The Bitcoin Network

How Bitcoin works?

Bitcoin network

A standard p2p network:

- Nodes connect and disconnect
- New nodes enter the network
- There is no perfect connectivity
- Nodes listen to the messages by their neighbours
- Nodes transmit messages to their neighbours

Bitcoin network

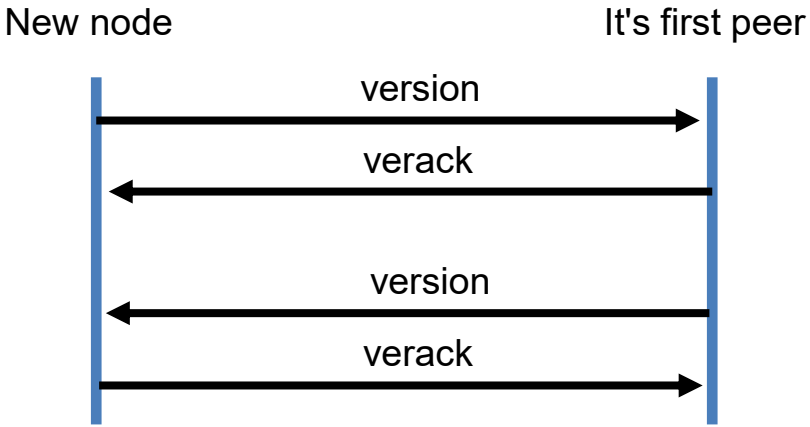
How does a new node get to have neighbours?

- Static DNS Seed
- DNS Seed BIND (Berkeley Internet Name Daemon)
- A specific IP of a node already known to the new node

Bitcoin network

Basic messages to establish a connection:

- *version*
- *verack*



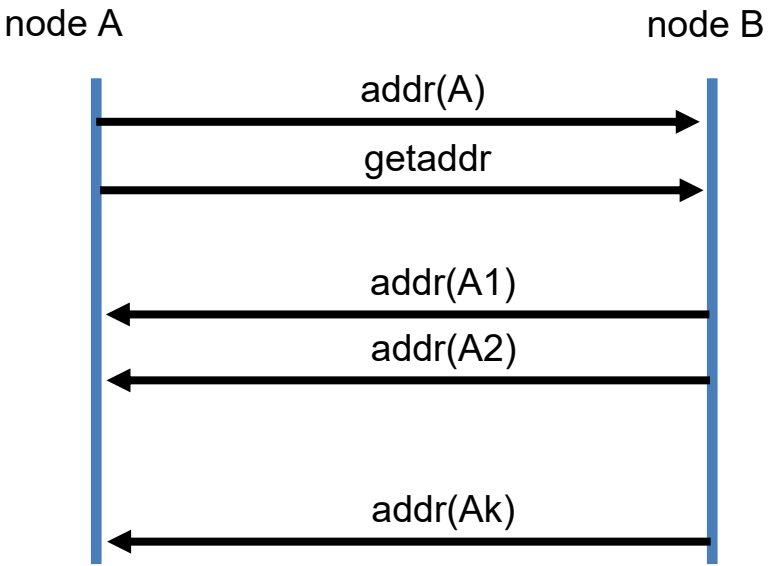
Bitcoin network

Discovering new peers:

- A connects to B
- B will pass on the address of A to its peers
- A can also ask B for the addresses of its peers
- B replies with these addresses

Bitcoin network

Discovering new peers:



Bitcoin network

Nodes enter and leave the network:

- A dynamic process
- Node stores its peers and upon enering again tries to connect to them
- If there are no messages from a node for 30 min, a message is sent
- If there are no messages for 90 min, the node is disconnected (one less edge)

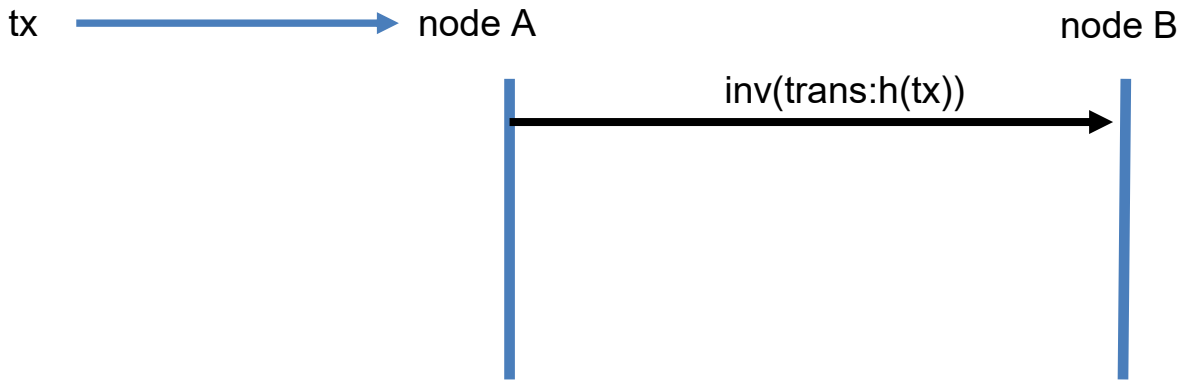
- It is recommended to have no more than 100 peers
- Too many connections put pressure onto the network

Bitcoin network

Basic communication:

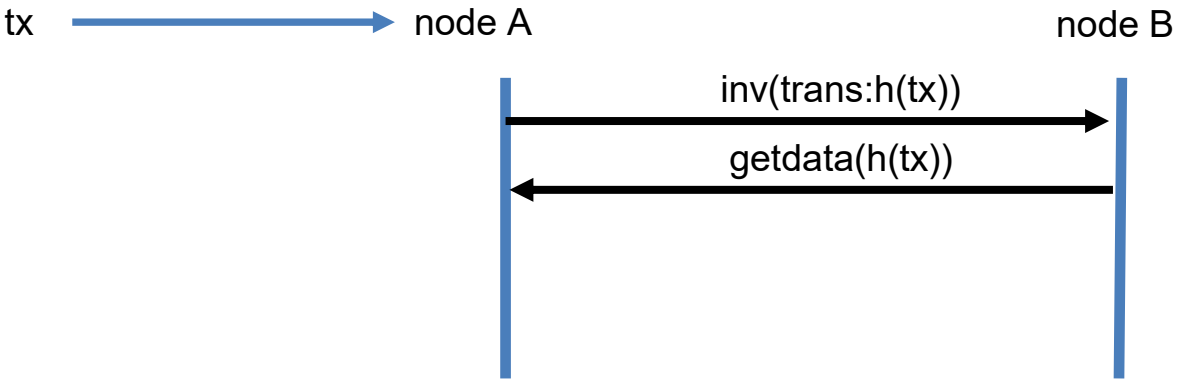
Bitcoin network

Basic communication:



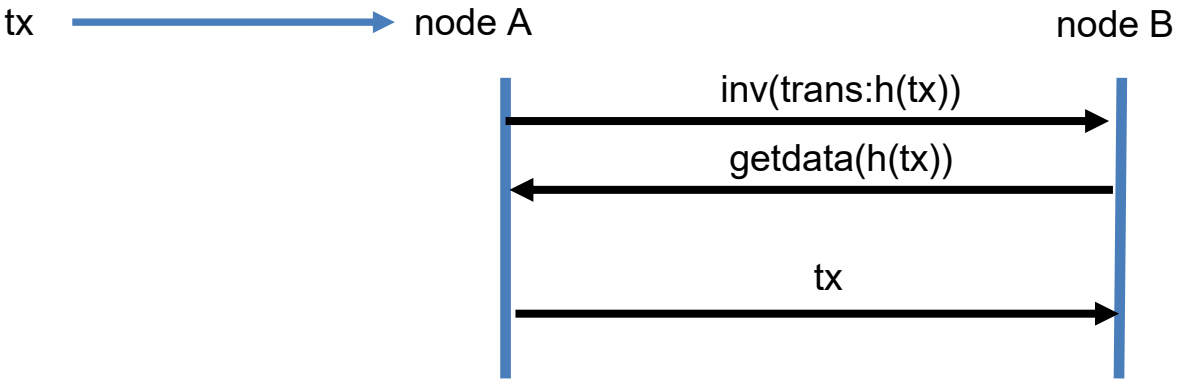
Bitcoin network

Basic communication:



Bitcoin network

Basic communication:

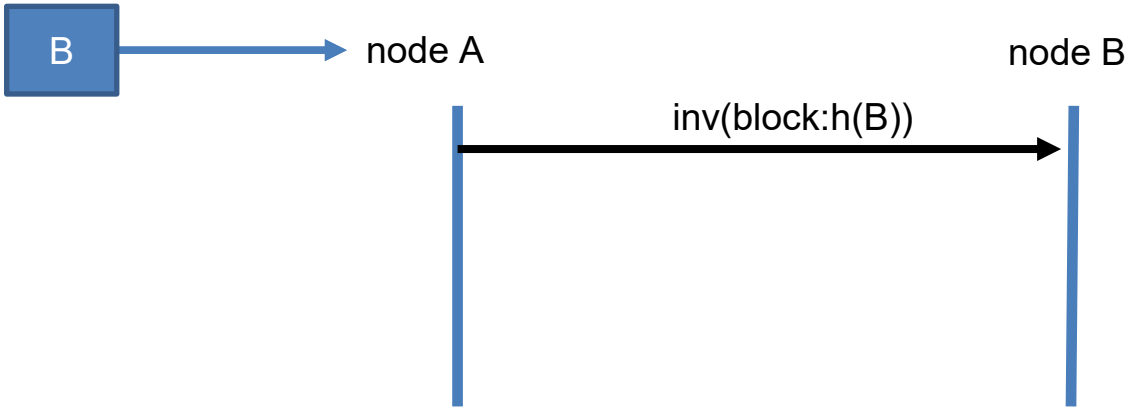


Bitcoin network

Basic communication (blocks):

Bitcoin network

Basic communication (blocks):



Bitcoin network

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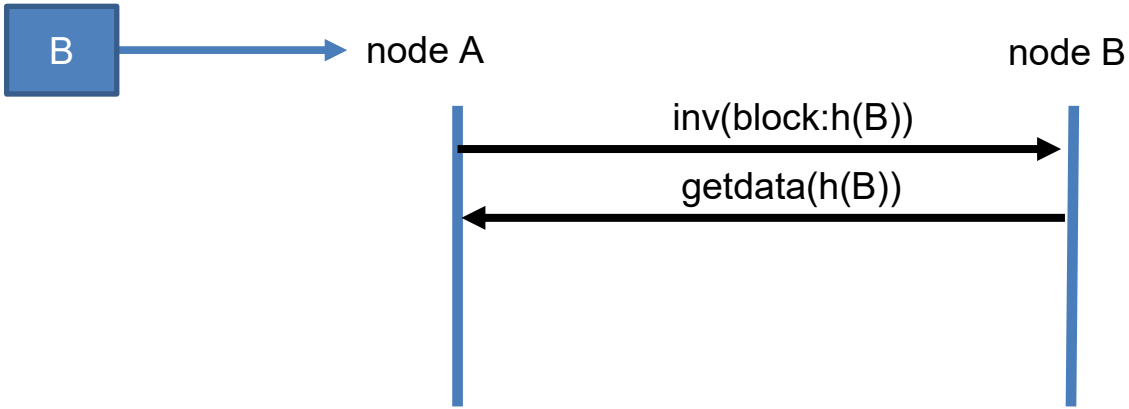
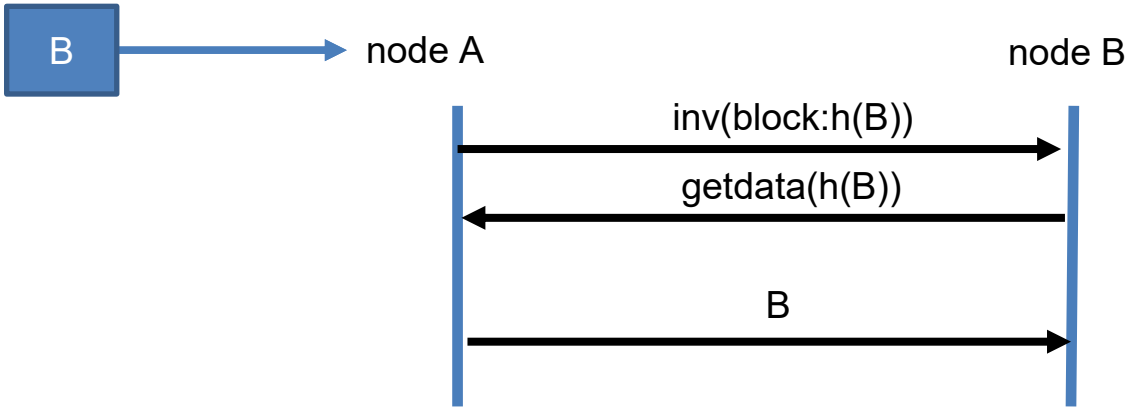


Bitcoin network

Basic communication (blocks):



Bitcoin network

Full nodes:

- Store the entire blockchain
- Verify all the transactions and blocks

- How does a full node obtain the blockchain upon entering the network?

