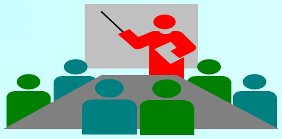
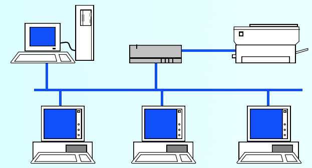




Distributed Systems
600.437
Multicast & Group Communication Services

Department of Computer Science
The Johns Hopkins University

Multicast & Group Communication Services

Lecture 3

Guide to Reliable Distributed Systems (Birman).

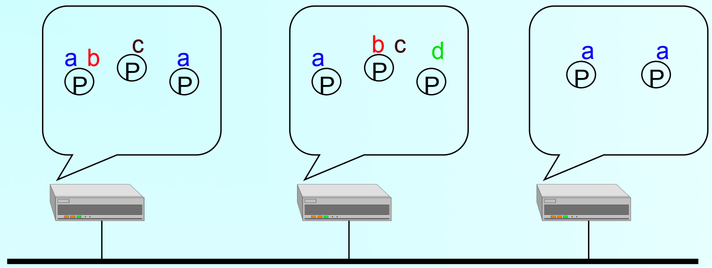
Also: slides and resources can be found at:

http://www.dsn.jhu.edu/courses/cs437/

IP Multicast is documented in IETF RFC's and Internet-Drafts

which can be found at: http://www.ietf.org/

The Multicast Paradigm



- Ordering (Unordered, FIFO, Causal, Agreed).
- Delivery guarantees (Unreliable, Reliable, Safe/Stable).
- Open groups versus close groups.
- Failure model (Omission, Fail-stop, Crash & Recovery, Network Partitions).
- Multiple groups.

Using Traditional Transport Protocols for Multicast

Point to point (TCP/IP)

- Automatic flow control ✓
- Reliable delivery ✓
- Connection service ✓
- Complexity (n^2)
- Linear (?) degradation in performance

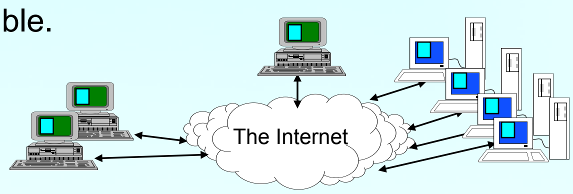
Using Traditional Transport Protocols for Multicast (cont.)

Unreliable broadcast/multicast
(UDP, IP-Multicast)

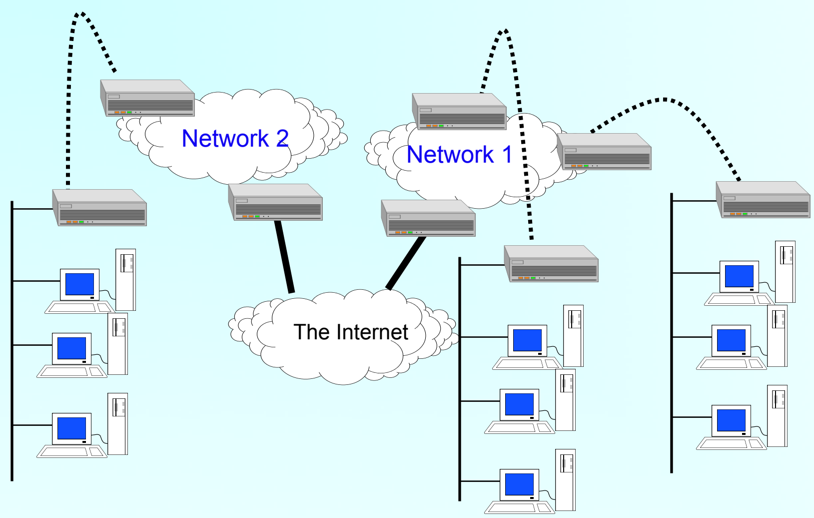
- Employs hardware support for broadcast and multicast.
- Message losses : 0.01% at normal load, 10%, 20%, 30% or more at high load.
  - Buffers overflow (in the network and in the OS).
  - Interrupt misses.
- Not a connection-oriented service.

IP Multicast

- Multicast extension to IP.
- Best effort multicast service.
- No accurate membership.
- Class D addresses are reserved for multicast: 224.0.0.0 to 239.255.255.255 and are used as group addresses.
- The standard defines how hardware Ethernet multicast addresses can be used if these are possible.



IP-Multicast Logical Design



IP Multicast (cont.)

Extensions to IP inside a host:

- A host may send IP multicast by using a multicast address as the destination address.
- A host manages a table of groups and local application processes that belong to this group.
- When a multicast message arrives at the host, it delivers copies of it to all of the local processes that belong to that group.
- A host acts as a member of a group only if it has at least one active process that joined that group.

IP Multicast Group Management

Extensions to IP within one local area network

The Internet Group Management Protocol (IGMP)

- A host that joins a group transmits a report message to IP multicast address 224.0.0.1 (all hosts group)
- A multicast router sends periodic general query messages to discover IP multicast groups with local hosts to 224.0.0.1
- A host replies after setting a random timer for each group it is a member of
  - The host sends a report message for that group only if no other host replied by the random timer expiration.

IP Multicast Group Management

Extensions to IP within one local area network

The Internet Group Management Protocol (IGMP) – cont.

