Resource Control in P2P Cryptocurrency Networks

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Abstract

For decentralised P2P networks, it is very important to have a mechanism in place that allows the nodes to control resource usage and prevent flooding and denial-of-service attacks with spam. In this paper, we discuss and compare the different approaches to fully decentralised resource control that are used by projects in the cryptocurrency space. The introduced methods are then applied to design a decentralised exchange for Namecoin names (or more generally, crypto assets) as an example.

Keywords: P2P Network, Resource Control, Cryptocurrency, Transaction Fees, Namecoin, Decentralised Exchange

1 Introduction

The launch of the Bitcoin network [14] in 2009 fuelled the interest in decentralised P2P networks. It also enabled such networks for the first time to work with money and, more generally, value. This made them suitable for an entire field of new applications that is to date still being explored. The fundamental property of many of these networks is that they lack any kind of central point of failure, and enable or even encourage every network participant to "verify and not trust". But this also means that it is much harder if not impossible by design to split any processing load of the network. Instead, typically every node retrieves and verifies all information, based on a gossip protocol [13]. Therefore, it is vitally important to restrict the load on the network to such levels that every node can process and handle all data; especially so if it is desired that "ordinary users" can run nodes on commodity hardware at home. (This issue was central to the block-size debate [7], that paralysed the Bitcoin community for quite some time.)

In this paper, we want to review and compare various approaches that can be used to limit the amount of data sent to and processed by P2P networks that either directly underpin a cryptocurrency or provide additional services based on one (like a decentralised cryptocurrency and asset exchange). While the methods discussed are not new and already employed by existing projects in the field, we are not aware of any previous work that collects and compares all of these approaches.

Below, we first discuss the exact goal we want to achieve with any of the data-limitation methods in Section 2. We also introduce basic properties of such methods in that section, which will serve as the basis for comparisons between approaches. In Section 3 and Section 4, we introduce the various methods grouped broadly into "fee-based" and "identity-based" approaches, respectively. To conclude this paper, we apply our results to design a decentralised exchange for names on the Namecoin blockchain [2] as an example (see Section 5).

2 The Goal and Basic Properties of Resource Control

For all methods discussed in the following, our goal is always to enforce an upper limit to the usage of some network resource like node bandwidth, processing power, memory usage or disk space. In other words, while concepts like a minimum transaction fee (see also Subsection 3.1) are useful to this end, we

will never explicitly try to enforce a certain transaction fee as the primary goal. Instead, the fee paid by transactions can be used as a tool to order transactions by their importance and discard those that do not fit into the resource limit anymore (through the emergence of a fee market).

In Bitcoin itself, the primary limit is the *block size*. Transaction fees are used by miners to decide which transactions to put into the scarce space in a block and which to delay. The minimum fee itself is dynamic, though, and depends on the current demand for the existing supply of block space. Similarly, nodes can decide to relay only transactions that pay a high-enough fee if they run low on available network bandwidth, and they discard the lowest-fee transactions from their mempool if its memory usage is too large.

In this context, the actual transaction fee serves as a "knob" that can be controlled to achieve the primary goal (reduction in the number of transactions until they fit into a block). All data-limiting methods must have such a knob, but its exact nature can vary. This is the first important property that we can use in the following to classify the different approaches. In addition, we will use the following two properties for our comparison:

Blockchain Usage As blockchains have inherent scalability limits, block space is a particularly scarce and expensive resource. Thus it is important whether the method used to limit data on some P2P network needs to store data on a blockchain, and if it does, whether this data usage is the primary goal of the P2P network anyway (e.g. Bitcoin transactions) or an additional cost that is a consequence of the data-limiting method (e.g. paying a fee in bitcoin for data sent on a second network, see Subsection 3.2).

Economic Efficiency To ensure that the network resources are allocated to the most important uses, it should be possible for any user to have their data prioritised if they are willing to pay enough for it (in some way, not necessarily as a direct transaction fee). For instance, if the requirement is to "just" pay a certain fee then this is the case; but if a new user has to be a member of the P2P network for a month before they are able to send their data, then the mechanism is not economically efficient.

3 Methods Based on Transaction Fees

Let us now start to discuss different approaches for limiting data usage in detail. In this section, we will look at the first big group of methods: Those based in some sense on a *fee paid per operation* on the P2P network.

