Passively Measuring IPFS Churn and Network Size

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Abstract—The InterPlanetary File System (IPFS) is a popular decentralized peer-to-peer network for exchanging data. While there are many use cases for IPFS, the success of these use cases depends on the network. In this paper, we provide a passive measurement study of the IPFS network, investigating peer dynamics and curiosities of the network. With the help of our measurement, we estimate the network size and confirm the results of previous active measurement studies.

Index Terms—Network Measurement, IPFS, P2P Networks

I. INTRODUCTION

In the last years, new peer-to-peer (P2P) data networks emerged, providing new opportunities for distributed and decentralized storage and exchange of files [1]. A prime example is the InterPlanetary File System (IPFS) [2]. By combining ideas from BitTorrent, Kademlia, Git, and informationcentric networking, IPFS has become a major supplement for distributed storage solutions. IPFS is often combined with blockchains serving as off-chain storage [3, 4, 5]. Furthermore, IPFS is the originator and a major user of the *libp2p* library [6], which could become a quasi-standard for P2P communication.

In this paper, we take a look at a key component of IPFS: the P2P network. Our goal is to gain a better understanding of the dynamics of the IPFS network, with the help of passive measurements. In particular, the churn rate is an important aspect for identifying possible protocol and configuration weaknesses. Furthermore, we investigate changes in peer roles and are interested in finding an answer to a seemingly simple question: How large is the IPFS network? In contrast to active measurement, e.g., crawler [7, 8], which might influence a peer's connection limit, triggering connection trimming, passive measurements are less intrusive. Due to the usage of the *libp2p* library, insights in the IPFS network might be applicable to other P2P projects as well.

By deploying two passive measurement clients (go-ipfs, hydra-booster), we record basic information about the network's characteristics. We perform multiple short-term measurements, spanning a period of 1 d to 3 d in December 2021. Concerning the network dynamics, we found that the default configuration, which defines certain thresholds for connection trimming, causes a high connection churn rate for DHT-Servers, resulting in very short-lived connections. While the client did not have more than $\approx 16k$ simultaneous connections, the client established connections to 40k-65k different peer IDs (PID). This indicates either a high amount of nodes with changing PIDs, very volatile nodes, or many one-time users. The meta data of PIDs remains mostly constant. Naturally, the client version changes over time due to the appearance of new versions, however, we observed up- and downgrades. A small part of the PIDs changes their role in the network, by switching from a DHT-Server to a DHT-Client and vice versa. We also identified some anomalies, e.g., go-ipfs clients not supporting Bitswap or an Ethereum client.

With our passive measurement study, we contribute a novel perspective on IPFS peer dynamics that we utilize to approximate the network size. To this end, we explore two methods: distinguishing peers based on meta data and classifying peers based on their connection behavior. As a result, we conclude that during our measurement period the network consisted of roughly 48k peers. Based on the classification the core network of IPFS has at least a size of 10k nodes. With our results, we can also confirm the general observations of the overlay network made by Henningsen *et al.* [9].

The remainder is structured as follows. In Section II, we give a brief overview of related work. The measurement method and setup is described in Section III. We present an overview of the measurement results in Section IV, before attempting to estimate the network size in Section V. Section VI concludes the paper and shows our future research direction.

II. RELATED WORK

There exists some literature evaluating IPFS metrics, e.g., Bitswap [10] or in general I/O performance [11]. Here, we focus mainly on paper investigating the IPFS P2P network. Guidi et al. [12] investigated the data persistence mechanisms and made a similar analysis about origin, distribution, and usage of transport protocol of peers. Prünster et al. [13] analysed an earlier version of the IPFS client software identifying the libp2p's connection manager's scoring system as a potential vulnerability, allowing a Sybil attack. The presented attack is mitigated in later versions (>v0.5). Balduf et al. [14] investigate the nature and information of Bitswap messages, focusing on content privacy. Henningsen et al. [9] estimated the size of the network and structure of the overlay network. The authors first get an impression of the default behavior with passive measurements and compare the results with results from a developed crawler [7]. They further report peer distribution, and uptime of peers. The measurements of the developed crawler is ongoing and the results are publicly available¹. Another crawler monitoring peer availability and liveness is the libp2p DHT "Nebula Crawler" [8].

