

## Master Thesis title

*subtitle*

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*Master Thesis in Computer Science*





# **Abstract**



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# **My list of definitions**



# / 1

## Introduction

**1.1 Problem Statement**

**1.2 Method / Context**

**1.3 Outline**



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## Related Works

This chapter summarizes the most relevant papers or works that talks about Bitcoin, decentralized cryptocurrencies, concepts behind them and statistical analysis on the blockchain. In a previous paper that we wrote [41], we enhanced the importance of paying for having a certain bandwidth in the Bitcoin network. A paper from Peter R. Rizun [37], explains how a rational Bitcoin miner should select transactions from his node mempool, when creating a new block, in order to maximize his profit. Analysis on the blockchain in matter of scalability is showed in the Position Paper of Kyle Croman [22], they analyze how fundamental bottlenecks in Bitcoin limit the ability of its current peer-to-peer overlay network to support substantially higher throughputs and lower latencies. We are going to test the throughput as well, comparing it with the one showed in this paper.

### 2.1 A Transaction Fee Market Exists Without a Block Size Limit

This paper shows how a Bitcoin miner should select transactions from his node's mempool, when creating a new block, in order to maximize his profit in the absence of a block size limit. *Block space supply curve* and *mempool demand curve* are explained, and the paper shows how the supply and demand curves from classical economics are related to the derivatives of these two

curves.

They claim that the block-size limit determines the transaction throughput and one of their concern regards whether, in the absence of such a limit or if that limit is far above the transactional demand, a *healthy transaction fee market* would develop which charges users the full cost to post transactions. The object of this paper is indeed to consider whether or not such a fee market is likely to emerge if miners, rather than the protocol, limit the block size. In this paper they derive the *miner's profit equation* and then they introduce two novel concepts called the *mempool demand curve* and the *block space subbly curve*.

### 2.1.1 Miner's Profit Equation

Every time a block is mined, the miner expects to generate a revenue  $\langle V \rangle$  at hashing cost  $\langle C \rangle$  to earn profit per block

$$\langle \Pi \rangle = \langle V \rangle - \langle C \rangle. \quad (2.1)$$

Miner's profit equation in 2.1 shows the gain of a miner  $\langle \Pi \rangle$ , where the hashing cost is represented as follows:

$$\langle C \rangle = \eta h T. \quad (2.2)$$

So the hashing cost  $\langle C \rangle$  is directly dependent from the miner's individual hash rate,  $h$ , the cost per hash,  $\eta$ , and the creation time,  $T$ . Moreover, is important to consider the expectation value of a miner's revenue per block, this value is represented with  $\langle V \rangle$  and is equal to the amount he would earn if he won the block multiplied by his probability of winning. So the expected revenue would be:  $\langle V \rangle = (R + M)h/H$ , where the amount he would earn is the sum of the block reward,  $R$ , and the transaction fees,  $M$ . His probability of winning, assuming all blocks propagating instantly, is equal to the ration of his hash rate,  $h$ , to the total hash rate of the Bitcoin network,  $H$ . The problem with this equation is that it does not reflect the miner's diminished chances of winning if he chooses to publish a block that propagates slowly to the other miners. If a miner finds first a valid block, but his solution is received after most miners are working on another, then his block will likely be discarded. This effect is called *orphaning*. The equation, considering the orphaning factor,  $\mathbb{P}_{\text{orphan}}$ , is the following:

$$\langle V \rangle = (R + M) \frac{h}{H} (1 - \mathbb{P}_{\text{orphan}}). \quad (2.3)$$

Where the chance that a block gets orphaned increases with the amount of time it takes the block to propagate to the other miners. Indeed, if  $\tau$  is the block propagation time, the probability of orphaning is defined as:

$$\mathbb{P}_{\text{orphan}} = 1 - e^{-\frac{\tau}{T}}. \quad (2.4)$$

In conclusion the *miner's profit equation* is defined as:

$$\langle \Pi \rangle = (R + M) \frac{h}{H} e^{-\frac{\tau}{T}} - \eta h T \quad (2.5)$$

A *rational miner* selects which transactions to include in his block in a manner that maximizes the expectation value of his profit. This selection is explained with the *mempool demand curve* and the *block space supply curve*.

### 2.1.2 The Mempool Demand Curve

The set of transactions that still need to be approved and included in a block is called *mempool*. The mempool set is denoted with  $\mathcal{N}$  and the number of transactions contained within it as  $n$ . According to the size limit, a block can select a  $b \leq n$  transactions from  $\mathcal{N}$  to create a new block  $\mathcal{B} \subset \mathcal{N}$ .