3.1 Direct Fees

For networks that have their own cryptocurrency (i.e. cryptocurrency networks themselves), the most straight-forward way to control the number of transactions is by imposing a *direct fee*. In other words, transactions are required to pay a certain amount F of the network's internal cryptocurrency in order to be considered for processing. This payment is typically received by miners to incentivise them for confirming a transaction, but it could of course also be paid to the network's operator, a development fund or burnt.

This approach is used in most cryptocurrency networks, including Bitcoin and Ethereum [6]. Since the size s of a transaction in bytes is an important metric approximating the "overall resource usage" (in particular, space used in the ever-growing blockchain), the fee rate f = F/s can be used to order transactions by importance. Miners on the Bitcoin network typically choose the highest-paying transactions to be included in the available block space, and nodes can use the fee rate to decide which transactions to relay and keep in their mempool if they run low on network bandwidth and memory, respectively.

Of course, the transaction size s is not the only relevant metric that can be used as basis for the computation of a relative fee. Ethereum uses the estimated cost of execution for a transaction, expressed in terms of gas. For Bitcoin itself, it has been suggested to make the size of the UTXO set more important rather than using just the pure transaction size (see, for instance, [10]). So the actual quantity used to describe the cost of a transaction to the network can be chosen depending on the particulars.

The additional impact that direct fees as control mechanism have on the blockchain size is limited: They are applicable only for transactions on the cryptocurrency network itself, which need to be stored on the blockchain already. So the additional cost incurred due to the fee payment is often negligible, especially if fees are "implicit" as is the case for Bitcoin (where not even an additional transaction output is needed for the fee).

Direct fee payments also ensure that resource control is economically efficient, since a sufficiently large monetary payment is all that is needed to prioritise one's transactions; this means that it is easy for everyone to do so as long as there is enough economic value in the transaction to outweigh the fee.

3.2 Indirect Fees

For P2P networks that are not a cryptocurrency themselves, one can still utilise the currency of another network to pay fees; we call this approach indirect fees. Roughly speaking, to send some message X on the primary P2P network, a user has to also send a transaction T on a secondary cryptocurrency network. T has to pay a fee in the second network's native currency; as with a direct fee, this payment can go to miners, the network operator / developer, or be burnt. Furthermore, T has to reference X somehow, to prove that the fee being paid is meant for X and to ensure that a single fee payment cannot be used for multiple messages on the primary network. If Bitcoin is used as secondary network, then T could, for instance, include a hash of X in an OP_RETURN output; see [16] for a thorough summary of all the available methods to store data in Bitcoin (those are mostly applicable to other cryptocurrencies as well).

An indirect fee is used, for instance, to control the number of offers made on the Bisq P2P bitcoin exchange [11]. In order to be allowed to broadcast an offer on the Bisq P2P network, one has to first create a transaction on the Bitcoin network that pays the required offer fee.

Using an indirect fee makes it possible to use fee-based resource control in P2P networks that do not have a native cryptocurrency themselves. The drawback, however, is that it requires two transactions to be made; this means that it puts strain on the secondary cryptocurrency network as well as the primary P2P network and requires blockchain space for the fee transactions which would not be necessary otherwise. This means, in particular, that a user has to pay an additional transaction fee on the secondary network just for paying the fee on the primary one. For instance, during the usage spike on the Bitcoin network that occurred in late 2017, the transaction fees necessary to pay the Bisq maker fee were orders of magnitude larger than the actual Bisq fee itself.

Despite being quite inefficient and costly in that respect, this approach has a distinct advantage over "fee-less" methods (like the ones discussed later in Section 4): It is possible to use the fee requirement not just to control resources on the P2P network, but also to fund development or network operations through the fees. Bisq uses the fees to pay for its arbitration system, such that a fee-less method could not be used.

As with a direct fee payment, an indirect fee is economically efficient—it allows anyone who sees enough value in a transaction to pay for it, assuming that the cryptocurrency that is used for fee payment is widely available and liquid.

