Taler as a synthetic Central Bank Digital Currency

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Abstract

A synthetic Central Bank Digital Currency (sCBDC) is a privately issued payment instrument fully backed by central bank liabilities. GNU Taler is a token-based digital payment system that offers a range of unique features to its users, pairing ease-of-use with payment privacy and informational self-determination. As it is Free Software, any retail bank can easily adopt the technology to create an sCBDC, benefitting from its unique features and low operational costs, while receiving risk-free interest rates from central bank reserves. Our work introduces the concept and contrasts it with related payment instruments.

Keywords: self-custody, privacy, retail, sCBDC, business model

1 Introduction

This chapter will first give a definition of "tokens" inspired from their use in information security. We will then give some background on GNU Taler, the free-software [17] reference implementation of the Taler payment system, which uses digital coins, a special type of token representing fiat currency ownership. [10] Next, we elaborate on the requirements on synthetic CBDCs and how GNU Taler could be used to implement one. Finally, we will discuss the advantages and disadvantages of this approach, and compare it with existing alternatives, including so-called stablecoins and the proposed design for the Digital Euro.

2 Definitions: Tokens and Nonces

Tokens represent units of value or rights to use a resource. In information security, bearer tokens allow the "bearers", that is anyone with knowledge of the token's representation, access to certain resources. Paper tokens are commonly used to represent the value of a ride on a local public transport and stamping them grants the owner a single-use ride after which the token is void. Nonces are **n**umbers that are only used **once** in cryptographic protocols to prevent replay attacks or linkability. Tokens can also be nonces for the same reasons: the buyer of a ticket for some attraction (be it a movie, bus or rollercoaster ride) is supposed to only use the token once (no replay), but also no information should be retained that would link multiple rides to the rider's identity. Such nonce-tokens thus have a key advantage: they allows individuals to prove that they have a right to certain resources without necessarily linking these rights to a history of transactions or even their identity.

Checking one-time tokens requires validators to ensure that the token was issued by the proper authority, and has not yet been used. For digital tokens, the former is straightforward by checking if the token carries a digital signature from an acceptable authority. Preventing double-spending requires an online check at the time of the transaction with a database that either tracks the numeric values of all tokens that remain in circulation, or the numeric values of all tokens that have already been spent.

Our definition of tokens differs from the use of the term "token" as a unit of value for some non-fiat currency in the context of ERC-20 tokens [26] and similar technologies.

3 GNU Taler

GNU Taler is the Free/Libre Open Source Software (FLOSS) implementing the Taler protocol. FLOSS licenses grant their users the irrevocable right to (1) execute the software for any purpose, (2) read the source code (defined as the preferred format for making modifications), (3) make modifications to the source code and (4) to share the modified sources (and derived executables) with third parties. These conditions are necessary for informational self-determination as otherwise the owner of the software is put into a position to control the use of the software. In the context of critical infrastructures, the use of FLOSS is a decisive factor for maintaining sovereignty. [24]

The Taler protocol uses *coins* stored in wallets by their owners in self-custody. Such coins are both nonces and tokens: they are unique bit-strings, are used only in relation to a single transaction, and have a fixed value due to a digital signature. They are issued by the payment service provider called *exchange*. However, Taler coins are not random bit-strings, but have a slightly more complex token structure: Each coin is made out of a public-private key pair, where the hash of the public key is signed by the exchange. The private key is generated by the coin's owner and never disclosed to any other party. It is used to sign messages that authorize spending the coin.

When a wallet *withdraws* digital cash, they ask an exchange to digitally sign coins. Tokens are signed by the exchange in return for an incoming wire transfer from the respective customer. The wire transfer subject is used by the wallet to authenticate for the withdrawal of the corresponding amount of digital coins (Figure 1). The Taler

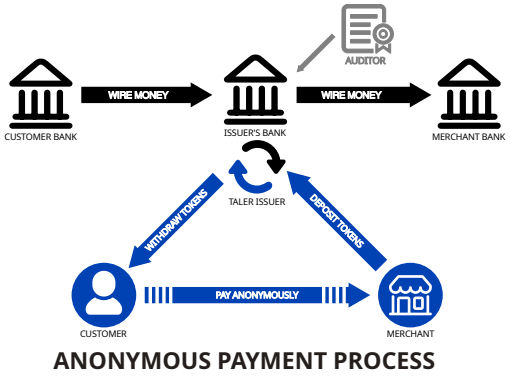

Fig. 1 Monetary flows in the Taler payment system.

