Reference Architecture for Cryptocurrency in Banking

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Abstract—**The Internet has now become an environment and source for innovation development that has impacted a wide range of industries. The platform has enabled entrepreneurs to create groundbreaking solutions that have had a disruptive and transformative effect on the lives of many people. While banking had dealt with several innovations such as internet payment providers, more recently a virtual alternative to cash has begun to emerge. Although the notion of true electronic cash has been considered for some time, the availability of a practical electronic currency has only recently gained actual adoption that is forcing many financial institutions to reconsider the potential long-term impact. We provide some insight into the latest trends in cryptocurrency and propose a reference architecture for adopting this form of financial asset in a central banking scenario; i.e. a Fiat based cryptocurrency. The presently used cryptocurrency are based on a peer to peer scheme and hence we outline an IT solution that will accommodate a centrally issued electronic currency.**

Keywords—cryptocurrency; electronic cash; fiat money; banking

I. Introduction

Cryptocurrencies have received considerable attention recently by consumers and merchants as a viable form of currency for the payment of goods and services online. For some time, a range of Internet based payment systems have provided alternative means for transacting purchases. However those systems have largely been based upon traditional forms of payment instruments such as credit cards, bank account transfers, and third party accounts. These forms of financial transactions are essentially tied back to central bank issued physical currencies. Conversely, the present cryptocurrency notes and coins are not issued by banks. Rather, they are created by peer operators in a network of electronic currency mining operations. The result is the creation of virtual electronic cash, and its integrity is underpinned by a set of cryptographic primitives making it intractable to forge and at the same time the cryptocurrency attempts to preserve the properties of true cash as a transferrable electronic form of currency that cannot be traced (i.e. anonymous). The emergent systems gaining adoption are based upon peer-to-peer electronically generated coins. Hence, it may be anticipated that a centrally bank issued electronic currency (Fiat cryptocurrency) make take root at some point to compete or perhaps regulate in some fashion the distribution and use of cryptocurrency. As such, we outline in this paper an IT solution framework to support a central bank issued electronic currency by complementing the existing peer-to-peer systems, which have gained favor with merchants and customers.

In this paper, we provide some background to the genesis of electronic currencies and how these have transformed to the more recent peer-to-peer based cryptocurrencies in circulation today. We discuss some of the motivations for adopting both the peer-to-peer and a central bank issue Fiat Cryptocurrency. Based upon the needs for supporting the issuance of both forms of cryptocurrency we propose a reference architecture for supporting two forms of electronic currency. The frameworks may be used as a building block for central and retail banks that may elect to support cryptocurrencies as the need arises. This paper is an extended version of preliminary work that was accepted at [13].

In the next section, the related work to electronic forms of cash is reviewed and discussed. Following in Section III, we discuss the various forms of cash and currency systems that have evolved over time. In Section IV, we identify the key properties that need to be supported in a payment system based upon electronic cash. This is then followed in Section V with the proposed IT solution framework for supporting a Fiat cryptocurrency issued by a central bank. We then demonstrate how this framework can be used in practice as we examine the interactions of each IT component in more detail in Section VI. We conclude our paper in Section VII with a discussion of the observations in this paper and discuss the potential areas of further work.

II. Previous and Related Work

The recent work on cryptocurrencies has focused upon a number of well known schemes that are in active circulation today [1–3]. These popular schemes are based on a peer-to-peer system of trust, and the most popular protocol is BitCoin introduced by Satoshi Nakamoto [1], where a network of payment approvers validate transactions and are rewarded financially with new Bitcoins and transaction fees. In this and related systems [2, 3], the electronic currency comes into circulation during this transaction approval stage (called mining) and generally takes a level of computational effort. The underlying feature of this peer-to-peer currency system is the ability to function without the need of a central bank to issue the currency. In addition to these schemes, there is considerable earlier work on cryptocurrency schemes based on a central issuing authority. We now discuss these related

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papers. It is important to note that several terms are used in the literature to describe this form of currency including cryptocurrency, electronic cash, and digital coins.