Our passive measurement study is similar to the passive method of [9]. Through our measurements we can confirm their results and provide a more recent and closer look at peer dynamics. Furthermore, due to the passive approach of the measurement, we provide a different perspective on the IPFS network compared to different ongoing active measurements.

III. MEASUREMENT SETUP

In general, a network can be measured actively or passively. In an active measurement, probing packets are sent to participants in the network. While this allows for detailed information on nodes at almost any time, it can disrupt normal node behavior. A passive measurement records data without creating additional or modified traffic in the network. Due to the decentralized nature of a P2P network, the horizon, i.e., the amount of reachable nodes at a time, is limited: there is no node which knows the exact amount of nodes in the network. While active nodes aggressively try to maximize their horizon by seeking peers, the passive nodes' horizon is mainly dependent on its neighbors. Fig. 1 visualizes the different network perspectives. In case of IPFS, active measurements like crawlers, which explore and search the Kademlia-based DHT, only gain information about peers actively participating in the DHT (DHT-Server). A passive measurement can potentially see all peers independent of their participation in the DHT routing, which also includes clients (DHT-Client). The horizon of a "normal" node, e.g., go-ipfs, also depends on its position in the DHT, which determines the priority of other nodes to maintain or establish a connection to the node. Special nodes, e.g., Hydras, can establish multiple identities providing the node with a broader horizon.

Passive measurements are a common method for gaining an understanding of peer-to-peer networks [15, 16]. The basic procedure of a passive measurement is the same for any P2P network. A node conforming to the protocols behavior is deployed. This measurement node itself behaves normally, i.e., answering requests. At most a node tries to establish and maintain as many connections as possible, with the goal to ideally connect to all nodes in the network. Internally, the node records data about the network.

For our measurement, we deployed two different measurement nodes on a VM hosted in Hesse, Germany by Google Cloud. The VM had 32 GB RAM, 8 cores, Intel(R) Xeon(R) CPU @ 2.20 GHz, and Ubuntu 21.10. as the operating system (OS). During the measurement the VM had a public IPv4 address and was not externally reachable via IPv6. Toward the outside, the measurement nodes were a go-ipfs v0.11.0-dev² and a hydra-booster v0.7.4 node. The clients were mostly deployed simultaneously on port 4001 for go-ipfs and started by port 3001 for hydra-booster. Additionally, we deployed another go-ipfs v0.13.0-dev³ on a different VM reachable via



Fig. 1. Illustration of network horizons for passive measurements with different measurement clients: go-ipfs with a single identity and Hydra with multiple simultaneous identities.

 TABLE I

 Overview and duration of the measurement periods. Used

 Versions: go-ipfs v0.11.0-dev/v0.13.0-dev (P3), Hydra v0.7.4

Period	Measurement Duration	Low	High	go-ipfs	Hydra
$P0_1$	2021-12-03 - 2021-12-06	600	900	Server	_
$P0_2$	2021-12-03 - 2021-12-06	1.2k	1.8k	_	3
P1	2021-12-09 - 2021-12-10	2k	4k	Server	2
P2	2021-12-13 - 2021-12-14	18k	20k	Server	2
P3	2022-02-16 - 2022-02-17	18k	20k	Client	-
P4	2021-12-10 - 2021-12-13	18k	20k	Server	-

IPv4 and IPv6. This VM had 16 GB RAM, 8 cores, Intel(R) Xeon(TM) CPU 3.20 GHz, and Debian 9 as the OS.

