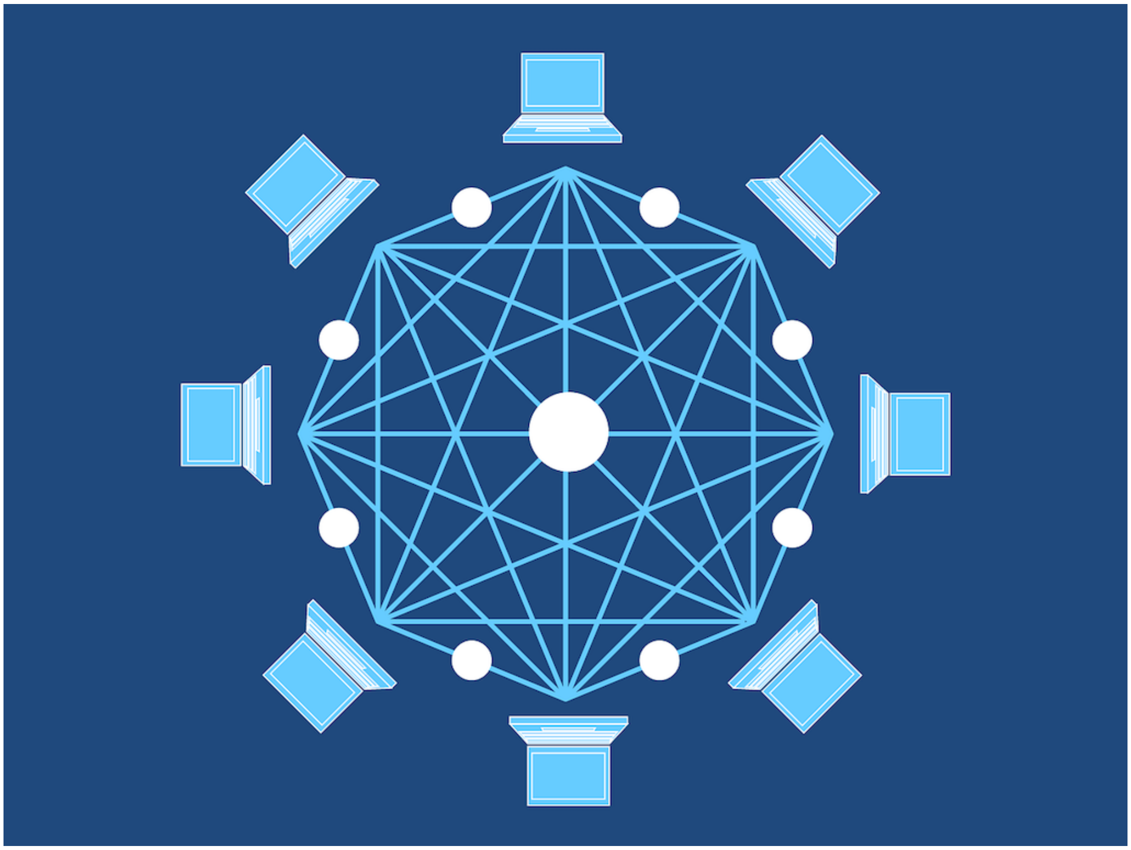

DLT Implementation & Internals

Assignments:
Part 1: Problem set for Custom DLT Implementation
Part 2: Problem set for Substrate

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Course: DLT5400: DLT Implementation and Internals

