A Blockchain Consensus Protocol With Horizontal Scalability

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Outline

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The dangers of centralisation

- Technological advancements give us convenience
- But it puts central authorities in control
- Most are motivated exclusively by profit
- Not always in the interest of the “users”[1]

[1] Typically users of some free service X are, in fact, used by X.

The dangers of centralisation: Examples

- Facebook can predict your opinions and desires from your "likes" [1], and then create a "psychographic" profile for use in political campaigns [2]
- Baidu's promoted search result on medical care caused death of a student [3]

Blockchain: a new hope?

- Blockchains are distributed (replicated) ledgers with no central control[2]
- They enable internet-scale consensus for the first time
- Some initial applications include:
  - Digital cash (e.g., Bitcoin, Litecoin)
  - Domain name system (e.g., Namecoin)
  - Storage rental (e.g., Filecoin)
  - General purpose (e.g., Ethereum)

[2] In practice, some central control exist.

Blockchain: not there yet

- All blockchain systems have a consensus algorithm
- Early consensus algorithms (PoW) do not scale
- Bitcoin is limited to 7 transactions per second
- 100,000 transaction backlog in May 2017
- We require horizontal scalability for ubiquitous use
- More users → more transactions per second globally

Related work

Table: Summary of the scalability properties of many blockchain systems.

Not scalable	**Somewhat scalable**	**Limited horizontal scalability**	**True horizontal scalability**
Bitcoin Litecoin	Hyperledger ByzCoin	Elastico OmniLedger	CHECO (this work)

scalability

Research question

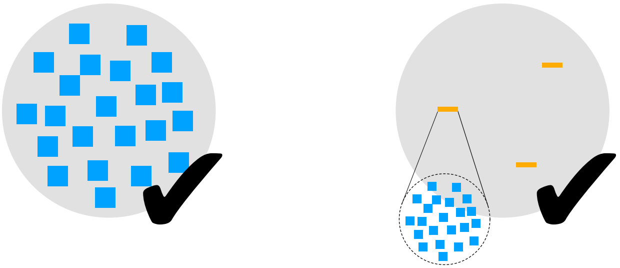
How can we design a *blockchain consensus protocol* that is *fault-tolerant*, *horizontally scalable*, and able to reach *global consensus?*

- Blockchain consensus protocol—application neutral, e.g., PoW
- Fault-tolerant—tolerate a number of malicious nodes
- Horizontal scalability—more nodes in the network leads to higher transaction throughput
- Global consensus—all node should agree on a global state

Outline

Intuition and idea explored in this thesis

- It is expensive to verify and reach consensus on all transactions
- Our idea: we decouple consensus and validation
- A single digest represents an arbitrarily large number of transactions
- Reach consensus on the small digest
- Nodes then independently check the validity of the transactions of interest

