

Cryptocurrencies and Bitcoin: Charting the Research Landscape

Full Paper

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Abstract

This systematic literature review examines cryptocurrencies (CCs) and Bitcoin. Because cryptocurrency research has not gained much attention from Information Systems (IS) researchers and needs a more vivid discussion, this review summarizes the main concepts of 42 papers and aligns them to IS Research. Although, cryptocurrency research has not reached IS mainstream yet, there is massive potential for multifaceted research ranging from protocol development to designing alternative digital currency schemes. Cryptocurrencies entail a core digital artifact and present a rich phenomenon based on the intertwining of technological artifacts and social contexts. We argue that cryptocurrencies are an alternative payment method that may replace intermediaries with cryptographic methods and should be embedded in the research areas of SIGeBIZ and SIGSEC. At the end of this literature review, we discuss some open research gaps like new business models based on cryptocurrencies or the influence of culture on cryptocurrencies and Bitcoin.

Keywords

Cryptocurrencies, Bitcoin, Literature Review

Introduction

Economists and Anthropologists do not always agree on how money came to be intrinsic to societies (Graeber 2011), but such monetary system is nevertheless an essential medium to exchange goods, store value and as a unit of account (Greco 2001, p. 27, Samuelson 1968). However, although money allows for the easy purchase of goods, its usage is sometimes restricted. Government and other parties' regimes have built strict restrictions, including how money is introduced into a system, how much of a currency can be owned and how it can be converted into other currencies. To enforce these restrictions, central institutions are needed to supervise the currency scheme (Karlstrøm 2014). In systems of fiat currencies, these central institutions are central banks like the Federal Reserve Bank or the European Central Bank (Cecchetti 2003). Due to the financial crisis of 2007–2008 and the following debt crisis, centralized currency schemes came under pressure and people worldwide began to lose faith in centralized financial institutions (Teigland et al. 2013) and called for decentralization and alternative currency schemes (Bollen 2013). The call was answered by cryptocurrencies (CCs), decentralized digital currency schemes based on peer-to-peer networks and cryptographic tools. Users of CCs can transfer virtual money to other users, and thus sell or buy goods and services. The most prominent example of a CC is Bitcoin, the most used CC today (coinmarketcap.com 2015, 2015). Cryptocurrencies, especially Bitcoin, have raised a lot of attention in practice and media. On the one hand they are praised for their low transaction fees and promoted as a viable alternative to banks and credit cards (Brito and Castillo 2013). On the other hand, it is warned that CCs are an easy-to-use tool for money laundering and trade in illicit goods like drugs (Brezo and Bringas 2012, Trautman 2014). Nevertheless, CCs present an opportunity to establish new business models in eCommerce and Finance by allowing direct worldwide transactions with lower transaction costs and reduced inflationary risk (Kelly 2015, Papp 2014). So far, research on cryptocurrencies has not gained much attention from Information Systems (IS) researchers and needs a more vivid discussion. Hence, we want to identify existing literature on cryptocurrencies based on a systematic literature review.

The focus of this review is on cryptocurrencies, with an emphasis on Bitcoin as the most used cryptocurrency, that I believe needs a summarization and identification of open research gaps as a starting point for future research. The following questions form the basis for this research:

1. Which methods, concepts, ideas and approaches of cryptocurrencies have been researched in scientific literature?
2. Which IS research areas can be linked to cryptocurrency research and what are future research topics for cryptocurrency related IS research?

This literature review provides a synopsis of the relevant points in IS related cryptocurrency research, an alignment of IS research areas and consequently, to present further potential fields of IS research. It defines the concept of a cryptocurrency, with reference to Bitcoin, in section 2. In the third section, I outline our methodology for the literature review and present its results in section 4. In section 5, I discuss the links between cryptocurrency research and IS research, as well as present future research opportunities. Lastly, a conclusion is given and limitations of the literature review are discussed.

Cryptocurrencies and Bitcoin

In recent years, interest in cryptocurrencies and Bitcoin has grown. Given the growing number of cryptocurrency users as well a rising media attention, CCs and Bitcoin cross the traditional borders of monetary systems and present alternative approaches to exchanging goods, store value and as unit of account. However, cryptocurrencies and Bitcoin have not drawn much attention in IS research yet. In this section, I present the theoretical background of cryptocurrencies as well as describe Bitcoin in detail.