During the 1990s two electronic cash schemes that underwent significant trials were Mondex and Digicash. Mondex was conceived by Tim Jones and Graham Higgins in 1991 and involved the use of an electronic wallet deployed to a smartcard accepting electronic cash [4]. Despite early adoption and backing by the banking and retail industries during the trial, the scheme did not proceed. Digicash was introduced by David Chaum [5] and supported digital cash that was anonymous, transferrable, and divisible. Moreover, the early work by David Chaum on the use of a blind digital signature technique to sign a transaction [6] is acknowledged to be the first work relating to a true form electronic of cash and hence a cryptocurrency.

Subsequent to the pioneering work of David Chaum on electronic cash, which was based on multiple interactions with the bank (called cut-and-choose), a number of additional electronic cash systems were published that extended or proposed alternative protocols [7–12]. In [7], Okamoto and Ohta suggested the first scheme with the ability to withdraw one electronic cash amount (based on cut-and-choose) that could be later sub-divided and then used in several subsequent smaller payment transactions. Later, Brands [8] outlined a more efficient scheme with a cash withdrawal protocol that only required one interaction exchange with the bank, while independently Ferguson also proposed an alternative scheme to achieve a similar single interaction transaction to withdraw cash [9]; both approaches forgoing the need for multiple interactions of the cut-and-choose method. Alternative cash protocols have also been proposed using distinctive cryptographic techniques. For instance, Traore outlines a cash scheme that applies the use of group digital signatures [10]. There is also work on the application of batch cryptography to make the modular exponentiation operations for digital signing and verification more efficient through the use of multiplication and hash tree methods that combine multiple coin denominations during the signature and verification phases of cash withdrawal and payment [11]. Although there is significant work on the security protocols and cryptographic tools in electronic cash, there is less work on the practical application of the ICT frameworks supporting these emerging cash schemes, and hence, we treat this subject in this paper.

III. Currency and Cash Systems

Before the appearance of any form of widely accepted payment mechanism, early exchanges of goods and services were done directly in the form of a bartering system. The exchanges can also be considered as an early form of a peer-to-peer system that did not require the presence of a central authority to back the transactions. It was not until much later that a currency based on coins became available, and these were initially based upon some precious metal. This evolved further when the precious metal was substituted for a minted form of paper currency. However the currency issued by the governing authority was originally backed by some form of asset orcommodity, most commonly gold (standard), and were referred to as commodity money. More recently, the gold standard was abandoned in 1971 and hence the backing for currency came from the central bank sponsored by the governing authority for the land. This form of currency is referred to as Fiat money, with no tangible asset supporting the currency other than the promise of redemption by the governing authority. The removal of a commodity backing has meant that the ceiling for the creation of money was removed. This has allowed currency to be manufactured as deemed necessary by the governing body, and its creation is moderated to balance the mood of the economy in lieu of the prevailing economic conditions impacting local and global markets (i.e. inflationary, recessions, boom).

In addition to the central bank creating new notes and coins, commercial banks (regulated by the central bank) also create money when loans are provided to customers. The volume of money that may be created by commercial banks is determined by the deposits held by the bank. Moreover, for every dollar a bank has on deposit they are only required to retain a fraction of this, as a cash reserve, whilst the remainder may be reused as a loan. When this is done the original depositor of the funds actually has the funds withdrawn and the bank gives you credit for the amount deposited while lending the actual funds out, less the fractional reserve, to others. Recipients in turn who receive those loaned funds can also deposit the received amount with another bank, who can repeat the same process of holding a fraction whilst loaning out the remainder. This system is referred to as fractional reserve banking where a fraction of any deposit is kept in reserve by the bank and the remainder may be used as the basis for a new loan. This activity is also a form of money creation, albeit differing from central bank issued currency, resulting in increased money in circulation.