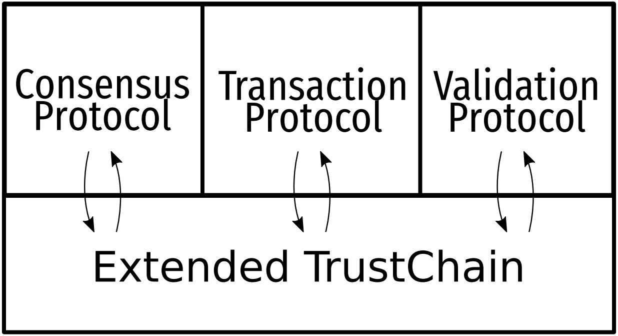


Early blockchains

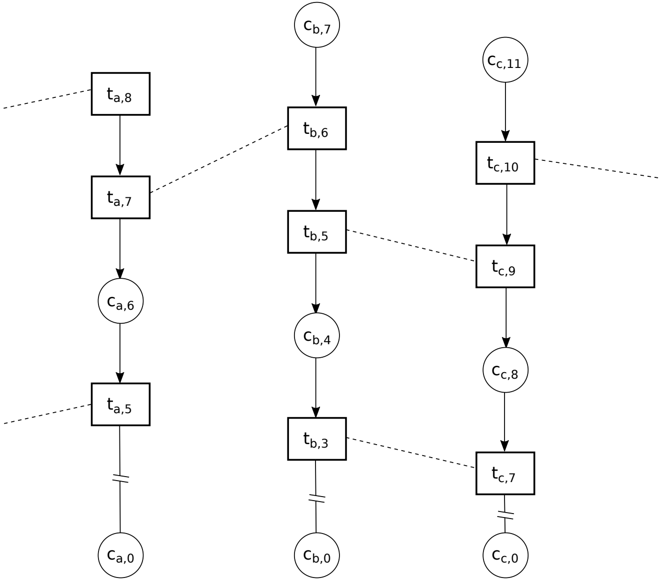
Our idea

Architecture overview

The four components of CHECO

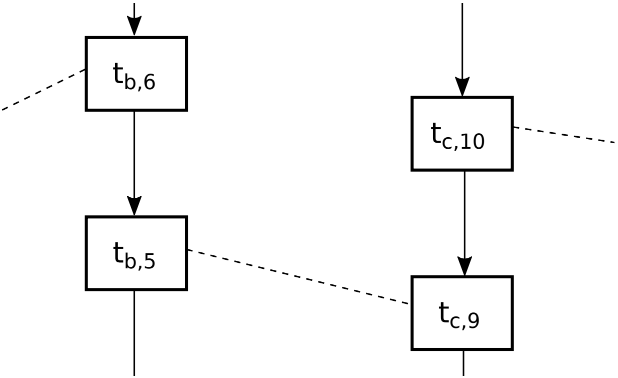


Extended TrustChain



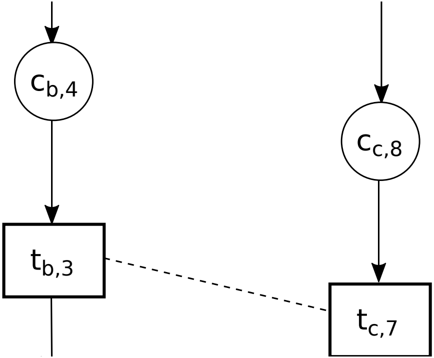
Extended TrustChain: Transaction (TX) block

- Goal: record transactions
- A transaction is represented by a pair of TX blocks, i.e. a contract signed by both parties

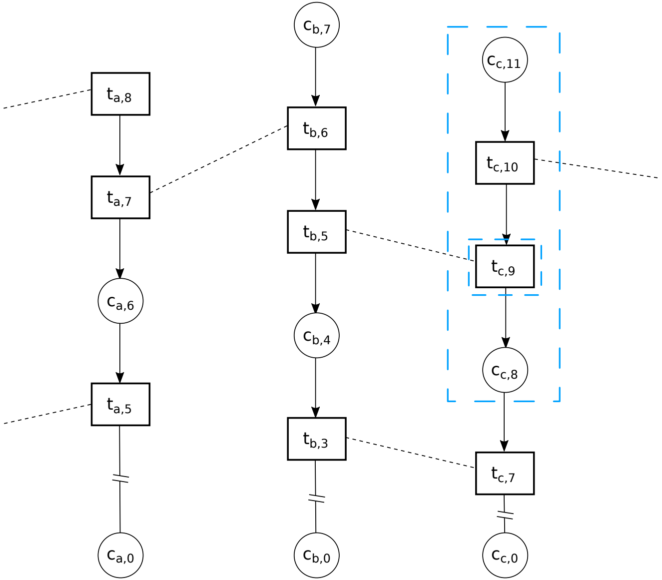


Extended TrustChain: Checkpoint (CP) block

- Goal: represent the state of the chain using a single digest
- A collection of CP blocks from all the nodes represent the state of the system
- Nodes become aware of the system state by running our consensus protocol