Cryptocurrencies are a subset of digital currencies, which may have either have centralized institutions or are based on a decentralized network (Trautman 2014). For a centralized currency scheme, the digital currency is issued by one institution, which ensures that the digital coins can be exchanged back to fiat currencies or can be used to buy and sell (digital) goods (Bryans 2014). One example for this centralized digital currency is the Linden Dollar, issued by Linden Lab, which can be used in the online virtual world Second Life. It shares some characteristics with fiat currencies and, like in the traditional money system, a central institution serves as a source of trust. However, decentralized currency schemes try to avoid central institutions as much as possible and are built on a network of transaction partners (Karlström 2014). As long as the transaction partners can observe each other, they can build up trust based on their behaviors. If observation of the transaction partners is not possible, other mechanisms have to be found to establish reliable transactions. One solution lies in cryptocurrencies, which are decentralized currency schemes based on cryptography. One of the first cryptocurrencies was introduced by a person or a group under the pseudonym Nakamoto Satoshi in a white paper in 2008 (Nakamoto 2008). The entity named this cryptocurrency Bitcoin and defined it as "an electronic cash system" (Nakamoto 2008). In 2009 Satoshi made Bitcoin to an open-source project and retired from the project. Today, Bitcoin is the most used cryptocurrency with a market capitalization of 3.3 billion USD (mid February 2015) followed by Ripple with a market capitalization of around 400 million USD (coinmarketcap.com 2015).

In researching cryptocurrencies, three different layers next to the currency unit have to be teased out: the protocol the CC is based on, and the transaction network or the surrounding ecosystem (Böhme et al. 2014). The currency unit is, however, often the general name given to the cryptocurrency system. For simplicity, if the name of cryptocurrency is used in the paper, it refers to the currency unit. Every other layer is named directly. Following this, the different layers are explained with reference to the example of Bitcoin.

For instance, Bitcoin (currency) users rely on the Bitcoin protocol to receive and send payments over the internet (Brito and Castillo 2013). Participants who want to exchange Bitcoins connect to a peer-to-peer network (transaction network), the Bitcoin network established on the basis of the Bitcoin protocol (Meiklejohn et al. 2013). Every partner is anonymous, only the enabling Bitcoin protocol encrypt and verify a transaction from one user's "wallet" to another's. To avoid double-spending of Bitcoins, each transaction is verified by Bitcoin network nodes or "Miners", who have to solve a cryptographical puzzle (calculation of a predefined hash value). The Miner who has solved the puzzle, includes the transaction into a public ledger, the blockchain, and is rewarded with Bitcoins (Nakamoto 2008). A copy of the blockchain is stored at each node of the Bitcoin network. Therefore, as the encryption, verification and

transfer for each transaction is based on the Bitcoin protocol, and transactions are publicly available through the ledger that is shared by peers in the network, there is no need for trust in any individual actors and no central institution for money transactions is required (Maurer et al. 2013). Both the Bitcoin protocol, the Bitcoin network and Bitcoin are supported and enabled by a community of active supporters, who update the Bitcoin protocol and ensure the healthiness of the Bitcoin network (Yelowitz and Wilson 2015). In addition, the first firms were formed to exchange Bitcoins for fiat currencies like the Dollar, Euro and Yen soon after the introduction of Bitcoin (Maurer et al. 2013). Entrepreneurs introduce new business models (e.g. mining pools) or adapt existing business models to work with Bitcoin (e.g. peer-to-peer lending of Bitcoins). Today, around 80 000 merchants accept Bitcoins as payment methods, with Microsoft and Dell as the two largest Bitcoin accepting retailers (CoinDesk 2015b). The merchants, the entrepreneurs and the active Bitcoin community form the Bitcoin ecosystem (Grinberg 2012).

