Threshold Logical Clocks

Manuel Vidigueira
Distributed and Decentralized Systems Lab (DEDIS)
École polytechnique fédérale de Lausanne (EPFL)

Supervised by Bryan Ford and Ceyhun Alp

Outline

- Motivation
- Threshold Logical Clocks (TLC)
- Experimental Results
- Using TLC
- Conclusion

Outline

- **Motivation**
- Threshold Logical Clocks (TLC)
- Experimental Results
- Using TLC
- Conclusion

Network models

Synchronous

- Synchronized clocks
- Bounded message transmission delay
- Bounded processing time

Partially Synchronous

- (Mostly) Asynchronous
- Eventually it behaves like a synchronous network

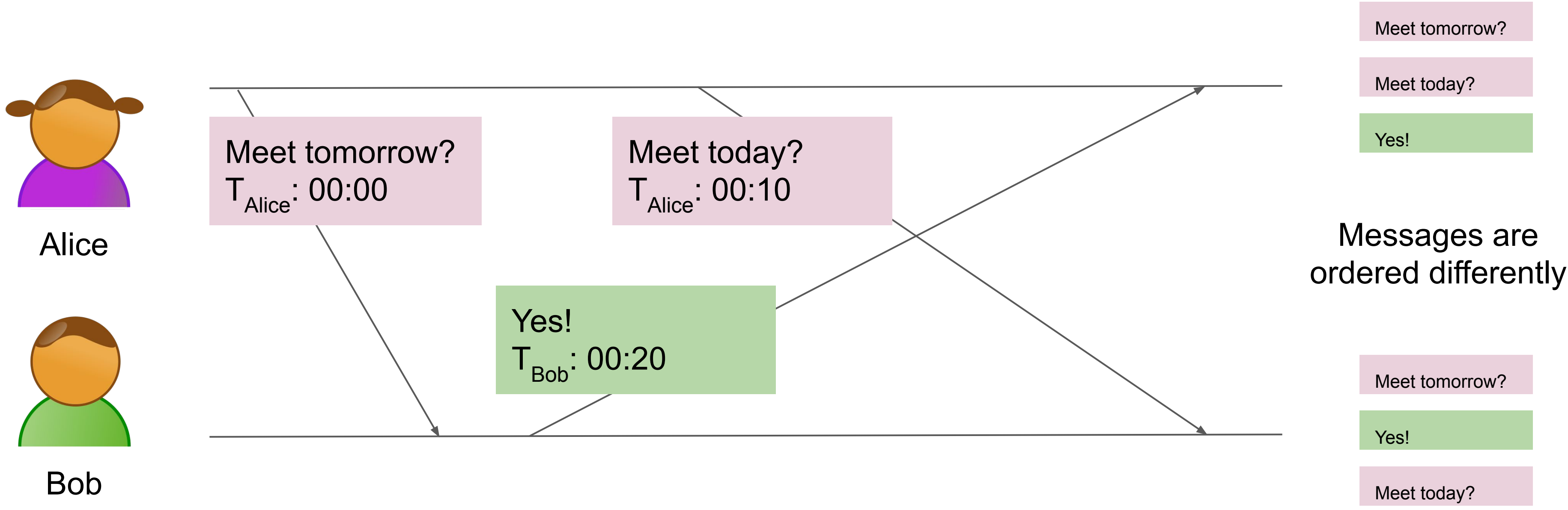
Asynchronous

- No assumptions

Easier to prove/analyse ⟷ More robust

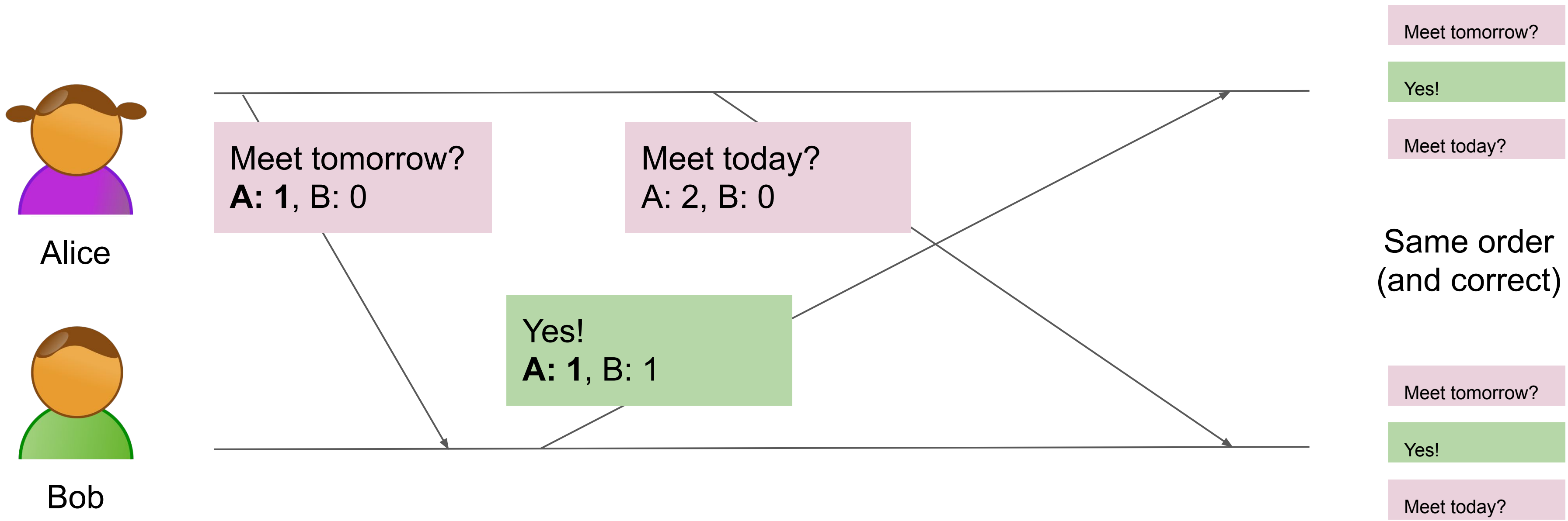
Can we get the best of both worlds?