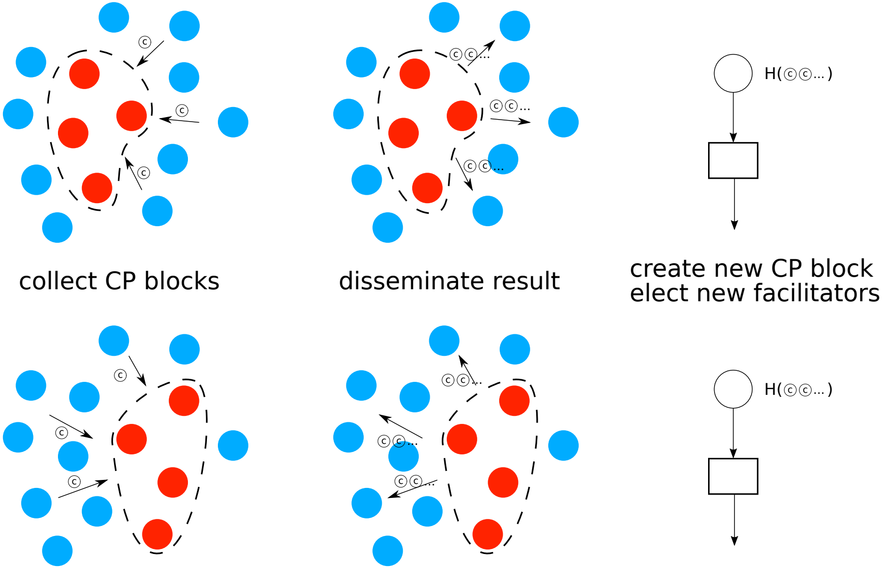
Extended TrustChain: Fragment of a TX block



Consensus protocol

- Goal 1: reach consensus on a collection of CP blocks amongst all the nodes
- Goal 2: create new CP blocks at the end of the protocol
- Uses an existing fault-tolerant consensus algorithm (HoneyBadgerBFT [4]) as the building block
- But it cannot be used in a large network due to high communication complexity
- We overcome this limitation by selecting a small number of *facilitators* from the network to run HoneyBadgerBFT

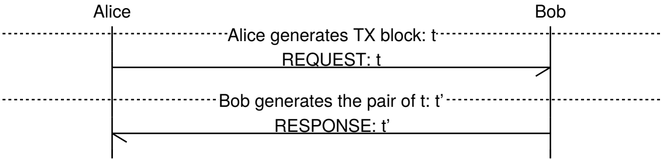
Consensus protocol



Consensus protocol: properties

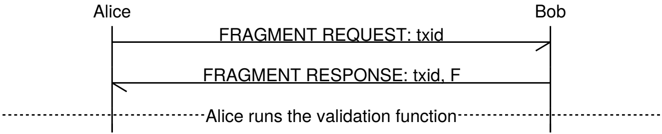
- *Agreement*: Every correct outputs the same set of facilitators.
- *Validity*: The consensus result is valid such that a new set of facilitators can be computed from it.
- *Fairness*: Every node with a CP block in the consensus result should have an equal probability of becoming a facilitator.
- *Termination*: Every correct node eventually outputs a set of facilitators.

Transaction protocol



- Two TX blocks are generated on the chains of Alice and Bob
- No guarantee that nodes follow this protocol

Validation protocol



- To check that the transaction protocol is correctly followed
- Alice needs the fragment of the TX on Bob's hash chain
- Validation function checks whether the fragment is OK and contain the transaction
- Can be generalised—any node may run the validation protocol on any transaction (does not need to be their own)

Validation protocol: properties

Consensus on CP blocks → consensus on transactions

- CP blocks of the fragments are "anchored" due to the consensus protocol
- It is difficult to modify the fragment once "anchored"
- Since the transaction protocol and the validation protocol only use point-to-point communication, we achieve horizontal scalability.

