# Not Enough IoT After All: Visiting Transactional Characteristics of IoT Blockchains

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Abstract

IoTeX and Helium are among the top Internet of Things (IoT) blockchains designed to serve the needs of the IoT ecosystem. IoTeX aims to enhance scalability and support decentralized applications (dApps) for IoT use cases, while Helium is intended to connect millions of IoT devices utilizing specialized hardware over the public internet. However, little to no effort has been put into understanding their true transaction throughput capabilities, adaptability to IoT-related applications, and traffic management. Our paper extends a measurement framework to analyze IoT blockchains by exploring all on-chain transactions on both blockchains since their respective genesis blocks were mined. Our analysis shows that IoTeX's blockchain has achieved very low throughput, with a significant portion of governance-related transactions. Specifically, 95% of total smart contract transactions were carried out with only 50 smart contracts, and very few real IoT use case-related dApps exist. More than half (51%) of the mined blocks are entirely empty, with an overall throughput of just 1.5 transactions per block. On the other hand, the Helium network has been highly congested and has failed to attract any real-world application traffic. Protocol design issues in Helium can be traced by analyzing the graphical representation of transactions, and understanding such patterns might help future protocol developers. Additionally, we identified a pattern in which the price of IoTeX's token correlated with a substantial increase in the number of transactions. Our paper also examines the design choices and adoption trends of IoTeX and Helium blockchains. Notably, the number of non-IoT dApps on these blockchains far exceeds the number of IoT-related applications by a significant margin.

**Keywords**

IoT, Helium, IoTeX, Blockchain, Measurements

## 1. Introduction

Since the inception of Bitcoin [1] and Ethereum [2], more than 1,000 blockchains and over 12,000 cryptocurrencies [3] have been created. However, only a select few of these blockchains are designed to meet the specific requirements of the Internet of Things (IoT) ecosystem, which poses unique challenges due to limited resources, unreliable connectivity, and the real-world accessibility of IoT devices. These challenges are distinct from those encountered when using a typical blockchain for decentralized applications, such as cryptocurrency transfers or Decentralized Finance (DeFi).

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IoTeX [4] blockchain addresses these challenges by offering a highly scalable, fast, cost-efficient, and decentralized blockchain that is compatible with IoT applications (Dapp). Compared to other notable IoT blockchains, such as IOTA and Helium, IoTeX has unique features, such as instant block finality and programmability in terms of smart contracts, among others [5]. Helium blockchain aims to connect millions of IoT devices across the globe using specialized hardware aka hotspots, via the public internet. The Helium blockchain is distinctive in that it does not support smart contracts but instead is specifically designed to incentivize hotspot operators to provide connectivity for IoT devices.

While IoT blockchains have been around for several years, to the best of our knowledge, no comprehensive evaluation of their actual on-chain usage has been conducted. Without proper assessment, the economic feasibility and widespread adoption of IoT blockchains remain uncertain. Analyzing the quantity (transactional capacity) and quality (real-use IoT Dapp) of on-chain transactions could provide a deeper and interesting insight into the efficiency and utilization of current IoT blockchain design, potentially leading to better utilization of these blockchains.

Our analysis of IoT blockchains aims to provide insights into the current state of user activities and whether they address the intended issues. The measurement and analysis framework utilized in this study can be extended to support other IoT blockchains as well. In this paper, we examine the transactional data of the IoTeX and Helium blockchains, seeking to answer the following research questions:

**RQ1** To what extent are IoTeX and Helium blockchains adopted for the IoT use cases?

**RQ2** Can we classify transactions by analyzing the kind of on-chain transactions and patterns they follow?

**RQ3** Who are the most active transaction initiators, and what is the nature of the transactions (useful or fake/spam) they conducted?

**RQ4** Are IoTeX and Helium blockchain design specific to IoT ecosystem, and what lessons can be drawn by next-generation IoT blockchain designers?

Following are our contributions to the body of literature on the IoTeX and Helium blockchain:

1. We perform the first large-scale detailed analysis of the transaction history of the high-capacity IoTeX blockchain, which supports up to 32,000 transactions per block and is EVM-compatible, as well as the Helium blockchain, which incentivizes the creation of decentralized, public wireless networks focused on IoT devices starting from the genesis block. Our findings showcase a poor utilization of the transaction capacity, waste of resources in the form of real application data (empty/underutilized blocks in IoTeX), lack of IoT traffic, and poor protocol design choices in Helium.
2. We classify on-chain transactions based on their kind/type and measure their realized throughput in terms of transactions and economic volume. 95% of the smart contract (SC) transactions account for just 50 SCs out of 5,688 deployed and around 2/3rd (62%) of all SC transactions from just 5 smart contracts. A single address made more than 14% of the overall transfer transactions with spam-like activity. In Helium 95% of the traffic is utilized to maintain the network state and less than 1% is used by application-specific use cases.

3. We highlight in IoTeX the block utilization for non-governance transactions is slightly above 1 transaction per block, this number merely goes around 1.5 including governance transactions. The majority of on-chain transactions are initiated for non-IoT Dapps. Helium suffers significantly from the congested network state while just having to maintain the network consensus, average transactions per block overall remains around 320 per block and in periods of higher activity, it could climb up to 1700 per block. Eventually, some components of the consensus protocol have been shifted off-chain, for a long time it was evident from the transactions pattern.
4. We extend a measurement framework used in previous studies to support IoT blockchains in order to access the qualitative and quantitative aspects of on-chain activities.

This paper does not analyze the IOTA [6] protocol because it is block-less, doesn't charge a transaction fee thus accounts for a significantly large number of spam transactions [7]. IoTeX and Helium are considered among the top peer blockchains based on factors such as market dominance, technological novelty, public auditability, programmability, among others.

The remainder of this paper is organized as follows. Section 2, we mention the relevant past studies and how ours fills the gap. Section 3, we provide IoTeX and Helium blockchain background that lays a foundation for further analysis. Section 4, we introduce the methodology and definitions of various entities used in our study. Section 5, we present the high level illustration of IoTeX and Helium on-chain data and patterns. In Section 6, we go through the case studies to better understand the nature of the transaction patterns observed during this research. In Section 7, we discuss in detail the core findings of our paper. Finally, Section 8 concludes the paper.

## 2. Related Work

Related work on IoT blockchains are mostly structured around the literature survey focusing on IoT needs (ad-hoc connectivity, lowered operating cost and transaction fee, support for micro-transactions, reduced complex computation overhead, etc.), what are the available solutions and what future solution might look like [8, 9, 10, 11]. Work [12] by Rawat et. el., showcased the protocol level peculiarities of the IOTA blockchain, exposing how viably the offline transactions are offered on IOTA blockchain.

