Blockchain Demo - Mining in Centralized Network using Proof of Work (TO BE COMPLETED IN JAN 2019)

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Contents

1. Introduction

Bitcoin, the most well-known blockchain network, is described as

> *"A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution. Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending. We propose a solution to the double-spending problem using a peer-to-peer network.* ***The network timestamps transactions by hashing them into an ongoing chain of hash-based proof-of-work, forming a record that cannot be changed without redoing the proof-of-work. The longest chain not only serves as proof of the sequence of events witnessed, but proof that it came from the largest pool of CPU power****. As long as a majority of CPU power is controlled by nodes that are not cooperating to attack the network, they'll generate the longest chain and outpace attackers. The network itself requires minimal structure. Messages are broadcast on a best effort basis, and nodes can leave and rejoin the network at will, accepting the longest proof-of-work chain as proof of what happened while they were gone."* [1]

In this project, I am going to demonstrate below two characteristics of a proof-of-work blockchain network.

i) building a chain of blocks using hash-based proof-of-work
ii) the Miner who has highest CPU power could add new blocks to the blockchain.

Bitcoin	**This project**
◆ Transactions data, which are verified using digital signature, are packed into blocks.	◆ Arbitrary strings data are packed into blocks.
◆ Data are packed into blocks using merkle tree root hash.	◆ Data are packed into blocks using merkle tree root hash.
◆ Each block could be represented by a byte stream under a pre-defined protocol.	◆ Each block could be represented by a byte stream under a pre-defined protocol.
◆ Blocks are chained using hash-based proof-of-work. It is nearly impossible to change data that are already added into the blockchain.	◆ Blocks are chained using hash-based proof-of-work. It is nearly impossible to change data that are already added into the blockchain.
◆ New blocks are broadcast on a best effort basis in a decentralized network. Usually the Miner who has highest CPU power could add new blocks to the blockchain.	◆ New blocks are broadcast in a centralized network. The Miner who has highest CPU power could add new blocks to the blockchain.

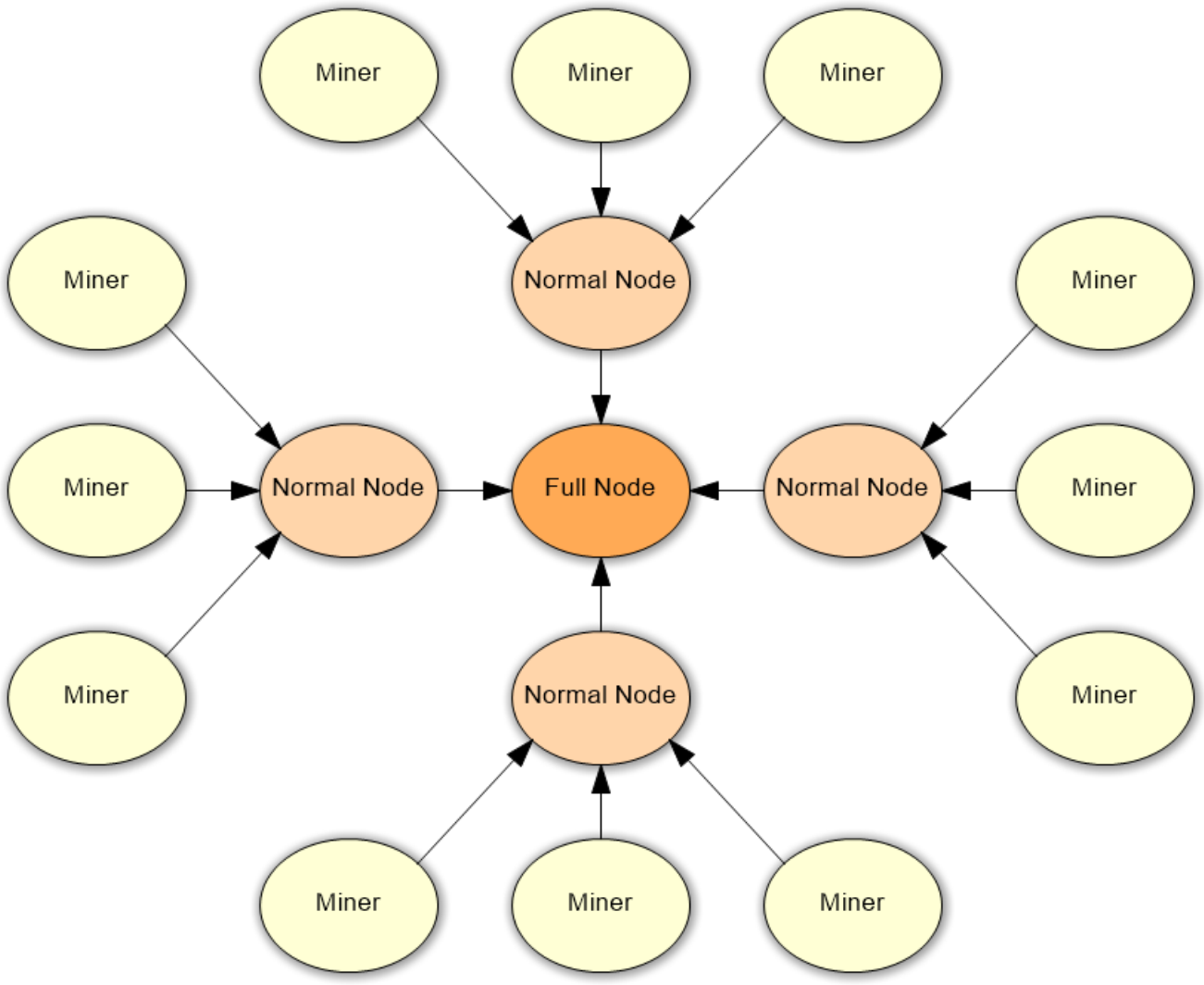
The project is written in GO language. Each port in localhost represents one node. Other characteristics of bitcoin, e.g. digital signatures, peer-to-peer network, broadcasting on a best effort basis, blockchain forks and etc, are ignored in this project.

2. Overview of System

The blockchain platform is a multi-layer server-client network. Three types of application are involved in this centralized network.

- Miner
- Normal Node (as a server)
- Full Node (as a server)

End user could input arbitrary strings in the user interface provided by Miner. The strings data will be saved in the blockchain if the Miner mined successfully.



Miner, who

- receive data from end user
- receive previous block hash from Normal Node
- perform hash-based proof-of-work to pack the data to a new block
- return the new block to Normal Node and try broadcasting

Normal Node, who

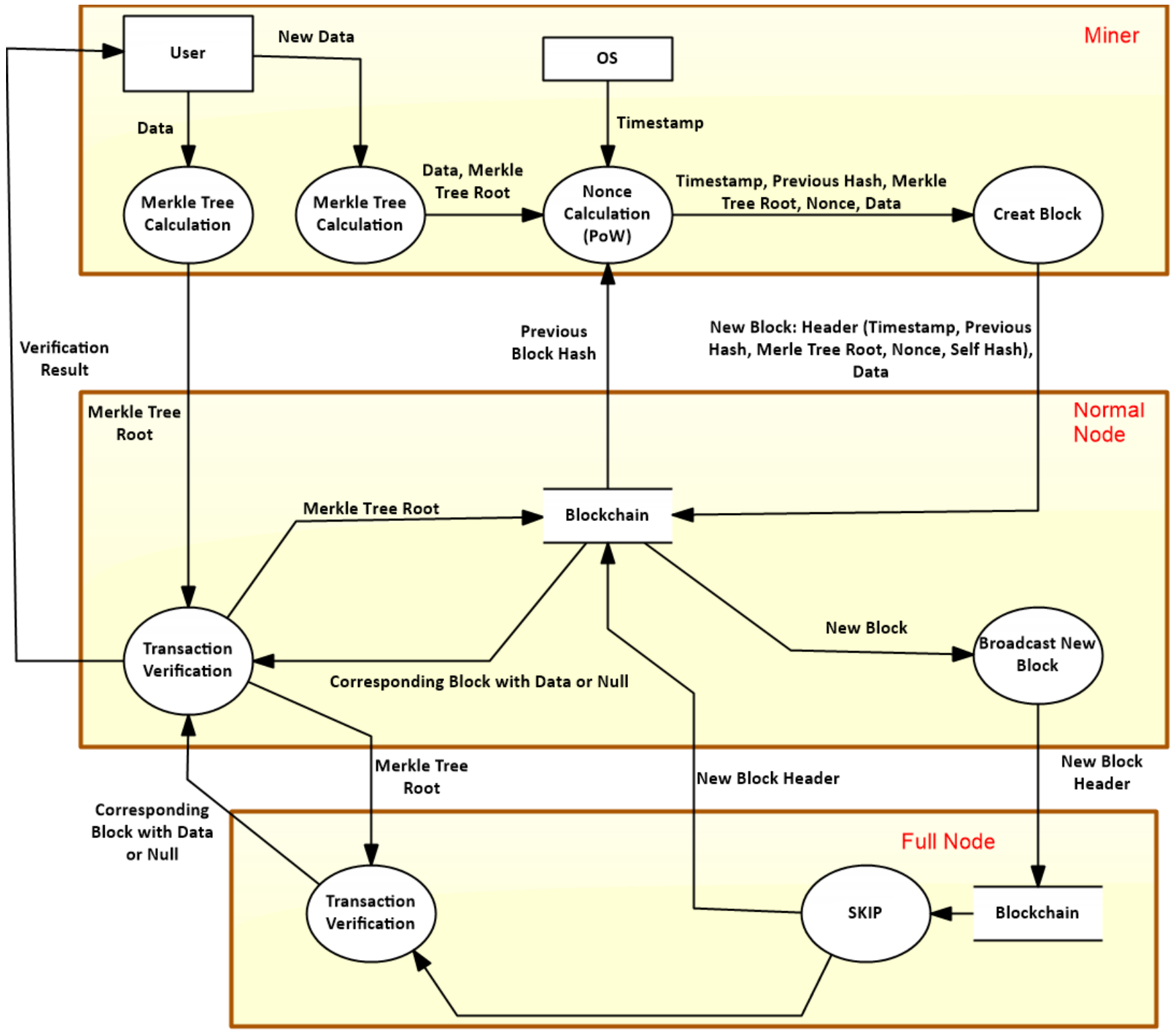
- download blockchain from Full Node.
- receive and verify block from Miner
- try broadcasting new blocks to Full Node
- update locally saved blockchain if Full Node admit the new blocks in blockchain