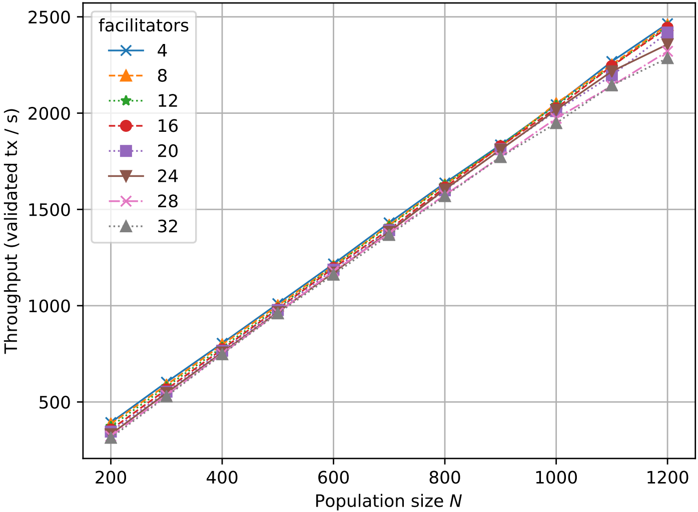
Outline

Implementation and experiment setup

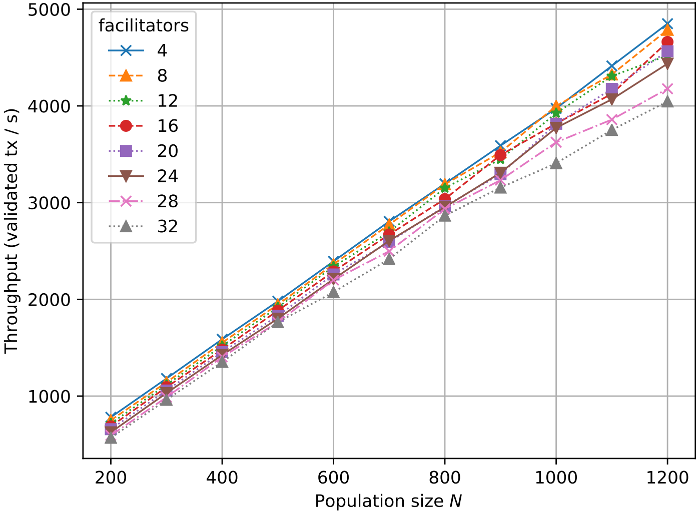
- Free and open source implementation on Github: `https://github.com/kc1212/checo`
- SHA256 for hash functions and Ed25519 for digital signature
- Experiment on the DAS-5[3]
- Up to 1500 nodes

[3] `http://www.cs.vu.nl/das5/`

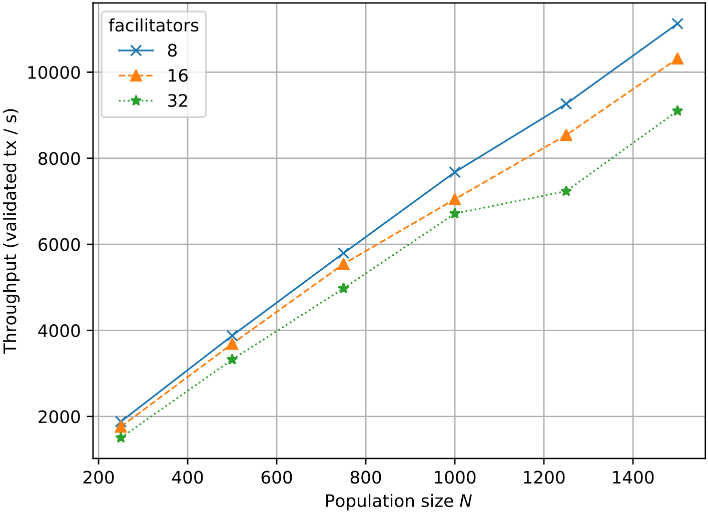
Validated transaction throughput (random node)



Validated transaction throughput (fixed neighbour)



Stress test (fixed neighbour)



Outline

Conclusion

Our work answers the research question.

How can we design a *blockchain consensus protocol* that is *fault-tolerant*, *horizontally-scalable*, and able to reach *global consensus?*

- Fault-tolerance is achieved using HoneyBadgerBFT
- Horizontal-scalability is achieved by separating consensus and validation, demonstrated experimentally
- Global-consensus on transactions is achieved via consensus on CP blocks

Bibliography

[1] W. Youyou, M. Kosinski, and D. Stillwell, "Computer-based personality judgments are more accurate than those made by humans", *Proceedings of the National Academy of Sciences*, vol. 112, no. 4, pp. 1036–1040, 2015.

[2] [Online]. Available: `https://www.theguardian.com/technology/2017/jul/31/facebook-dark-ads-can-swing-opinions-politics-research-shows`.

[3] [Online]. Available: `https://en.wikipedia.org/wiki/Death_of_Wei_Zexi`.

[4] A. Miller, Y. Xia, K. Croman, E. Shi, and D. Song, "The honey badger of bft protocols", in *Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security*, ACM, 2016, pp. 31–42.

