An Analysis of the Fees and Pending Time Correlation in Ethereum

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***Abstract*—Ethereum is a new blockchain platform for decentralized applications that has gained attention due to the ability to run smart contracts. Like any new technology, there is a need to understand its main current network characteristics and transactions behavior. In this work, we study the main features of an Ethereum transaction. In special, we focus on the latency between the first time a transaction is observed and the time this transaction is properly added to the blockchain, here referred to as pending time. Moreover, we also correlate the pending time with important fee-related features (i.e., gas, gas price, etc.). First, we show that the gas price is not a key feature to determine whether a transaction will be validated or not. Furthermore, we also show that smart contracts and cryptocurrency transactions do not present significative differences in their characteristics. Finally, despite the popular belief, our empirical analysis, based on two months of Ethereum data, show that there is no clear correlation between fees and pending time.**

***Index Terms*—Ethereum, blockchain, correlation, time.**

I. Introduction

Cryptocurrencies are digital assets based on cryptography technologies to secure financial transactions and control the creation of additional currency units [1]. One of the attractive features of cryptocurrencies is their decentralized nature, where none participant has full control of their operational platforms, as opposed to central banking systems. Ethereum [2] has recently emerged as a popular cryptocurrency with a market capitalization above 27bn US Dollars and more than 470M transactions (about 9 transactions per second) as those observed in June 2017[1]. Different from Bitcoin [3], the pioneer cryptocurrency, Ethereum added the smart contracts to its financial transactions, which are autonomous computer programs that execute pre-defined program logic automatically once they are started.

The Ethereum's central operation, like other cryptocurrencies, is the maintenance of a global and public log, called the blockchain, that records all transactions between participants. The security of the blockchain is established by a chain of cryptographic puzzles, solved by participants called miners, which are connected by a peer to peer network. The miner that first solves a crypto puzzle can record a block of transactions, and then receive a fee from users as a reward for its mining (computational and power) effort, also known as proof of work (PoW). This fee works as an incentive for miners to contribute their resources to the network and is essential to the decentralized nature of cryptocurrencies [4].

Every user who carries out a financial transaction or smart contracts in Ethereum has to pay the transaction fee to a miner. Currently, the Ethereum's fee is based on a simple auction mechanism, where users submit their bid (fee) for how much they are willing to pay to have their transaction recorded in the chain. Usually, miners select transactions ranked by the highest fees. However, as Ethereum becomes popular, users have reported difficulty to estimate transactions fees, along with unexpectedly long pending time and high fees [5]. Addressing this problem has been a priority for the Ethereum community, as it impacts on retaining existing users as well as attracting new users to the Ethereum ecosystem.

Despite the popularity of blockchain and, in special, the Ethereum cryptocurrency, only a few works address its management. Without the proper knowledge of Ethereum's network and its behaviour, one is not able to properly address, for instance, security issues of one of the most important services on the Future Internet.

The popularity of Ethereum has directed researches to understand how its blockchain behaves. A few woks investigate the security and the performance aspects of Ethereum [6]–[8]. Graph analysis to measure the behavior of users and miners in Ethereum's network were conducted in [9], [10]. In turn, the delay of block confirmation was investigated in [11], [12] only for the Bitcoin system. None of those previous efforts, however, focus on understanding the subject regarding long delays to confirm some Ethereum's transactions, which we are going to refer as pending time, and high fees.

In this paper, we study the main features of an Ethereum transaction. In special, we focus on the delay between the first time a transaction is observed in Ethereum's network and the time this transaction is properly added to the blockchain, here referred to as pending time. We investigate the relationship between the Ethereum's transactions features, as the fees paid by users to record their transactions on the Ethereum's blockchain, and the pending time. We then propose to answer the following research question: *is there any correlation between attributes from the Ethereum's transactions and the time transactions take to enter into the blockchain?*

To answer this question we conduct a data collection of the transactions that have not yet entered the network, along with a subsequent collection of the data that joined the network,

[1] https://etherscan.io

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seeking to identify the time interval for each transaction. We perform an analysis of the data, searching for correlations between this pending time and the transactions fees. The academia establishes that this correlation exists [12], [13] and it is also supported by the media[2], so we expect that this interconnection exists. Our results show that there is no correlation between the time a transaction took to be mined and its rates.