Methodology

As seen above, cryptocurrencies present a rich context with a huge potential for research. To summarize and categorize recent literature on cryptocurrencies and Bitcoin, an extensive and systematic literature review was undertaken (see vom Brocke et al. 2009 and Webster and Watson 2002). Firstly, I limited the scope to the search terms “cryptocurrency”, “cryptocurrencies”, “crypto AND currency”, “crypto AND currencies” and “bitcoin” to get a comprehensive overview about the literature on cryptocurrencies. The search term “Bitcoin” was also added as Bitcoin is currently the most used cryptocurrency. The search terms “virtual currency” or “digital currency” were not used as I focused our literature review on decentralized currency schemes based on cryptography. I did not restrict the timeframe of the search, but did not expect to find much prior to 2008. No cryptocurrency was excluded from the literature review.

		Found papers	Relevant papers
IS Journals	European Journal of Information Systems	0	0
	Information Systems Journal	0	0
	Information Systems Research	0	0
	Journal of AIS	0	0
	Journal of Information Technology	0	0
	Journal of MIS	0	0
	Journal of Strategic Information Systems	0	0
IS Conferences	MIS Quarterly	0	0
	AMCIS	0	0
	ECIS	4	1
	HICSS	0	0
IS databases	ICIS	0	0
	ABI/Inform	7	4
	ACM	17	16
	AIS eLibrary	4	0
Total	IEEE	22	21
		54	42

Table 1: Number and sources of found and relevant papers

The search terms were applied to AIS Senior Scholars' Basket of Journals (Members of the Senior Scholars Consortium 2011), as well as in the highly ranked Information Systems conferences AMCIS, ECIS, ICIS and HICSS, in order to see if Bitcoin and cryptocurrencies were being discussed and, if so,

which concepts were under discussion. Based on the results of a full text search for each journal and conference, only one paper was found. I therefore enlarged our search to include digital databases and libraries from ABI/Inform, ACM, AIS and IEEE. In total, 50 papers were found in these databases. Duplicates were removed from the result set. The established literature was then reviewed by reading the full text and 41 papers from the databases were identified as relevant, in that they explicitly addressed the concepts of cryptocurrencies or Bitcoin. Other papers that merely mentioned cryptocurrencies or Bitcoin were not considered further. In total, 42 papers were considered relevant for this literature review (see Table 1). In order to link research on Bitcoin and CCs to Information Systems (IS) Research, I used the Call for Papers and Track Descriptions from AMCIS 2015, ECIS 2015 and ICIS 2014 as well as AIS SIG list to affiliate each paper to research topics of IS. In addition, I conducted an open search for the website of the authors to find their research interests for further alignment of cryptocurrency research and IS Research. Open research questions were gathered by a critical analysis of the literature (Torraco 2005). The critical analysis was based on the contributions, limitations and open question described in the reviewed papers, the overall picture of the reviewed literature as well as own contextual knowledge.

Essentials of the Literature Review

In the following section, the essentials of the reviewed papers will be presented. The first peer reviewed paper (Reid and Harrigan 2011) about cryptocurrency was published in 2011, the majority of paper (25 out of 41 reviewed papers) was made public in 2014. 29 reviewed papers were accepted to be included in conference proceedings, only 13 papers were published in a journal, most of them as introductions to Bitcoin. Both publication dates and types support the argument, that cryptocurrency research is a new research field.

The results of the literature review can be found in Table 2. Firstly, the type of cryptocurrencies researched is categorized. In the next columns, the research methods of the papers are reflected. In the fourth column, the contribution of each paper to cryptocurrency research is named. The last column aligns the reviewed papers to IS research areas. The sub-headings group the papers to their equivalent cryptocurrency layer.