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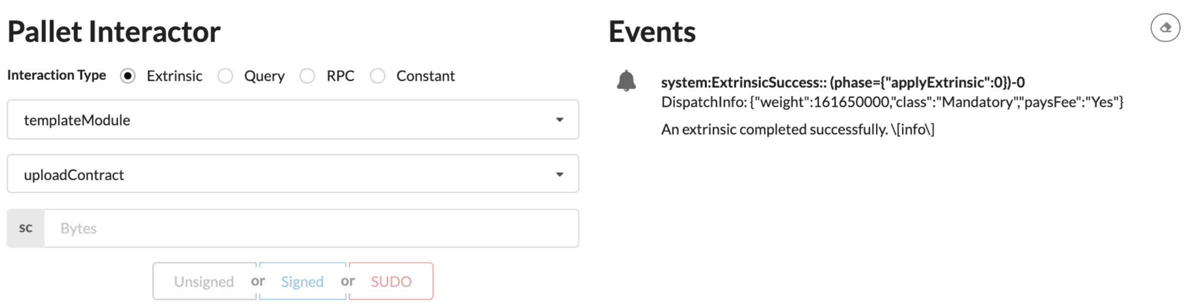
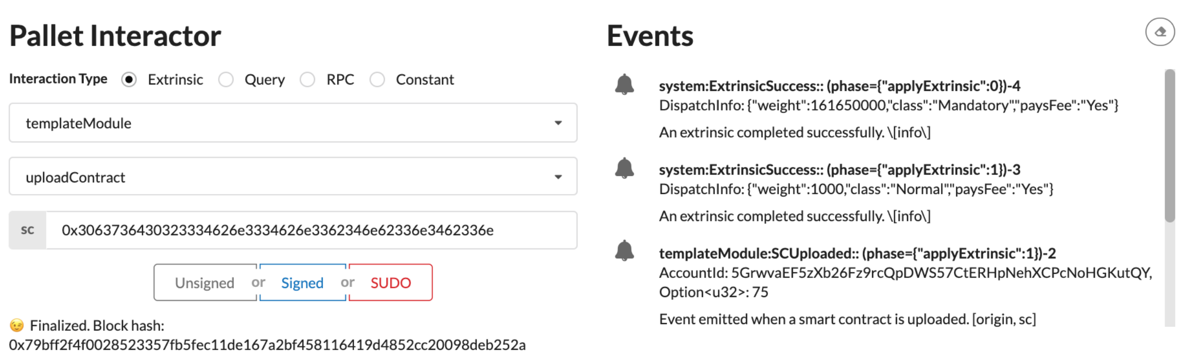
Part 2:

1. Smart Contract Upload and Retrieval

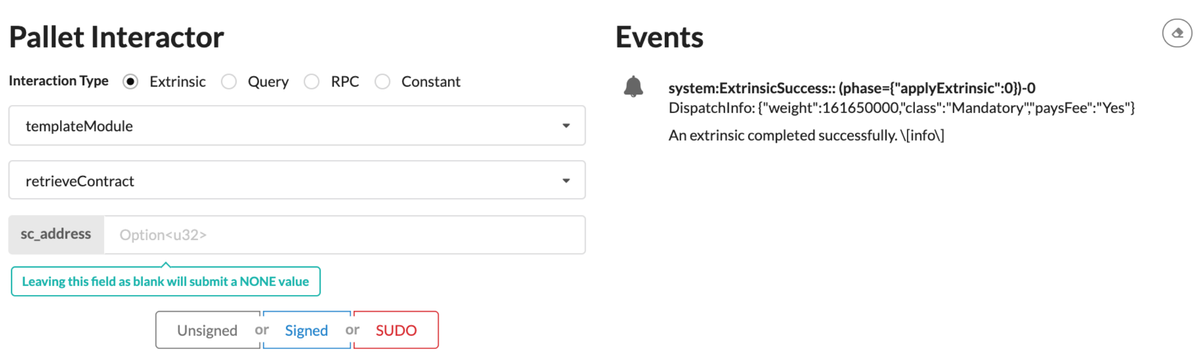
```
Example Smart Contract (Bytes):
0x30637364303233334626e3334626e3362346e62336e3462336e
```