Full Node, who

- receive and verify blocks from Normal Nodes' broadcasting
- save new blocks to blockchain
- provide the latest blockchain to every Normal Node in the network

Please refer to **Section 7 Demonstration** for examples.

Below is a simplified data flow diagram the shows how the system works.



Miner provides a user interface to end user, and performs proof-of-work. It does not store any data on disk.

Normal Node is responsible for verify blocks from Miner, and performs some searching functions. It stores a partial blockchain on disk. The local blockchains contains (i) all blocks' header and (ii) some block data only.

Full Node is responsible for verify blocks from Normal Node, and performs searching functions if data is not found in Normal Node. It stores the full blockchain on disk. The full blockchains contains (i) all blocks' header and (ii) all block data.

Eight modules are created in this project, and they are responsible for:

Name	**Description**
sysUI.go	Provide a user interface and some network functions.
sysInputConvertor.go	Convert the user's input to byte stream.
nodeMiner.go	Perform network functions and data flow management for Miner.
nodeServer.go	Perform network functions and data flow management for Normal Node/ Full Node.
calMerkleTree.go	Calculate Merkle Tree.
calBlock.go	Create a new block by proof-of-work.
blockchainSyn.go	Valid blockchain, and keep blockchain in Normal Node/ Full Node be consistent. i.e. synchronization.
blockchainDB.go	Manage how the blockchain is stored on disk.

3. System Design – Data & Merkle Tree Root

How Merkle Tree Root is used in Blockchain?

In Bitcoin, a block is composed of a 104-bytes header and variable-size data. [2]

Message Header	start string (magic number)	*4 bytes*	*char[4]*
	command name	*12 bytes*	*char[12]*
	payload size	*4 bytes*	*uint32*
	checksum	*4 bytes*	*char[4]*
Block Header	version	*4 bytes*	*uint32*
	previous block header hash	*32 bytes*	*char[32]*
	merkle root hash	*32 bytes*	*char[32]*
	time	*32 bytes*	*uint32*
	nBits	*4 bytes*	*uint32*
	nonce	*4 bytes*	*uint32*
Data	Transaction 1	*variable*	
	Transaction 2	*variable*	
	…		

Hash is generated from Transactions by using SHA256 and merkle tree. This hash, as known as **merkle tree root**, is a component of block header. Then the block header is chained into blockchain by another hash function. Hence, it is nearly impossible to change transactions that are already added into the blockchain. Further details of merkle tree root is discussed in next page.

In this project, a block is composed of an 80-bytes header and variable-size data.

Message Header	MagicNumber	*8 bytes*	*16-digit hex integer*
Block Header	Timestamp	*4 bytes*	*uint32*
	PrevBlockHash	*32 bytes*	*64-digit hex integer*
	MerkleTreeRoot	*32 bytes*	*64-digit hex integer*
	Nonce	*4 bytes*	*uint32*
Data	String 1	*variable*	
	String 2	*variable*	
	…		

which could be refer to source code *calBlock.go* line 11 to line 32.

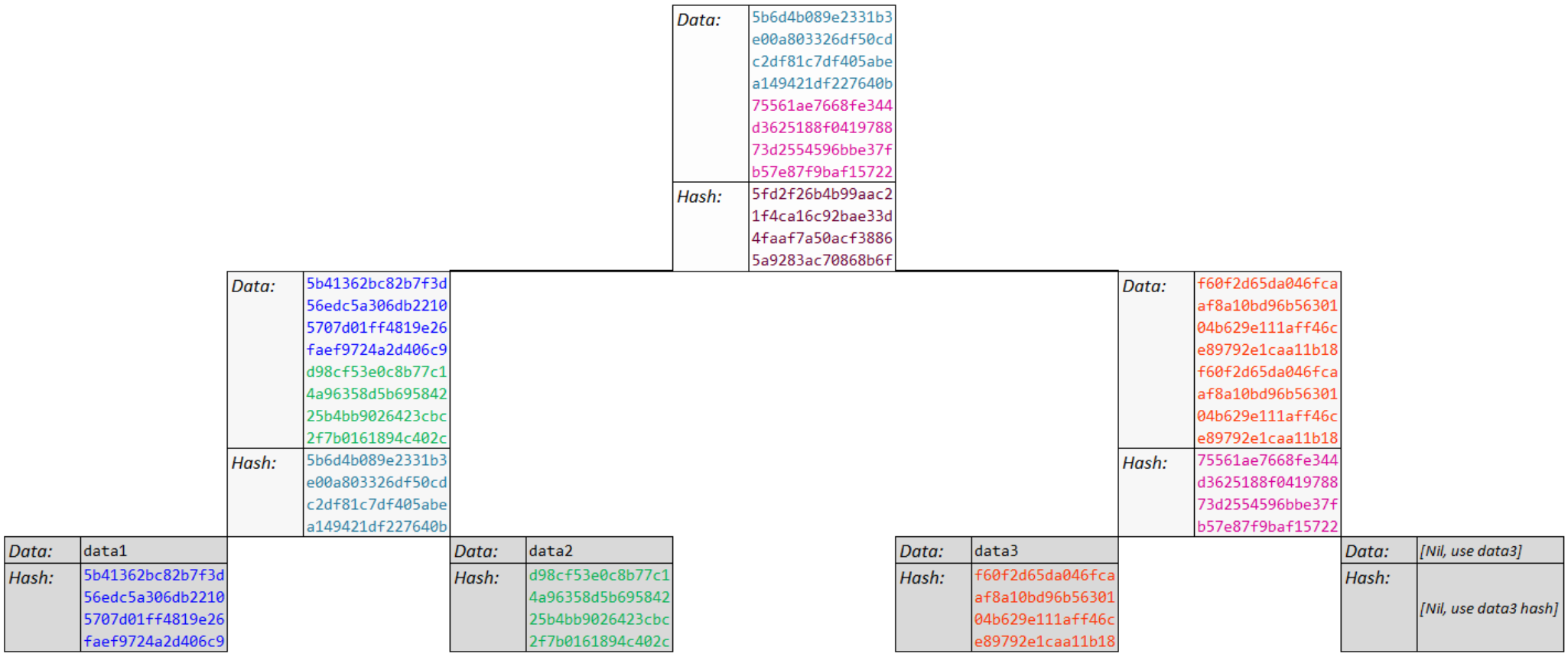
```go
// Block : Define object Block
type Block struct {
    // Block Header
    Timestamp     uint32
    PrevBlockHash []byte
    Root          []byte
    Nonce         uint32
    // Block Data
    Data [][]byte
    // Block hash,  can be computed using header
    CurrBlockHash []byte
    // Byte Stream : Serialized Block Header
    //  Block is defines as
    //  8   bytes:  MagicNumber     (16-digit hexadecimal integer, 00004B61726C4E67)
    //  4   bytes:  Timestamp       (10-digit decimal positive integer)
    //  32  bytes:  PrevBlockHash   (64-digit hexadecimal integer)
    //  32  bytes:  MerkleTreeRoot  (64-digit hexadecimal integer)
    //  4   bytes:  Nonce           (10-digit decimal positive integer)
    //  Variable :  Data            (UTF-8)
    // Length of Header = 80 bytes
    ByteStream []byte
}
```

The two additional attributes, *CurrBlockHash* and *ByteStream,* could be calculated using block header. They are included in blocks for the purpose of easier computation only, which is not necessary attributes for blocks.

