Tokens and Distributed Ledgers in Digital Payment Systems

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Abstract

In this article, we consider the roles of tokens and distributed ledgers in digital payment systems. We present a brief taxonomy of digital payment systems that use tokens, and we address the different models for how distributed ledger technology can support digital payment systems in general. We offer guidance on the salient features of digital payment systems, which we comprehend in terms of consumer privacy, token issuance, and accountability for system operators.

1 Introduction

Modern digital payments make use of tokens and distributed ledgers in various ways. Digital tokens underpin much of decentralised finance in the form of cryptocurrency, and they can also be used to create central bank digital currency and stablecoins. Although tokens and distributed ledgers are often found together, tokens can be used without distributed ledgers, and distributed ledgers can be used without tokens.

The use of digital tokens as a means of payment is not new. The core problem underpinning the tussle surrounding digital payment mechanisms is the absence of a perfect substitute for physical cash. Cash is a suigeneris kind of asset, uniquely functioning as both a physical possession and a claim on the central bank. In particular, account-based money, such as that which is offered by banks and closed-loop payment systems, are intrinsically linked to the identities of their users and subject to the performance of their fiduciaries, whereas token-based money can be used as bearer instruments. From the perspective of consumers, using accounts to make payments carries a set of intrinsic costs and risks associated with custodial relationships, including unwelcome surveillance and profiling, as well as the potential for paternalistic or abusive behaviour enabled by the power relationship between the account-holder and the fiduciary. Such costs and risks have been recognised for over five decades [1, 2] and motivated the development of token-based digital currency [3].

A distributed ledger is a "ledger that is shared across a set of DLT nodes and synchronized between the DLT nodes using a consensus mechanism" [4]. Distributed ledger technology (DLT) allows a set of participating peers to externalise their commitments, thus rendering themselves mutually accountable by establishing a shared version of the history of transactions. Cryptocurrencies are often implemented as decentralised systems with permissionless DLT systems at their core, although DLT can be used in other ways to support electronic payments.

This report considers the different manifestations of token-based payment systems and the use of distributed ledgers to support payment systems in general. We provide a taxonomy of token-based payment systems according to their technical characteristics, and we characterise the various ways in which DLT can enable digital payments.

2 Taxonomy of token-based digital payment systems

Token-based digital currency has many manifestations, including cryptocurrency, private digital currencies, and central bank digital currency. The Bank for International Settlements has characterised different forms of money in terms of *administrative* dimensions of digital currency, such as whether it is publicly available, whether it can

be transacted in a peer-to-peer way, and whether it is issued by a central bank [5]. It is also possible to consider the following *technical* dimensions of digital currency:

- whether the ledger is centralised,
- whether transactions are private by design, and
- whether tokens are intrinsic to the consensus mechanism.

	centralised	decentralised
transparent	electronic vouchers (e.g. store credits)	most UTXO cryptocurrency (e.g. Bitcoin, Litecoin)
private	DigiCash, e-gold Chaumian CBDC	Monero, Zcash

Figure 1: Token-based digital payment systems whose ledgers track the state of individual assets.

There are two principal methods to track tokens using a ledger: *endogenous*, wherein the ledger maintains the state of each asset, and *oblivious*, wherein assets maintain their own state.

With endogenous tracking, tokens are generally intrinsic to the operation of the ledger and cannot be moved from one ledger to another. Figure 2 offers a classification of token-based digital payment systems that use endogenous tracking. Such systems can be:

- centralised and transparent, wherein tokens are created, maintained, and accepted by a single authority, as is the case with electronic vouchers:
- centralised and private, wherein tokens are issued in a manner in which they cannot be individually recognised when they are spent, using blind signatures or other privacy-enhancing technology;
- decentralised and transparent, wherein tokens are created and transacted within a distributed ledger, using a mechanism that tracks the state of the output of each transaction and the flow of assets can be monitored by observers of the ledger; or
- decentralised and private, wherein tokens are created and transacted within a distributed ledger, using a mechanism that tracks the state of the output of each transaction but the flow of assets cannot be monitored by observers of the ledger.