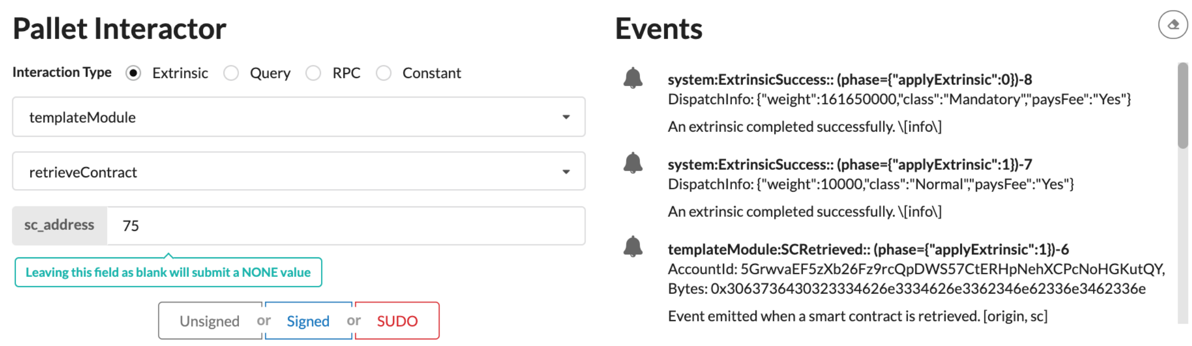
Upload Contract





Retrieve Contract





Code

pallets/template/src/lib.rs

```
#![cfg_attr(not(feature = "std"), no_std)]

// Re-export pallet items so that they can be accessed from the crate namespace.
pub use pallet::*;

#[frame_support::pallet]
pub mod pallet {
   use frame_support::{dispatch::DispatchResultWithPostInfo, pallet_prelude::*};
   use frame_system::pallet_prelude::*;
   use sp_std::vec::Vec;
   use sp_std::convert::TryInto;

   /// Configure the pallet by specifying the parameters and types on which it depends.
   #[pallet::config]
   pub trait Config: frame_system::Config {
       /// Because this pallet emits events, it depends on the runtime's definition of an
event.
       type Event: From<Event<Self>> + IsType<<Self as frame_system::Config>::Event>;
   }

   // Pallets use events to inform users when important changes are made.
   // Event documentation should end with an array that provides descriptive names for
parameters.
   // https://substrate.dev/docs/en/knowledgebase/runtime/events
   #[pallet::event]
   // #[pallet::metadata(Option<u32> = "Metadata")]
```

```
    #[pallet::metadata(T::AccountId = "AccountId")]
    #[pallet::generate_deposit(pub(super) fn deposit_event)]
    pub enum Event<T: Config> {
        /// Event emitted when a smart contract is uploaded. [origin, sc]
        SCUploaded(T::AccountId, Option<u32>),
    /// Event emitted when a smart contract is retrieved. [origin, sc]
        SCRetrieved(T::AccountId, Vec<u8>),
    }

    #[pallet::error]
    pub enum Error<T> {
            /// The smart contract has already been uploaded.
            SCAlreadyUploaded,
            /// The smart contract does not exist, so it cannot be retrieved.
            NoSuchSC,
        }

    #[pallet::pallet]
    #[pallet::generate_store(pub(super) trait Store)]
    pub struct Pallet<T>(_);

    #[pallet::storage]
    pub(super) type SC<T: Config> = StorageMap<_, Blake2_128Concat, Option<u32>, Vec<u8>,
ValueQuery>;

    #[pallet::hooks]
    impl<T: Config> Hooks<BlockNumberFor<T>> for Pallet<T> {}

    // Dispatchable functions allows users to interact with the pallet and invoke state
changes.
    // These functions materialize as "extrinsics", which are often compared to transactions.
    // Dispatchable functions must be annotated with a weight and must return a DispatchResult.
    #[pallet::call]
    impl<T: Config> Pallet<T> {
        #[pallet::weight(1_000)]
        pub(super) fn upload_contract(
            origin: OriginFor<T>,
            sc: Vec<u8>,
```

```
        ) -> DispatchResultWithPostInfo {

            // Check that the extrinsic was signed and get the signer.
            // This function will return an error if the extrinsic is not signed.
            // https://substrate.dev/docs/en/knowledgebase/runtime/origin
            let sender = ensure_signed(origin)?;

            // Get the block number from the FRAME System module.
            let current_block_uncasted =
<frame_system::Module<T>>::block_number();//::from(10u32);
            let current_block = TryInto::<u32>::try_into(current_block_uncasted).ok();

            // Verify that the specified smart contract has not already been uploaded.
            ensure!(!SC::<T>::contains_key(current_block), Error::<T>::SCAlreadyUploaded);



            // Store the smart contract with the sender and block number.
            SC::<T>::insert(current_block, &sc);
            // Emit an event that the smart contract was uploaded.
            Self::deposit_event(Event::SCUploaded(sender, current_block));
            Ok(().into())
        }

        #[pallet::weight(10_000)]
        fn retrieve_contract(
            origin: OriginFor<T>,
            sc_address: Option<u32>,
        ) -> DispatchResultWithPostInfo {
            // Check that the extrinsic was signed and get the signer.
            // This function will return an error if the extrinsic is not signed.
            // https://substrate.dev/docs/en/knowledgebase/runtime/origin
            let sender = ensure_signed(origin)?;

            // Verify that the specified smart contract has been uploaded.
            // ensure!(SC::<T>::contains_key(&sc), Error::<T>::NoSuchSC);
            let sc = SC::<T>::get(&sc_address);
            // Emit an event that the smart contract was retrieved.
            Self::deposit_event(Event::SCRetrieved(sender, sc));
```

```
            Ok(().into())
        }
    }
}
```