We conducted five measurements with durations between $\approx 1 d$ and $\approx 3 d$. Between the measurement periods, we adjusted *LowWater* and *HighWater* values of the connection manager to reduce connection trimming. Connections are selectively trimmed to the *LowWater* value, once the number of simultaneous connections reaches the *HighWater* threshold. An overview of the measurement periods and the used configuration is provided in TABLE I.

A. Go-IPFS

Go-ipfs refers to the go reference client⁴ maintained by Protocol Labs. The reference client is open source and can be deployed by anyone to join the IPFS network or build a private IPFS network. It supports a wide range of functions to exchange and distribute data.

The client is started utilizing the default configuration, a random $2048 \, bit$ key, and a temporary repository. Neither key

¹https://trudi.weizenbaum-institut.de/ipfs_crawler.html (2022-05-30)

²Commit: 0c2f9d5950c4245d89fcaf39dd1baa754587231b

³Commit: b2efcf5ce3bba997997962122f85d12500962927

⁴https://github.com/ipfs/go-ipfs (2022-05-30)

nor repository persisted over different measurement runs. For the measurements only the *LowWater* and *HighWater* values of the swarm connection manager were adjusted.

After the initial bootstrap, no further user activity was introduced such as actively connecting to specific peers or requesting data. During the deployment every 30 s peer and connection data was recorded and updated. It recorded for the PID of all known peers in the *Peerstore*, agent version, protocols, and multiaddresses. Furthermore, changes to the information were recorded with a timestamp. Additionally, information of all PeerHost connections per connection-id, e.g., direction, multiaddress, opened, connectedness were checked. The whole information was exported periodically to a json-file.

The go-ipfs client can be deployed as a DHT-Server or DHT-Client, determining its participation in the Kademlia-based DHT routing. Depending on the setting the clients significance in the network changes. Other nodes rather connect and maintain a connection to a DHT-Server since the node can answer routing requests and is detectable via the DHT. Due to the Kademlia-based DHT peers actively seek a connection with the measurement node. The view of a single node, however, is limited due to its location based on the PID.

B. Hydra-booster

Hydra-booster, in the following Hydra, refers to a node type designed to accelerate IPFS content provision and routing⁵. The node's main purpose is the provision and collection of DHT records by deploying multiple "heads", which provide basic networking functionality and DHT management, and the same "belly" for storing records. The heads of the Hydra have different PIDs, allowing the heads to be responsible for different parts of the DHT.

For our measurement, we added two new *PeriodicTasks* to the Hydra, to update and export measurement data. The client was configured to record and update peer data every 1 *min*. The Hydra recorded each head's known PIDs in the Peerstore, agent version, protocols, and multiaddresses. Furthermore, changes to the information were recorded with a timestamp. Additionally, during a connection and disconnection event information about the connection, e.g., duration, timestamp, and direction was logged. All information was periodically exported to a json-file.

Due to the nature of the Hydra, the node is a DHT-Server participating in the Kademlia-based DHT routing. Since every head is located in a different location of the DHT, the Hydra can cover a broader range of the network, increasing its range by increasing the number of heads. As indicated in Fig. 1, a head's view on the network is not distinctly different from other heads and peers might be observed by multiple heads.

C. Measurement Horizon

As previously mentioned, passive measurements can have a limited view on the network. To determine if our passive measurement covers a sufficient range of the network, we



Fig. 2. Comparison of the number of peers for active and passive measurements. Showing the number of DHT-Server PIDs (solid) and total PIDs (whole bar) for the passive measurement and a range of min. (solid) and max. (whole bar) PIDs for the active measurement.

compare our measurement results with public crawler results⁶ (WB Crawler). Fig. 2 shows the total number of observed PIDs (whole bar) and the number of identified DHT-Server nodes (solid) for our passive approaches and an active crawler. Since crawls are executed every 8h, the crawler reports varying number of nodes. We therefore decided to show the results as a range with the reported min. (solid) and max. (whole bar) values. The number of PIDs for the Hydra are the union of all heads. It should be noted that the crawler can only see DHT-Server nodes and our measurement node can only determine if a node is a DHT-Server, if protocol information were exchanged between the nodes.