In comparison to the central authority Fiat currencies, the popular cryptocurrencies in circulation today are based upon a peer-to-peer system and hence do not fall into the category of fiat or commodity based cash systems. In some way, these cryptocurrencies have similarities to a bartering type of exchange, since the historical bartering systems support a peer-to-peer exchange of goods and services. Notwithstanding, a fiat based cryptocurrency is an electronic currency that may be securely created by the central bank and is the key theme of this paper. However, given the prevalence of peer-to-peer based cryptocurrency we present an IT framework that enables exchange in both forms of currency.

IV. Properties of a Cryptographic Based Electronic Currency

Although the idea of fully autonomous electronic cash has been considered for some time now, this form of currency is still new and very much an emerging domain. We now briefly consider the properties of cryptocurrency to place this into perspective relative to traditional currency that uses physical cash, bank transfers, and payment cards. We are also able to draw upon the similarities of the traditional forms of financial exchange as we then propose an IT architecture for banking that supports the emerging cryptocurrency.

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A. *Properties of Physical Cash*

Physical cash exhibits a number of properties that enable the exchange of good and services in commerce. Several key properties of cash include anonymity, transferability, and portability [12]. In addition, the cash must be difficult (if not impossible) to forge, verifiable, and be universally accepted. We now explore each of these attributes further.

The attribute of anonymity can be seen in that physical cash may be exchanged between parties and it is not necessary to establish the identity of the person to accept the currency as legal tender. Furthermore, as the same physical cash is exchanged once again the identity of the intermediate parties are not required. There are of course methods by which law enforcement authorities may track cash using serial numbers, but this provides a limited form of surveillance of persons at the points of issuance or deposit at the bank (or co-operating merchants). We can also see in the anonymous exchange of cash the feature of transferability and portability is demonstrated. The cash can be transferred between parties and may be carried about in a portable fashion. In contrast, payment cards allow funds to be exchanged only when connected to a central server. When carried out offline, there is still the need to perform verification with the server at some point. Conversely, verification of cash is seldom carried out properly, or is sometimes done on high-value notes.

Most people will accept cash on first (and very brief) inspection, without necessarily verifying watermarks, print and texture quality of the physical note. In some cases, merchants may verify bank notes at the point of sale, but in general most exchanges of cash are accepted upon first glance. Whilst this supports the property of universal acceptance, the process presents the opportunity of forged notes to enter the monetary system. Hence one of the most important properties of cash is that of difficulty to forge (i.e. copy). In addition, there are several additional properties of cash such as trusted, secure, and durable.

B. *Payment Cards, Electronic Transfer, and Cashless Devices*

As a next step in the evolution of cash to an electronic medium, the use of physical cash can be replaced with the transfer and exchange of the same currency without this being physically withdrawn from the bank for payment purposes. Hence, the use of credit cards, payment cards, and bank transfers all provide a means to transfer cash directly into the bank account of other parties (i.e. this is from computer server to server). There is increased opportunity for fraud in these transfers as the exchange of currency is fundamentally a transaction that numerically indicates the financial amount to transfer, with the transaction bound and wrapped tightly with several layers of secure protocols to prevent tampering, replay, eavesdropping and other forms of cyber attack. These forms of electronic cash transfer possess no intrinsic value, where true electronic cash in the form of cryptocurrency does possess its own tenable value.

C. *Properties of Electronic Cash (Cryptocurrency)*

Electronic cash (both peer-to-peer and Fiat based) in its elementary form aims to replicate the same properties and features exhibited by physical cash. But due to the nature of its virtual existence, several additional characteristics must be observed. We briefly explain several of these features, which include prevention and detection of double spending, protocol efficiency, and off-line transferability.

