Distributed Systems
Master of Science in Engineering in Computer Science

AA 2018/2019

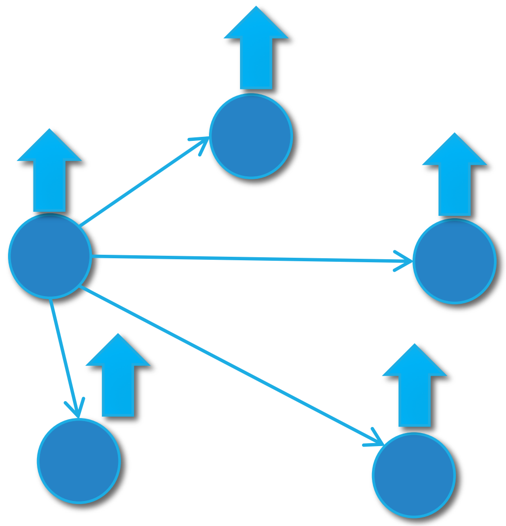
LECTURE 6: BROADCAST COMMUNICATIONS

Recap: what we know up to now

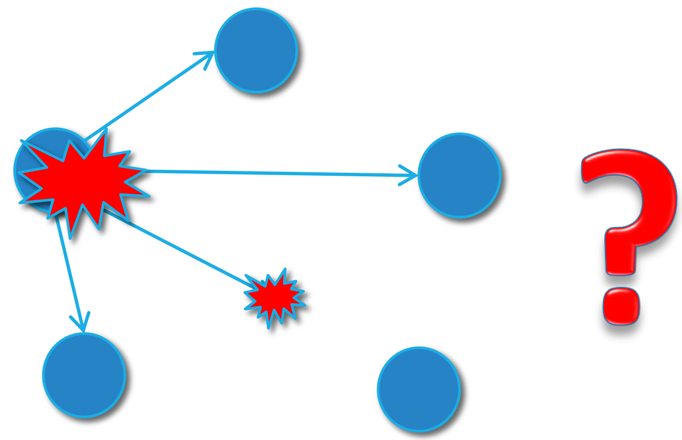
- Define a system model and specify a problem or an abstraction in terms of safety and liveness
- point-to-point communication abstractions
  - fair-loss, stubborn or perfect links
- how to timestamp events
  - physical clocks
  - logical clocks
- handling failures
  - Failure Detector
  - Leader Election

Up to now, the focus has been on the interaction between two processes (like in a client/server environment)

Communication in a group: Broadcast



No Failures



Crash Failures

Best Effort Broadcast (BEB) Specification

Module 3.1: Interface and properties of best-effort broadcast

Module:

Name: BestEffortBroadcast, **instance** *beb*.

Events:

Request: $\langle$ *beb*, *Broadcast* | m $\rangle$: Broadcasts a message m to all processes.

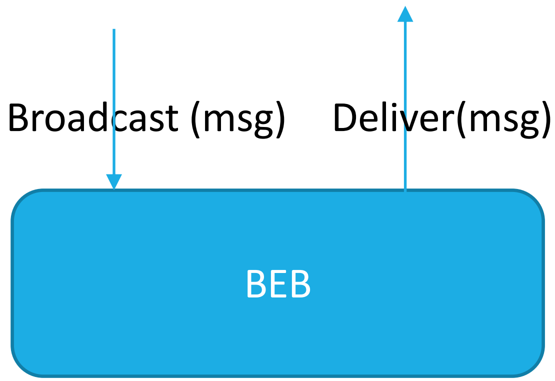
Indication: $\langle$ *beb*, *Deliver* | p, m $\rangle$: Delivers a message m broadcast by process p.

Properties:

BEB1: *Validity:* If a correct process broadcasts a message m, then every correct process eventually delivers m.

BEB2: *No duplication:* No message is delivered more than once.

BEB3: *No creation:* If a process delivers a message m with sender s, then m was previously broadcast by process s.



Best Effort Broadcast (BEB) Implementation

Algorithm 3.1: Basic Broadcast

Implements:
  BestEffortBroadcast, **instance** *beb*.

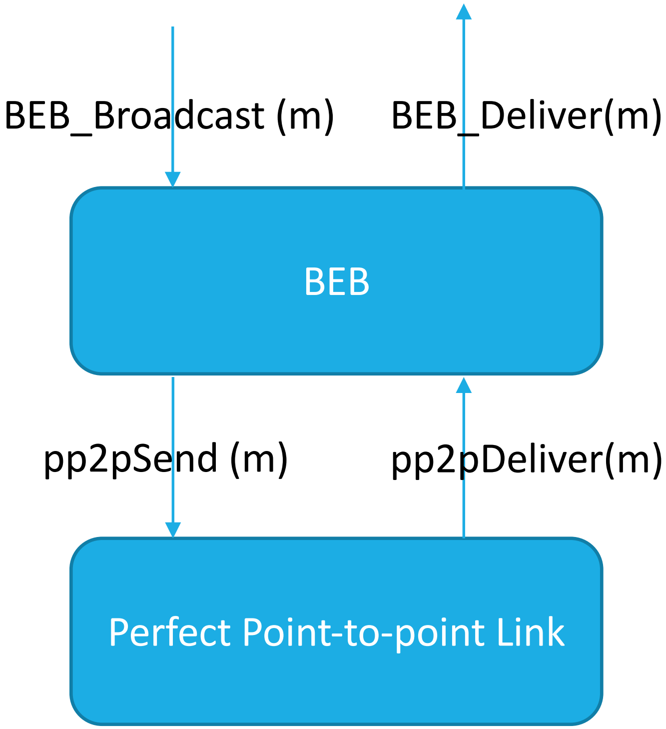
Uses:
  PerfectPointToPointLinks, **instance** *pl*.