How to transform Data to Merkle Tree Root?

A hash function is any function that can be used to map data of arbitrary size to data of a fixed size. SHA256 is used in Bitcoin and this project.

Merkle tree is a method to generate a hash for an array of arbitrary size to data. Then the resulting hash, as know as merkle tree root, is packed into blockchain. Below is an illustrative example of merkle tree root generation.



Step 1: Prepare leaf nodes by calculating the SHA256 hash of each data.
Step 2: Use the combination of two leaf nodes hash as upper level node data. Calculate the hash of upper level node data.
Step 3: Repeat Step 2 until there is only one upper level node. It is the root node.

In this example, the merkle tree root is `5fd2f26b4b99aac21f4ca16c92bae33d4faaf7a50acf38865a9283ac70868b6f`.
And below is the execution result.

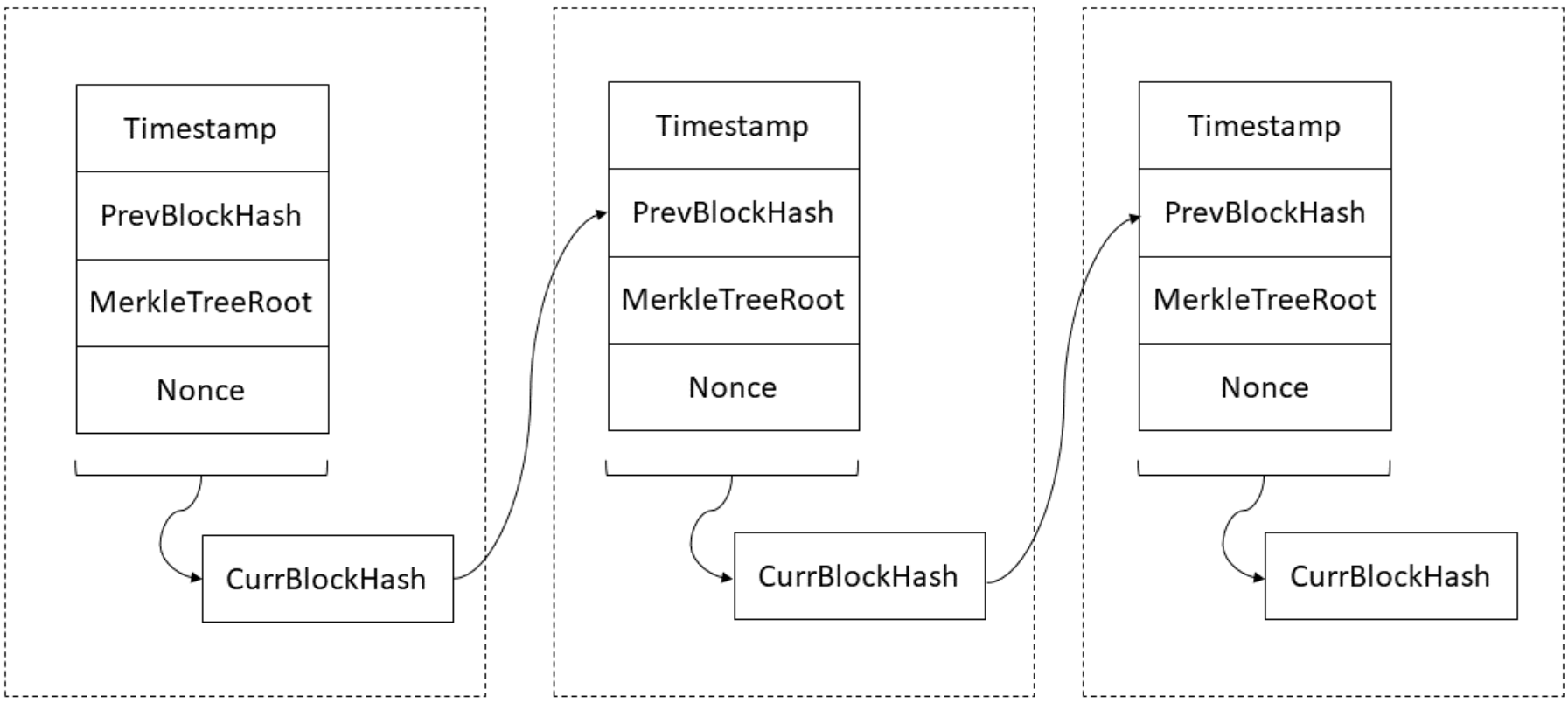
```
C:\Windows\System32\cmd.exe
Self Node port 9999 ; Server Node port 9999 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
30
Tree:   Enter data to be used for Merkle Tree Calculation (seperated by ',')
data1,data2,data3

Leaf Nodes:
5b41362bc82b7f3d56edc5a306db22105707d01ff4819e26faef9724a2d406c9, [data1]
d98cf53e0c8b77c14a96358d5b69584225b4bb9026423cbc2f7b0161894c402c, [data2]
f60f2d65da046fcaaf8a10bd96b5630104b629e111aff46ce89792e1caa11b18, [data3]

Upper Nodes:
 Hash[0]        5b6d4b089e2331b3e00a803326df50cdc2df81c7df405abea149421df227640b
 Data[0]        5b41362bc82b7f3d56edc5a306db22105707d01ff4819e26faef9724a2d406c9d98cf53e0c8b77c14a96358d5b69584225b4bb9026423cbc2f7b0161894c402c
 Hash[1]        75561ae7668fe344d3625188f041978873d2554596bbe37fb57e87f9baf15722
 Data[1]        f60f2d65da046fcaaf8a10bd96b5630104b629e111aff46ce89792e1caa11b18f60f2d65da046fcaaf8a10bd96b5630104b629e111aff46ce89792e1caa11b18

Upper Nodes:
 Hash[0]        5fd2f26b4b99aac21f4ca16c92bae33d4faaf7a50acf38865a9283ac70868b6f
 Data[0]        5b6d4b089e2331b3e00a803326df50cdc2df81c7df405abea149421df227640b75561ae7668fe344d3625188f041978873d2554596bbe37fb57e87f9baf15722


Tree:   The Merkle Tree Root is 5fd2f26b4b99aac21f4ca16c92bae33d4faaf7a50acf38865a9283ac70868b6f

C:\Development - Go\Blockchain - Mining in Centralized Network using PoW\code>
```

Please refer to source code *calMerkleTree.go* for details. You may also refer to https://bitcoin.org/en/developer-reference#merkle-trees for more information about algorithm.

4. System Design – Block & Proof-of-Work

How blocks are chained?

Blocks are chained by hash-based proof-of-work. *PrevBlockHash* in block header represents a hash calculated using previous block header. Each block contains the hash of previous block header, then all blocks forms a blockchain.



Timestamp is the Unix epoch time.
PrevBlockHash is obtained from previous block. In this project, the *PrevBlockHash* of Genesis Block is set to be 64-digits zero.
MerkleTreeRoot is calculated using block data that wish to be packed into the blockchain.
The remaining component, *Nonce*, is obtained from performing proof-of-work.

In this project, a blockchain an array of blocks as below. Please refer to source code *blockchainSyn.go* line 11 to line 16.

```
//Blockchain : Define object Blockchain
type Blockchain struct {
    UserID string
    Blocks []*Block
}
```

The method ValidateChain() in *blockchainSyn.go* line 217 to line 241 shows how this blockchain property is achieved.

```
// ValidateChain :  Check if the whole chain is valid. i.e. all CurrBlockHash & PrevBlockHash match.
func (bc *Blockchain) ValidateChain() bool {

    validFlag := true
    if len(bc.Blocks) == 0 {
        validFlag = false
    } else {

        // Check Genesis Block first:   Only Check CurrBlockHash is Valid
        if bc.Blocks[0].ValidateBlock() == false {
            validFlag = false
        }
        // Then check other Blocks :    Check CurrBlockHash is Valid & PrevBlockHash Matches
        if len(bc.Blocks) > 1 {
            for i := 1; i < len(bc.Blocks); i++ {
                if bc.Blocks[i].ValidateBlock() == false {
                    validFlag = false
                }
                if string(bc.Blocks[i-1].CurrBlockHash) != string(bc.Blocks[i].PrevBlockHash) {
                    validFlag = false
                }
            }
        }
    }
    return validFlag
}
```

How to get Nonce?