In the paper [13] by Alberto Partida et. al., the time series price correlation of the IOTA and the IoTeX blockchain is presented. However, in the study, no real transaction or on-chain activity is considered. The price is obtained from the exchanges and evaluated. In the work [14] by Fan et. al., Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs) are explored with the Pebble tracker, which is a hardware oracle by IoTeX. Again, no real transaction or on-chain classification is performed in any way.

On-chain analysis literature on Bitcoin and Ethereum is widely available. Initial Bitcoin analysis [15] by Ron et.al., showcased the Mt. Gox exchange dominance represented a massive on-chain footprint. Ethereum analysis [16] by Somin et. al., studied the wallets on the network graph, exposing the degree distribution of buy-sell trades. Work [17] by Daniel et. al., showcased the holistic view into the on-chain transactions, the nature and pattern of transaction revealed Denial of Service (DoS) like indicators and throughput aspects of the EoS, XRP, and Tezos blockchain. In Befekadu et.al. [18], traffic characteristics of the Bitcoin blockchain are put forward.

To the best of our knowledge, our paper is the first ever large-scale study of the IoT blockchains at an on-chain level. It aims to fill the research gap of IoT blockchain study using real data and on-chain patterns that emerged in the last 3 and a half years.

# 3. Background

In this section, we briefly explain the fundamentals of the blockchains, a brief introduction to the IoT blockchains, and describe the protocol details of the IoTeX and Helium blockchain.

## 3.1. Blockchain Basics

A blockchain is a data structure that consists of a growing list of ordered records, called blocks, which are linked and secured using cryptography. Each block contains a timestamp and a link to the previous block, which allows the blocks to be ordered chronologically and creates a chain of blocks. It is a decentralized, distributed ledger that is used to record transactions across many computers so that the record cannot be altered retroactively without the alteration of all subsequent blocks and the consensus of the network. This allows for the creation of a secure and transparent record of transactions that is resistant to tampering and revision.

Most blockchains use "transactions" to record the on-chain activities. A transaction contains information about its sender, receiver, and/or the kind of action they perform. Actions can be anything from a peer-to-peer (P2P) token transfer, a complex smart contract execution command, to consensus governance activities. Within a regular interval, the transactions are grouped into a block, which is appended to the blockchain and considered valid as per the consensus protocol rules. Blockchains are immutable and require new blocks to progress the state change.

## 3.2. Consensus Mechanism

A consensus mechanism is a method for reaching an agreement among the members of a distributed network in order to validate transactions and achieve network consensus. In a blockchain network, a consensus mechanism is used to ensure that the network is secure and that the record of transactions is accurate and tamper-proof. Some common types of consensus mechanisms include Proof-of-work (PoW), Proof-of-Stake (PoS), among others. Details on the same are described in Appendix A.

## 3.3. IoT Blockchain

IoT-focused blockchains were first introduced around 2015, following the emergence of Bitcoin and Ethereum [19]. One of the earliest IoT blockchains was IOTA [6], which offered blockchain features tailored to the IoT ecosystem and is still under active development. IOTA does not follow a block-based blockchain, instead, it uses a Directed Acyclic Graph (DAG) ledger, designed to be lightweight but with limited programmability. One advantage of the IOTA blockchain is that its nodes can operate using a sub-graph of the DAG rather than storing the entire transaction tree, making it a suitable choice for installation on IoT devices. The blockchain operates using a central consensus mechanism, whereby a specific node marks a point on the DAG (known as the coordinator transaction), and all transactions referred to directly or indirectly are considered confirmed.The resource-intensive nature of Proof of Work (PoW) blockchains presents scalability challenges, which are antithetical to the needs of the IoT ecosystem. As such, a consensus mechanism that is low-resource and highly scalable is better suited for IoT blockchains.

### 3.3.1. IoTeX Blockchain

The IoTeX blockchain provides a platform for IoT devices to leverage the benefits of blockchain technology. It is built as an Ethereum Virtual Machine (EVM) compatible blockchain with a similar transaction and blockchain structure as the Ethereum ecosystem. However, unlike Ethereum's (1.0) resource-intensive PoW consensus mechanism, IoTeX uses a variant of PoS consensus protocol that enables high throughput, cost efficiency (due to lower transaction execution costs), and general programmability to support DApps. Processing a transaction on IoTeX blockchain is not free, IoTeX takes a small fee which is in proportion to the computational capacity required to process a transaction. A fee is paid in the form of gas, as in the case of Ethereum, IoTeX has a native unit of measuring the gas i.e. Rau ($10^{18}$ Rau = 1 IOTX). It uses Roll-DPoS consensus mechanism, described in Appendix A.

We briefly explain the categories of transactions and accounts on IoTeX blockchain.

- **Account and Transaction Types** Similar to Ethereum, the IoTeX blockchain has the concept of External Owned Accounts (EOAs) and Contract Accounts (CAs)[1]. Given a private key, the public key corresponds to both IoTeX as well as Ethereum and its compatible chains. The contract account represents a smart contract deployed on-chain similar to Ethereum. The state of the IoTeX blockchain can be modified by executing a transaction on a smart contract account. There are three different types of transactions on the IoTeX blockchain:
- **Transfer Transaction** In a transfer transaction, IOTX tokens are transferred between peer EOA accounts or a contract account, much like exchanging physical currency. These are simple transactions that consume a constant gas (10,000) to execute.
- **Execution Transaction** In this type of transaction, a smart contract is executed and the state of the blockchain is changed. Here smart contract code is run by the block producer node and output in terms of state change can be observed. Different types of smart contracts consume different quantities of gas based on the nature of computation and memory (storage) operations performed. IoTeX uses an EVM engine for smart contract execution. Any contract written for Ethereum can also be deployed to IoTeX blockchain.
- **Governance Transaction** Governance transactions are low-level actions between an account and IoTeX blockchain. They are used to manage and track the voting mechanism, delegate registration, rewards, etc. Currently, there are 11 different types of on-chain transactions related to governance. The governance transactions on IoTeX blockchain

[1]https://ethereum.org/en/developers/docs/accounts/

have a direct impact on the consensus protocol, and having them on-chain ensures transparency and accountability in the process.[2].