Measuring time in asynchronous systems



Node clocks can be out of sync!

Logical time: vector clocks



Nodes keep track of how many messages they saw from others

Adversarial models

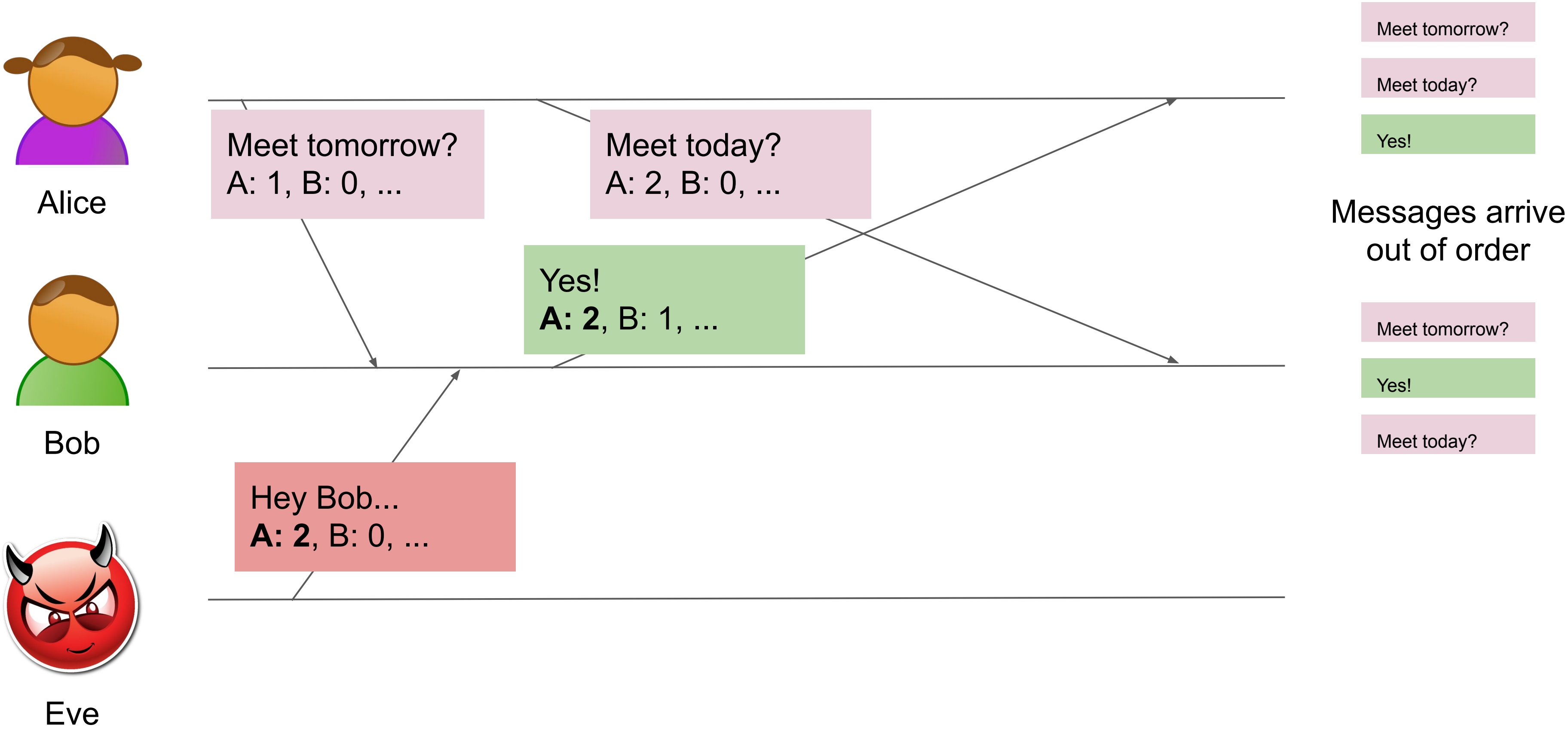
Crash-stop

