Ch8. The Bitcoin Network

Mastering Bitcoin of O'Reilly

P2P Network Architecture

- Bitcoin is constructed on a P2P network architecture on top of the Internet.
- P2P networks are inherently resilient, decentralized, and open.
- Today's Internet architecture is more hierarchical, but the IP still retains its flat-topology essence.

Bitcoin Network

- The term *bitcoin network* refers to the collections of nodes running the bitcoin P2P protocol.
- There are some other protocols such as Stratum that are used for mining and lightweight or mobile wallets. > Provided by gateway routing servers that access the bitcoin network using the bitcoin P2P protocol and then extend that network to nodes running other protocols.
- The term *extended bitcoin network* refers to the overall network that includes the bitcoin P2P protocol, pool-mining protocols, the Stratum protocol, and any other related protocols connecting the components of the bitcoin system.

Node Types and Roles

- A bitcoin node is a collection of functions: routing, the BC DB, mining, and wallet services.

The Ns: Network Routing

- All nodes include the routing function to participate in the network and might include other functionality.
- All nodes validate and propagate TXs and blocks, and discover and maintain connections to peers.

The Bs: Full BC

- Some nodes, called full nodes, also maintain a complete and up-to-date copy of the BC.
  - Autonomously and authoritatively verify any TX without external reference.
- While some nodes maintain only subset of the blockchain and verify any TX using a method called *simplified payment verification* (SPV).
  - They're called SPV nodes or lightweight nodes.
  - Not drawn with the "B" circle.

The Ms: Miner

- Mining nodes compete to create new blocks (PoW).
- Some of which are also full nodes, while others depend on pool servers to maintain a full node.

The Ws: Wallet

- Increasing, many user wallets, especially those running on resource-constrained devices, are SPV nodes.

Others

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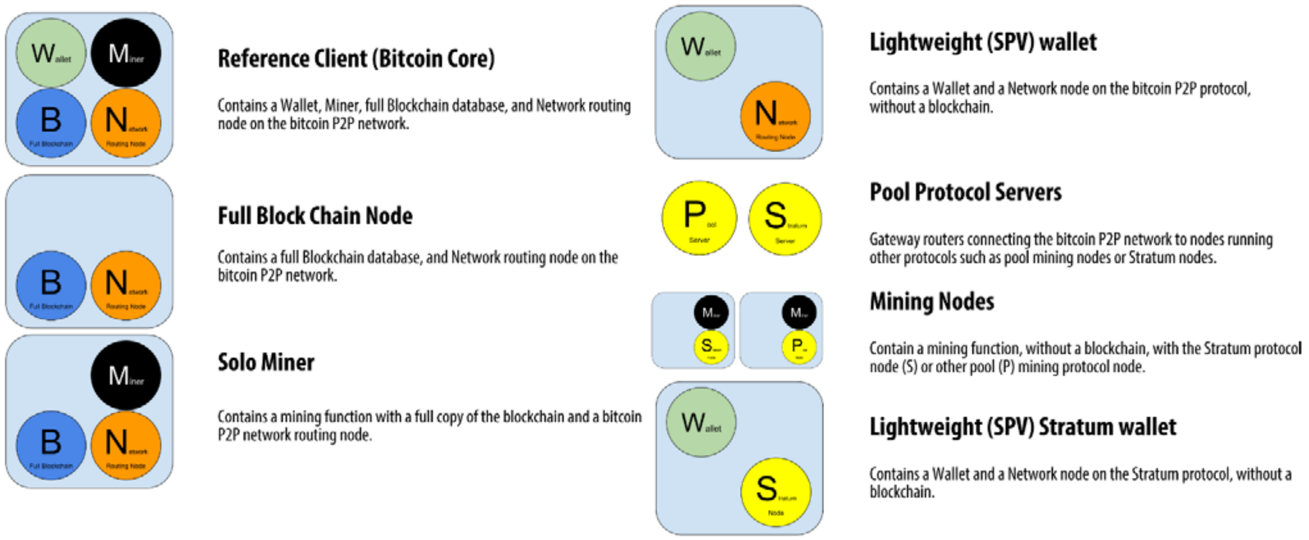
- There are servers and nodes running other protocols, such as specialized mining pool protocols and lightweight client-access protocols.