### 3.3.2. Helium Blockchain

Helium [20] is a blockchain network that utilizes a block-based architecture to transfer data between IoT devices using LoRaWAN, a popular radio communication standard. The Helium network seeks to provide network coverage for IoT devices, utilizing a unique consensus mechanism known as Proof of Coverage, which allows nodes to mine Helium's native cryptocurrency (HNT) by providing wireless coverage to the network. Physical hotspots are installed in different geographic locations and they cover a geo-radius to provide connectivity to IoT devices. All the data is recorded on-chain and validated by a group of validators that uses PoS + HBBFT [21] consensus protocol, described in Appendix A. To become a validator a huge stake of 10,000 HNT tokens is required. Earlier the hotspots used to act like a validator i.e. capability to add blocks but it was changed to make the network scalable and the resource-rich federated group of nodes were chosen to generate blocks. Hotspots can verify the geographic location of each other through a protocol-backed challenge phase, which involves becoming a witness of hotspots placed in their wireless vicinity.

There are currently 33 different types of activities registered over the Helium network[3]. Activities such as Proof-of-coverage and Proof-of-receipts are the core part of the Helium network as they provide incentives for the hotspots to provide connectivity to the nearby IoT devices.

- **Proof-of-Coverage request** This is a type of transaction using which the Helium network continuously verifies that Hotspots are accurately reporting their location and the wireless network coverage they provide from that location. Proof-of-Coverage leverages the inherent characteristics of radio frequency (RF) to generate evidence that is verified on-chain. Earlier other hotspots used to generate the challenges, but currently, validators do it.
- **Proof-of-Coverage receipt** When a Light Hotspot receives a transmitted packet, it will act as a Witness, as it is currently the case on the Helium network. The Light Hotspot submits its Witness report over gRPC in the form of a PoC receipt and uses the Validator(s) it is connected to as a client to look up the Challenger Validator using the hash of the PoC packet. The Light Hotspot then uses this routing information to directly submit the Witness receipt to the Challenger.

# 4. METHODOLOGY

In this section, we describe the methodology used to analyze the on-chain data of the IoTeX blockchain.

[2]https://docs.iotex.io/basic-concepts/blockchain-actions
[3]https://docs.helium.com/blockchain/blockchain-primitives/#transactions

| Helium Blockchain | | | |
|---|---|---|---|
| **Category** | **Action name** | **Count** | **Percentage %** |
| Proof of Coverage Challenge | PoC Request | 292,828,528 | 59% |
| Proof of Receipts | Version 1 | 141,012,708 | 28% |
| | Version 2 | 39,419,556 | 8% |
| Validator | Heartbeat | 18,498,289 | 4% |
| | Stake Validator | 4121 | |
| | Transfer Stake | 706 | |
| | Unstake Validator | 492 | |
| Assert Location | Version 1 | 65,971 | 0.4% |
| | Version2 | 2,202,359 | |
| Payment | Version 1 | 381,502 | 0.5% |
| | Version2 | 2,140,718 | |
| Hotspot | Add gateway | 950,300 | 0.2% |
| | Transfer Hotspot V1 | 82,616 | |
| | Transfer Hotspot V2 | 94,434 | |
| Others | rewards, state channels, etc. | 609,272 | 0.1% |
| **Total** | | 498,291,572 | 100% |

**Table 1**
Distribution of action types in Helium Blockchain, along with their count. The transactions are divided into different types, PoC and PoR type counts (95%) for the majority of them.

| IoTeX Blockchain | | | |
|---|---|---|---|
| **Category** | **Action name** | **Count** | **Percentage %** |
| Peer-to-peer transactions | Transfer | 1,718,711 | 6% |
| Smart Contract | Verified SCs | 11,498,337 | 39% |
| | Unverified SCs | 9,224,124 | 31% |
| Others transactions | Governance | 6,971,696 | 24% |
| **Total** | | 29,412,868 | 100% |

**Table 2**
Distribution of action types in IoTeX Blockchain, along with their count. Verified smart contracts have their source code open to explore, while Unverified has not opened their source code. Governance-related transactions consume a large chunk of the capacity while P2P transfer remains the lowest.

### 4.1. Preliminaries

**Blockchain specific definitions.** In the following, we define the terminology used throughout the blockchain analysis infrastructure for this paper. We may deviate from the definitions provided by the IoTeX and Helium blockchains in order to maintain consistency throughout.

- **Action** The entity that is part of a transaction provides semantic information about what actions should be taken with the data it carries. Depending on the transaction's action, IoTeX EVM executes specific types of operations, while Helium changes the relevant state as per consensus rules. Two fundamental actions in IoTeX are the transfer of IOTX cryptocurrency and the execution of a code in a smart contract. While in Helium it is

PoC requests and PoC receipts, state channel open, among others. IoTeX also supports governance-related actions which are specific to the consensus protocol.

- **Non-Governance Transactions** The transaction that is not used to maintain the consensus of the blockchain but is used in the application of the blockchain. Peer-to-peer (P2P) transfer and smart contract (SC) execution transactions counts under this category. In the case of Helium blockchain, data transfer between IoT devices accounts to it.
- **Smart Contract Transaction Signature** In a SC transaction a function call is made on a Dapp deployed on-chain. The functions are identified by hashing their signature using KECCAK-256 [22] hash function. If a standard function signature is used then the KECCAK-256 value must be unique therefore one can predict the behavior of a SC.

**Throughput-related definitions.** We have quantified the throughput in terms of block utilization, which is defined as the number of transactions per block since the time to generate a new block is fixed in both of the blockchains, as well as the number of blocks assigned to a specific category.

- **Empty Block** No transaction of any type i.e., governance or non-governance is present inside the block. The empty block is mined by a block producer or miner.
- **Zero-Transaction Block**: This type of block does not contain any peer-to-peer (P2P) or smart contract (SC) execution transactions, but it does include at least one governance-related transaction, which classifies it as a governance-only block.

In the case of the Helium blockchain, transactions such as PoC or Proof of Receipt are not directly related to serving data across IoT devices, but they are required to maintain the incentivization mechanism of the network. Therefore, we consider any transaction that does not directly serve the application or IoT device as a governance overhead transaction.

### 4.2. Measurement Framework

We extend the capabilities of an existing measurement framework[4] to capture different attributes from an IoT-based blockchain. The extended framework allows the capturing of historical data of IoTeX and Helium blockchain and computes various statistics related to blocks, transactions, and different actions related to other agents of the consensus protocol. All the captured attributes are aggregated by time, type, miner, sender or receiver, etc. We are making our codebase and dataset fetch guide publicly available[5] for anyone to recreate and verify experiments, and to extend to other blockchains and new statistics easily. More details on the data collection are mentioned in the following subsection.