In sum, the main contributions of this paper are:

- the data collection methodology
- knowledge regarding the relationship between fees and pending time of the transaction in Ethereum's blockchain
- understanding the behaviors of transactions and smart contract executions

The remaining of this paper is organized as follows. Section II talks about the current state of the art on Ethereum's research. The Section III explains how blockchain and Ethereum works. More specific to this research the Section IV shows us what was made to collect the data and the next Section, V, focus on how we analyze the data we collected. The last section contains the main conclusions of this work.

II. Related work

The vast majority of cryptocurrency studies are directed to Bitcoin. Rodrigues et al. [4] analyze the level of security of Bitcoin transactions through an analytical evaluation of its protocol incentive for miners. Meiklejohn et al. [14] characterize the Bitcoin network, by verifying the anonymity of users as well as the risks of maintaining this anonymity. In turn, Ron and Shamir [15] characterized costs of Bitcoin users and proposed statistical methods to determine the cost for users to ensure their anonymity through address exchange. Other studies [16], [17] focus on graph models to characterize financial transactions in Bitcoin.

The increasing popularity of Ethereum has attracted the attention of researchers interested in understanding the dynamics of this new blockchain ecosystem. Payette et al. [18] propose a categorization of Ethereum users, observing the behavior of their transactions from anonymous addresses. Other studies focus on security and performance aspects of Ethereum. For example, Li et al. [7] conduct a systematic study on the security threats to the blockchain, whereas Chen et al. [8] conduct an investigation on Solidity, Ethereum's main language, and reveal its fails to optimize costly programming patterns.

Some recent studies have also proposed graph analysis with new methods due to the difference in functionalities and protocols between Ethereum and Bitcoin. Mascarenhas et al. [9] propose multi-aspect graphs and complex networks techniques to analyze the centrality of participants in Ethereum's network. Chen et al. [10] characterize financial transactions in Ethereum, taking into consideration the characteristics of users, smart contracts and the relationship among them (user to users, a user to a smart contract and smart contract to smart contract) using multi-flow graph analysis.

More related to our work are the studies which analyze fees of cryptocurrencies. Chan et al. [6] analyze current gas fee model in Ethereum and identify denial of service (DoS) attacks. The authors then proposed a new gas cost mechanism to find the accounts controlled by the attacker and prevent DoS attacks. Easley et al. [12] investigate the impact of transactions fees on the participation of users in Bitcoin through a game-theoretic approach. Authors conclude that in the absence of fees, eventually, the blockchain of Bitcoin is not viable for both miners and users. Ricci et al. [11], proposed a model to estimate the time of acceptance of a transaction in Bitcoin based on queuing theory and a supervised classifier that includes characteristics of transactions. Those studies are similar in spirit to ours, as the broad goal is to characterize transaction fees. However, the study in [6] focus on Ethereum's security, whereas the analysis proposed in [12] and [11] focus on characteristics of the Bitcoin system.

III. Blockchain Background

Before Nakamoto's proposal [3], almost all virtual commerce was done through financial institutions, which serve as a reliable platform to mediate transactions. This is due to trust in these institutions and virtually every trade in the modern world is done in this way. This system, although functional for most people, has some problems, such as the high cost of transactions, since the institutions in question have large physical structures, employees and many other direct and indirect costs, which are passed on to users.

Another problem with traditional methods of monetary transactions is that most payments are reversible. For example, when purchasing with a check, you can cancel it, making the payment invalid, hurting the confidence of the parties involved. Blockchains do not require trust in people or institutions to execute transactions since their operation is managed by a decentralized algorithm. Thus, no group of people has control, except in cases where there is more than 50% representation of the network, which involves enormous computational power [19]. A notable advantage of the blockchain technology is that its code is open, resulting in greater transparency for its customers, plus the non-reversibility of the transactions give both parties greater security.

New technologies have emerged to improve the functioning of the blockchains. This is the case of Ethereum, which has in its architecture the execution of contracts. These contracts are algorithms [20] inserted in this network and that, given some variables, which can be sent by blockchain, have automated behaviors, allowing third parties to be unnecessary and providing greater security to all parties.

There are two main ways to mine in a blockchain and reach a consensus: the Proof of Work, a protocol based on a user effort, and the Proof of Stake, based on the users' currency stake.

[2]https://medium.com/@preethikasireddy/how-does-ethereum-work-anyway-22d1df506369

A. Blockchain

A peer-to-peer network without hierarchy or special nodes running over the TCP protocol and a random topology [13], where each node peers with other random nodes. The entrance is open and everyone can join the network, having equal rights to mine and use it as any other node. It is a growing list of blocks linked using cryptography, each block containing a hash of the previous block, timestamp and transaction data.