upon event $\langle$ *beb*, *Broadcast* | m $\rangle$ **do**
  forall $q \in \Pi$ **do**
    trigger $\langle$ *pl*, *Send* | q, m $\rangle$;

upon event $\langle$ *pl*, *Deliver* | p, m $\rangle$ **do**
  trigger $\langle$ *beb*, *Deliver* | p, m $\rangle$;

System model

- Asynchronous system
- perfect links
- crash failures



Correctness

Validity

- It comes from the *reliable delivery* property of perfect links + the fact that the sender sends the message to every other process in the system.

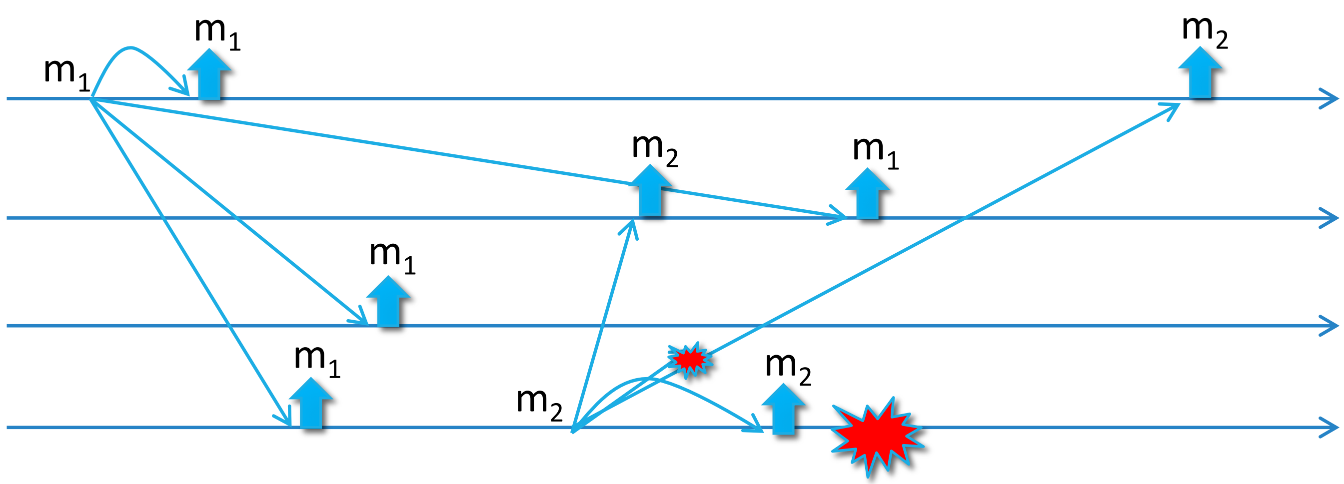
No Duplication

- it directly follows from the No Duplication of perfect links + assumption on the uniqueness of messages (i.e., different messages have different identifiers).

No Creation

- it directly follows from the corresponding property of perfect links.

Observations on Best Effort Broadcast (BEB)



- BEB ensures the delivery of messages as long as the sender does not fail
- If the sender fails processes may disagree on whether or not deliver the message

(Regular) Reliable Broadcast (RB)

Module 3.2: Interface and properties of (regular) reliable broadcast

Module:

Name: ReliableBroadcast, **instance** *rb*.

Events:

Request: $\langle$ *rb*, *Broadcast* $\mid m \rangle$: Broadcasts a message m to all processes.

Indication: $\langle$ *rb*, *Deliver* $\mid p, m \rangle$: Delivers a message m broadcast by process p.

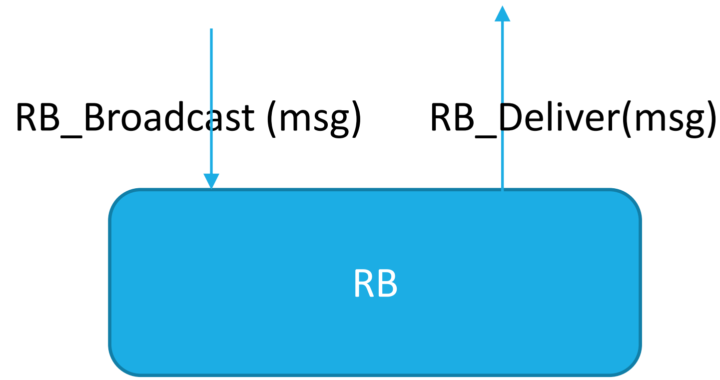
Properties:

RB1: *Validity:* If a correct process p broadcasts a message m, then p eventually delivers m.

RB2: *No duplication:* No message is delivered more than once.