### 4.3. Data Collection

We collect historical data of the IoTeX blockchain starting from block number 1 (April 2019) to block number 19,500,000 (September 2022) spanning a period of 3 and half years. The number

[4]https://github.com/danhper/blockchain-analyzer/tree/master/bc-data-analyzer
[5]https://github.com/WiSeCom-UPF/blockchain-analyzer

of blocks and all transactions in this time frame includes both governance and non-governance transactions. The whole dataset is stored in compressed JSON Gzip format occupying 8.5GB storage. Throughput is mentioned in terms of block utilization per 5 seconds (block time) i.e. number of transactions present inside the block, average accounts for the number of transactions among all blocks observed throughout the dataset. Theoretically, it is possible to fit 32,000 transactions inside a block, but currently, only 1.50 transactions per block is the average. In Table 2, transactions on the IoTeX blockchain are classified into different categories based on their actions. This table includes details such as the number of transactions in each category and the percentage of their represented volume.

The extended measurement framework captured blocks from the beginning to the end of the block index. To retrieve blockchain data, we utilized publicly available endpoints such as **https://rpc.ankr.com/iotex**. IoTeX supports both Ethereum ETL-based API and its native IoTeX API to retrieve data from public endpoints. To fetch data from the endpoint, we use **eth_getBlockByNumber** along with the block number written in hex. The data is then stored in compressed JSON format, with each line representing the data of a block. We use Gzip format with level 6 compression for the storage.

We collect historical data of the Helium blockchain starting from block number 1 (July 2019) to block number 1531124 (September 2022) spanning around 3 years. The number of blocks and all transactions in this time frame includes all the recorded on-chain transactions. The entire dataset is stored in compressed JSON Gzip format, occupying 500 GB of storage space. Throughput is measured in terms of block utilization per minute, which refers to the number of transactions present in each block. The average number of transactions across all blocks observed in the dataset is 325. Table 1 categorizes transactions on the Helium blockchain based on their actions. The table provides corresponding details, such as the number of transactions within each category and the percentage of their represented volume.

Publicly available endpoints for the Helium blockchain were frequently down and highly unreliable. To retrieve blockchain data, we downloaded the Postgres DB snapshot[6], which is approximately 3.6 TB in size, and restored the database. We deployed the entire setup on a 32-core CPU with 128 GB RAM within a Docker container and fetched the data using the standard Helium API call against our instance. The data obtained from the endpoint is stored in line-by-line JSON format, with each line representing the data of a block, and is compressed using Gzip with level 6 compression.

## 5. Data Analysis

In this section, we analyze the IoTeX and Helium blockchain data and present a high-level illustration of the transactions contained in IoT blockchains. From the genesis block a total of 19,500,000 IoTeX and 1,531,124 (until September 2022 for both) Helium blocks are analyzed.

[6]https://github.com/helium/blockchain-etl

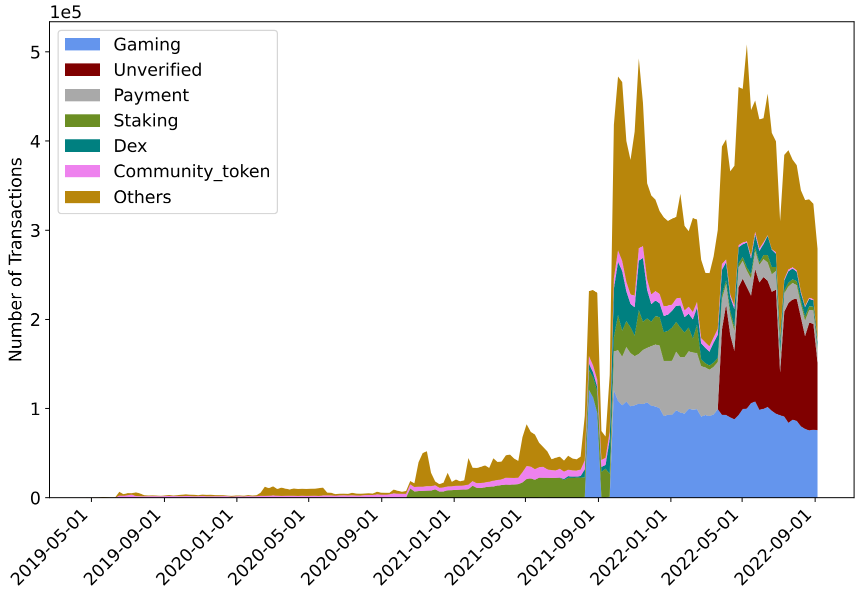


**Figure 1:** Transaction share of the top 5 smart contracts along, others represents every other smart contract related transaction. The majority of on-chain transactions are meant for these top 5 different types of smart contracts.

| IoTeX Smart Contract Data | | |
|---|---|---|
| Smart contract | Transaction count | Category |
| 0x17Df9fBFC1CdAB0f90eDDC318C4f6FcADA730cf2 | 5,145,293 | GFT, Gaming |
| 0x04C22AfaE6a03438b8FED74cb1Cf441168DF3F12 | 2,941,710 | Unknown |
| 0xEc0cd5c1D61943A195bcA7b381dc60F9F545A540 | 2,028,948 | Aliana, Payment |
| 0x4752456e00def6025c77b55A88A2F8A1701F92F9 | 1,560,668 | Metanyx, Staking |
| 0x95cB18889B968AbABb9104f30aF5b310bD007Fd8 | 1,197,112 | Mimo, Dex |

**Table 3**
Top 5 Smart contracts, followed by their respective number of transactions observed and type of application. Most of them are general applications i.e not IoT specific use case. 3 of the above smart contracts are XRC20 tokens and all except one of them have their source code available for verification.

## 5.1. IoTeX - Transactions and Blocks Overview

In the IoTeX blockchain, both transactions and blocks showcase interesting statistics. Blocks are generated by miners aka block producers and following the protocol rules the blocks are produced rapidly. A total of 117 block producers took part in the mining process. Figure 4 in Appendix B showcases the time series chart of the total number of empty blocks produced (shown in bold red line) and the number of zero transaction blocks (as described in Section 4.1) produced in the last three and a half years. During the accounted period, a total of 9,998,700 empty blocks and 1,822,280 zero transaction blocks are mined. During this period the total block utilization is 1.15 transactions per block for non-governance transactions and this rate goes up to 1.50 if governance transactions are also included. Block production is rewarded to both block producers and delegates. A total of 93,858,328 IOTX cryptocurrency for empty block creation and 14,682,400 IOTX cryptocurrency for zero transaction blocks creation were given as a reward directly to the block producers. These blocks had no real-world purpose for IoT applications, but rather a burden for node operators to store the blocks. 64% of the total block mining rewards go to the empty block or zero block production.