Many electronic cash/cryptocurrency protocols have a general vulnerability where the same electronic coin may be spent more than once. Since it is easy to copy the binary sequence that represents the cryptocurrency, there must be a mechanism in place to both detect the replay of a used electronic coin and prevent this from occurring. As such, all true electronic cash systems possess some form of cryptographic protocol that provides a capability to detect and prevent double spending. The efficiency of the protocol is an important feature to observe as many cryptographic operations are computationally expensive, and when processed by a merchant, may overwhelm the gateway server processing capability. Hence the ability to have an efficient protocol is a very desirable feature. Finally, physical cash can be transferred in an off-line manner between parties, with no intermediate party involved. Hence cryptocurrency is intended also to replicate this feature. Given the prevalence of being always on-line for users, this characteristic is perhaps not as significant now compared to when electronic cash was devised during the 90s.

V. Fiat Based Cryptocurrency Architecture

As discussed, the prevalent cryptocurrencies in circulation today are based upon a peer-to-peer protocol. This includes the well known systems such as BitCoin, Litecoin, and Paycoin. In these cryptocurrency environments, new coins are actually issued by peer entities as they validate transactions that have been conducted, during what is called the mining process. A peer-to-peer system has provided the breakthrough opportunity for true electronic cash to gain a mainstream footing in the market. Other disruptive innovations that entered the market initially as a peer-to-peer system such as file and music sharing were also followed by (central authority based) server solutions. Hence, we investigate this possible line of technology evolution and propose an IT framework that will support a central bank issued cryptocurrency.

Fig. 1 below illustrates the set of IT components necessary to provide a central bank issued cryptocurrency in conjunction with the peer-to-peer solutions. The IT framework supports the exchange of funds between conventional physical cash systems and peer-to-peer cryptocurrencies and enables the issuance of digital wallets, secret keys, with associated security and cryptocurrency protocols. We now describe the major components followed by example system interactions in the next section.

