Generic DAO primitives for Full Academic Decentralization and Scalability

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***Abstract*—This thesis describes a new architecture for a completely decentralized and scalable decentralized autonomous organization based on multi-signature and thresh-hold signature schemes. To demonstrate the feasibility, we design, implement, evaluate, and deploy a DAO centered around music where artists can share their music in a decentralised manner and listeners can invest in artists using the DAO.**

***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

Decentralized autonomous organizations (DAOs) are a mechanism for economic activity by an unbounded group of people within an adversarial environment. Numerous organizations have been deployed succesfully, demonstrating the potential for this mechanism to enable able a trustless and transparent ecosystem. For instance the decentralized exchange Uniswap, which is governed by a DAO, reached transaction volumes of up to $85.5 billion in November 2021 [5] and is controlled by a DAO. The token associated with the DAO is utilized for the collective management of its funds and modification of the exchange's protocols. Prior to the emergence of DAOs, partially decentralized protocols and platforms such as BitTorrent and Wikipedia enabled millions of individuals to collaborate in file sharing and information accumulation. The increasing emergence and popularity of decentralized protocols highlight their potential for fostering collaboration between individuals.

Despite wide deployment of DAOs, many of them exhibit forms of centralization in their governance structure and infrastructure. This centralization is reflected in the lack of true decentralized governance. For instance, the second-largest DAO by market capitalization, APE DAO, is characterized by an initial token distribution in which 38% of tokens were distributed to various founders. Since every token is equivalent to a vote, these founders now hold a disproportionate amount of voting power. Additionally, proposals are vetted by a centralized moderation team, and all execution of proposals is carried out by the foundation members of the DAO. Another example is Solend, one of the largest decentralized lending systems. In 2022, there was an incident in which the development team took control of and liquidated the account of a whale with approximately $170 million worth of cryptocurrency. The team claimed it allegedly posed a systemic risk to the ecosystem at the time. This incident highlights the prevalence of centralized decision-making in DAOs.

The root cause of the failure of contemporary DAOs to decentralise lies in the underlying blockchain. Proof-of-work and proof-of-stake have failed to scale, despite a full decade of attempts to boost transaction rates, without the loss of decentralisation. Attempts to circumvent this by working with fewer miners which process more transactions have resulted in systems akin to those of traditional authorities, such as VISA. Centralization might even be inevitable, with Cong et al. showing that in the long run, due to centralized mining pools, Bitcoin will have a centralized market structure [10]. Proof-of-stake distributed ledgers run the risk of reinstating a centralized elite. To validate the network, a substantial amount of capital must be placed at risk. This set of validators can then be subjected to regulatory pressure or collide with one another to alter transaction validation rules at the infrastructure layer. They run the risk of moving to a new centrality with a new elite, who can afford to buy enough tokens to put up to stake to validate the network.

In this paper, we propose a new architecture for DAOs which is completely decentralized and scalable. To demonstrate the feasibility of this architecture, we design, implement, and evaluate a prototype for a DAO centered around music, referred to as the Music DAO. This implementation solely utilizes smartphones and is currently live. We conduct a real-world test with users and analyze the performance of our voting mechanism. The results show that our proposed architecture is a viable and sustainable solution. We argue that pure academic decentralisation within a viable and sustainable DAO represents a key milestone in the evolution of Web3. We believe an as-simple-as-possible DAO with basic governance, membership voting, and treasury management is a key step forward in achieving this goal.

1) **A Simple DAO Architecture** We design and justify an infrastructure for DAOs which is completely decentralized and scalable. To achieve this, we propose a set of technologies and primitives that must be followed. In particular, we separate the settlement mechanism and validation of rules using multi-signature and thresh-hold signature schemes.
2) **Music DAO: a true decentralised DAO** We design and implement a real-world DAO that revolves around the music industry using the proposed infrastructure. We use a combination of networks, including the TU Delft created IPv8, to create a music platform where artists

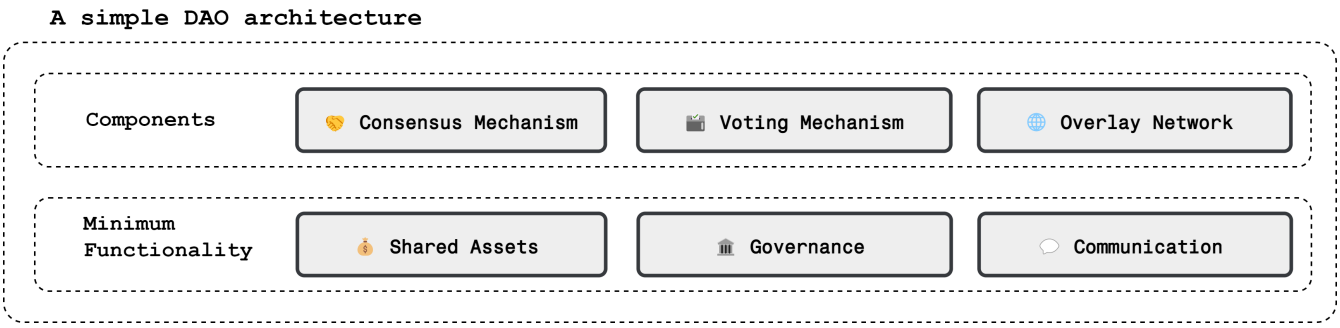

Fig. 1. A visual representation of the architecture of the simple DAO.

can share music and receive funds from a flexible DAO crowdfund structure. This DAO runs on smartphones only, has no central components and is deployed on the Android Play store.