Source	Crypto-currency	Research method	Contribution	IS research area
Protocol layer				
Andrychowicz et al. 2014	Bitcoin	Prototyping	Protocol development to secure multiparty lotteries without a trusted authority	E-Business (SIGeBIZ)
Babaioff et al. 2012	Bitcoin	Conceptual	Protocol development for information propagation in the Bitcoin system	E-Business (SIGeBIZ)
Bentov et al. 2014	Bitcoin and other CCs as derivatives of Bitcoin	Conceptual	Protocol development to improve security of the Bitcoin protocol	Security (SIGeBIZ)
Danezis et al. 2013	Zerocoin	Conceptual	Protocol development for Zerocoin as an “anonymous decentralized e-cash System” (Danezis et al. 2013)	e-Business (SIGeBIZ) / Security (SIGSEC)
Jayasinghe et al. 2014	Bitcoin, Zerocash, Zerocoin	Prototyping	Design of a protocol for optimistic fair-exchange	e-Business (SIGeBIZ)

Source	Crypto-currency	Research method	Contribution	IS research area
Protocol layer				
Kumaresan and Bentov 2014	Bitcoin	Prototyping	Protocol development for “incentivizing correct computations of cryptographic tasks” (Kumaresan and Bentov 2014)	Security (SIGSEC)
Miers et al. 2013	Bitcoin, Zerocoin	Prototyping	Protocol development for Zerocoin	e-Business (SIGeBIZ) / Security (SIGSEC)
Network layer				
Anish Dev 2014	Bitcoin and other CCs as derivatives of Bitcoin	Experiment	Analysis of Bitcoin collaborative mining methods	Services (SIGSVC)
Bamert et al. 2013	Bitcoin	Experiment	Fast transaction support in Bitcoin	E-Business (SIGeBIZ)
Biryukov et al. 2014	Bitcoin	Experiment	Analysis of method for deanonymizing Bitcoin users	E-Business (SIGeBIZ) / Security (SIGSEC)
Bissias et al. 2014	Bitcoin and Litecoin	Prototyping	Analyzing and developing mixing methods for Bitcoin	Security (SIGSEC)
Decker and Wattenhofer 2013	Bitcoin	Quantitative data analysis	Analyzing information propagation in Bitcoin	e-Business (SIGeBIZ)
Gervais et al. 2014a	Bitcoin	Experiment	Analyzing privacy on simplified payment verification clients and proposing a modification for SPV clients	e-Business (SIGeBIZ) / Security (SIGSEC)
Karame et al. 2012	Bitcoin	Quantitative data analysis and experiment	Analysis of double spending attacks on fast Bitcoin payments	e-Business (SIGeBIZ) / Security (SIGSEC)
Luo et al. 2013	Bitcoin	Experiment	Analyzing the Bitcoin network via transaction graphs	--
Miller et al. 2014	Bitcoin	Conceptual	Concept to use the Bitcoin network for distributed storage of archival data	e-Business (SIGeBIZ)
Reid and Harrigan 2011	Bitcoin	Quantitative data analysis	Analyzing anonymity in the Bitcoin network	Security (SIGSEC)
Singh et al. 2013	Bitcoin	Experiment	Researching fast transaction support in the Bitcoin network	e-Business (SIGeBIZ)

Source	Crypto-currency	Research method	Contribution	IS research area
Ecosystem layer				
Ben-Sasson et al. 2014	Bitcoin, Litecoin and Zerocash	Conceptual and simulation	Introducing Zerocash as an alternative for decentralized anonymous payments	e-Business (SIGeBIZ) / Security (SIGSEC)
Bohr and Bashir 2014	Bitcoin	Quantitative data analysis	Analysis of the Bitcoin community	Adaption and Diffusion of Information Technology (SIGADIT) / Cross-Cultural Research in Information Systems (SIGCCRIS)
Christin 2013	Bitcoin	Quantitative data analysis	Analysis of a Large Anonymous Online Marketplace and their transaction share in the Bitcoin ecosystem	e-Business (SIGeBIZ)
Cusumano 2014	Bitcoin	Archival data analysis	Introduction to the Bitcoin ecosystem	e-Business (SIGeBIZ)
El Defrawy and Lampkins 2014	Bitcoin and other CCs as derivatives of Bitcoin	Conceptual	Design of an alternative digital currency scheme	e-Business (SIGeBIZ) / Security (SIGSEC)
Evans-Pughe et al. 2014	Bitcoin	Archival data analysis	Introduction to the Bitcoin ecosystem	e-Business (SIGeBIZ)
Gad 2014	Bitcoin	Archival data analysis	Examining the actors, value chains, and modes of operation in eCrime marketplaces and Bitcoin as facilitating technology	Security (SIGSEC)
Gervais et al. 2014b	Bitcoin	Archival data analysis and experiment	Discussing decentralization in the Bitcoin ecosystem	Security (SIGSEC) / Human Behavior and IS (ICIS)
Glaser et al. 2014	Bitcoin	Quantitative data analysis	Analysis of Bitcoin users' intentions	e-Business (SIGeBIZ) / Adoption and Diffusion of Information Technology (SIGADIT)
Grier 2014	Bitcoin	Archival data analysis	Introduction to the Bitcoin ecosystem	e-Business (SIGeBIZ)
Hurlburt and Bojanova 2014	Bitcoin	Archival data analysis	Introduction to the Bitcoin ecosystem	e-Business (SIGeBIZ)
Kitahara et al. 2014	Bitcoin	Conceptual	Concept for digital rights management based on the Bitcoin protocol	e-Business (SIGeBIZ) / Services (SIGSVC)