- Nodes only fail by crashing

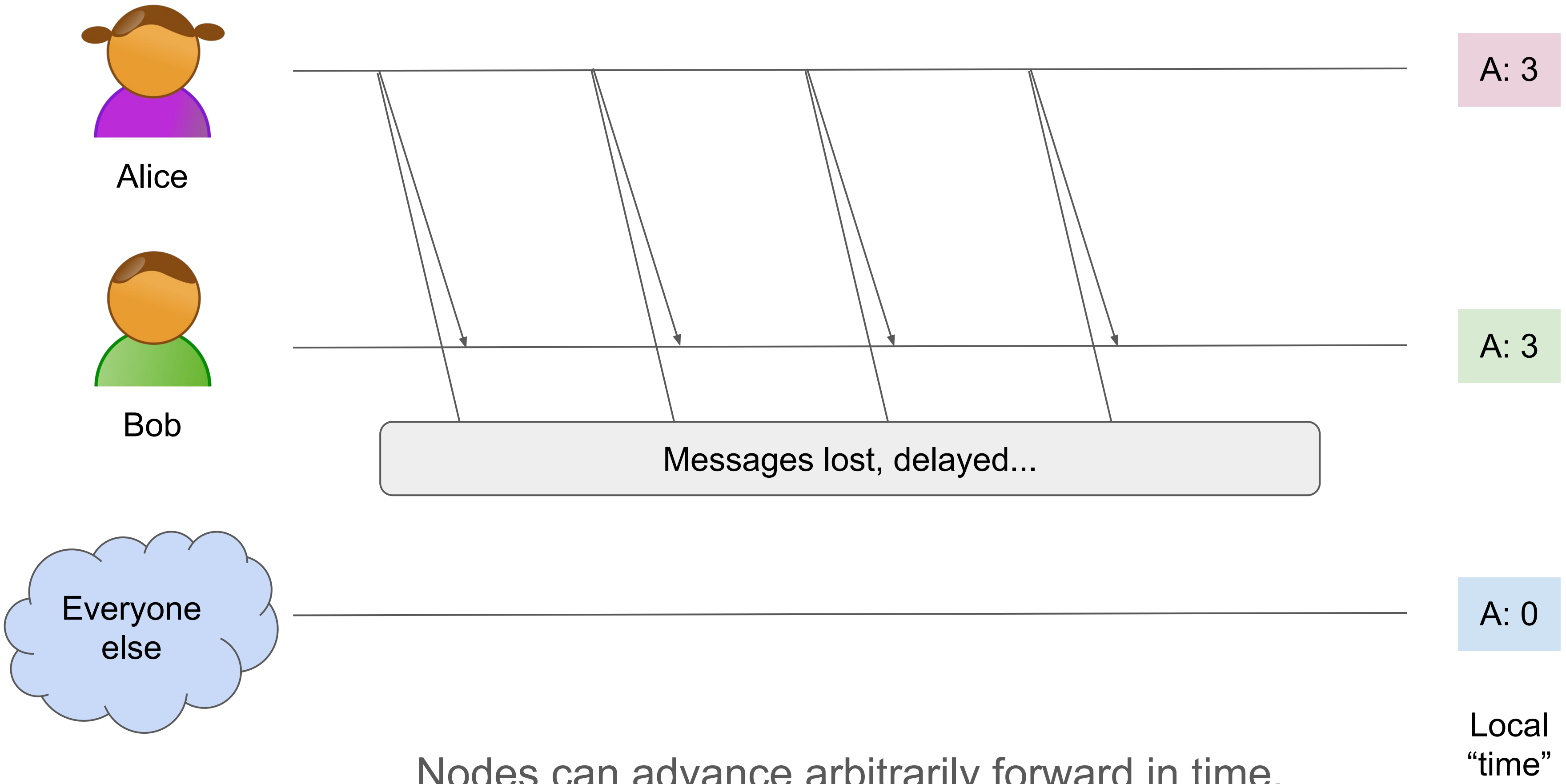
Byzantine

- Nodes can do anything (behave arbitrarily)

Stronger →



No tolerance of byzantine failures!



Nodes can advance arbitrarily forward in time.
No enforced group synchronization!

