

Master Thesis title

subtitle

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Master Thesis in Computer Science



Abstract

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My list of definitions

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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.

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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].

References

- [1] Bitcoin api's, api-v1-client-python. <https://github.com/blockchain/api-v1-client-python>.
- [2] Bitcoin mining hashing rate. <https://blockchain.info/charts/hash-rate>.
- [3] Bitcoin nodes. <https://bitnodes.21.co/>.
- [4] Bitocoin's blockchain website. <https://blockchain.info>.
- [5] Construct a linear, no-fork, best version of the bitcoin blockchain. <https://github.com/bitcoin/bitcoin/tree/master/contrib/linearize>.
- [6] Ethereum api's, pyethereum. <https://github.com/ethereum/pyethereum>.
- [7] Ethereum wiki/patricia tree. <https://github.com/ethereum/wiki/wiki/Patricia-Tree>.
- [8] Ethereum's blockchain analysis website. <https://etherscan.io>.
- [9] Ethereum's blockchain website. <https://etherchain.org/>.
- [10] Ethereum's white paper. <https://github.com/ethereum/wiki/wiki/White-Paper>.
- [11] Matplotlib for data plotting. <https://matplotlib.org>.
- [12] Mining hardware comparison. https://en.bitcoin.it/wiki/Mining_hardware_comparison.
- [13] Ethereum foundation - the solidity contract-oriented programming language. Technical report, <https://solidity.readthedocs.io/en/develop/>, 2014.

- [14] Bitcoin mining process. <http://bitcoinminer.com/>, 2015.
- [15] Bitcoin website – mining. <https://www.bitcoinmining.com>, 2016.
- [16] Ethereum project – website. <https://www.ethereum.org>, 2016.
- [17] tradeblock.com – analysis on the blockchain. <https://tradeblock.com>, 2016.
- [18] Alfred V. Aho and Jeffrey D. Ullman. *Foundations of Computer Science*. Computer Science Press, Inc., New York, NY, USA, 1992.
- [19] Adam Back. Hashcash - a denial of service counter-measure. Technical report, 2002.
- [20] Paul Baran. *On Distributed Communications: Introduction to Distributed Communication Networks*. The Rand Corporation, 1964.
- [21] Georg Becker. *Merkle Signature Schemes, Merkle Trees and Their Cryptanalysis*. 2008.
- [22] Kyle Croman, Christian Decker, Ittay Eyal, Adem Efe Gencer, Ari Juels, Ahmed Kosba, Andrew Miller, Prateek Saxena, Elaine Shi, Emin Gün Sirer, Dawn Song, and Roger Wattenhofer. *On Scaling Decentralized Blockchains*, pages 106–125. Springer Berlin Heidelberg, Berlin, Heidelberg, 2016.
- [23] Kevin Delmolino, Mitchell Arnett, Ahmed Kosba, Andrew Miller, and Elaine Shi. *Step by Step Towards Creating a Safe Smart Contract: Lessons and Insights from a Cryptocurrency Lab*, pages 79–94. Springer Berlin Heidelberg, Berlin, Heidelberg, 2016.
- [24] Jacob Donnelly. Bitcoin network still backlogged with tens of thousands of unconfirmed transactions, causing delays. *Bitcoin Magazine*, July 2015.
- [25] Cynthia Dwork and Moni Naor. Pricing via processing or combatting junk mail. In *Proceedings of the 12th Annual International Cryptology Conference on Advances in Cryptology*, CRYPTO ’92, pages 139–147, London, UK, UK, 1993. Springer-Verlag.
- [26] Ittay Eyal, Adem Efe Gencer, Emin Gün Sirer, and Robbert van Renesse. Bitcoin-ng: A scalable blockchain protocol. *CoRR*, abs/1510.02037, 2015.
- [27] Rui Garcia, Rodrigo Rodrigues, and Nuno Preguiça. Efficient middleware for byzantine fault tolerant database replication. In *Proceedings of the*

- Sixth Conference on Computer Systems, EuroSys '11*, pages 107–122, New York, NY, USA, 2011. ACM.
- [28] Begnaud Francis Hildebrand. *Introduction to Numerical Analysis: 2Nd Edition*. Dover Publications, Inc., New York, NY, USA, 1987.
 - [29] John E. Hopcroft, Rajeev Motwani, and Jeffrey D. Ullman. *Introduction to Automata Theory, Languages, and Computation (3rd Edition)*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 2006.
 - [30] Nicolas Houy. The economics of bitcoin transaction fees. Working Papers 1407, Groupe d'Analyse et de Théorie Economique (GATE), Centre national de la recherche scientifique (CNRS), Université Lyon 2, Ecole Normale Supérieure, 2014.
 - [31] Håvard D Johansen, Robbert van Renesse, Ymir Vigfusson, and Dag Johansen. Fireflies: A secure and scalable membership and gossip service. *ACM Transactions on Computer Systems (TOCS)*, 33(2):5:1–5:32, May 2015.
 - [32] Craig Larman. *Applying UML and Patterns: An Introduction to Object-Oriented Analysis and Design and Iterative Development (3rd Edition)*. Prentice Hall PTR, Upper Saddle River, NJ, USA, 2004.
 - [33] Aldelir Fernando Luiz, Lau Cheuk Lung, and Miguel Correia. Mitra: Byzantine fault-tolerant middleware for transaction processing on replicated databases. *SIGMOD Rec.*, 43(1):32–38, May 2014.
 - [34] Loi Luu, Duc-Hiep Chu, Hrishi Olickel, Prateek Saxena, and Aquinas Hobor. Making smart contracts smarter. In *Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security*, CCS '16, pages 254–269, New York, NY, USA, 2016. ACM.
 - [35] Loi Luu, Jason Teutsch, Raghav Kulkarni, and Prateek Saxena. Demystifying incentives in the consensus computer. In *Proceedings of the 22Nd ACM SIGSAC Conference on Computer and Communications Security*, CCS '15, pages 706–719, New York, NY, USA, 2015. ACM.
 - [36] Satoshi Nakamoto. Bitcoin: A peer-to-peer electronic cash system,” <http://bitcoin.org/bitcoin.pdf>, 2008.
 - [37] Peter R. Rizun. A transaction fee market exists without a block size limit. Technical report, 2015.
 - [38] Chaitya B. Shah and Drashti R. Panchal. Secured hash algorithm-1: Review

- paper. Technical report, Indus Institute of Technology and Engineering, Gujarat Technological University, 2014.
- [39] William Stallings. *Cryptography and Network Security: Principles and Practice*. Pearson Education, 3rd edition, 2002.
 - [40] M. Swan. *Blockchain: Blueprint for a New Economy*. O'Reilly Media, 2015.
 - [41] Enrico Tedeschi. Paying for bandwidth in blockchain internet applications. Technical report, UiT Arctic University of Norway, 2016.
 - [42] Ben Vandiver, Hari Balakrishnan, Barbara Liskov, and Samuel Madden. Tolerating Byzantine Faults in Transaction Processing Systems Using Commit Barrier Scheduling. In *ACM SOSP*, Stevenson, WA, October 2007.
 - [43] Dr. Gavin Wood. Ethereum: A secure decentralised generalised transaction ledger. Technical report, 2014.



Terminology

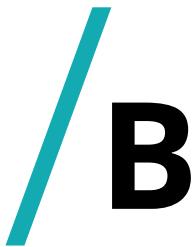
RLP: Stands for recursive length prefix. It is a serialization method for encoding arbitrary structured binary data (byte arrays).

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
```