A DISTRIBUTED OPERATING SYSTEM FOR PERMISSIONED BLOCKCHAINS

HYPERLEDGER FABRIC

BYZANTINE GENERALS' PROBLEM

- An agreement problem
- A group of generals wants to attack a city
- They must to know when to attack or when to retreat
- They cannot see or hear each other
- What do they need? –> A PLAN
- We should build a network (nodes, communication channels, protocols)

BYZANTINE GENERALS' PROBLEM

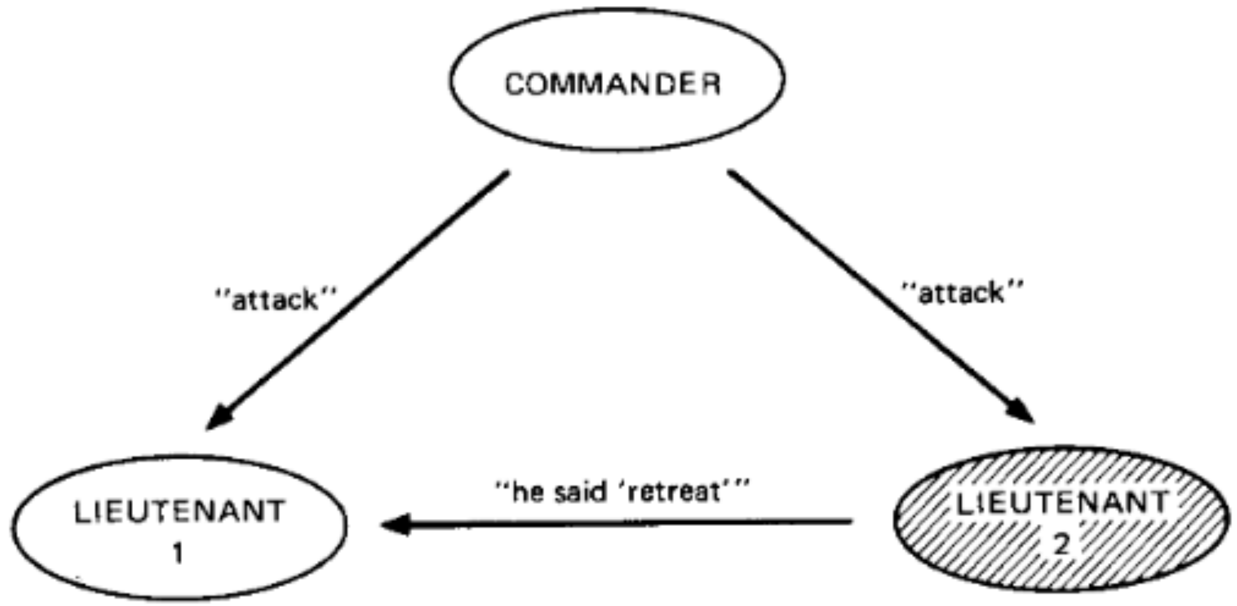


Fig. 1. Lieutenant 2 a traitor.