Figure 1 decomposes the top 5 smart contract entities in terms of transaction count, clustered with the type of service/application they provide; and "Others" represents any other type (including P2P transfers) of transaction. Gaming smart contract (Game Fantasy Token) accounts for the maximum on-chain transactions, even though, was released around September 2021. Overall, as mentioned earlier, and as shown in Table 3, around 62% of all transactions belong only to 5 SCs among 5,688 smart contracts deployed on-chain. Governance transactions account for a total of 6,971,696, which is around 24% of the overall transactions. Governance transactions themselves achieve utilization of 0.36 transactions per block. Considering the total traffic gathered on-chain, it is a significant number, as shown in Table 2 and graphically plotted in Appendix B Figure 5.

#### 5.1.1. Transaction Pattern

70% of traffic on IoTeX comes for smart contract applications, we study the top smart contract function calls and see if a pattern can be witnessed for a better understanding of the on-chain utilization.

- **approveAndCall** This topmost function signature is used to approve the token transfer. The applications using token generation and assignment vastly use them.
- **0x34e8e145** The second most used function call has been used more than 2,897,354 times, but its function signature is not found in the EVM function signature database. Most probably, it is a non-standard function name.
- **transfer** The third most counted function is related to the first **approveAndCall** function signature, here the actual transfer of the token takes place. This showing that the IoTeX blockchain is widely used for token transferring. Mostly originating from the GFT token, which is a gaming token, widely used for NFTs (non-fungible tokens)[7].
- **mix** and **claim** function signatures are used in decentralized exchanges and payment-related smart contracts.

### 5.2. Helium - Transactions and Blocks Overview

The Helium blockchain platform was built to incentivize the hotspots providing the IoT devices connectivity. As seen in Figure 2, the majority of transactions are PoC requests followed by the PoC receipt, they are interconnected since the receipt corresponds to the request sometime in the past. There are two different versions of PoC receipts (v1 and v2, they are non-overlapping) as they denote a major change in protocol. The Helium protocol has undergone drastic changes

[7] https://eips.ethereum.org/EIPS/eip-721

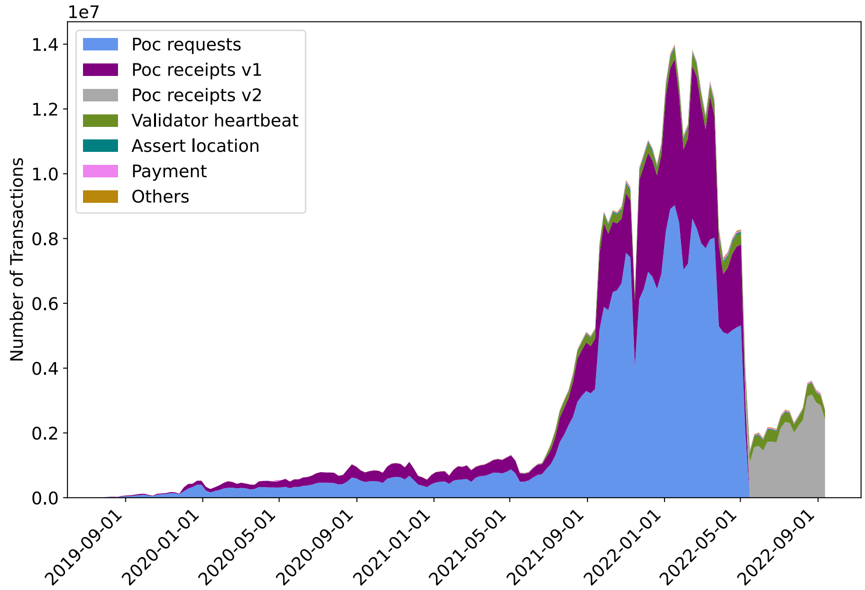


**Figure 2:** Transactions based on the different types of activities recorded on Helium blockchain. Data represents that majority of transactions are solely to maintain consensus protocol.

from time to time and the same is reflected in Figure 2. Although the application efficiency is limited by the block mining time i.e. 1 minute, which makes it difficult to scale for applications such as cryptocurrency transfer since if a transaction comes at the beginning of block time then it has to wait for 1 minute to get confirmed.

The block level of statistics shown in Table 1 showcases the different types of transactions based on their respective category. Although the network is not optimized for payment, still 0.5% of 498,291,572 transactions account for just P2P payments.

#### 5.2.1. Transaction pattern

In Figure 2 the transaction pattern is overwhelmed by the PoC requests which are roughly 60% of the total transactions recorded over the network. Meanwhile, there is state channel-related transactions that let the IoT device operators actually utilize the Helium network for the use case it was built. But the number of transactions is hardly 0.5% ( half a million) of the total transactions observed. It appears that the network is mostly working without any traction towards IoT applications using the Helium network and hence the chain is stale of actual data packets to-and-from the IoT-specific applications.

## 6. Case Study

In this section, we present several case studies of how some traffic spikes on the IoTeX and Helium blockchain can be better understood for both legitimate and less legitimate purposes.

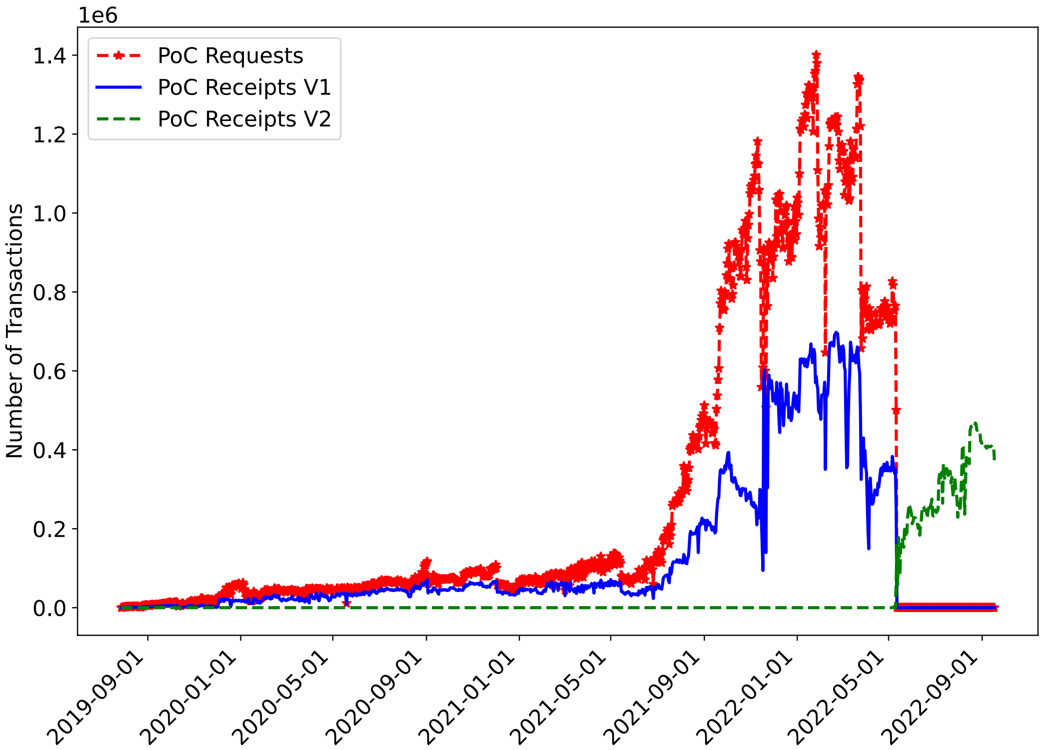


**Figure 3:** The ratio of PoC request and PoC receipt started growing significantly around March 2021 and it was fixed around May 2022, leading to a waste of resources.