3) **Evaluation** To evaluate the proposed infrastructure and implementation, we perform a real-life deployment test amongst a set of participants who work closely with DAOs. In addition, we perform a set of performance tests on our voting and joining mechanism to see assess the performance in a real-world deployment. The results of these tests provide insights into the feasibility and effectiveness of our proposed architecture and implementation

II. Problem Description

The goal of this study is to develop and deploy an academically pure decentralised DAO. We define a DAO as *a mechanism for economic activity by an unbounded group of people in a competitive environment devoid of infrastructure, leadership, and legal centralized authority.* An organisation which relies on no central intermediary nor central authority and one which is truly unstoppable.

In the field of decentralized autonomous organizations (DAOs), developing a mechanism that simultaneously achieves trust, pure academic decentralization, and scalability is a major challenge. Real DAOs only exist in theory. Every technology claiming to be a DAO has central points of control and critically relies on central servers. Bitcoin and Bittorrent are the only examples of technology stacks which are not reliant on central infrastructure. Numerous startups claim to offer a DAO with decentralisation. To date, all DAOs are still centralised to some extend. The problem is to actually engineer what has been dubbed the future of the firm. The challenge is to incrementally realise a new organisational method to coordinate socio-economic activities. In theory a true DAO will be more efficient than a traditional company, replace middleman with code, and scale beyond any work-from-home company operating on informal email exchanges. In principle, a DAO should be able to replace current Big Tech companies. This requires scalability beyond 1 billion contributing users. Irrefutable proof that a decentralised DAO is possible is the first near-term problem.

Complete decentralization of all components is essential to avoid the issues associated with traditional organizations. If even a single component remains centralized while others are decentralized, the DAO may still be vulnerable to the drawbacks of centralization.

In traditional organizations, individuals work towards a common objective, but the rules are enforced by a central authority. Third-parties such as institutions, large technology companies, governments, and legal systems ensure that individuals can trust one another and cooperate, providing efficiency gains through their top-down control. However, their interests may not align with the interest of the participants. They may alter the rules in alignment with their own interest or not follow them at all. Even if participants have some influence on this process, it often is outdated and slow (democracy) or relegated to a select wealthy group (share-holders). For example, commercial companies, such as big-tech companies, are ultimately primarily interested in maximizing their own profits. They often use increase user retention rate, at the expense of social and economic problems,. This problem is exacerbated when power becomes concentrated more among a small group of people.

III. Related Work

The concept of DAOs in academia is relatively new, it has mostly been developed by open source developers in the blockchain sphere. One of the first deployed and successfully used DAOs was created in 2016 by Christoph Jentzsch and was called “The DAO”. The goal of the project was to create a new business model for non-profit enterprises. With an internal capital of 150 million
USD from 11.000 investors at its peak, it was extremely large for its time. It however suffered from an exploit in the smart contract [2], after which the Ethereum blockchain was forked to return the money to investors.

There has been considerable effort invested in observing and researching the phenomenon of deployed DAOs. Shuai et al. have developed a comprehensive framework for DAOs that identifies their characteristics, problems, implementations, and upcoming trends [23]. In addition, they suggest a five-layer architecture for DAOs. They do not, however, give a concrete implementation of such a DAO utilizing the design.

Hassan et al. conducted a similar study with the objective of identifying the largest unresolved issues in DAO research [13]. They pose the questions of which DAO layers should be decentralized, to what extent a DAO should be autonomous, and whether a DAO should be considered a legal entity. The identification of these obstacles eases the entry of new researchers into the field.

IV. A Simple DAO Architecture

We present a generic and as simple as possible architecture for DAOs. We deliberately remove all unnecessary features and complexity in order to provide a flexible and strong building block. Our building block represents a milestone within the evolution of actual DAO realisations: it is the first to achieve hyper decentralisation. Our minimal function decomposition results in three key architectural primitives, a set of minimal functionality a DAO handling economic activity should have and the accompanying components which should be implemented. An overview of this decomposition can be found in Figure 1.

A. Architectual Primitives

All accompanying components should adhere to these architectural primitives in order to satisfy the definition of a decentralized autonomous organization.

Trustless Any decision within the organization must be independent of third-party involvement or intermediaries. To ensure trust in the fairness of decision-making processes and the execution of those decisions, cryptographic and verifiable means should be employed.

