

# Braidpool: Decentralised Mining Pool for Bitcoin

## Abstract

Bitcoin P2Pool's usage has steadily declined over the years, negatively impacting bitcoin's decentralisation. The variance in earnings for miners increases with total hashrate participating in the pool, and payouts require a linearly increasing block space with the number of miners participating in the pool. We present a solution that uses a DAG of shares replicated at all miners. The DAG is then used to compute rewards for miners. Rewards are paid out using one-way payment channels by an anonymous hub communicating with the miners using Tor's hidden services. Using the payment channels construction, neither the hub nor the miners can cheat.

## 1 Motivation

P2Pool [1] helps bitcoin's decentralisation by allowing miners to select the transactions they mine. This avoids any potential transaction censorship by pool operators. However, the construction used by P2Pool faces a number of problems that has resulted in miners abandoning the pool. The most often cited problems are:

1. large variance in earnings for miners,
2. large number of stale blocks, and
3. large block space requirement for payouts.

The first two problems are a direct consequence of the shares block rate limited to 30 seconds on the bitcoin p2pool. Intuitively, as the hash rate participation in the pool goes up, the difficulty for 30 seconds block rate goes up and smaller miners find it harder to find shares within a 30 second period. This results in an increase in the variance for shares found by miners and thus for the rewards earned by the miners. Ethereum's inclusive protocols [5] address the problem by building a DAG of blocks and rewarding blocks that otherwise would have been left out as stale blocks. As miners get rewarded for more of their work, the variance on their earnings reduces enabling smaller miners to remain economically viable.

Payouts in P2Pool are included in the coinbase of the block being mined. As the number of participants in P2Pool increase the size of the coinbase transaction

increases taking up valuable block space that the miners could have earned fees from instead. This imposes an upper bound on the number of participants in P2Pool.

Knowing the challenges faced by P2Pool, we list the goals of a new decentralised mining pool as:

1. Reduce variance for miners with increasing pool hash rate.
2. Make payouts to miners with constant size block space requirement.
3. Allow miners to select transactions they want to mine, with no potential for a censor to deny payouts.

## 2 Current Proposals

TeraHash Coin [6], Jute [13] and Spectre [12] use a DAG for faster block times and focus on changing the consensus layer of bitcoin. These proposals allow miners to produce shares that include conflicting transactions and then apply rules to find a set of transactions acceptable at various cuts of the DAG, such that the bitcoin consensus rules are not violated.

Braiding the blockchain proposal [6] shows how, smaller more frequent blocks can form a DAG of blocks, called a braid, with each block pointing to one or more one previous blocks. Blocks in the braid are called beads and transactions can be repeated in different beads. The proposal describes how duplicate and double spend transactions can be resolved to reach a decision on the state of the ledger at any cut of the DAG.

Belcher [2] proposes using payment channels to avoid using block space for making payouts to miners. The construction uses payment channels between federated hubs to pay miners after a block has been successfully mined. The payouts are made after a long period, similar to the 100 blocks requirements for spending from coinbase transactions. The hub locks in BTC for each miner by opening payment channels for each of the miners. The construction shows how both miners and the hub can not cheat and how the funders of the hub earns rewards for funding the payment channels.

The two ideas of using a DAG and payment channels for rewards payouts together present a potential path for rebooting P2Pool.

## 3 Decentralised Bitcoin Mining

In this section we describe how a DAG of miner's shares is maintained by each miner and how the same is used to determine the payout distribution between miners.

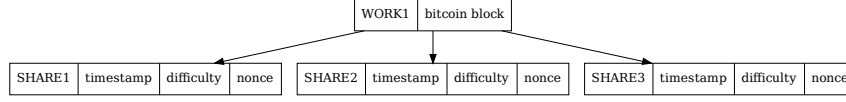


Figure 1: Each WORK generated and shared by a miner is then followed by the SHARES the miner finds.

WORK		
Field	Description	Size in bytes
Version	Bitcoin block's version field	4
Previous block	Hash of the previous bitcoin block	32
Difficulty	Current bitcoin difficulty	4
Coinbase	Coinbase for payment channel setup, see Section 5	38
Transactions	Transaction ids included in the block	variable
WORK hash	Hash of the above fields	32

Table 1: The structure of WORK broadcast by miners. Timestamp and nonce are left out and are included in SHARES instead.

### 3.1 Work and Share

Each miner can build their own block, selecting transactions according to their own criteria. We call this block the WORK and it is derived from the results of the `getblocktemplate` bitcoin API call.