B. Proof of Work

Proof of Work (PoW) [3] is a protocol in which one can effectively prove to others that it has employed a significant amount of computational effort. Usually, they are established in the form of challenges, and they are cryptographic in the current context. Although the protocol demands an effort that will impact in time to generate a correct answer, this however is easily verified. As an example, we need to generate a hash of a block with a specific number of zeros at the beginning, by oscillating the value of a cryptographic nonce field for this. The correct number may be slow to find, but given a block and the correct number quickly the function will apply and the response will be verified in a short time.

In the case of Ethereum, each block follows a predetermined difficulty, which is set so that the time between blocks is close to a desired constant. This difficulty is directly proportional to the time expected for mining the current block. This convention generates an expectation that miners will look for transactions with higher processing rates, to increase their profit, which is achieved by the resulting fee, consisted by the product of gas and gas price, whose meaning to this work will be defined in Section IV.

C. Proof of Stake

Created as an alternative to PoW, Proof of Stake (PoS) defines that a person can mine or validate the transactions of a block according to the number of coins it has. As the previous protocol causes multiple people to do the same process repeatedly, with only the fastest ones remaining, Proof of Stake has shifted this line of thinking to converge to a more ecologically sustainable protocol.

Its operation is based on addressing mining proportionally to the number of miner's coins, so instead of using energy to solve PoW problems, the PoS miner is limited to mine a percentage of transactions proportional to how much it owns. For example, a miner who with 5% coins is theoretically able to mine only 5% of the blocks.

D. Ethereum

Ethereum is a platform with many features similar to Bitcoin since it is based on transactions, it has a crypto-currency with market value, it uses blockchain as its structure it is currently the second most valued virtual currency. Out of open funding, widely known as crowdfunding, the Ethereum was launched on July 30, 2015.

The basic Ethereum-user interaction is a financial transaction or a smart contract, where the user inserts a value, a gas, a gas price and it will be executed by the Ethereum Virtual Machine (EVM) until it is completed or it runs out of gas, an attribute that will be explained in Table I. At this point, it joins the *mempool*, a waiting queue for transactions that historically presents itself with a considerable number of backlogs, until a miner decides to mine it, and then it joins the blockchain itself.

The major difference from this platform concerning the Bitcoin is the Ethereum's possibility of smart contracts execution and programming your contracts, as defined in their official documentation [20]. The language is Turing-complete and so it supports a wide range of computational instructions [20]. Among the capabilities of the contracts are[3]:

- Multi-signature accounts in which expenditures are only carried out with a minimum amount of agreement between parties.
- Management agreement between users, for example, when someone makes the purchase of insurance from a third party.
- Storing information of an application, such as domain registration information or user data.
- They serve as a basis for other contracts and can be used as a library for some software, for example.

All transaction and Ethereum related attributes that were used in the analyses presented here are presented in Table I. Most of them are directly provided by the blockchain, although some attributes suchlike pending time, Value and avg are generated in this work to help the analysis with correlated data.

E. Ethereum's transactions

To understand the concept of data collection, it is necessary first to understand the possible states of a transaction. Figure 1 illustrates the life cycle of a transaction.

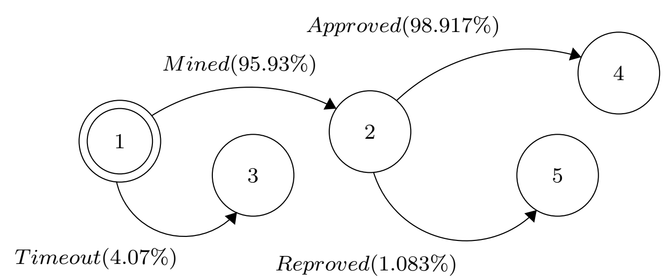


Fig. 1. Life cycle of a transaction. 1-Just inserted transaction 2-Mined transaction 3-Transaction never mined 4-Transaction mined and approved 5-Transaction mined and reproved

A transaction has its life cycle started as a disclosed transaction, where the miners become aware of its processing feasibility. As a reference, we will use the information released by Etherchain [4].

Subsequently, in case of mining, the transaction joins the network as an executed transaction. Its approval depends on

[3]https://www.coindesk.com/information/ethereum-smart-contracts-work

[4]https://www.etherchain.org/

TABLE I
ATTRIBUTES USED IN THIS STUDY.