Reference Client (Bitcoin Core)

Contains a Wallet, Miner, full Blockchain database, and Network routing node on the bitcoin P2P network.

Full Block Chain Node

Contains a full Blockchain database, and Network routing node on the bitcoin P2P network.

Solo Miner

Contains a mining function with a full copy of the blockchain and a bitcoin P2P network routing node.

Lightweight (SPV) wallet

Contains a Wallet and a Network node on the bitcoin P2P protocol, without a blockchain.

Pool Protocol Servers

Gateway routers connecting the bitcoin P2P network to nodes running other protocols such as pool mining nodes or Stratum nodes.

Mining Nodes

Contain a mining function, without a blockchain, with the Stratum protocol node (S) or other pool (P) mining protocol node.

Lightweight (SPV) Stratum wallet

Contains a Wallet and a Network node on the Stratum protocol, without a blockchain.

The Extended Bitcoin Network

- The main bitcoin network consists of 5000+ listening nodes running various versions of the bitcoin reference client (Bitcoin Core).
  - Other few hundreds running various other implementations of the bitcoin P2P protocol.
- A small percentage of the nodes on the bitcoin P2P network are also mining nodes.
- Large companies interface with the bitcoin network by running full-node clients based on the Bitcoin Core client, but without mining or wallet functions.
  - These nodes act as network edge routers, allowing other services to be built on top.
- Attached to the main bitcoin P2P network are a number of pool servers and protocol gateways that connect nodes running other protocols.
  - These nodes are mostly pool mining nodes and lightweight wallet clients.

Bitcoin Relay Networks

- In mining, network latency is directly related to profit margins.
- Relay networks appears.
  - NOT replacements for P2P network.
  - Overlaying networks providing additional connectivity between nodes with specialized needs.
  - Like freeways and rural roads.

- A *Bitcoin Relay Network* is a network that attempts to minimize the latency in the transmission of blocks between miners.
  - The original *Bitcoin Relay Network* consist of several specialized nodes hosted on the Internet infrastructure around the world and served to connect the majority of miners and mining pools.
  - Next original, Fast Internet Bitcoin Relay Engine (*FIBRE*) is a UDP-based relay network hat relays blocks within a network of nodes.
  - *Falcon* by Cornell University, uses "cut-through-routing", propagates parts of blocks upon receiving.

Network Discovery

In this section, everything is under Bitcoin P2P network if not specified.

Protocol

- When a new node boots up, it must discover other nodes on the network in order to participate.
  - Must find at least one existing node on the network and connect to it.
  - Any existing nodes can be selected at random.
  - (Port 8333 is generally known as the one used by bitcoin)
- Upon establishing a connection, the node will start a *handshake* by trasmitting a version message including:
  - `nVersion`: P2P protocol version the client "speaks".
  - `nLocalServices`: a list of local services supported by the node, currently just `NODE_NETWORK`.
  - `nTime`: current time.
  - `addrYou`: IP address of the remote node as seen from this node.
  - `addrMe`: IP address of the local node, as discovered by the local node.
  - `subver`: a sub-version showing the type of software running on this node.
  - `BestHeight`: block height of this node's BC.

Finding New Peer

- The receiving local peer will check if `nVersion` is compatible.
  - If so, it will acknowledge the version message and establish a connection by sending a `verack`.
- Methods
  - DNS query
    - Using *DNS seeds*: DNS servers providing a list of nodes.
    - Some DNSs provide static list, others return a random subset from a list.
    - Bitcoin Core client contains the names of 5 different DNS seeds.
    - Diversity of ownership and implementation of different seeds offers a high level of reliability for the bootstrapping.
  - Given IP address
    - Establish connections through further introductions.
    - After the initial seed node is used to form introductions, client will disconnect form it and use the newly discovered peers.

Address Exchange

- Once connection(s) are established, the new node will send an `addr` message to make itself known and better connected.