protocol uses *blind signatures* [10]: Here, the wallet first *blinds* the token before sending it to the exchange to be signed. The resulting signature is then *unblinded*, resulting in a valid signature on the unblinded coin. These cryptographic operations performed by the wallet prevent the exchange from learning the unique value of the coin being signed. As a result, the exchange knows how many coins it issued, but does not know which customer has which coin. When coins are later *deposited*, the exchange can check its signature to determine that the coin is one that it issued, but it cannot link the deposited coin to the withdraw process. As a result, customers are identified when they withdraw funds, merchants are identified when they receive funds (enabling Anti-Money Laudnering (AML) compliance), but customers can privately *spend* digital cash at merchants without these purchases being linkable to their identity.

A key difficulty with simplistic approaches to tokenizing assets is the need for giving change. If tokens have a fixed value and are used only in one transaction, it is not obvious how to ensure that buyers can pay arbitrary amounts with a small number of tokens. GNU Taler's *refresh* protocol provides a mechanism to efficiently give unlinkable change [10] without negatively impacting other key properties of the protocol.

GNU Taler has shown to support more than 25'000 transactions per second on a single server with latencies dominated by a single network round-trip time with negligible costs per transaction. [3] It can be safely used by merchants that are offline and is available on a broad range of platforms (Android, Chrome, F-Droid, Firefox, iOS, Ubuntu Touch, etc.). Integrations exist for various e-commerce solutions (Adobe E-Commerce, Drupal, Joomla!, Magento, Pretix, etc.). The code for the complete system and its integrations is publicly available under FLOSS licenses from https://git.taler.net/. Taler Operations is operating the GNU Taler payment system in Switzerland. The company issues digital coins denominated in CHF in exchange for wire transfers into its escrow account. The incoming funds are kept separate from the company's own assets and the business is not legally allowed to issue loans. The bank account is with PostFinance, which is also currently excluded from the credit and mortgage business by law [25].

4 Synthetic CBDCs and other Types of Money

Money serves three basic purposes: unit of account, store of value, and medium of exchange (means of payment). While measuring the value of a certain good only needs commonly understood denominations irrespective of the concrete form of money, the extent to which the other two purposes are served may change. For most of history, money took physical forms such as coins, notes, or tangible goods, supplemented by paper-based account records. End-users would use fully anonymous cash as a means of payment and identifiable accounts as *commercial bank money* at retail banks mostly for savings and loans. Under a fractional reserve system, banks are not required to hold assets that would fully back all user deposits. Failed business strategies of retail banks, such as bad loans or investments, can thus put customer's savings at risk. Government policies often require retail bank deposits (commercial bank money) to be insured up to a certain limit, but insurance coverage is limited and state interventions are frequently used to bail out wealthy stakeholders when larger banks collapse. [20]

Regulated payment providers such as WeChat Pay, Alipay, M-Pesa or Taler Operations without banking licenses have started offering so-called *electronic money (e-money)*, where users hold a claim against the payment provider which promises convertibility at full face value to a certain (national) currency. [1] Such payment systems closely resemble traditional commercial bank accounts, including that they may only hold liquid assets sufficient to back regular net outflows with some safety margin. The key distinction between banks and e-money providers is that e-money providers are generally prohibited from giving out loans and investing in assets like stocks and equities. Furthermore, e-money, in contrast to commercial bank money, often cannot expect to benefit from government backing or deposit insurance.