Permissionless Any person should have the opportunity available to participate or access in the organization, without needing any approval of intermediaries. They should not be discriminated based on factors which are not relevant for the workings of the DAO. This does however mean that members in the organization can still collectively decide to block or not allow a person in the organization.

Transparent All information regarding the organization, its decision making process and decisions made should be available to access for everyone. This transparency should extend to both internal and external stakeholders, allowing unrestricted access to the relevant information. Transparency is required for verifiability and serves as a means to foster trust and accountability within the organization and its interactions with the wider community.

B. Architectural Minimum Functionality

The DAO must have a minimum set of functions which provide the ability for participants to coordinate economic activity among each other.

Shared Assets For a DAO to fund its activities and achieve its objectives, it must have some notion of shared assets. Although DAOs without any assets can rely on altruism to some extent, most of the time financial incentives are needed to make work possible in practice. An obvious choice for DAOs are cryptocurrencies, as they conform to all three primitives we previously established.

Governance In order for a DAO to achieve its objectives in an orderly and ”fair” manner, a set of governance rules should be established dictating how decisions are made in the organization. Generally, individuals who contribute more and take on responsibility should have more benefits in the decision making process than others. However, this primitive is often a matter of debate, and the concept of ”fairness” in decision making is also an open research question [CITE]. Some proponents for example argue that every real human should have one vote. Nevertheless, it is essential to establish some form of governance to enable effective decision-making.

Communication In order to coordinate governance and other activities, participants need to able to communicate with one another. The communication protocol must be tamper-proof and authenticated, so that participants can hold each other accountable for any decisions they make in i.e. governance procedures. Furthermore, the conversations should be available to all participants, in order to uphold the primitive of transparency. This will allow new participants to review the history of the DAO, thereby enabling them to make informed decisions that align with the objectives of the organization.

C. Architectural Components

To meet the minimum functional requirements of a DAO, it is necessary to define a basic set of components that should be present in the organization. These components can be interchanged with any other implementation that adheres to the requirements of the component.

Consensus Mechanism A secure, decentralized and immutable blockchain is essential to enable participants who do not trust each other to coordinate economic activity. The decisions made by the organization should be stored in such a ledger of trust. The blockchain acts as a foundation of trust upon which participants rely to enforce the existing rules of the DAO and possibly also provide a mechanism to change the rules according to a set of meta-rules, i.e. a vote to change the rules. It is important that such a blockchain must have the capabilities for validating transactions using at-least multi-signature and thresh-hold signature schemes in order to facilitate off-chain transaction settlements.

A blockchain network is a network wherein participants come to consensus on a set of transactions. The network ensures the 1) validity and 2) ordering of the transactions. Transactions are grouped in blocks, which contain a set of transactions and the hash of the previous block. This makes it difficult for the chain to be tampered with. In order to agree on the same chain (ordering of transactions), consensus mechanisms are used. These are a collection of rules and financial incentives that determine which chain is favored and thus which ordering is used. For instance. in the case of Bitcoin, Proof-of-Work is utilized, where the chain with the most computational work is preferred over the others.

Voting Mechanism A voting mechanism is necessary in order to facilitate decision-making within in a DAO and al-

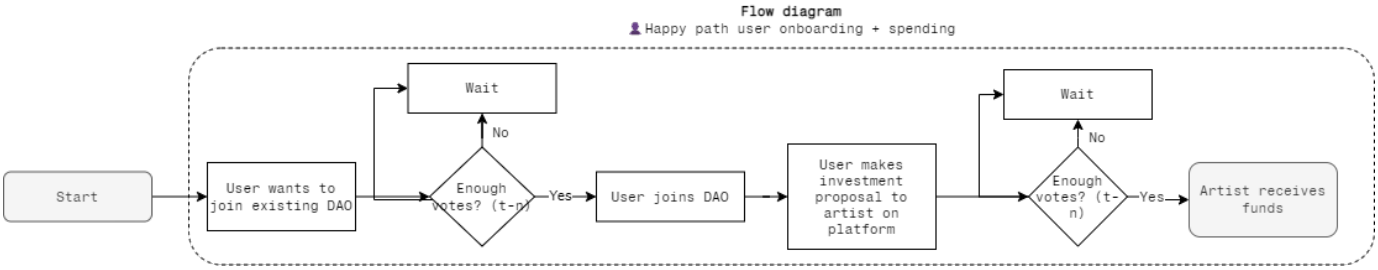

Fig. 2. Spending process

TABLE I
COMPARISON OF SIZE REQUIRED ON BLOCKCHAINS FOR DIFFERENT VOTING SCHEMES

Governance Mechanism	Signatures Required	Public Keys Published	Signatures Published	Transactions Required	Size
Smart Contracts	up to n	up to n	up to n	up to n	n
Naive Bitcoin Multisignatures	n	n	n	1	n
Schnorr MuSig	n	1	1	1	1
Schnorr MuSig 2	n	1	1	1	1
Threshold Signatures FROST	$m < n$	1	1	1	1

lowing participants to come to reach on consensus on decisions that require a vote. This includes decisions on modification of existing rules, and decisions that adhere to the current rules, such as the election of new members. The mechanism should be transparent and accessible to all members. The design of meta-rules should also be fair, however the definition of fairness is subjective and varies depending on the context and organization. This is still an unsolved problem and subject to ongoing research.

