



9:28:32 PM

N0

9:28:32 PM

N2

9:28:32 PM

N1

3:17:31 AM

N3

What happens?

Lamport clocks

- Each client has its own Lamport clock, with monotonically increasing timestamp t_c
- Every event is tagged with its timestamp
  - For us, events are m-send() invocations and message receptions
- When a local event occurs on node c (m-send(m) is invoked):
  - $t_c = t_c + 1$
- When a message with timestamp t_s is received at c:
  - $t_c = \max(t_c, t_s) + 1$

Finally, the Implementation

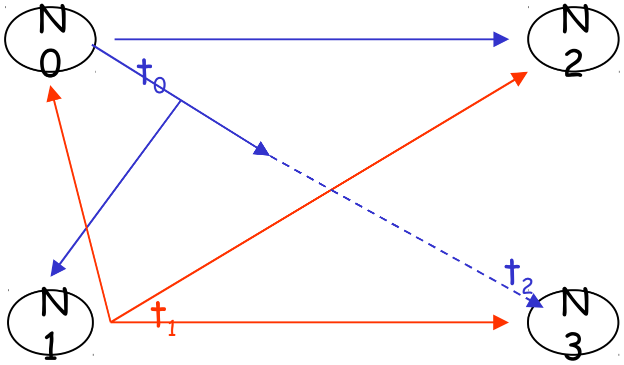
- On m-send(m) at client s:

```
t_s = t_s + 1;
foreach client c {
    net-send(c,m,t_s);
}
```

- When (m,t_s) is received at c:

```
t_c = max(t_c, t_s) + 1;

// broadcast an acknowledgement of m to everyone else
if (the message received is not itself an ACK) {
    foreach client q {
        net-send(q,ACK(m),t_c);
    }
}

put (m,t_s) in a sorted queue;
while (the first non-ACK message in the queue has been ACK'ed by all clients) {
   deliver(that first non-ACK message);
   remove that message and its ACKs from the queue;
}
```

An Example

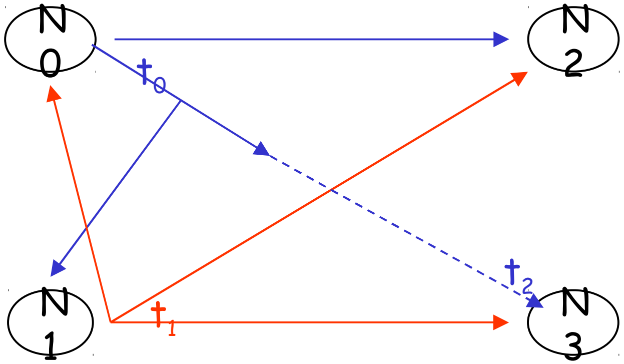


Vectors show what each node knows about the local time at all of the nodes. The algorithm doesn't explicitly keep these vectors – the times for other nodes are in the messages in the queue.

Except for the first send from N0, we're assuming all other messages are received by all nodes, and that no two messages are ever in the network at the same time. (That last bit just for simplicity in constructing this example.)

Event	N0	N1	N2	N3
Startup	(0,*,*,*)	(*,0,*,*)	(*,*,0,*)	(*,*,*,0)
N0 sends	(1,*,*,*)	(1,2,*,*)	(1,*,2,*)	(*,*,*,0)
N1 ACKs	(3,2,*,*)	(1,2,*,*)	(1,2,3,*)	(*,2,*,3)
N2 ACKs				
N1 sends				
N3 receives				
N3 ACKs				

An Example



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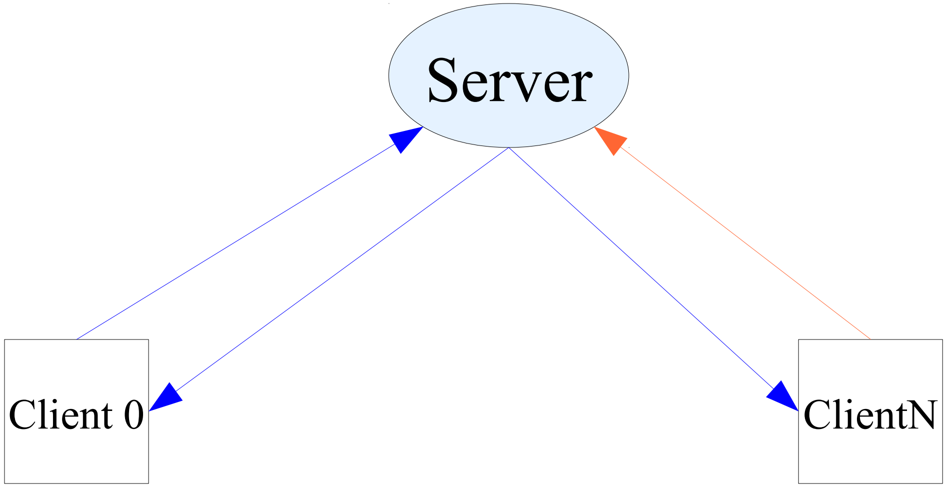
N0 sends	(1,*,*,*)	(1,2,*,*)	(1,*,2,*)	(*,*,*,0)
N1 ACKs	(3,2,*,*)	(1,2,*,*)	(1,2,3,*)	(*,2,*,3)
N2 ACKs	(4,2,3,*)	(1,4,3,*)	(1,2,3,*)	(*,2,3,4)
N1 sends	(6,5,3,*)	(1,5,3,*)	(1,5,6,*)	(*,5,3,6)
N3 receives	(6,5,3,*)	(1,5,3,*)	(1,5,6,*)	(1,5,3,7)
N3 ACKs	(8,5,3,7)	(1,8,3,7)	(1,5,8,7)	(1,5,3,7)

Two Last Things

- Is RPO realistic?
  - Does the Internet provide RPO guarantees?
  - Does a local Ethernet? A local 802.11 wireless?
- RTOM: What about this solution


Server
Client 0
ClientN