3.3 Hashcash

Hashcash [4] is an approach that was initially introduced to combat email spam by requiring senders of emails to perform a proof-of-work for each message. It also serves as one important building block for Bitcoin itself. True to the original intention of preventing spam, Hashcash can be used to control resource usage in P2P networks. This is how it works on a high level:

Suppose Alice wants to send a message X to some P2P network. She then has to choose a difficulty $d \ge 1$ and find a nonce $n \in \mathbb{N}$ such that

$$H(X|d|n) \le \frac{2^b}{d}. (1)$$

Here, | denotes the concatenation operator, b is a number of bits (e.g. b=256) and H is a hash function with b-bit output (e.g. SHA-256). If we assume that H is not susceptible to preimage attacks, then the only way to find such n is by brute force. This means that Alice has to compute H on average d times to find a valid nonce n, and thus spend potentially a large amount of computation power (and electricity). Once she has found a suitable nonce, she can broadcast the tuple (X, d, n) to the P2P network.

Bob, who operates a node on the network, now verifies that (1) holds for each message the node receives. This can be done very cheaply, since only one application of H has to be computed per message (independent of d). As resource usage increases for his node, he can set a difficulty target \underline{d} and only process messages that have $d \geq \underline{d}$ —this gives him a knob that can be used to control the load on his node.

This is the basic method used in Bitcoin's PoW consensus mechanism. It can, however, also be used in practice for the original purpose of controlling spam. See [4] for a list of applications in that spirit; more recently, it has also been used to control P2P network traffic on the Bitmessage network [17].

One specific property Hashcash for controlling messages in a P2P network is that it is independent of any cryptocurrency. A Hashcash PoW can be verified simply by checking (1). Thus it is very simple to implement, and it does not use any space in a blockchain nor require transaction fees to be paid for that space.

The main disadvantage, on the other hand, is that computation of a valid PoW may not be easily doable for ordinary users. If the threshold \underline{d} is low enough to make it feasible to solve (1) on a typical user's computer, then it is likely very cheap to flood the network with messages using mining rigs with many GPUs or by renting computation power at some cloud provider. Conversely, if the threshold \underline{d} is high enough to prevent this, then PoW's can only be computed by high-end GPUs or the likes. Users without such hardware can of course pay someone else to solve the PoW for them, similar to how Bitcoin miners "rent out" their computational power to a mining pool. But this adds at least another layer of complexity in the ecosystem, and such a "market for PoW's" may not exist or not be very efficient. Thus, Hashcash as a method to control resource usage has limited economic efficiency.

3.4 Coinage

In Bitcoin and similar cryptocurrencies, the concept of destroyed coinage can be defined: For a transaction spending k outputs with values v_i and ages a_i , i = 1, ..., k, it is

$$c_{\rm tx} = \sum_{i=1}^k v_i a_i.$$

In this context, the *age* of an output is the difference between the timestamps of the spending transaction and the previous transaction (which created the output).

The maximal theoretical value of c_{tx} at any time is the coinage of the full UTXO set,

$$c_{\mathbf{u}} = \sum_{i=1}^{K} v_i a_i,$$

where K is now the number of all unspent outputs. This has the interesting property that its time derivative

$$\dot{c}_{\mathbf{u}} = \sum_{i=1}^{K} v_i \dot{a}_i = \sum_{i=1}^{K} v_i \le M$$

is equal to the amount of money currently in the UTXO set and thus strictly bounded from above by the money supply (e.g. M = 21,000,000 for Bitcoin).

Because of this, the "available" coinage grows at a limited rate. Thus, instead of requiring a monetary transaction fee, one can instead require that each transaction must destroy a certain amount of coinage to limit the total transaction rate. This means that coinage can effectively prevent spam attacks while allowing non-spamming users to send transactions for free (if they are willing to wait long enough): If we denote the network's capacity (transactions per second) by C, then a user holding m coins can collect enough coinage to send a transaction after $M/(m \cdot C)$ seconds on average; the only potential way in which an attacker can flood the network and prevent this is by using up previously collected coinage, and thus not sustainable.

This upper bound on the "cost" of a transaction is unlike systems based on a real fee similar to Bitcoin: There, miners can in theory spend their earned transaction fees immediately again to send more transactions, driving up the transaction fee in an almost unlimited way. (Since each coin can still be spent only once in a single block, there is a theoretical limit also here. But it is much higher.) With

coinage, legitimate users can gain an advantage over such an attacker by waiting longer before spending their coins again (which is the typical behaviour for non-spamming users anyway).