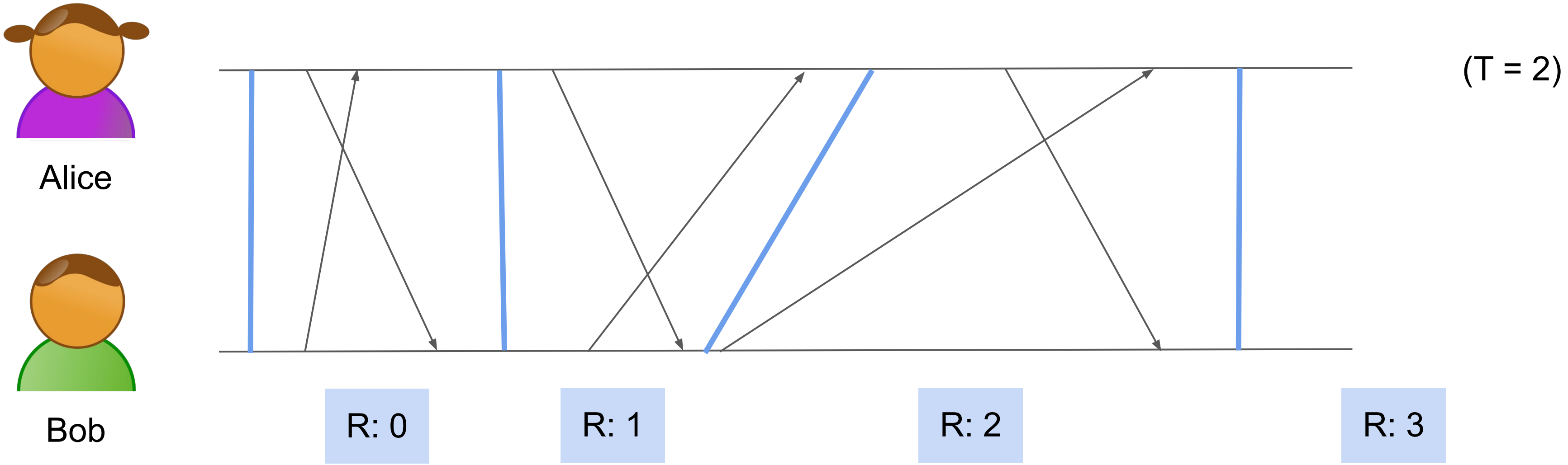
Outline

- Motivation
- **Threshold Logical Clocks (TLC)**
- Experimental Results
- Using TLC
- Conclusion

Threshold Logical Clocks

Idea:

- Time is represented by a **round** number **R**
- Nodes must have received a threshold **T** of messages to **advance** to the next round and send another message.



TLC - Design goals

Security goals

1. Fully Asynchronous
No use of timeouts or synchronous assumptions.

2. Byzantine Fault Tolerant
Can tolerate as many byzantine or malicious nodes as possible

Performance goals

3. Liveness
Honest nodes must be able to make progress (go to next round)

4. Low latency
Rounds should be fast and use few round trips.

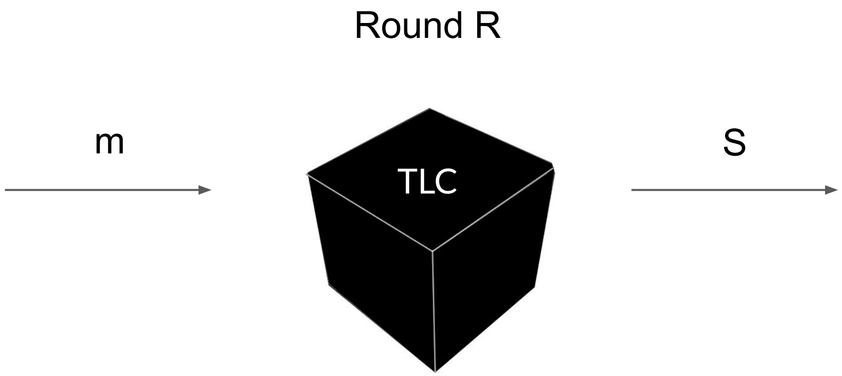
5. Low bandwidth usage
Should scale to at least 100s of nodes

TLC Interface

Every round:

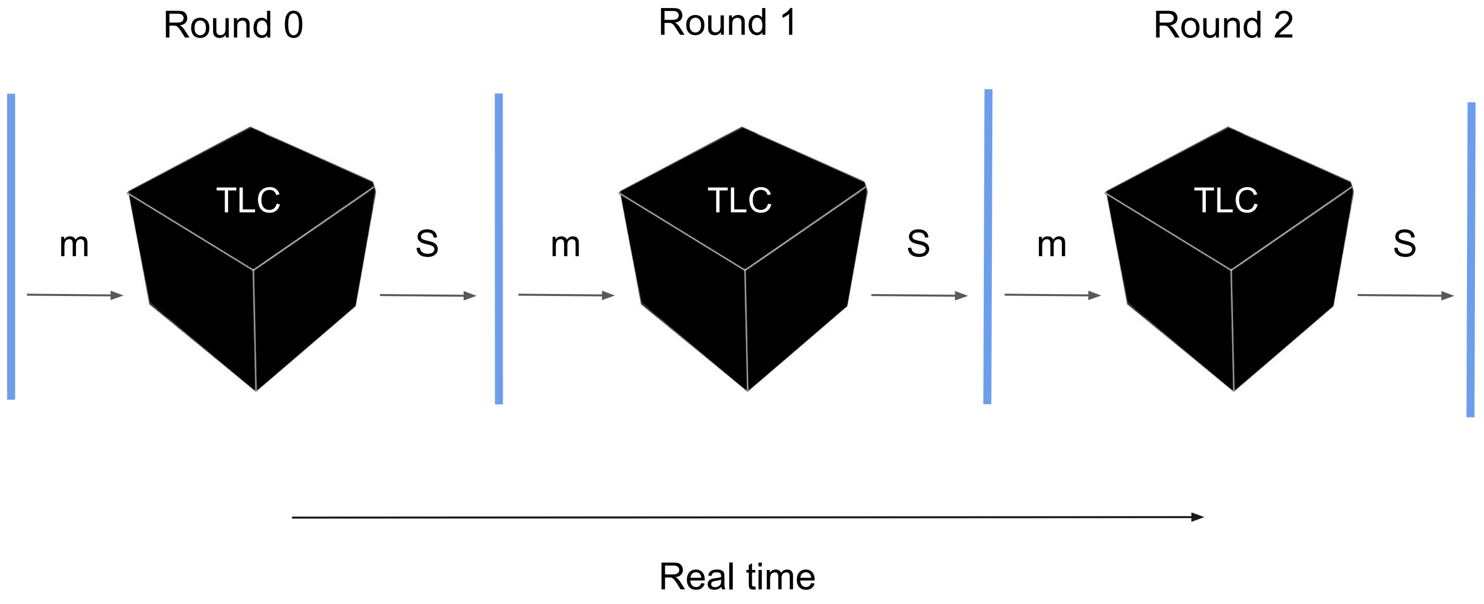
- Provide a valid message *m*

- Receive a set *S* of valid messages (#S >= **T**)