The WORK definition leaves out the merkle root and the timestamp. Instead it includes the coinbase transaction so that other pool participants can verify that the WORK definition includes the correct payout scripts. Table 1 shows the WORK built by miners. To reduce bandwidth consumption the transactions field is compressed using compact block specifications [3].

Miners then start mining on WORK and generate their SHARES. Figure 1 shows the relationship between WORK and its SHARES. Each WORK created by a miner can result in multiple SHARES and both the WORK and SHARES are broadcast to the p2p network. When a miner receives a WORK from other miners it validates this WORK using a local bitcoin node. When a SHARE is received by a miner it is validated against the WORK referenced by the SHARE. Table 2 shows the structure of SHARES broadcast by the miner.

Each SHARE includes the hash of the WORK the miner is working on, along with the public keys that the hub uses to setup payment channels, and finally the public key for the Tor hidden service run by the miner. The Tor hidden service is used for facilitating anonymous communication between the hub and

SHARE		
Field	Description	Size in bytes
WORK hash	Hash used to identify the WORK for this share	32
Nonce and extra nonce	Nonces used	4 + 8
Merkle root	New merkle root to include extra nonce	32
Timestamp	UNIX timestamp used	4
Public keys	Two pubkeys used by the hub for channel management	66
$list < \text{SHARE hashes} >$	List of share hashes referenced by this SHARE	$N \times 32$
Tor Service	PubKey for onion service address, see Section 5.6.	32
Total size		$134 + N \times 32$

Table 2: The structure of SHARES broadcast by miners. Size of the SHARE is dependent on the number of shares referenced by a share ( $N$ ).

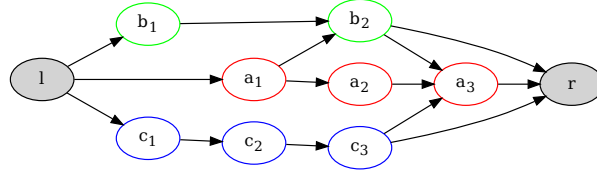


Figure 2: SHARES mined between two bitcoin blocks

the miners as described later in Section 5.6.

### 3.2 DAG of shares

Miners broadcast their SHARES to the network using a gossip protocol and all the miners maintain the DAG of SHARES as a replicated database. Each node on the DAG is a SHARE generated by a miner and all miners track the most recently received SHARE from all other miners. Miners include hash pointers to the root nodes of the DAG, ensuring that the DAG is eventually consistent on all miner nodes. The DAG provides a “found before” relationship between shares which enables faster generation of shares without requiring a single chain of shares.

Figure 2 shows a DAG with three miners participating in the pool,  $a$ ,  $b$  and  $c$ . The nodes in the DAG are the shares generated by the three miners. Nodes

$l$  and  $r$  are two valid bitcoin blocks that have been mined such that they meet bitcoin’s difficulty at the time.

### 3.3 Miner Defined Difficulty

The nodes in the DAG are SHARES mined at difficulty level selected by the miner. This difficulty can be dynamically changed by the miner after each SHARE, depending on the miner’s observation of the p2p network’s hashrate. This dynamic difficulty adjustment allows miners to adjust the rate at which they produce SHARES. This is important as smaller miners can produce low difficulty shares to match the share rate of the larger miners in the pool. Even if smaller miners earn a smaller reward, they will earn these rewards for all their work.

The miner defined difficulty for shares is set in the input of the coinbase transaction where miners currently also set the `extraNonce`. This ensures that other miners on the network can verify the share was mined with the claimed difficulty.

## 4 Reward Calculation

All participating nodes, including the miners and the hub, maintain a local replica of the the SHARES DAG. Each SHARE includes a reference to the shares the miner was aware of when the SHARE was found. Each share also encodes the difficulty it was mined at as part of the nonce as described in Section 3.3. With these in mind, we describe the rules used to determine the rewards distribution between the miners.

We use a modified version of PPLNS (Pay Per Last N Shares) to calculate the reward distribution between miners. Variations of PPLNS have been shown to be most resistant to pool hopping [11].

1. Traverse the DAG in reverse order from the SHARE that found a bitcoin block and track the aggregate difficulty included in the SHARES.
2. Once the aggregate difficulty reaches a system defined value, stop the DAG traversal.
3. Distribute the reward between miners weighted by the sum of the difficulty of all SHARES found by each miner.

As an example, consider the p2p network of miners  $a$ ,  $b$  and  $c$  with the DAG of shares as shown in Figure 3. In the DAG, two new blocks have been found,  $a_5$  and  $b_5$ . For the round ending with  $a_5$ , the last “N” shares are  $\{a_1..a_5, b_1..b_3\}$ . The shares  $c_1..c_3$  are not included in this first round as they are not reachable from  $a_5$ . However they are included in the shares for the next round ending in  $b_5$ , because their inclusion was needed to reach the total difficulty for the round. The round ending in  $b_5$  therefore rewards the shares  $\{c_1..c_4, b_4, b_5, a_6\}$ .