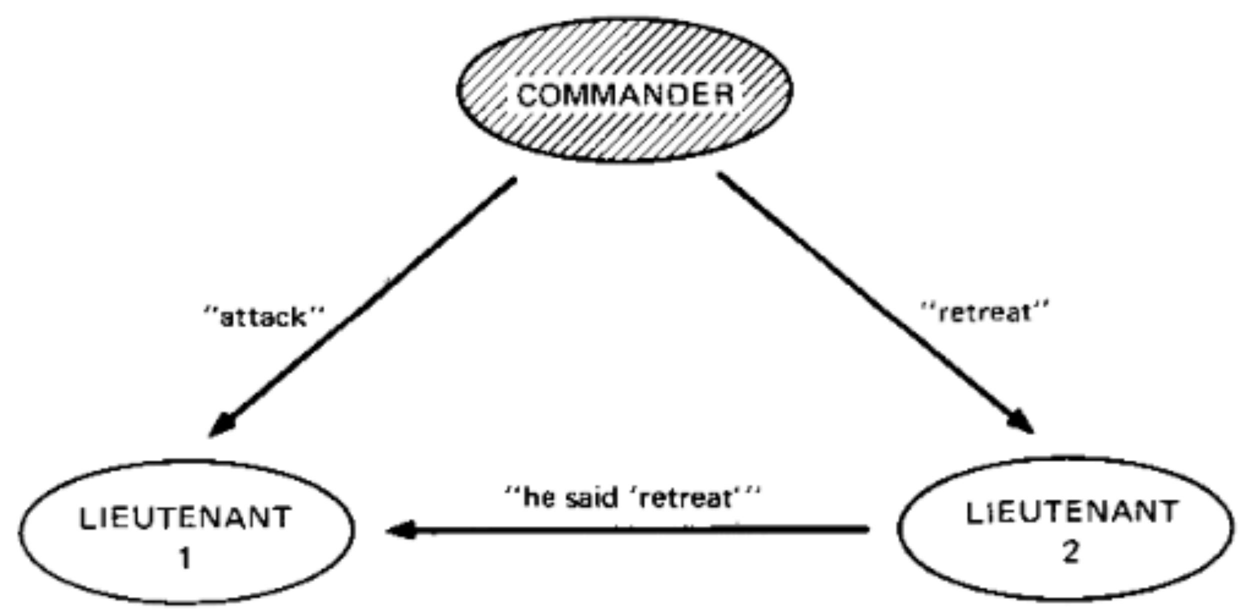


Fig. 2. The commander a traitor.

… take me to your commander

BYZANTINE GENERALS' PROBLEM IN PRACTICE

- Aircraft systems (Boeing 777 and 787 flight control systems)
- Spacecrafts (SpaceX Dragon flight system)
- Bitcoin

BLOCKCHAINS

- Simply, a blockchain is a huge ledger for recording transactions
- It is maintained within a distributed network of mutually untrusting peers (the generals)
- Every peer maintains a copy of the ledger
- They validate and order the transactions through a consensus protocol
- Blockchains have emerged with Bitcoin

BLOCKCHAINS

- In a public (*permissionless*) blockchain anyone can participate without a specific identity
- *Permissioned* blockchains run a blockchain (of course) among a set of *known*, *identified* participants. This is a way to secure the interactions among a group of entities that have a common goal but which do not fully trust each other
- Blockchains may execute arbitrary, programmable transaction logic in the form of smart contracts (as exemplified by Ethereum)

SMART CONTRACTS

- A smart contract functions as a trusted distributed application and gains its security from the blockchain and the underlying consensus among the peers
- Many existing smart contracts blockchains follow the blueprint of State-Machine Replication and implement so-called active replication: first, the transactions are ordered and propagated to all peers and second, each peer executes the transactions sequentially

SMART CONTRACTS

- Prior permissioned blockchains suffer from many limitations:
  - Smart contract must be written in a *fixed, non-standard, or domain-specific language*
  - The sequential execution of transaction by all peers *limits performance*
  - Transaction must be *deterministic*, which can be difficult to be ensured programmatically
  - Every smart contract runs on *all peers*, which is at odds with *confidentiality*

OK, LET'S SEE FABRIC

- Fabric introduces a new blockchain architecture aiming at *flexibility, scalability and confidentiality*
- Fabric support the execution of distributed applications written in *standard programming languages*
- Fabric is the first *distributed operating system* for permissioned blockchains

FABRIC

- The architecture of Fabric follows the *execute-order-validate* paradigm

FABRIC

- This design departs radically from the *order-execute* paradigm
- It combines the two approaches to replication, *passive* and *active*:
  - Every transaction is executed (endorsed) only by a subset of peers, which allows for parallel execution (passive)
  - The transaction's effects on the ledger state are only written after reaching consensus of a total order among them (active)

FABRIC

- This *hybrid replication design*, which mixes passive and active replication in the Byzantine model, and the *execute-order-validate* paradigm, represent the most innovation in Fabric architecture