In order to get a complete view of the network, we should deploy multiple vantage points. Therefore, we expect to see the least amount of nodes with the go-ipfs client, more clients with the hydra, and almost all nodes with the crawler. If we compare the numbers, we can see that for the measurement periods lasting more than 1 d the passive nodes see more DHT-Server nodes than the crawler. For the measurement periods of 1 d the Hydra sees more than the go-ipfs client. The crawler sees a similar amount of PIDs as the Hydra with two heads. In P0 with three heads, the amount of nodes seen by the Hydra is much higher. One explanation for the difference are disappearing nodes. The crawler provides a fresh snapshot of the network and does not consider results of previous runs. When peers remove a node's DHT entry, the crawler cannot gain information about the node, even though it was previously seen. Our passive measurement node provides a historic snapshot, keeping the record of all nodes once seen over time independent of their activity.

In general, the numbers show a similar range of PIDs. It therefore seems that one passive measurement node is enough to reach a reasonable sample of DHT-Server nodes. Assuming that the crawler covers most of the network and considering the results shown by the Hydra, two measurements nodes with strategically placed keys should be sufficient to cover almost

⁵https://github.com/libp2p/hydra-booster (2022-05-30)

⁶https://trudi.weizenbaum-institut.de/ipfs_crawler.html (2022-05-30)

the whole network. The geolocation of the measurement nodes should not have an influence on the number of seen nodes as IPFS does not enforce any geographic clustering of nodes. However, it is possible that the geolocation of the measurement node has an influence on the peer dynamics like connection churn.

IV. PEER DYNAMICS

In this section, we take a closer look at peer dynamics. We investigate connection churn with the measurement data from periods P0 - P3. P4 which has a longer duration covers observations of data directly related to the peers. In the following, we distinguish peers based on their PID.

A. Connection Churn

To investigate connection dynamics, we conducted different measurements with different Low-/HighWater values. Please note, that due to our measurement setup in go-ipfs the connection information is only refreshed every 30 s and the real values should be slightly smaller than shown. All connections still active at the end of the measurement are considered to be closed at that moment and are included in the statistics. An overview of the results of the different measurement values can be seen in TABLE II. In the statistic, we consider only peers with recorded connection information. Type "All" means that the results represent all connections from all peers, meaning that some peers provide multiple values. Type "Peer" means that the results are calculated over the average connection duration of each peer, giving each peer exactly one value.

Overall, the measurements show similar results for the goipfs DHT-Server and Hydra, except for P0 where the peer average is much lower compared to the Hydra value. This exception could be explained by the difference of the default *LowWater* and *HighWater* values. For the go-ipfs DHT-Client in P4, we see overall short connection durations.

We observe rather low connection durations lasting in general only a few minutes up to 1 h. The lower average value of all connections indicates peers initiating many short lasting connections. An example for such peers are crawlers, which connect to a node query their information, e.g., DHT buckets and then close the connection.

The increase of the connection duration between measurement periods indicates, however, that more connections are closed due to connection trimming than due to nodes leaving the network. Taking a closer look at the connection type, we observe vastly more inbound than outbound connections. In all periods, the duration of inbound connections is longer than the duration of outbound connections, which confirms the assumption that the connections are mainly closed due to connection trimming. With higher threshold values, the measurement node no longer trims its own connection, however, the connection still gets trimmed by the other nodes which most likely use the default threshold values.

B. Meta Data

To increase the versatility and for a better understanding of the roles of specific nodes, nodes reveal information about

 TABLE II

 CONNECTION STATISTICS FOR THE THREE MEASUREMENT PERIODS.