Source	Crypto-currency	Research method	Contribution	IS research area
Ecosystem layer				
Malone and O'Dwyer 2014	Bitcoin, Litecoin and dogecoin	Quantitative data analysis	Researching the energy footprint and profitability of Bitcoin mining	Economics behind Societal and Industrial Transformation through IS (ECIS)
Meiklejohn et al. 2013	Bitcoin	Quantitative data analysis and experiment	Characterization of the Bitcoin ecosystem	e-Business (SIGeBIZ) / Adoption and Diffusion of Information Technology (SIGADIT)
Moser et al. 2013	Bitcoin	Experiment	Analysis of money laundering (tools) in the Bitcoin ecosystem	e-Business (SIGeBIZ) / Security (SIGSEC) / Services (SIGSVC)
Parthemer and Klein 2014	Bitcoin	Archival data analysis	Introduction to the Bitcoin ecosystem	e-Business (SIGeBIZ)
Peck 2012	Bitcoin	Archival data analysis	Introduction to the Bitcoin ecosystem	e-Business (SIGeBIZ)
Peck 2013	Bitcoin	Archival data analysis	Introduction to the Bitcoin ecosystem	e-Business (SIGeBIZ)
Stokes 2012	Bitcoin	Archival data analysis	Money laundering in Bitcoin	e-Business (SIGeBIZ) / Security (SIGSEC)
Szefer and Lee 2013	Bitcoin	Conceptual	Securing cloud computing applications by using Bitcoins as deposit	Security (SIGSEC) / Services (SIGSVC)
Taylor 2013	Bitcoin, Litecoin	Case study research	Historical analysis of hardware development for Bitcoin mining	Adoption and Diffusion of Information Technology (SIGADIT)
van Alstyne 2014	Bitcoin	Conceptual	Discussing the value and contribution of Bitcoin	e-Business (SIGeBIZ)
van den Hooff et al. 2014	Bitcoin	Experiment	Conceptualizing of outsourcing computations over public logs to distributed servers	Security (SIGSEC)
Wörner and Bomhard 2014	Bitcoin	Conceptual	Concept for using Bitcoin to build a data market with automated data sensors	Decision Support and Analytics (SIGDSA) / e-Business (SIGeBIZ) / Services (SIGSVC)

Table 2: Cryptocurrency research and IS research areas

Protocol Layer

One part of our literature review focuses on the protocol layer. Table 2 shows that the majority of the seven papers have grounded their research on the Bitcoin protocol (Andrychowicz et al. 2014, Babaioff et al. 2012, Bentov et al. 2014, Jayasinghe et al. 2014, Kumaresan and Bentov 2014). In addition, Bentov et al. (2014) state, that all other cryptocurrencies share the same fundamentals and ideas with Bitcoin. Only

Danezis et al. (2013) and Miers et al. (2013) have researched Zerocoin, which implements a stronger transaction anonymity than other CCs.