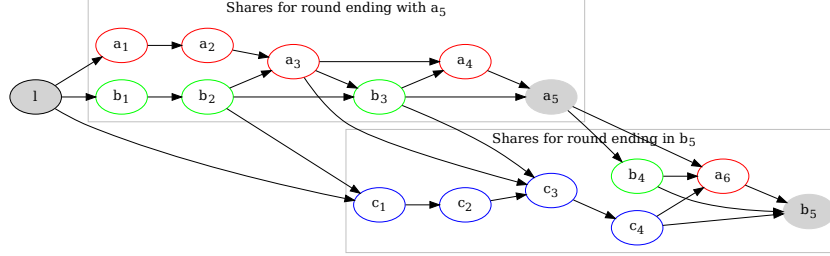


Figure 3: Reward calculation for two periods. Shares are mined by three mines —  $a$ ,  $b$  and  $c$ . The shares in grey meet the bitcoin difficulty at the time they were mined.

## 5 Payment Channels

We propose using Payment Channels for paying miners based on the proposal by Belcher [2]. The construction of the payments channels we present is similar to Belcher’s construction, but there are a few changes and we highlight them before describing the details.

- In the Belcher proposal, the pool had to predict how much work miners will be able to contribute for the next block. Instead our DAG based scheme results in an incentives compatible distribution of rewards among miners.
- Belcher proposes using multiple hubs to prevent DDoS attacks on hubs, we instead use a single hub, and prevent DDoS attacks by keeping the hub hidden using Tor’s v3 hidden services [4] for communication between the hub and miners.

The rest of the construction is similar to the early versions presented by Belcher — there is a one-way channel between the hub and each of the miners. The hub updates the state of each channel with appropriate reward after each block is found.

### 5.1 Coinbase

We use Belcher [2] construction where each miner builds a coinbase transaction that can be spent in one of the following three ways:

1. Co-operatively by Hub and Miner, or
2. By the Hub with a hash lock for pre-image  $X$ , or

Coinbase		
2 H M 2 CHECKMULTISIG		( $cb_1$ )
OR		
hash(X) + Hub P2WPKH		( $cb_2$ )
OR		
M and CHECKSEQUENCEVERIFY 6 months		( $cb_3$ )

Table 3: Coinbase transaction with hub and miner public keys.

3. By the Miner that found the bitcoin block, but after waiting for six months.

The scriptPubKey for the above conditions in the coinbase is shown in Table 3. These conditions mean that the hub can not spend the coinbase without revealing the pre-image  $X$ . This pre-image is included in the construction of payment channels, as we will see in the next section. This use of pre-image in both the coinbase and the payment channel definition guarantees that miners get paid for their accumulated payouts if the Hub defects and spends through the  $cb_2$  branch. We discuss how the miner and the hub don't gain by defecting in Section 5.5.

## 5.2 One-way Channels

One-Way payment channels between hub and all miners allow miners to receive payouts while consuming a constant size block space in the bitcoin block they mine. The use of payment channels is what makes the pool scale without losing block space. The miners therefore avoid losing the fees that can be earned from the block space.

We use one-way instead of bidirectional payment channels as an initial implementation. If required we can switch to bidirectional channels [10] allowing miners to spend their mining payouts over the lightning network. However, for now, we deliberately stay away from the complexity of making the hub a lightning node. If there is interest from miners to use the lightning network, we can build it in the future.

Each miner has a one-way payment channel with the hub using a two of two multisig with a time lock of six months. For each payout a miner receives over the payment channel, the hub will charge an agreed upon fees between the miner and the hub. Belcher's proposal recommends a 0.1% fees for the hub.

## 5.3 Payment Channel Transactions

The hub creates a funding channel for each miner and locks  $R$  bitcoin in the channel. The miner then creates a refund transaction, spending the funding transaction and sending the  $R$  bitcoin back to the hub. The refund transaction has a locktime of six months allowing the miner to accumulate their payout

Fund Transaction		
Input	Output	
Hub's UTXO (Signed by the hub)	2 H M	2 CHECKMULTISIG $(f_1)$
	OR	
	2 H' M'	2 CHECKMULTISIG + Hash(X) $(f_2)$
	(R coins)	

Table 4: Fund transaction for payment channel between hub and miner.