ORDER-EXECUTE ARCHITECTURE

- All previous blockchain systems follows *order-execute architecture*
- Let's take Ethereum for example:
    1. every peer assembles a block containing valid transactions
    2. the peer tries to solve the puzzle
    3. if the peer is *lucky* and solves the puzzle it disseminates the block to the network
    4. every peer receiving the block validates the solution *and* all transaction in the block
- Simply said, every peer repeats the execution of the lucky peer from its first step
- If this is not enough, all transactions must be executed sequentially

LIMITATIONS OF ORDER-EXECUTE ARCHITECTURE

- Sequentially execution
    - It limits the effective throughput that can be achieved
    - Since the throughput is inversely proportional to the execution latency, this may become a performance bottleneck
    - A *Denial-of-Service* attack could simply introduce smart contracts that take very long time to execute

LIMITATIONS OF ORDER-EXECUTE ARCHITECTURE

- Non-deterministic code
    - This is usually addressed by programming blockchains in domain-specific languages (e.g. Ethereum Solidity) that are expressive enough for their applications but limited for deterministic execution
    - Only one non-deterministic contract created with malicious intent is enough to bring the entire blockchain to a halt

LIMITATIONS OF ORDER-EXECUTE ARCHITECTURE

- Confidentiality of execution
  - Many permissioned systems run all smart contract on all peers
  - However, many intended use cases for permissioned blockchains require confidentiality

EVALUATION

- Fabric is a complex distributed system
- Its performance depends on many parameters
    - The choice of distributed application
    - Transaction size
    - The ordering service
    - Consensus implementation
    - Topology of nodes in the network
    - Number of nodes
    - The hardware on which nodes runs

FABRIC COIN

- In the absence of a standard benchmark for blockchains, it is used a simple authority-minted cryptocurrency that uses the data model of Bitcoin – Fabcoin

FABCOIN

- The data model introduced by Bitcoin has become known as "unspent transaction output" or UTXO
- UTXO represents each step in the evolution of data object as a separate atomic state on the ledger
- Such a state is created by a transaction and destroyed (or "consumed") by another unique transaction occurring later
- Every given transaction destroys a number of input states and creates one or more output states

FABCOIN

- A "coin" in Bitcoin is initially created by a coinbase transaction that rewards the "miner" of the block
- This appears of the ledger as a coin state designating the miner as the owner
- Any coin can be spent in the sense that the coin is assigned to a new owner by a transaction that atomically destroys the current coin state
- Every state may be seen as a KVS entry with logical version 0 after creation
- When it is destroyed again, it receives version 1
- There should not be any concurrent updates to such entries

FABCOIN IMPLEMENTATION

- Each state in Fabcoin is a tuple of the form (key, val) = (txid.j, (amount, owner, label)), denoting the coin state created as the j-th output of a transaction with identifier txid
- Labels are strings used to identify a given type of a coin ('USD', 'EUR', 'FBC')
- The Fabcoin implementation consists of three parts
    - A client wallet
    - The Fabcoin chaincode
    - A custom VSCC (validation system chaincode) for Fabcoin implementing its endorsement policy

CLIENT WALLET

- By default, each Fabric client maintains a Fabcoin wallet that locally stores a set of cryptographic keys allowing the client to spend coins
- The client wallet signs, with the private keys that correspond to the input coin states
- The client wallet includes the Fabcoin request into a transaction and sends this to a peer of its choice

FABCOIN CHAINCODE

- A peer runs the chaincode of Fabcoin which simulates the transaction and creates readsets and writesets.
- In the case of a transaction, for every input coin state the chaincode first performs *GetState(in)*
- This includes *in* in the readset along with its current version
- Then the chaincode executes *DelState(in)* for every input state *in*, which also adds *in* to the writeset and effectively marks the coin state as "spent"

CUSTOM VSCC

- Every peer validates Fabcoin transaction using a custom VSCC (validation system chaincode)
- This verifies the cryptographic signature(s) in sigs under the respective public key(s) and performs semantic validation
- Note that the Fabcoin VSCC does not check transactions for double spending, as this occurs through Fabric's standard validation that runs after the custom VSCC
- In particular, if two transactions attempt to assign the same unspent coin state to a new owner, both would pass the VSCC logic but would be caught subsequently in the read-write conflict checked performed by the PTM