### 6.1. Spike of Non-IoT Related Token

More insights on the IoTeX blockchain utilization can be studied by analyzing the periods of immense activity where the transactions count along with IOTX token value grew multiple folds. From Figure 1 and Table 3, a sudden spike in traffic activity can be observed. Upon inspecting the on-chain traffic, we found out that from 4 Aug 2021 to 24 Aug 2021 (20days period), traffic spiked 10 folds, with only the Game Fantasy Token (GFT) smart contract accounting for almost half of the transactions. A similar spike around half of its magnitude can be observed for Aliana token and Metanyx which are payment and staking services respectively. They started growing exponentially on IoTeX soon after IOTX started trading on Coinbase[8]. The next big traffic spike comes from Mimo which is a decentralized exchange on par with Uniswap [23] and Sushiswap[9]. Mimo uses the IoTeX blockchain since its fast and cheap[10] as compared to the other L1 chains. Finally, Vitality is a community token that is given as a reward for application developers to encourage good projects to deploy on IoTeX blockchain.

Another period of interest is witnessed between September to December 2021, where around

[8]https://blog.coinbase.com/iotex-iotx-orion-protocol-orn-quickswap-quick-tribe-tribe-and-terrausd-ust-are-1c257deb6ed4
[9]https://www.sushi.com/
[10]https://learn.bybit.com/blockchain/blockchain-transaction-fees-explained/

25% of all receiving smart contract transactions (GFT) and 10% of all sender to a smart contract (Metanyx) out of 5 million transactions come through a single address. Notably, none of the top 5 SCs projects described above directly contribute toward an IoT use case. Even after 3 and a half years of existence IoTeX blockchain still has a significantly low turnout for useful IoT applications in comparison to other general applications described above.

## 6.2. Low-Value Transaction Spam on IoTeX

During the period of interest i.e. post-August 2021, we observe that an address 0xE3DF5D103551B1D3D8117C59223AB62F1AD15552 doing very small P2P transfers of 0.1 IOTX to a lot of random addresses. Upon further inspection, it is observed that the addresses in its lifetime have not repeated a transfer i.e. 0.1 IOTX (which is US \$ 0.003, at the time of writing) to the same addresses, so all of its 237,354 transactions went to 237,354 unique addresses. Overall, the transaction from this address accounts for 33% of the total P2P transfers in the aforementioned period. The address to date still transfers the same amount of tokens to random addresses, consequently accounting for 14% of all P2P transfers on the IoTeX blockchain. It appears to be spam-type behavior since IOTX tokens and making a transaction on IoTeX is way cheaper than other L1 blockchains. More so because the recipient addresses are also not spending the received microtransactions or 0.1 IOTX, such an activity can be easily fabricated via automated script-generating random addresses.

## 6.3. Misses in PoC request and receipt

The concept of PoC request and receipt design was novel to maintaining healthy network stats. As shown in Figure 3, the ratio between the PoC requests made and the PoC receipts observed is way off. It is estimated from the data that more than 50% of the PoC requests remained unaccounted for from July 2019 to May 2022 as after that PoC requests have moved to off-chain (not recorded on the blocks) thus there is no way to check what is the miss ratio for version 2 of POC request/receipt. Such an observation is due to the flawed design of the protocol, around 150 million PoC requests are part of the blockchain but with no supporting PoC receipt transaction.

## 6.4. Towards a modular Helium design

Figures 2 and 3 suggest that modularizing parts of the consensus protocol can result in better utilization of the blockchain network. Moving PoC requests off-chain is the first step toward making the IoT infrastructure blockchain more modular by design. To maximize the efficiency of the protocol, governance should prioritize moving operations off-chain whenever possible. This would also allow for the introduction of supplementary functions such as a smart contract execution engine, on-chain protocol governance, integrated oracles, and more. Meanwhile, the existing mechanism of block time can be further reduced from 60 seconds.

## 7. Discussion

In this section, we refer to the results and what they mean to the IoT blockchains in the context of IoTeX and Helium design in Appendix B and answer the research questions presented in Section 1 in the light of our analysis.

**RQ1:** Utilization of IoTeX and Helium blockchain. Based on the data analyzed, it is apparent that both IoTeX and Helium blockchain have not been fully utilized. IoTeX, despite being an IoT blockchain, has a higher proportion of general applications than those specifically designed for IoT. On the other hand, the Helium blockchain is inefficiently utilizing resources and has yet to achieve significant traction. IoTeX provides a more cost-effective alternative to blockchains like Ethereum, where P2P transfers typically cost around US$1-2 per transaction, while on IoTeX, the current transaction fee is approximately US$0.0003. However, it is important to note that IoTeX still maintains a level of semi-decentralization with permissioned mining from over 100 block producers, in contrast to Solana's 1,000+ and Ethereum's fully permissionless network with over 100,000 block producers.

**RQ2:** Classifying transaction types using on-chain patterns. It is easier to classify based on the kind of transaction such as P2P transfer, smart contract execution, or governance transactions. Following the EVM further classification based on types of tokens such as XRC-20 and NFT,[11] can be easily made. While the governance-related transactions count can be observed from the public API historic data of IoTeX, the actual transactions are not currently accessible. In Helium, the data represent the dire need of decongesting the network and introducing more modularity among the components.

