The Celo Protocol: A Multi-Asset Cryptographic Protocol for Decentralized Social Payments

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Abstract

Two of the biggest barriers to the large-scale adoption of cryptocurrencies as a means of payment are ease-of-use and purchasing-power volatility. We introduce the Celo protocol, a protocol that addresses these issues with an address-based encryption scheme and a stable-value asset. We show how these attributes together can be used to foster a monetary ecology that includes global reference currencies, local and regional stable-value currencies, and a social dividend. Our first application is a social payments system centered around mobile phones.

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1 Introduction

Cryptocurrencies have several advantages to fiat currencies as a means of payment. They enable transfer of value that is much faster than a bank wire, at lower cost (especially for international payments), in a publicly auditable and secure manner, using a technology that is globally accessible so long as you have a smartphone. Further, cryptocurrencies can be programmed; allowing financial contracts, escrow, and insurance, all without intermediaries.

However, at the moment, there are several barriers to the mainstream adoption of cryptocurrencies as a means of payment. First, due to deterministic supply rules and unpredictable coin demand, successful coins[1] experience deflationary price instability. As a result, users rationally prefer to use them as a store of value rather than a medium of exchange. Second, even when people do wish to use price-volatile cryptocurrencies as a means of payment, they need to generate a private/public key pair to receive a payment, and enter in somebody's public key in order to send a payment. While these may seem small obstacles, experience has shown that small differences in user experience lead to large differences in usage outcomes.

For a cryptographic social payments system to prosper, sending a payment should be as easy as sending a text message, and the volatility of the currency should be minimal. We describe the Celo protocol, a protocol that addresses each of these issues. To address ease of sending payments, the Celo protocol introduces a cryptographic scheme that we call address-based encryption, in which participants verify a series of cell-phone number-to-public-key mappings, allowing users to then use their friends' cell phone numbers as public keys.

To address stability of value, the Celo protocol introduces an asset whose value is stabilized using a monetary policy with elastic supply rules, backed by a variable-value reserve. Further, it introduces a governance structure that allows the protocol to create a family of local, regional, and utility stable-value currencies, where the introduction of new successful stable-value coins to the family strengthens the stability characteristics of the existing coins.

Finally, the Celo protocol introduces a mobile block reward mechanism in which all users involved in transactions are also able to participate in verifications, creating a broad participant base and making block rewards more accessible to day-to-day users.

Together, these underpin a compelling social payments protocol.

2 Ease of Use through Lightweight Identity

An important obstacle for the mainstream adoption of cryptocurrencies as a means of payment is the lack of intuitive, decentralized public key infrastructures. As a result, in order to send a payment in today's decentralized systems, users must know the public key of the intended recipient (unless they are operating through a centralized gateway). And in order to receive a payment, a user must first set up a private/public keypair and broadcast it. It would be far easier to send a payment directly to an email address or phone number, and to be able to receive a payment without having to first set up a wallet.

Identity-based encryption [18] holds promise towards this end. In this scheme, when Alice wants to send an encrypted message to Bob at bob@company.com, she can simply use the public key string bob@company.com, without needing to obtain Bob's public key certificate. While a cryptocurrency system based on identity-based encryption would lead to a much more seamless user experience, both the original proposal and subsequent implementations [4, 6] are hindered by the fact that they require a trusted third party, called a private-key generator, to generate private keys. As a result, these schemes are less useful in open, permissionless systems.

[1] Academics, regulators, entrepreneurs and others use "coin" and "token" interchangeably to describe assets that function as a digital representation of value native to a distributed ledger. In this paper, we refer to 'digital assets,' 'coins,' 'cryptocurrencies' and 'tokens' with general interchangeability.

2.1 Address-Based Encryption

We propose a variant on identity-based encryption, called address-based encryption. Rather than directly using an e-mail address or phone number as a public key, and then relying on a trusted private-key generator to generate a corresponding private key, we have users generate their own private/public key pair in the traditional manner. The user then registers their public key in a public, append-only database that stores `[address -> public key]` tuples. This database is functionally decentralized, so that no central owner is responsible for storing, managing, or maintaining the database, but logically unified, so that everybody can at any time see all the entries in the database. Crucially, the `[address -> public key]` tuples are attested to by a peer-to-peer network. To perform attestation, randomly selected validators in the network send a signed and secure message to the registrant, who then signs the message with her private key and returns it to an Attestations smart contract. The Attestations contract checks that the validator did indeed send the message, and that the signature matches the public key of the recipient.