A block first includes transactions with an higher *fee density*. This last, is a ratio between the *transaction fee* and the *transaction size*. To construct the mempool demand curve, is necessary first sorting the mempool from greatest fee density to least and then associating an index  $\{i : 1, 2, \dots, n - 1, n\}$  with each transaction in the resulting list.

The mempool demand curve will be then a graphical representation of the sum of the fees offered by each transaction in this sorted list:

$$M_{\text{demand}}(b) \equiv \sum_{i=1}^b \text{fee}_i, \quad (2.6)$$

and the sum of each transaction's size in bytes:

$$Q(b) \equiv \sum_{i=1}^b \text{size}_i. \quad (2.7)$$





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## Technical Background



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## **Blockchain Analytics System**

### **4.1 Blockchain Data Sources**

### **4.2 System Architecture**

#### **4.2.1 Data Retrieval**

#### **4.2.2 Data Manipulations**

#### **4.2.3 Methods**

### **4.3 Version Control**



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## **Blockchain Observations**

- 5.1 Blockchain Growth**
- 5.2 Retrieval Block Time**
- 5.3 Block Analysis**
- 5.4 Bandwidth**
- 5.5 Block Fee**
- 5.6 Models**



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## Conclusions

### 6.1 Discussion

### 6.2 Future Implementation

### 6.3 Comments

show bibliography [36], [43], [19], [25], [34], [23], [10], [13], [35], [38], [29], [31], [15], [27], [42], [33], [1], [6], [21], [7], [40], [20], [39], [4], [8], [9], [14], [17], [16], [32], [18], [11], [22], [26], [28], [12], [2], [3], [37] [5], [41], [24], [30].



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## Terminology

**RLP:** Stands for recursive length prefix. It is a serialization method for encoding arbitrary structured binary data (byte arrays).

**KEC-256:** Another serialization method generating a 256-bit hash.

**full node:** A full node in a decentralized digital currency peer-to-peer network, is a node that stores and processes the entirety of every block, storing locally the entire size of the blockchain.

**light node:** A light node in a decentralized digital currency peer-to-peer network, is a node that only stores the part of the blockchain it needs.

**satoshi:** Unit of the Bitcoin currency. 100,000,000 satoshi are 1 BTC (Bitcoin).





## Listing

**Listing B.1:** Smart contract transaction code in Ethereum.

```
1 function transfer(address _to, uint256 _value) {
2     /* Add and subtract new balances */
3     balanceOf[msg.sender] -= _value;
4     balanceOf[_to] += _value;
5 }
```

**Listing B.2:** Example of a smart contract that rewards users who solve a computational puzzle [?].

```

1 contract Puzzle {
2     address public owner ;
3     bool public locked ;
4     uint public reward ;
5     bytes32 public diff ;
6     bytes public solution ;
7
8     function Puzzle () // constructor {
9         owner = msg. sender ;
10        reward = msg . value ;
11        locked = false ;
12        diff = bytes32 (11111); // pre - defined
13            difficulty
14    }
15
16    function (){ // main code , runs at every
17        invocation
18        if ( msg. sender == owner ){ // update reward
19            if ( locked )
20                throw ;
21            owner . send ( reward );
22            reward = msg . value ;
23        }
24        else
25            if ( msg . data . length > 0){ // submit a
26                solution
27            if ( locked ) throw ;
28            if ( sha256 (msg. data ) < diff ){
29                msg. sender . send ( reward ); // send
                    reward
                solution = msg. data ;
                locked
            }}}

```

**Listing B.3:** Application usage.

```

1 Usage: observ.py -t number
2   -h | --help      : usage
3   -i              : gives info of the blockchain in
4     the file .txt
5   -t number       : add on top a number of blocks.
6     The blocks retrieved will be the most recent
7     ones. If the blockchain growth more than the
8     block requested do -u (update)
9   -e number       : append blocks at the end of the .
10    txt file. Fetch older blocks starting from the
11    last retrieved
12   -P              : plot all
13   -p start [end] : plot data in .txt file in a
14     certain period of time, from start to end. If
15     only start then consider from start to the end
16     of the .txt file
17   -R              : plot the regression and the
18     models that predict the blockchain
19   -r start [end] : plot the regression and the
20     models in a certain period of time, from start
21     to end. If only start then consider from start
22     to the end of the .txt file
23   -u              : update the local blockchain to
24     the last block created