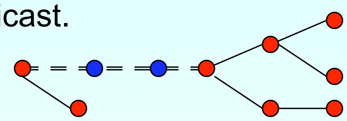
- When the host that replied last leaves the group, it sends a Leave Group message on IP multicast address 224.0.0.2 (all routers group).
- The multicast router then sends a group specific query to check whether there are additional members in the group
- After a timeout with no positive host responses for a certain group, the IP Multicast router stops participating in that group (beyond the local area network)

IP-Multicast Routing

Extensions to IP between routers in one network

Distance Vector Multicast Routing Protocol (DVMRP, PIM-DM)

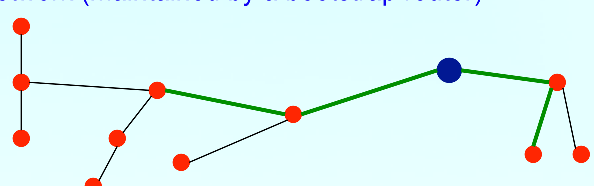
- Messages *ABOUT* groups are sent on the special *all hosts* group 224.0.0.1
- Time to live: limits the distance messages travel.
- Dense method: Flood & Prune. All routers get packets initially, then prune out parts of the network that do not have group member hosts.
- Tunneling: encapsulates multicast packets in regular packets in order to pass through routers that do not support IP Multicast.



IP-Multicast Routing (cont.)

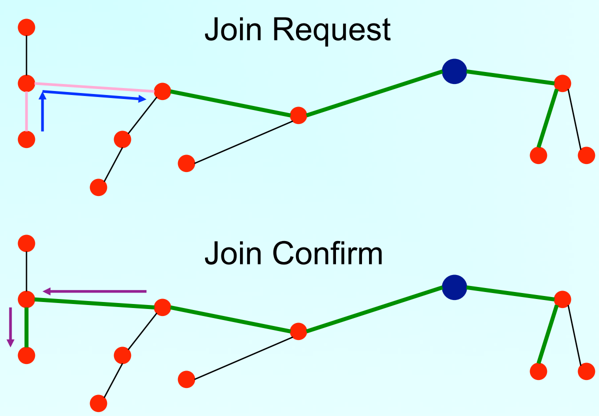
IP Multicast between routers in one network
PIM-SM

- Sparse Method for better scalability
  - only routers that participate, or are on the way to routers that participate, get IP multicast messages
  - In contrast to Dense Method that employs Flood and Prune
- Utilizes rendezvous points for each group
  - Rendezvous point router is determined via hashing the group address into a list of possible RP routers in the network (maintained by a bootstrap router)



IP-Multicast Routing(cont)

PIM-SM (Sparse Method) Join Operation



IP-Multicast Routing(cont)

IP Multicast between routers in one network
MOSPF

- Extensions to Open Shortest Path First – the link state routing protocol common in the Internet
- Group membership of local areas in the network is based on IGMP and is flooded between the routers on the network.
- Shortest path trees are calculated on demand for each source to each group (of destinations) it participates on
- Can work with inter-AS Multicast Routing (MBGP+) to support IP Multicast operation beyond a single network (beyond an AS Autonomous System)

IP Multicast Challenges

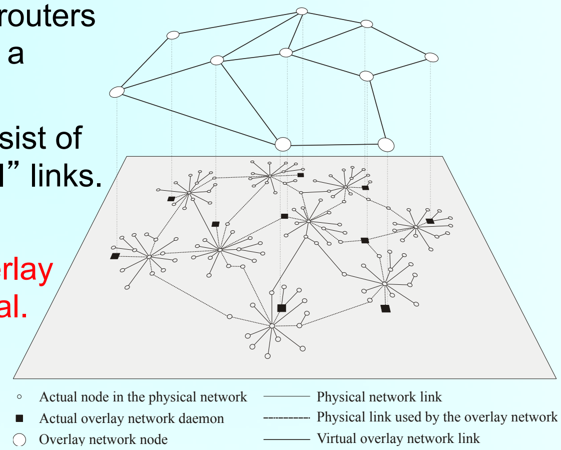
- Scalability with the number of applications / groups.
  - How many groups are needed on a world-wide basis?
  - What happens to the core routers with many global groups?
- Turned off by ISPs.
  - Can you think why?
- What can be done about that?

IP Multicast Challenges

- Scalability with the number of applications / groups.
  - How many groups are needed on a world-wide basis?
  - What happens to the core routers with many global groups?
- Turned off by ISPs.
  - Can you think why?
- What can be done about that?
  - Private networks – using IP multicast – e.g. for IPTV
  - Overlay networks – using unicast.

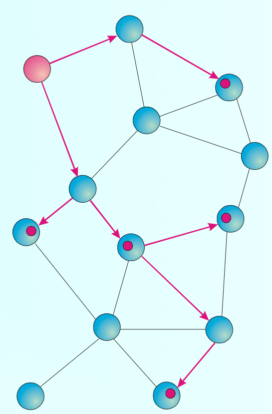
The Overlay Networks Approach

- Application-level routers working on top of a physical network.
- Overlay links consist of multiple “physical” links.
- Incurs overhead.
- Placement of overlay routers not optimal.
- **Flexible use of peer-protocols.**
- **Provides added value.**



Multicast Using Overlay Networks

- Routing is not optimal. But functional and does not require state at intermediate routers – just at overlay routers.
- Multiple overlay networks can coexist in the Internet without overhead to Internet routers.
- All the multicast traffic is seen as unicast packets at the network level. No need for hardware support.
- Group names space extends only to the scope of the application (no longer global).



Reliable Multicast Services

Service-Type

SAFE
AGREED
CAUSAL
FIFO
RELIABLE

$\uparrow$ Cost (latency)

Reliable Multicast Services (cont.)

Fifo Order

$m \xrightarrow{\text{cause}} m'$ if $send_q(m) \dashrightarrow send_q(m')$

Causal Order

$m \xrightarrow{\text{cause}} m'$ if $deliver_q(m) \dashrightarrow send_q(m')$

Agreed Order

- Total order
- Consistent with Causal order and overlapping groups

Safe Delivery

* Not ordering

- Consistent with Agreed order
- Message is delivered after received by all processors

Multicast Protocols Outline

- Vector Timestamps (ISIS System)
- Trans Protocol (used by Transis)
- Lamport Timestamps
- Single Ring Protocol (Totem)
- Accelerated Ring Protocol (Spread)

Vector Time Stamp: Reliability and Causal Ordering (ISIS system)

- Each process maintains a time vector of size n.
- Initially VT[i] = 0.
- When p sends a new message m: VT[p]++
- Each message is stamped with VTm which is the current VT of the sender.
- When p delivers a message, p updates its vector: for k in 1..n:

  VTp[k] = max{ VTp[k], VTm[k] }.