**RQ3:** Classify active participants and nature of transactions. Adopting the Ethereum structure and API standards facilitates the analysis and categorization of participants. Auditing is simplified through the identification of token types and verified smart contracts. Although traffic largely originates from a handful of participants, connections can be established to a certain extent. Nonetheless, de-anonymization on a large scale is beyond the scope of this study. Based on our analysis, three of the top five smart contracts in terms of observed traffic are XRC20 tokens. IoTeX blockchain is significantly under-utilized, and the increase in utilization is not uniform during periods of activity, allowing for easy pattern detection. Table 3 illustrates how targeted traffic can be narrowed down to specific sources. Furthermore, a striking finding is that 95% of smart contract traffic is generated by only 50 contracts, which represents less than 1% of the total deployed contracts. Our results indicate that there is a clear trade-off between scalability and economic misincentives in the case where a large number of block rewards are distributed for totally empty blocks. Additionally, we observed that a single address accounted for 14% of P2P transfers, which suggests that some of the traffic may be inorganic. Helium has experienced approximately 150 million stale proof-of-coverage (PoC) requests, which have recently been moved off-chain. However, there still may be overhead involved in reaching witnesses for stopped or damaged hotspots. Due to protocol design issues, the blockchain has become overly monolithic and this has resulted in frequent downtimes.

**RQ4:** IoT design choices. IoT blockchains should prioritize design decisions that cater to IoT use cases over general applications. While the cost-effectiveness of blockchain technology is

[11] https://docs.iotex.io/dapp-development/smart-contracts/introduction

attractive to a wide range of use cases, it is important for IoT blockchains to remain focused on the unique needs of IoT devices. The Helium network could see an increase in demand if custom solutions are implemented, such as faster P2P modular components and reduced computation and storage overheads. However, such proposals would require significant protocol changes. Such a requirement is apparent as described in section 6.4.

## 8. Conclusions

We conducted an analysis of the on-chain transaction patterns of IoTeX and Helium blockchain. Fetching the historic blockchain data of the last 3 and a half years i.e. from the genesis to 19,500,000 blocks for IoTeX and 1,531,124 blocks for Helium. IoTeX blockchain is underutilized with around 1 percent transaction per block for regular transactions and 1.5 percent if governance transactions are also included. In contrast, the Helium blockchain has been found to be congested and to waste both computational and storage resources. There are around 150 million PoC receipts that serve no purpose to the Helium network. At times in IoTeX network, the governance transactions outnumbered the regular transactions. Only 76% of the transactions are non-governance related with 51% of the blocks produced carrying no useful transaction (with 9% blocks totally empty). 95% of all SCs-related transactions were made against 0.8% (50) SCs, narrowing down, the top 5 smart contracts accounted for 62% of all SC-related traffic.

Non-IoT applications dominate the on-chain traffic, as the lower transaction fees and increased capacity attract more general-purpose applications rather than IoT-specific ones. Additionally, we observed a possible spam activity with 14% of all P2P transfers originating from a single address distributing 0.1 IOTX (valued at US $0.003 at the time of writing) to random addresses. On the other hand, the Helium blockchain still lacks real utility usage from the IoT ecosystem, with only 0.5% of transactions being accounted for by IoT-related activity.

In summary, the IoTeX blockchain has the capacity to support higher transactions but thus far the potential has not been realized for the intended IoT applications use cases, but used by general blockchain applications. Helium blockchain, on the other hand, needs to address its protocol and design-related issues for wider adoption in the IoT ecosystem.

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# A. Appendix A

## A.1. Proof-of-Work (PoW)

Proof of work is a mechanism used by some blockchain networks to achieve distributed consensus. In a proof of work system, network participants (called "miners") compete to solve complex mathematical puzzles in order to validate transactions and add them to the blockchain. The first miner to solve the puzzle receives a reward in the form of a transaction fee or new units of the cryptocurrency being mined. The proof of work mechanism is designed to make it expensive and time-consuming to add new blocks to the blockchain, which helps to secure the network and prevent attacks. Proof-of-Work (PoW) consensus mechanism [1] introduced by Bitcoin is also implemented by Ethereum 1.0 [2]. Solving the puzzle on average takes 10 minutes on Bitcoin but this time can be lowered by adjusting the difficulty level of the puzzle. PoW maintains consistency quite well but comes with a trade-off being time and energy-consuming, leading to a slow block production rate.

## A.2. Proof-of-Stake (PoS)

To counter PoW, Proof-of-Stake (PoS) consensus mechanism acts on a shared stake inside the system to produce blocks where dishonest behavior can lead to the slashing of stakes. Here the incentive is to act as per the consensus protocol or risk losing your financial stake. Proof of stake is a type of consensus mechanism used by some blockchain networks. In a proof of stake system, the creator of a new block is chosen in a deterministic way, depending on the stake they hold in the network. This means that the more cryptocurrency a miner holds, the greater their chance of creating a new block and receiving the associated reward. This is in contrast to proof of work systems, where miners compete to solve complex mathematical puzzles in order to validate transactions and add them to the blockchain. Proof of stake is designed to be more energy efficient and scalable than proof of work. PoS significantly improves the block generation time since the block producers are trusted and bad behavior is recognized and punished fast.

## A.3. IoTeX Randomized Delegated Proof-of-Stake (Roll-DPoS):

IoTeX uses a special type of Delegated Proof of Stake consensus algorithm known as Roll-DPoS [24]. Nodes/users in the IoTeX network have voting power as 1 IOTX token equals 1 vote, they can vote for their delegates. Delegates are parties in the process to become block producers. Block-producing nodes are elected per-epoch, and each epoch lasts for 1 hour. In every epoch 36 block producers are selected based on the highest number of votes they obtain, and among them, 24 block producers are elected randomly [4] to produce blocks. Block producers take turns proposing and validating blocks reaching consensus by using the PBFT algorithm [25]. Each block at present is created every 5 seconds making around 720 blocks per hour. At the time of writing this paper, a block producer gets a fixed 8 IOTX block reward per block produced, which was changed from 16 IOTX per block reward from block number 1816201. Delegates also share a proportion of reward per epoch, but this detail is out of scope for our study.

As per the white paper [4], the IoTeX blockchain was designed to operate on subchains and root chain fundamentals. A Subchain design enables different types of applications catering to their respective use case category and eventually are made consistent with a root chain [26]. A subchain solution is considered as good when it comes to scaling different kinds of applications on a single chain since it doesn't hinder other subchains. While a subchain model was planned, in its current state, IoTeX does not operate with a subchain solution and has no future plans for it.

## A.4. Helium Proof-of-Stake + HBBFT:

In Helium, data is recorded on-chain and validated by a group of validators that uses PoS + HBBFT [21] consensus protocol. HBBFT is an asynchronous atomic broadcast protocol designed to enable a group of known nodes to achieve consensus over unreliable links. A consensus group of elected Validators receives encrypted transactions as inputs and proceeds to reach a common agreement on the ordering of these transactions before forming a block and adding it to the blockchain. The Helium Consensus Protocol achieves censorship-resistant transactions through the use of HBBFT, which relies on a technique known as threshold encryption. In this scheme, transactions are encrypted using a shared public key and can only be decrypted by the elected consensus group working together.