Together, all such digital forms of money are increasingly displacing traditional cash controlled by the central bank, which is nevertheless presumed to anchor all of them. In face of this evolution, central banks have started investigating *Central Bank Digital Currencies (CBDCs)*: a digital form of money directly issued by a central bank instead of commercial banks or other financial intermediaries. Same as cash, a CBDC is a liability of the central bank, which entails that holders are not subject to insolvency risks of private financial institutes. Retail CBDCs, such as the envisioned Digital Euro (cf. Section 6.2), are available to the general public, i.e., private households and firms, while wholesale CBDCs are only offered to selected financial institutions, much like central bank reserves are usually only accessible to banks. [22]

Synthetic CBDCs (sCBDCs) are a middleground between these two options: Here, private financial institutions offer e-money to the general public, whose value is fully backed by the institution in central bank money (e.g., in the form of central bank reserves or a wholesale CBDC). While technically not a direct liability of the central bank [6], such money is equivalent to a CBDC for most practical matters, but has the advantage of possible competition between different operators. [1] From the perspective of asset backing, this is very similar to the concept of *narrow banks*, which back all their deposits by central bank reserves and sometimes government fonds. But while the focus of narrow banks lies on the store-of-value purpose of money, sCBDCs are rather meant to be used as a medium of exchange, as a potential competition to other forms of e-money that are backed in commercial bank money.

5 GNU Taler as sCBDC

To create an sCBDC with GNU Taler, one needs a private e-money operator who would issue digital cash of some fiat currency in return for incoming final wire transfers of the same currency. The operator would keep central bank money corresponding to the digital cash in circulation in an escrow account in the deposit facility of the respective central bank. By depositing 100% of the escrowed assets at the deposit facility, the operator would earn some modest risk-free interest from the central bank. Depending on the interest rate of the central bank, the resulting interest may even be sufficient to cover the cost of operating the payment system.[1]

However, the assets would still be at risk in cases where the operator were to go bankrupt, for example due to other business activities. To create an sCBDC that is risk-free in the same way that a CBDC would be, the operator would furthermore need to use asset segregation to ensure that the escrow account could not be used for other liabilities. Should the operator go bankrupt, GNU Taler's revocation mechanism could be used to notify wallets that their digital cash cannot be used for payments anymore. At that point, the wallets would deposit the digital cash back into each customer's bank account, erasing the remaining liability of the operator in a timely fashion. This would only reveal the remaining balance of each customer to the banking system; the transaction histories would remain private.

6 Alternative Approaches

This section discusses different forms of money that may serve a similar function as the sCBDC based on GNU Taler discussed above: Stablecoins, and the proposed design of the Digital Euro by the European Central Bank (ECB).

6.1 Stablecoins

Stablecoins are a distributed ledger-based payment instrument that is tied to assets in a fiat currency. They emerged as a variation on e-money promising to bridge highly volatile, unregulated and decentralized cryptocurrencies. In contrast to regulated e-money providers, early stablecoin operators often operated without any regard to regulation. As a result, the legal status of stablecoin assets was—and in some cases remains—unclear. [4]

Most current implementations of stablecoins use an account-based model. They are smart contracts, which define the rules for alternations of account balances on a blockchain, for example ERC20 "tokens" on the Ethereum Virtual Machine (EVM). In theory, the owner of the account can have full custody over the keys to spend money from the account. In practice, however, many users prefer the simplicity of custodial wallets where the keys are held by a fully trusted third party. In any case, there are no individual stablecoins and no tokens in the sense of our technical definition which have an inherent value.

[1] Should central bank interest rates be negative, the operator would have to charge fees including possibly holding fees from its customers. GNU Taler's *refresh fees* combined with expiration dates on coins in circulation could be used to implement a demurrage currency.

The term "stablecoin", apart from wrongly suggesting a bearer instrument similar to physical coins, also promises stability of the asset. However, many stablecoins that were said to be pegged to a fiat currency lost their "peg" after a certain amount of time. [9, 23, 27] Some stablecoin issuers have pursued and received regulatory approvals, and some, like Gemini, subsequently ran into trouble for misrepresentation of their operations towards these regulators [7].

Contemporary regulated stablecoins operations are designed like traditional e-money, often resembling a *narrow bank* [21] with a reserve made up of high-quality liquid assets, which provides stability. These regulated operations mostly distinguish themselves from traditional e-money systems by their marketing and support for integration with distributed ledgers. The key difference between an sCBDC and the operation of a stablecoin is that the latter can include government securities in its backing. Given that interest rate changes on government securities can cause these assets to rapidly lose in value, this model is thus strictly less stable for investors (but possibly more profitable for operators) than what is required for an sCBDC.