Isis Causal Order (Cont)

Comparing messages:

$$VT1 < VT2 \text{ iff for } k = 1..n \; VT1[k] \le VT2[k]$$
$$\text{and}$$
$$\exists k \; VT1[k] < VT2[k]$$

Determining causality:

$$m1 \rightarrow m2 \text{ iff } VT1 < VT2$$

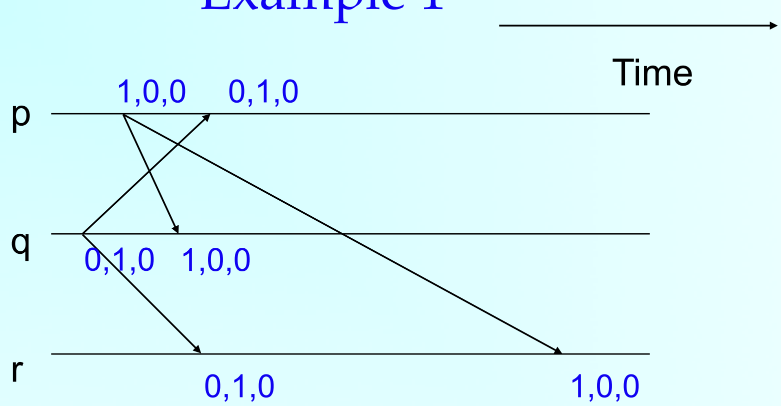
Determining whether a message sent by q can be delivered:

for any k in 1..n:

$VTm[k] = VT[k]+1$ if $k=q$.

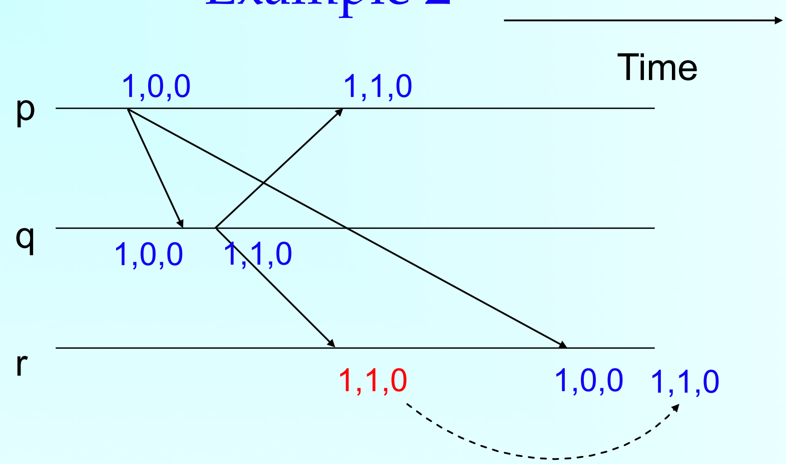
$VTm[k] \le VT[k]$ otherwise.

Example 1



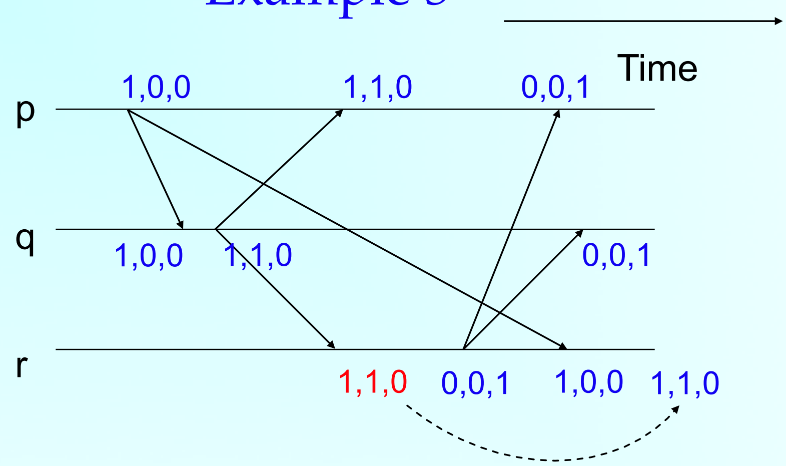
Messages {1,0,0} and {0,1,0} are not causally related, so they can be delivered in any order

Example 2



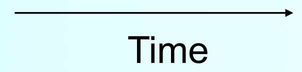
Message {1,0,0} causally precedes {1,1,0}, so {1,0,0} must be delivered before {1,1,0}

Example 3

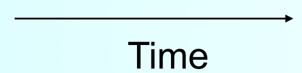


A process does not update its timestamp until it delivers a message, so r sends {0,0,1}, even though it received {1,1,0}

Example 4



Example 4



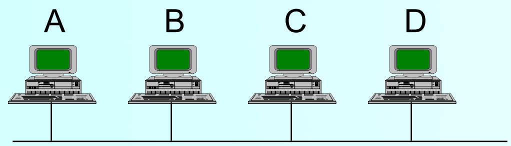
Isis Agreed (Total) Order

- Preserves causality.
- From time to time, the token holder sends an "ordering" message for all the previous Agreed-order messages it knows that are not yet ordered.
- Non-token holders cannot deliver Causal messages that are causally after an Agreed message that is not yet ordered.
- A new token holder may be determined after a membership change.

Multicast Protocols Outline

- Vector Timestamps (ISIS System)
- Trans Protocol (used by Transis)
- Lamport Timestamps
- Single Ring Protocol (Totem)
- Accelerated Ring Protocol (Spread)

The Trans Protocol



A Emits: A_1 A_2 A_3 ...

Scenario: A_1 a_1B_1 b_1B_2 b_2C_1 ...