```

**Listing B.4:** Block object represented in Python according to api-v1-client-python to retrieve data on the blockchain. The function get\_block() will return an object of this type [1].

```
1 class Block:
2     def __init__(self, b):
3         self.hash = b['hash']
4         self.version = b['ver']
5         self.previous_block = b['prev_block']
6         self.merkle_root = b['mrkl_root']
7         self.time = b['time']
8         self.bits = b['bits']
9         self.fee = b['fee']
10        self.nonce = b['nonce']
11        self.n_tx = b['n_tx']
12        self.size = b['size']
13        self.block_index = b['block_index']
14        self.main_chain = b['main_chain']
15        self.height = b['height']
16        self.received_time = b.get('received_time', b['time'])
17        self.relayed_by = b.get('relayed_by')
18        self.transactions = [Transaction(t) for t in b['tx']]
19        for tx in self.transactions:
20            tx.block_height = self.height
```

**Listing B.5:** Transaction object represented in Python according to api-v1-client-python to retrieve data on the blockchain. The function get\_transaction() will return an object of this type [1].

```

1  class Transaction:
2      def __init__(self, t):
3          self.double_spend = t.get('double_spend', False)
4          self.block_height = t.get('block_height')
5          self.time = t['time']
6          self.relayed_by = t[' relayed_by ']
7          self.hash = t['hash']
8          self.tx_index = t['tx_index']
9          self.version = t['ver']
10         self.size = t['size']
11         self.inputs = [Input(i) for i in t['inputs']]
12         self.outputs = [Output(o) for o in t['out']]
13
14         if self.block_height is None:
15             self.block_height = -1

```

**Listing B.6:** Json object returned from the method `get_block()` in the Bitcoin application programming interface (API) class blockexplorer.py [1]

```

hash : str
version : int
previous_block : str
merkle_root : str
time : int
bits : int
fee : int
nonce : int
n_tx : int
size : int
block_index : int
main_chain : bool
height : int
received_time : int
relayed_by : string
transactions : array of Transaction objects

```

**Listing B.7:** Structure of the latest block retrieved. The function `get_latest_block()` will return an object with this structure.

```

1 class LatestBlock:
2     def __init__(self, b):
3         self.hash = b['hash']
4         self.time = b['time']
5         self.block_index = b['block_index']
6         self.height = b['height']
7         self.tx_indexes = [i for i in b['txIndexes']]
```

**Listing B.8:** Collecting data starting from the last element in the `blockchain.txt` file.

```

1 earliest_hash = get_earliest_hash()
2 get_blockchain(n, earliest_hash)
3
4 def get_blockchain(n, hash = None):
5     [...]
6     if (hash): # start the retrieval from the hash
7         append_end = True # in that way the
8             write_blockchain method knows that has to
9                 append blocks and not write them at the
10                  beginning
11     last_block = blockexplorer.get_block(hash)
12     [...]
13
14 def get_earliest_hash():
15     hash_list = get_list_from_file("hash") # method to
16         collect data from blockchain.txt file having
17             as attribute "hash"
18     length = len(hash_list)
19     earliest_hash = hash_list[length - 1]
20     return earliest_hash
```

**Listing B.9:** Calling blockchain.info through python API and retrieving part of the blockchain.

```

1 from blockchain import blockexplorer
2 # get the last block
3 last_block = blockexplorer.get_latest_block()
4 hash_last_block = last_block.hash
5
6 # current block now is the last block
7 current_block = blockexplorer.get_block(
    hash_last_block)

```

**Listing B.10:** How read bandwidth is calculated, using the function `datetime.now()` before and after the API call.

```

1 start_time = datetime.datetime.now() # -----
2 current_block = blockexplorer.get_block(
    current_block.previous_block)
3 end_time = datetime.datetime.now() # -----
4 time_to_fetch = end_time - start_time
5 time_in_seconds = get_time_in_seconds(time_to_fetch)
6
7 #latency
8 fetch_time_list.append(time_in_seconds)
9
10 # calculate Bandwidth with MB/s
11 block_size = float(current_block.size) / 1000000
12 bandwidth = block_size / time_in_seconds
13 bandwidth_list.append(bandwidth)