RB3: *No creation:* If a process delivers a message m with sender s, then m was previously broadcast by process s.

RB4: *Agreement:* If a message m is delivered by some correct process, then m is eventually delivered by every correct process.

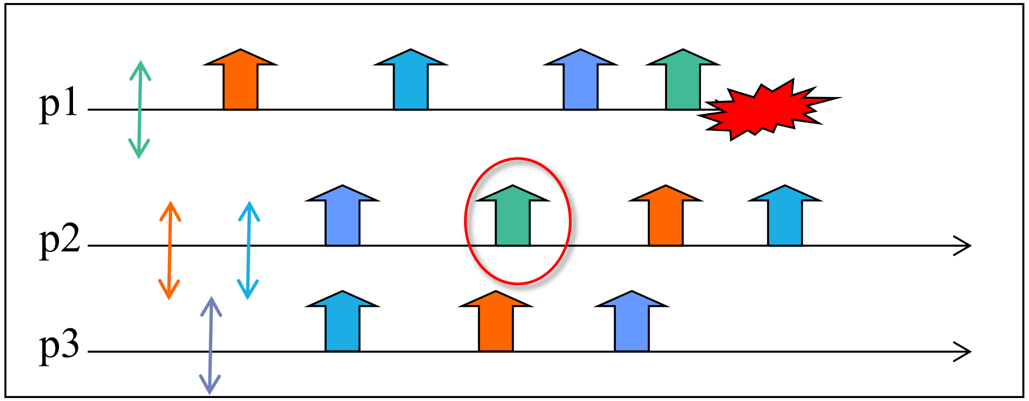


Same as BEB

+

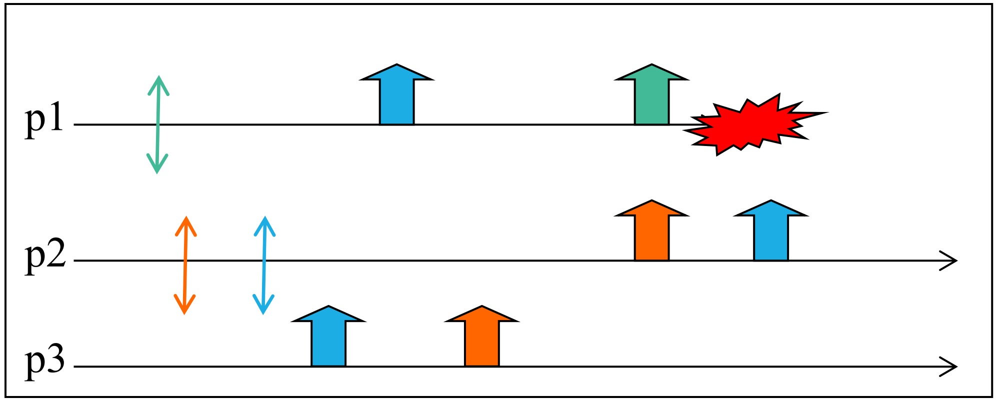
Liveness: agreement

BEB vs RB



Satisfies BEB but not RB (violation of the Agreement Property)

Satisfies RB



(Regular) Reliable Broadcast (RB) Implementation in Synchronous Systems

Algorithm 3.2: Lazy Reliable Broadcast

Implements:
ReliableBroadcast, **instance** *rb*.

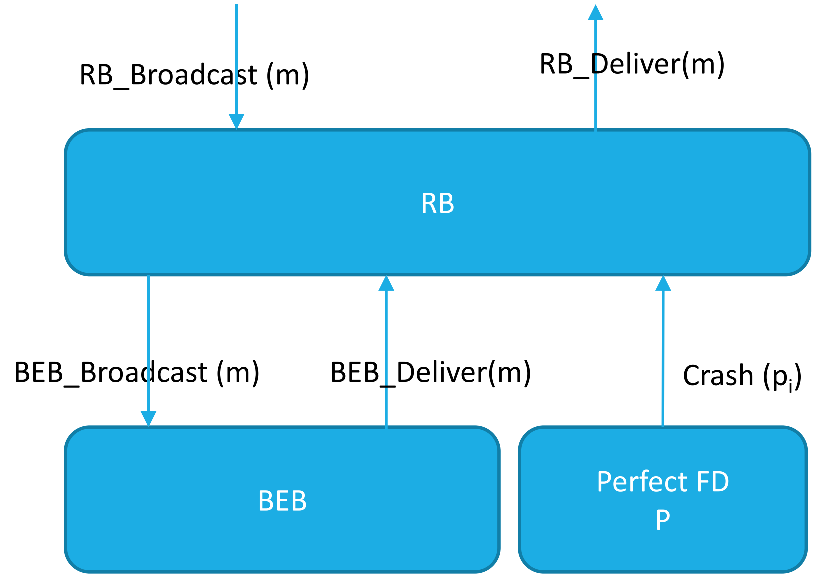
Uses:
BestEffortBroadcast, **instance** *beb*;
PerfectFailureDetector, **instance** $\mathcal{P}$.