Bitcoin network

Up to version 0.9.3 of BitcoinCore

How does node X obtain the blockchain?

- Always starts with the genesis block (hardcoded in its software)
- Other blocks are received by its peers on the network

- First message sent/received by X: *version (contains the field BestHeight)*
- X sends *getblocks* to its peer with the highest BestHeight (call this node Y)
- The message *getblocks* has the hash of the last block in the blockchain of X
- Y identifies the first 500 blocks that X does not yet have
- Y sends the message *inv* with the hashes of these 500 blocks
- To obtain a block, X sends to Y *getdata(hash)* message
- Maximum of 500 *getdata* can be active per connection

Initial block download

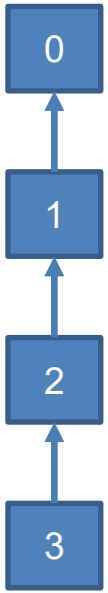
node A

node B

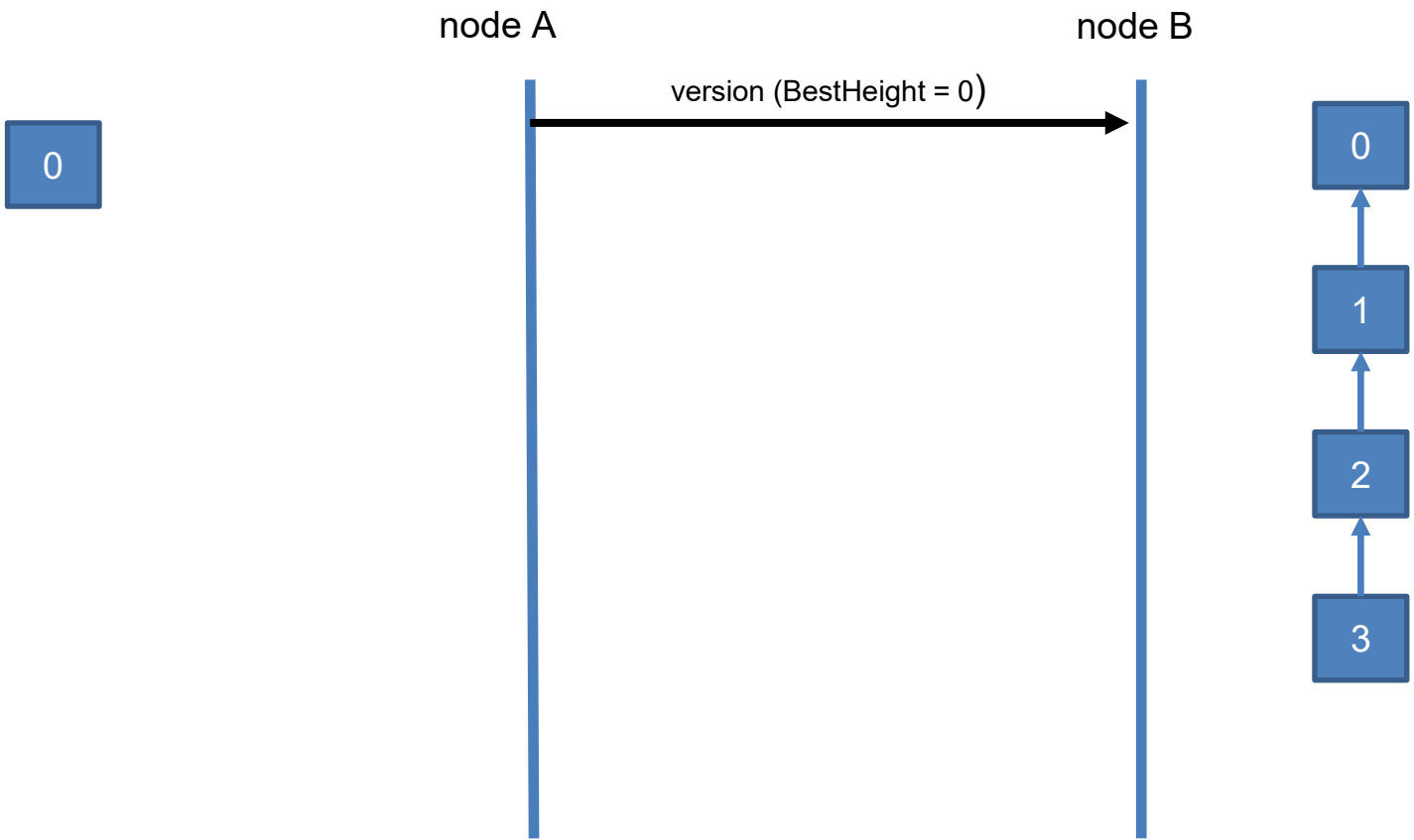
Initial block download

node A

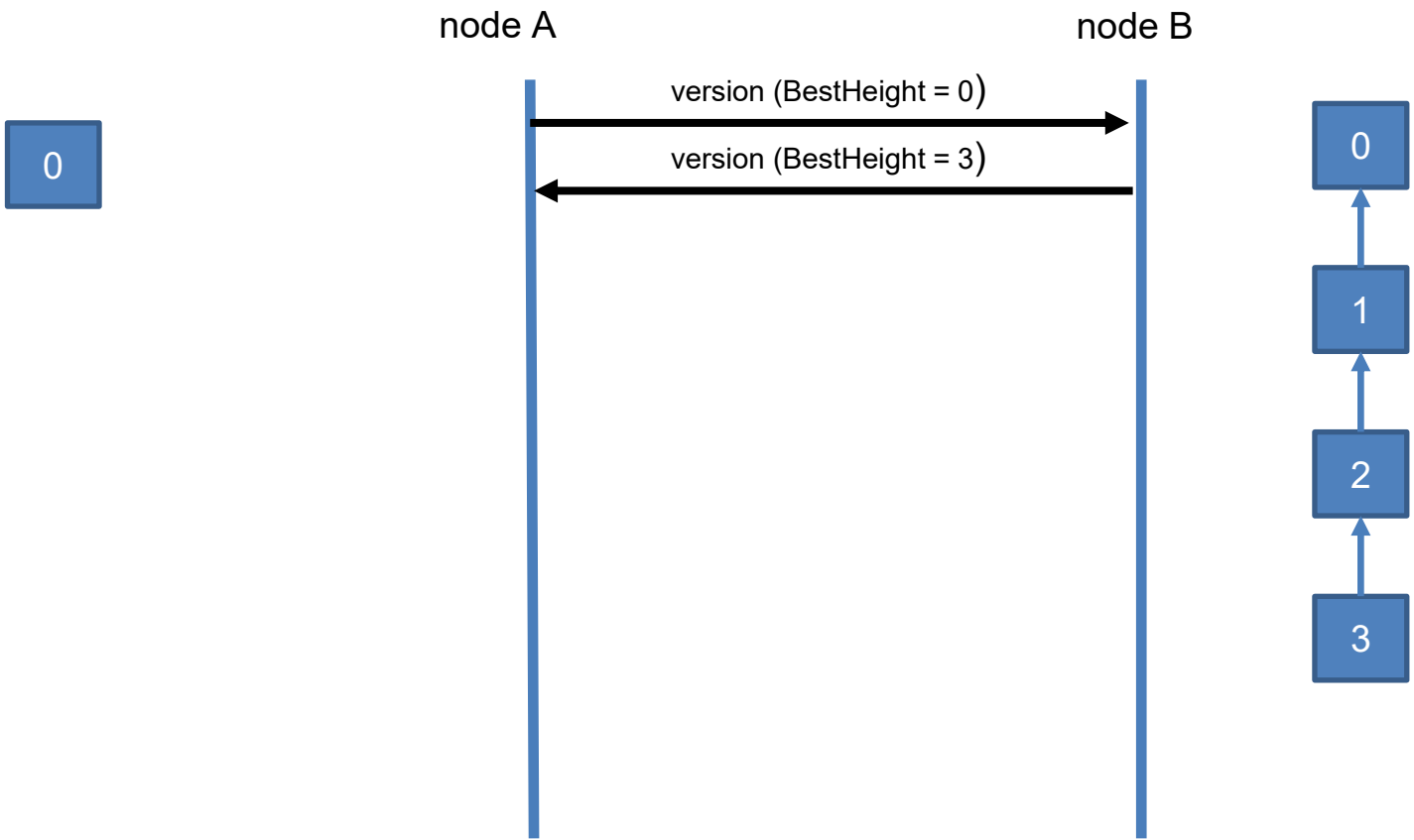
node B



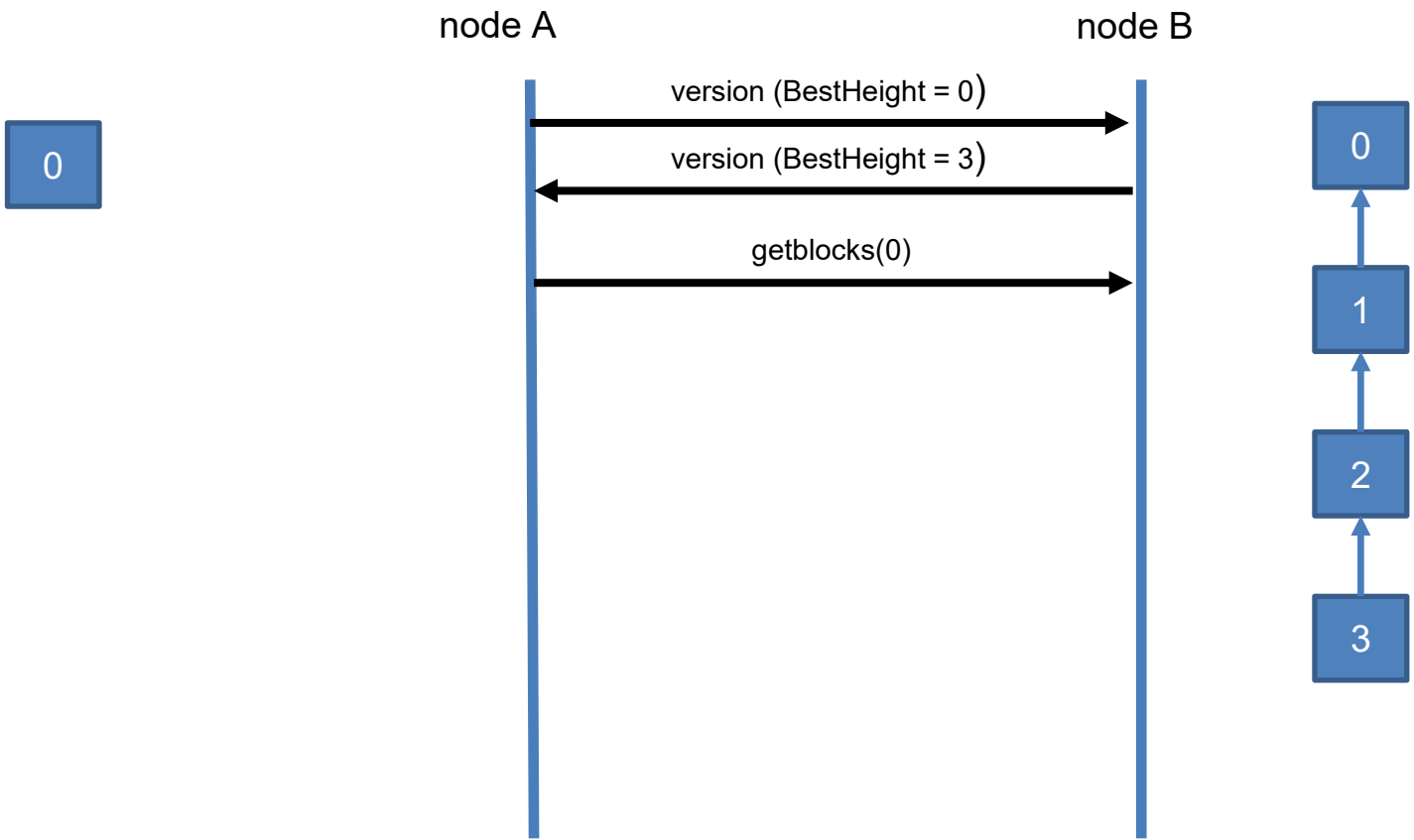
Initial block download



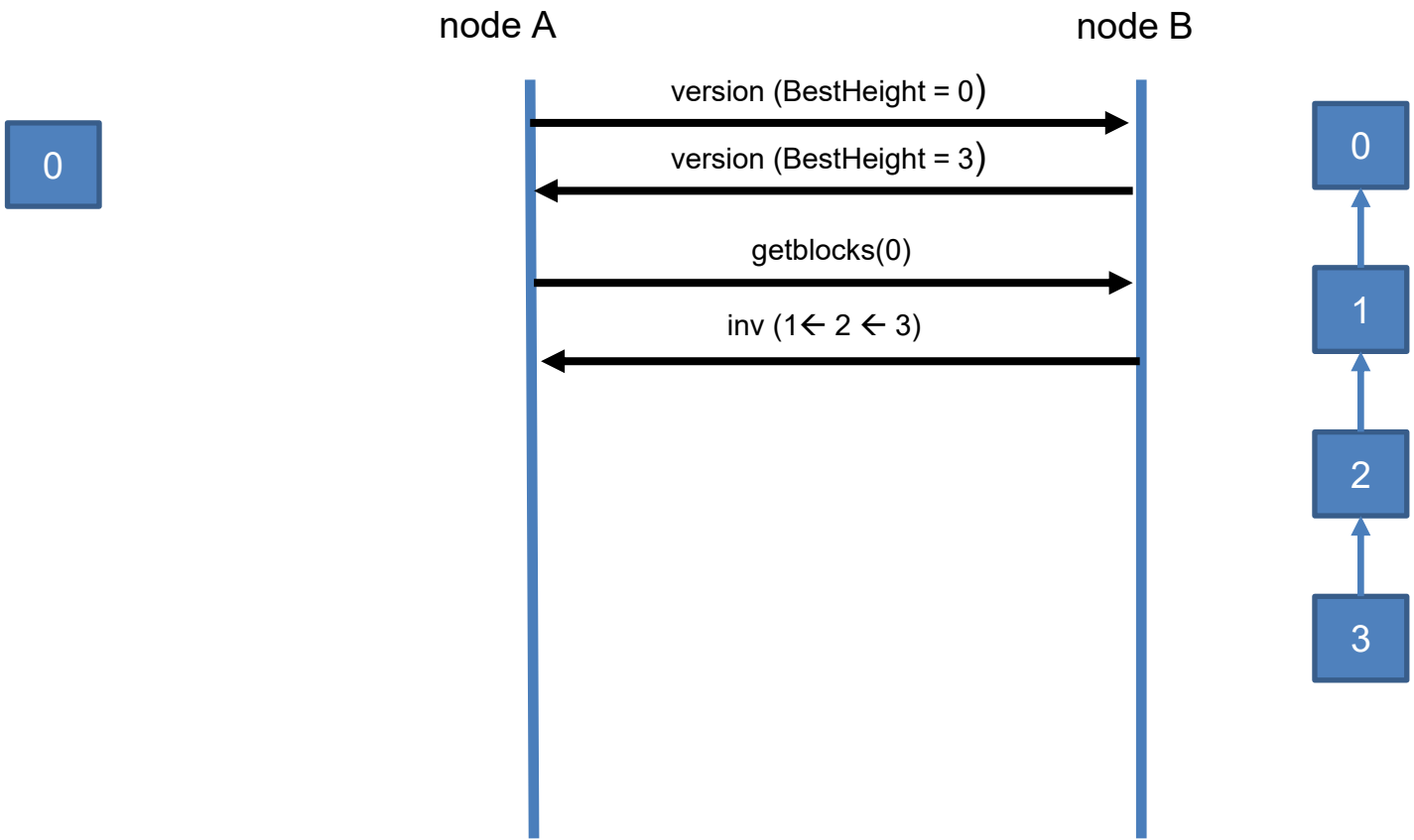
Initial block download