This protocol works not just with email addresses, but with any channel to which a secure message can be sent, for example, a cell phone number, an IP address, or even a bank routing and account number. Further, arbitrary strings may be appended to the address in the database key, allowing multiple public keys to be stored for each address, each for a different application. As a consequence, the encryption scheme supports a large number of cryptographic applications, from two-factor authentication to decentralized social networks, without relying on trusted third-parties.

For the social payments use case, it allows for two important features. First, a user can send Celo currencies to a friend by using her phone number as the public key, allowing easy payments to contacts. Second, a user can send Celo currencies to a friend even if the friend has not yet downloaded a Celo wallet.

2.1.1 Single-Node Address-Based Encryption

For the purposes of explanation, we begin by describing a simplified version of the address-based encryption scheme in which a single node, called a validator node, maintains the state of the system.

The key role of the validator node is to maintain a public, append-only database of `[address -> public key]` mappings. In the single node case, the validator node is similar to a traditional key server except that it not only stores the `[address -> public key]` mappings, but also attests to them as follows:

When a user wishes to register a public key with the scheme, they generate a private/public key pair, and then submit their `[address -> public key]` mapping to the validator node. (In our use case, the address is the cell phone number of the user, but in the general case it could be any address to which a secret message can be sent.) The validator node sends a signed secret message to the address in the entry. The user then sends that message to an Attestations smart contract, which verifies both signatures by decrypting them with the public keys of the user and the validator. If the decrypted message matches the secret message, the smart contract writes the following entry to the database `[address, user public key, secret message, user signed secret message, validator signature]`.

2.1.2 Drawbacks

This simplified version has the following drawbacks:

Address harvesting. A publicly viewable database with unencrypted phone numbers allows spammers to harvest the cell phone numbers of all of the users. To address this, we can store a one-way hash of the address rather than the address itself. To increase the entropy of the underlying string (to make reversing the hash more difficult) we may append a pepper to the string to be hashed[2].

[2]Even with an appended pepper, the following scenario is possible: a spammer one-way hashes every possible 10 digit number along with every possible pepper, and then checks to see which hashed values are in the database. However, harvesting at high cost is possible even today, by taking every possible 10 digit number, sending an SMS to each, and seeing if it goes through. Therefore, our goal would be to make the effective cost of decryption more expensive than the cost of sending a bulk SMS.

Single key per address. In practice, people may want to store multiple public keys associated with their address. The simplified protocol gives no mechanism to do so. As a solution to this, we can allow the key to be the hash of an address concatenated with an optional arbitrary string. This allows, for example, Bob to store an application key at `hash(“4155551212 || application_name”)`, or an ephemeral application key at `hash(“4155551212 || application_name || 20171117”)`.

Node failure. Any model that relies on a single node to maintain state is susceptible to that node failing. We can address this by having multiple nodes participate in maintaining the state. (In doing so, we must also ensure that only a small number of nodes send a secret message to a user issuing a attestation request, to avoid overloading the user.) In this model, the secret message must also be verifiable by other validators, even if they did not construct it. This is achieved by signing the message with the private key of the validator sending it. To avoid repeat-attacks, each message from the same validator must be unique.

Malicious Validator. A malicious validator node may choose to bypass the message/response step, and instead, write an entry to the ledger in which they choose somebody else's address, generate their own key pair for that address, and then sign the secret message with the private key that they generated. Doing so allows the validator to spoof an address, claiming payments intended for somebody else. We can address this by requiring consensus between multiple validators who have no mechanism to collude.

Transaction Transparency. If we are using hashed phone numbers as public keys, then a traditional bitcoin-style blockchain will allow a user to see the transactions of the contacts in their address book. We can address this by implementing the computationally efficient version of zk-snarks as described in [12].