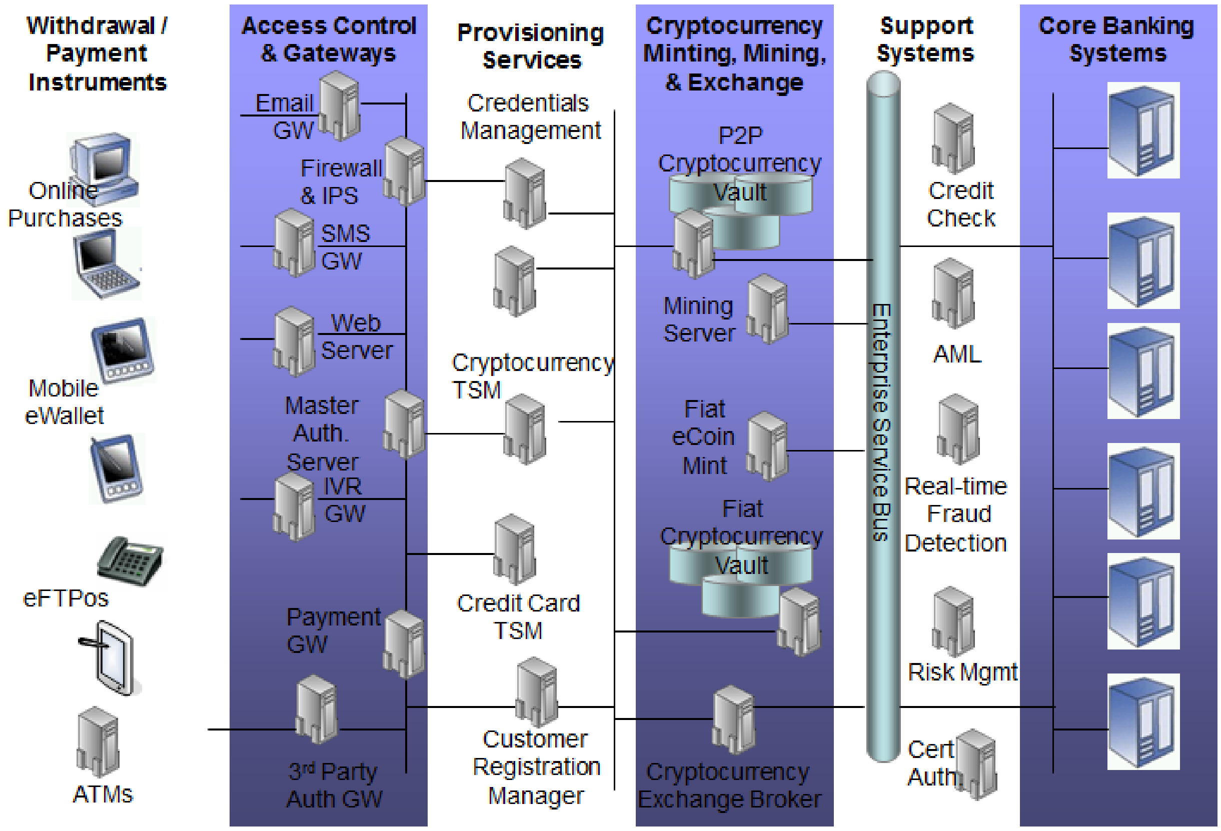

Fig. 1. An IT Framework for Supporting Cryptocurrency in Banking

A. *Withdrawal and Payment Instruments*

The withdrawal and payment instruments represent the physical and virtual devices that are used by consumers to conduct financial transactions. This includes traditional payment cards such as credit and debit cards used in ATMs, eftpos, or merchant Near Field devices. While an emerging trend is to deploy electronic wallets (eWallet) to mobile devices, such as smartphones, for holding credit cards, and a further set of electronic wallets will be used for the new cryptocurrency entrants. This includes central bank issued Fiat and peep-to-peer cryptocurrencies. Both these denominations will require different electronic wallets on the smartphones' SIM chips. Furthermore, the eWallets may be stored on fixed computers to conduct (for example) online purchases from home. Hence, there is likely to be demand for supporting cryptocurrency transfers between a customers' fixed computer and mobile device. In the interim, this could be supported by having the customer to transfer funds from the personal computer to their bank account, and then to withdraw the cryptocurrency funds to their personal mobile devices.

B. *Access Control & Financial Gateways*

The Access Control gateways provide the increasingly important task of user authentication and authorization. This domain also includes web servers, internet payment gateways, email, IVR gateways that are all routed via a central master authentication server for verification. This will often include multi-factor authentication that apply challenge and response security protocols. There are many new attacks being created in an attempt to usurp customer interaction with their bank. Any illegal seizure of links must be detectable by the bank and only verified users and transactions permitted. As such, a number of additional security protection systems are deployed to the cryptocurrency support layer to ensure that all known defensive measures are applied to incoming requests and transactions. In addition to managing access from the public network of the Internet, similar access control mechanisms are in place to offer protection from incoming requests over private financial networks such as COIN, eftpos, and Swift.

C. *Provisioning Services*

Provisioning services include the operations to firstly setup and configure the electronic wallets on customer devices and then to securely transfer their credentials and payment instruments to the eWallets. This involves identity checking (using points), credit checks, risk management, and other verification steps to establish the credentials of the customer. This will often involve several distribution channels for interaction including web, mobile device, and possible fixed line calls, or traditional physical mail. Whilst the peer-to-peer cryptocurrency systems allow the user to remain completely anonymous, the conventional security checks are applied when dealing with banks that need to comply with regulatory bodies. The component used for distribution and management of eWallets is the Trusted Service Manager. This is supported by the user registration, verification, and credentials management systems.