- Additionally, it can send `getaddr` to the neighbors, asking them to return a list of other peers.

Path

- A node must connect to a few different peers in order to establish diverse paths into the bitcoin network.
  - Only 1 connection is needed to bootstrap, for introduction.
  - Unnecessary and wasteful of network resources to connect too many nodes.
  - A most-recent-success is remembered for next bootstrap.
- If there's not traffic on a connection, nodes will periodically send a message to maintain the connection.
  - Disconnection timeout: 90 minutes.

Full Nodes

- Full nodes are nodes that maintain a full BC with all TXs.
  - In the early year, all nodes are full nodes.
  - (Maybe should be called "full BC nodes" for accuracy.)
  - Later, *lightweight client*s are introduced as new forms of Bitcoin clients.
- Traits
  - Maintain a complete and up-to-date copy of Bitcoin BC, from the genesis block to the latest known block.
  - Can independently and authoritatively verify any TX without any other nodes or sources.

Exchanging "Inventory"

- The first thing a full node will do once it connects to peers is try to construct a complete BC.
  - A new full node only knows the genesis block, and it will download all the blocks afterwards.
- Syncing
  1. Check `version` message: contains `BestHeight`, a node's current BC height.
  2. Receive `version` messages from peers, compare to its own BC.
  3. Peered nodes exchange `getblocks` messages: contains the hash of the top block on their BC.
  - The peer that has the longer BC can identify which blocks the other node needs.
    - Then share the first 500 blocks' hash using an `inv`(inventory) message
    - Other nodes will retrieve them using the hashes from the `inv` message.

Simplified Payment Verification (SPV) Nodes

- Most common form of bitcoin node, especially bitcoin wallets.

- Only save the block headers.
  - Thus about 1000 times smaller than the full BC.
  - But cannot picture all UTXOs.
- TX verification
  - Verification of TXs relies on peers to provide partial views of relevant parts.
  - Referencing TX *depth* instead of *height*. (merkle path)
  - In most cases, 6 block ahead is stable enough for Bitcoin, and show that it was not a double-spend.
- An SPV node knows if a block (a TX) exists.
  - However, it cannot verify it, due to the lack of full record.
  - Thus, SPV nodes usually connect randomly to several nodes, to increase the contact chance to at least one honest node.
    - Making SPV nodes vulnerable to ++network partitioning attacks++ or ++Sybil attacks++.
- For most practical purposes, well-connected SPC nodes are secure enough, striking a balance between resource needs, practicality, and security.
  - However, running a full BC node is the safest after all.
- SPV nodes use a `getheader` message instead of `getblocks`.
  - Responding peer will send up to 2000 block headers using single `headers` message.
  - Otherwise the same as that used by a full node to retrieve full blocks.
  - Any TXs of interest are retrieved using a `getdata` request.

- Privacy issue
  - SPV nodes need to retrieve specific TXs to selectively verify them.
  - The request for specific data can inadvertently reveal the addresses.\

Bloom Filters

- A feature to address the privacy risks of SPV nodes.

- A probabilistic search filter, a way to describe a desired pattern without specifying it exactly.
  - Allow specifications to search patterns for TXs that can be tuned toward precision or privacy.
  - More specific bloom filter will produce accurate results, but at the expense of privacy.

Implementation

- Foundation
  - A variable-size N-bit array indexed 1 to N.
  - A variable number of M hash functions ranging $[\ 1, N\ ]$.
  - Different N and M result in variable level of accuracy and privacy.

- Pattern recording
  - Let P_i be the original filter pattern.
  - For each hash function H_i , set Array[H_j(P_i)] to 1. (That is, to set 1 to its corresponding index.)
    - If a bit had already been set to 1, it is not changed.
    - If more patterns record on overlapping bits, the accuracy decreases.
    - Thus, a larger bit array and more hash functions can record more patterns with higher accuracy.
- Pattern matching
  - A pattern Q is hashed by each hash function to match the bloom filter.
  - Q is hashed by each hash function and tested against the bit array.
  - If all bits indexed are set to 1, then Q is *probably* recorded in the filter. (Due to the probable overlapping.)
    - Thus, a (positive) match is a “Maybe, yes.”
    - Similarly, a mismatch (negative match) is a “Definitely Not.”