upon event $\langle$ *rb*, *Init* $\rangle$ **do**
  $correct := \Pi$;
  $from[p] := [\emptyset]^N$;

upon event $\langle$ *rb*, *Broadcast* $\mid m \rangle$ **do**
  trigger $\langle$ *beb*, *Broadcast* $\mid [\text{DATA}, self, m] \rangle$;

upon event $\langle$ *beb*, *Deliver* $\mid p, [\text{DATA}, s, m] \rangle$ **do**
  if $m \notin from[s]$ **then**
    trigger $\langle$ *rb*, *Deliver* $\mid s, m \rangle$;
    $from[s] := from[s] \cup \{m\}$;
    if $s \notin correct$ **then**
      trigger $\langle$ *beb*, *Broadcast* $\mid [\text{DATA}, s, m] \rangle$;

upon event $\langle \mathcal{P}$, *Crash* $\mid p \rangle$ **do**
  $correct := correct \setminus \{p\}$;
  forall $m \in from[p]$ **do**
    trigger $\langle$ *beb*, *Broadcast* $\mid [\text{DATA}, p, m] \rangle$;



The algorithm is Lazy in the sense that it retransmits only when necessary

Performance of Lazy RB Algorithm

- Best case

  1 BEB message per one RB message

- Worst case

  n-1 BEB messages per one RB (this is the case with n-1 failures)

- What if the FD is not perfect?

(Regular) Reliable Broadcast (RB) Implementation in Asynchronous Systems

Algorithm 3.3: Eager Reliable Broadcast

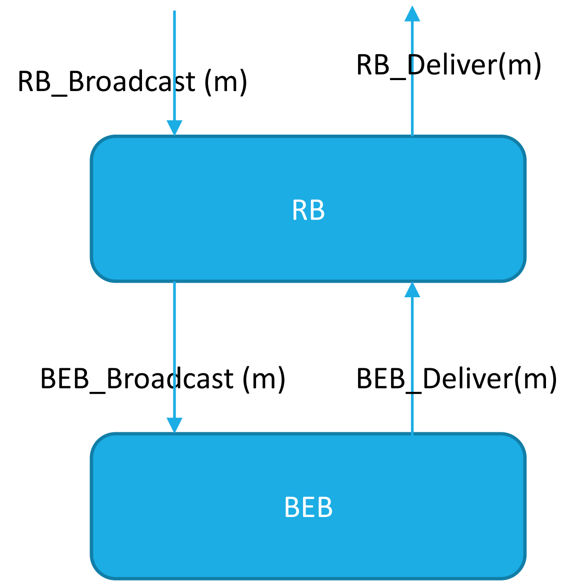
Implements:
ReliableBroadcast, **instance** *rb*.

Uses:
BestEffortBroadcast, **instance** *beb*.

upon event $\langle$ *rb*, *Init* $\rangle$ **do**
delivered := $\emptyset$;

upon event $\langle$ *rb*, *Broadcast* | m $\rangle$ **do**
trigger $\langle$ *beb*, *Broadcast* | [DATA, *self*, m] $\rangle$;

upon event $\langle$ *beb*, *Deliver* | p, [DATA, s, m] $\rangle$ **do**
if $m \notin$ *delivered* **then**
delivered := *delivered* $\cup \{m\}$;
trigger $\langle$ *rb*, *Deliver* | s, m $\rangle$;
trigger $\langle$ *beb*, *Broadcast* | [DATA, s, m] $\rangle$;