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D. *Cryptocurrency Minting, Mining, & Exchange*

The cryptocurrency minting, mining, and exchange systems are the key components that provide direct support for the virtual commerce. At this framework layer, there exist two cryptocurrency vaults: one to store peer-to-peer coins and a second for storing central authority generated electronic coins. These vaults are configured to be highly available and fault tolerant, with frequent backup capability; since any loss of data in these vaults means a direct loss of raw currency. Although the mining operations enable the bank to participate in generating new peer-to-peer electronic currency, perhaps the key motivation is participation in the shared general ledger as a trusted entity for risk and compliance management. The minting factory is, of course, the component that allows the bank to manufacture new Fiat electronic cash. Although the central bank may create cryptocurrency, traditional banking permits the bank to create additional cryptocurrency based on fractional reserve banking. To engage in money markets that span both the traditional cash systems and electronic cash, the cryptocurrency exchange broker is required.

E. *Cryptocurrency Support Systems*

The support systems for electronic cash are composed of the conventional risk, anti-money laundering, and fraud detection components that are in use for conventional financial transactions. However, these components are extended with further capabilities to integrate with and support the cryptocurrency environment. The capabilities will include more rigorous multi-factor authentication, enhanced real-time risk and fraud detection to prevent double spending of electronic coins, key management of cryptographic keys and PKI to generate and manage keys and digital certificates for electronic wallets. Finally, as further regulations are imposed or refined for cryptocurrency, it is anticipated that the governance and compliance of existing bank systems will require modification to support these changes. This will include guidelines on the storage and access to cryptocurrency ledgers, adherence to the usage of security services, and the auditing of 3rd party (including cloud) IT service providers.

F. *Banking Systems*

The traditional banking systems include loans, deposits, checking accounts, payment cards, general ledger, etc. Although it will be necessary to manage deposit accounts for cryptocurrency, it is perhaps less likely that loans accounts will be required, rather this may be managed using traditional currencies and then perhaps converted to cryptocurrency for use by the customer.

VI. System Interaction

We now highlight the principles of the architecture by illustrating the system interactions when conducting financial transactions. This helps to clarify how the components in Fig. 1 function together in order to fulfill a transaction request. The examples shown are the withdrawal of cryptocurrency coins to an eWallet installed on the customers' mobile device (smartphone) and payment with cryptocurrency to a merchant.

A. *Cryptocurrency Withdrawal Using Cash Account*

In this instance, the customer elects to withdraw (Fiat) cryptocurrency coins by accessing their bank account. Through this action, the user is effectively purchasing cryptocurrency using conventional funds from their transaction account. However, the purchase and conversion steps are hidden from the user as they merely experience a withdrawal action. Fig. 2 illustrates the system interactions that will occur.