Application of Bloom Filters on SPV Nodes

- Bloom filters are used to filter the TXs (and the containing block) that and SPV nodes receives.

- Steps
  - Requesting node
    - All bits in bloom filter set to 0.
    - List owning addresses, keys and hashes.
      - Extracting PKH, SH and TX IDs from any UTXO in the node.
    - Send a `filterload` message to peers, containing the bloom filter.
  - Peers
    - Check matching:
      - TX ID
      - Data components from the locking scripts of the TX outputs
      - TX inputs
      - Input signature data components (or witness scripts)
    - Send back probably matching TXs.
      - Only a `merkleblock` message containing only block headers is sent.
  - Back to requesting node
    - Discard false positives.
    - Update UTXO and wallet balance.
    - Modify the bloom filter for future matching.
- Filter modification
  - Send `filteradd` message to interactively add patterns to the filter.
  - Send `filterclear` message to clear the filter.
  - Pattern removal is not possible, it must clear and resend the new bloom filter.

SPV Nodes and Privacy

- SPV nodes have weaker privacy than full nodes.

- Bloom filters are a way to reduce the loss of privacy. However, even with bloom filters, some methods can still collect enough information over time to learn the addresses of the SPV node.

Encrypted and Authenticated Connections

- The original implementation of Bitcoin communicates entirely in the clear.
  - Not a major concern for full nodes, but a big problem for SPV nodes.
- Solution:
  - *Tor Transport*
  - *P2P Authentication and Encryption* with BIP-150/151.

Tor Transport

- Tor stands for *The Onion Routing network*.

- Offering encryption and encapsulation of data through randomized network paths that offer anonymity, untraceability and privacy.

- Bitcoin Core supports Tor.

Peer-to-Peer Authentication and Encryption

- Two Bitcoin Improvement Proposals, BIP-150 and BIP-151, add support for P2P authentication and encryption in the network.

- BIP-150 (Peer authentication)
  - Optional peer authentication
  - Using ECDSA and private keys
  - Requires BIP-151 communications.
- BIP-151 (Peer-to-peer communication encryption)
  - Enabling negotiated encryption for all communications between nodes supporting BIP-151.
- Benefits
  - Prevent man-in-the-middle attack.
  - Strengthen resistance of bitcoin to traffic analysis and privacy-eroding surveillance.

Transaction Pools

- Memory pool: a per-node temporary list of unconfirmed TXs.
  - Keep track TXs that are known to the network but are not yet on the BC.
  - Wallet nodes use TX pool to track (unconfirmed) incoming payments.
- Upon reception and verification, TXs are added to the TX pool and relayed to the neighbors.

- Some also maintain a separate pool of orphaned TXs.
  - When a TX is added to the pool, the orphan pool is checked if there are any of its children.
  - Any matching orphans are then validated, removed from the orphan pool, and added to the TX pool.
    - Recursively find in the orphan pool, until there is no orphans or no descendants are found.
- Both TX pool and orphan pool (if implemented) are in local memory.
  - Empty on node startup.
  - Gradually populated with new TXs received.
- Some maintain UTXO DB or pool.
  - Not initialized empty but instead contains millions of entries of all UTXO.
  - May be a pool on local memory or an indexed DB on mass storage.
- Differences
  - TX and orphan pools represent a single node's local perspective.
    - Might vary significantly from one node to another.
    - Depending on when the node starts.
    - Only contains unconfirmed outputs.
  - UXTO pool represents the emergent consensus of the network.
    - Vary little between nodes.
    - Only contains confirmed outputs.

Table of Terms (Lexicographical order)

Abbr.	Term
BC	blockchain
BIP	Bitcoin improvement proposals
DB	database
DNS	domain name server
ECDSA	Elliptic Curve Digital Signature Algorithm
P2P	peer-to-peer
PKH	public key hash
PoW	proof of work
SH	script hash
SPV	simplified payment verification
TX	transaction
UTXO	unspent transaction output