EXPERIMENT 1

- Choosing the blocking size
- A critical Fabric configuration parameter that impacts both throughput and latency is block size
- We can observe that throughput does not significantly improve beyond a block size of 2MB, but latency gets worse (as expected)

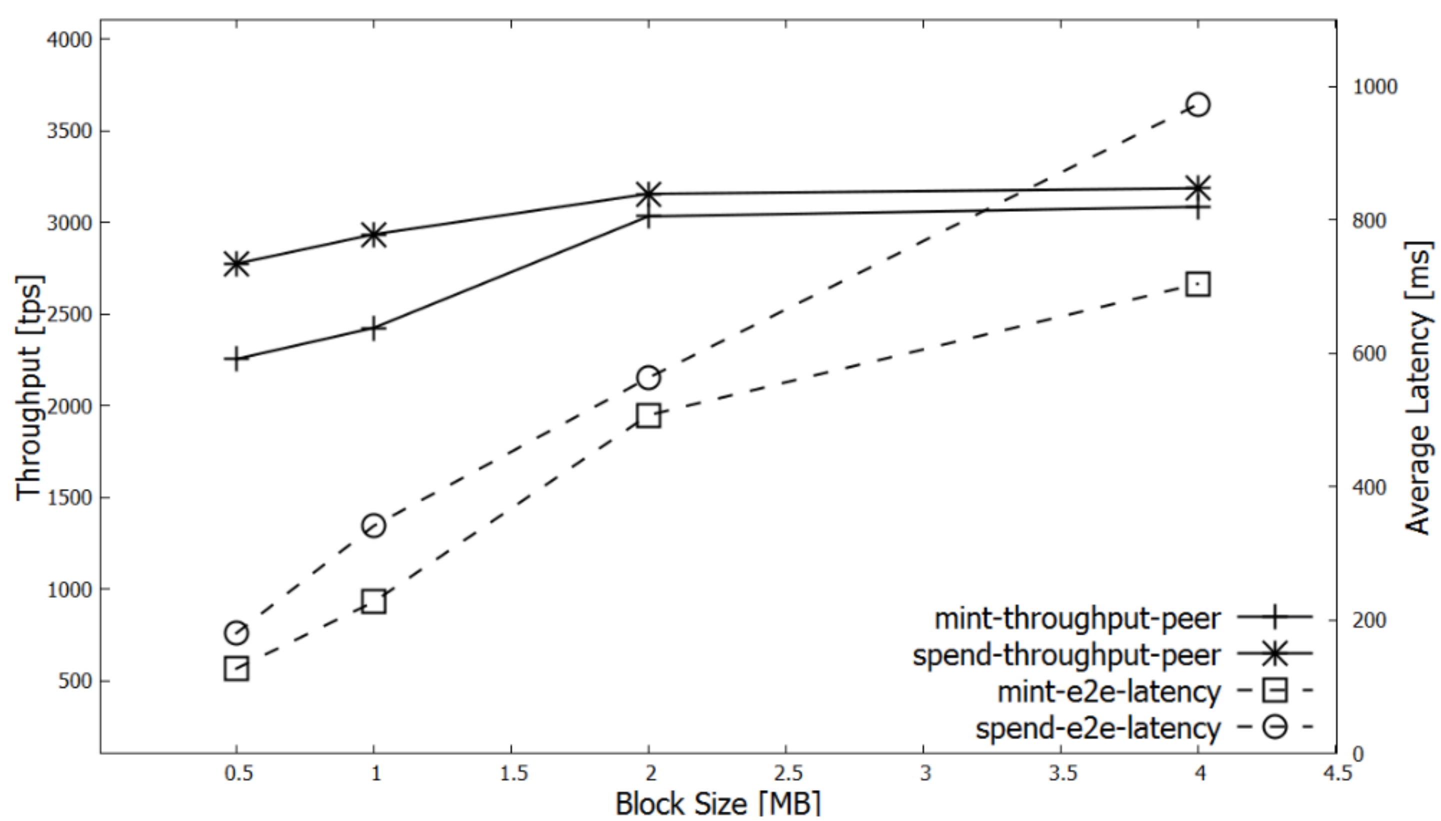


Figure 6: Impact of block size on throughput and latency.