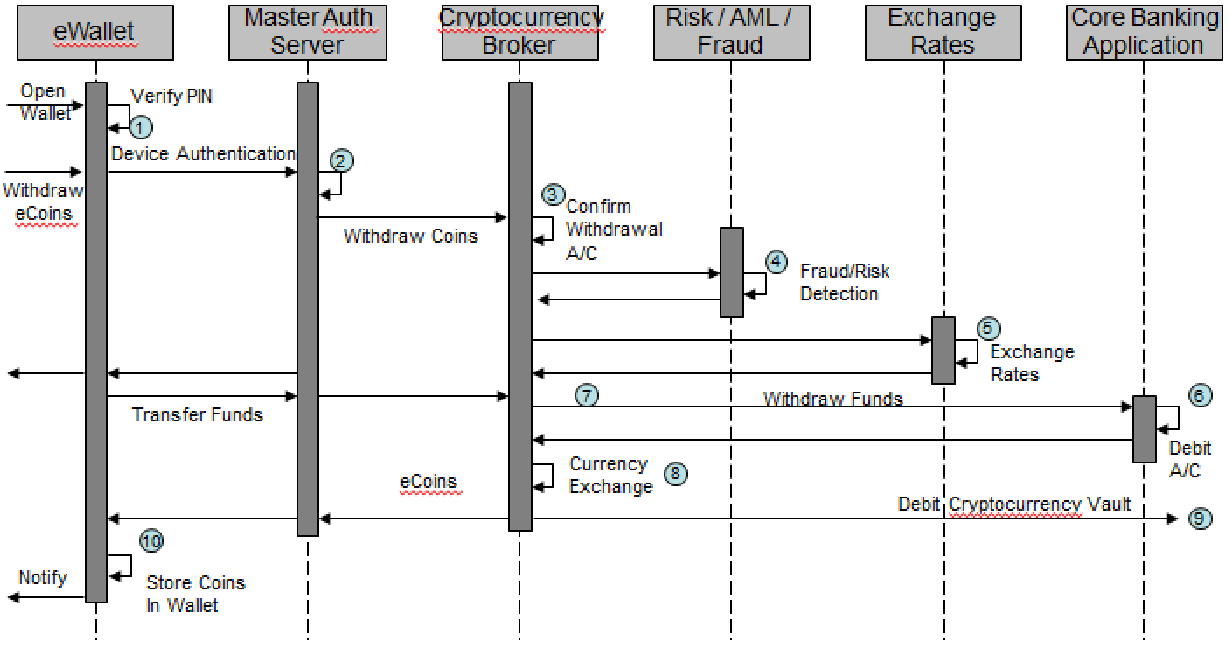

Fig. 2. Withdrawal of Cryptocurrency Coins from Bank Cash Account

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We now describe further the sequence of interactions shown above (Fig. 2). It is assumed the customer has previously accessed their phone with the appropriate PIN entry code. The customer opens their eWallet and is prompted for an additional authentication code and PIN specific to their electronic wallet (1). On correct entry, the user then selects to withdraw cryptocurrency coins nominating that they wish to obtain them using funds from their conventional transaction cash account. This request is forwarded (over a secure encrypted link) to the online banking system via the master authentication server which verifies the device along with the previous PIN entry verification (2). Upon successful verification, the withdrawal request is forwarded onto the cryptocurrency broker, which then initiates a withdrawal protocol. The first step of the withdrawal protocol involves confirming the target account from which funds are to be debited (3). In this case, a conventional cash account is the source of funds. However, prior to executing the withdrawal, several risk, fraud, and anti-money laundering checks are performed (4). When complete, a currency conversion rate must then be obtained (5) so that the correct cash amount may be debited. Where the user selects to withdraw coins from an account that specifically stores cryptocurrency this step is not required and also highlights that an alternative deposit account specifically designed for storing cryptocurrency coins may be necessary. Such coins will be stored in the appropriate cryptocurrency vault. With the current conversion rate the cash account is then debited with a withdrawal transaction (6). The withdrawn funds are then converted into the selected cryptocurrency coins (8) and at this point the coins may be obtained from the cryptocurrency vault used for storing central bank issued (Fiat) cryptocurrency (9). The electronic coins retrieved are then returned to the customers' device and securely stored in the eWallet (10).

It is noted that at step (8) where the user selects to withdraw cryptocurrency coins from a peer-generated coin vault, that these coins are then transferred from the bank deposit eVault account (essentially an eWallet address) to the wallet of the device that the user initiates the withdrawal from. As such, this transfer transaction must be validated by the peer cryptocurrency network and entered into the shared general ledger, so this may be subsequently used for payments.

B. *Payment using Cryptocurrency*

During the payment transaction, the customer has cryptocurrency (logically) coins stored within their eWallet on a mobile device and uses this to pay for goods at a merchant shop. It is assumed that the merchant terminal is suitably equipped with an eWallet to receive the transferred funds and has undergone a registration and enrollment process with the bank to establish itself as a participating cryptocurrency merchant. Note also that the merchant would require multiple registrations, and will have multiple eWallets, one for each different type of cryptocurrency supported.