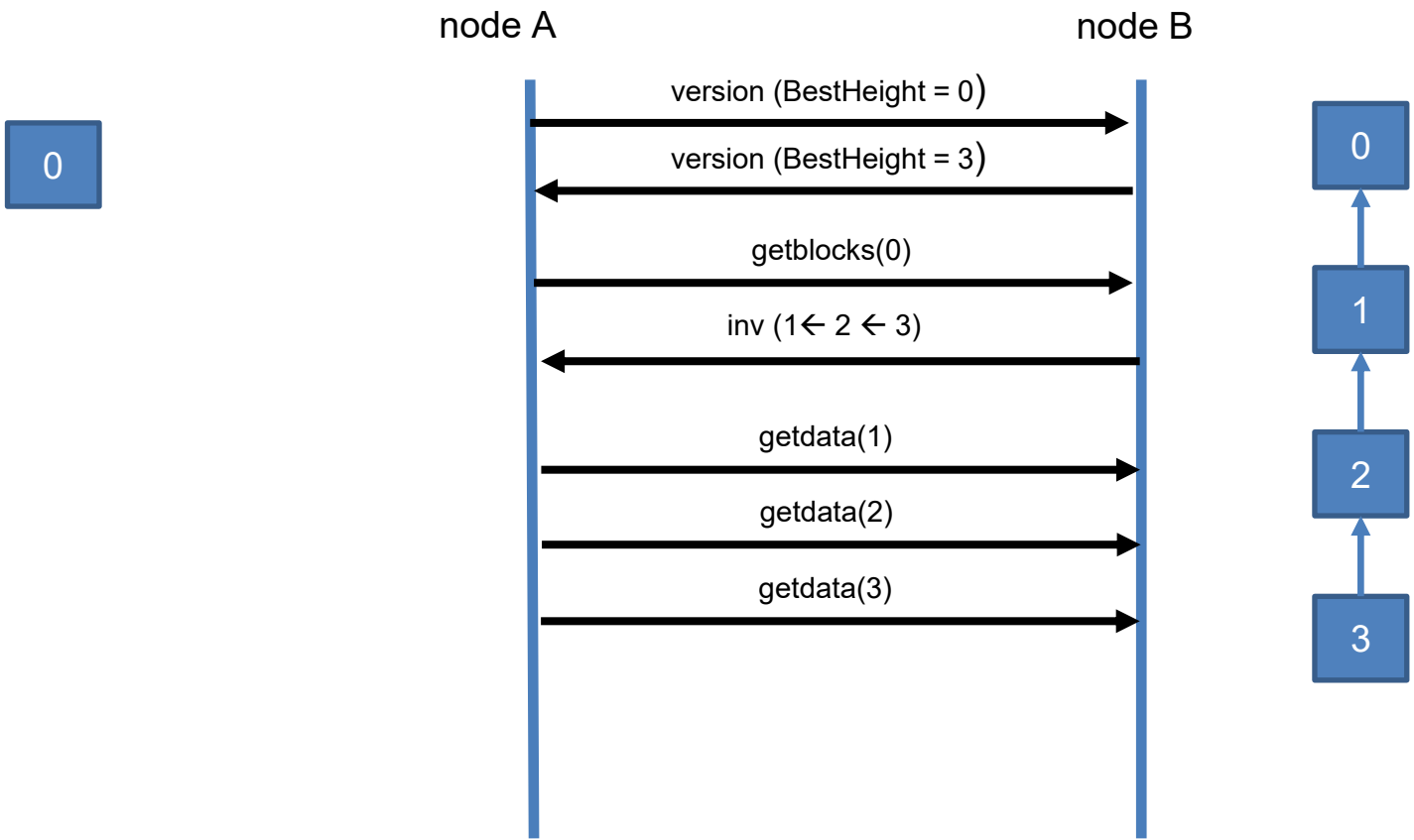
Initial block download



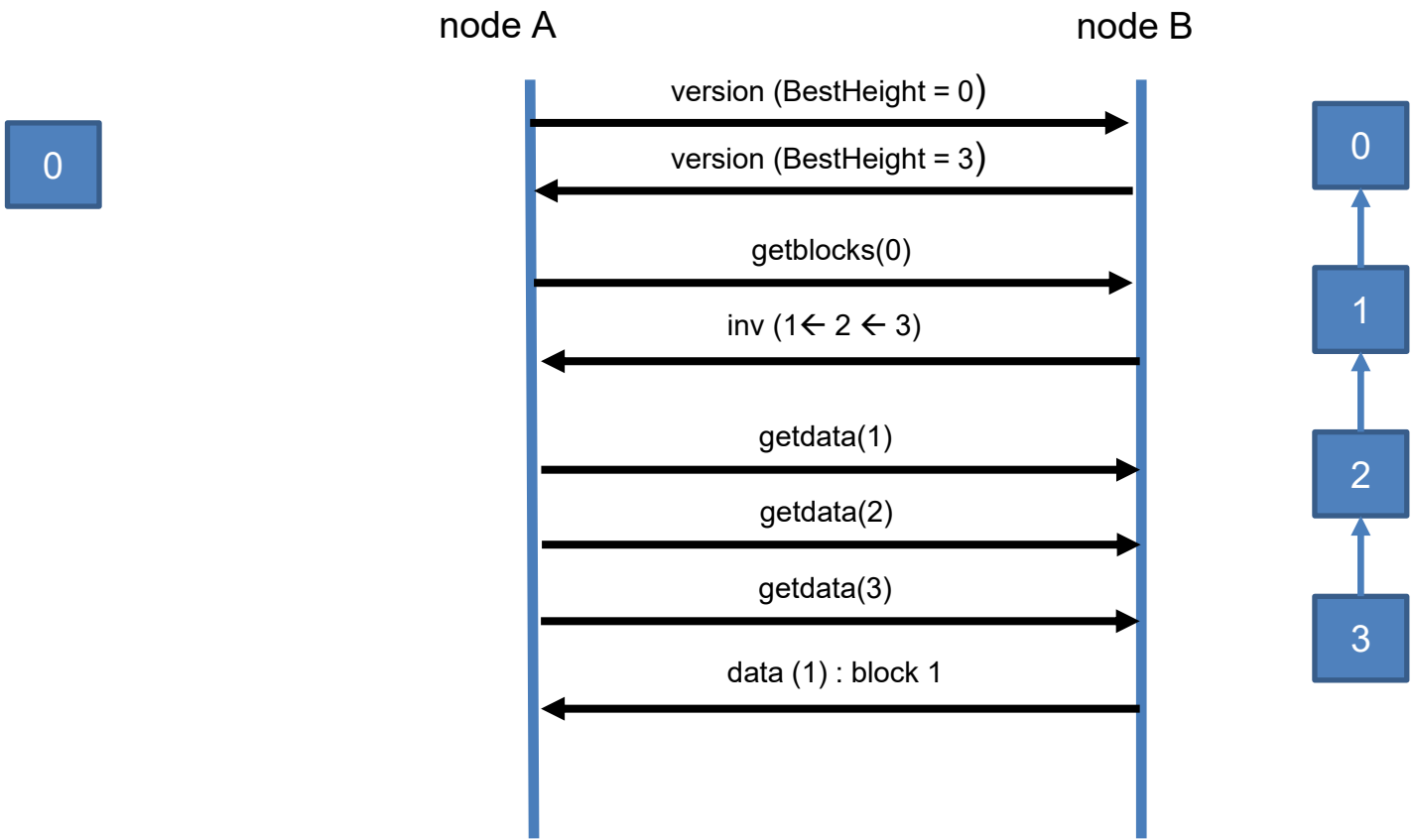
Initial block download



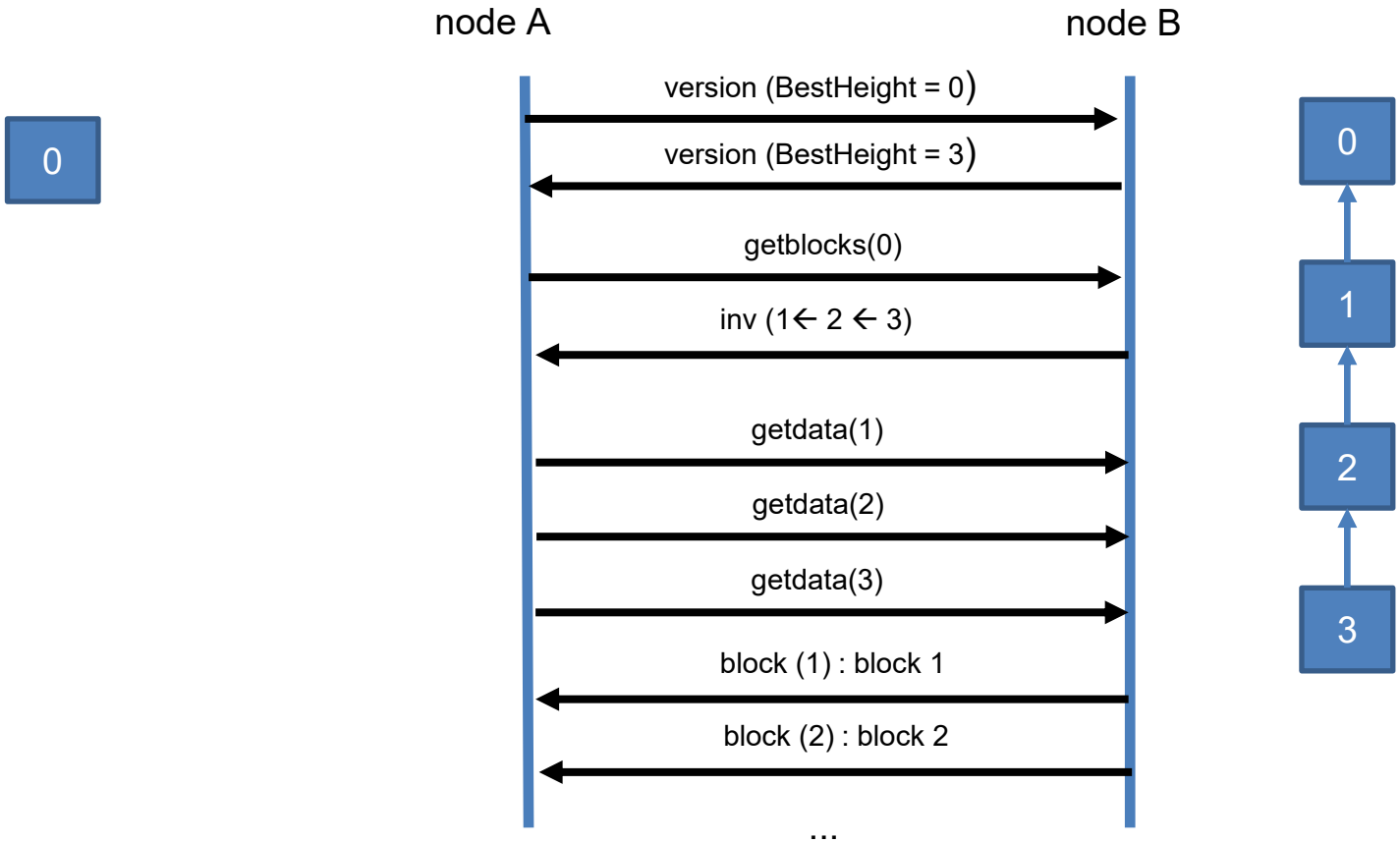
Initial block download



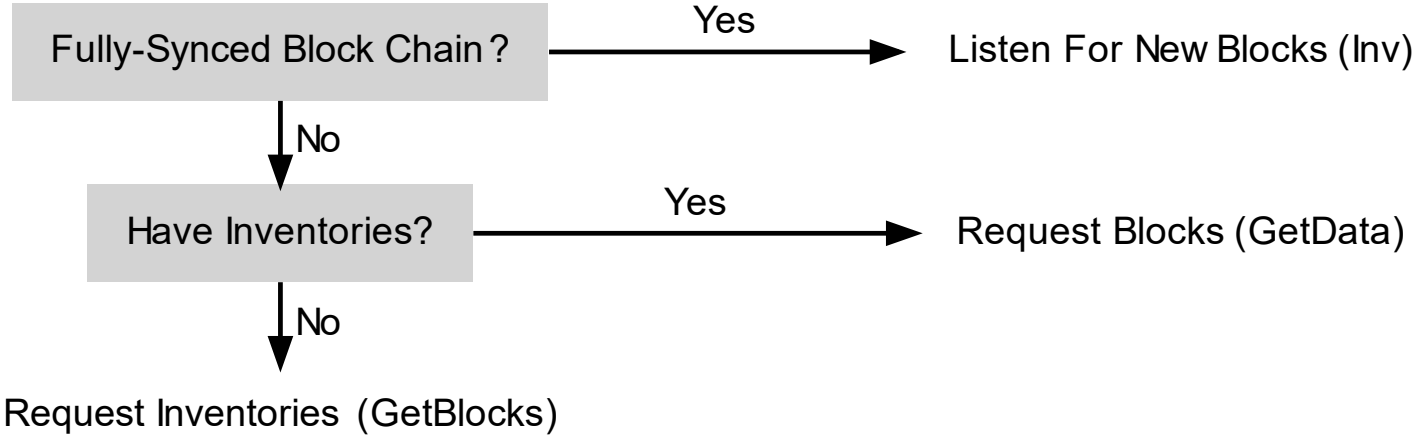
Initial block download



Initial block download



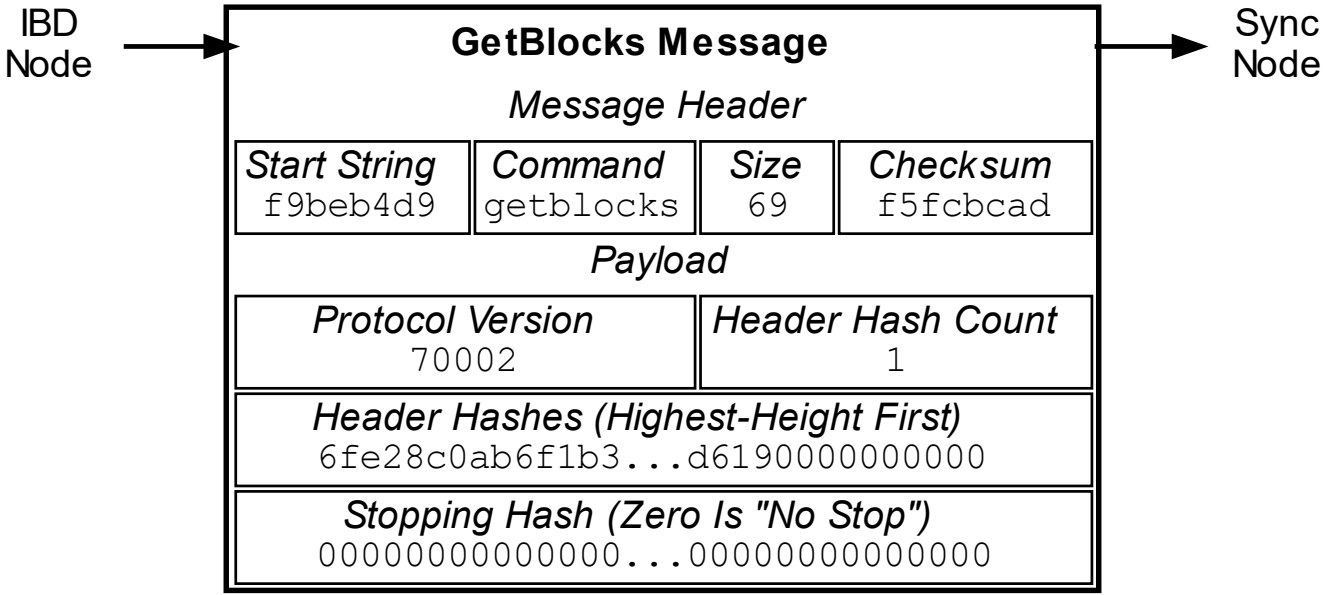
In reality (IBD)



Overview Of Blocks-First Initial Blocks Download (IBD)

https://bitcoin.org/en/developer-guide#peer-discovery

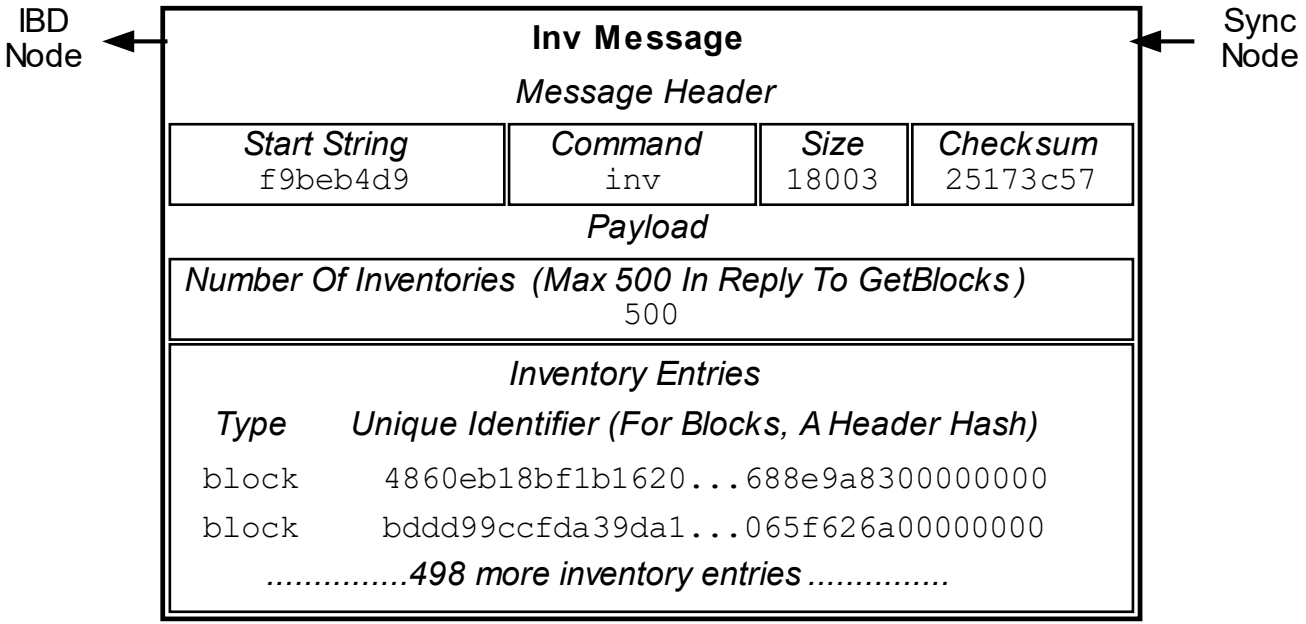
In reality (IBD)