Thank you

Any questions?

TX block

1. Hash pointer to the previous block
2. Sequence number
3. Transaction ID
4. Public key of the counterparty
5. Transaction message m
6. Signature the five items above

A transaction is represented by a *pair* of TX blocks

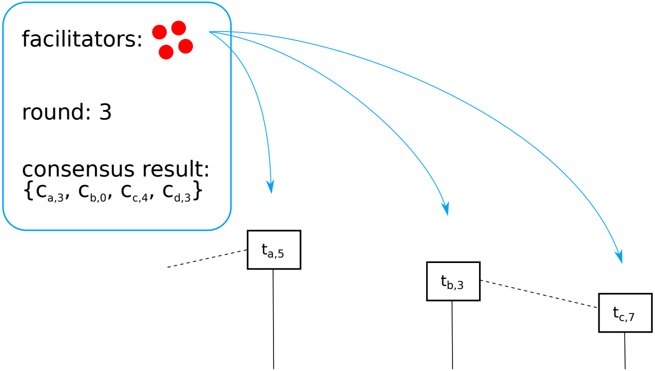
CP block

1. Hash pointer to the previous block
2. Sequence number
3. Digest of consensus result, i.e. a set of CP blocks
4. Round number r
5. Signature on the four items above

Background on ACS

- Asynchronous common subset
- A simplification of HoneyBadgerBFT [4]
- n nodes
- t nodes may be malicious
- Input: every node proposes a set of values, e.g., $\{A, B\}, \{B, C\}, \ldots$
- Output: set union of the majority, e.g., $\{A, B, C, \ldots\}$

Consensus protocol: part 1

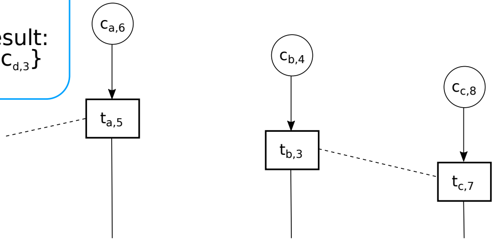


Consensus protocol: part 2

facilitators:

round: 3

consensus result:
$\{c_{a,3}, c_{b,0}, c_{c,4}, c_{d,3}\}$

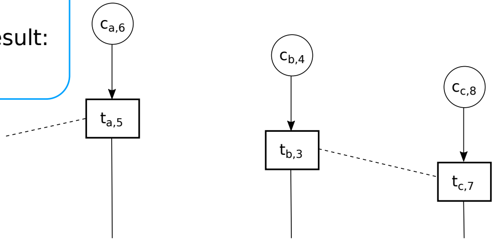


Consensus protocol: part 3

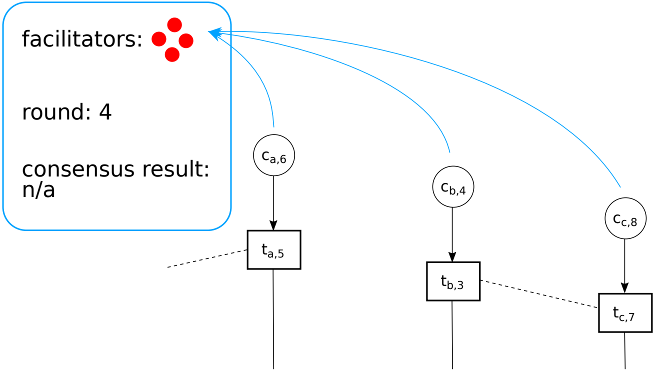
facilitators: lottery
$\{c_{a,3}, c_{b,0}, c_{c,4}, c_{d,3}\}$