DDoS. Finally, a malicious user may submit thousands of bogus requests to the validator, both tying up the validator and effectively using the validator as a spam agent. We can mitigate this by introducing a cost to attestation.

2.1.3 Distributed Scheme

We introduce here a distributed scheme that introduces each of the features suggested above. In this scheme, rather than the single validator node we describe in Section 2.1.1, a peer-to-peer network of multiple validator nodes maintains the database. The network is open and permissionless; anybody may join as a validator, and validators may leave and rejoin the network at will. Each validator maintains a full copy of the attestation pending queue and attested user database. For each attestation request, validators are chosen at random to handle the attestation.

An attestation workflow would then look like this. First, a user will issue an attestation request by sending the request to the Attestations smart contract, along with an attestation fee. The Attestations contract then selects a validator at random from the validator set and generates a message for the validator; the validator then signs that message, sends it to the registrant, who also signs it and sends it back to the Attestations contract. The Attestations contract then verifies the signatures of the registrant and the validator, and if they match, then records the attestation. Most dapps will require multiple attestations, in which case, if there are not enough attestations recorded on the chain, they will simply request more.

Having multiple validators addresses the node failure issue. Requiring multiple attestations addresses the malicious validator issue. The attestation fee addresses the DDos issue. And the attestation requests are issued as a hash of the `(address | pepper | application string)`, so as to avoid address harvesting, and to allow for multiple keys per address.

2.1.4 Summary of Operations

An alternative way of framing the protocol is in describing the roles and operations allowed to each node in the system.

Any user may:

- request verification of a public key associated with her address, by broadcasting her `[hash(address | optional appended string) -> public key]` tuple to the verification pending queue

A verified user may:

- add a new public key by creating a `[hash(address | optional appended string) -> public key]` mapping
- revoke any public key associated with their address
- change any public key associated with their address

A validator may:

- compete with other validators for the right to write a block and send a secret message to the addresses on the verification pending queue, and validate the signed responses of the previous block's verifications.

Anybody may:

- look up the public key for a given address hash (or address hash || string concatenation) in the verified user database.

2.2 Aggregating Reputation Signals through Encrypted EigenTrust

Once there exists a decentralized mapping of phone numbers to public keys, it can be used to bootstrap a reputation system that helps users determine the trustworthiness of any new users they may transact with.

A person's cell phone contact list is a rough first-order proxy for a list of people in whom she has a certain level of trust. One can imagine refining this trust proxy through explicit signals (for example, a user may rate people in her contact list in an application-specific manner, or attest to whether a contact in their address book is a person or not), and implicit signals (for example, if a user makes a payment to somebody in her contact list). These signals can be maintained locally, on the user's cell phone, without sharing them with anybody else.

Such address-book based trust signals define a trust network that is both logically decentralized and functionally decentralized. No single entity stores or has visibility into the entire trust network; each user simply knows the people whom they trust, and the level to which they trust them. We describe below how to compute sybil-resistant, privacy-preserving aggregate reputation scores given this decentralized trust network.

2.2.1 EigenTrust

EigenTrust [14] is a decentralized algorithm for computing global reputation scores, given pairwise local trust scores. The key intuition behind EigenTrust is that a person's reputation score can be defined as the number of people who trust that person, weighted by their reputation scores. This recursive computation converges for all nodes to the principal eigenvector $\vec{t}$ of the trust matrix T, where T_{ij} is number between 0 and 1, and whose magnitude is proportional to the relative level that node i trusts node j[3].

In EigenTrust, the principal eigenvector of T is computed using a distributed variant of the Power Method [20]. In the context of a social payments network, it would proceed as follows: The trust network T_{ij} would be some variant of the payment network, where T_{ij} would be nonzero if node i has paid node j, and node j is in the address book of node i. Each node stores their own current t_i, and has access to the values of T_{ij} in row i and column j (the people with whom the node has interacted). The principle eigenvector $\vec{t}$ would then be computed in an iterative fashion as follows. At

[3]An alternative way to frame the problem is to compute the stationary distribution of the ergodic Markov chain described by the trust network.

each iteration, each node send across their $t_i \cdot T_{ij}$ scores to each node j that they've paid in the past. The nodes j wait to receive all of the scores from the nodes that have paid them in the past, and then compute their own t_j, and then pass their $t_j \cdot T_{jk}$ along to the nodes k that they have paid.