Period	Туре	Sum	Avg.	Median
go_infs				
P0	Δ11	1'285'513	196 556 @	73 739 .
P_0	Peer	55'258	695 946 s	83.008 s
P1	A11	355'965	802 617 s	130 464 s
P1	Peer	41'880	2/428 966 s	580 312 s
P_2	A11	285'357	2/883 828 s	85 404 s
P2	Peer	42'038	19/676 930 s	3/017 252 s
P3	A11	42'050	120 613	75 192 s
P3	Peer	10'004	182 043 s	72 964 s
10	1 001	10 004	102.0403	12.0040
Hydra H0				
P0	All	1'733'511	302.257 s	78.833s
P0	Peer	56'465	2'445.300 s	124.226s
P1	All	422'164	660.900s	76.530s
P1	Peer	43'550	2'512.923 s	541.492s
P2	All	416'711	2'941.519 s	65.181s
P2	Peer	52'134	16'553.299s	1'923.119s
Hydra H1				
P0	All	1'851'308	285.506 s	78.204s
P0	Peer	64'147	2'122.097 s	117.375s
P1	All	538'366	524.595 s	77.110s
P1	Peer	43'810	2'099.077s	439.847s
P2	All	408'621	3'003.313s	65.339s
P2	Peer	48'889	18'049.269s	2'365.113s
Hydra H2				
P0	All	1'890'556	280.438s	79.585 s
P0	Peer	63'981	1'883.970s	113.643s

themselves, e.g., agent version, supported protocols, and reachable multiaddresses. This information can be used to, e.g., identify DHT-Server nodes. It can also be used to estimate node behavior and identify anomalies.

From the data set, we observe overall 323 different agent strings and 101 different supported protocols. Fig. 3 and Fig. 4 show the occurrences of the different agents and protocols. For a better overview, agents used by 100 or less and protocols supported by 300 or less are grouped as other. The go-ipfs versions are grouped by their version number. From the 323 different agent strings 263 are different versions of go-ipfs and 61 are other agent strings. Overall from the 65'853 known PIDs, 50'254 claim to use some sort of go-ipfs version, 1'028 are Hydra nodes, 586 are some kind of crawler, 10'926 use a different agent, and from 3'059 no version string was obtained. One of the agents claimed to be a go-ethereum node.

However, agents are prone to change. During the three days, we could observe some version changes, mainly affecting goipfs clients. Surprisingly, we could identify not only upgrades but also downgrades. An overview of the version changes can be seen in TABLE III. As an upgrade, we define an increase in the version number. A downgrade is, therefore, a decrease in the version number. A change is indicated by a change of the commit part of the go-ipfs version string. A dirty version is a version, containing changes from the release's main version as indicated by the commit message, e.g., our used go-ipfs versions are dirty versions. The version of agents other than go-ipfs did not change in the observed time period. Once the agent changed from a non-go-ipfs agent to a go-ipfs agent.



Fig. 3. Occurrences of the different agent version strings.



Fig. 4. Occurrences of the different supported protocols.

The announced agent can be used as an indicator, for peers' behavior. This should be further distinguishable by the announced protocol. Almost all of the clients support the basic IPFS protocols like *ipfs/id* and *ipfs/ping*. A few custom protocols are used by only a distinct number of peers. Surprisingly, only 44'463 support *ipfs/bitswap* when 50'163 use go-ipfs. There are 7'498 go-ipfs v0.8.0 clients which do not support Bitswap and instead support *sbptp*, a protocol, which is otherwise only supported by storm nodes. Furthermore, libp2p/circuit/relay is support by almost all clients. The *ipfs/kad* protocol, which should indicate an IPFS DHT-Server, is supported by 18'845 peers.

The combination of agent version and supported protocol can be used to detect unusual behavior. In case of curiosities like a go-ipfs agent, which does not support *ipfs/bitswap*, it reveals information about the configuration or reveals an attempt to hide potentially malign agents, e.g., storm nodes, identified to be part of a botnet [17].

During normal operation, we do not expect a change in the announced supported protocols, except when the used client

TABLE III OVERVIEW OF GO-IPFS VERSION CHANGES.