Overlay Network A peer-to-peer communication solution is necessary for enabling individuals to effectively communicate with each other and coordinate activities without intermediaries. This includes both protocol-level communication, as well as communication related to the organization's internal operations. The creation and dissemination of proposals for instance must be communicated among all members. This information however does not necessarily need to be stored in an immutable blockchain, since there is no relevant double-spending attack possible. Instead, a peer-to-peer communication solution would be sufficient for transmitting information that does not need to be permanently stored.

V. VOTING MECHANISM

A voting mechanism allows a group of individuals to cast their votes and reach a collective decision in a verifiable and transparent manner. In order to achieve this, the votes must be authenticated in order for individuals to verify individual votes.

In this section we review several existing voting mechanisms and compare them based on their features and performance. Based on this, we then propose the usage of a voting mechanism which best fits and suits our needs.

The most common voting mechanism in use currently is through the usage of smart-contracts. The industry-standard for such contracts is OpenZeppelin Governor [CITE]. Participants

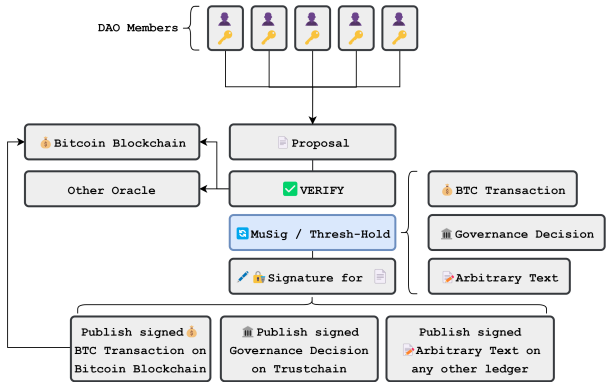

Fig. 3. Multi-party signature based voting mechanism

use their wallets and tokens to interact with the contract. They can cast votes on a proposal by creating and publishing a transaction interacting with the contract. Once the voting period ends, the proposal is closed and the result is considered final. The main advantage of this approach is its extendibility: custom smart contracts can support advanced features such as delegating votes and automatically transacting funds after a successful proposal. The main downside is that in order to complete a vote many transactions are needed, which is hindered by the scalability problem of blockchains.

A different class of voting mechanisms is based on multi-party signature schemes. A multi-party signature scheme is a scheme in which a set of participants collectively create a signature over a message. Participants use their public keys in order to make a collective public key. In order to make a signature, each participant creates a partial signature of the message which are then combined into a single valid signature valid for the collective public key.

Participants vote in favor of a *decision* by participating in the scheme or implicitly against by not participating. If enough

partial signatures are available, the vote is over and a signature for the decision can be made. Note that there is no time limit possible, and votes cannot be revocated. An optional *pre-condition* can be defined by the participants. This is a function in an arbitrary language which verifies some condition, such as the state of the blockchain at that moment. The mechanism can be seen in Figure IV.

A. Multi-party Signature Voting

We can use this voting mechanism to make the management of collective funds possible on a blockchain. A collective fund is a set of transactions which output is locked by the collective public key of the participants.

In order to spend the funds, participants must sign a new transaction sending the funds to a new address. The remaining funds should be locked up again by the collective key. This process is also described in figure 2.

In order for a new partipant to join, a new collective key must be made with the public key of the new participant included. The new transaction then sends the funds from the old key to the new key. Additionally, a pre-condition can be set-up, such as the requirement for the new participant to add some funds from his own wallet to the collective fund. The removal of a participant follows a similar process, a new key is created without the participant and the funds are sent to the new key. If needed, the participants can send the initial funds of the removed participant back to their own wallet.

In a DAO using multi-party schemes, the collective funds are locked up by a collective public key of all participants. A set of transactions which outputs are locked up by this key represent the collective fund. In order to spend these funds, the participants must sign a new transaction sending the funds to a new address. This process is implicitly a voting process on a spending proposal. Participants vote in favor of the proposal by participating in the scheme or implicitly against it by not participating. Note that there is no time limit possible in this mechanism. This process is also described in figure 2.

The implicit governance structure exhibited here is founded on the ownership of private key shares. A one-token-one-vote [25] model can be implemented using sybil-resistance mechanisms. In the absence of this restriction, a single user can create sybils to acquire additional shares based on the required criteria for membership. This can be desirable if, for instance, the members of the DAO wish to incentivize greater participation in the DAO (financial or otherwise), which can be rewarded with additional private key shares.