2.2.2 Privacy-Preserving EigenTrust through Zero-Knowledge Proofs

There are two differences between the algorithm we propose and the original EigenTrust algorithm.

First, the simplified description above allows nodes to lie about their own t_i. The original EigenTrust algorithm addresses this by relying on score managers to steward the computation of t_i for each node. In the original scheme, each node has three score managers, assigned at random through a distributed hash table, who store the T_{ij} values for each node and compute and store t_i for each node. While this addresses the dishonest node attack, it is not ideal in the social payments scenario, as it requires sharing transaction information with other peers in the network. We address this by having each peer perform the computation themselves, as per the simplified version, but also prove, to a high probability, to all adjacent nodes that they have performed the computation correctly. One can do so by constructing a zero-knowledge proof using a variety of cryptographic means, including [10, 3, 5].

2.2.3 Personalized Pre-Trusted Peers

Second, in order to break malicious cliques, and to ensure convergence of the power method and uniqueness of the principal eigenvector, EigenTrust introduces the notion of pre-trusted peers, a group of peers that are active and assumed to be universally trusted. This ensures that the graph is acyclic and strongly connected (and that the matrix is irreducible and that the problem is well-conditioned). However, it requires the system to define a set of universally trusted peers, and concentrates outsized power to confer reputation in those pre-trusted peers.

We can address this through personalization. Rather than computing a single global reputation vector, the system can compute a personalized global reputation vector for each peer, that gives the reputation score of each peer j in the network from the point of view of a single peer i. To compute personalized EigenTrust for peer i, one can simply perform a traditional EigenTrust computation, but use the contact list of peer i as the set of pre-trusted peers.

This is far more computationally expensive than a single EigenTrust computation; however, we apply many of the computation-saving techniques that enabled personalized PageRank [13] to a personalized EigenTrust computation.

2.2.4 Practical Implications

For the social payments case, in which people text money to friends, the address-based encryption scheme suffices as a lightweight identity proxy, allowing people to send money directly to people's cell phone numbers, even if they have not signed up for a wallet.

As people are interested in using the protocol to pay people outside of their direct circle of contacts, it is useful for a user to be able to aggregate the trust signals of those in their network to make purchase, payment, and credit decisions, and to mitigate bad actors.

Further, a reputation scheme as we described enables a more robust identity scheme. Most identity schemes are based on attestations from others, and it would be useful to be able to weight those attestations by the reputation score of the attestor.

3 Stabilizing Value

Perhaps the biggest hurdle to the use of cryptocurrencies as a means of payment is their volatility. Consumers are unlikely to want to buy a volatile cryptocurrency to spend it, since the purchasing power of their accounts would fluctuate widely with market demand for the currency. Merchants who accept cryptocurrencies are likely to convert to fiat upon payment, because their business model does not involve speculating on cryptocurrencies. And the most successful cryptocurrencies today are not just volatile but deflationary – their success leads to their price rising; as a result, prices denominated

in the currency fall. Rational behavior would be to use such currencies as a store of value rather than a medium of exchange, and in practice that is what has happened.

Stable-value cryptocurrencies would bring a number of benefits to the cryptocurrency ecosystem. For one, stable prices remove a considerable barrier for using cryptocurrencies as a medium-of-exchange; salaries, prices of goods, fixed obligations, can all be set in a stable value cryptocurrency without requiring either party to speculate on the future value of the currency. Further, financial contracts are more easily built with a stable value coin, because the issuer can separate the function of the contract from the price risk of the currency in which it's denominated.

While a single stable-value currency would be helpful, a thriving cryptoeconomy is best-served by a family of stable-value currencies, much as it is well-served by the family of variable-value crypto-assets that we have today. Certainly a cryptocurrency pegged to the US Dollar has several uses, from social payments in the US, to user-initiated dollarization in hyper-inflationary markets, to the efficient settlement of high-frequency crypto-asset trades. At the same time, a cryptocurrency pegged to the Euro would also be useful for many purposes, as would a cryptocurrency pegged to the price of a basket of goods in Greece, as would a cryptocurrency pegged to the price of a barrel of oil, or housing in San Francisco. Stable-value local, regional, and utility currencies allow people to hedge price risk in their lives by denominating a portion of their personal economy in currencies that are stable vis-a-vis the price of the goods they regularly use.