round: 4

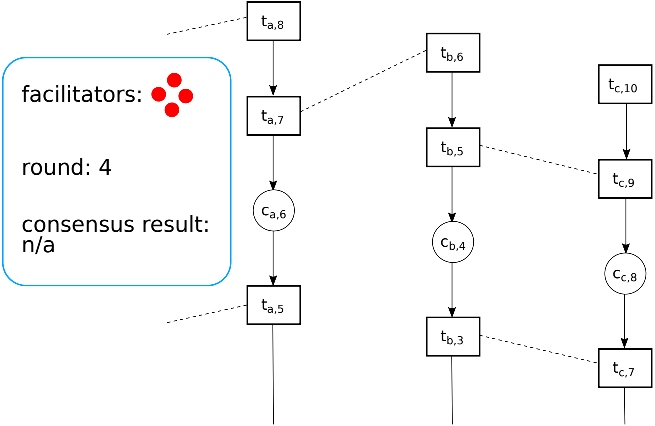
consensus result:
n/a



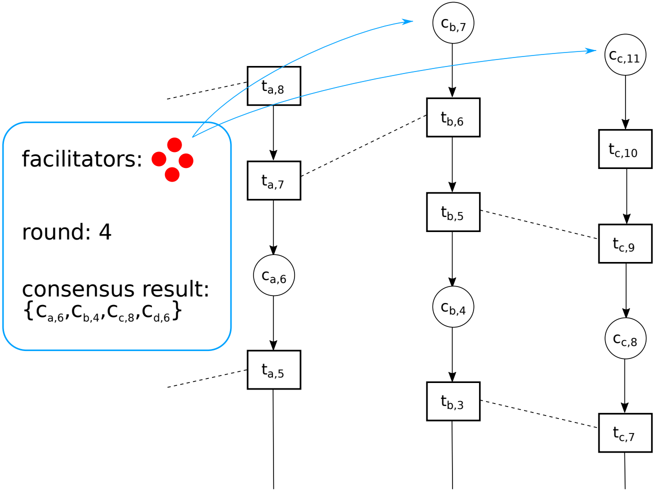
Consensus protocol: part 4



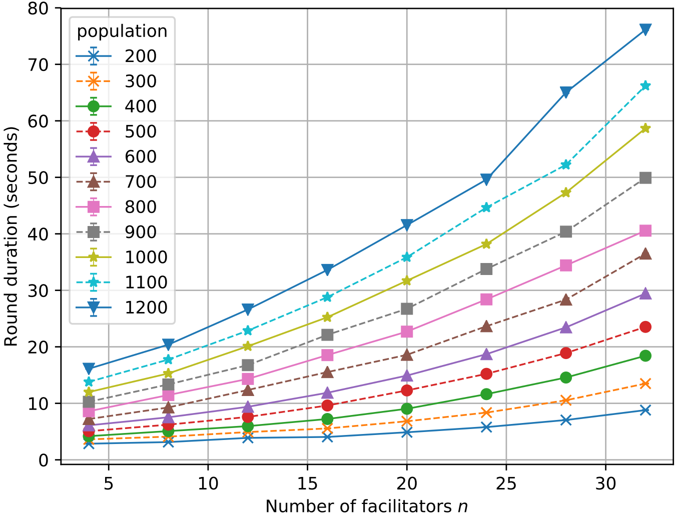
Consensus protocol: part 5



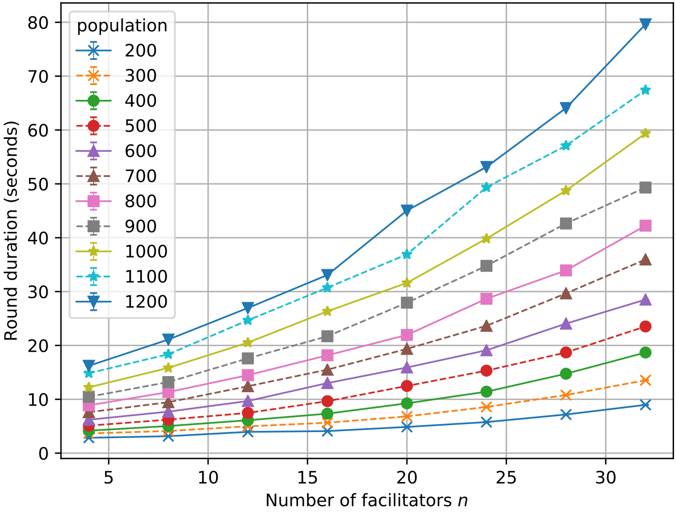
Consensus protocol: part 6



Effect of the number of facilitators (fixed neighbours)



Effect of the number of facilitators (random neighbours)



Future work

- Implement and experiment with a concrete application
- Analyse the system in the permissionless environment
- Improve fault tolerance