B. Security Model

In this proposed architecture, the security model differs significantly from that of a smart contract platform run on a blockchain with global consensus. In a traditional blockchain, transactions are validated according to a set of rules that are determined by a group of miners. If 51% of all miners agree to, for example, commit fraud, it is possible for them to do so. In other words, the validator set consists of all the miner nodes in the network and the accompanying hash-rate.

In contrast, our security model rests on the number of particiapnts in the DAO that are part of the group signature group. If 51% of the people (or any other percentage, depending on the n-k threshold) want to commit fraud, it is possible for them to do so. The main advantage of this model is that the complexity of the client-side rules can be arbitrarily complex and is essentially free to compute, since we only need to verify the transaction on the client side. The other nodes in the network, which do not have anything to do with the DAO, do not have to validate the client-side rules. 51% of the DAO members can run the client-side rules, verify their correctness, and if they are valid, participate in the threshold signature scheme. If they do not verify, they can simply not participate, after which no signature will be created.

In this design, we do not rely on advanced turing-complete smart contract capabilities. Instead, we use a blockchain of choice, namely Bitcoin, which is simple and secure, and does not require advanced smart contract capabilities. In this way, we can achieve a high level of security and scalability, while keeping the complexity of the system at a minimum.

VI. Music DAO: a truly decentralised DAO

New outline:

- What?: real deployed DAO for music industry
- Purpose of DAO and problem in music industry
  - Platform lock-in, revenue sharing, monopolies
  - Help invest in artists: funds, donations, tokens
- Zero-server architecture focus: no central point
  - IPv8-stack: messaging
  - Android: Smartphones only + open source
- Collective DAO fund management
  - No governance token, native Bitcoin: reasons
  - MuSig: voting mechanism (BIP340!), native in kotlin
  - Protocol is TrustChain based
  - Bitcoin: collective funds + donations + taproot + integrated lite wallet (!)
  - Overall flow for voting and publishing
- Music availability and sharing (BitTorrent)
  - BitTorrent: usage and BitTorrent DHT
  - Music/data availability strategy:
    - Info-hash (and other meta-dat) availability in TrustChain
    - Seeding strategy
    - Naive gossiping protocol
    - Overal flow for creating a release
- Go over software testing / validation / deployment shortly

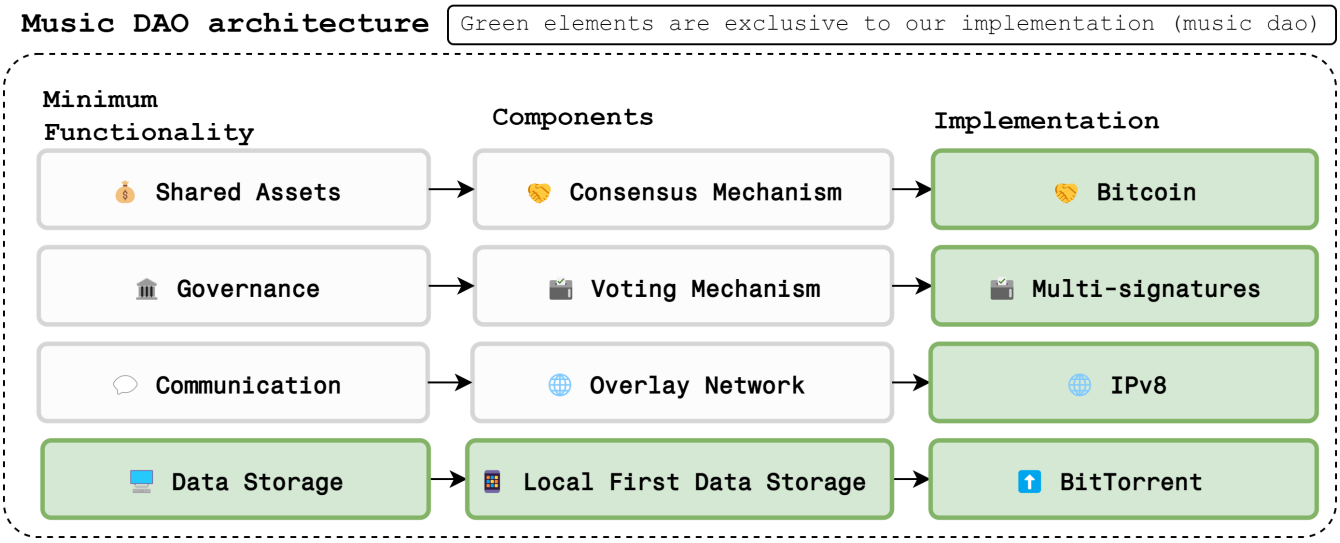

Fig. 4. A visual representation of the Music DAO based on our architecture.