2. Limited JVM-like Interpreter

Attempted to write an execute_contract method based on newly designed bytecode operations given below and utilizing built-in instructions but didn't succeed (due to very limited rust knowledge and experience).

3. Report

(i) a description of the bytecode operations you implemented;

Mnemonics	**Opcode (in hex)**	**Description**
iconst_2	05	load the int value 2 onto the stack
irem	70	logical int remainder
ifeq	99	if value is 0, branch to instruction at branchoffset (signed short constructed from unsigned bytes branchbyte1 << 8 | branchbyte2)
goto	a7	goes to another instruction at branchoffset (signed short constructed from unsigned bytes branchbyte1 << 8 | branchbyte2)
return	b1	return void from method
blockno	cb	push the constant u32 onto the stack
emit	cc	push the constant string onto the output

- JVM has left the opcodes (cb-df) unassigned for future use, so we have used them as per our need.

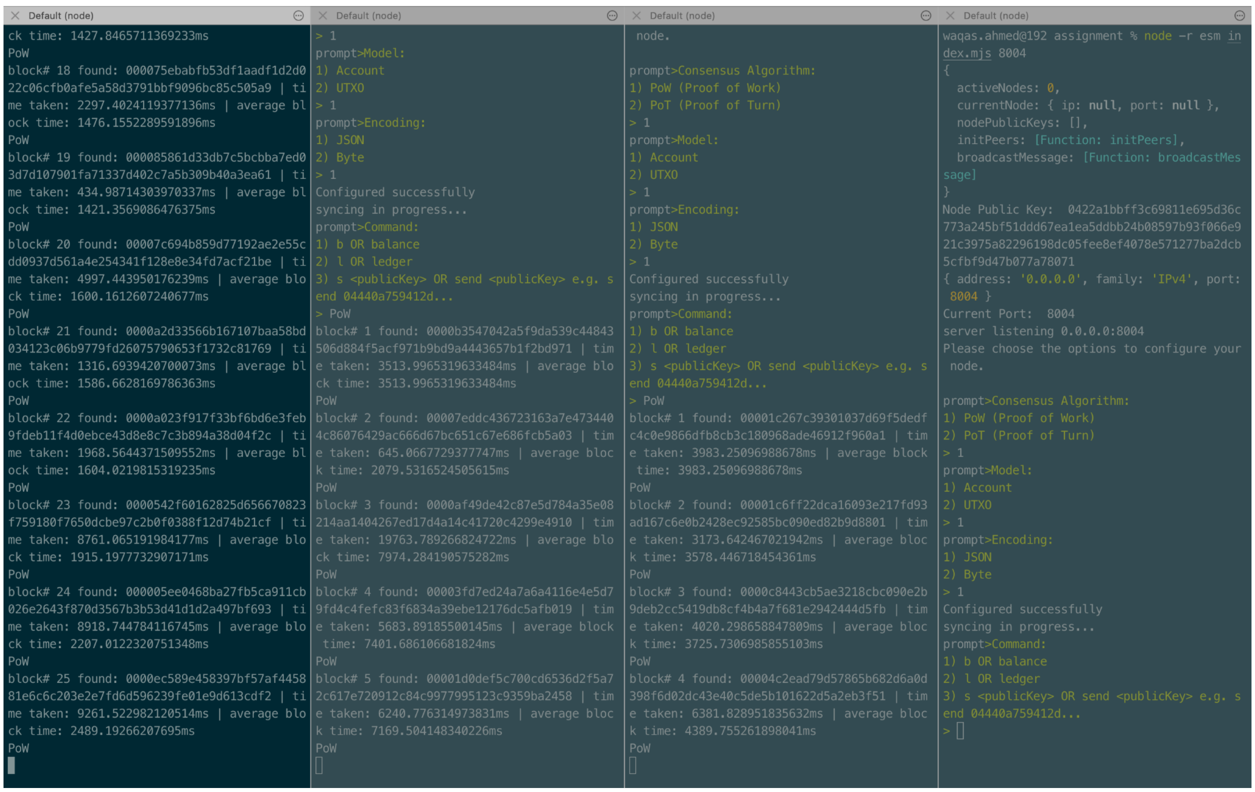
(ii) listing any functionality that you did not implement.