3.1 Elastic Coin Supply and Shifting Volatility Risk

Several protocols have been proposed for a decentralized stabilized value cryptocurrency (for example [17, 2, 1, 19]). While a full review of these proposals is outside of the scope of this paper, they generally share two properties. First, rather than a deterministic coin supply rule (in which the coin supply and growth rate are determined in advance, independent of exogenous information), they each introduce an elastic coin supply rule, that stabilizes the value of the coin by adjusting the supply of the coin to match the demand. Second, they each introduce a multi-asset ecology, in which one coin is intended to be stable, while one or more complementary crypto-assets bear the risk of a decrease in stablecoin demand (and receives a reward in the case of an increase in stablecoin demand). In essence, they each shift volatility risk from the coin holders to the complementary asset holders.

The Celo protocol utilizes the same two key intuitions, with five novel features: (a) it introduces a multi-asset tiered reserve that supports several local and regional stable value currencies, (b) it sets expansion and contraction parameters that are tuned to the reserve ratio defined by the tiered reserve, (c) it introduces a decentralized exchange in which the different local and regional currencies and the reserve currency can be traded amongst one another without a central party, and that the protocol can use to perform expansions and contractions, (d) it releases block rewards and other incentives in the reserve currency, and (e) it has a governance mechanism in which long-term stakeholders in the reserve currency are responsible for governing the assets held in reserve and the new local currencies that are introduced.

3.2 Protocol Summary

At a high level, the protocol proceeds as follows:

1. The protocol establishes a fixed supply of assets, called Celo (also referred to as the Celo native asset), a portion of which is distributed over time. From the initial asset distribution, a portion is placed in reserve and diversified.

2. The protocol also establishes a means-of-payment currency, called the Celo Dollar, that is intended to be pegged roughly to the US Dollar, that adheres to the following elastic coin supply rule:

   When coin supply needs to expand (when the price of Celo Dollar is above the peg), the protocol creates new coins, as in [17, 1, 2]. But rather than distributing them to token holders, it uses

them to purchase a basket of cryptocurrencies[4] at market rates through a smart contract. These purchases get added to the reserves. This is analogous to a central bank expanding the money supply by buying financial assets on the open market and depositing them in the reserves.

When the coin supply needs to contract, the protocol uses reserve assets to buy Celo Dollars on the open market. This is analogous to a central bank selling financial assets on the open market in order to contract the money supply.

3. The protocol has a variable rate transfer fee on Celo's native asset, to encourage long-term holding of the reserve currency. The proceeds from the fee goes to bolster the reserves, and the rate is based on the reserve ratio – the lower the reserve ratio, the higher the transfer fee.

4. The protocol uses a proof-of-stake model for governance. The weight of a node in governance decisions is dependent on the amount of Celo they stake[5]

5. Every time a block reward is distributed, an equivalent portion of Celo is released. If the reserve ratio is substantially higher than the target reserve ratio, then the released amount is largely allocated for incentives (e.g. to developers and users). If the reserve ratio is substantially lower than the target reserve ratio, the released amount goes mostly to towards bolstering the reserves.

An analysis of the stability characteristics of this protocol is given in [7].

3.3 Shared Reserves

While a single stable coin would be useful for several purposes (for example in cryptoasset trading and internet commerce), a more robust ecosystem would involve a family of local, regional, and utility stable value coins. The benefits of such a monetary ecology has been discussed broadly, for example in [9, 16, 15], but here we focus on one: a stable currency is only meaningful if it is stable vis-a-vis the price of goods and services that are purchased using that currency. Using a global currency for local transactions would introduce price volatility in regions where regional consumer price dynamics vary from the global consumer price dynamics[6].