Refund Transaction. Locktime 6 months	
Input	Output
Fund Tx (Signed by miner)	P2WPKH Hub's address (R coins)

Table 5: Refund transaction signed by miner and held by hub.

over the six month period. The protocol can be extended to allow each miner to agree upon a locktime with the hub. In this case, the trade-off will be between the fees charged by the hub and the length of the locktime.

The funding transaction includes an input from the hub and an output that can be spent in one of the two conditions shown in Table 4.  $H$  and  $M$  are the public keys for hub and miner, they are called the co-operative keys by Belcher. While  $H'$  and  $M'$  are alternative public keys for hub and miner, and are called the uncooperative keys in the Belcher proposal.

The hub doesn't broadcast the funding transaction, instead it waits for the miner to create refund transaction. This is the same as any other timelocked one-way channel construction, i.e. the miner creates a refund transaction with a timelock, signs it and sends it to the hub. The refund transaction is shown in Table 5.

With the refund transaction, if the miner stops responding, the hub can get a refund in six months time. However, the hub can be attacked by sending requests to open new channels and locking up the hub's liquidity. We resolve this by requiring the hub to open a channel to a miner only after it has contributed enough shares. This can be a parameter of the pool instantiation, with values anywhere between one to 100 bitcoin blocks. The threshold number of shares required before opening the channel is a configuration parameter for the hub. The miner will still receive the payouts for the shares generated, it is only that the channel opening is delayed.

On receiving the refund transaction, the hub broadcasts the funding transaction. Once the funding transaction is confirmed, the hub can start sending payouts to the miner. These payouts are determined in proportion to the shares found by the miner and included in the DAG as described in Section 4.

The payment transactions are updates to the channel where each update



Payment Transaction	
Input	Output
Fund Tx (Signed by the hub using $H'$ )	$2\ H\ M\ 2\ \text{CHECKMULTISIG}$ <span style="float: right;">(<math>p_1</math>)</span> OR $2\ H'\ M'\ 2\ \text{CHECKMULTISIG} + \text{Hash}(X)$ (Hub: $R - \text{earnings}$ ; Miner: $\text{earnings}$ ) <span style="float: right;">(<math>p_2</math>)</span>

Table 6: Payment channel update transaction sent from hub to the miner.

increases the earnings of the miner. The payment transactions are signed by the hub using the non-cooperating key,  $H'$ . Table 6 shows the structure of the payment transactions. In the next section we present how the payouts are distributed, we then show how the hub and the miners are dis-incentivized to cheat.

## 5.4 Channel Updates for Payouts

Once a miner mines a share that also meets the current bitcoin difficulty, the miner immediately broadcasts the block to the bitcoin network. The coinbase of this block is shown in Table 3 and can now be spent by one of the following branches:

**Co-operative Branch:** ( $cb_1$ ) The miner and the hub by both signing the first branch co-operatively.

**Hub Branch:** ( $cb_2$ ) The hub alone, by publishing the pre-image  $X$ .

**Miner Branch:** ( $cb_3$ ) the miner alone, after waiting for six months.

The proposal by Belcher specifies a payout algorithm that requires the hub updates the state of all channels, i.e. make payment to all miners. Once it has done so, the miner who found the block signs the first branch of the coinbase transaction and hands the coinbase to the hub. The hub can now redeem the entire payout. We use the same approach, requiring the miner to receive all channel updates from the hub before signing the co-operative branch. The miner first verifies that that the channel updates are properly signed by the hub, and there is one update for all miners in proportion to the rewards distribution algorithm.

## 5.5 Defecting Does Not Pay

Using the above construction of the payment channel and the distributed payout algorithm, we now show that defecting by the hub or the miner doesn't pay.

### 5.5.1 Hub Defection

If the hub defects and pays itself from the coinbase it uses the  $cb_2$  branch of the coinbase. In doing so, the hub has to reveal the pre-image  $\mathbf{X}$ . With the pre-image available, all miners will use the  $p_2$  branch of their payment channel transactions and close their channels receiving all the payouts earned up to that block.

It is possible that the hub defects on the very first block mined and the miners lose their earnings for that single block. But that will end the pool before it could be useful.

The hub could defect after a few blocks have been mined. In such a case the miners will receive their fair share of earnings for all previous blocks, but it will again be the end of life for the pool.

We recall that the hub charges fees to fund the payment channels between the itself and the miners. When the pool ends, the hub loses a profit making opportunity. We argue that the incentive to defect reduces as the size of the pool grows.

It is worth noting that if the hub is co-opted, all it can do is deny miners a payout for the number of blocks the pool delays the payments by. We introduced the idea of this ranging from one to 100 blocks. Further, if the hub is co-opted, all miners will immediately close their channels, collect their payouts and re-organise with a different hub.