First getblocks message sent from Initial Blocks Download (IBD) node

https://bitcoin.org/en/developer-guide#peer-discovery

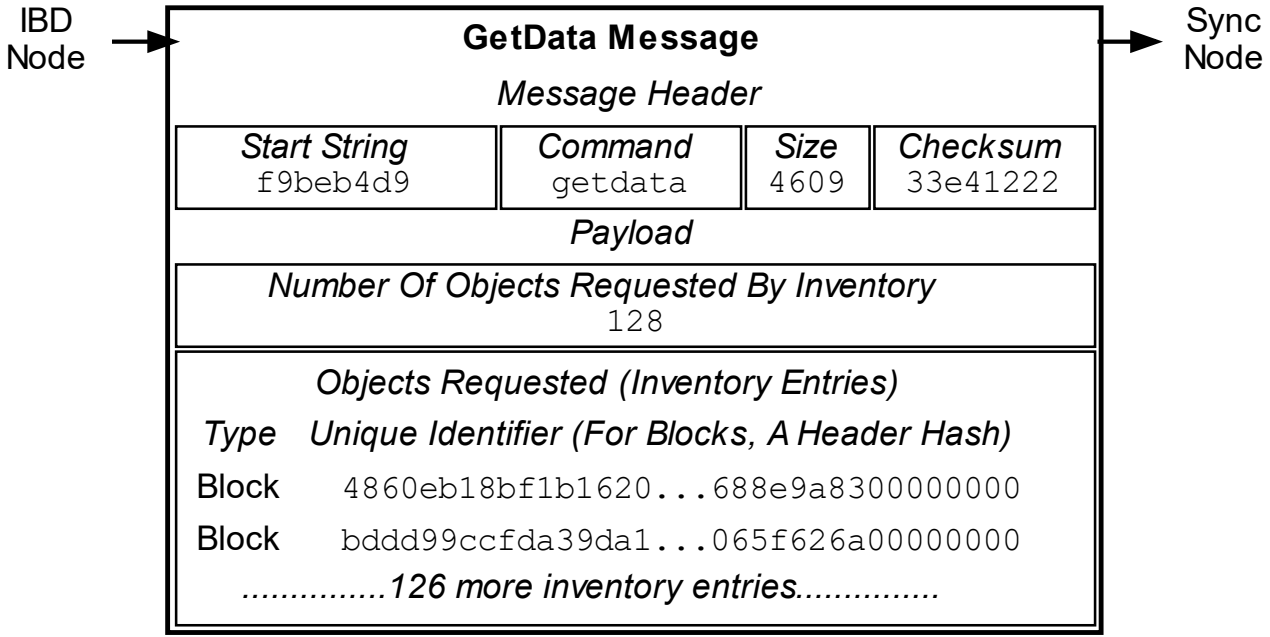
In reality (IBD)



First inv message reply sent to Initial Blocks Download (IBD) node

https://bitcoin.org/en/developer-guide#peer-discovery

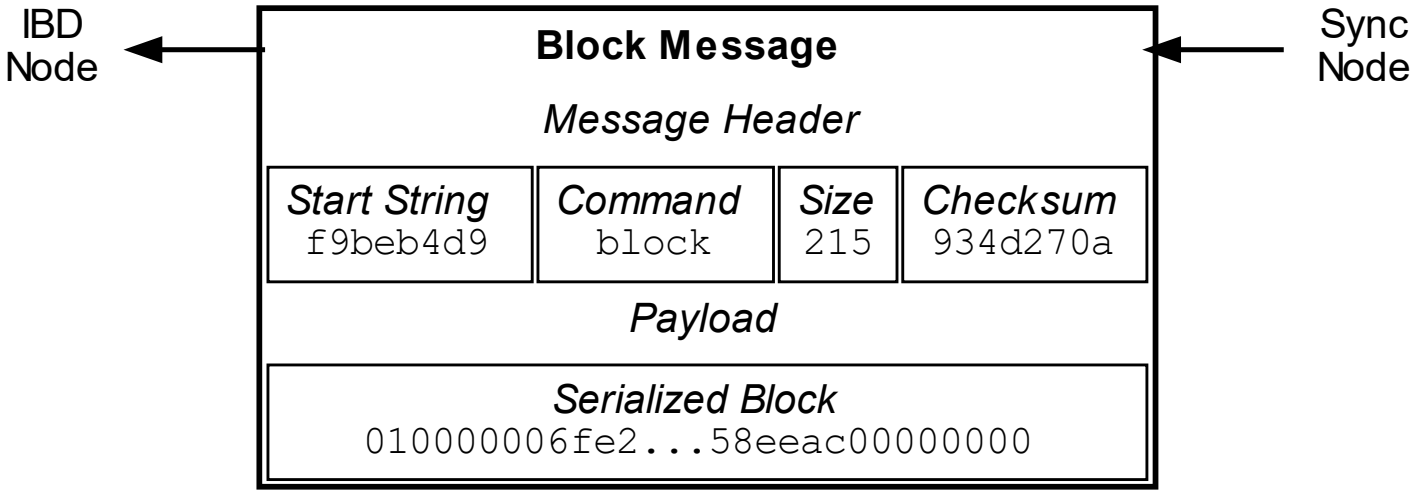
In reality (IBD)



First getdata message sent from Initial Blocks Download (IBD) node

https://bitcoin.org/en/developer-guide#peer-discovery

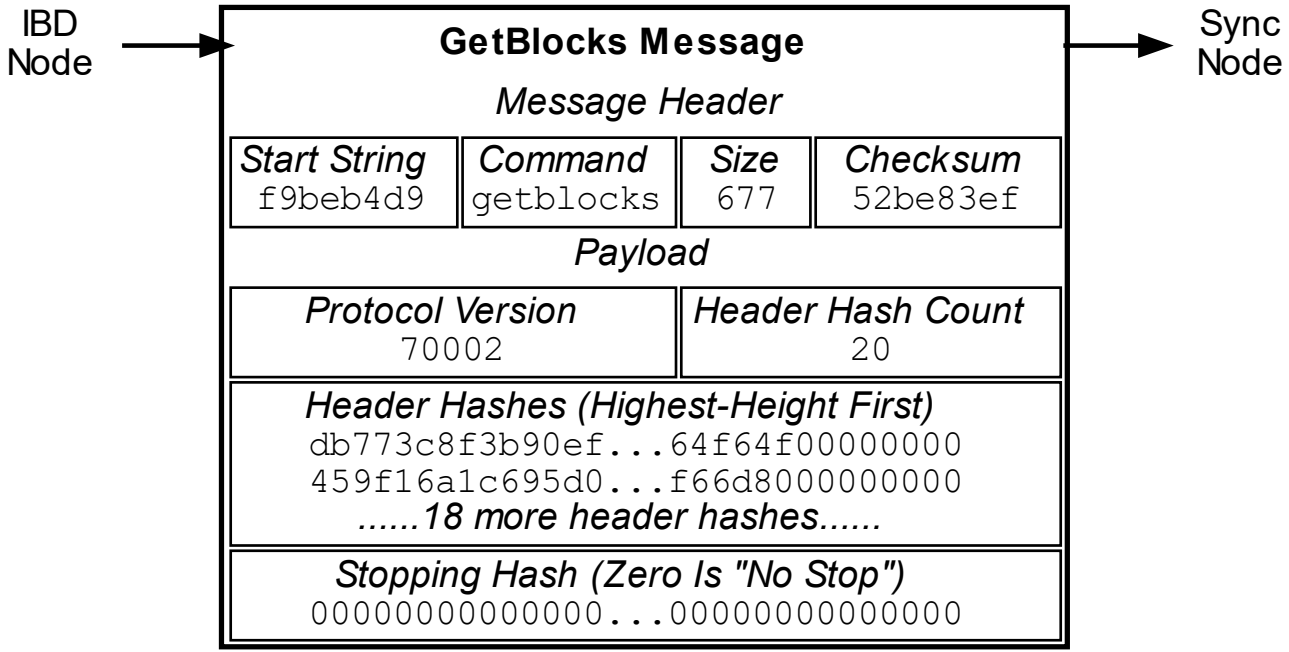
In reality (IBD)



First block message sent to Initial Blocks Download (IBD) node

https://bitcoin.org/en/developer-guide#peer-discovery

In reality (IBD)



Second getblocks message sent from Initial Blocks Download (IBD) node

https://bitcoin.org/en/developer-guide#peer-discovery

SPV nodes

Simple payment verification (SPV):

- A typical user is only interested in transactions using her own address
- A typical use of a Bitcoin wallet

- SPV nodes do not store the entire blockchain
- They store only the block headers (80 bytes per block = 4.2MB per year)
- Much smaller than a full node
- But they can not validate all the UTXOs

SPV nodes

An SPV node can verify only two things:

1. That a transaction *tx* belongs to the block *blockX*
2. That a block *blockX* has k confirmations

SPV nodes

How does an SPV node verify that tx belongs to blockX?

- An SPV node store the block headers

Field	Purpose	Updated when...	Size (Bytes)
Version	Block version number	You upgrade the software and it specifies a new version	4
hashPrevBlock	256-bit hash of the previous block header	A new block comes in	32
hashMerkleRoot	256-bit hash based on all of the transactions in the block	A transaction is accepted	32
Time	Current timestamp as seconds since 1970-01-01T00:00 UTC	Every few seconds	4
Bits	Current target in compact format	The difficulty is adjusted	4
Nonce	32-bit number (starts at 0)	A hash is tried (increments)	4

SPV nodes

How does an SPV node verify that tx belongs to blockX?

- An SPV node store the block headers
- An SPV node A asks a full node B for a certificate for *tx*

- And validates the certificate against *hashMerkleRoot*

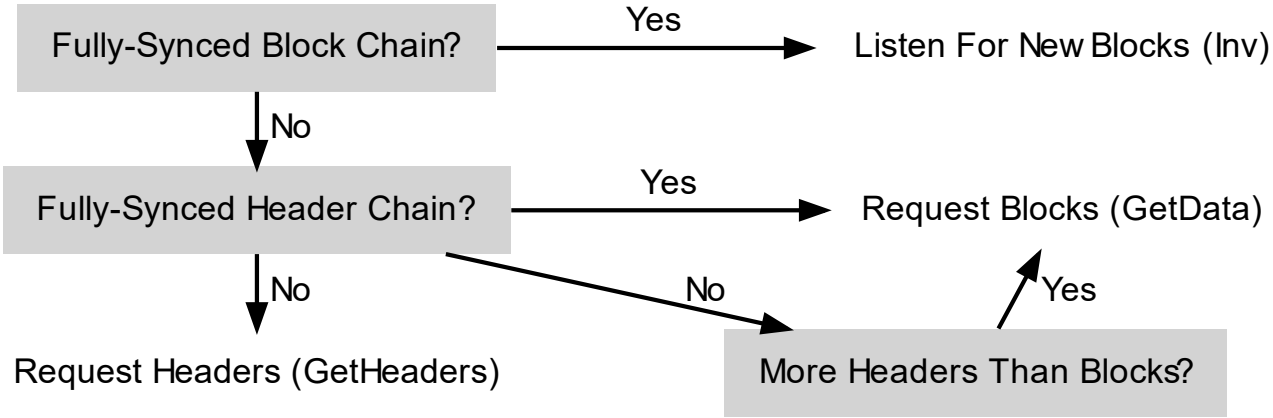
SPV nodes

How does an SPV node A verify that tx has k confirmations?

- A has the headers up until the current end of blockchain

- Can A verify that the headers are valid?