Theoretically, the specifications have been drafted as per the given instructions, however, didn't implement the JVM as part of lib.rs

Part 1:

Git repo: https://github.com/wakqasahmed/dlt_implementation/tree/main/assignment

1. SBB Completion



2. Configurable Blockchain

```
Default (node)
waqas.ahmed@192 assignment % node -r esm index.mjs 8001
{
  activeNodes: 0,
  currentNode: { ip: null, port: null },
  nodePublicKeys: [],
  initPeers: [Function: initPeers],
  broadcastMessage: [Function: broadcastMessage]
}
Node Public Key:  0469aaf9217806c617432274fad1ddcfa79ce4512e06cb23120ebe144bc73605c77deabb084d5aa0238cd15eb94c66d886550b3b22252c83001a62f0580f0470a0
{ address: '0.0.0.0', family: 'IPv4', port: 8001 }
Current Port:  8001
server listening 0.0.0.0:8001
Please choose the options to configure your node.

prompt>Consensus Algorithm:
1) PoW (Proof of Work)
2) PoT (Proof of Turn)
> 2
prompt>Model:
1) Account
2) UTXO
> 1
prompt>Encoding:
1) JSON
2) Byte
> 1
Configured successfully
syncing in progress...
prompt>Command:
1) b OR balance
2) l OR ledger
3) s <publicKey> OR send <publicKey> e.g. send 04440a759412d...
> 
```

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3. Blocktime Calculation

Bitcoin Difficulty Calculation Formula [1]

new_difficulty = old_difficulty X (2016 blocks X 10 minutes) / (the time took in minutes to mine the last 2016 blocks)

SBB Difficulty Calculation Formula

new_difficulty = old_difficulty X (100 blocks X 10000 ms) / (the time took in ms to mine the last 100 blocks)

Genesis difficulty = 1

100 blocks = 110ms

Average Block Time = 1.10 milliseconds

new_difficulty = 1 * (100 * 10000) / (110 * 100) = 91

Genesis difficulty = 2

100 blocks = 692ms

Average Block Time = 6.92 milliseconds

new_difficulty = 2 * (100 * 10000) / (692 * 100) = 28.90

Genesis difficulty = 3

100 blocks = 8224ms

Average Block Time = 82.24 milliseconds

new_difficulty = 3 * (100 * 10000) / (8224 * 100) = 3.65

Genesis difficulty = 4

100 blocks = 122300ms

Average Block Time = 1223 milliseconds

```
new_difficulty = 4 * (100 * 10000) / (122300 * 100) = 0.33
```

```
Genesis difficulty = 5

100 blocks = 2262000ms

Average Block Time = 22620 milliseconds

new_difficulty = 5 * (100 * 10000 ) / (2262000 * 100) = 0.02
```

- Difficulty: _4 zeros_
- Average Block Time: _1223 milliseconds_
- Test # of Blocks: _100_
- Maximum Nonce Limit: _50000000_ (to prevent infinite loop)
- Method: _stored each block mine time in an array and computed average_