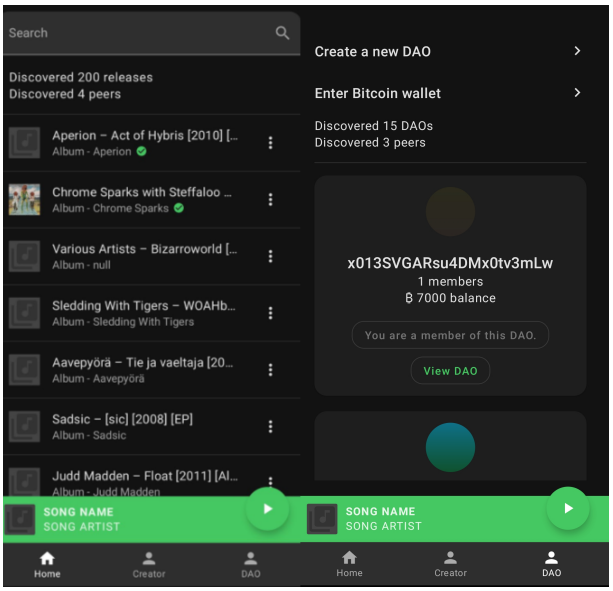

Fig. 5. A list of releases and DAOs in the application

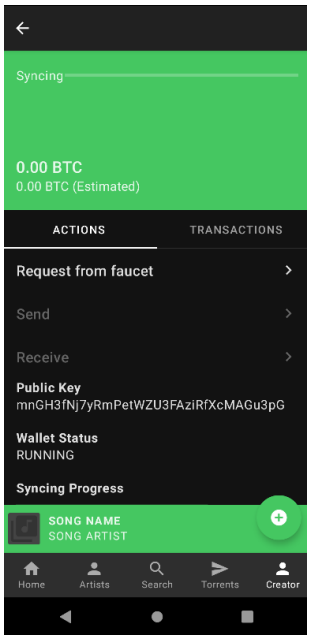

Fig. 6. The integrated Bitcoin lite wallet

We have created an implementation of a DAO centered around music using our proposed architecture. This implementation uses all the specified architectual components and adheres to the architectural primitives that we have laid out in Section IV. In this section we describe its functionality, the implementation choices we made and any additional components we added.

The objective of the Music DAO is to enable artists to earn a living through music and to allow listeners to listen to their preferred music and support artists. While music platforms and labels also facilitate this process, these intermediaries often take a significant portion of the revenue, create platform lock-in for both artists and listeners, and have a disproportionate amount of power over artists [CITE].

In order to realize this objective, the DAO consists of two main components: the music platform, and the crowdfund platform. The music platform enables the dissemination and availability of music and it's meta-data. The crowdfund platform allows listeners to collectively manage funds, which they can use to fund new projects of their favorite artists.

Music Publishing Artists can publish music to the platform. Published music is shared on the IPv8 peer-to-peer overlay network. The music is first encoded to the correct format and an accompanying torrent file/torrent meta-data is created for the formatted data. This meta-data is then published on the personal trustchain of the user and gossiped around to other

users. At the same time, the torrent file is published on the BitTorrent DHT network and is available to seed from the phone. Additional meta-data such as album art cover is also included in the published music and is displayed in the GUI.

Data Availability Listeners keep seeding a part of their music according to some type of a set of rules, for instance based on popularity. The optimization of this process is out of scope for this work. For this implementation, the most popular music and a selection of the less popular music (tail-end) is randomly selected and seeded.

Music Listening Different users on the network can receive the signed trustchain blocks and add them to their local storage of published music. They use the meta-data in the block to query the DHT network and download peer information to download the torrent from seeders. After the music has been downloaded, everything is verified, and the listener can listen to the music with the accompanying data.

The implementation is created using Kotlin and Android on the JVM platform. This allows for deployment on the Play Store and accessibility for hundreds of users. Cross-platform mobile application is outside the scope of our use case, due to many of our libraries not being available, such as our chosen overlay network IPv8. Android additionally provides extensive service APIs that allow services to continously run in the background, allowing for the upkeep of the network.

We chose to limit our implementation to smartphones only for several reasons, all of which align with our primitive of creating a permissionless system. Additionally, smartphones have a lower barrier to entry, as almost everyone has a phone, especially in developing countries, and not everyone has a PC. The zero-architecture server stack also supports the idea that smartphones are the superior device for maintaining and using P2P networks.

The use of BitTorrent in our implementation is due to its reliability and decentralization. BitTorrent has a proven track record of stability and security, with 19 years of incremental improvements to the protocol. While other technologies such as IPFS offer similar functionality, BitTorrent is more widely adopted and has a larger user base. By extracting torrent info hashes from the platform, we can facilitate mass seeding of the network, or allow users to download content using popular torrent clients without the need for our application. The use of the accompanying Distributed Hash Table (DHT) network in our implementation is to remove the need for tracker servers, which are centralized and may be taken down by law enforcement agencies. DHT networks are much harder to take down and only require a simple bootstrap node, which can be any node with sufficient knowledge, after which you can get almost any swarm info about a info-hash in the network.

