Round-Efficient Byzantine Broadcast under Strongly Adaptive and Majority Corruptions

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Byzantine Broadcast [Lamport et al. 82]

- A set of users aim to reach consensus, one of them is the designated sender.
- The sender is given an input bit $b \in \{0, 1\}$
  - *Consistency*: all honest users must output the same bit; and
  - *Validity*: all honest users output the sender's input bit if the sender is honest.

Background and Previous Work

- Under synchronous setting,
- [Dolev and Strong, 83]: no deterministic protocol can achieve Byzantine Broadcast within $f+1$ rounds, where f is the number of corrupted users.
- Focus on randomized protocols

Previous work

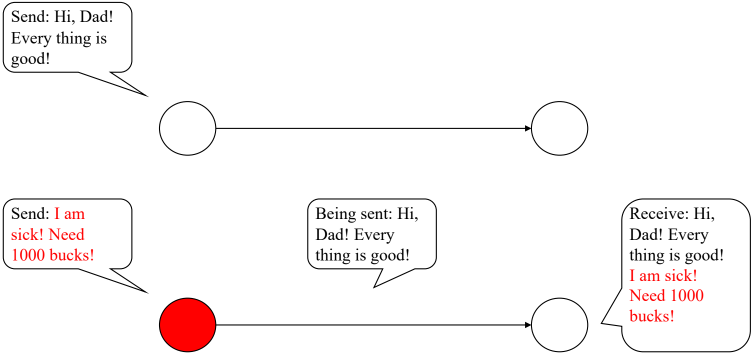
- Honest majority: expected constant rounds [Katz and Koo 09, Abraham et al. 19], even under a strongly adaptive adversary.
- Dishonest majority: expected constant rounds [Chan et al. 20, Wan et al. 20], but only under a weakly adaptive adversary.

Byzantine Broadcast: adversary model

Static: decide who to corrupt before the protocol.

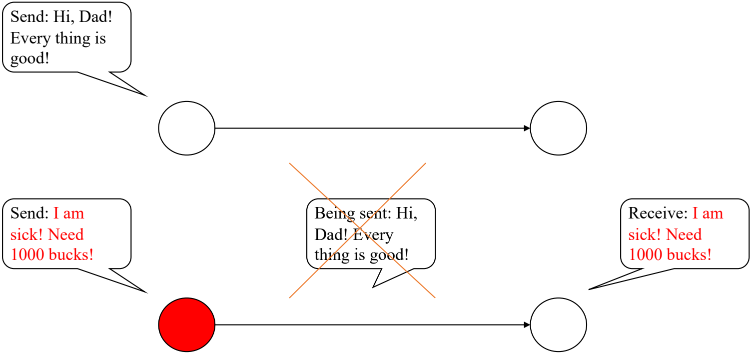
Byzantine Broadcast: adversary model

Weakly adaptive: can corrupt during the protocol, but any message sent in the round of corruption must be delivered.



Byzantine Broadcast: adversary model

Strongly rushing adaptive: can perform “after-the-fact removal”, can erase the messages any node had sent in the same round it became corrupt.



Question

Is it possible to achieve sublinear round complexity under

- dishonest majority and
- a strongly rushing adaptive adversary?

Byzantine Broadcast: main theorem

Assuming the existence of a trusted setup and time-lock puzzles,

Theorem

There exists a protocol that achieves BB in $(\frac{n}{n-f})^2 \cdot \mathit{polylog}(\lambda)$ *number of rounds with probability* $1 - \mathit{negl}(\lambda)$.

Chan et. al.'s construction

- Define two committees: the 0-committee and the 1-committee.
- The b-committee consists of all nodes whose VRF evaluation on b is smaller a parameter.

Chan et. al.'s construction

- Define two committees: the 0-committee and the 1-committee.
- The *b*-committee consists of all nodes whose VRF evaluation on *b* is smaller a parameter.
- Parameters are chosen such that each committee's size is polylogarithmic in expectation.

Chan et. al.'s construction

- Each committee's size is polylogarithmic in expectation.
- Committee members engage in poly-logarithmically many rounds of voting.
- All nodes, including non-committee members, keep relaying the votes they have seen.

How to change it

- If only adversary cannot corrupt users before votes are delivered!
- How about we “encrypt” the votes:
  - Adversary need one round of time to “decrypt” the vote.
  - Non-committee members send dummy message.

Time-lock puzzle: high level intuition

A time-lock puzzle with parameter ξ and T,

- For any message, can generate a puzzle in polylog(T) steps.
- Given a puzzle, can solve it in T steps under a sequential Random-Access Machine.
- Even parallel adversary cannot solve it in less than ξT steps.

Intuitions for using time-lock puzzle

- Voters lock the votes in a time-lock puzzle.
- Non-voters send chaff of the same length, also locked in puzzles.
- Even if the adversary has unbounded parallelism,
  - cannot distinguish voters and non-voters within one round of time.

Challenge

- Adversary has access to unbounded parallelism, but honest users don't.
- Honest users do not have a consistent view of the puzzles being distributed.
  - Hard to coordinate who solves which puzzles.

The Age-based Sampling Protocol

Allow all honest users to each distribute a time-lock puzzle embedding some messages.

- Liveness: every honest node will receive the solution of all honest puzzles.
- Momentary secrecy: the adversary cannot learn any information about honest users' encoded messages within one round of time,
    - even if it has unbounded parallelism.

A high level description

- Every user computes and sends a time-lock puzzle on the message.
- Repeat $\Theta(\log n)$ iterations: in the i^{th} iteration,
  - each iteration has time $T_{solve} \cdot polylog(\lambda)$.
  - for each unsolved puzzle, solve it with probability $\min(2^{\alpha} \cdot p, 1)$ where $p = \ln(16n/h)/n = \Theta(1/n)$.
    - α is the age of the puzzle.
  - send solutions of newly solved puzzles to other users.

Proof of Correctness

- Liveness: at least half of the unsolved puzzles is solved by honest users in each iteration (no matter who the adversary corrupt).
- Momentary secrecy: follows from properties of time-lock puzzle.
- Failure probability for the i^{th} iteration:

$$(1 - 2^i \cdot p)^{h \cdot n/2^{i-1}} \cdot \binom{n}{h} \cdot \binom{n}{n/2^{i-1}} \leq exp(-\Theta(n)).$$

Round complexity

- Round complexity: $\mathrm{E} \cdot \mathrm{P} \cdot (T_{solve}/T_{\emptyset})$:
  - E: number of epochs / iterations, $\Theta(\log n)$.
  - P: number of puzzles an honest user need solve per iteration, upper bounded by $polylog(n, \lambda)$ by Chernoff Bound.
  - T_{solve}: time to solve each puzzle.
  - $T_{\emptyset}$: time per round.
- By definition of time-lock puzzle: $(T_{solve}/T_{\emptyset})$ is upper bounded by $1/\xi$.

Apply the Age-based Sampling Protocol

- Combine it with techniques proposed in Chan et al. [CPS20]:
  - replace normal message relay with Distribute protocol.
- Most challenging aspect: how to prove security.

Conclusion

We propose a Byzantine Broadcast protocol under

- dishonest majority
- a strongly adaptive adversary.
- round complexity: polylogarithmic.

Open questions

Is it possible to achieve Byzantine Broadcast under a strongly adaptive adversary in expected constant rounds?

Acknowledgement

Thank you.