Payment systems with endogenous token tracking are also called unspent transaction output (UTXO) systems because of the method they use to ensure that every token can be spent exactly once. During each transaction of a particular value, a set of new tokens with that specific value is created, and the ledger incorporates a record of the tokens involved in specific transactions to ensure that tokens are not spent twice. The protocol developed by David Chaum in 1982 [3] and commercialised as DigiCash [6] is an example of a centralised UTXO system with a privacy-preserving ledger that allows untraceable payments. Chaum's more recent work with the Swiss National Bank [7] follows the same principle. Bitcoin [8] is an example of a decentralised UTXO system with a transparent ledger. For the architects of Bitcoin, the purpose of decentralisation is to provide immutability, ensuring that system operators would not be able to reverse a transaction [8]. Unlike DigiCash tokens, however, Bitcoin tokens are neither private nor truly fungible, since the use of specific tokens can be linked to their individual creation, thus allowing the history of assets to be traced [9]. Privacy-oriented UTXO cryptocurrencies, notably Monero [10], address this limitation by combining both decentralised transactions and privacy by design.

	centralised	decentralised
transparent	standard USO assets	USO assets with mitigation against equivocation
private	fungible USO assets	fungible USO assets with mitigation against equivocation

Figure 2: Token-based digital payment systems whose assets track their own state.

Payment systems with oblivious tracking do not use the ledger to track individual tokens. Instead, the assets contain their own histories in the form of a proof of provenance, and the ledger is used to assess the validity of assets by verifying that the transactions referenced in the proof of provenance had taken place and that no other transactions had taken place. Authenticity of an asset can be assessed by verifying a signature contained within the asset at the time of its initial creation and satisfaction of rules that apply to successive transactions. Creating or transacting an asset requires posting the hash value of the transaction to the ledger. Because it is not necessary for the operator of the ledger to know anything about what is being transacted, we can say that the operator is oblivious to the transaction, and the assets themselves can be described as unforgeable, stateful and oblivious, or USO assets [11]. Token issuance is separate from ledger consensus, and because assets track their own state, double-spending is avoided without the need for the issuer or the ledger to maintain a database of the individual assets. Figure 2 shows how payment systems with oblivious tracking can be organised into categories:

• centralised and transparent, wherein each asset contains its complete history including the details of its creation, as is the case, for example, with TODA assets [12];

- centralised and private, wherein asset issuance uses privacy-enhancing technology such as blind signatures [13] to decouple an asset from its initial creation;
- decentralised and transparent, wherein the system is operated by a set of peers that externalise their commitments by periodically publishing the hash value of their accumulated set of transactions to the distributed ledger, but for which the assets themselves are transparent; and
- decentralised and private, similarly to the case for decentralised and transparent systems for oblivious tracking, except that details of the issuance of a particular asset are obscured using privacy-enhancing technology [11].

In principle, payment systems with oblivious tracking depend upon the system operator not equivocating, or signing proofs of provenance with different versions of history, although this can be mitigated through the use of DLT. The effectiveness of the mitigation is determined in part by the independence of the participants in the distributed ledger. Privacy-enhancing technology serves the same purpose as for payment systems with endogenous token tracking, to separate token issuance from the transaction in which it is spent. Observe that because commitments to the distributed ledger are periodic and only involve hash values over an accumulated set of transactions, the size of the ledger does not grow with the number of transactions. In exchange for this efficiency, users of the assets bear the burden of verifying the authenticity of assets and the validity of their proofs of provenance.