To avoid double spending and other attacks, Bitcoin use the hash-based proof-of-work to increase the difficulties in adding new blocks to blockchain. Miners are required to obtain a Nonce by try-and-error to create a valid *CurrBlockHash*, where a valid *CurrBlockHash* means a hash with the first n-bits is zero (i.e. threshold) .

In this project, we will set the threshold to be "the first 4-digit of hex integer is zero". It is different from Bitcoin, but easier for demonstrate. Hence is an example.

Miner added a new block to blockchain:

C:\Windows\System32\cmd.exe

Miner

```
Self Node port 5000 ; Server Node port 3000 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
20
Miner:  Connection 127.0.0.1:5000 <--> 127.0.0.1:3000
- Enter 21 to Mine
- Enter 22 to Retrive all Block Hashes at server node
- Enter 23 to Retrive block in blockchain using a block hash
- Enter 24 to Retrive data  in blockchain using a Merkle Tree Root
21
Miner:  Request PrevBlockHash from Node
Miner:  ...sending message to nearby node
Miner:  ...received message from nearby node
Miner:  Received 0000f2a515696d342bca8a524d9e48d448a5d0d93b7374f5b1bb57c1e72c0c57
Miner:  Enter data to be packed in blockchain (seperated by ',')
testing1,testing2,testing3
Miner:  ...mining...
Miner:  Success! Block information here:
Miner:  Block Information
        > Timestamp     : 1546327649
        > PrevBlockHash : 0000f2a515696d342bca8a524d9e48d448a5d0d93b7374f5b1bb57c1e72c0c57
        > Root          : 98025ab9058eb4796cd45401bb37666f5073a980c35fc140995adb5618993e6b
        > Nonce         : 0000019602
        > CurrBlockHash : 00001035eba13b6dd16bb1d2c9b76844d3bdbfe751b7b2eeb93f8c61536c15ba
        > Data          : [testing1 testing2 testing3]
        Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#       ][TS    ][PrevBlockHash                                                  ][Root                                                  ][Nonce ]
        00004b61726c4e675c2b16610000f2a515696d342bca8a524d9e48d448a5d0d93b7374f5b1bb57c1e72c0c5798025ab9058eb4796cd45401bb37666f5073a980c35fc140995adb5618993e6b00004c92

Miner:  Now send the Block to server node.
Miner:  ...sending message to nearby node
Miner:  ...received message from nearby node
Miner:  Result -  Success - Blockchain is updated.
```

Take the **block with *Timestamp* = 1546327649** as example.

The user would like to save strings *[testing1, testing2, testing3]* into the blockchain. First user told Miner to start mining procedures. Then the Miner

1) Obtain pervious block hash from Nodes.
   The result is `0000f2a515696d342bca8a524d9e48d448a5d0d93b7374f5b1bb57c1e72c0c57`.
2) Obtain strings from user.
3) Calculate the merkle tree root using the strings.
   The result is `98025ab9058eb4796cd45401bb37666f5073a980c35fc140995adb5618993e6b`.
4) Start creating a new block. From the screenshots, we can see that *Nonce* = 0000019602 for the new block.
   It means that the Miner found the valid *Nonce* after 19,602 trials.
5) The block header of this new block is:

Magic Number	`00004b61726c4e67`
Timestamp	`5c2b1661`
PrevBlockHash	`0000f2a515696d342bca8a524d9e48d448a5d0d93b7374f5b1bb57c1e72c0c57`
MerkleTreeRoot	`98025ab9058eb4796cd45401bb37666f5073a980c35fc140995adb5618993e6b`
Nonce	`00004c92`

   The hash of this header, *CurrBlockHash*, is `00001035eba13b6dd16bb1d2c9b76844d3bdbfe751b7b2eeb93f8c61536c15ba`. The first 4-digits are zero which means it is a valid block.

Proof-of-work is a time-consuming algorithm. In Bitcoin, it takes approximately 10 minutes to get a valid *Nonce*. Only the Miner who first obtain a valid *CurrBlockHash*, i.e. the one who has the highest CPU power, could add a block into the blockchain. This "First Come First Serve" characteristic will be further discussed in next section.

5. System Design – Blockchain in Centralized Network

In Bitcoin, blockchain is distributed in a peer-to-peer decentralized network. Miner will add new blocks to "the most-difficult-to-recreate chain"[2] to ensure only one chain exists.

In this project, a centralized network is adopted and there is always one chain only. All Miner will add new blocks to blockchain held by Full Node. Miner who send a new block to Full Node first could add new block to the blockchain.

I will discuss about how data are exchanged among nodes in this section. Nodes send messages to nearby nodes to request desired information using TCP. "GetBlock", "GetData" and "Inv" will be discussed.

"*inv*":	the *Inv* message (inventory message) transmits one or more inventories of objects known to the transmitting peer.
"*GetBlock*"	the *GetBlocks* message requests an *inv* message that provides block header hashes starting from a particular point in the blockchain.
"*GetData*"	The *GetData* message requests one or more data objects from another node. The objects are requested by an inventory, which the requesting node typically received previously by way of an I*nv* message.

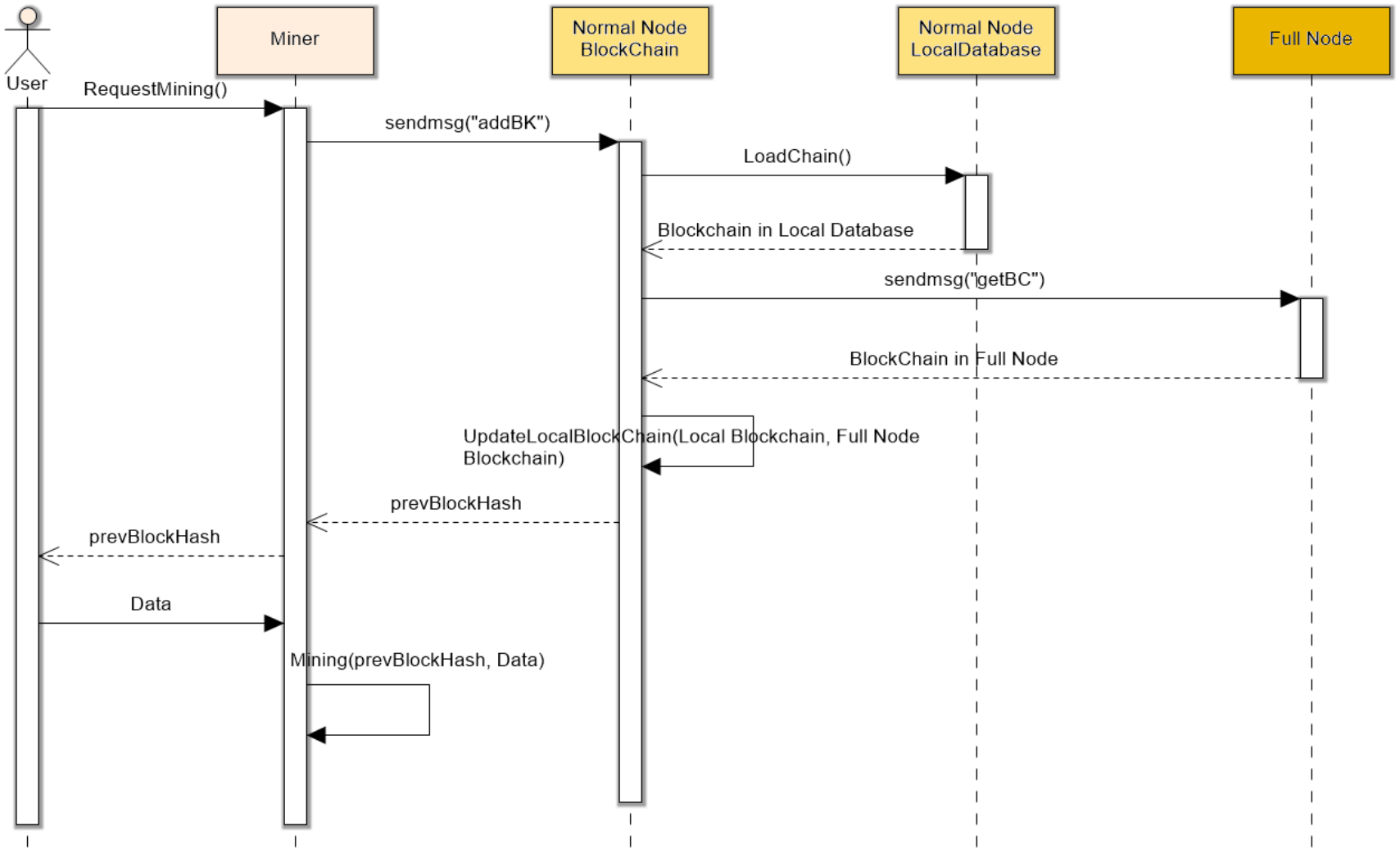
This set of messages are also used in Bitcoin. [3]

<u>Synchronization of Blockchain</u>

It is a centralized network and synchronization could be achieved by:

- Only Full Node contains the most updated blockchain.
- Only blocks admitted by Full Node could be added to the blockchain.
- The block reach Full Node first will be admitted.
- Normal Node should update its local blockchain database from Full Node before performing any actions.