IBD for an SPV node



Overview Of Headers-First Initial Blocks Download (IBD)

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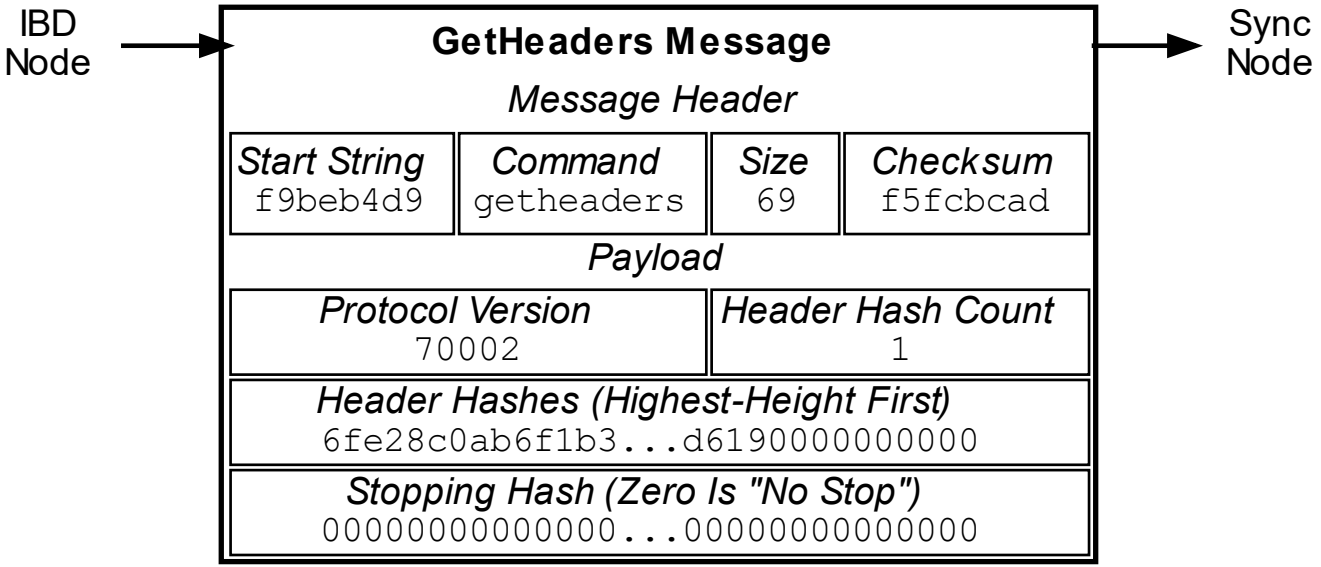
IBD for an SPV node



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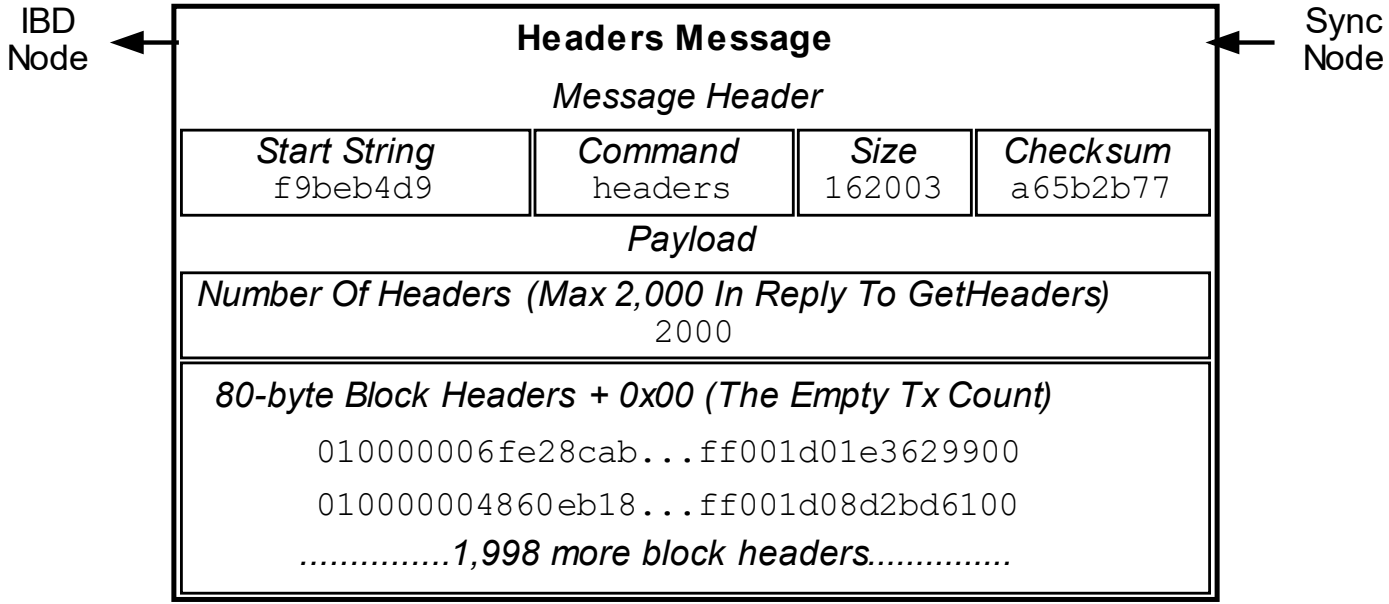


First headers message reply sent to Initial Blocks Download (IBD) node

https://bitcoin.org/en/developer-guide#peer-discovery

Vulnerabilities of SPV nodes

First vulnerability: partial DOS attack

- If a full node is malicious can it pretend that *tx* belongs to *blockX*?
- Can it pretend that *tx* does not belong to *blockX*?

Solution:

- The SPV node should use more than one full node
- Merkle trees should be ordered

Vulnerabilities of SPV nodes

Second vulnerability: loss of privacy

- If the SPV node queries node B a lot
- B will know all the addresses of A
- It can track A
- It can prohibit A to broadcast transactions

- How to solve this?

Bloom filters

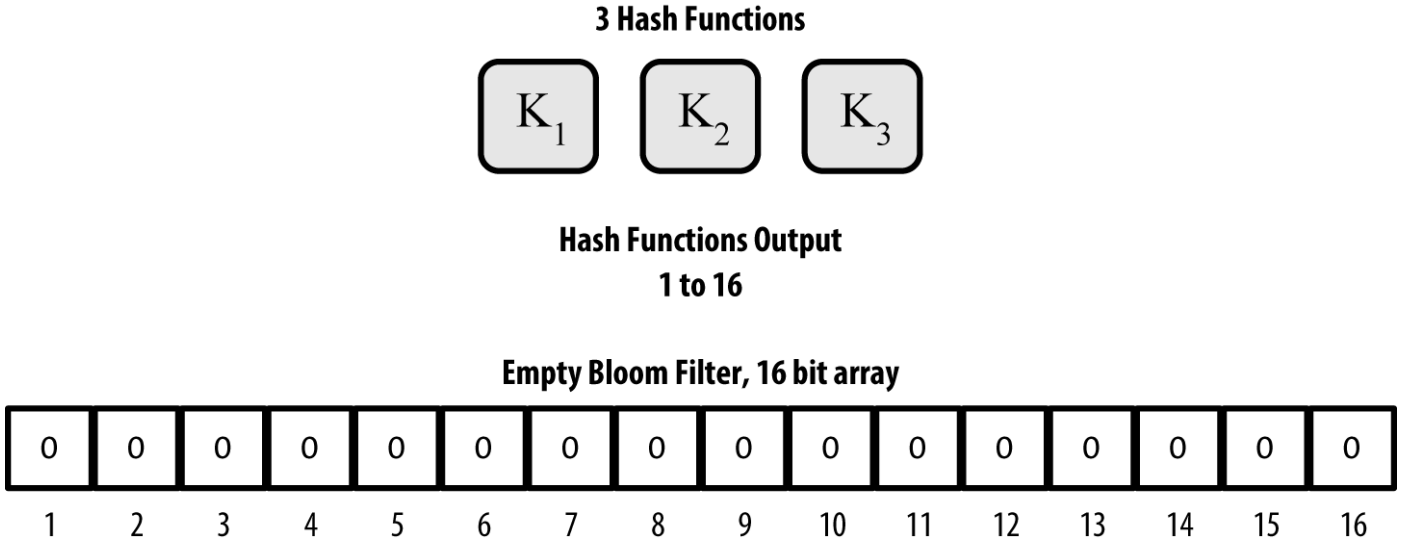
A probabilistic search filter:

- The filter starts empty
- Elements are added to the filter

- One wishes to check if an element was added to the filter

- Can give false positives
- Can not give false negatives

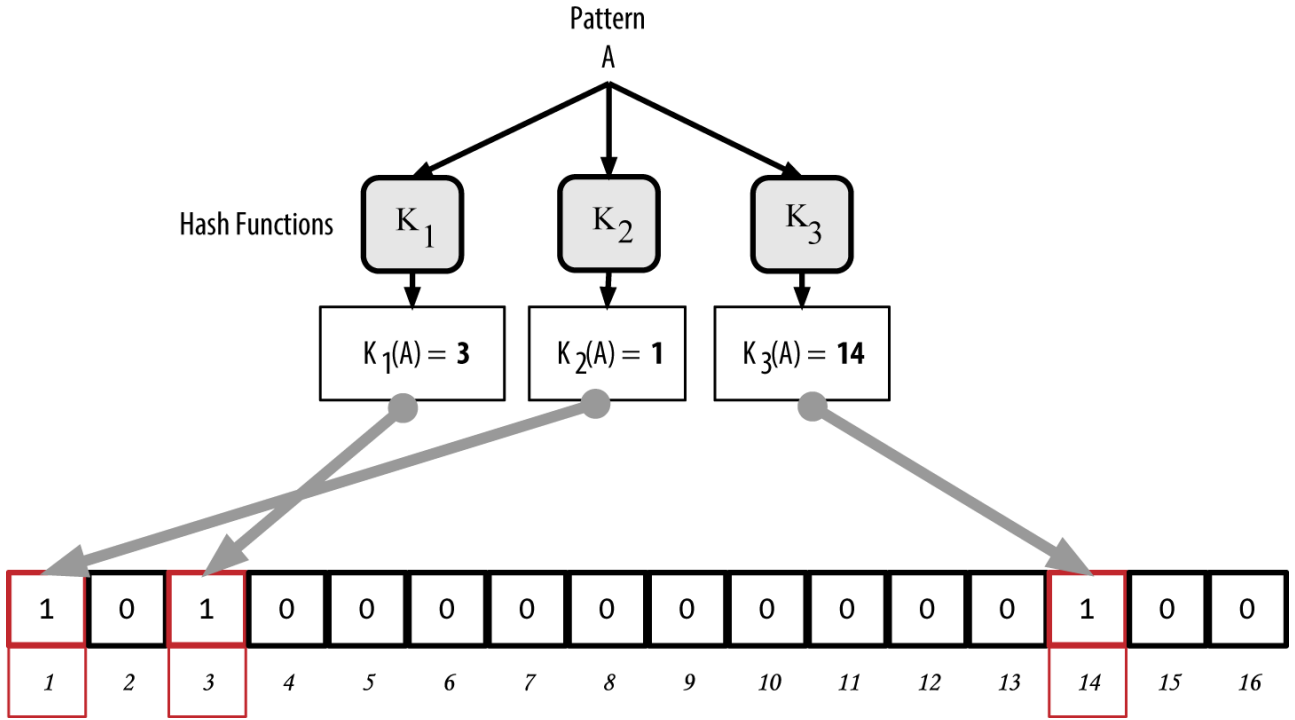
Bloom filters



https://github.com/bitcoinbook/bitcoinbook/blob/develop/ch08.asciidoc

Bloom filters

Inserción



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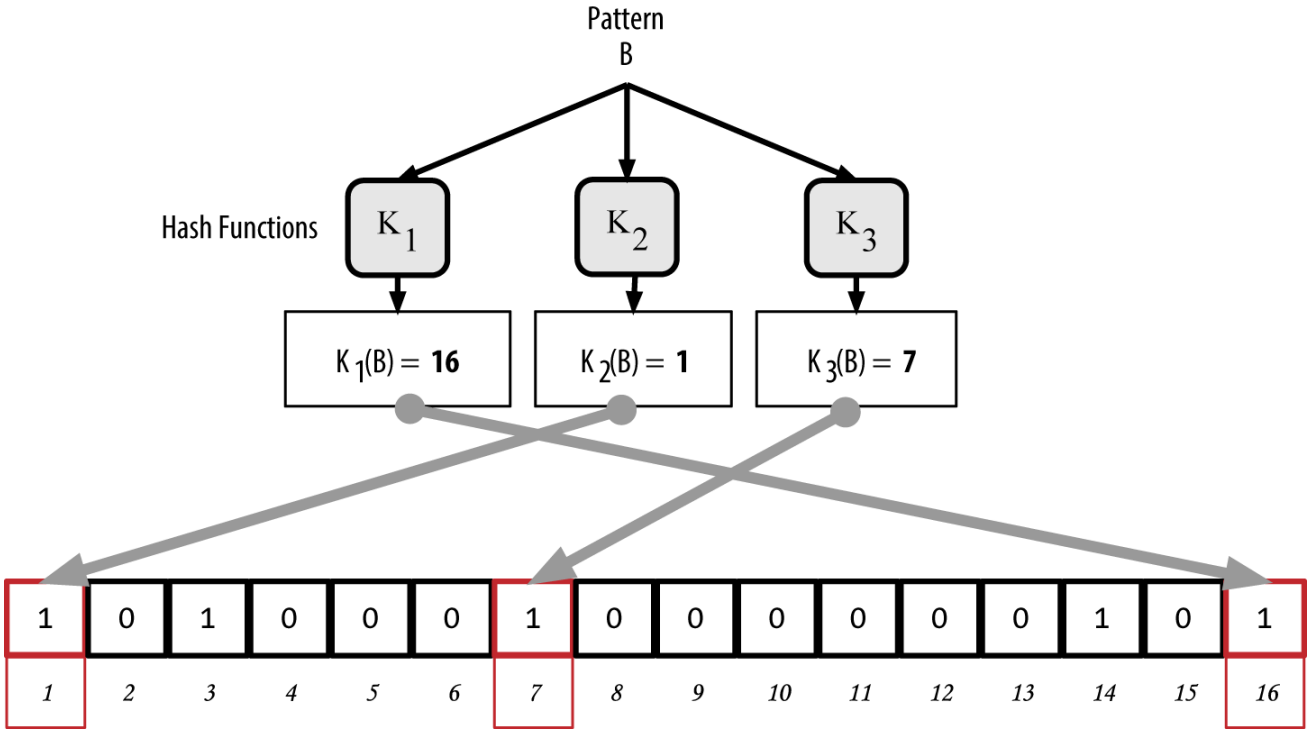
Bloom filters