Direct Ack: $a_1B_1 \longrightarrow A_1$

Indirect Ack: $b_2C_1 \longrightarrow A_1$, B_1

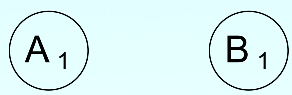
Example

Scenario: A_1 B_1 $a_1b_1B_2$ a_1C_1 $c_1b_2C_2$ ...

A_1

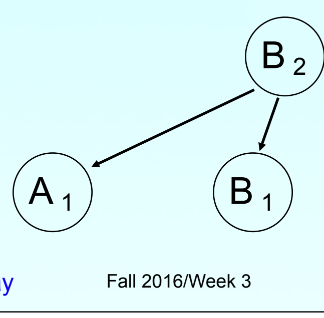
Example

Scenario: A_1 B_1 $a_1 b_1 B_2$ $a_1 C_1$ $c_1 b_2 C_2 \ldots$



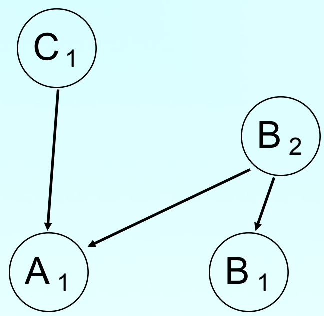
Example

Scenario: A_1 B_1 $a_1 b_1 B_2$ $a_1 C_1$ $c_1 b_2 C_2 \ldots$



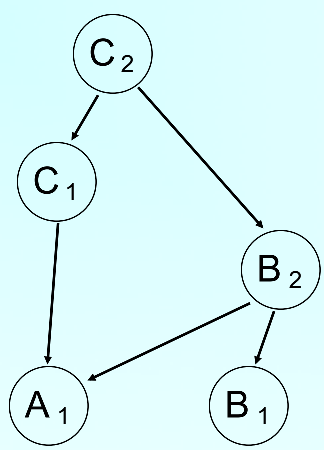
Example

Scenario: A_1 B_1 $a_1 b_1 B_2$ $a_1 C_1$ $c_1 b_2 C_2$ ...



Example

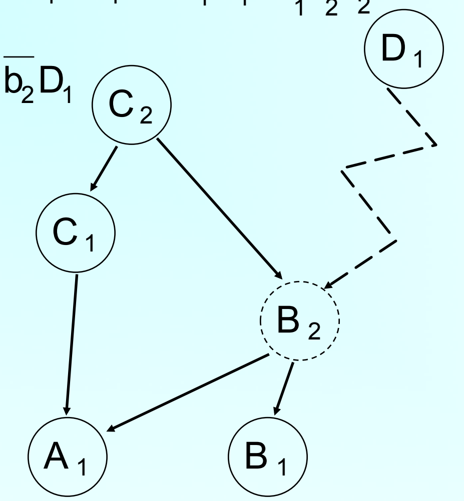
Scenario: A_1 B_1 $a_1 b_1 B_2$ $a_1 C_1$ $c_1 b_2 C_2$ ...



Example (Cont.)

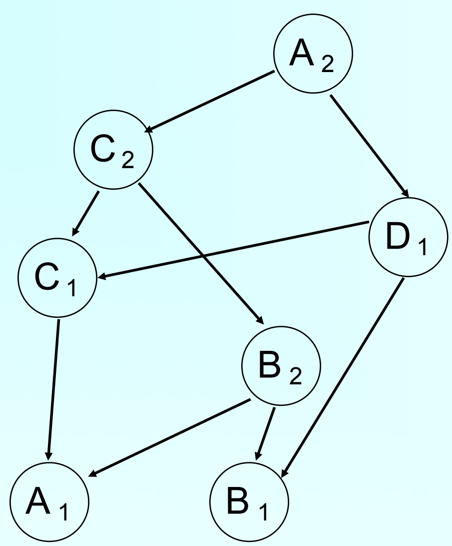
D received: A_1 B_1 a_1C_1 $c_1b_2C_2$ ...

Nack:: $c_1b_1\overline{b_2}D_1$



The DAG

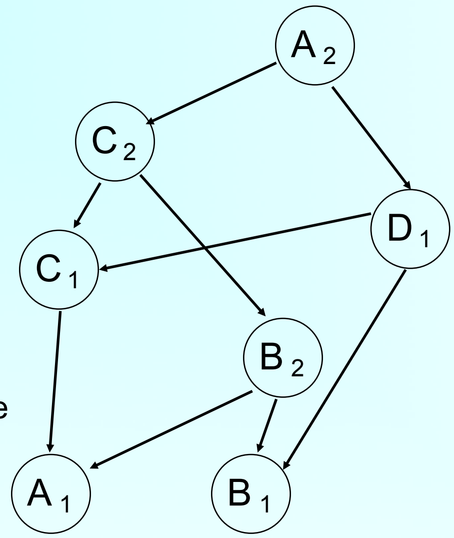
The DAG may be revealed in a different way, but its structure will be identical at all the processors!!



The DAG

The DAG may be revealed in a different way, but its structure will be identical at all the processors!!

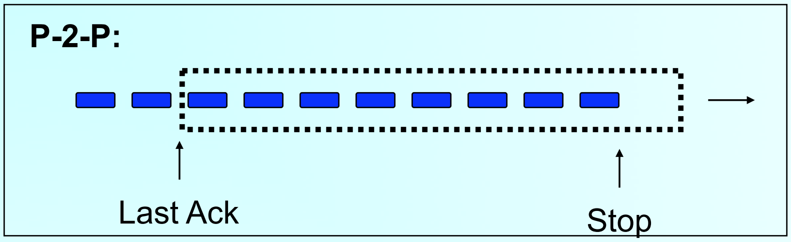
Total order can be based on the structure of the graph