<u>Example – Mining Part 1: Collect Information to Create a New Block</u>

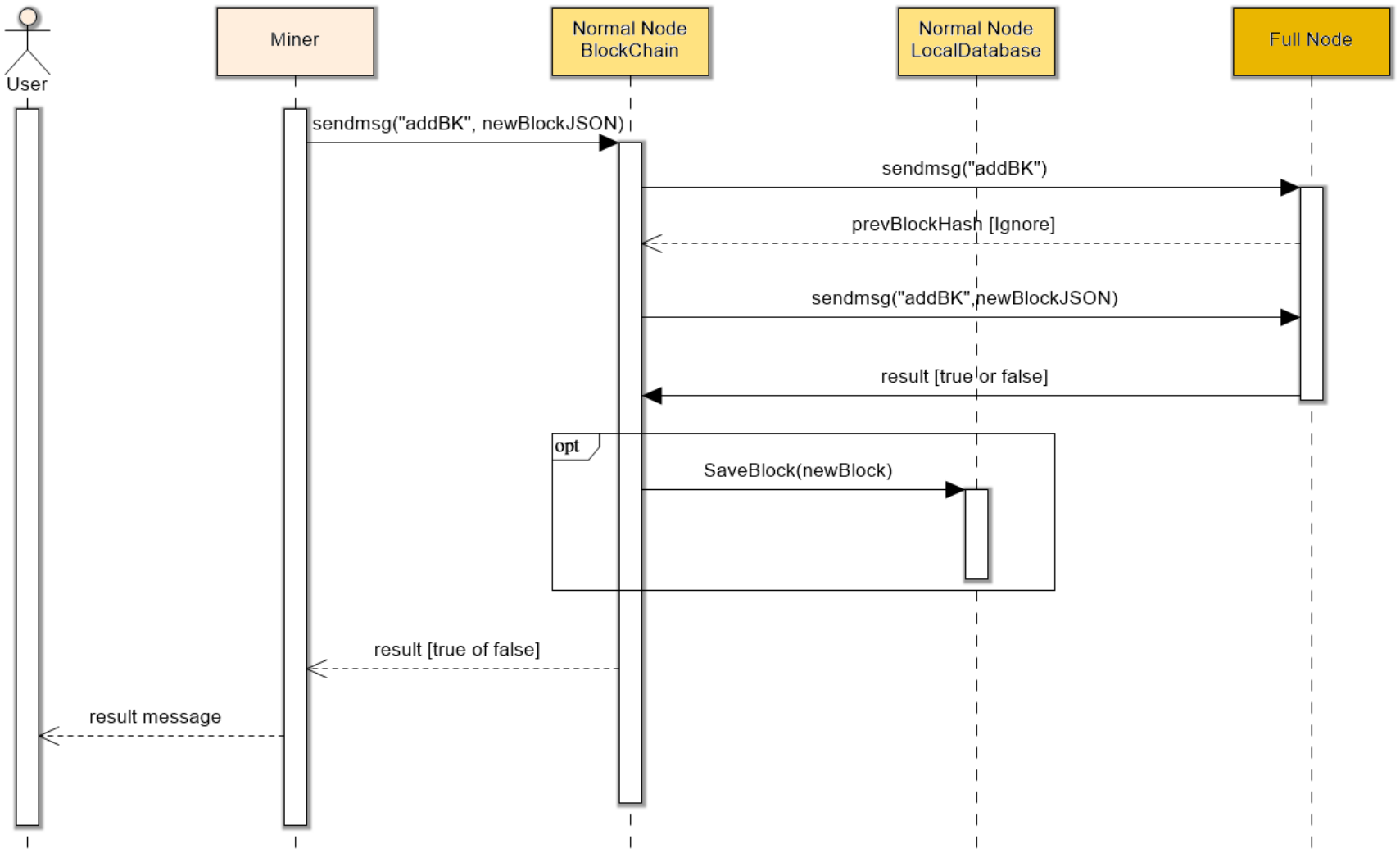


Note: "getBC" is equivalent to "GetBlock" in Bitcoin. Only block header hashes are returned.

Explanation:

Step 1: Miner sends a message "addBK" to Node.
Step 2: Node reads blockchain from database on disk.
Step 3: Node requests blockchain from Full Node.
Step 4: Node updates its local database on disk.
Step 5: Node returns prevBlockHash to Miner.
Step 6: Miner starts mining (i.e. Merkle Tree Calculation & Proof of Work).

Example – Mining Part 2: Try to Add a New Block to Blockchain

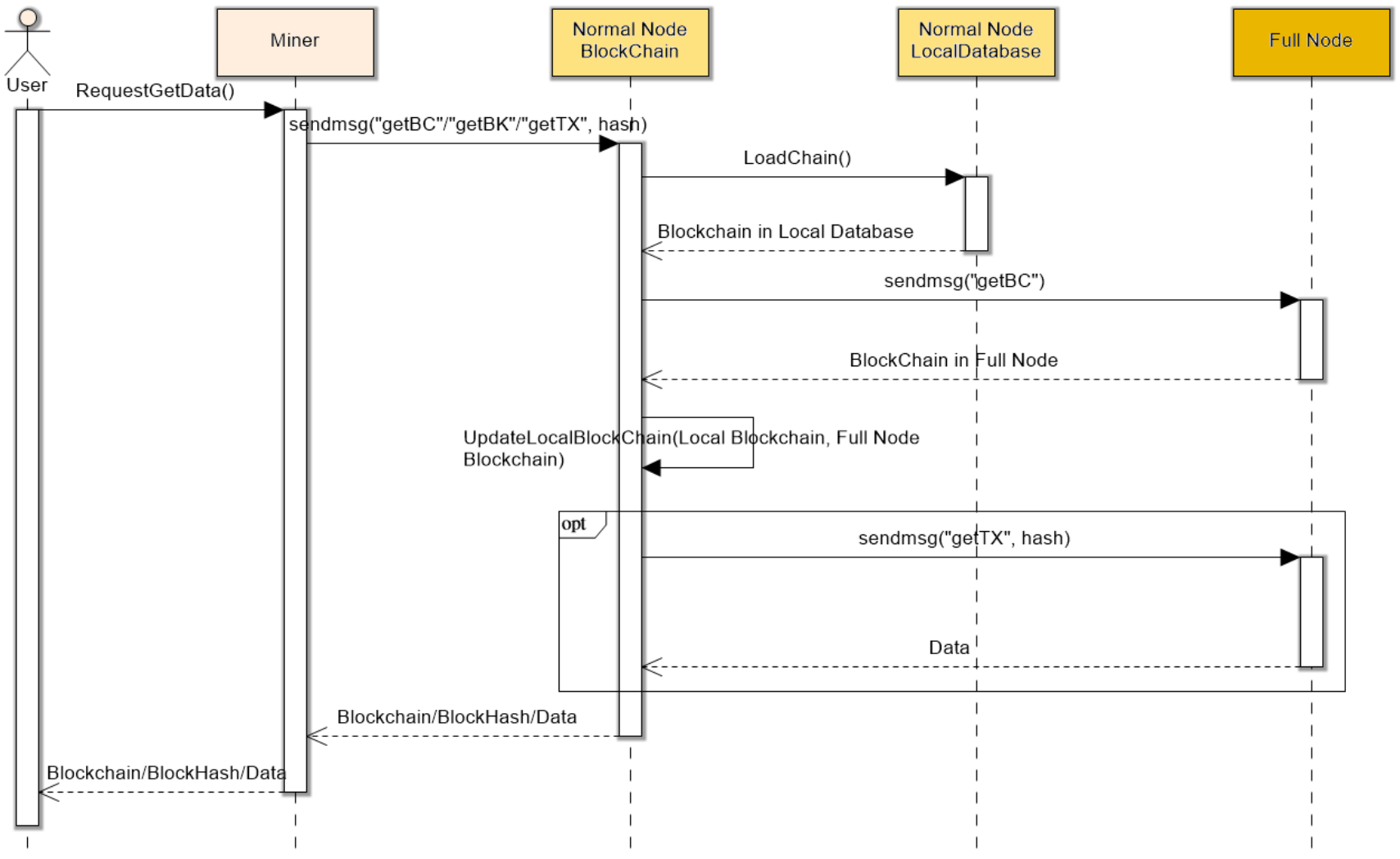


Note: Miner is expected to send "addBK" twice. Node should first reply a "PrevBlockHash", then reply a "True or False" result.