VII. Performance Evaluation

In this section, we present a comprehensive evaluation of MusicDAO in terms of performance and usability. In terms of performance, we analyze the voting mechanism in both a local and peer to peer setting. To evaluate the usability, we perform various experiments on time to discovery on listening and discovering DAOs. Additionally, we conducted a real-life deployment test involving experts in the field of DAOs, who actively engaged with our deployed application..

A. Voting Mechanism

We measure the performance of our voting mechanism described in Section V in both a local and peer-to-peer setting. We measure the time it takes to create a single signature for an increasing number of voters. We only measure this, and do not concern ourselves with creating and measuring the time it takes to create Bitcoin transactions as well. The multi-party scheme used is the same as in our MusicDAO implementation, a BIP340 compatible version of MuSig, which can be found on our Github. We run the experiments on an Android Emulator within an consumer grade PC with 32GB RAM and a Intel i7-12700H, following our assumption that the DAO will be run by smartphones only.

1) Local MuSig: For this evaluation, we analyze the performance of MuSig and get insight into a lower bound for our voting mechanism. To do this, we run the whole protocol in a single process and function on the emulator. We measure the time it takes for a number of public keys to collectively run the protocol, that is: create an aggregated public key, aggregated nonce, a list of partial signatures and an aggregated signature. The key generation of the individual nodes is not included in this measurement and cached before the experiment is run. This is because we assume users have a keypair already, and this process takes up a relative large amount of time otherwise, since key generation is expensive. We run the experiments for up to 10.000 keys with a 100 key interval. For every amount of keys we run the experiment 10 times, in order to get a accurate result. The results can be found in 9.

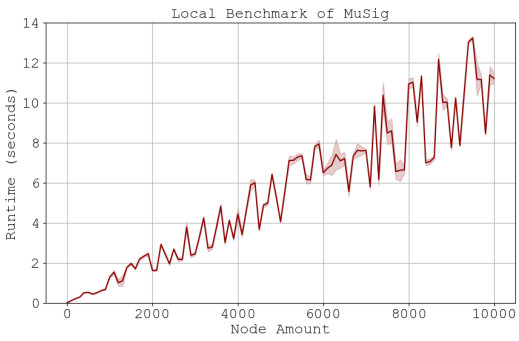

Fig. 8. Performance of implemented voting mechanism in the local setting

Figure 8 shows that the run-time of the algorithm scales linearly with the the amount of nodes, with 10.000 nodes running in around 11 seconds. We observe that we have fluctuations of up to 30% in our experiment. Upon further inspection, we determined this is due to the BIP0340 [CITE] specific changes made to MuSig. Public keys in BIP0340 are encoded in such a way that the y-coordinate is always even. If this is not the case, the point is negated. The aggregated public key will be odd in 50% of the cases, which requires

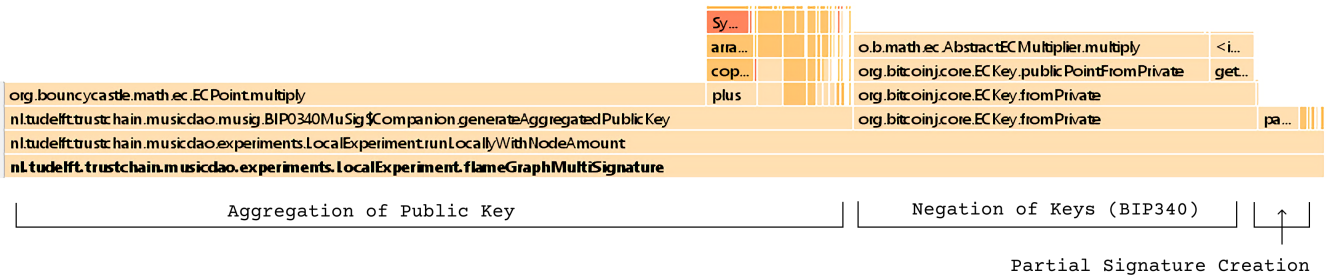

Fig. 7. Flame graph of local MuSig with 10.000 keys

all participants to negate their own keys as well. This process causes increases runtime in 50% of the cases.

2) Peer to Peer MuSig: For the peer to peer experiment, we measure the mechanism in a peer to peer setting, which closely resembles the actual use case of a DAO. We measure how the mechanic performs with an increasing number of nodes. We implement a protocol on top of an IPv8 overlay network. This protocol specifies which UDP messages are sent and how nodes react to these messages, ultimately leading to a collective key and collective signature. The experiment design aims to achieve the best-case scenario for performance.