Version		Туре	
Upgrade	218	main–main	291
Downgrade	107	dirty-main	9
Change	205	main-dirty	5
-		dirty-dirty	225

changes. In general, only a few nodes changed their supported protocols. However, we observed many changes concerning /*ipfs/kad/1.0.0* and /*libp2p/autonat/1.0.0*. 2'481 peers changed in sum 68'396 times their support announcement of the /*ipfs/kad/1.0.0* protocol switching their roles from a DHT-Server to DHT-Client. 3'603 peers changed in sum 86'651 times their support announcement of /*libp2p/autonat/1.0.0*. While autonat is not a crucial feature, switching roles from a DHT-Server to a DHT-Client could have a negative influence on the network, e.g., due to many control messages.

While the meta data is useful for the operation of the network, it shows potential for misuse. Due to the almost homogeneous distribution of agent versions and supported protocols, exotic combinations or exotic names could be used to re-identify or track specific peers independent of their PID. Furthermore, the meta data seems to be rather constant, which means that this information could be further utilized for peer identification. However, long term observations are necessary to confirm or deny this assumption.

V. NETWORK SIZE

Previously, we differentiated peers by their PID. Therefore, the network size would be equal to the number of PIDs.

Looking at the number of PIDs in TABLE II, we see between 40k-65k peers. Since the position in the network and the day of the measurements vary, it is plausible that the number of peers vary as well. However, looking at the number of simultaneous connections provides a different perspective on these numbers. A comparison of the number of connections over time for the different periods can be seen in Fig. 5. For better comparison, the figure shows only the connections of the first 24 h. In case of P0 and P1, we can directly see our nodes' connection trimming due to the configured threshold values. For P2, we can see around 15k-16k simultaneous connection, which does not even reach the LowWater threshold. P4 probably shows other nodes' connection trimming, since even peak values are below the default go-ipfs LowWater value. The passive DHT-Client node, which does not even provide any files is a prime candidate for connection trimming. Naturally, not every peer needs to establish a connection to our measurement node. Investigating the number of PIDs over a longer time, however, shows a certain trend. In Fig. 6, we can see the number of PIDs over time and the number of PIDs that were more than three days disconnected from the measurement node and never returned. To this end, we conducted an additional measurement of approximately 14 d (from 2022-03-29 to 2022-04-12). The measurement shows a continuous grow



Fig. 5. Comparison of the trend of the total simultaneous peer connections.



Fig. 6. Number of PIDS over time.

in the number of seen PIDs and a plateau of connected PIDs. The difference between simultaneous connections, connected peers, and the amount of seen PIDs over time are indicators for a possible misinterpretation of one peer as one PID.

In general, one participant can use multiple PIDs, e.g., to use a different outer profile, different IPNS entries, or increasing the privacy against nodes monitoring the Bitswap traffic [14]. The difference between simultaneous connections and known PIDs in our measurement would suggest that every peer has around two PIDs.

To determine the size of the network, it is therefore necessary to group PIDs or find a different method to distinguish peers. In the following, we discuss two approaches to estimate the network size: based on the multiaddress and based on the connection time and number of connections.

A. Multiaddress

A simple approach to group PIDs is the usage of the connected multiaddress, especially, the IP address part. PIDs establishing a connection from the same IP address belong to the same group. In case of the data of P4 with 65'853 PIDs, we had a connection with 62'204 PIDs, communicating from 56'536 different IP addresses. Grouping the PIDs by connected IP address results in 47'516 different groups, with 44'301 groups consisting of only one PID and overall 40'193 PIDs with unique IP addresses.

This method can detect non-persistent or rotating PIDs to some degree. For example, we observed one IP address with 2'156 PIDs, where all PIDs have the same agent version and support the same protocols. However, the amount of groups are still three times the amount of simultaneous connections. Additionally, this method has some serious flaws: Hydra nodes operate a multitude of heads not necessarily deployed on different IP addresses. In our data set, the 1'028 Hydra nodes 1'026 operate from 11 IP addresses 9 with 100, one with 98, and one with 28 nodes. The last two are run on one IP address with two go-ipfs nodes. These are most likely simultaneously active peers but would be grouped to 12 peers. Other problems consist in non-persisting PIDs in combination with NAT, NAT in general, smaller Cloud provider sharing IP addresses, or one-time users.