A validation function f_{val} filters bad messages

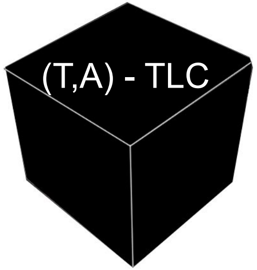
What we want:



TLC Interface

Two main parameters:

- message threshold **T**
- acknowledgement threshold **A**



Certified message:

- appears in the set S of **A** different nodes (same round)

Every set S returned by TLC:

- contains at least **T** different **certified** messages

Simple TLC

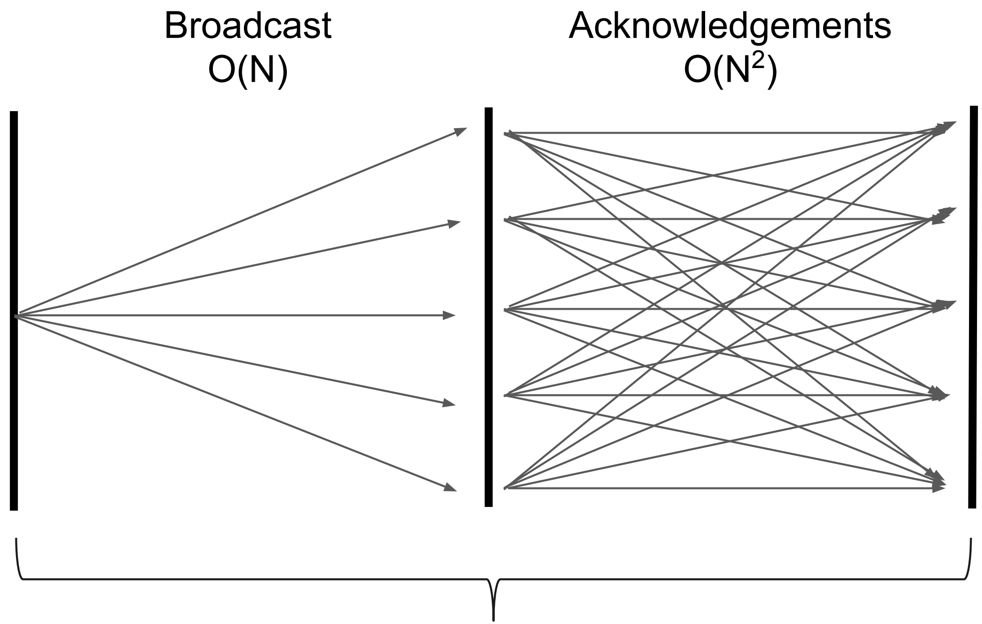
Every round has a logical time associated to it (0, 1, 2…)

Every round, each node:

1. Broadcasts its message, appending the round time
2. Broadcasts signed ACK for messages of that round
3. Waits for T messages where each has A different ACK
4. Delivers messages received and broadcast in that round
5. Increments round.

Communication pattern

Messages for **one** node



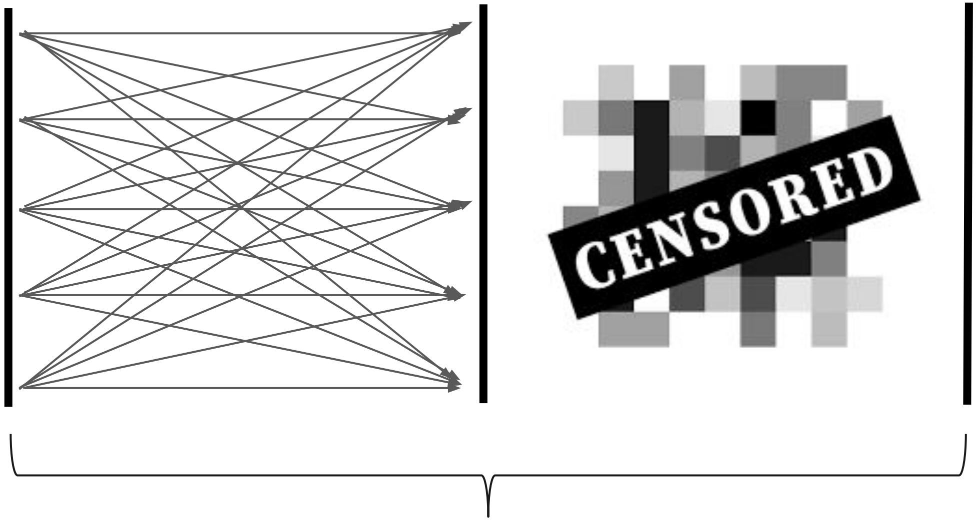
Simple TLC round split by trip time

Communication pattern

Messages for **all** nodes

Broadcast
$O(N^2)$

Acknowledgements
$O(N^3)$

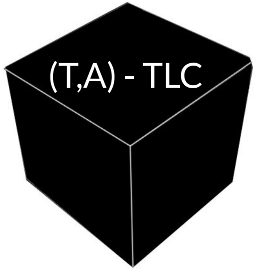


~TLC round split by trip time

Threshold Witnessed TLC

Every round, each node:

1. Broadcasts its message, appending the round time
2. Sends signed ACK for messages of that round to their sender
3. Waits for A Acks for its message, aggregates signatures and sends certified message (message + signature).
4. Waits for T certified messages.
5. Delivers messages received and broadcast in that round
6. Increments round.