```

**Listing B.11:** Function that get the average write bandwidth of the block, calculating the time for each transaction to be visible in the public ledger of data.

```
1 def get_avg_transaction_time(block):
2     # take transactions the block
3     transactions = block.transactions
4
5     # get block time -- when it is visible in the
6     # blockchain, so when it was created
7     block_time = block.time
8
9     # list of the creation time for all the
10    # transaction in the block
11    transactions_time_list = []
12
13    # list of the time that each transaction needs
14    # before being visible in the blockchain
15    time_to_be_visible = []
16
17    for t in transactions:
18        transactions_time_list.append(float(t.time))
19
20        for t_time in transactions_time_list:
21            time_to_be_visible.append(float(block_time -
22                t_time))
23
24    average_per_block = sum(time_to_be_visible) / len(
25        time_to_be_visible)
26
27    return average_per_block
```

**Listing B.12:** How the file.write is performed in the blockchain analytics system. Differences with add and append.

```

1 if (append):
2     for i in range(n):
3         file.write("block_informations")
4
5 else: # add on top
6     hash_list_in_file = get_list_from_file("hash")
7     first_hash = hash_list_in_file[0]
8     elements = len(hash_list_in_file)
9     last_hash = hash_list_in_file[elements - 1]
10    met_first = False
11    with io.FileIO(file_name, "a+") as file:
12        file.seek(0) # place at the beginning of the
13        file
14        existing_lines = file.readlines() # read the
15        already existing lines
16        file.seek(0)
17        file.truncate() # delete all the file
18        file.seek(0)
19        i = 0
20        while (i < n):
21            if (first_hash == hash[i]):
22                met_first = True
23            while((met_first == False) and (i < n)):
24                # append on top
25                file.write("block_informations")
26                i = i + 1
27                if ((i < n) and (first_hash == hash[i])):
28                    met_first = True
# when the block retrieved meets the one
# already in the blockchain write the old file
file.writelines(existing_lines)

```

**Listing B.13:** Changing all the values inside a Python list in one code line.

```

1 # size_list from byte to MB
2 size_list[:] = [x / 1000000 for x in size_list]
3 # time_list from seconds in minutes
4 time_list[:] = [x / 60 for x in time_list]

```

**Listing B.14:** Method that allows, given an attribute present in the blockchain.txt file, to create a list containing informations only about this quality using *regular expressions*.

```
1 hash_list = get_list_from_file("hash")
2
3 def get_list_from_file(attribute):
4     list_to_return = []
5     if (os.path.isfile("blockchain.txt")):
6         # open the file and read in it --
7         blockchain_file
8         with open("blockchain.txt", "r") as
9             blockchain_file:
10                for line in blockchain_file:
11                    # regular expression that puts in a list the
12                    # line just read: eg. ['hash', '<block_hash
13                    >']
14                    list = re.findall(r"\w'+'\w", line)
15                    # list[0] --> contains the attribute
16                    # list[1] --> contains the value
17                    if ((list) and (list[0] == attribute)):
18                        list_to_return.append(list[1])
19
20 return list_to_return
```

**Listing B.15:** Generation of the growing size and time lists. Calculated following the Equations ??, ??.

```

1 def create_growing_time_list(time_list):
2     reversed_time_list = time_list[::-1]
3     time_to_append = 0
4     previous_time = 0
5     growing_time_list = []
6     growing_time_list.append(previous_time)
7     for time_el in reversed_time_list:
8         time_to_append = (float(time_el) / (60 * 60)) +
9             previous_time # time in hours
10        growing_time_list.append(time_to_append)
11        previous_time = time_to_append
12    return growing_time_list
13
14 def create_growing_size_list(size_list):
15     reversed_size_list = size_list[::-1]
16     growing_size_list = []
17     value_to_append = 0
18     size_back = 0
19     growing_size_list.append(value_to_append)
20     for size_el in reversed_size_list:
21         value_to_append = size_el + size_back
22         growing_size_list.append(value_to_append)
23         size_back = value_to_append
24     return growing_size_list

```

**Listing B.16:** Example of a polynomial interpolation of two lists using NumPy libraries.

```

1 import numpy as np
2
3 model = np.polyfit(list1, list2, deg) # polynomial
4         interpolation between list1 and list2 with the
5         degree of the return polynomial
6 # deg = 1 --> linear interpolation
7 # deg = 2 --> quadratic
8 # deg = 3 --> cubic
9 # ...
8 predicted = np.polyval(model, list1)
9 plt.plot(list1, predicted, 'b-', label="pol_interp")

```

**Listing B.17:** Check the status of the local blockchain, True if valid, False if not.

```
1 def check_blockchain():
2     check = True
3     list = get_list_from_file("height")
4     number = int(list[0])
5     length_list = len(list)
6     for i in range(length_list):
7         if (number != int(list[i])):
8             check = False
9         number = number - 1
10    return check
```