Explanation:

Step 1: Miner sends a message "addBK" and the newly mined block (in JSON) to Node.
Step 2: Node sends a message "addBK" and the newly mined block (in JSON) to Full Node.
Step 3: Full Node saves the block in Full Node blockchain if it is the fastest one reached.
Step 4: Node saves the block in local blockchain if Full Node admitted the block.
Step 5: Miner receives a result message of success/ fail.

Example – Data Extraction from Blockchain: Block Header Hashes/ Single Block/ String Data



Note: "getBK"/"getTX" is equivalent to "GetData" in Bitcoin.

Explanation:

Step 1: Miner sends a message "getBC/ getBK/ getTX" to Node.
Step 2: Node updates its local database on disk by checking with Full Node. Start searching desired data in local database.
Step 3: In case that desired data is not found, Node will request the data from Full Node.
Step 4: Node send the requested data to Miner.

6. System Design – Data Storage

In this project, blockchain is stored in JSON on disk. It allows us to read the blockchain using text editor, which makes demonstration easier.

Below is a typical blockchain stored by a Full Node.


```
[
    {
        "Timestamp": 1546327577,
        "PrevBlockHash": "AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA=",
        "Root": "yBySmtuUuIFg8ZSduYoSMJb2v71wtqXYKjDTc6DMk9Q=",
        "Nonce": 6516,
        "Data": [
            "TmV3",
            "R2VuZXNpcw==",
            "QmxvY2s="
        ],
        "CurrBlockHash": "AADypRVpbTQryopSTZ5I1Eil0Nk7c3T1sbtXwecsDFc=",
        "ByteStream": "AABLYXJsTmdcKxYZAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAADIHJKa25S4gWDxlJ25ihIwlva/vXC2pdgqMNNzoMyT1AAAGXQ="
    },
    {
        "Timestamp": 1546327649,
        "PrevBlockHash": "AADypRVpbTQryopSTZ5I1Eil0Nk7c3T1sbtXwecsDFc=",
        "Root": "mAJauQWOtHls1FQBuzdmb1BzqYDDX8FAmVrbVhiZPms=",
        "Nonce": 19602,
        "Data": [
            "dGVzdGluZzE=",
            "dGVzdGluZzI=",
            "dGVzdGluZzM="
        ],
        "CurrBlockHash": "AAAQNeuhO23Ra7HSybdoRNO9v+dRt7LuuT+MYVNsFbo=",
        "ByteStream": "AABLYXJsTmdcKxZhAADypRVpbTQryopSTZ5I1Eil0Nk7c3T1sbtXwecsDFeYAlq5BY60eWzUVAG7N2ZvUHOpgMNfwUCZWttWGJk+awAATJI="
    }
]
```


Below is a typical blockchain stored by a Normal Node.


```
[
    {
        "Timestamp": 1546327577,
        "PrevBlockHash": "AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA=",
        "Root": "yBySmtuUuIFg8ZSduYoSMJb2v71wtqXYKjDTc6DMk9Q=",
        "Nonce": 6516,
        "Data": null,
        "CurrBlockHash": "AADypRVpbTQryopSTZ5I1Eil0Nk7c3T1sbtXwecsDFc=",
        "ByteStream": null
    },
    {
        "Timestamp": 1546327649,
        "PrevBlockHash": "AADypRVpbTQryopSTZ5I1Eil0Nk7c3T1sbtXwecsDFc=",
        "Root": "mAJauQWOtHls1FQBuzdmb1BzqYDDX8FAmVrbVhiZPms=",
        "Nonce": 19602,
        "Data": [
            "dGVzdGluZzE=",
            "dGVzdGluZzI=",
            "dGVzdGluZzM="
        ],
        "CurrBlockHash": "AAAQNeuhO23Ra7HSybdoRNO9v+dRt7LuuT+MYVNsFbo=",
        "ByteStream": "AABLYXJsTmdcKxZhAADypRVpbTQryopSTZ5I1Eil0Nk7c3T1sbtXwecsDFeYAlq5BY60eWzUVAG7N2ZvUHOpgMNfwUCZWttWGJk+awAATJI="
    }
]
```


Please note that the Genesis Block is mined by Full Node when the system is initialized. Hence, the Normal Node does not store data of Genesis Block.

Please refer to *blockchainDB.go* for details.

7. Demonstration

Demonstration of Mining

Step 1: Set up the Full Node. Full Node mine the Genesis Block if not blockchain database is found on disk.

```
C:\Windows\System32\cmd.exe - run
The is a program to demonstrate some key characteristics of Blockchain.                                    Full Node
To run this program, you should set up at least two node and one miner.
> One Full Node, UserID = 9999
> At least one Normal Node
> At least one Miner
> UserID of Normal Node/ Miner could any integer between 1025 and 65535

Please enter userID of you: 9999
Please enter userID of Node you wish to connect: 9999

Self Node port 9999 ; Server Node port 9999 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
10
- Enter 11 to Show Blockchain in this server
- Enter 12 to Start acting as a server
12
Node:   Blockchain at local Database:
Chain:  Block #0
        > Timestamp     : 1546337922
        > PrevBlockHash : 0000000000000000000000000000000000000000000000000000000000000000
        > Root          : c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
        > Nonce         : 0000012774
        > CurrBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Data          : [New Genesis Block]
        Block #0 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#       ][TS    ][PrevBlockHash                                                    ][Root                                                    ][Nonce ]
        00004b61726c4e675c2b3e8200000000000000000000000000000000000000000000000000000000000000c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4000031e6

Node:   Server Listening on port 9999
```

Step 2: Set up Normal Node. The Normal Node should be connected to Full Node (Port 9999).

```
C:\Windows\System32\cmd.exe - run
The is a program to demonstrate some key characteristics of Blockchain.                                    Normal Node
To run this program, you should set up at least two node and one miner.
> One Full Node, UserID = 9999
> At least one Normal Node
> At least one Miner
> UserID of Normal Node/ Miner could any integer between 1025 and 65535

Please enter userID of you: 3000
Please enter userID of Node you wish to connect: 9999

Self Node port 3000 ; Server Node port 9999 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
10
- Enter 11 to Show Blockchain in this server
- Enter 12 to Start acting as a server
12
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   Blockchain at local Database:
Chain:  Block #0
        > Timestamp     : 1546337922
        > PrevBlockHash : 0000000000000000000000000000000000000000000000000000000000000000
        > Root          : c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
        > Nonce         : 0000012774
        > CurrBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Data          : []
        Block #0 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#       ][TS    ][PrevBlockHash                                                    ][Root                                                    ][Nonce ]


Node:   Server Listening on port 3000
```

Step 3: Set up Miner. Miner should be connected to Normal Node (Port 3000).

```
C:\Windows\System32\cmd.exe - run
The is a program to demonstrate some key characteristics of Blockchain.                                    Miner
To run this program, you should set up at least two node and one miner.
> One Full Node, UserID = 9999
> At least one Normal Node
> At least one Miner
> UserID of Normal Node/ Miner could any integer between 1025 and 65535

Please enter userID of you: 5000
Please enter userID of Node you wish to connect: 3000

Self Node port 5000 ; Server Node port 3000 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
20
Miner:  Connection 127.0.0.1:5000 <--> 127.0.0.1:3000
- Enter 21 to Mine
- Enter 22 to Retrive all Block Hashes at server node
- Enter 23 to Retrive block in blockchain using a block hash
- Enter 24 to Retrive data  in blockchain using a Merkle Tree Root
21
Miner:  Request PrevBlockHash from Node
Miner:  ...sending message to nearby node
```

Step 4: Normal Node received request from Miner. After update the local blockchain from Full Node, it reply PrevBlockHash.

C:\Windows\System32\cmd.exe - run

Normal Node

```
The is a program to demonstrate some key characteristics of Blockchain.
To run this program, you should set up at least two node and one miner.
> One Full Node, UserID = 9999
> At least one Normal Node
> At least one Miner
> UserID of Normal Node/ Miner could any integer between 1025 and 65535

Please enter userID of you: 3000
Please enter userID of Node you wish to connect: 9999

Self Node port 3000 ; Server Node port 9999 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
10
- Enter 11 to Show Blockchain in this server
- Enter 12 to Start acting as a server
12
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   Blockchain at local Database:
Chain:  Block #0
        > Timestamp     : 1546337922
        > PrevBlockHash : 0000000000000000000000000000000000000000000000000000000000000000
        > Root          : c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
        > Nonce         : 0000012774
        > CurrBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Data          : []
        Block #0 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                          ][Nonce ]


Node:   Server Listening on port 3000
Node:   <127.0.0.1:5000> Connection established
Node:   <127.0.0.1:5000> Miner would like to add a block to blockchain
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   <127.0.0.1:5000> Return PrevBlockHash to Miner
Node:   <127.0.0.1:5000> Waiting for new block
```

Step 5: Miner received PrevBlockHash. After end user input strings, it starts mining by trying Nonce.
Once mining is completed, it sends the new block to Normal Node.