Please Note: `performance.now()` is used instead of typical `new Date().getTime()` for comparison, as suited better to measure performance according to the following article: https://developers.google.com/web/updates/2012/08/When-milliseconds-are-not-enough-performance-now

```
$ node -r esm index.mjs 8001

Node Public Key:
04995cca93aa091a81409ce4d7e21c296959ce22edba86642e4125db851f7cf27908cf0f2cdcc
524ce32d1f4c38b1651303c1c6f5fec495683b699d1acdd0e11a8

wallet.publicKey:
04995cca93aa091a81409ce4d7e21c296959ce22edba86642e4125db851f7cf27908cf0f2cdcc
524ce32d1f4c38b1651303c1c6f5fec495683b699d1acdd0e11a8

{ address: '0.0.0.0', family: 'IPv4', port: 8001 }

server listening 0.0.0.0:8001

syncing in progress...

prompt>command> You are the first SBB miner, history is being written... The
SBB genesis block
```

```
block# 1 found:
0000734a58a322096864ccb77008cd2f815ec630c2d56f1214640201ad0052db | time
taken: 417.7852739095688ms | average block time: 417.7852739095688ms

block# 2 found:
000076e122cd3d14cd2606140d6acd824680082c3e84c0c2e4ec4521cd02fc6a | time
taken: 3238.020353913307ms | average block time: 1827.902813911438ms

block# 3 found:
0000f9bd4dab0e344f5ad01cc07a6e0c91b32c5a114c08caa21e7b1116d89223 | time
taken: 326.27406990528107ms | average block time: 1327.359899242719ms

block# 4 found:
0000e14a9c3016f7523f0e67f7d24b77836b2222e45b8a19fab7b328c3e1226a | time
taken: 401.649307012558ms | average block time: 1095.9322511851788ms

block# 5 found:
0000dd83915aa170f0ddebc7b2a8a310437534bcd85442b0a91a4097426365d3 | time
taken: 6.875347971916199ms | average block time: 878.1208705425263ms

.

.

.

block# 96 found:
0000ea79fba479a4567ed9efc21090fa075ced107d4cd14c0e370b8c617e35a0 | time
taken: 839.1855989694595ms | average block time: 1236.1563069125016ms

block# 97 found:
00000e42f3506de9c3345be1e697801901e1214272953aa0adde2566318540e0 | time
taken: 1649.7632240056992ms | average block time: 1240.420295748514ms

block# 98 found:
0000e95e93e25137a2451a41af2d814ffe3afa5c3165cdb451232cd4d8e20b32 | time
taken: 367.73071002960205ms | average block time: 1231.515299975872ms

block# 99 found:
00006d0efff4708a6059c7f41e1cd620efd1c8ef4340927835211bcdfa1ea917 | time
taken: 508.8213880062103ms | average block time: 1224.215361471128ms

block# 100 found:
0000582530f84bcaf32bf56f2a26a89145b8c243c5dc43117210fb11b431bf1a | time
taken: 1118.7283039093018ms | average block time: 1223.1604908955096ms
```

- Difficulty: _5 zeros_
- Average Block Time: _22620 milliseconds_
- Test # of Blocks: _100_
- Maximum Nonce Limit: _50000000_ (to prevent infinite loop)
- Method: _stored each block mine time in an array and computed average_

```
$ node -r esm index.mjs 8001

Node Public Key:
049ca6a4defc2708dc3b1cd17412d517d1e3405e3aacc50f1249dc4f8823bd30210d4368720de
cfc32f6c46d658c685a4593ca5f2e7c033e65590c3cb89c4a943b

wallet.publicKey:
049ca6a4defc2708dc3b1cd17412d517d1e3405e3aacc50f1249dc4f8823bd30210d4368720de
cfc32f6c46d658c685a4593ca5f2e7c033e65590c3cb89c4a943b

{ address: '0.0.0.0', family: 'IPv4', port: 8001 }

server listening 0.0.0.0:8001

syncing in progress...

prompt>command> You are the first SBB miner, history is being written... The
SBB genesis block

block# 1 found:
000003f522d093c5d12c197f18190408610f772baba5b612c8b4572b6ae27355 | time
taken: 5974.994300961494ms | average block time: 5974.994300961494ms

block# 2 found:
00000a5ce377fe0561efee6d7972a4d01e23fb22fcc447fe60e7de1d2ad5940e | time
taken: 3685.7001559734344ms | average block time: 4830.347228467464ms

block# 3 found:
00000358f45998edb65d32f4cfcbac2a65e8fb0a01ae1f39c0dffcd845f2ddec | time
taken: 12747.79771900177ms | average block time: 7469.4973919789ms

block# 4 found:
000007306ec85f52e70a2cc7a7ab469f33c45f3d041ce2a9e77d9c1e8ff59727 | time
taken: 1822.564227938652ms | average block time: 6057.764100968838ms

block# 5 found:
00000ae9463bc75044f52b2324ce9ef4dda3c191eec247a5490cecf0b06adb73 | time
taken: 27306.965486049652ms | average block time: 10307.604377985ms

.
```

```
.

.

block# 96 found:
000002e3fc320e072a10a0cddb291136876d7cb3a7605bca1e0cf211a074b13f | time
taken: 17598.125045895576ms | average block time: 22803.48438367496ms

block# 97 found:
0000005f652eecd55a94c7a3a472dba3040416d8f16e61cd7651c03210c6bfdf | time
taken: 11692.683795928955ms | average block time: 22688.940047718814ms

block# 98 found:
000004e1c281397bf5cc97327f56cc27002f8ee10e5d093e4d6ff860d5f0efd3 | time
taken: 14165.0240598917ms | average block time: 22601.96131314915ms

block# 99 found:
000001c2955aeef1cffd4fbd75255dcf29738d32459729bb65fd331f80b5ef49 | time
taken: 15955.567401051521ms | average block time: 22534.82602110776ms

block# 100 found:
0000061c267eac786b8955cdcd0d6c9e8af266c110a7ff9984572598b347974e | time
taken: 31129.543534994125ms | average block time: 22620.773196246624ms
```