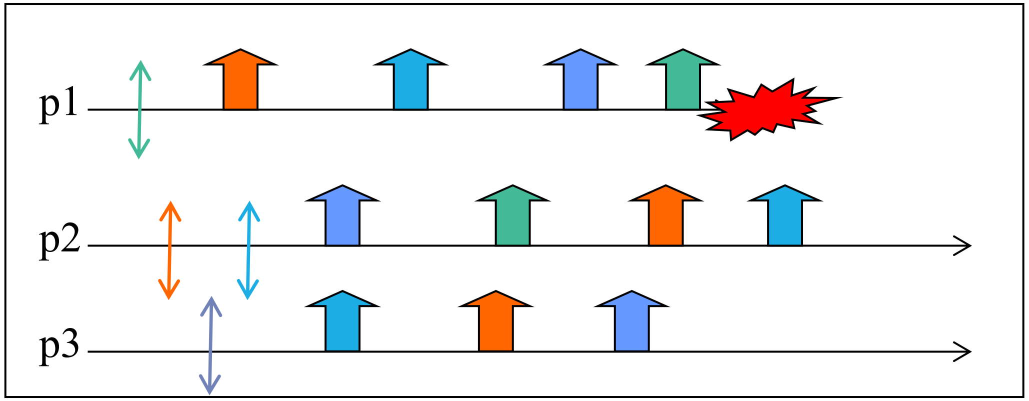


The algorithm is Eager in the sense that it retransmits every message

Performance of Eager RB Algorithm

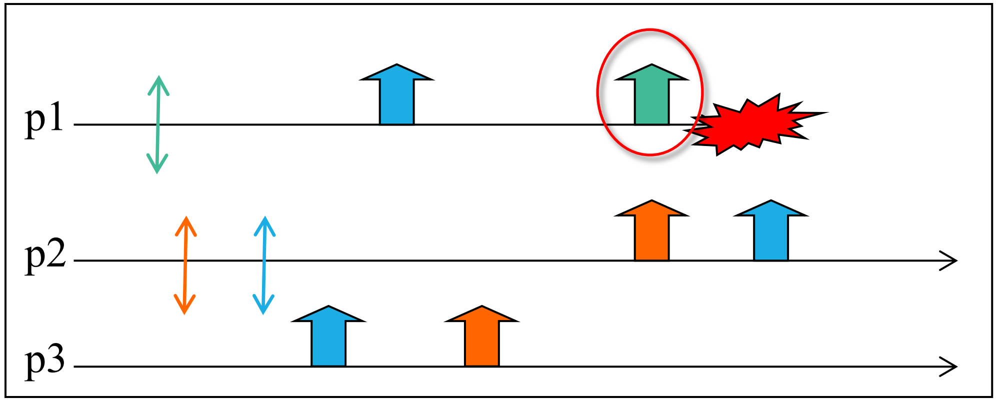
- Best case = Worst case
  - n BEB messages per one RB

BEB vs RB



Satisfies BEB but not RB (violation of the Agreement Property)

Satisfies RB



Uniform Reliable Broadcast (URB) Specification

Module 3.3: Interface and properties of uniform reliable broadcast

Module:

Name: UniformReliableBroadcast, **instance** *urb*.

Events:

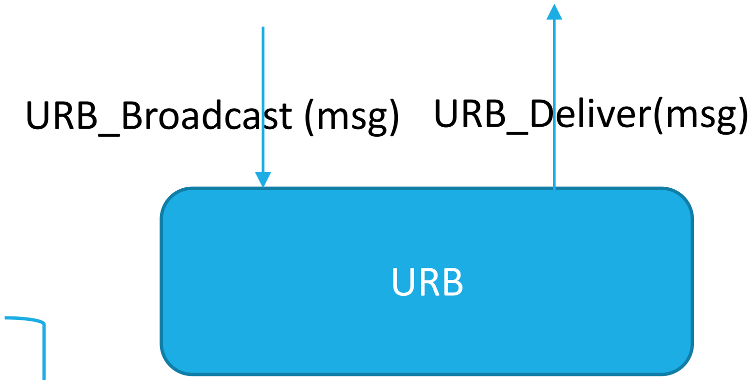
Request: $\langle$ *urb*, *Broadcast* | m $\rangle$: Broadcasts a message m to all processes.

Indication: $\langle$ *urb*, *Deliver* | p, m $\rangle$: Delivers a message m broadcast by process p.

Properties:

URB1–URB3: Same as properties RB1–RB3 in (regular) reliable broadcast (Module 3.2).

URB4: *Uniform agreement:* If a message m is delivered by some process (whether correct or faulty), then m is eventually delivered by every correct process.



Same as BEB and RB

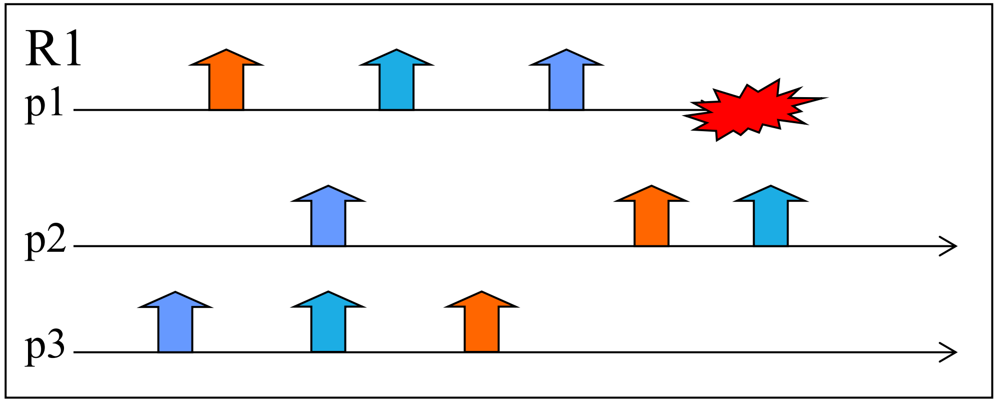
+

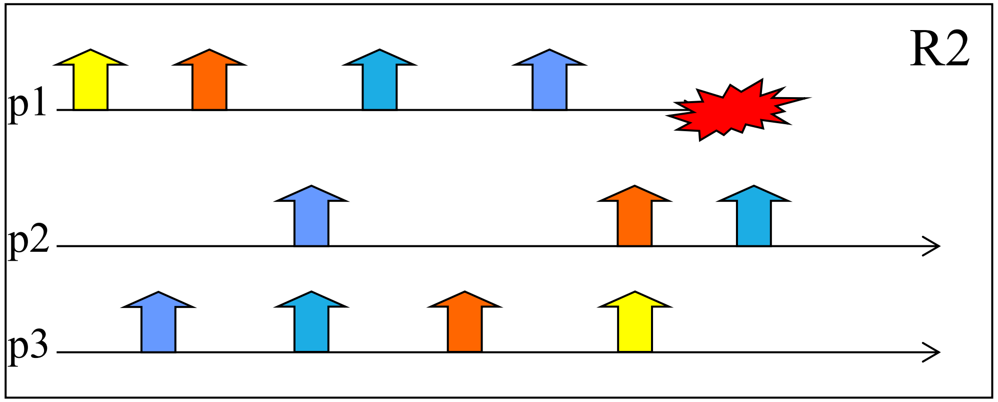
Uniform agreement

Agreement on a message delivered by any process (crashed or not)!