### 5.5.2 Miner Defects

A miner that found the block could chose to not sign the co-operative branch ( $cb_1$ ) of the coinbase. In such a case, the hub will wait for a timeout period much shorter than the locktime on the miner branch ( $cb_3$ ) and receive the payout using the ( $cb_2$ ) branch of the coinbase. In response to this, all other miners will close their channels by signing the ( $p_2$ ) branch of the payment transaction by using the pre-image  $\mathbf{X}$  included in ( $cb_2$ ) broadcast by the hub. This will close all channels and require that all these channels are opened again. Such an attack by the miner will hurt miners on the network who have not yet earned enough payouts to amortise the cost of closing the channel.

Say a miner starts participating in the pool, and after  $N$  blocks successfully mines a bitcoin block, but refuses to sign the co-operative branch of the coinbase allowing the hub to claim the coinbase reward. In such a case all miners have to close their channels and claim the rewards they have earned. Miners who recently joined the pool stand to lose the most because of the forced closure of channels.

However, the miner also loses any payouts for all the shares it mined since the last block was found by the pool. A malicious miner could contribute a large portion of the pool's hash rate and then refuse to sign the co-operative branch. This will disrupt the functioning of the pool and a well funded censor could be willing to execute such an attack. The only defence here is that the miners re-organise and start a different instance of the pool.

### 5.5.3 Hub and Miner Collude

The hub and the miner could collude where they co-operate to spend the coinbase to themselves without requiring that the hub pays all other miners as per the reward schedule. The motivation for the miner is a big payout it can receive. However, such an action by the hub will end the pool and the stream of future profits for the hub.

### 5.5.4 DDoS on the Hub

The hub can be attacked using a distributed denial of service attack rendering it unable to process requests to open new channels and to distribute payouts to miners. Belcher in his proposal suggested the use of multiple hubs as a defence against such an attack. The proposal also points out that using multiple hubs will also reduce the liquidity required to open channels with miners.

According to Belcher’s proposal, with multiple hubs available on the p2p network, miners will open channels to all hubs and receive payouts from all of the hubs. The coinbase is split between hubs in such a way that if any hub defects, the other hubs can still spend the coinbase and split the block reward between them. In this way all miners receive payouts in proportion to the shares contributed by them.

Creating a larger coinbase for multiple hubs scales if we can use Taproot [9, 7, 8] once it is activated. The solution uses staggered timeouts for hubs to spend the coinbase in case of hubs defecting or coming under DDoS attacks. The only problem is that in case of hubs defecting, the staggered timeouts can result in a large wait for the payouts to be distributed.

We propose a different solution that requires a single hub. The advantage is a simpler channel construction and allow us to build the mining pool without waiting for Taproot activation. The single hub approach required that all miners run a Tor v3 hidden service and publish the public key used to generate the service’s address. The public key is published in each share the miner publishes. The hub can now contact the miners anonymously as a client and therefore avoids DoS attacks on the hub or on the miners hidden services.

## 5.6 Anonymous Hub Miner Communication

The hub and the miner need to exchange messages at the time of channel creation as well updating the channel state when the hub makes a payout to the miners. The channel management messages are exchanged infrequently as compared to the SHARES broadcast messages and don’t have the same timeliness requirements as the shares broadcasts. We propose adopting a solution that doesn’t compromise on the hub’s anonymity and makes a trade-off with increased latency of the channel management messages. We use Tor’s hidden services to avoid compromising the hub’s anonymity.

Miners will run a Tor hidden service next to their mining controller. Once the service is ready, miners include their service’s public key in their share headers.

The hub can then communicate anonymously with the miners to create payment channels and to update the payment channels. The hub also publishes a well known public key on a publicly accessible location like a github repository or an IRC channel. The hub then participates in the shares broadcast p2p network and identifies a new miner along with the new miner’s hidden service address. Once the miner has mined for a certain time period, the hub contacts the miner to set up the payment channels. The hub signs all their messages using their well known public key.

To send payouts as channel state updates, the hub sends the updates to all miners using their hidden service address. The hub sends all miners the updates to all payment channels, allowing the miner who discovered a block to verify that the hub has paid everyone, before it sends the channel update transaction to the hub as described in Section 5.4.

## 6 Future Work

We have not covered the goal of providing tools for building hashrate futures markets in this paper. The initial ideas for the same are captured in a gist<sup>1</sup>. Further, Taproot provides other possibilities for enabling trading of shares published on a p2p network of miners.

## 7 Conclusion

We propose a new decentralised mining pool for Bitcoin that enables miners to build their own blocks and doesn’t increase the variance nor the blockspace required for payouts as the mining pool grows.

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