Thoughts on Blocktime Calculation

The result obtained by mining for 100 blocks with a difficulty of **5 zeros** (whose average is about **22620 ms per block**) is significantly higher than the targeted block time of 10 seconds / block.

In contrast, the difficulty level of 4 zeros averaged about **1223 ms per block** is closer to targeted block time of 10 seconds / block.

4. Proof-of-Turn

The algorithm has been implemented as per the pseudocode given. For the sake of simplicity, a simple version of Peer discovery has been implemented.

Initial Peer Discovery and getting their public keys

0.0) GET_PEERS message - return publicKey of this node and all other peers its connected to

GET_PEERS - request publicKey of peers from neighbour

- ○ Respond with PEERS message
  - ■ Contains public keys of peers

Request:

- <OPID>: ‘p’
- <OBJ>: null/None/empty

Response:

- <OPID>: ‘q’
- <OBJ>: {'peers': []}

0.1) Upon receiving PEERS message - add peers publicKeys to an array (where missing)

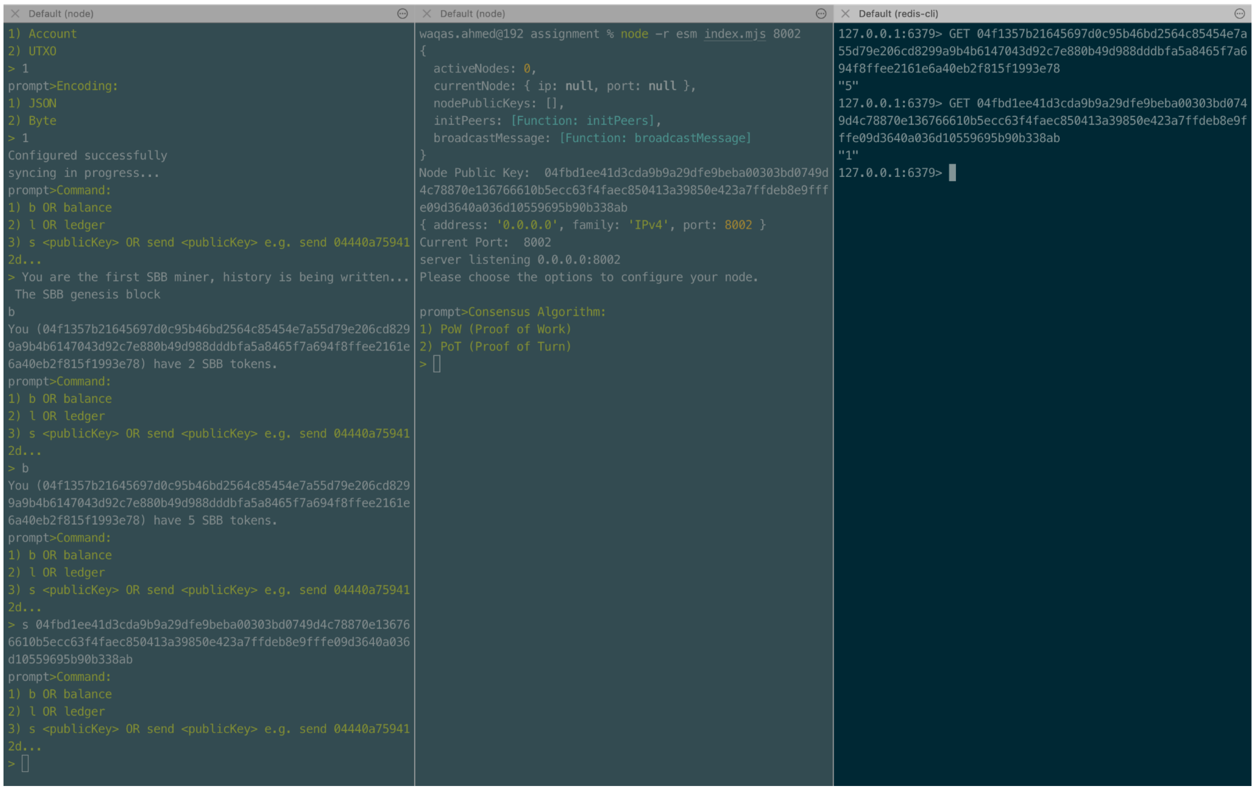
PEERS - contains the public keys of the neighbouring peers