the set of messages delivered by a correct process is a superset of the ones delivered by a faulty one

BEB vs RB vs URB





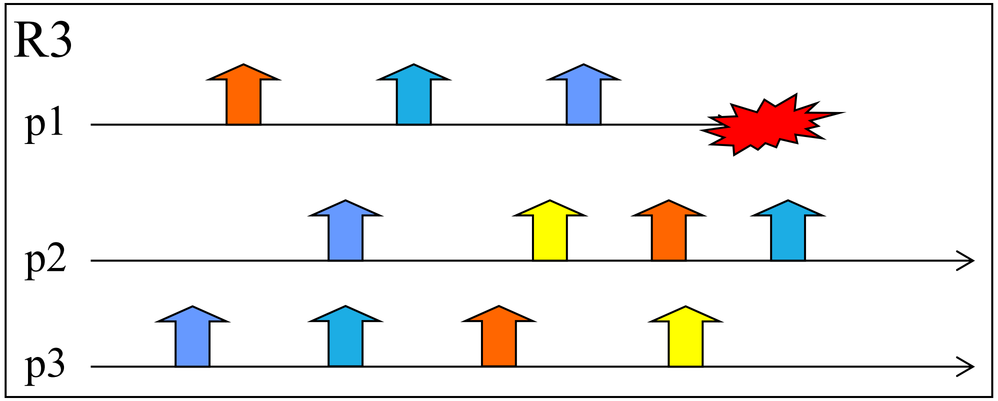
URB

BEB if yellow message is sent by p1

Non-correct otherwise

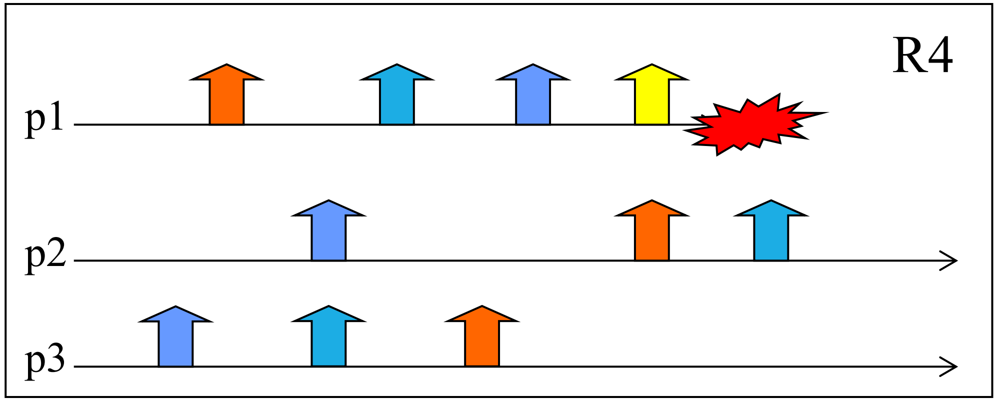
BEB vs RB vs URB

URB



RB if yellow message is sent by p1

Non-correct otherwise



Uniform Reliable Broadcast (URB) Implementation in Synchronous System

Algorithm 3.4: All-Ack Uniform Reliable Broadcast

Implements:
UniformReliableBroadcast, **instance** *urb*.

Uses:
BestEffortBroadcast, **instance** *beb*.
PerfectFailureDetector, **instance** $\mathcal{P}$.

upon event $\langle$ *urb*, *Init* $\rangle$ **do**
delivered := $\emptyset$;
pending := $\emptyset$;
correct := Π;
forall m **do** *ack*$[m]$:= $\emptyset$;

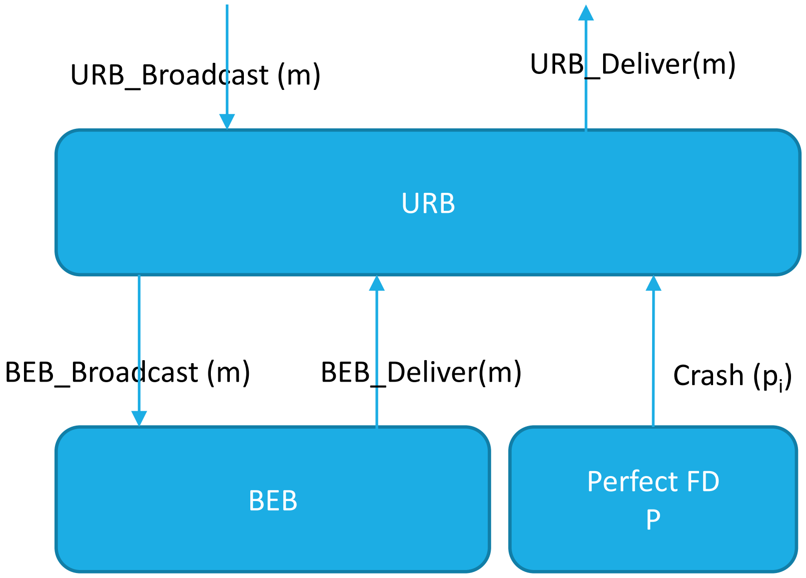
upon event $\langle$ *urb*, *Broadcast* | m $\rangle$ **do**
pending := *pending* $\cup$ $\{(self, m)\}$;
trigger $\langle$ *beb*, *Broadcast* | [DATA, *self*, m] $\rangle$;

