Bitcoin Core – Conceptual Architecture

Cain Susko & Yash Patel

What is Bitcoin?

- Bitcoin is a unit of currency used to retain, send, & receive value among participants in the Bitcoin network.
- Participants in the Bitcoin network communicate with each other through the Internet – using a protocol which can be run on a wide range of computing devices (including laptops and smart-phones).
- The Bitcoin protocol uses a peer-to-peer architecture which means that participants in the network communicate directly with each other – rather than through a centralized server.

What is Bitcoin Core?

- Bitcoin Core is a reference implementation of the Bitcoin system and the authoritative reference for technology implementation.
- Goals: open-source, peer-to-peer, private electronic payment system.
- Main architecture style: peer-to-peer with layers dividing the user interface, local system, and peer network.
- Submodules and components: nodes, wallet, keys, transactions and `blockchain`.

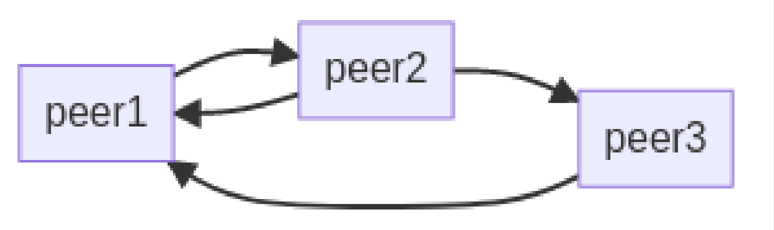
About Bitcoin Core

- About the Bitcoin Core system
- Nodes
- `BlockChain` and Blocks
- Wallets, Keys, and Transactions

About the Bitcoin Core System

- Purely peer-to-peer electronic payment system
- Network formed by nodes (computers running Bitcoin software)
- Three main node types: full, miner, and light nodes
- Full nodes store full copy of `blockchain` and verify transactions
- Nodes broadcast valid transactions to others, leading to agreement and addition to pool of valid transactions.

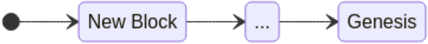
Peer to Peer



Blockchain

- `Blockchain` is a back-linked list of blocks and transactions, can be thought of as a stack
- Blocks placed at the top, referencing previous block (parent block) through header
- Genesis block is the first block ever created

Blockchain



Blocks

- Container data structure scheduling transactions for inclusion in public ledger (`blockchain`)
- Two components: header and body
- Header contains metadata (previous block hash, difficulty, timestamp, nonce, merkle tree root)
- Body contains all transaction data (on average, more than 1900 transactions)

Miner Nodes

- Miner nodes pick transactions from pool of valid transactions, package into blocks, and broadcast to nodes
- Full nodes verify blocks and add to `blockchain`, reaching consensus and adding to public ledger
- Miners rewarded for adding blocks to `blockchain`

Light Nodes

- Maintain only subset of `blockchain` and verify transactions using simplified payment verification method
- Designed for power and space constrained devices (e.g. smartphones)
- Verify chain of blocks and link to transaction of interest

Wallets, Keys, and Transactions

- Wallet is the primary user interface, controls access to user's money
- Manages keys and addresses, tracks balance, creates and signs transactions
- Does not contain bitcoin, but rather keys to "coins" on the network

Types of Wallets

- Nondeterministic: keys independently generated, each key must be backed up
- Deterministic (seeded): keys derived from common master key (seed), seed is the only thing that needs to be backed up for efficient system.

Node Architectural Style

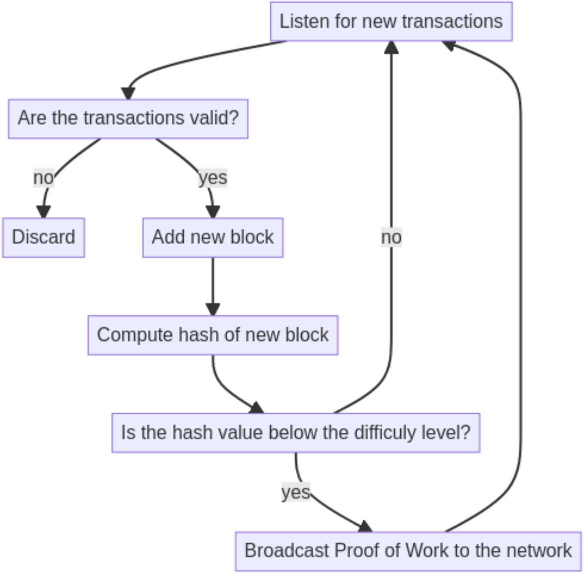
- Peer-to-peer architecture in operational view
- Layered style in functional viewpoint
- Top layer: user interface (cell phone apps or websites)
- Second layer: local version of Bitcoin software (full, miner, or light node)
- Third layer: connection layer (peer-to-peer network for formatting, sending, and receiving messages)

Layered Architecture

Control and Data flow

- The secure transaction process begins with a timestamp server taking a hash of a block of items and publishing the hash
- New transactions are broadcast to all nodes in the network, and each node collects the transactions into a block and finds a proof-of-work
- The nodes accept a block if its transactions are valid and not spent, and they work on extending the longest `blockchain` as the correct one
- In the event of two nodes broadcasting two different blocks, the nodes will work on the one received first, and save the other in case it becomes longer
- Block broadcasts are tolerant of dropped messages, and nodes can leave and rejoin the network, accepting the longest proof-of-work chain as the correct one.