From a protocol perspective, we are interested in two mechanisms here: (a) a governance scheme that determines how the protocol makes decisions on introducing new regional stable coins, and (b) a structure in which the introduction of a new successful stable coin increases the stability characteristics of the coins in the family.

As a starting point, we can imagine a protocol where each new stable coin is independent – there is a blockchain and reserve for each new currency introduced. In this scheme, the governance question is straightforward – teams will independently choose to introduce new stable value coins outside of the protocol, and people can choose independently to purchase the new coins and their complementary reserve assets. Governance on this issue is determined outside of the protocol, by the market.

However, this simplicity comes at a cost: the introduction of a new successful stable coin has no stabilizing effect on existing stable currencies, and on the margins it has a small destabilizing effect [7].

To address this issue, we introduce the idea of shared reserves. When the protocol introduces a new stable value coin – for example, a stablecoin pegged to the Euro – the reserves for that coin are the same reserves for Celo Dollars. When the supply of Celo Euros needs to expand, it expands using the same mechanism as with Celo Dollars – the protocol creates new Celo Euros, and uses those to purchase a basket of crypto assets for its reserves. When the supply of Celo Euros needs to contract, the protocol uses the same mechanism as before: it sells reserve assets in exchange for Celo Euros and retires the Celo Euros.

[4] Initially, the Celo native asset, and longer-term through a basket of cryptoassets via cross-chain decentralized exchanges once available

[5] future versions of the protocol could be based on amount at stake and length of time remaining in their stake.

[6] For example, with Greece and the Euro, or with dollarization in Uruguay

[7] If the demand for the new stable coin is high enough, it could potentially cause a contraction in demand for existing stable coins, reducing the value associated with the complementary assets of those existing coins, and increasing uncertainty around long-term demand of the existing coins.

The protocol can make this process more efficient in the following manner: before selling the reserves, it first looks to see if the supply of Celo Dollars needs to expand. If so, it creates Celo Dollars, exchanges them directly for Celo Euros at the prevailing exchange rate, and retires the Celo Euros. This is functionally equivalent to selling reserves in exchange for Celo Euros, retiring the Celo Euros, and then buying reserves in exchange for Celo Dollars; it just disintermediates the reserves. It only uses the reserves directly if the need for contraction of the Celo Euros is greater than the need for expansion of all the other stablecoins supported by the protocol.

A shared reserve system must come together with a thoughtful method of governing decisions on what new stable coins to introduce, and when to introduce them. If a new stablecoin is introduced that has negative utility to the ecosystem, it can have a marginal negative impact on the stability of the other currencies if the demand for that currency is high enough and volatile enough (for example, a celebrity vanity stablecoin early on), or if the coin decreases aggregate demand for other coins supported by the protocol (for example, the introduction of several duplicative regional currencies in the same region with no differentiating features, causing confusion). For this reason, it is useful to have a governance model that introduces a new stablecoin only if there is a widespread expectation that its introduction would increase the aggregate demand for the family of coins over the long run. We describe this governance model in Section 4.4.2.

It is useful to note that the shared reserve system does not require all new currencies to use the shared reserve. In fact, for local or functional currencies, there are several reasons why it would be useful to not engage in the shared-reserve model; we discuss these in Section 4.4.4. To support these currencies, we also allow for new stabilized assets to be created with their own reserve; we call this partitioned reserves. At a high level, the mechanism works in the same manner as the single stabilized asset case, except that a third party can create the asset and initiate the reserve for that asset. For the partitioned-reserve case, each reserve allocation is initialized at 25% Celo, 25% a local reserve currency, and the remainder the same allocations as the shared reserve.

3.4 Price Discovery and Mechanics of Reserve Asset Purchasing

The Celo protocol is implemented as a fork of Ethereum. The cost of computation in the Celo network is paid in Celo, just as Ether is used to pay for gas on the Ethereum network. Celo stable assets are implemented as the equivalent of ERC20 tokens. One difference between the Celo protocol and Ethereum is that while Ether itself is not compliant with the ERC20 token standard, Celo is. This allows a decentralized exchange, through smart contracts, between Celo stable value assets as well as Celo native asset, much like 0x [21]. This allows the automatic purchasing of reserves and distribution of coins without cross-chain decentralized exchanges.