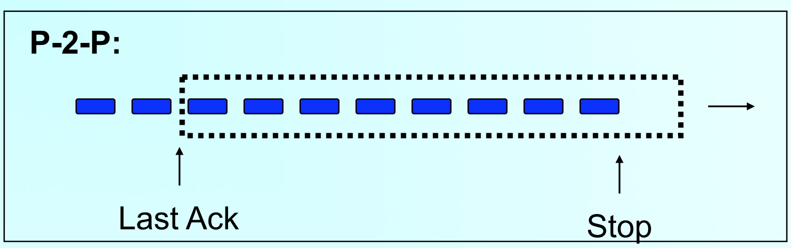
Vector Timestamps vs DAG

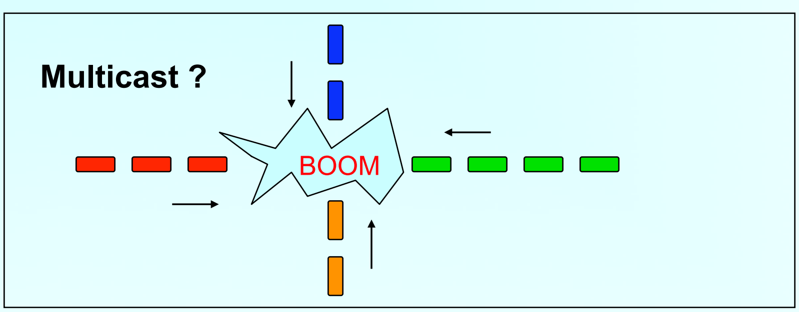
- DAG is a compaction of a vector timestamp
- The DAG method is more efficient network-wise and can scale better with the number of participants
- However, the DAG requires maintaining a more sophisticated data structure

Flow Control



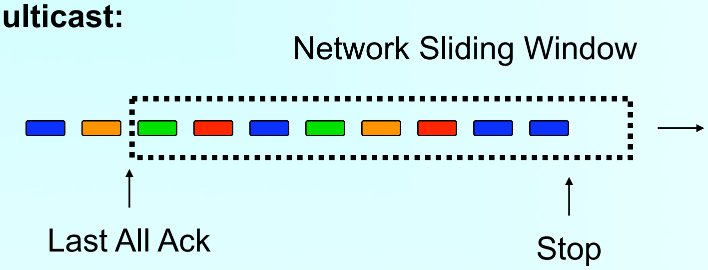
Flow Control





Flow Control for Trans
(from the Transis system)

Multicast:



Multicast Protocols Outline

- Vector Timestamps (ISIS System)
- Trans Protocol (used by Transis)
- Lamport Timestamps
- Single Ring Protocol (Totem)
- Accelerated Ring Protocol (Spread)

A Lamport Time Stamp Approach

- A Lamport Time Stamp (LTS) contains two fields:
  - **Counter.**
  - **Process id.**
- When sending a message.
  - **Increment your counter.**
  - **Stamp your message.**
  - **Send your message.**
- When receiving a message
  - **Adopt the counter on the message if it is bigger than your local counter.**
- Unique for every message.

A Lamport Time Stamp Approach

- A Lamport Time Stamp (LTS) contains two fields:
  - **Counter.**
  - **Process id.**
- When sending a message.
  - **Increment your counter.**
  - **Stamp your message.**
  - **Send your message.**
- When receiving a message
  - **Adopt the counter on the message if it is bigger than your local counter.**
- Unique for every message.
- It is useful to add an index next to the LTS, such that the index is incremented only when sending new messages.
  - The index helps track how many messages were sent by a process as well as how many were missed from that process.

A Lamport Time Stamp Approach

- A Lamport Time Stamp (LTS) contains two fields:
  - **Counter.**
  - **Process id.**
- When sending a message.
  - **Increment your counter.**
  - **Stamp your message.**
  - **Send your message.**
- When receiving a message
  - **Adopt the counter on the message if it is bigger than your local counter.**
- Unique for every message.
- It is useful to add an index next to the LTS, such that the index is incremented only when sending new messages.
  - The index helps track how many messages were sent by a process as well as how many were missed from that process.
- Agreed order of messages can be achieved by comparing (counter, process id) on message.
- FIFO and Causal order as a by-product.

Multicast Protocols Outline

- Vector Timestamps (ISIS System)
- Trans Protocol (used by Transis)
- Lamport Timestamps
- Single Ring Protocol (Totem)
- Accelerated Ring Protocol (Spread)

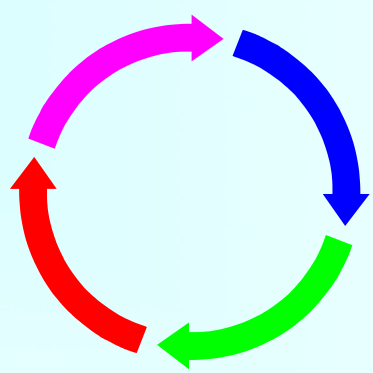
The Single Ring Protocol (Totem)

- The communication is multicast (UDP/IP).
- Services: Agreed (which is also FIFO and Causal), Safe.
- supports message omissions, network partitions, crashes and recoveries.

The Ring Ordering Scheme

Token fields

- type - {regular, form}.
- seq - of last message.
- **aru** - replaces acks.
- rtr - retrans. requests
- fcc - flow control.



The Ring Ordering Scheme (cont)

How to update the token aru?

- If token.aru = token.seq and have all the messages then should raise aru together with the seq (when sending new messages).
- If the token.aru is higher than the highest in-order message (local aru), lower the token.aru to the local aru.
- If is the one that lowered the aru, and the token.aru is still the same, should set token.aru to its local aru.