upon event $\langle$ *beb*, *Deliver* | p, [DATA, s, m] $\rangle$ **do**
ack$[m]$:= *ack*$[m]$ $\cup$ $\{p\}$;
if $(s, m) \notin$ *pending* **then**
pending := *pending* $\cup$ $\{(s, m)\}$;
trigger $\langle$ *beb*, *Broadcast* | [DATA, s, m] $\rangle$;

upon event $\langle$ $\mathcal{P}$, *Crash* | p $\rangle$ **do**
correct := *correct* $\setminus$ $\{p\}$;

function *candeliver*(m) **returns** Boolean **is**
return (*correct* $\subseteq$ *ack*$[m]$);

upon exists $(s, m) \in$ *pending* such that *candeliver*(m) $\wedge$ $m \notin$ *delivered* **do**
delivered := *delivered* $\cup$ $\{m\}$;
trigger $\langle$ *urb*, *Deliver* | s, m $\rangle$;



Uniform Reliable Broadcast (URB) Implementation in Asynchronous System

---

Algorithm 3.5 Majority-Ack Uniform Reliable Broadcast

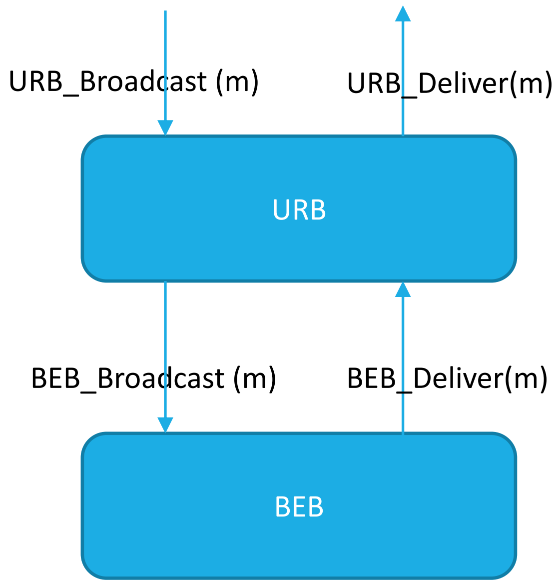
Implements:
UniformReliableBroadcast (urb).

Extends:
All-Ack Uniform Reliable Broadcast (Algorithm 3.4).

Uses:
BestEffortBroadcast (beb).

function canDeliver(m) **returns** boolean **is**
return ($|\text{ack}_m| > N/2$);

// Except for the function above, and the non-use of the
// perfect failure detector, same as Algorithm 3.4.



! We need to assume a majority of correct processes

Uniform Reliable Broadcast

- There exists an algorithm for synchronous system using Perfect failure detector

- There exists an algorithm for asynchronous system when assuming a "majority of correct processes"

- Can we devise a uniform reliable broadcast algorithm for a partially synchronous system (using an eventually perfect failure detector) but without the assumption of a majority of correct processes?

Probabilistic broadcast

- Message delivered 99% of the times
- Not fully reliable
- Large & dynamic groups
- Acks make reliable broadcast not scalable

Ack Implosion and ack tree

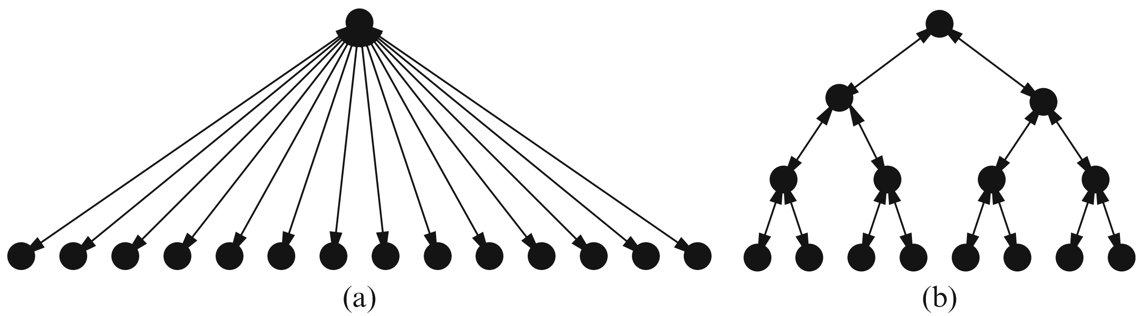


Figure 3.5: Direct vs. hierarchical communication for sending messages and receiving acknowledgments

Problems:

Process spends all its time by doing the ack task

Maintaining the tree structure

Probabilistic Broadcast

Module 3.7: Interface and properties of probabilistic broadcast

---

Module:

Name: ProbabilisticBroadcast, **instance** *pb*.

Events:

Request: $\langle$ *pb*, *Broadcast* | m $\rangle$: Broadcasts a message m to all processes.