Insertion



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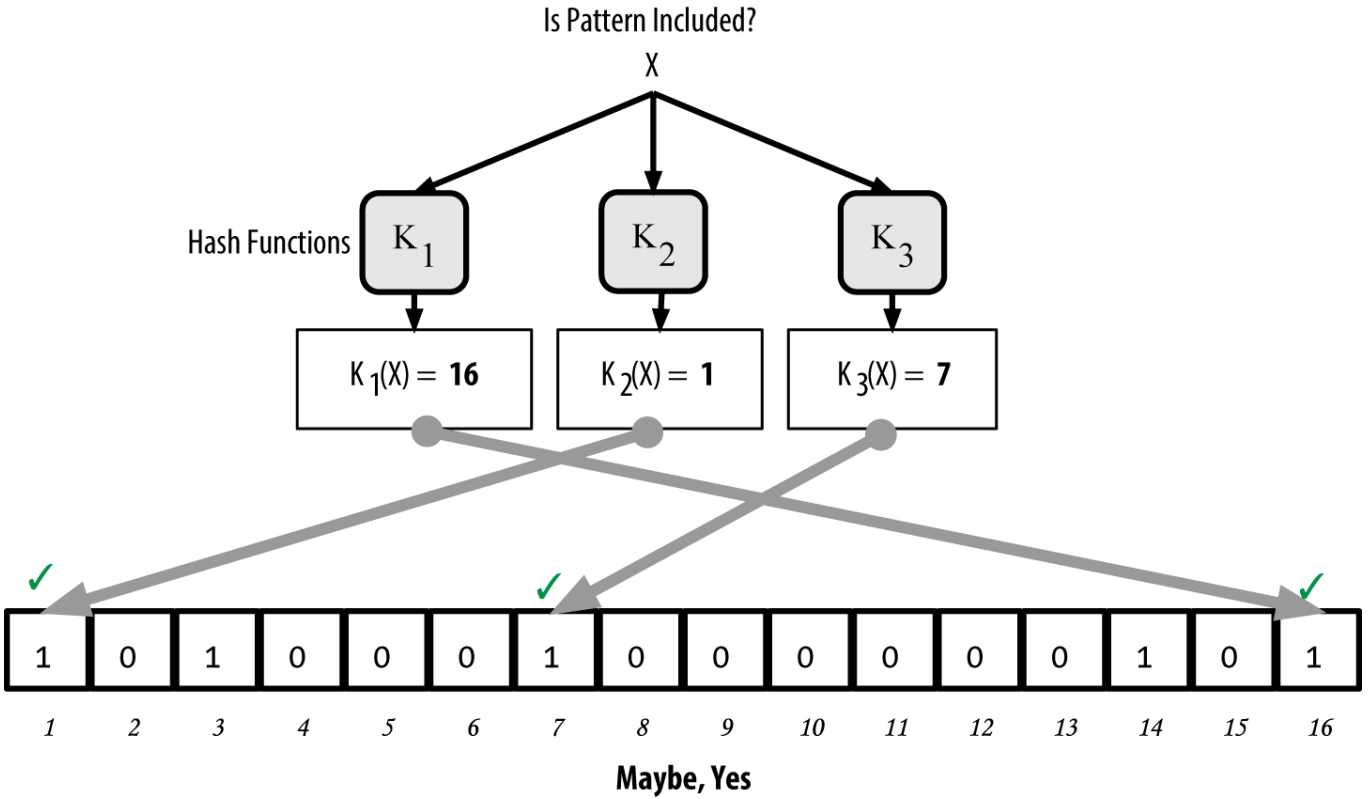
Bloom filters

Search



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Bloom filters

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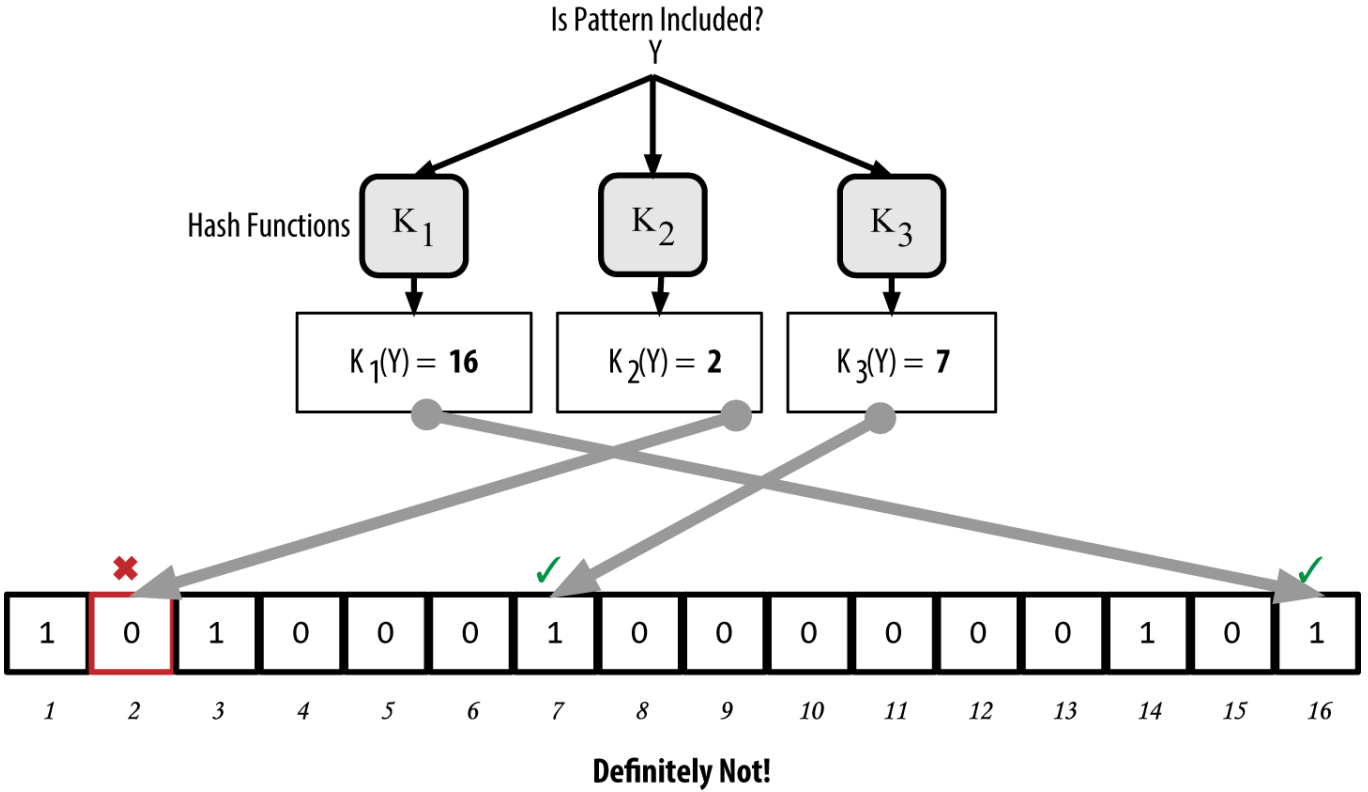

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SPV nodes and Bloom filters

SPV A and its full node B:

- A inserts the UTXOs and addresses of interst to a Bloom filter (BF)
- A inserts a bit of junk data into the BF
- A sends its BF to B
- B uses the BF in the communication channel with A
- For each *tx* that B receives, if *tx* matches the BF, *tx* is sent to A

- A validates whether *tx* was a false positive and in this case it discards *tx*

SPV nodes and Bloom filters

What B checks in a transaction:

- Hash of the transaction (the ID)
- Inputs
- Outputs
- All the addresses

Read more on this:

- https://github.com/bitcoin/bips/blob/master/bip-0037.mediawiki#filter-matching-algorithm

SPV nodes and Bloom filters

Numbers used in Bitcoin:

- The size of the filter is 36.000 bytes max
- 50 hash functions
- Full node sends the header + the certificate for the transactions matching the filter

Read more on this:

- https://github.com/bitcoin/bips/blob/master/bip-0037.mediawiki#filter-matching-algorithm

Bitcoin network

References:

1. Antonopoulos: https://github.com/bitcoinbook/bitcoinbook/blob/develop/ch08.asciidoc
2. Protocol specification: https://en.bitcoin.it/wiki/Protocol_documentation
3. Network: https://en.bitcoin.it/wiki/Network
4. P2P network: https://bitcoin.org/en/developer-guide#peer-discovery
5. SPV nodes: https://bitcoin.org/en/developer-guide#simplified-payment-verification-spv
6. Bloom filters: https://github.com/bitcoin/bips/blob/master/bip-0037.mediawiki#filter-matching-algorithm

Mining pools

What does a miner do on her own:

- Buys hardware
- Spends electricity to compute the hashes

- Gets Bitcoins (ocassionally)

- A huge variance on when it will discover the blocks
- It can happen it does not discover a block for two years

- Not a sustainable bussiness strategy

Mining pools

Solution:

- Several miners join a *mining pool*
- Similar to a producers collective (i.e. zadruga)
- They all solve the same mining puzzle
- *Pool manager* gives them the puzzle = block

- How does a pool manager know how much to pay each miner?
- Proportional to the work the miner did
- How can we measure this?

Mining pools

Mining shares:

- An incomplete solution to the mining puzzle
- Puzzle to mine the block has the difficulty of 70 zeros
- A share has a difficulty of 50 zeros

- Each time a miner mines a share, it sends it to the pool manager
- Manager pays in proportion with the number of mined shares

- It can happen that the miner that mined the block receives less than others

Mining pools

Mining shares:

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```
4AA087F0A52ED2093FA816E53B9B6317F9B8C1227A61F9481AFED67301F2E3FB
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9C20B06B01A0136F192BD48E0F372A4B9E6BA6ABC36F02FCED22FD9780026A8F
```

Mining pools

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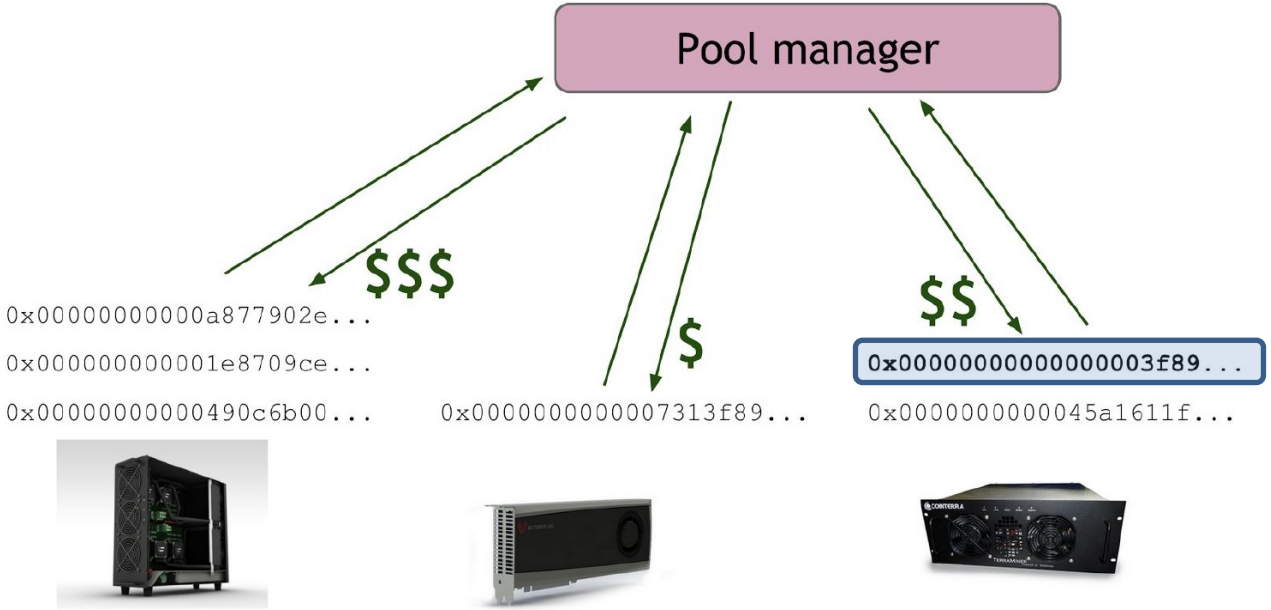
Mining pools

It can happen that the miner that mined the block receives less than others



Mining pools

Operating a pool:

- How to pay the miners?
- Op1: flat fee – manager assumes the risk (pays even no block is mined)
- Op2: proportional – manager pays when a block is mined

- Miners can play with all these options

Mining pools

Mining pools and the 51% attack

- Ghash.io – in 2014 had 50% of the hash power

- The market autoregulates (at least that's what capitalism is based on)

Electricity

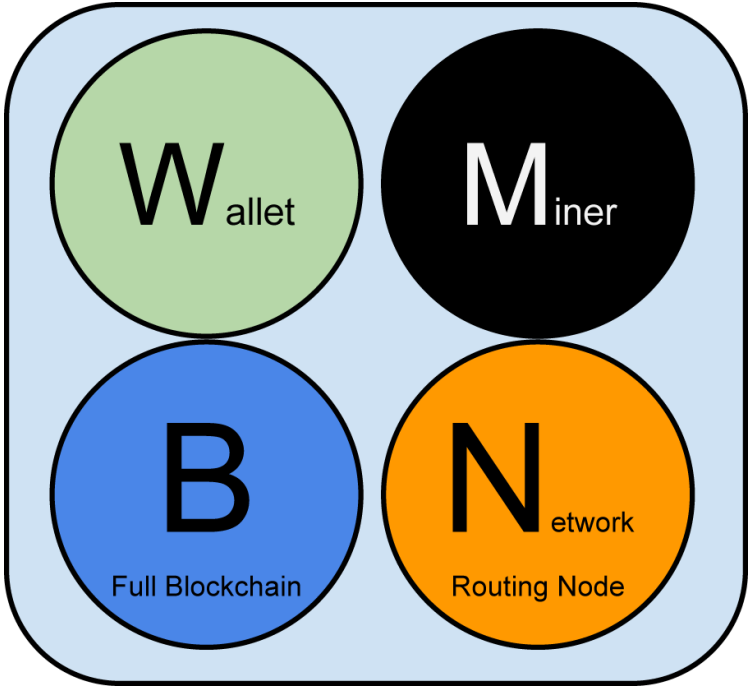
Two schools of thought:

1. Bitcoin mining is wasteful

2. Bitcoin mining is environmentaly friendly in the long term

Network recap

Node functionality



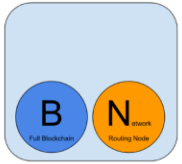
https://github.com/bitcoinbook/bitcoinbook/blob/develop/ch08.asciidoc

Network recap

Node type

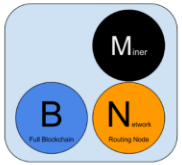
Reference Client (Bitcoin Core)

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



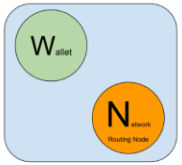
Full Block Chain Node

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

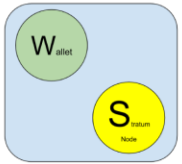
Contains a Wallet and a Network node on the bitcoin P2P protocol, without a blockchain.

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.

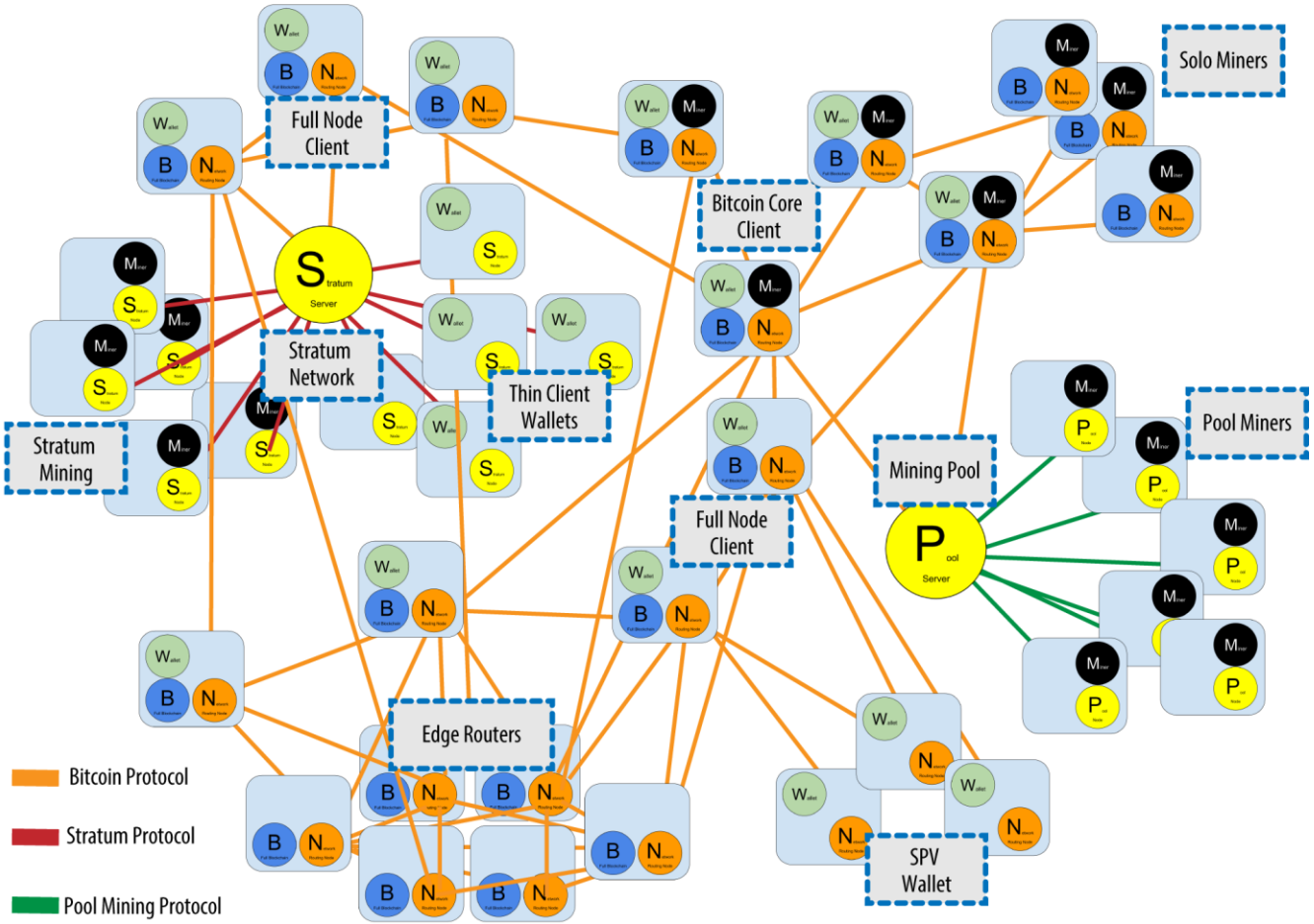


Lightweight (SPV) Stratum wallet

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

https://github.com/bitcoinbook/bitcoinbook/blob/develop/ch08.asciidoc

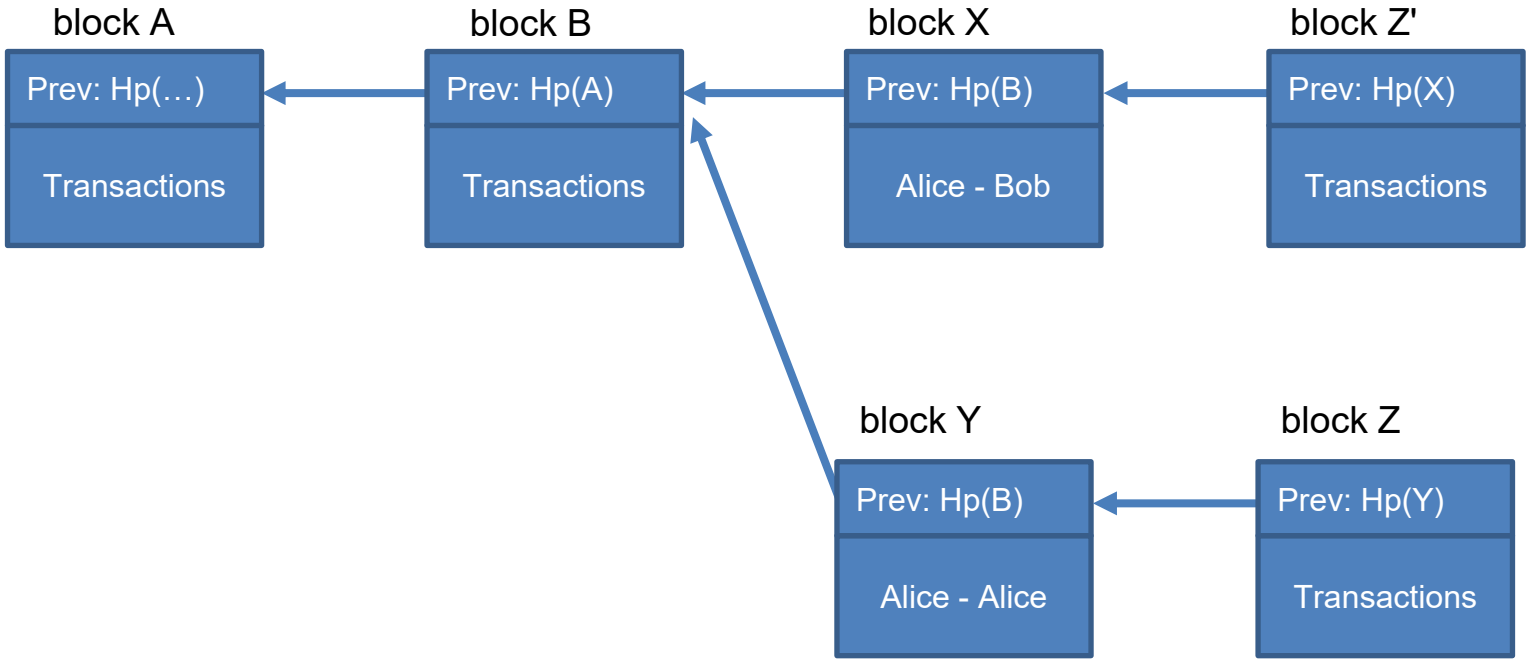
Network recap



https://github.com/bitcoinbook/bitcoinbook/blob/develop/ch08.asciidoc

Forks

Two (or more) branches in the blockchain:



Forks

A rule change

- All the nodes need to upgrade their software
- Does not happen naturally

- **Hard forks vs. Soft forks**

Forks

Hard fork:

- A change that is not forward compatible
- Introduces rules that were not valid previously

- E.g. you should sign double hash of a transaction H(H(tx)), and not only H(tx)

- Nodes that did the upgrade are OK, but the rest are not
- Blockchain divides

- Example: Bitcoin Cash

Forks

Soft fork:

- A change that is forward compatible
- Introduces stricter rules

- Nodes with the old software will accept all new blocks
- Nodes with the new software will reject some blocks that were previously valid
- Miners with the old software can realize that they need to upgrade

- Example: (almost) any BIP; e.g. P2SH