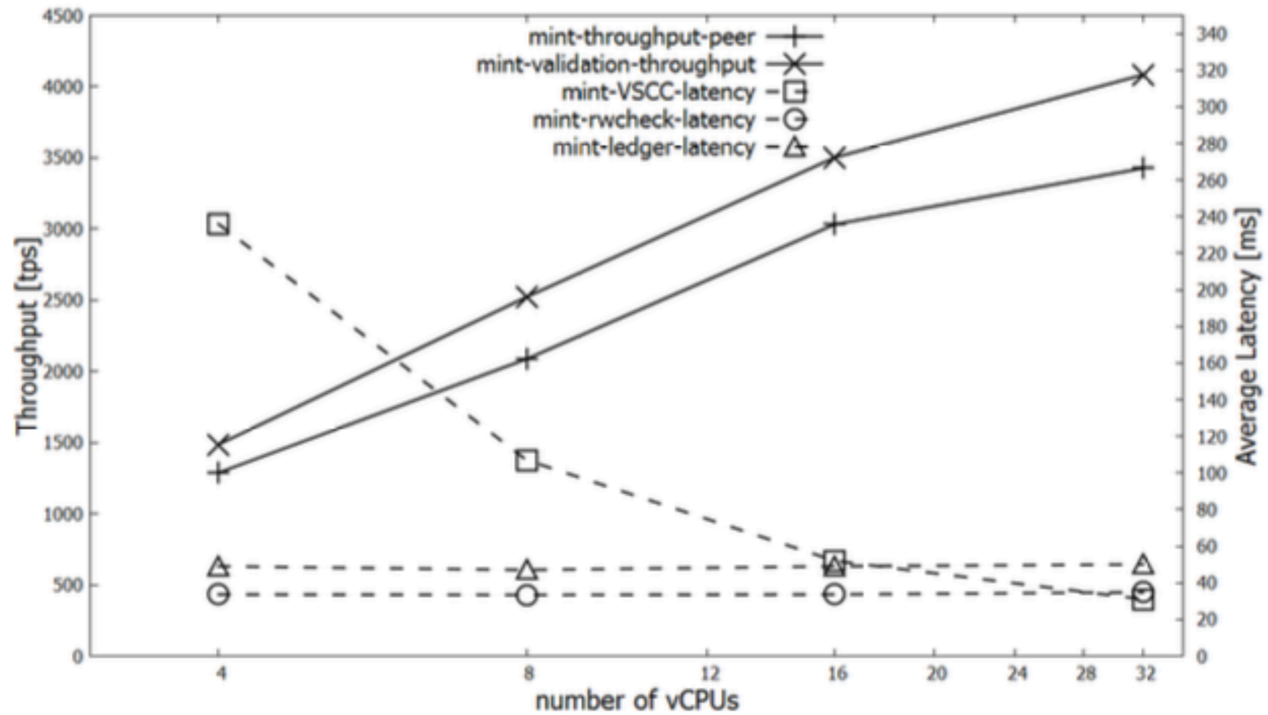
EXPERIMENT 2

- Impact of peer CPU
- Fabric peers run many CPU – intensive cryptographic operations
- This experiment focused on the validation phase, as ordering with the Kafka ordering service has never been a bottleneck in our cluster experiments
- The validation phase, and the particular the VSCC validation of Fabcoin, is computationally intensive, due to its many digital signature verification
- We calculate the validation throughput at the peer based on measuring validation phase latency locally at the peer