The trick: Everyone has all the messages up to:

min(token.aru, previous token.aru)

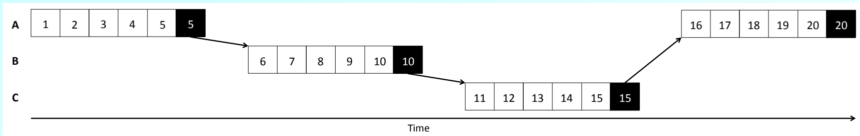
Multicast Protocols Outline

- Vector Timestamps (ISIS System)
- Trans Protocol (used by Transis)
- Lamport Timestamps
- Single Ring Protocol (Totem)
- Accelerated Ring Protocol (Spread)

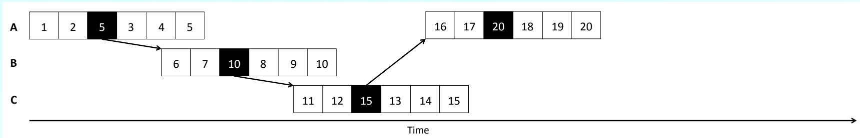
Accelerated Ring Protocol

- Original Ring Protocol
  - Token is passed around a ring of participants
  - A participant multicasts while it holds the token, then passes the token to the next participant
- Accelerated Ring Protocol
  - Participants pass the token while multicasting
  - Circulates the token faster, allowing more rounds of sending per second
  - Allows controlled parallelism, while maintaining semantics
  - Designed for modern data centers

Accelerated Ring Protocol



Original Protocol



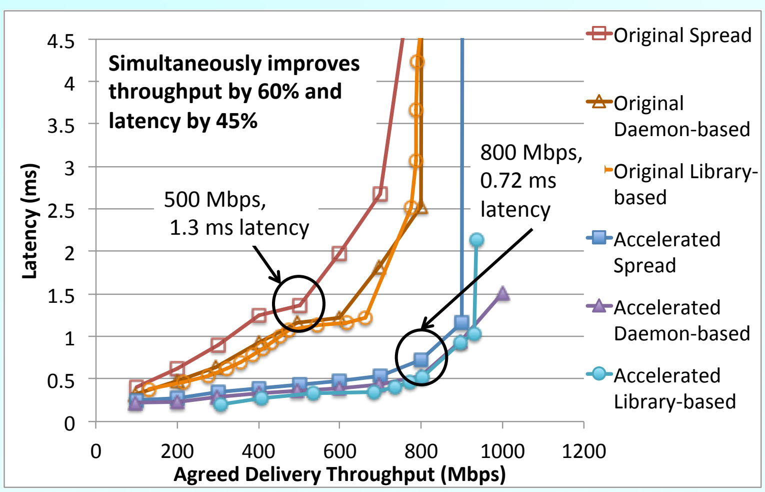
Accelerated Protocol

Accelerated Ring Protocol

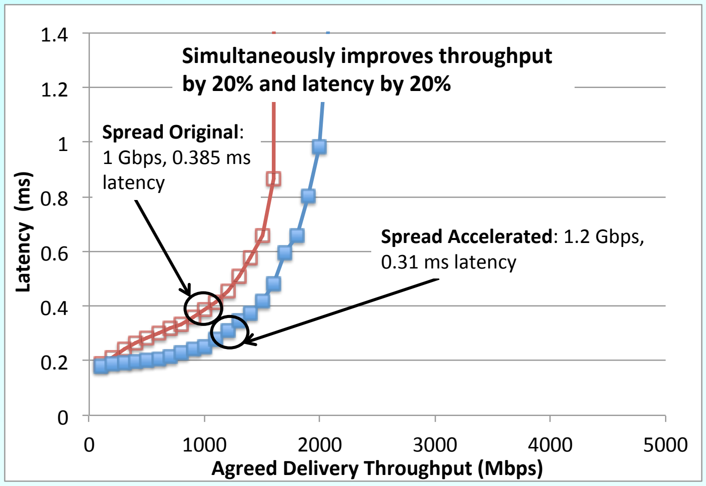
Updating token fields

- seq
  - Original: sequence number of last message sent
  - Accelerated: last sequence number claimed (message will be sent by the time the next token is processed)
- rtr - how do you decide what to request?
  - Original: request any missing messages with sequence numbers less than seq
  - Accelerated: request any missing messages with sequence numbers less than the value of seq on the token received in the previous round
    - seq may reflect messages that are still on their way or even not yet sent; you don't want to request them unless they are really lost