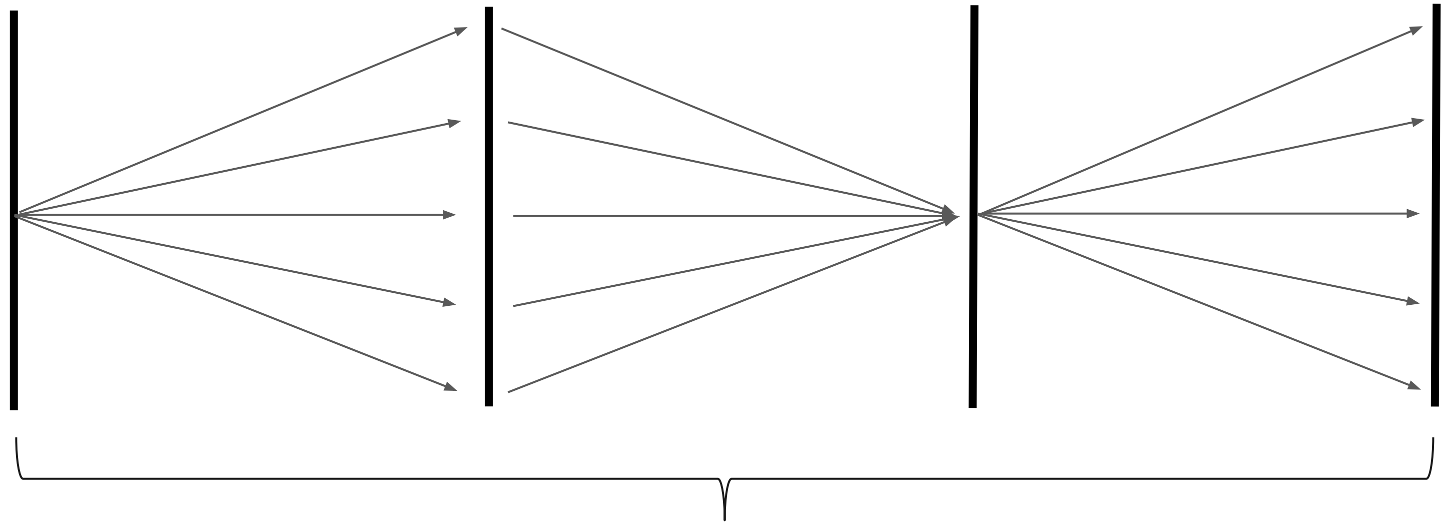
Communication pattern

Messages for **one** node

Broadcast
O(N)

Acknowledgements
O(N)

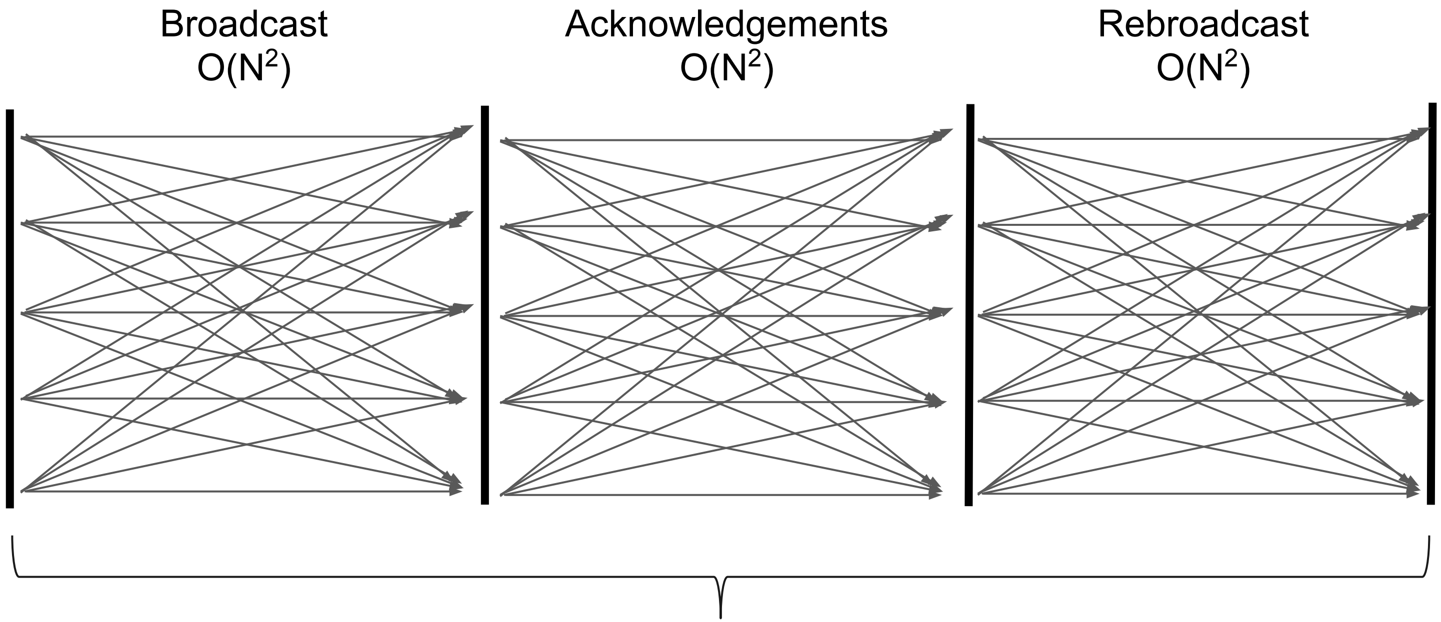
Rebroadcast
O(N)