C:\Windows\System32\cmd.exe

Miner

```
The is a program to demonstrate some key characteristics of Blockchain.
To run this program, you should set up at least two node and one miner.
> One Full Node, UserID = 9999
> At least one Normal Node
> At least one Miner
> UserID of Normal Node/ Miner could any integer between 1025 and 65535

Please enter userID of you: 5000
Please enter userID of Node you wish to connect: 3000

Self Node port 5000 ; Server Node port 3000 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
20
Miner:  Connection 127.0.0.1:5000 <--> 127.0.0.1:3000
- Enter 21 to Mine
- Enter 22 to Retrive all Block Hashes at server node
- Enter 23 to Retrive block in blockchain using a block hash
- Enter 24 to Retrive data  in blockchain using a Merkle Tree Root
21
Miner:  Request PrevBlockHash from Node
Miner:  ...sending message to nearby node
Miner:  ...received message from nearby node
Miner:  Received 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
Miner:  Enter data to be packed in blockchain (seperated by ',')
test1,test2,test3
Miner:  ...mining...
Miner:  Success! Block information here:
Miner:  Block Information
        > Timestamp     : 1546338594
        > PrevBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Root          : 726f390d1bce78e5494841a6dc794be84eac770ad999294a31e346aa2f8304a3
        > Nonce         : 0000016112
        > CurrBlockHash : 000075a9e88e1de123981ad0214c9ee708806c56c1dea2b19d81bcf1adc2be80
        > Data          : [test1 test2 test3]
        Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                          ][Nonce ]
        00004b61726c4e675c2b41220000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395726f390d1bce78e5494841a6dc794be84eac770ad999294a31e346aa2f8304a300003ef0

Miner:  Now send the Block to server node.
Miner:  ...sending message to nearby node
```

Step 6: Normal Node received new block and transfer it to Full Node.

C:\Windows\System32\cmd.exe - run

Normal Node

```
C:\Development - Go\Blockchain - Mining in Centralized Network using PoW\code>run
The is a program to demonstrate some key characteristics of Blockchain.
To run this program, you should set up at least two node and one miner.
> One Full Node, UserID = 9999
> At least one Normal Node
> At least one Miner
> UserID of Normal Node/ Miner could any integer between 1025 and 65535

Please enter userID of you: 3000
Please enter userID of Node you wish to connect: 9999

Self Node port 3000 ; Server Node port 9999 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
10
- Enter 11 to Show Blockchain in this server
- Enter 12 to Start acting as a server
12
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   Blockchain at local Database:
Chain:  Block #0
        > Timestamp     : 1546337922
        > PrevBlockHash : 0000000000000000000000000000000000000000000000000000000000000000
        > Root          : c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
        > Nonce         : 0000012774
        > CurrBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Data          : []
        Block #0 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                  ][Nonce ]


Node:   Server Listening on port 3000
Node:   <127.0.0.1:5000> Connection established
Node:   <127.0.0.1:5000> Miner would like to add a block to blockchain
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   <127.0.0.1:5000> Return PrevBlockHash to Miner
Node:   <127.0.0.1:5000> Waiting for new block
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Chain:  Connected to Full Node for Adding Block: 127.0.0.1:9999
```

Step 7: Full Node check if the block is the first one reach. If yes, it will be added to blockchain. Then return result to Normal Node.

C:\Windows\System32\cmd.exe - run

Full Node

```
Node:   Server Listening on port 9999
Node:   <127.0.0.1:1264> Connection established
Node:   <127.0.0.1:1264> Client would like to retrive all block hashes
Node:   <127.0.0.1:1264> Return information to client.
Node:   <127.0.0.1:1264> Connection is closed
Node:   <127.0.0.1:1475> Connection established
Node:   <127.0.0.1:1475> Client would like to retrive all block hashes
Node:   <127.0.0.1:1475> Return information to client.
Node:   <127.0.0.1:1475> Connection is closed
Node:   <127.0.0.1:1639> Connection established
Node:   <127.0.0.1:1639> Client would like to retrive all block hashes
Node:   <127.0.0.1:1639> Return information to client.
Node:   <127.0.0.1:1639> Connection is closed
Node:   <127.0.0.1:1640> Connection established
Node:   <127.0.0.1:1640> Client would like to retrive all block hashes
Node:   <127.0.0.1:1640> Return information to client.
Node:   <127.0.0.1:1640> Connection is closed
Node:   <127.0.0.1:1641> Connection established
Node:   <127.0.0.1:1641> Miner would like to add a block to blockchain
Node:   <127.0.0.1:1641> Return PrevBlockHash to Miner
Node:   <127.0.0.1:1641> Waiting for new block
Chain:  Success in adding Block to Local Database.
Node:   Blockchain now:
Chain:  Block #0
        > Timestamp     : 1546337922
        > PrevBlockHash : 0000000000000000000000000000000000000000000000000000000000000000
        > Root          : c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
        > Nonce         : 0000012774
        > CurrBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Data          : [New Genesis Block]
        Block #0 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                  ][Nonce ]
        00004b61726c4e675c2b3e8200000000000000000000000000000000000000000000000000000000000000c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4000031e6

Chain:  Block #1
        > Timestamp     : 1546338594
        > PrevBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Root          : 726f390d1bce78e5494841a6dc794be84eac770ad999294a31e346aa2f8304a3
        > Nonce         : 0000016112
        > CurrBlockHash : 000075a9e88e1de123981ad0214c9ee708806c56c1dea2b19d81bcf1adc2be80
        > Data          : [test1 test2 test3]
        Block #1 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                  ][Nonce ]
        00004b61726c4e675c2b41220000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395726f390d1bce78e5494841a6dc794be84eac770ad999294a31e346aa2f8304a300003ef0

Node:   <127.0.0.1:1642> Connection established
Node:   <127.0.0.1:1641> Connection is closed
Node:   <127.0.0.1:1642> Client would like to retrive all block hashes
Node:   <127.0.0.1:1642> Return information to client.
Node:   <127.0.0.1:1642> Connection is closed
```

Step 8: Normal Node is informed that the block is added to Full Node. It updates the local database, then return result to Miner.

選取 C:\Windows\System32\cmd.exe - run

Normal Node

```
- Enter 11 to Show Blockchain in this server
- Enter 12 to Start acting as a server
12
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   Blockchain at local Database:
Chain:  Block #0
        > Timestamp     : 1546337922
        > PrevBlockHash : 0000000000000000000000000000000000000000000000000000000000000000
        > Root          : c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
        > Nonce         : 0000012774
        > CurrBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Data          : []
        Block #0 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                            ][Nonce ]


Node:   Server Listening on port 3000
Node:   <127.0.0.1:5000> Connection established
Node:   <127.0.0.1:5000> Miner would like to add a block to blockchain
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   <127.0.0.1:5000> Return PrevBlockHash to Miner
Node:   <127.0.0.1:5000> Waiting for new block
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Chain:  Connected to Full Node for Adding Block: 127.0.0.1:9999
Chain:  Result -  Success in adding Block to Full Node
Chain:  Success in adding Block to Local Database.
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   Blockchain now:
Chain:  Block #0
        > Timestamp     : 1546337922
        > PrevBlockHash : 0000000000000000000000000000000000000000000000000000000000000000
        > Root          : c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
        > Nonce         : 0000012774
        > CurrBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Data          : []
        Block #0 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                            ][Nonce ]


Chain:  Block #1
        > Timestamp     : 1546338594
        > PrevBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Root          : 726f390d1bce78e5494841a6dc794be84eac770ad999294a31e346aa2f8304a3
        > Nonce         : 0000016112
        > CurrBlockHash : 000075a9e88e1de123981ad0214c9ee708806c56c1dea2b19d81bcf1adc2be80
        > Data          : [test1 test2 test3]
        Block #1 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                            ][Nonce ]
        00004b61726c4e675c2b41220000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395726f390d1bce78e5494841a6dc794be84eac770ad999294a31e346aa2f8304a300003ef0

Node:   <127.0.0.1:5000> Connection is closed
```

Step 9: Miner is informed that the block is added to Blockchain.