3) Peer to Peer MuSig: We create a new protocol using messages, as opposed to the currently used Trustchain based protocol described in VI. This decision is made because the Trustchain-based protocol relies on gossiping and polling, which could impose limitations on performance. We want to get probable lower bound for voting in a peer to peer setting, and with the Trustchain based protocol we would be limited by our gossiping and polling logic. By using a direct UDP messaging protocol, we can instantly respond to incoming messages and get the best possible performance.

The experiment involves running multiple IPv8 nodes in an emulator, each assigned to an unique port. It should be noted that this setup minimizes latency, since all packets are confined to a local network. The experiment begins by instructing a single node to initiate a signature round with the other nodes. The time required for this node to create a valid signature using the other nodes is measured. This process is repeated 10 times for an increasing number of nodes up to 20.

The limitation of the experiment to 20 nodes is due to the use of UDP messages in IPv8, where some messages exceed the UDP packet limit because of the large size of keys. Although this limitation could be addressed by using protocols such as the EVA protocol [CITE], it falls beyond the scope of this experiment. Nonetheless, the results obtained still offer valuable insights.

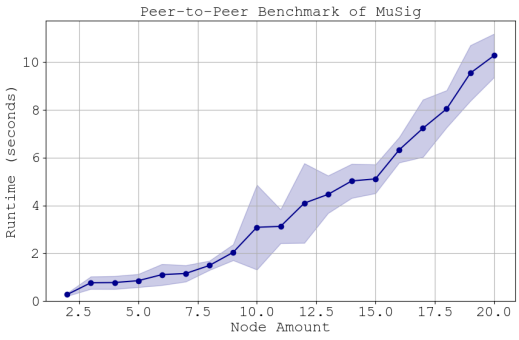

Fig. 9. Performance of implemented voting mechanism in the Peer to Peer setting

TODO: results and interpretation

4) Flamegraph of Local MuSig: Figure 7 shows a flame graph of a single signing round of MuSig on the aforementioned Android Emulator. The function shown computes a signature for 10.000 keys in 10 seconds. From the figure we can show that (?) (60%) of time is spent is on aggregating the public key. The rest of the time of 25% (?) is mostly used for the negation of keys, which is only required for Bitcoin signatures in theory. The rest of the time 15% is spent on aggregating the nonces, creating the partial signatures and combining these signatures until the final signature.

The results indicate that the aggregation of public keys is the most computationally expensive cryptographic task. This is due to the fact that aggregating public keys requires multiplication of elliptic curve points. The other operations do not require this, or only require this in a constant amount of time. Furthermore, we observe that negation of keys is an expensive task. This is because a new key has to be generated for every negation. This is an artifect of the Bitcoin specification of Schnorr signatures, and can be avoided by using other blockchains.

B. Usability Experiment: discovering music

We measure the time it takes for music to show up in the application using two phones using benchmark code within the application. One phone will act as a seeder and one phone will

receive new releases. The phones are connected to the same local network. The experiment is run 10 times and the results can be found in Figure 10. All measurements end up being under two seconds, which is a reasonable time to wait. Notice that in a setting with more phones, this time will decrease due to more chance of releases being gossiped to the receiver phone. This thus can be interpreted as an upper bound.

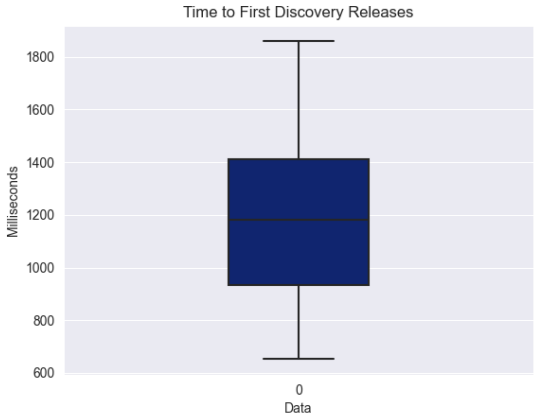

Fig. 10. Time to first discovery music

C. Usability Experiment: discovering DAOs

TODO

D. Real-life deployment test

In order to evaluate the usability of our tests, a real-life deployment test was conducted. Participants were given a presentation on DAOs and were subsequently provided access to the application, which is deployed on the Google Play Store. This allows us to gather valuable insight on the usability and user experience of our solution in a real-world setting.

Through the deployment test, we gained practical insights into how users perceived and utilized the application. User feedback during this real-life scenario provided valuable information for refining and improving the application's usability, ensuring that it meets the needs and expectations of its intended users.

VIII. Conclusion

In an increasingly connected world where big-tech and governments are centralizing power, decentralized autonomous organizations (DAOs) offer a bottom-up approach for collaboration on the internet. However, many DAOs suffer from issues caused by managerial and infrastructure centralization. In this work, we have proposed a simple and robust architecture for DAOs that allows for economic activity while maintaining complete decentralization. The Music DAO, which utilizes the most robust currently live-deployed networks, demonstrates the viability of this architecture, and our evaluations show that it is both scalable and user-friendly.

IX. Acknowledgment

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