To determine the price of Celo stable currencies, the protocol will use a Schelling-point scheme amongst stakeholders, with the weight of the a stakeholder's vote dependent on the amount of Celo at stake. One can imagine further augmenting the Schelling point scheme with price feeds from exchanges, as determined through a governance scheme.

4 Governance and Incentives

A primary incentive mechanism in the Celo protocol is the distribution of block rewards, which are allocated to the various contributors to the system – those who maintain the protocol (by selecting validators, validating transactions, verifying users, and participating in the Schelling-point price discovery mechanism), those who contribute to the robustness of the reserves, those who take on risk in the case that there is a contraction, those who use the protocol as their means of payment, those who invite others to use the protocol, and those who improve the protocol (by participating in governance, and by making technical contributions to the protocol). We describe these below.

4.1 Maintaining the System

The system uses a proof-of-stake mechanism for selecting the validator set and participating in governance decisions. Both validator election and governance decisions are made through a bonded-stake

weighted voting scheme. Any Celo holder may put up a bonded deposit, which involves locking Celo in a smart contract. Votes (for both validators and in governance) are weighted by the amount of Celo in the bonded deposit. Any locked Celo should continue to be locked up for a certain time period after voting, and in the future it would be helpful to weight voting by the length of time remaining in the lockup. This incentivizes long-term holding of the reserve currency and aligns governance decisions with long-term perspectives. Block rewards are distributed amongst those who participate in validator elections and governance decisions.

Users don't vote for validators directly. Instead, validators are expected to organize themselves into groups and account holders vote for these validator groups. Just as anybody in a democracy can create their own political party, or seek to get selected to represent a party in an election, any Celo user can create a validator group and add themselves to it, or ask an existing validator group to include them. Validator elections are held once every epoch, which corresponds to approximately once per day.

Validators, once elected, put up a slashable bonded deposit, participate in the consensus scheme, send verification messages, participate in the Schelling-point scheme for price discovery, and receive block rewards to cover their costs and as an incentive for their work to maintain the system.

4.2 Bolstering Reserves and Contracting Stable-Value Currency Supply when Needed

Celo holders, through their purchase, give the initial value to Celo's native asset and introduce other crypto assets into the reserves. Further, Celo holders bear some risk in the case of contracting supply or a dip in the reserves: transfer fees are imposed if the reserve ratio goes below the target reserve ratio, and the value of Celo may go down if there is a contraction in demand for Celo stable currencies. Celo holders may be rewarded for playing these roles in two ways: first, as there is greater demand for Celo stable currencies, there will be more protocol-directed purchases of Celo, increasing the demand for fixed supply. Second, if the reserve ratio is greater than the target reserve ratio, Celo holders are rewarded with a portion of the block rewards (provided that they are participating in consensus on transaction validation, sending verification messages when selected, and participating in Schelling-point voting for price discovery). These rewards are paid in proportion to the amount of Celo at stake [8].

4.3 Increasing User Base and Usage of the System

Active users (people who use the payments protocol, participate in phone number validation through the mobile wallet, and maintain a nominal stake in Celo) are rewarded through block rewards. In effect, this reduces transaction fees for active users. (One can even imagine a scenario in which these block rewards are issued by waiving transaction fees for a certain number of transactions in the stable currency per unit time, implemented through part of the block reward going to paying transaction fees of users, set at a rate to ensure a certain transaction speed, and prioritized based on the amount of their stake.)

4.4 Improving the Protocol

And finally a continuously evolving protocol requires incentives, and a governance scheme, for improving the protocol.

4.4.1 Technical Improvements

For technical improvements to the protocol, anybody may put up a bonded deposit to make a technical proposal, with a proposed fee-for-implementation, on a regular cycle[9]. Proposals will be voted on by long-term stakeholders, similar to the voting scheme with Dash's masternodes [8], with their votes weighted by the amount of their stake and notice period. Funds that are not allocated in a particular cycle are added to the reserves.

[8] and in future versions of the protocol, the time remaining in the stake

[9] This mechanism can also be applied to other types of proposals, for example for marketing proposals.