C:\Windows\System32\cmd.exe

Miner

```
The is a program to demonstrate some key characteristics of Blockchain.
To run this program, you should set up at least two node and one miner.
> One Full Node, UserID = 9999
> At least one Normal Node
> At least one Miner
> UserID of Normal Node/ Miner could any integer between 1025 and 65535

Please enter userID of you: 5000
Please enter userID of Node you wish to connect: 3000

Self Node port 5000 ; Server Node port 3000 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
20
Miner:  Connection 127.0.0.1:5000 <--> 127.0.0.1:3000
- Enter 21 to Mine
- Enter 22 to Retrive all Block Hashes at server node
- Enter 23 to Retrive block in blockchain using a block hash
- Enter 24 to Retrive data  in blockchain using a Merkle Tree Root
21
Miner:  Request PrevBlockHash from Node
Miner:  ...sending message to nearby node
Miner:  ...received message from nearby node
Miner:  Received 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
Miner:  Enter data to be packed in blockchain (seperated by ',')
test1,test2,test3
Miner:  ...mining...
Miner:  Success! Block information here:
Miner:  Block Information
        > Timestamp     : 1546338594
        > PrevBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Root          : 726f390d1bce78e5494841a6dc794be84eac770ad999294a31e346aa2f8304a3
        > Nonce         : 0000016112
        > CurrBlockHash : 000075a9e88e1de123981ad0214c9ee708806c56c1dea2b19d81bcf1adc2be80
        > Data          : [test1 test2 test3]
        Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                            ][Nonce ]
        00004b61726c4e675c2b41220000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395726f390d1bce78e5494841a6dc794be84eac770ad999294a31e346aa2f8304a300003ef0

Miner:  Now send the Block to server node.
Miner:  ...sending message to nearby node
Miner:  ...received message from nearby node
Miner:  Result -  Success - Blockchain is updated.
```

Demonstration of Searching Data

Step 1: Miner would like to search if *[New, Genesis, Block]* is stored in blockchain.
The merkle tree root is `c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4`.
Miner send search request to Normal Node.

C:\Windows\System32\cmd.exe - run

Miner

```
The is a program to demonstrate some key characteristics of Blockchain.
To run this program, you should set up at least two node and one miner.
> One Full Node, UserID = 9999
> At least one Normal Node
> At least one Miner
> UserID of Normal Node/ Miner could any integer between 1025 and 65535

Please enter userID of you: 6000
Please enter userID of Node you wish to connect: 3000

Self Node port 6000 ; Server Node port 3000 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
20
Miner:  Connection 127.0.0.1:6000 <--> 127.0.0.1:3000
- Enter 21 to Mine
- Enter 22 to Retrive all Block Hashes at server node
- Enter 23 to Retrive block in blockchain using a block hash
- Enter 24 to Retrive data  in blockchain using a Merkle Tree Root
24
Miner:  Please input the Merkle Tree Root here c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
Miner:  Request the Block with Merkle Tree Root c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
Miner:  ...sending message to nearby node
```

Step 2: Normal Node received search request from Miner. It searches local database, but the data is not found.
Hence, Normal Node send search request to Full Node.

C:\Windows\System32\cmd.exe - run

Normal Node

```
Node:   <127.0.0.1:6000> Connection established
Node:   <127.0.0.1:6000> Client would like to check if a data exists
Node:   <127.0.0.1:6000> The Merkle Tree Root is c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   <127.0.0.1:6000> Target Block is not found in local Blockchain, now search in Full Node
```

Step 3: Full Node received search request from Normal Node. It searches local database, and the data is found.
Hence, Full Node reply the corresponding block to Normal Node.

C:\Windows\System32\cmd.exe - run

Full Node

```
Node:   <127.0.0.1:2314> Connection established
Node:   <127.0.0.1:2314> Client would like to check if a data exists
Node:   <127.0.0.1:2314> The Merkle Tree Root is c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
Node:   <127.0.0.1:2314> Target Block is found in local Blockchain
Node:   <127.0.0.1:2314> Return information to client.
Node:   <127.0.0.1:2314> Connection is closed
```

Step 4: Normal Node received block from Full Node. It transfers the block to Miner.

C:\Windows\System32\cmd.exe - run

Normal Node

```
Node:   <127.0.0.1:6000> Connection established
Node:   <127.0.0.1:6000> Client would like to check if a data exists
Node:   <127.0.0.1:6000> The Merkle Tree Root is c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
Chain:  Connected to Full Node for Synchronization of Blockchain : 127.0.0.1:9999
Node:   <127.0.0.1:6000> Target Block is not found in local Blockchain, now search in Full Node
Node:   <127.0.0.1:6000> Target Block is found in Full Node Blockchain
Node:   <127.0.0.1:6000> Return information to client.
Node:   <127.0.0.1:6000> Connection is closed
```

Step 5: Miner received block from Normal Node. It displays the result.

C:\Windows\System32\cmd.exe

Miner

```
Self Node port 6000 ; Server Node port 3000 ; (Full Node @ Port 9999 as a Server)
Enter 10 to become a Node
Enter 20 to become a Miner
Enter 30 to calculate a Merkle Tree Root
20
Miner:  Connection 127.0.0.1:6000 <--> 127.0.0.1:3000
- Enter 21 to Mine
- Enter 22 to Retrive all Block Hashes at server node
- Enter 23 to Retrive block in blockchain using a block hash
- Enter 24 to Retrive data  in blockchain using a Merkle Tree Root
24
Miner:  Please input the Merkle Tree Root here c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
Miner:  Request the Block with Merkle Tree Root c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
Miner:  ...sending message to nearby node
Miner:  ...received message from nearby node
Miner:  Received the Block
Miner:  ...Decoding the Block...
Miner:  Target Block is found
Chain:  Block #0
        > Timestamp     : 1546337922
        > PrevBlockHash : 0000000000000000000000000000000000000000000000000000000000000000
        > Root          : c81c929adb94b88160f1949db98a123096f6bfbd70b6a5d82a30d373a0cc93d4
        > Nonce         : 0000012774
        > CurrBlockHash : 0000f9e0ceaa0455dd687ca03d6ce5d88d728b84d1c5a82d6d3b9b399e353395
        > Data          : [New Genesis Block]
        Block #0 Header in Byte Stream (80 bytes, equals to 160 digits in hex)
        [Magic#        ][TS    ][PrevBlockHash                                                  ][Root                                                  ][Nonce ]
```

8. Summary and Extra Information – Blockchain should be in a decentralized network

Blockchain is a distributed, open and unalterable digital ledger which is suitable for data storage of a decentralized system.

Open and Unalterable

In this project, I demonstrated
- why blockchain is unalterable
- why blockchain is an open ledger

Blockchain is unalterable because merkle tree root of data is saved in header hashes chain. Any modification of data will lead to a change of the whole chain, which make it nearly impossible to change the data.

Blockchain is an open ledger because any node can help verify data without connecting to a centralized server. All node holds a part of the blockchain, which could be used for verifying data. In case data is not found in this part of blockchain, a node could send request to other nodes in the network to ask for help in verifying data.

Decentralized

In this project, the blockchain works in a centralized system. It could be modified to work in a decentralized system.

Blockchain will be a decentralized network if any node can perform mining (i.e. save data in blockchain) without the approval of a centralized server. In this project, a centralized Full Node model is adopted for easier demonstration. Normal Node need to update its header hashes chain from Full Node before mining. To modify this project to create a decentralized system, we could replace the Full Node by any nodes (i.e. Normal Node update its header hashes chain asking nearby nodes, but not a Full Node, before mining).

A major problem in a decentralized system is if two miners successfully mined simultaneously, new miner need to decide which blockchain to follow, i.e. make consensus. Bitcoin solves the problem by using proof-of-work algorithm. New blocks to should be added to "the most-difficult-to-recreate chain", and proof-of-work is an algorithm to increase the difficult in creating a chain.

Please refer to https://bitcoin.org/en/developer-reference#p2p-network for further information of how blockchain works in a decentralized network.

Although proof-of-work can solve the consensus problem, it is criticized because huge computational power and energy are consumed to calculate a *Nonce*. There are other consensus algorithms used in different blockchain networks, e.g. "proof-of-stake" in Ethereum, "delegated byzantine fault tolerance" in NEO, … which solves the weaknesses of proof-of-work.

9. Reference

1. "Bitcoin: A Peer-to-Peer Electronic Cash System", Satoshi Nakamoto, https://bitcoin.org/bitcoin.pdf
2. "Bitcoin Developer Reference", Bitcoin.org, https://bitcoin.org/en/developer-reference
3. "Bitcoin Developer Reference – P2P Network", Bitcoin.org, https://bitcoin.org/en/developer-reference#p2p-network

The source codes are written using Visual Studio Code. https://code.visualstudio.com/
The diagrams are drawn using Software Ideas Modeler. https://www.softwareideas.net/

This project is a rebuild of student project I worked on for Hong Kong Polytechnic University COMP5311 (Semester 1 Year 2018-2019). Special thanks to Dr Bin Xiao and Mr Haotian Wu, who taught me the fundamentals of Bitcoin and blockchain.

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