Attribute	Description
gas	Processing and storage unit.
gas offered	Amount of gas offered to process a transaction.
gas price	Amount in Ether currency paid per gas unit.
avg	Average value of gas price in a region.
Value	Monetary value of the Ether currency at the time the block was mined.
fee	Fee paid for transaction or invocation of contract in Ether.
paid	Fee paid for the transaction or invocation of contract in dollars.
pending time	Time between the disclosure of the transaction and its appearance in blockchain.

the amount of gas offered by the user to be sufficient to act on the network, otherwise, it enters into the network to reward the mining the execution of the processing, but without the user's desired effects. Also, some transactions were not mined during the time window of our observation. We considered these cases as time out and these transactions are placed in the mempool.

F. Ethereum's client

To run Ethereum on any machine it is mandatory to have a client, such as go-ethereum, Parity, cpp-etheruem, pyethapp, ethereumjs-lib, Ethereum(J), ruby-ethereum, ethereumH and others. Ethereum runs on a virtual machine and, due to the larger number of options, some variables may differ from client to client suchlike the size of the mempool and time a transaction can stay there.

IV. DATA SUMMARY AND CRAWLING METHODOLOGY

Figure 2 shows a graph with the number of pending transactions over time. It shows that the mempool has a substantial number of transactions, having a small reduction of its volume at the weekends. As the maximum interval setting for a transaction to stay in a queue is set by the miner, one can not define when the transaction expires, thus the figure refers specifically to Etherscan's mempool.

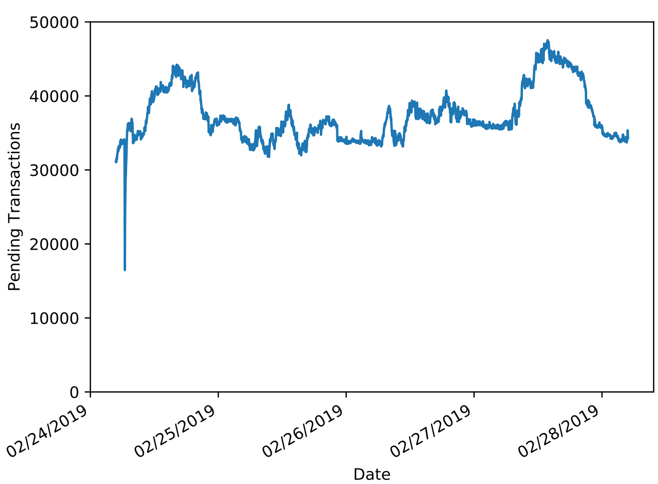


Fig. 2. Transaction queue by time.

First, data from pending transactions are collected in the blockchain of Ethereum through Etherchain and added to a dataset. At this stage, it was possible to collect the following attributes: value, recipient, sender, gas text, and hash, along with the time the transaction first appeared.

We analyzed 10,508,960 transactions from 04/15/2019 to 06/13/2019. As the data collect inserts errors in the metrics, we considered 4,381,816 of these transactions as only the contracts and transactions with pending time greater than 1s were used to avoid problems suchlike negative values in the mentioned field, although it does not affect the final results and provides a range of dates sufficient enough for a non-biased dataset. The values at the time the transaction joined the mempool are not highly accurate, with values such as 'a few seconds ago', '1 minute ago', '5 minutes ago', '1 hour ago' and so on. We only record transactions that are listed as 'a few seconds ago' to reduce the error. Even so, there are errors in the measure, as a given transaction with the first metric is considered with the current time.

Then, we have obtained data from the Ethereum blockchain through the API provided by Etherscan. At this step, we collect information about the transactions that have been inserted in the Ethereum blockchain, including the insertion time. With this information, we can identify which transactions —from the previous step— that entered the blockchain and when this occurred. We identify transactions using the hash field (i.e., a transaction identification field), making an exact match.

Two different sources of data on the blockchain were chosen due to the limitation of requests per unit of time for a single API (Etherscan and Etherchain), to increase the amount of data obtained. Both sources are widely used in academic circles and are well accepted [10].

Once the transaction is identified using its hash, the data representing the moment this transaction entered the blockchain is also stored in the dataset. It is then possible to calculate the time interval between the transaction being disclosed and appearing for the first time in blockchain; this time value is referred to in the dataset as pending time.