3 The use of distributed ledger technology in digital payments

Ledgers are designed to be immutable [4]. Distributed ledgers are designed to achieve immutability by soliciting and recording consensus among a set of peers about the specific history of transactions. As a result, a record can be considered authentic without the requirement to trust any particular operator of the ledger system to behave as promised. In principle, with a set of independent peers, transactions that had previously been validated will not be repudiable, and claimed transactions that had not previously been validated by consensus will be recognised as invalid. Because commitments by the system operators are externalised, they can be independently verified.

DLT can support both payment systems that maintain balances representing the assets held by identified users (account-based systems) and payment systems that allow assets in the form of tokens to be transferred between transacting parties (token-based systems). DLT can support these systems in several ways:

- Recording transactions between accounts. For account-based payment systems, DLT can be used to provide a record of transactions, potentially reducing the costs and risks of pairwise account reconciliation procedures. In particular, DLT can be used in the following ways:
 - 1. To provide evidence that value has been transferred between externally managed accounts. If accounts are managed independently by fiduciaries, then a distributed ledger can be used to record commitments by those fiduciaries that a transaction between those accounts has occurred. By providing a way for the fiduciaries to externalise their commitments, the DLT system allows claims about the authenticity of a transaction to be independently verified.
 - 2. To implement transfers of value between externally managed accounts. If accounts are managed independently by fiduciaries that agree to use a distributed ledger as the official record of their transactions, then the distributed ledger can record the size of the transaction and identifiers representing the accounts of the two counterparties. By providing a way for the fiduciaries to externalise their commitments, the DLT system allows claims about the authenticity of a transaction to be independently verified.
 - 3. To implement transfers of value between internally managed accounts. A DLT system can be used to directly manage accounts on behalf of its users. The use of balances rather than tokens forms the basis of some cryptocurrency systems, notably Ethereum [14], which uses a DLT system to record messages representing the state transitions that result from executing the transaction. The immutability of the ledger ensures that state transitions are non-repudiable, allowing claims about the authenticity of a transaction or its effect on the balances of transacting parties to be independently verified.

- Managing tokens in payment systems with endogenous token tracking. Payment systems with endogenous token tracking are generally designed so that tokens can be spent at most once. During a transaction, old tokens are retired, and new tokens are created in their place. Transactions are recorded on the ledger, referencing an address that specifies the destination of an asset during a transfer. The ledger also records an identifier specifying the token that has been spent, either along with the transaction or as part of the transaction, for the purpose of ensuring that the token will not be spent twice. Depending upon the specific architecture, transactions can contain the identifiers of new tokens that are created ("minted") during a transaction. However, privacy-preserving UTXO systems, such as Monero, use privacy-enhancing technology, such as blind signatures or zero-knowledge proofs, to avoid revealing information that links the transaction in which a token was created to the transaction in which a token is spent. In all cases, the immutability of the ledger allows claims about the validity of a token to be independently verified at the time that it is spent.
- Memorialising commitments in payment systems with oblivious token tracking. In payment systems with oblivious token tracking [12, 11], each token tracks its own state, which is updated during a transaction. The state of an asset generally includes an encumbrance that prevents its state from being updated by anyone other than the user that controls it, and control is generally demonstrated by possession of a private key. Assets can be created or transferred between users via state updates, whose hash values are delivered to a third-party system operator, who uses the hash values to incorporate the updates into recorded history in a way that can be proven by the users. Because the system operator receives only hash values, it generally does not learn the details of assets being transferred or even both counterparties to the transaction. The system operator provides a proof of provenance demonstrating that a specific sequence of updates to the asset has taken place. For this approach to work, counterparties to the transaction must trust that the system operator does not equivocate by presenting different versions of history.

DLT can be used to prevent equivocation by providing a way for system operators to externalise their commitments among a set of peers. Each system operator commits to a specific version of history by periodically publishing to a distributed ledger a hash value that represents the accumulated set of transactions that it has received over some period of time. Because every proof of provenance received from a system operator can be cross-referenced against the hash values in the distributed ledger, the claims intrinsic to the proofs of provenance can be verified, and the integrity and uniqueness of the asset is ensured.

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