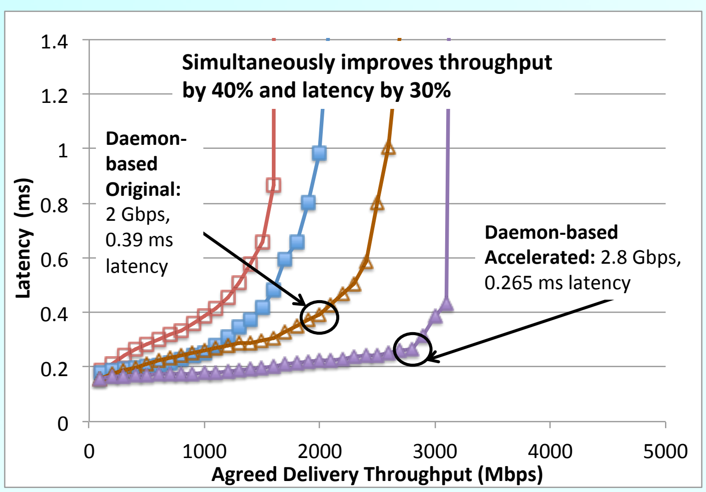
1G Network Results



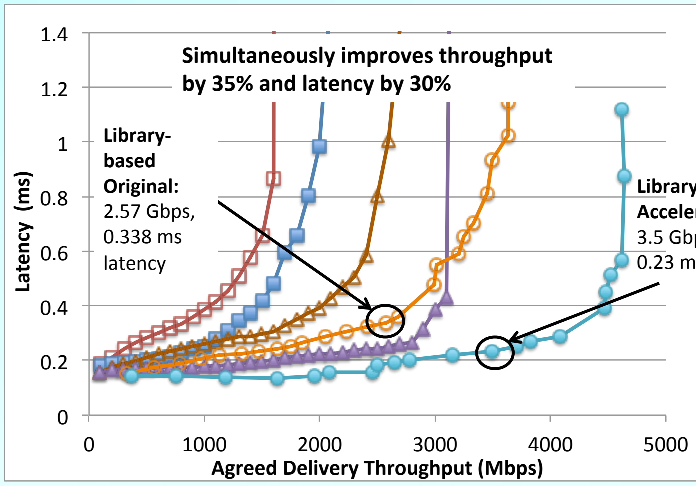
10G Network Results



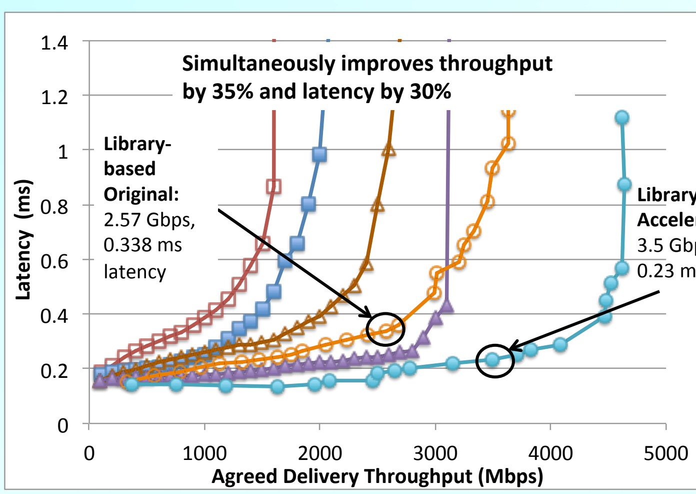
10G Network Results



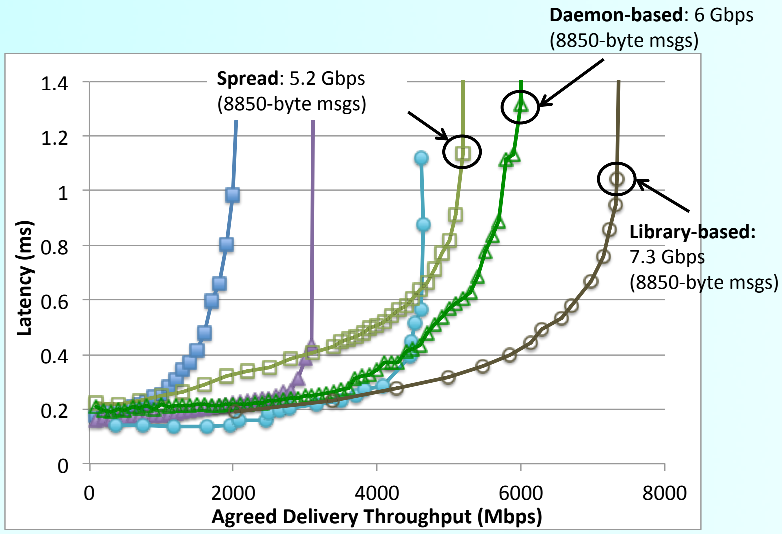
10G Network Results



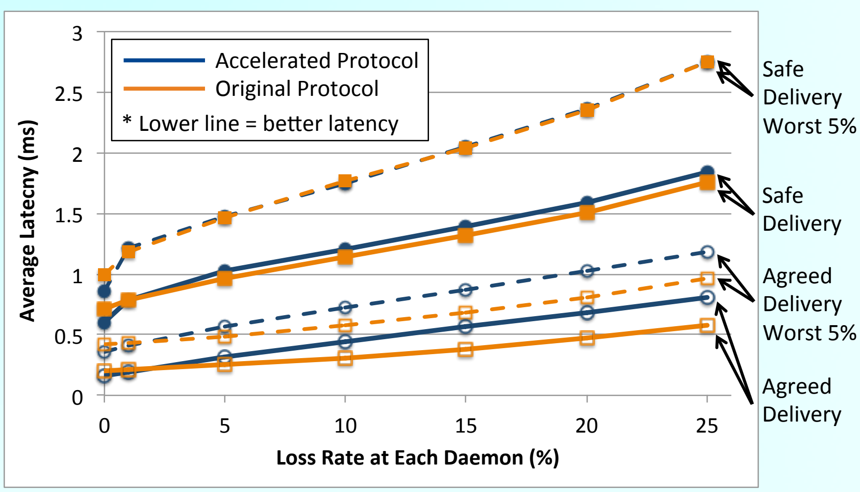
10G Network Results



10G Network Results



10G Network Results with Loss (480 Mbps)



Failure Models

Possible faults:

- Message omissions and delays
- Processor crashes and recoveries
- Network partitions and re-merges

Most of the time it is assumed that:

- Message corruption is detected
- There are no malicious faults

Transis Membership Algorithm

- Utilizes hardware broadcast
- Ordering and Reliability optimized by DAG
- Handles crashes and recoveries.
- Handles network partitions and merges.
- Terminates in a bounded time (to do that, it allows the extraction of live but "inactive" processors).
- Guarantees extended virtual synchrony (relationship between messages and membership events).

Transsis Membership (cont.)

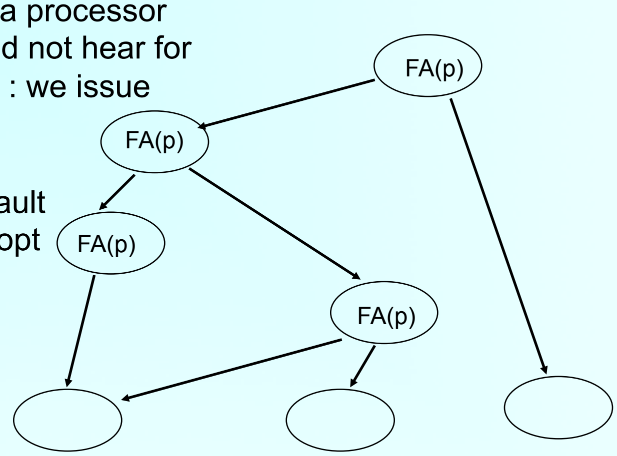
- Partitioning / crashes detection
  - Timeout: invoked by timeout.
- Merging
  - Symmetric: no joining-side, accepting-side
  - Spontaneous: invoked after receiving Join messages or "foreign" messages.
- Faults may occur at any time (even while merging).