B. Connection Time

In addition to distinguish peers based on IP addresses, we also make an attempt to classify peers based on connection information. To this end, we will consider the number of connections established by a peer and duration of a connection with a PID. This goes beyond differentiating between clients and non-clients [9] and is able to identify the core network.

To see if there are certain trends, we use the data of P4. The left side of Fig. 7 shows the cumulative distribution function (CDF) for the maximum duration per PID for DHT-Clients, DHT-Server, and all PIDs. Around 53 % are connected less than 1 h and around 16 % of the nodes maintained a



Fig. 7. CDF of the maximum connection duration of all PIDs, grouped into 30 s intervals and the CDF of the number of connections.

TABLE IV CLASSIFICATION OF PEERS IN THE P4 data set.

Class	Time	# Conn.	Peers	DHT-Server
Heavy	> 24 h	$\stackrel{-}{\underset{<}{\overset{>}{_3}}}$	10'540	1'449
Normal	> 2 h		15'895	1'420
Light	$\leq 2 h$		16'880	9'755
One-time	< 2 h		18'889	6'108

connection longer than 24 h. The trend for shorter durations of DHT-Server nodes, might be due to the connection trimming as also experienced by our node. On the right side of Fig. 7, we can see the CDF for the number of connections a PID had with the measurement node. The figure shows that only around 10% have more than 15 connections and around 50% have one connection. From the results of Fig. 7, we can conclude that most PIDs connected only a few times and a small amount of nodes maintained the connection for a long time.

In order to classify peers based on connection information, we define four classes: heavy, normal, light, and one-time. We consider heavy peers to be stable and constantly active i.e., more than a day. Normal peers have comparably shorter but still somewhat long connection durations, e.g., more than two hours but less than a day. Light peers have many short connections i.e., repeatedly connecting to the networking, which summarizes recurring, experimental, faulty, or malicious peers. Lastly, one-time peers connect once or twice to the network in a short time frame for a short period of time (max. 2 h).

TABLE IV shows the classification of peers. We observed $\approx 1.5k$ heavy DHT-Server nodes, yielding $\approx 9k$ heavy DHTclient nodes. Since the DHT clients do not participate in DHT routing, we can also refer to them as the core user base. The number of heavy DHT-Server nodes seems rather low, which is not surprising as it represents a subset of all core nodes only. That is, some light and one-time DHT-Server nodes might be core nodes as well. This misclassification of nodes is a weakness of the passive measurement approach, because we can only see connection churn and not node churn. Connection churn can be triggered by connection trimming, due to new nodes joining the network, or new connections caused by file exchange and search. While the number of core nodes might be higher, it is, however, unlikely that the number is lower.

VI. CONCLUSION AND FUTURE WORK

In this paper, we presented a passive measurement study of the IPFS network, revealing a different perspective of the network compared to previous active measurements. While in many other P2P networks connection churn can be expected to be approximately equal to node churn, it is different in IPFS: We identify a rather high connection churn. Instead of nodes joining and leaving the network, we believe that the reason for the high connection churn is IPFS's connection trimming mechanism. Due to these results, we recommend to investigate the default threshold values for DHT-Server nodes further and possibly adjust it to a higher value.

Moreover, we show the complexity of determining the network size. To this end, we presented two methods for estimating network size and conclude that both methods cannot capture the full complexity. Additionally, the short measurement period, cannot capture long-term behavior. In the future, we will investigate, if it is possible to improve our method to distinguish peers by utilizing a wide range of peer meta data, e.g., latency, agent version, and history of announced multiaddresses. However, the possibility of a clear distinction of every peer can be cause of concern considering the privacy of users.

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