Our collection has an obstacle to reach a greater number of transactions collected since the number of new transactions that are in the mempool per unit of time provided by the API is smaller than the adhesion of new transactions. Observing the collection during the period from 04/15/2019 to 04/16/2019 was detected the insertion of 162,317 new transactions in mempool and the adhesion of 667,115 new transactions in blockchain in this same period. Thus the data collect volume was 24.03% of the maximum capacity, which 154,068 had adhesion to the network and 6,271 were still in pending status with waiting time of approximately 700 seconds.

Users inform the values of gas limit, which is the maximum of gas it will provide for the transaction to be executed and the price he wants to pay for that unit, for each new transaction Gas, here understood as the gas used, means how much processing and storage this transaction or contract invocation required. Thus, here gas is the unit of computational cost in the Ethereum network.

Much related to the aforementioned field is the gas price, which is the value in GWei (0.000000001 Ether) that will be paid per processing unit when executing the transaction and/or contract invocation. To illustrate, if a user defines a gas limit, which in case of cost the same, become a gas used of the same value. In addition, setting a gas price of 20 GWei has a consolidated transaction costing 50000 $\times$ 20 Gwei = 1000000000000000 Wei = 0.001 Ether.

Other fields are calculated using the data collected. One of them is the fee, which is defined by

$$fee = gas\ used \times gas\ price.$$

Semantically, this attribute refers to how much was paid in Ether for a transaction, having no relation with values of the external market, for example with the Real or Dollar. This and other fields were generated with values derived from transaction data to support the analyses conducted here.

To verify temporal locality factors of the gas prices, a simple solution was found, which was established as follows: given any N block, the average gas prices of the transactions belonging to this N block, together with the transactions belonging to the N + 1 and N-1 blocks. We denote this value as avg.

V. Data analysis

In this section, we empirically verify the relationship between several fields contained in the monetary item, such as the value paid per unit of processing (gas),the local average price paid per processing unit, which time a transaction obtained between its disclosure and entry into the blockchain, the rate paid by a user in the crypto-currency and the rate paid by the user in real monetary amount.

In this work we look for possible correlations between attributes of a given transaction with its time between the disclosure and the time it first appears in blockchain, which is, for convenience, we called here the pending time. This search is made due to the expected correlation on a Proof of Work system or hybrid of [11] since miners mostly look for transactions greedily, searching for those whose fee is higher than the others in the mempool.

Ethereum's blockchain allows users to extract a wide range of information through its data, whichever can be embedded in contexts that describe patterns of behavior and interaction of this network.

In the following subsections will be presented our data analysis separated by subject. First, we are going to introduce general characteristics of Ethereum on the purpose to know what it is overall behavior. Furthermore, an analysis seeking to answer one of our main questions: *is there a correlation between fees and the pending time?* will be introduced.

A. Ethereum's general characteristics over time

First, we will analyze the period of adhesion of the network, given (i) Ether's market value, (ii) the number of transactions per day. These data come from the Etherscan and are presented in the Figure 3.

As observed in the Figures 3(a) and 3(b), one can perceive: (i) high network adherence between the end of 2017 and the beginning of 2018, and (ii) a similarity between the data of the two graphs.

The great adhesion to the network at the end of 2017 and the beginning of 2018 is closely linked to the increase of the market price of Bitcoin. This feature attracted many investors to the currency of Satoshi Nakamoto and ended up also leveraging the investment in other currencies on the rise, which is the case of Ethereum, our object of study.

Figure 4 shows the likelihood that a contract or transaction will be approved solely because of the pending time. The x-axis contains the probability P(X$\leq$x) and the y-axis contains the elapsed time to a transaction be mined, being this graph an empirical distribution function. Through this graph, it can be seen that both transactions and smart contracts percentages are similar, presenting a little representative variation between the curves. Besides, in most cases, blockchain adherence occurred in less than 10 minutes, giving a characterization of the behavior of transactions/contracts with miners.

B. Correlations

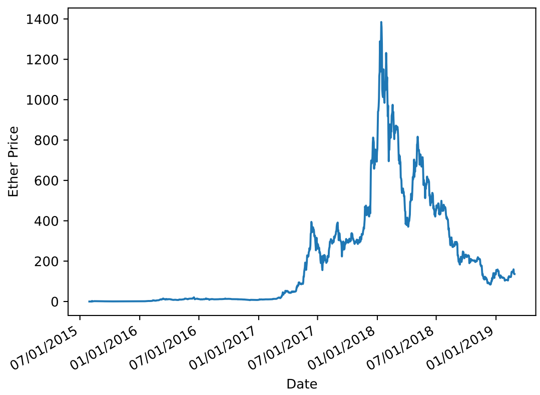
This subsection contains a range of correlation investigation, presenting graphs using our data collected in Section IV to provide a better understanding of the information.