4.4.2 Introducing Regional Currencies and Broadening the Reserve Base

Over time, it would also improve the protocol to introduce more stable value currencies, and to broaden the reserve holdings. If new stable value currencies are introduced appropriately, they can increase the usefulness of the protocol, increase long-term growth in coin demand, and reduce aggregate demand volatility. And if new crypto-assets are chosen appropriately, they can decrease reserve volatility. Both of these have the effect of further stabilizing the coins supported by the protocol. The governance procedure for introducing these is similar to the governance around technical improvement.

At regular intervals, any Celo holder may stake a certain amount of Celo to make a proposal on introducing a new stable value currency (by specifying a peg). Long-term Celo holders vote in proportion to the amount of Celo they own[10]. If a certain vote threshold is passed, a new stablecoin is introduced on the shared reserve.

Similarly, any Celo holder may stake a certain amount of Celo to make a proposal on introducing a new crypto asset to the reserves (by specifying a suggested percentage of future reserve purchases to be allocated to that asset). Long-term Celo holders vote in proportion to the amount of Celo they have at stake[11]. If a certain vote threshold is passed, then future purchases for the reserves will include the new crypto-asset with an allocation given by the median percentage of all votes (with the allocation of all other assets being diluted pro-rata).

The criteria by which these proposals should be evaluated is the extent to which they would increase in the long-term stability of the stable currencies. Introductions of crypto-assets to the reserves that increase the expected appreciation of reserves and decrease the volatility of the reserves would have positive benefits to the long-term coin stability. Introductions of new stable-value coins that increase long-term aggregate coin demand and decrease the possibility of an aggregate crash in coin demand also increase the stability characteristics of the coin.

4.4.3 Futarchical Governance

It is possible that in the future, we introduce prediction markets as a supplemental form of governance – where prediction markets will also weigh in on whether a change in the composition of the reserves or the composition of stablecoin portfolio would increase or decrease long-term coin stability. It is even possible to have the prediction markets serve directly as the voting mechanism, in a futarchical governance paradigm [11]. This is a direction for future work.

4.4.4 Partitioned Reserves

The introduction of a new local currency does not need to go through the governance process if it is not backed by the shared reserve. One can introduce a new local currency backed by its own reserve, with its own affiliated local reserve currency. In these cases, the default reserve would include in its reserve a basket of diversified crypto assets that can include Celo, the local reserve currency, Celo Dollars, and others.

Doing so opens many possibilities. First, these local protocols may choose to distribute some of the local reserve currency to all local inhabitants, effectively creating a social dividend that allows local residents to benefit from the increased adoption of a local currency.

These local protocols may also choose to implement the transfer fee in a different way; rather than having the transfer fee payable in the local reserve currency when the reserve ratio is low, they may choose to bolster the reserves by issuing the fee directly on the local stable currency, at regular intervals rather than just when the reserve ratio is lower than the target reserve ratio. This implementation of demurrage has the effect of bolstering the reserves and encouraging circulation of the local means-of-payment currency, at the expense of giving people a moderate incentive to switch out of the currency when possible. Despite this drawback, the literature on demurrage (see, for example, [9, 15]) suggests that more experiments with demurrage are useful.

And finally, as more assets get tokenized in the future, the partitioned reserve mechanism allows for the reserves to include real assets. This is helpful from a stability perspective, and also allows for

[10] and in future versions of the protocol, the amount of time remaining in their stake

[11] and in future versions of the protocol, the amount of time in their notice period

natural-capital-backed means-of-payment currencies (for example, currencies backed by forestland), where the growth in demand for those currencies will increase the amount of natural capital backing them. For a detailed discussion of natural-capital-backed currencies, see [9].

5 Conclusion

We have introduced a protocol for social payments, called the Celo protocol. The Celo protocol combines an address-based encryption protocol that allows a sender to use a phone number or email address directly as a public key, with a reserve-backed stabilization protocol to minimize volatility through an elastic supply rule. Together, these allow for a more seamless experience using cryptocurrencies as a means of payment. Further, they enable a monetary ecology that includes local and regional currencies, social dividends, demurrage-charged currencies, and in the future, natural-capital-backed currencies.

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