Bitcoin previously used a coinage-based system to allocate some part of the available block space and allowed "priority transactions" for free. This was removed for version 0.15, though (in pull request #9,602), where it switched to transaction ordering based purely on their fee. Coinage is also the basis for proof-of-stake consensus methods, as pioneered by Peercoin [12].

From the point of view of blockchain-space usage, coinage-based systems for resource control work similar to fees: They can be applied quite efficiently for cryptocurrency networks themselves, where transactions are sent anyway. But to apply them to non-currency P2P networks, a secondary transaction on a cryptocurrency network has to be created to "spend" the coinage.

Coinage is, however, not very efficient economically: If someone does not yet have accumulated coinage to spend, they are forced to wait and collect some before they can send a message; even if they are willing to pay, they cannot override this mechanism. The only potential solution would be a market for coinage (similar to Hashcash PoW's as described in Subsection 3.3 above); but the feasibility of this depends on the actual method in which coinage has to be spent, and it is likely hard to build an efficient market.

4 Methods Based on Identities

The second class of methods that can be used to control resource usage are not based on "per-message fees" but on the concept of *identities*: Each "real user" of the network is granted a certain quota of messages they may send. If there is too much load on the network, then this quota is reduced; and if it is already quite low (e.g. only one message per user per hour), then the criteria for who is considered a "real user" can be made stricter.

While this approach may sound straight-forward and intuitive (matching perhaps how one would naively design anti-spam measures in a network), the crux is of course in the definition of "real users"—particularly in a decentralised setting. In the following subsections, we will discuss several ways to do this; some that won't work in a fully decentralised network and some that will.

4.1 Real-Life Identities and IP Addresses

Perhaps the most naive way to define real users (as opposed to spam bots and attackers) is through real-life identities, i.e. by "one real person, one user". But this is, of course, impossible to do in a decentralised setting. It would require measures like verification of identity documents to determine who is a real person, or at least verification of email addresses. But in a P2P network without any trusted, central instance, this is not possible to do. (Furthermore, many decentralised P2P networks aim at least somewhat to increase user privacy—while an identity verification would be diametrically opposed to this goal.)

Another, related option is to assign network quota per IP address. This does not pose the same privacy problems, and if each node accounts the per-IP quota it allows by itself, this works without a central instance. However, it is still possible for attackers to gain access to many IP addresses and run Sybil attacks with them. This problem is also mentioned by Satoshi in the Bitcoin whitepaper [14], where he proposes proof-of-work to change "one IP address, one vote" into "one CPU, one vote". Thus, IP addresses are also not a viable and robust solution to control resource usage in a fully decentralised setting.

4.2 CAPTCHAs

A common approach to tell "real users" and "bots" apart in centralised systems is the use of CAPTCHAS. Hence it is natural that the idea of using them in decentralised cryptocurrencies is suggested from time to time, e.g. in [9]. This, however, can also not work in a fully decentralised network: There has to be some instance that creates the CAPTCHAS and thus knows the solution; and this has to be some trusted node, otherwise an attacker can create the CAPTCHAS to solve themselves or otherwise trick the system.

The project that to our knowledge came closest to using a "CAPTCHA-like" system in a cryptocurrency-setting is Motocoin [18]. This is a cryptocurrency that uses "proof-of-play" to reach consensus: Instead of computing partial hash collisions with hardware, users solve a puzzle game (set as a motorcycle video game) and submit their winning sequence of moves as proof. (This is very similar to how Section 2.4 of [3] uses the analogy of solving Sudoku puzzles to explain how Bitcoin mining works.) However, while Motocoin was a fascinating, innovative and pioneering project, it ended up being overrun by bots that could solve the puzzle more efficiently than humans (mainly by exploiting a loophole in the way in which the puzzles were created). Thus, also this approach cannot work in practice; and even if a puzzle could be found that only humans and not bots can solve, it would still not be practical to require every user of a P2P network to learn how to play some puzzle game.

4.3 Scarce Virtual Identities

Since real-world identities won't work, we can try for virtual identities (pseudonyms in a broad sense). For instance, Bitcoin addresses can be used as a "cryptographic identity". Of course, that by itself is also not helpful, as anyone can cheaply generate as many addresses as they wish. What we really need are virtual identities that are also scarce and/or expensive to create.