- <OPID>: ‘q’
- <OBJ>: {'peers': []}

The way PoT works is, every node finds the ***min*** of ***lsb64*** and checks if the node itself is eligible to mine or not. If not, it just waits for the **<*block_time*>** before starting to compute eligibility. By that time, the eligible node produces the block and propagates to the peers.

5. Account Model DB

Redis is used as the database for the given task which is quite similar but more popular then LevelDB which bitcoin core uses [2][3].



6. UTXO Model

UTXO model is not implemented.

7. Design a Well-Defined Byte Encoding

Message encoding is implemented but the byte-encoding of payload is not implemented.

8. Evaluation

I have only implemented Byte-encoding partially, while skipping UTXO Model (as it require quite a bit of time), theoretically, PoT results in significant reduction of the CPU usage as only the eligible node is going to do the mining process, however, in the current unoptimized implementation, eligibility has to be determined by every node, thus increasing an overhead a bit on each node.

Moreover, Byte-encoding is compressed in nature and more machine friendly, which should result in low memory usage, faster transfer and efficient I/O.

9. Report:

Provide documentation for:

(i) the average block time and target consecutive "0"s calculation including resultant average times and final parameters used.

Details have been mentioned above, in summary,

- Difficulty: 4 (target consecutive zeros)
- Average block time (closest): 1223 ms

(ii) The protocols used.

- Well-defined message encoding

(iii) Any flaws that you see with aspects of the systems.

- Inefficient peer discovery
- Not scalable (due to imperfect implementation)
- PoT and PoW can't run simultaneously, PoW nodes might take over due to skipping eligibility determination.

(iv) Analysis and thoughts regarding the evaluation metrics extracted.

- Mentioned above under the separate heading.

(v) Any parts of the requirements that you did not implement.

- UTXO Model
- Payload byte-encoding
- Block authenticity validation (though tested with hard-coded message in index.js)

(vi) A description of what a merkle tree is, and how it could be used in the implementations to provide better efficiency.

- Merkle trees facilitate the verification of content securely and efficiently. Technically, it is defined as a tree data structure where leaves are tagged with its own block content hash while the branches/non-leaf are tagged with the hash of its child nodes. Merkle tree ensures that data blocks received from other peers in a P2P network are received undamaged and unaltered, in other words, tamper-proof and immutable. It also ensures that the other peers are not lying by sending fake blocks.[4]

- Current implementation is similar to linear linked list which is prone to modification, so by definition, it's not immutable. Yes, every block has the hash of the previous block which makes it difficult for the miner to attack once the block is deep in the list, yet, it is inefficient as compared to merkle tree.