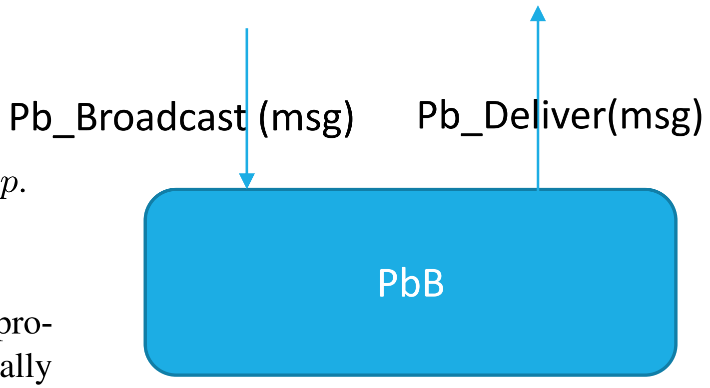
Indication: $\langle$ *pb*, *Deliver* | p, m $\rangle$: Delivers a message m broadcast by process p.

Properties:

PB1: *Probabilistic validity:* There is a positive value ε such that when a correct process broadcasts a message m, the probability that every correct process eventually delivers m is at least $1 - \varepsilon$.

PB2: *No duplication:* No message is delivered more than once.

PB3: *No creation:* If a process delivers a message m with sender s, then m was previously broadcast by process s.



Gossip Dissemination

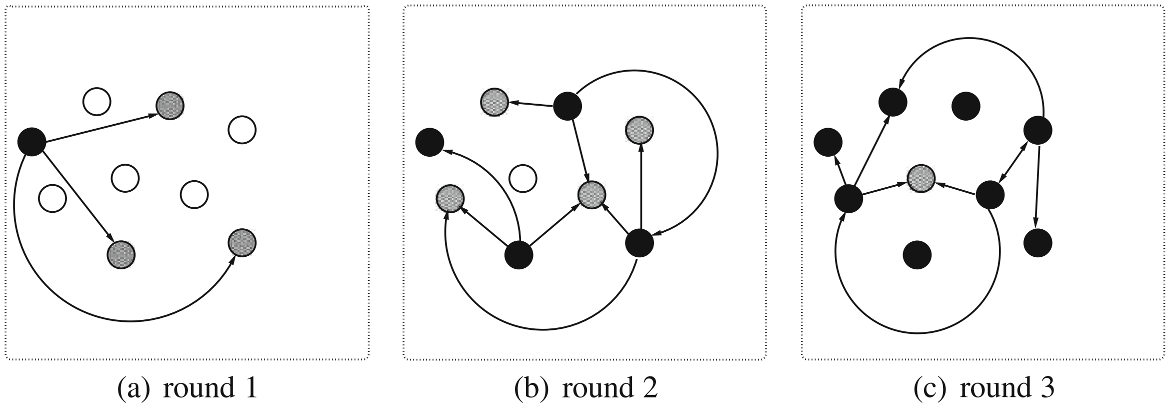


Figure 3.6: Epidemic dissemination or gossip (with fanout 3)

- A process sends a message to a set of randomly chosen k processes
- A process receiving a message for the first time forwards it to a set of k randomly chosen processes (this operation is also called a round)
- The algorithm performs a maximum number of r rounds

Eager Probabilistic Broadcast

Algorithm 3.9: Eager Probabilistic Broadcast

Implements:
  ProbabilisticBroadcast, **instance** *pb*.

Uses:
  FairLossPointToPointLinks, **instance** *fll*.

upon event ⟨ *pb*, *Init* ⟩ **do**
  delivered := $\emptyset$;

procedure *gossip*(*msg*) **is**
  forall $t \in$ *picktargets*(k) **do trigger** ⟨ *fll*, *Send* | t, *msg* ⟩;

function *picktargets*(k) **returns** set of processes **is**
  targets := $\emptyset$;
  while #(*targets*) $< k$ **do**
    candidate := random($\Pi \setminus \{self\}$);
    if *candidate* $\notin$ *targets* **then**
      targets := *targets* $\cup$ {*candidate*};
  return *targets*;

upon event ⟨ *pb*, *Broadcast* | m ⟩ **do**
  delivered := *delivered* $\cup \{m\}$;
  trigger ⟨ *pb*, Deliver | *self*, m ⟩;
  gossip([GOSSIP, *self*, m, R]);

upon event ⟨ *fll*, *Deliver* | p, [GOSSIP, s, m, r] ⟩ **do**
  if $m \notin$ *delivered* **then**
    delivered := *delivered* $\cup \{m\}$;
    trigger ⟨ *pb*, *Deliver* | s, m ⟩;
  if $r > 1$ **then** *gossip*([GOSSIP, $s, m, r-1$]);

References

C. Cachin, R. Guerraoui and L. Rodrigues. Introduction to Reliable and Secure Distributed Programming, Springer, 2011

- Chapter 3 - from Section 3.9 (except 3.9.6)
- Chapter 6 – Section 6.1

Stefano Cimmino, Carlo Marchetti, Roberto Baldoni *"A Guided Tour on Total Order Specifications"* WORDS Fall 2003: 187-194