One way to create such "expensive identities" is through a technique called *proof-of-burn*: With Bitcoin and other cryptocurrencies, it is possible to *provably destroy* coins (e.g. by sending them to OP_RETURN or an address for which no private key can exist). To give weight to a pseudonym or cryptographic key that is used as their identity, a user can issue one (or multiple) such burn transactions that reference the pseudonym. This way, the user has to pay real money to create identities, and can thus not (cheaply) create many. Each node in a P2P network can then verify the burn transactions and grant the corresponding identity a certain quota of messages it processes. (A process very similar to this is used by OpenBazaar to associate reputation to pseudonymous identities, see [15].) The amount of coins that are burnt for any one identity can be used to further control resource usage, by requiring a larger amount (thus restricting the set of valid identities) if resources get scarce.

A related technique is the use of unspent transaction outputs (UTXOs) to create scarcity. (This is less severe, as it does not require the actual destruction of coins.) The basic idea here is that unspent transaction outputs in Bitcoin or another cryptocurrency are scarce by design, at least if they are required to have a certain minimum value m. In that case, at most M/m such outputs can ever exist at any one time, where M is the maximum available money supply. Thus, by simply proving that one owns a suitable UTXO, one can claim quota to send messages in a P2P network. When that quota is no longer needed, the output can be spent, so that it does not cost any actual coins (but still allows the P2P network to control resource limits). This approach is used, for instance, to reduce potential spying [8] in JoinMarket [5].

Both of these related methods require the usage of a secondary cryptocurrency, but can still be implemented for primary P2P networks that are not currencies themselves. To create a proof-of-burn or UTXO, a transaction with associated blockchain usage and fees has to be sent; however, the resulting scarce virtual identity can be used afterwards for an arbitrary amount of time and number of messages on the primary P2P network, so that no *per-message* fee or blockchain usage is incurred. This is a big advantage of this method compared to those from Section 3. Since all that is required is a one-time payment or just the ownership of coins, these methods are economically efficient.

5 Example: A Decentralised Exchange for Namecoin Names

Namecoin [2] is a decentralised name-value storage based on Bitcoin's protocol (and source code). It allows its users to register human-readable names and associate values to them. Blockchain consensus is used to establish who was the first to register a name and thus who is the owner. While everyone can read values associated to names, only the owner can change them—this allows for the creation of a decentralised DNS, among other potential applications.

The owner can also change ownership of a name to an arbitrary Namecoin address, which either belongs to him as well or someone else. This allows to build *exchanges*, where users can trade their names with each other. In this section, we will discuss a hypothetical fully decentralised P2P exchange

for Namecoin names. Of course, the focus in the context of this paper will be on the mechanism to control resource usage and prevent abusive spam.

5.1 Atomic Name Trading

Namecoin transactions, including those that change ownership of a name, have the same format as transactions in Bitcoin: The spend one or more inputs and create one or more outputs. If a name is changed in the transaction as well, then one input-output pair is added in addition, which tracks the name in the same way (with a signature of the previous owner in the input to authorise the change and the new data in the output).

Due to this structure, one can quite easily trade names for namecoins *atomically*, i.e. in a single transaction. This makes it safe to do in a trustless manner, since either both the name and the corresponding payment are transferred or none are.

Let's assume that Bob wants to buy a name like d/bob from Sally for 100 NMC, and that they already negotiated and agreed on the deal. To finalise the transfer as an *atomic name trade*, the following steps are performed (see also [1]):

- 1. Bob prepares a Namecoin transaction that has coins from his wallet as well as d/bob as inputs. In the outputs, 100 NMC are sent to Sally's address, change is sent back to Bob, and the name is updated to list Bob as owner.
- 2. After creating the transaction, Bob signs the inputs that he owns, i.e. the inputs holding namecoins. The partially signed transaction is sent to Sally.
- 3. Sally verifies the transaction to make sure it corresponds to the negotiated deal. If all is fine, she signs the name input and broadcasts the fully signed transaction to the Namecoin network.
- 4. As soon as the transaction is confirmed, the trade has been completed. If the transaction does not get confirmed for any reason (e.g. one of the parties performs a double spend), then *none* of the transfers happen.