Threshold Witnessed TLC round split by trip time

Communication pattern

Messages for **all** nodes



Threshold Witnessed TLC round split by trip time

Outline

- Motivation
- Threshold Logical Clocks (TLC)
- **Experimental Results**
- Using TLC
- Conclusion

Implementation & Experimental Setup

Implementation

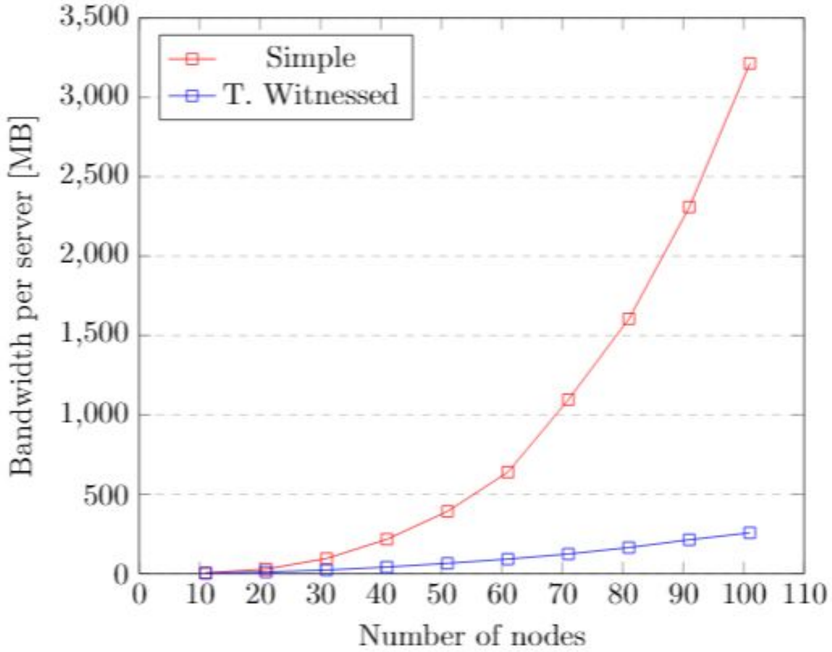
- Go
  - Simple: ~420 lines
  - Threshold Witnessed: ~575 lines
- Libraries:
  - Kyber crypto library
  - Onet network library
- https://github.com/dedis/student_19_tlc

Deterlab setup

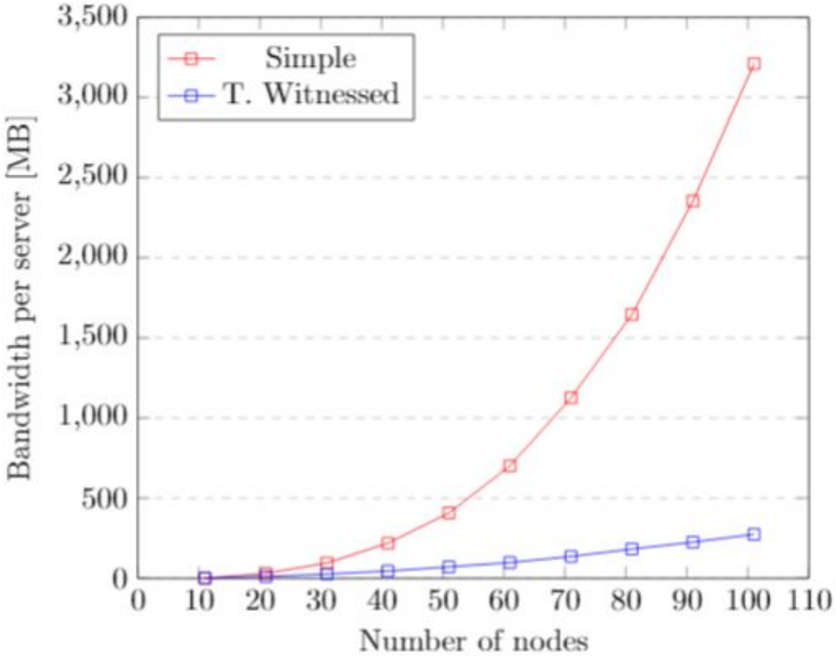
- 10 physical machines
- Network configuration:
  - 100 Mbps bandwidth
  - 200 ms round-trip latency
  - 1KB payloads