All papers analyze the Bitcoin protocol, identify existing weaknesses and develop enhancement to the existing protocol. Bentov et al. (2014) see a "Tragedy of the Commons" problem in the protocol, in that fees from transactions could not cover the mining costs. A Proof of Activity protocol is developed to solve the problem and to "decentralize the power that synchronizes the transactions in a quite pronounced fashion" (Bentov et al. 2014). Kumaresan and Bentov have also developed a Bitcoin protocol enhancement which "captures the amount of computational effort required to validate Bitcoin transactions" (2014). This change would foster honest behavior and boost the robustness of Bitcoin transactions. Babaioff et al. (2012) suggest changes to the Bitcoin protocol to incentivize information sharing in Bitcoin. The developed protocol from Jayasinghe et al. "guarantees strong-fairness while preserving anonymity of the consumer and the merchant" (2014). Andrychowicz et al. (2014) engineer a protocol to secure multiparty lotteries without a trusted authority which is built on the Bitcoin protocol. Only the work of Danezis et al. (2013) and Miers et al. (2013) are built on Zerocoins, a cryptocurrency for anonymous decentralized transactions. The protocol uses "modern techniques based on quadratic arithmetic programs resulting in smaller proofs and quicker verification" (Danezis et al. 2013).

As all papers focus on the technical development or enhancement of cryptocurrency protocols, a design science orientation for all papers can be stated (Hevner et al. 2004). Therefore, three of the papers discuss the protocol on a conceptual basis (Babaioff et al. 2012, Bentov et al. 2014, Danezis et al. 2013). Andrychowicz et al. (2014), Jayasinghe et al. (2014), Kumaresan and Bentov (2014) and Miers et al. (2013) use prototyping methods with their proposed changes implemented and tested iteratively.

Network Layer

The second cluster of cryptocurrency related research focuses on the network layer. The majority of the papers grouped in this section (see Table 2) examine the Bitcoin peer-to-peer network, only Bissias et al. (2014) included Litecoin as alternative to Bitcoin into their research. Anish Dev (2014) names also other cryptocurrencies, but sees them as derivatives of Bitcoin.

The research on the peer-to-peer network of cryptocurrencies is multi-faceted. One of the earliest papers on cryptocurrency research (Reid and Harrigan 2011) analyses the anonymity in the Bitcoin network. The authors state, that despite the claim that Bitcoin is a secure and anonymous currency, peers in the network can easily be identified by analyzing the topology of the Bitcoin network. Methods to analyze the Bitcoin network are described by Luo et al. (2013). They use a parallel computing approach to analyze transaction, making tracing and searching of transactions faster and easier. By adding available external information and the tracking of marked Bitcoins, de-anonymization of user is very easy for the everyday user. Biryukov et al. (2014) also use network topology methods to deanonymize user even if they are connected to the Bitcoin network via a Tor network (which masks the user's IP address). The authors state, that "the cost of the deanonymization attack on the full Bitcoin network is under 1500 EUR" (Biryukov et al. 2014). Therefore, anonymity should not be seen as a core feature of cryptocurrencies (Reid and Harrigan 2011). A possible way to unlink Bitcoins from known users and therefore hinder deanonymization of the network peers is a mixing method, "which is the process of transferring funds between two address without recording their relationship to the public block chain" (Bissias et al. 2014). As existing methods are vulnerable to various cyber attacks (e.g. denial-of-service attacks), Bissias et al. (2014) propose an alternative method named Xim, which has a strong robustness against these attacks and allows finding anonymous mixing partners.

The second stream of research on the network layer of cryptocurrencies analyzes fast transaction support in Bitcoin. As each transaction needs an average time of ten minutes to be included into the blockchain and up to one hour to be robust against double spending attacks, Bitcoin is not suitable for e-Commerce scenarios where the exchange of services or goods and Bitcoins happens at the same time (Karame et al. 2012). Singh et al. (2013) develop a scheme for fast transaction support in Bitcoin, as long as payer and payee know and trust each other. If both parties of the transaction do not trust each other, other mechanisms have to be found. Bamert et al. (2013) suggest that the payee connect to random peers in the network and check if inconsistencies occur during the validation phase of a Bitcoin transaction. This gives the attacker only a "0.088% chance of performing a successful double-spending attack" (Bamert et al. 2013). The authors tested their proposal at a snack vending machine accepting Bitcoins. An alternative,

suggested by Karame et al. (2012), introduces observer to the Bitcoin network which informs peers about double-spending attacks.