5.2 Brokering Trades with a P2P Network

So far, atomic name trading as described in Subsection 5.1 is only one part of a name exchange: We also need a way to broker trades between parties that are not yet in contact (or even aware of each other). For this, we can use a gossip P2P network to exchange offers. It could work like this:

- 1. Sally and everyone else who want to sell a name send a message through the network, announcing their offer: Which name they want to sell, what the asking price is and their Namecoin address to receive the payment, at a minimum. To prevent false offers, she has to sign her offer with the private key corresponding to the Namecoin address that currently owns the name.
- 2. Each node in the exchange network keeps track of the currently active offers and can show them to the user through some UI.
- 3. Bob and others can browse through the offers on their node. When he finds an offer that he wants to take, he prepares the partially signed transaction as described above and sends it again through the network.
- 4. Sally receives Bob's offer and potentially other offers as well on her P2P node. She can now pick the one she prefers (if any), sign her part and broadcast it to the Namecoin network.

This design is quite simple; however, one of the main issues that still need to be addressed is *how* to prevent flooding the network with spam offers. Let us now discuss which of the methods for resource control that were introduced before can be used in this situation.

First, let us consider fee-based methods as in Section 3: A direct fee is not applicable, since the exchange network is not a cryptocurrency itself. An indirect fee could be used similar to how it is done in Bisq, but that is wasteful and costly as it requires each offer to be accompanied by a Namecoin transaction. Similarly, coinage-based resource limits would also require separate Namecoin transactions

and are thus also not a good idea. Hashcash could be used similar to Bitmessage, but that has its own drawbacks (see Subsection 3.3). So none of the fee-based methods are really suitable here.

We can, however, very well use a method based on scarce virtual identities (see Subsection 4.3). In fact, both sellers and buyers have already a "scarce identity" based on an UTXO: For the seller, the name's current output can act as such; for the buyer, the transaction inputs paying the name's price. So a very simple way to limit the rate of offers in the network is to give each name and each Namecoin UTXO of a certain minimum size (e.g. 1 NMC) permission to send one offer (or partially signed transaction) to the network per hour (or day). Each of the network's nodes tracks the quota for itself, and prohibits messages that go over it. A rate limit like this will not impact legitimate users of the exchange at all, but immediately prevent spamming as UTXOs are limited. If that is not enough, then nodes can increase the minimum size of UTXOs they require to further limit the rate of messages they process.

6 Conclusion

In this paper, we have introduced different methods that are used in existing cryptocurrency (and cryptocurrency-related) P2P networks to limit resource usage and prevent flooding attacks. These methods have different properties, so that they are suitable in different situations. Table 1 is a summary of our comparison.

For cryptocurrencies themselves, direct fees (as used by the major networks) are a good and straightforward method to limit the number of transactions that are processed. For networks that are not a cryptocurrency it gets more complicated: In that case, usage of an explicit fee introduces the need to pay the fee on another network in a separate transaction, which adds *extra* blockchain usage and costs. For those networks, methods based on scarce virtual identities as discussed in Subsection 4.3 can make a lot of sense.

To showcase the methods on an example, we designed a P2P network that can be used as a decentralised exchange for Namecoin names. In that situation, we found that the usage of scarce identities based on UTXOs makes the most sense, as UTXOs are already directly involved in the name trading process. While this example is mainly intended to compare the different methods, we believe that such a decentralised name exchange could also be useful to build in practice; furthermore, the design can be easily adapted to build, for instance, a more general decentralised exchange for cryptocurrency assets.

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| Method | Class | Controlling Quantity | Currency | Non-Currency | Blockchain Usage | Economic Efficiency |
|--------------------|----------------|----------------------------|----------|--------------|------------------|---------------------|
| Direct Fee | Fee-Based | Relative Fee | ✓ | X | Yes | Yes |
| Indirect Fee | Fee-Based | Relative Fee | X | ✓ | Additional | Yes |
| Hashcash | Fee-Based | PoW Difficulty | ✓ | ✓ | No | Limited |
| Coinage (direct) | Fee-Based | Relative Destroyed Coinage | ✓ | X | Yes | No |
| Coinage (indirect) | Fee-Based | Relative Destroyed Coinage | X | ✓ | Additional | No |
| Proof-of-Burn | Identity-Based | Quota, Burnt Amount | ✓ | ✓ | Only Setup | Yes |
| UTXO | Identity Based | Quota, UTXO Amount | ✓ | ✓ | Only Setup | Yes |

Table 1: Comparison of the different methods introduced in Section 3 and Section 4.

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