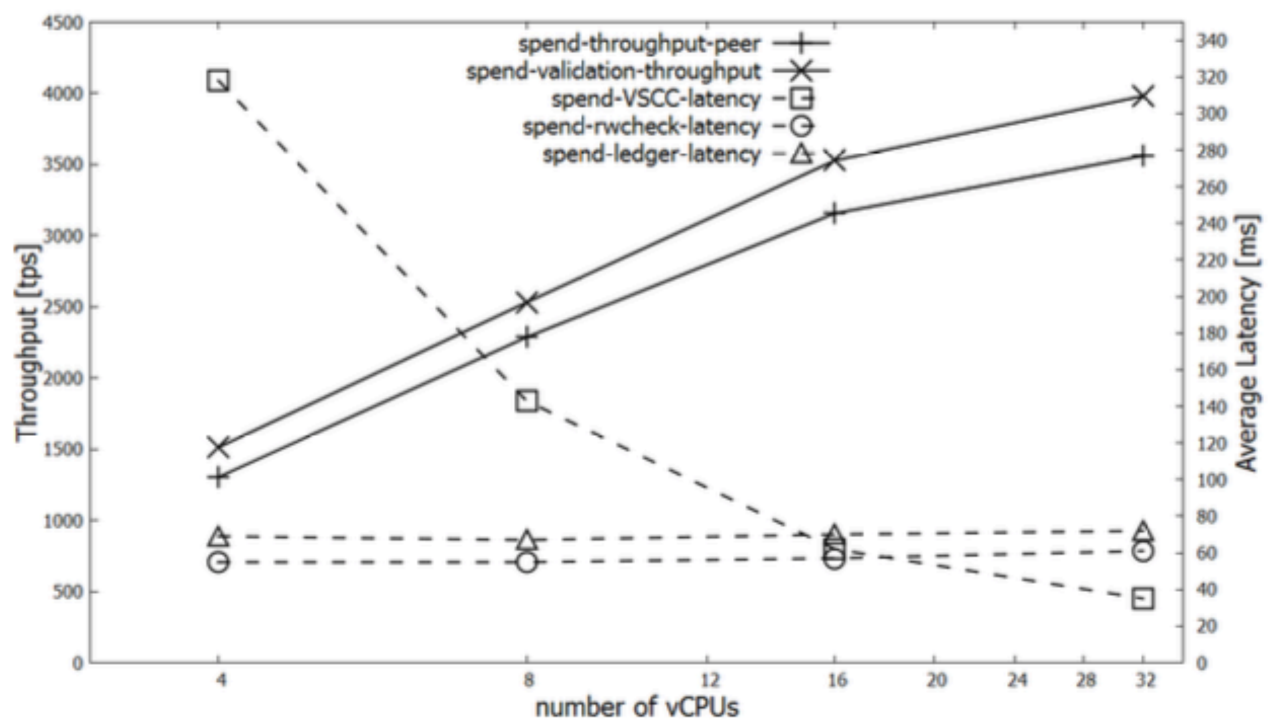
EXPERIMENT 2

- This experiment suggests that future versions of Fabric could profit from pipelining the validation stages
- The *MINT* throughput is, in general, slightly lower than that of *SPEND*, but the difference is within 10%

EXPERIMENT 2



(a) Blocks containing only MINT transactions.



(b) Blocks containing only SPEND transactions.

APPLICATIONS AND USE CASES

- Major cloud operators already offer (or have announced) "blockchain-as-a-service" running Fabric, including Oracle, IBM, and Microsoft
- Examples include a food-safety network, cloud-service block-chain platforms for banking, and a digital global shipping trade solution
- Foreign exchange (FX) netting. A system for bilateral payment netting of foreign exchange runs on Fabric. It uses a Fabric channel for each pair of involved client institutions for privacy
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CONCLUSION

- Fabric is a modular and extensible distributed operating system for running permissioned blockchains
- It introduces a novel architecture that separates transaction execution from consensus and enables policy-based endorsement and that is reminiscent of middleware-replicated databases
- Through its modularity, Fabric is well-suited for many further improvements and investigations
- Future work will address
    - Performance by exploring benchmarks and optimizations
    - Scalability to large deployments
    - Privacy and confidentiality for transactions and ledger data through cryptographic techniques

QUESTIONS