Data Flow – Miner

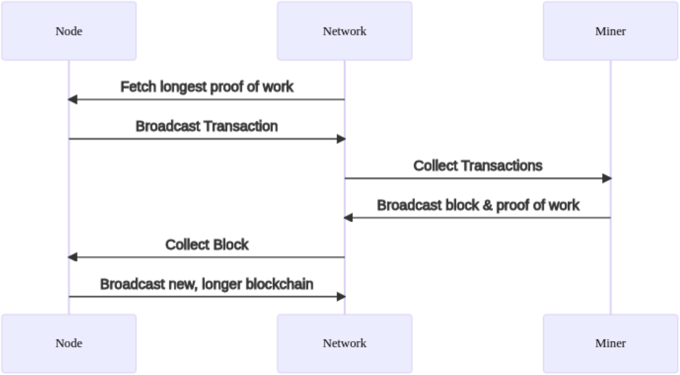


Concurrency

Bitcoin Core Nodes rely on decentralized consensus to ensure there are no discrepancies between nodes – and to decide which is the correct `blockchain`.

- Independent verification of each transaction by every full node based on a comprehensive list of criteria.
- Independent aggregation of those transactions into new blocks by mining nodes, coupled with demonstrated computation through a Proof-of-Work algorithm
- Independent verification of the new blocks by every node and assembly into a chain
- Independent selection, by every node, of the chain with the most cumulative computation demonstrated through Proof-of-Work

Consensus


Node
Network
Miner
Fetch longest proof of work
Broadcast Transaction
Collect Transactions
Broadcast block & proof of work
Collect Block
Broadcast new, longer blockchain
Node
Network
Miner

Responsibility Division between Developers

- Bitcoin Core developed by Satoshi Nakamoto in 2009 with goal of creating a new territory of freedom.
- After Satoshi's departure, open-source project sustained by a large community of programmers.
- Responsibility division between developers is loose & flexible, allowing for quick feature additions but lacking financial or social incentive for larger improvements.
- Consistent group of committers and designated maintainer ensure project stability.

System Evolution

- Bitcoin Core has been in development for over 10 years
- Supports `blockchain`, transactions, contracts, wallets, payment processing, mining, and P2P network
- Analysis covers version 12 (2016) to version 24 (most recent at time of writing)
- 2 version updates per year
- Analysis covers fee handling, wallet implementation, GUI changes, security updates, and future steps.

Fee Handling

- Fees are the amount paid to miner for including transaction in a block
- In v12, low fee transactions may not be included in blocks, leading to v12 introducing replace-by-fee
- V13 improved replace-by-fee with child pays for parent policy
- V14 allows users to prioritize transactions with higher fees
- V15 implements toggle for replace-by-fee
- V16 made replace-by-fee the norm, although users can opt out
- V23 improved fee estimation by taking replace-by-fee transactions into account.

Wallet Implementation

- **V12** introduced `blockchain` pruning for wallet users to reduce unnecessary space usage
- **V14** allows users to specify where they want to prune their `blockchain`
- **V15** allows users to create multiple wallets with separate addresses, private keys, and funds
- **V16** implemented Segregated Witness (SegWit) in wallet, increased transaction capacity and allowed for lower fees
- **V16** also introduced bech32 address format
- **V17** improved coin selection for wallets with branch and bound algorithm

Further Walet Improvements

- **V20** introduced Descriptor and Watch-Only wallets
- **V23** made descriptor wallets the default for improved backup and recovery
- **V23** can spot typos in bech32 addresses.

GUI Changes

- **V17** added toggle for pruning in GUI for casual users
- **V18** allowed access to multiple wallets from GUI
- **V19** set bech32 addresses as default option, disabled low-usage payment protocol support
- **V20** added hardware wallet compatibility in GUI
- **V21** provides full support for hardware wallets.

Security Updates

- **V12** introduced Tor support for anonymous network connection and faster signature validation.
- **V22** added I2P and CJDNS support for privacy protection and increased multi-sig signatures from 16 to 20.
- **V18** added hardware wallet compatibility through the Hardware Wallet Interaction tool.
- **V19** discontinued Bloom filters and introduced compact client-side block filtering.
- **V21** reduced transaction re-broadcasting to improve privacy and gave nodes 2 extra outgoing connections to increase connection to honest nodes.

Future Steps

- V24 introduces Miniscript support for Bitcoin Script programming language.
- Ongoing evolution of the system: replacing old protocols, improving infrastructural calculations, etc.
- Scalability and security are significant future steps.
- Need to accommodate larger user base and hardware limitations.
- Efficient pruning methods may be required for data storage in the future.
- Security is a concern as hacker capabilities evolve.
- Quantum computing could revolutionize cybersecurity and affect Bitcoin Core.
- Old security systems replaced and privacy aids added for security of thousands of user funds.

Final Thoughts

- Through analysing the bitcoin core system we have found that it is a peer to peer network, relying on cryptography to ensure the validity of transactions.
- The variation in node types allows for a flexible system – which would be integral for any system relying on community participation
- We have discovered that the system is constantly evolving and changing as new needs arise.
- The development of Bitcoin Core has been driven by a desire for greater freedom and has been aided by a large community of programmers around the world.
- It is evident that Bitcoin Core is a sophisticated and and complex system. While this report does not go into the implementation of the described architecture – understanding this is integral to getting a firmer grasp of the overall operation of the system.