Faults & Partitions

When Detecting a processor from which we did not hear for a certain timeout : we issue a fault message.

When we get a fault message, we adopt it (and issue our copy).

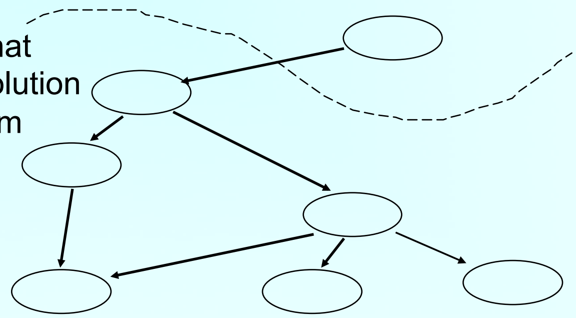
Problem:
maybe p is only slow.



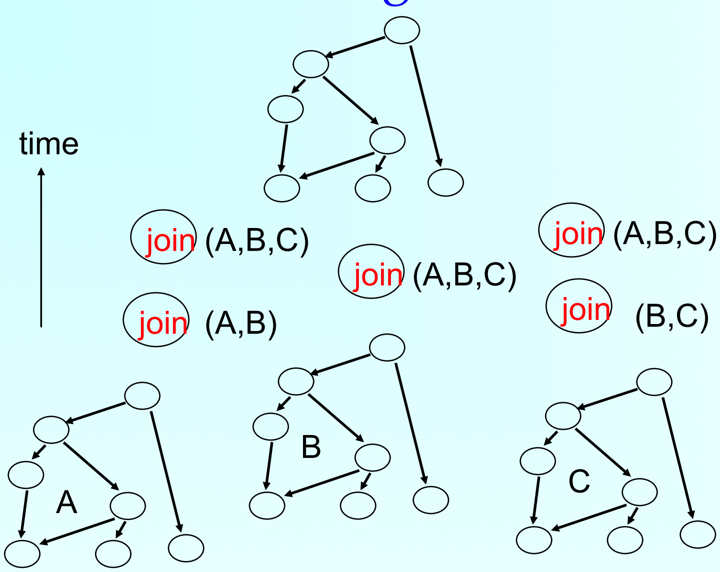
The Problem

When a partition occurs, we cannot always completely determine who received which messages.

It is proven that there is no solution to this problem (no common knowledge)



Merges



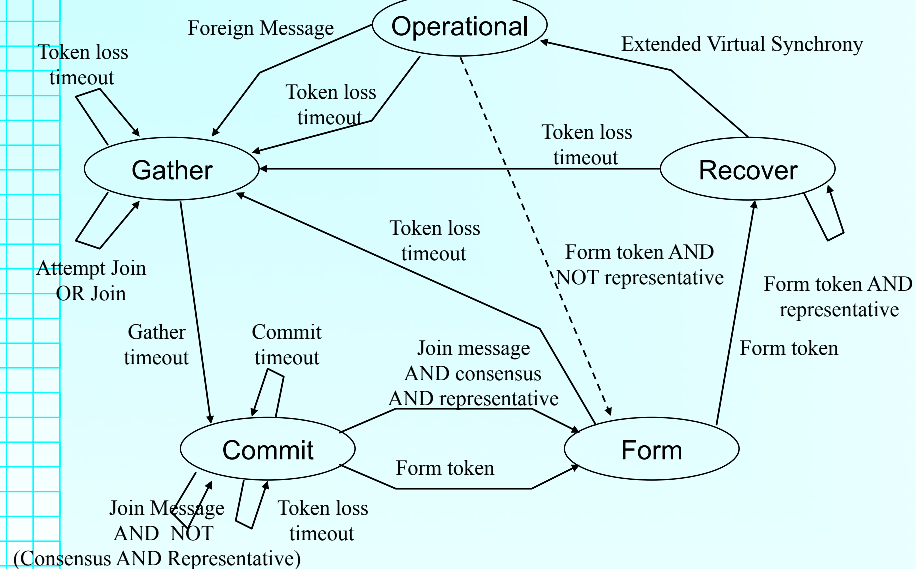
The Single Ring Protocol

- Membership has several stages:
  - Detect that old membership is lost.
  - Gather together all alive members.
  - Form a new ring and send old state.
  - Transfer missing messages.
  - Install new membership.
- Supports message omissions, network partitions, crashes and recoveries.

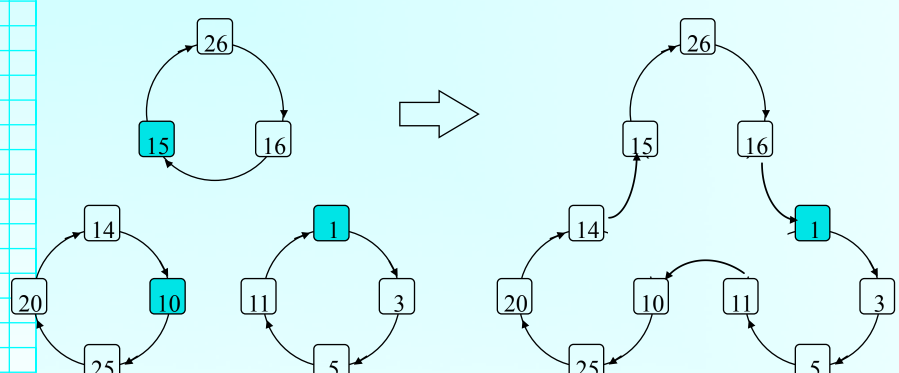
Membership

Events	States
• Foreign Message.	• Operational state.
• Attempt join/ Join.	• Gather state.
• Gather timeout.	• Commit state.
• Commit timeout.	• Form state.
• Form token.	• Recover state.
• Token loss timeout.	

Membership (cont)



Membership (cont..)



Representatives are shown shaded