In another investigation, we observed that 80% of both transactions and executions of contracts were approved within 200 seconds. It is a small time for approval when compared to Bitcoin. These values are highly intrinsic to the difficulty in the network [20].

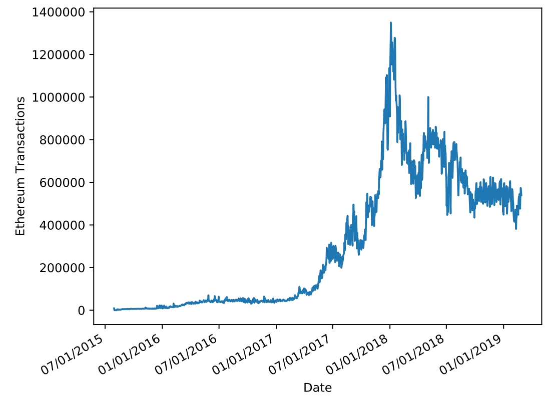
As there is a difference between the curve for a transaction and a contract to be approved in Figure 4, we will continue with this research further, in addition to further instigating the main point of this work. We established a gas price boxplot graph between transactions and contracts, removing the outliers for better visualization in Figure 5.

The median of the two groups is similar, but the contracts present a larger absolute number than transactions in Figure 5. In Figure 4, we observed that the transactions are approved with smaller time than contracts. On the other hand, Fig. 5 shows that the median of the gas prices of the contracts is larger than that of non-contracts, which are the transactions.

Our main intention is to observe possible correlations between the attributes of a transaction and the pending time.



(a) Ether's value per day



(b) Transactions per day

Fig. 3. Graphs showing the Ether values, the number of unique addresses, and the number of transactions over time.

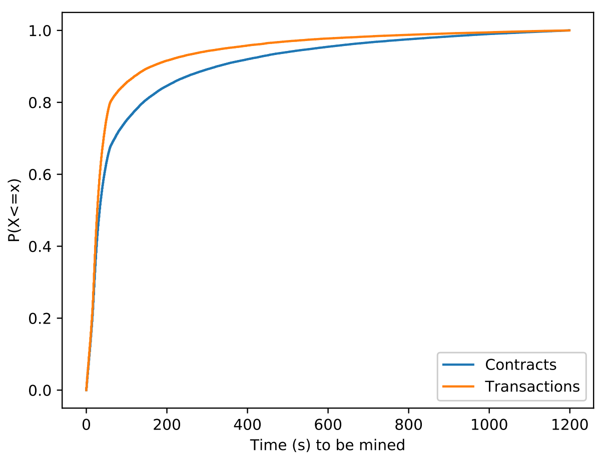


Fig. 4. Probability of a transaction or contract being approved solely because of its time.

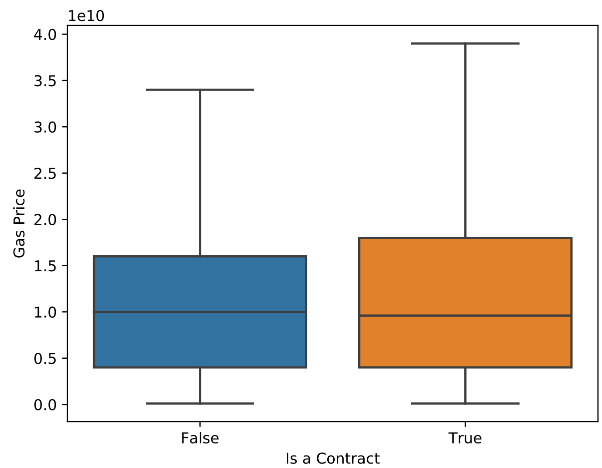


Fig. 5. Boxplot of Gas Price of Transactions and Smart Contracts without outliers.