Evaluation: Bandwidth

T = A = (n+1)/2

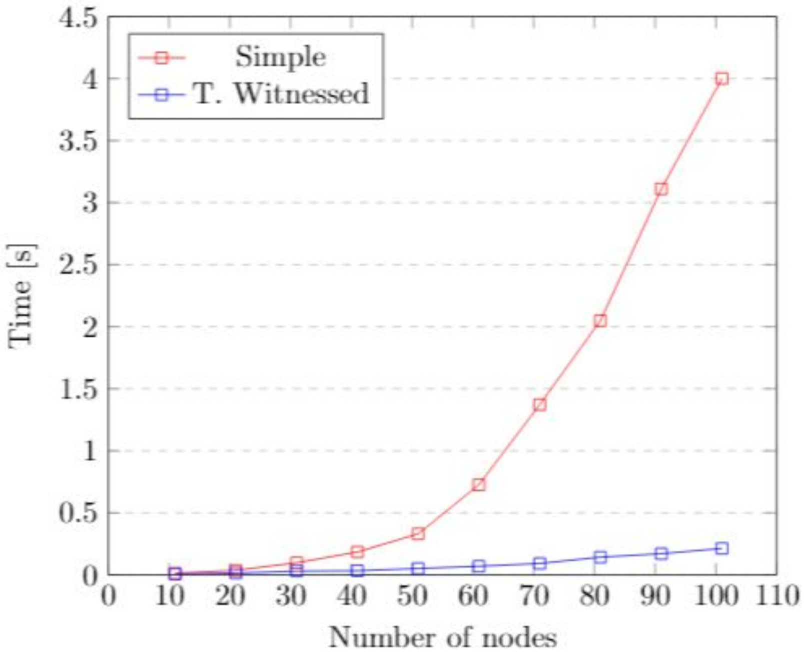


T = A = (2n+1)/3

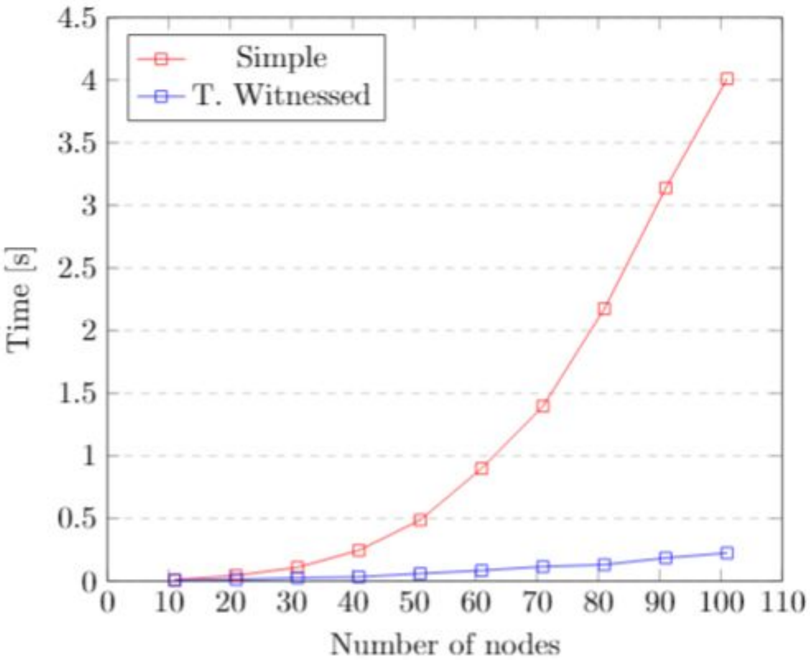


Evaluation: Round Time

T = A = (n+1)/2



T = A = (2n+1)/3



Outline

- Motivation
- Threshold Logical Clocks (TLC)
- Experimental Results
- **Using TLC**
- Conclusion

Potential Applications

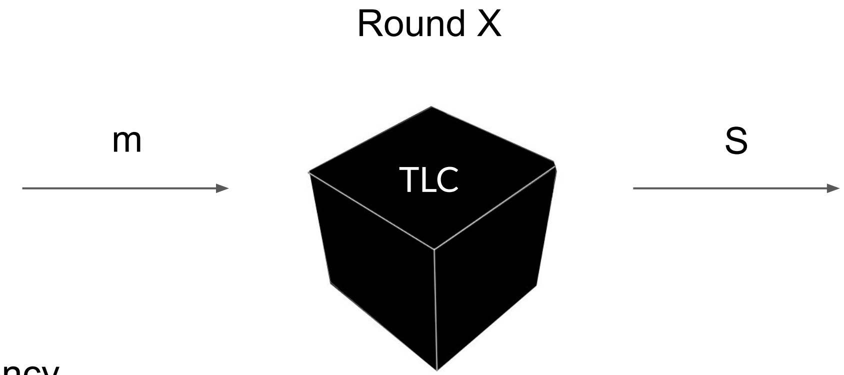
- Threshold Cryptographic Signing
- Threshold Cryptographic Randomness
- Randomized Asynchronous Consensus
    - The communication logic is reduced to TLC time-steps.
    - Can be used for Byzantine consensus as well.
    - Details are currently in the works.

Outline

- Motivation
- Threshold Logical Clocks (TLC)
- Experimental Results
- Using TLC
- **Conclusion**

Conclusion

- Threshold Logical Clocks:
    - robust round based communication
    - group based notion of time
    - implementation with reduced bandwidth and latency
    - scales to 100s of nodes
    - many potential applications



Thanks!