The diagram at Figure 3 illustrates the sequences of interactions when the customer conducts payment with a merchant. The merchant commences by entering the purchase amount into the sales terminal (1). The terminal then generates a QR Code and displays this for scanning by the customers' payment device (2). The customer may (for example) use the camera to scan the QR code and convert this into the payment amount (4) while initiating the transfer of funds from the eWallet to the merchant (5). The customer device subsequently transmits the payment to the merchant terminal (this may be achieved by near field wireless) (6). The merchant terminal receives the payment transaction and forwards this onto the bank for verification to check for double-spending (7). At this point, for small amount the merchant may decide to accept the risk and not wait for the result of the fraud check by the bank and approve the transaction immediately. An approval is displayed on the merchant terminal (8) and the coins committed to the eWallet. Alternatively, for larger amounts the merchant may elect to wait for the fraud check to be completed (9) before displaying the approval outcome and then commit the coins to the merchant eWallet (10).

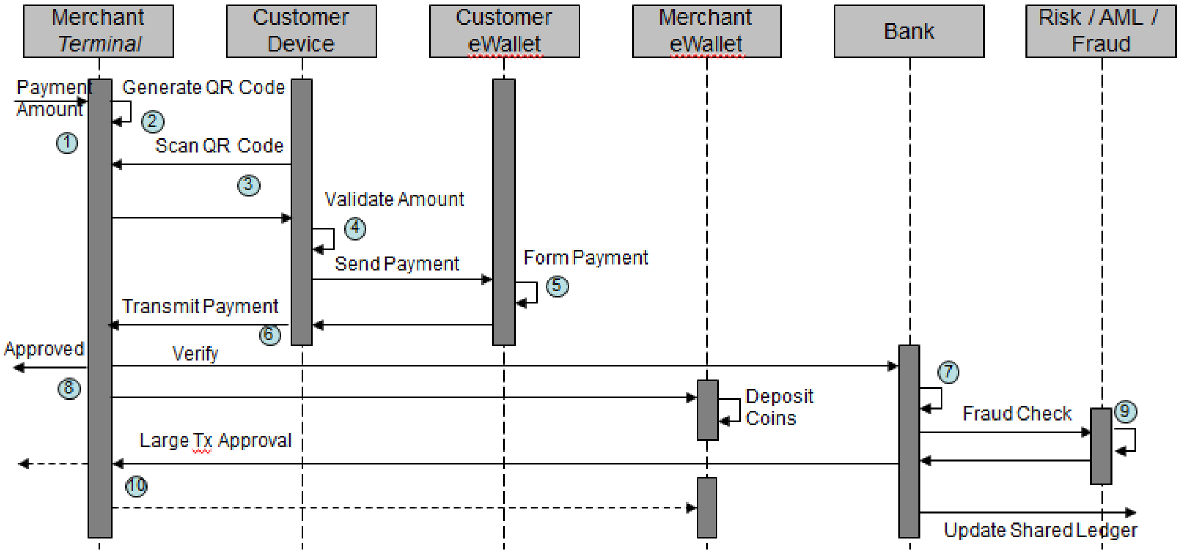

Fig. 3. Payment of Cryptocurrency Coins to a Merchant

VII. SUMMARY OF WORK AND AREAS TO BE EXPLORED FURTHER

In this paper, the notion of a Fiat based cryptocurrency as a complementary solution to the recent emergence of peer based cryptocurrency is examined. The properties of physical cash that are likely to be the preserved characteristics of any cryptocurrency are also discussed. A Fiat based central bank issued cryptocurrency may well be favorably received by merchants and customers as the recent trends in peer-based cryptocurrency systems indicates that the broader community is perhaps ready to adopt these newer electronic style cash technologies. With this in mind, a reference architecture for banking is presented that illustrates the key technical components and security controls required to support both a Fiat and peer-to-peer based cryptocurrency environment. Since these technologies are still relatively new, there is considerable further work in understanding how commercial trading systems and money markets will evolve and be impacted by these new financial technologies.

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