Over the history of stablecoin development, diverse sets of user groups emerged, each with distinct motivations for adopting stablecoins. Initially, stablecoin users were mostly crypto-native actors: traders, liquidity providers, and early DeFi adopters. Their motivations include the desire to hedge volatility, park liquidity between trades, and maintain assets on-chain instead of exposing them to traditional banking. Stablecoins serve as a de facto unit of account and base currency for decentralized exchanges, lending markets, and yield farming protocols [2]. This usage pattern reflects a preference for composability, and autonomy over traditional financial products.

In countries with unstable monetary systems, stablecoins became a tool to hold US dollar denominated assets without the need for a bank account. Individuals use stablecoins to preserve purchasing power, remit funds internationally, and circumvent capital controls. Particularly in regions with high inflation or limited access to foreign exchange markets, stablecoins represent a practical alternative to both local fiat currencies and formal financial institutions. Stablecoins bypassed the regulatory complexity and cost associated with foreign exchange conversions and international transfers. By easing the transfer of dollar-denominated assets globally without friction, stablecoins enable borderless payroll. Bypassing the traditional banking system also makes such income harder to trace for tax authorities and creates opportunities for tax evasion. [5]

6.2 The Digital Euro

The most prominent and obvious alternative to a synthetic CBDC is a native retail CBDC: A digital form of central bank money that could be accessed by citizens and merchants. The Digital Euro, a CBDC proposed by the European Central Bank (ECB), has been in the planning phase for several years at the time of this writing [15]. The current design consists of two parts. The offline version is based on so-called "secure hardware" which is supposed to prevent double-spending while at the same time promising transitive anonymity subject to limits enforced by the hardware. However, given that hardware security modules under physical control of an adversary

have a horrific track record [18], we predict that the offline version will not be secure and thus does not warrant further discussion.

In the online version citizens are provided with a limited bank account at the central bank administered by private payment service providers (PSPs). Different to common bank accounts, these will be interest free and subject to a holding limit which is claimed to be necessary to ensure financial stability of the contemporary commercial bank system [14], even though there are other options of mitigating the risk of bank runs [19]. The holding limit for non-business users is discussed to be around 3000 euros [13], while business users will have a holding limit of zero.

As the Digital Euro becomes legal tender, merchants will be required to accept it. This mandate may entail significant adaptation costs, as businesses will need to update their payment systems, train staff, and implement additional measures to integrate the Digital Euro into their operations. Furthermore, banks and payment service providers (PSPs) must incorporate the new currency into their existing infrastructures and applications. These adjustments represent economy-wide costs—an unintended side effect of introducing the Digital Euro.

Beyond economic considerations, concerns about privacy are prevalent among citizens. [12] Some political actors have gone so far as to suggest that the Digital Euro could become a tool of surveillance and control. Not all actors share the European Central Bank (ECB)'s self-assessment as an eternally trustworthy custodian of a central database of financial transactions of all citizens. [11] This is especially true as the current ECB design would enable linking transactions back to individuals [8]—in sharp contrast to the Taler protocol, but similar to account-based stablecoins and commercial bank money.

7 Discussion

Table 1 provides an overview of the design choices made for the different types of money discussed in this chapter. Key questions for their viability and success are (1) why citizens should put their money into the respective asset category *(demand)*, and (2) what economic incentives exist for the profitable operation of such systems *(supply)*.

The common selling point of CBDCs, sCBDCs and stablecoins is their promised value stability, either backed by central bank deposits, or government bonds and other high-liquidity assets. While several stablecoins have failed to hold up to this claim, both CBDCs and sCBDCs would only be subject to the volatility of the underlying currency that is arising from socio-economic factors including the monetary policy of the respective central bank—same as today's monetary anchor, cash. The demand for stablecoins is driven by their reduced regulatory or technical complexity for users who do not have a bank account in the respective currency or who need a fiat-currency to enter cryptocurrency trading. Stablecoins also enabled illegal activities including circumvention of capital-controls [16].