Block production is done in epochs, in each epoch 30 blocks are mined. Every minute a new block is mined (on average an epoch lasts for 30 minutes) by one of the validators that are part of the consensus group. There are around 43 validators that take part in a consensus group per epoch. To become a validator a huge stake of 10,000 HNT tokens is required. At the end of each consensus group, an election is performed. During this election process, 25% of the Validators in the current consensus group are chosen to be ejected and replaced with non-elected Validators[12]. As a part of the Helium Improvement Proposal (HIP) 70, the validators will soon be discarded.

# B. Appendix B

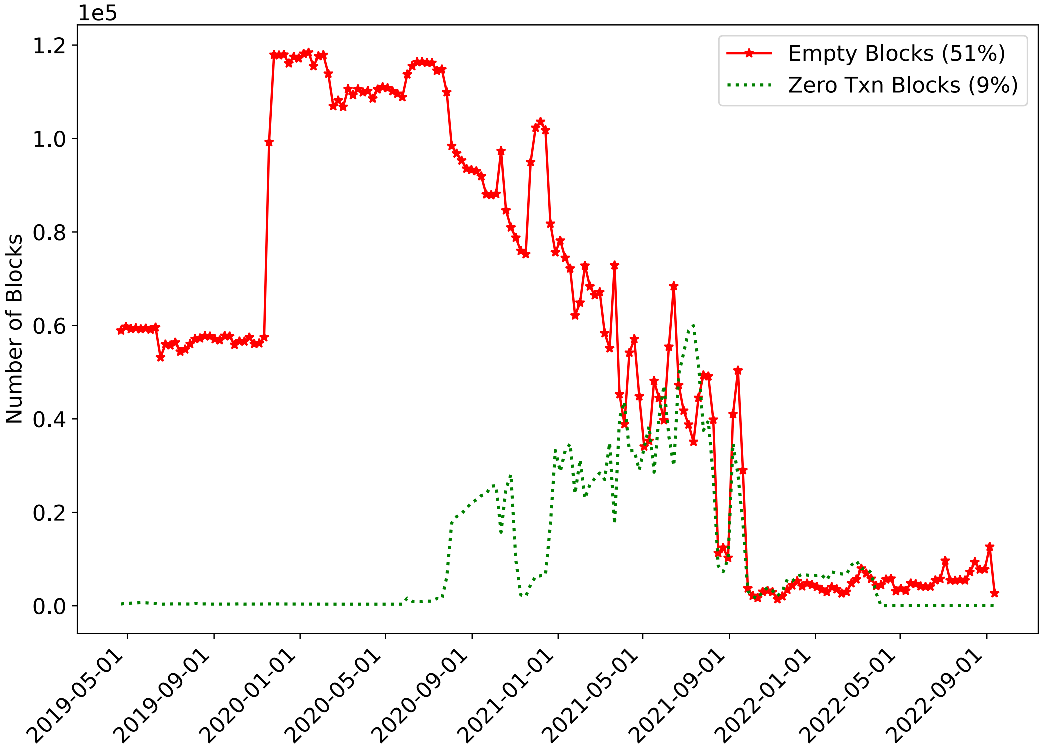


**Figure 4:** The number of empty blocks produced is shown in the red bold line and zero transaction blocks in the green dotted line. There is a huge number of blocks without any transaction present inside them. While zero transaction blocks contain only governance-related transactions. Each data point represents a collective value in the period of 24 hours.

[12]https://docs.helium.com/mine-hnt/validators/penalties/#the-election-process

**Table 4**
Top 5 Smart contracts function signatures, followed by their translated name/function they performed. Most of them are deployed less than two years ago.

| Function Signature | Function name | Count |
|---|---|---|
| 0xcae9ca51 | approveAndCall | 6,329,072 |
| 0x34e8e145 | unknown | 2,897,354 |
| 0xa9059cbb | transfer | 2,141,022 |
| 0xb4bb58fb | mix | 834,052 |
| 0x4e71d92d | claim | 750,638 |

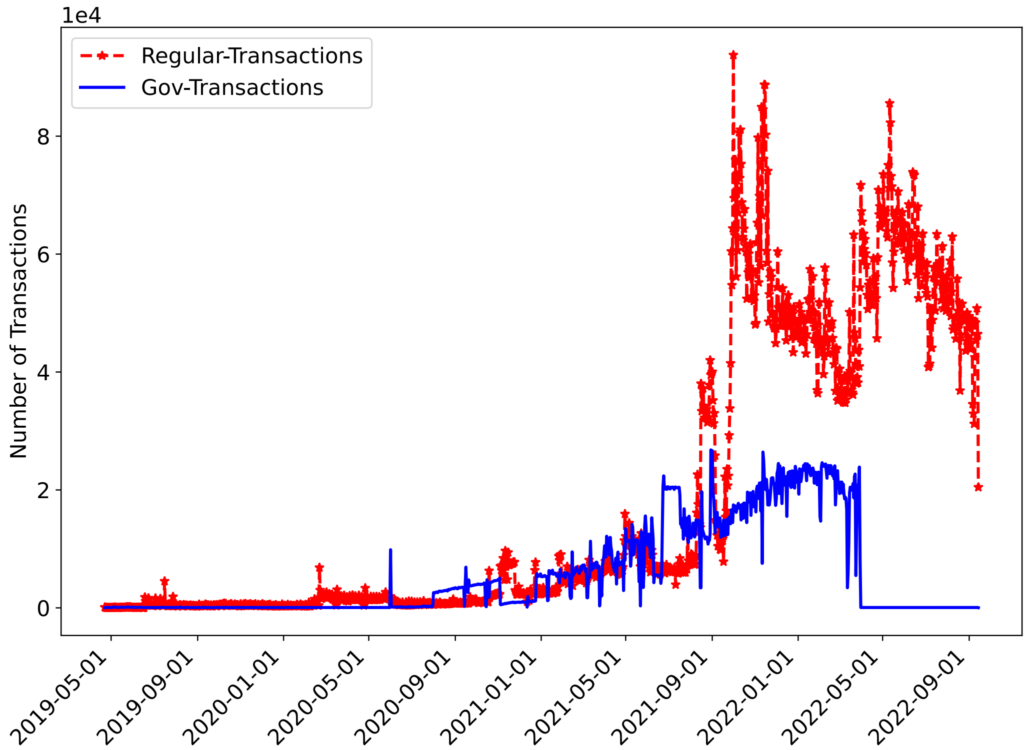


**Figure 5:** Transactions in terms of governance and non-governance (regular). There is a significant proportion of governance transactions present on-chain, at times, they are even higher than the regular transactions.