Therefore, Pearson's correlation coefficient was used to verify if it exists. We generate this index for all possible attribute combinations to get a general idea of how the fields relate. Particular attention was then given to pending time with fields such as paid, fee, Value, gas, gas price and avg, since it is the objective of the analysis of the work to seek for correlations with fees and the pending time. Thus, these Pearson's correlation coefficients between attributes were calculated and are presented in Figure 6 alongside with all the other attributes used in the dataset. The heatmap of this figure has colors ranging from blue (-1) to red (1) and external the correlations of pairs of variables.

Observing Figure 6 it is evident that the coefficient is strong between a field and its derivations, such as paid with the gas, gas price and fee. Because this is an attribute derived from the other, this type of correlation was already expected.

Following the idea of PoW, that a large computational effort will be made to mine a block, it is expected that mining users will always seek the blocks to maximize their reward greedily, that is, maximizing the value of paid[5]. A strong correlation between Value and pending time would indicate that the market value of the currency influences the pending time, which could mean, in case of a negative coefficient, that higher values of the currency cause a larger volume of transactions to be mined, decreasing the pending time.

Figure 7 shows that the gas price values of reproved transactions are in general smaller than those of approved ones. Nevertheless, the values are similar, strengthening the hypothesis that there is a low correlation between the gas price and the pending time.

The Pearson Correlation Matrix among the observed at-

[5]https://medium.com/@preethikasireddy/how-does-ethereum-work-anyway-22d1df506369

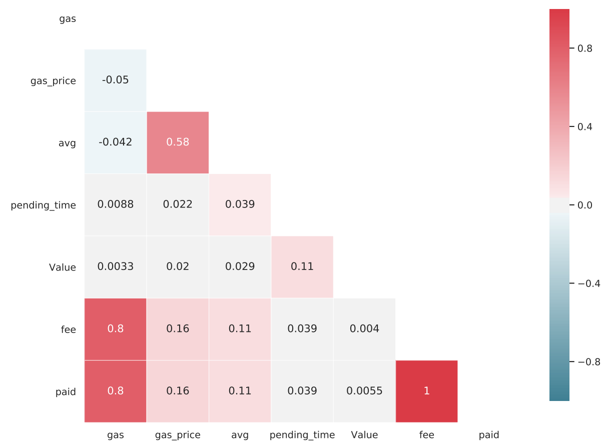


Fig. 6. Pearson's Correlation Matrix Heatmap.

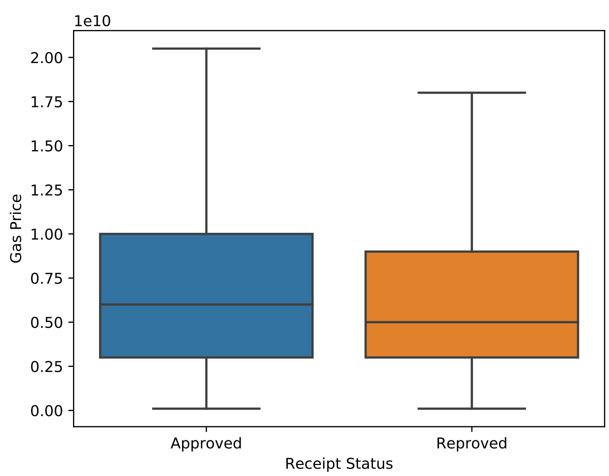


Fig. 7. Gas Price Boxplot by Receipt Status.

tributes of the Ethereum transactions shows that the correlation of pending time coefficients with the other attributes are close to zero. Correlation, in this case, is negligeble. However, this result is counterintuitive, as we expect the miners' greedy behavior regarding the fee attribute.

VI. Conclusion

In this paper, we created a specific cross-API data collect, using both Ethereum and Etherscan data. Equally important, we have highlighted new knowledge regarding the relationship between fees and pending time in Ethereum. In this sense, we establish background information such as the empirical distribution function of the time to be mined, comparisons of transactions and smart contracts regarding its gas price and verifying if a difference between approved and reproved transaction's gas price exists.

More in deep, we conducted a characterization study of the Ethereum by the aspect of pending time.

Our analyses show that the correlation between the pending time and any other attribute related to the fee has absolute values close to zero, which is counterintuitive. This paper also concluded that gas price values are similar between smart contracts and transactions and also between approved and reproved transactions/smart contracts.

In the future, we intend to conduct a study that is more focused on the classification and regression of transactions taking into account their state (mined and accepted, mined and rejected, and timeout), as this analysis becomes extensive enough not to we can approach it in this work, providing a different behavioral view of the blockchain for these types of consensus protocol.

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