The proponents of the Digital Euro sometimes point to offline payments as a key unique sales proposition in terms of usability. However, as long as physical cash remains an option, its usability properties will remain hard to beat. That is especially true as cash avoids the regulatory compliance checks the European Central Bank (ECB)

intends to impose on the Digital Euro. Instead of technical superiority to contemporary payment systems, the mandatory acceptance of the Digital Euro in virtually all points-of-sale across the Eurozone will be its most important advantage for citizens—at the likely very high cost of integration for merchants, indirectly covered by society at large. On the other hand, Taler as an sCBDC would offer a tangible improvement over the current payment system landscape by offering privacy-preserving one-click payments without customer traceability and identification at checkout. In addition, its accountless architecture with digital cash held in self-custody alleviates the burden of complex multi-factor account authentication. Compared to physical cash, the withdrawal of digital cash is possible anytime and from any place with Internet connectivity.

Apart from these benefits for users, pairing value stability with payer privacy and a frictionless user experience, offering an sCBDC based on Taler is also profitable for payment system operators: The reference implementation GNU Taler is Free Software, translating to low acquisition and maintenance costs. The centralized architecture allows for cost savings related to regulatory compliance compared to the distributed protocols at the base of stablecoins. It also enables higher transaction rates than distributed consensus algorithms. Self-custody of the token-based Taler payment system reduces the need for complex and costly user authentication as is the case for all account-based systems including most stablecoins and the Digital Euro. At the same time, the operator can earn risk-free interest with the users' deposits, as long as the central bank offers positive interest rates on reserves. In sharp contrast, banks would be legally required to distribute the Digital Euro without clear compensation for integration, onboarding, or support costs.

aspect	design space	cash	comm. bank	stable-coins	Digital Euro	GNU Taler (sCBDC)
purpose	store of value	◑	●	◑	◔	◔
	medium of exchange	●	◕	◑	●	●
backing	central bank (reserves)	●	◔	○	●	●
	government bonds	○	◔	●	○	○
liability/issuer	private sector	○	●	●	○	●
	central bank	●	○	○	●	○
medium	analog/hardware	●	◔	○	◔†	○
	digital/software	○	◕	●	●	●
privacy	payer	●	○	◑	◔	●
	payee	●	○	◑	◔†	○
instrument	account	○	●	◕*	◕	○
	token	●	○	◔*	◔†	●
architecture	centralized	○	●	◑	●	●
	decentralized	●	○	◕‡	◔†‡	●‡

Table 1 Comparison of different forms of money. From none to fully: ○,◔,◑,◕,●.
* Both design choices are made, accounts are more common.
† The envisioned offline version suggests a form of tokenization which relies on trusted hardware and promises transitive anonymity.
‡ Tokens may be held under self-custody in a decentralized manner.

8 Conclusion

Payment instruments have historically emerged in response to practical needs—facilitating exchange, managing credit, supporting savings and lending, or adapting to political and regulatory constraints. Today, the primary justification for introducing a Digital Euro appears to be reinforcing European monetary sovereignty, rather than advancing privacy, security, or usability. Given its limited technical innovation and proposed caps such as a €3000 holding limit, the Digital Euro offers few compelling reasons for widespread voluntary adoption, particularly considering the potential integration costs for merchants and payment providers.

In contrast, private and FLOSS-based initiatives like GNU Taler demonstrate how synthetic CBDCs can address both sovereignty and user demands. Fully backed by central bank reserves, a Taler-based synthetic CBDC could offer the same monetary stability while also providing privacy, self-custody, and operational efficiency—qualities that encourage voluntary adoption through genuine utility rather than through coercive mechanisms.

If the Digital Euro cannot compete on these terms, mandatory acceptance may become the only means of ensuring usage—a move that risks undermining free market principles. While nationalization may be justified for natural monopolies in critical infrastructure, many sectors with limited competition—such as public transport or telecoms—continue to rely on private services. In this light, enforcing retail CBDC acceptance appears less a necessity and more a policy choice, raising the question: is mandatory acceptance of the Digital Euro truly justified when synthetic CBDCs could achieve the same goals with greater user alignment and without coercion?

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