Simplified payment verification (SPV) clients are an additional important concept to foster Bitcoin as an alternative for e-Business transactions. As specific devices (like mobile phones) have a limited amount of data storage and cannot store the complete blockchain. SPV clients allow peers to extract Bitcoin transactions relevant for the client while outsourcing transaction validations to more powerful network peers (Gervais et al. 2014a). Gervais et al. show that these "filters incur serious privacy leakage in existing SPV client implementations" (2014a) and suggest a lightweight modification of the SPV clients.

Research on the network layer has a strong design science orientation (Hevner et al. 2004). Based on identified limitation of the existing cryptocurrency peer-to-peer network, several papers (like Biryukov et al. (2014), Luo et al. (2013) or Singh et al. (2013)) design solutions to meet the limitations. Research methods for designing concepts are based on conceptual work like Miller et al. (2014) who introduce a concept to use the Bitcoin network for distributed storage of archival data or use experiments (Anish Dev 2014) or prototyping methods (Bissias et al. 2014). In addition, a more descriptive or analytical approach can be identified. Authors like Decker and Wattenhofer (2013) analyze the public available Bitcoin blockchain to research information shared in the Bitcoin network. This quantitative data analysis approach is also used by Karame et al. (2012) and Reid and Harrigan (2011).

Ecosystem Layer

The majority of literature looked at examined the cryptocurrency ecosystem. Like in the previous sections, Bitcoin is the dominant CC examined. El Defrawy and Lampkins (2014), Malone and O'Dwyer (2014) and Taylor (2013) mention other cryptocurrencies like Litecoin, but base their research on Bitcoin. Ben-Sasson et al. (2014) present Zerocash as an alternative for decentralized anonymous payments.

Many papers in this section are new introductions to the Bitcoin ecosystem. Papers like Cusumano (2014), Evans-Pughe et al. (2014), Grier (2014), Hurlburt and Bojanova (2014), Parthemer and Klein (2014), Peck (2012) and Peck (2013) give positivistic insights to the ecosystem and explain how Bitcoin works. This type of research can be used as a good starting point for researchers who want to understand the Bitcoin ecosystem. Introductory papers without scientific rigor are reasonable if the research field is quite new. Meiklejohn et al. (2013) also give a characterization of the Bitcoin ecosystem but emphasize criminal behavior, notably fraud. Although, "Bitcoin does not provide a particularly easy or effective way to transact large volumes of illicitly obtained money" (Meiklejohn et al. 2013), the ecosystem is vulnerable to money thefts, money laundering and illegal transaction. Christin (2013) describes how Bitcoin was used to purchase illicit items like narcotics through the online marketplace Silk Road. The author shows, that 4.5% to 9% of all Bitcoin transactions can be linked to Silk Road sales. In addition, users with the intention of buying illicit goods "had about 25% - 45% more bitcoins (within the 95% Confidence Interval) than those who had not spent bitcoins on illicit goods" (Bohr and Bashir 2014). Moser et al. (2013) and Stokes (2012) research money laundering which is used to mask the illicit nature of money. With mixing methods and services like BitLaundry, described by Moser et al. (2013), it is possible to anonymize transactions. However, it has been suggested that this is only possible for small amounts of illicit money as a large "movement with money laundering, it would incur attention both within the Bitcoin community and, ultimately at a law enforcement level" (Stokes 2012). Gad (2014) suggests implementing regulations for exchanging Bitcoins into fiat currencies to prevent misuse of cryptocurrencies.

Users' intentions to participate in the Bitcoin ecosystems are described by Glaser et al., suggesting that "new users tend to trade Bitcoin on a speculative investment intention basis and have low intention to rely on the underlying network as means for paying goods or services" (2014). van Alstyne (2014) supports this argument, but sees this development as necessary to give Bitcoin a value.

Gervais et al. (2014b) examine the claim of Bitcoin as a decentralized currency and show that, despite the decentralized peer-to-peer network, parties can influence the development of Bitcoin. Protocol maintenance is performed by a small number of core developers, and other participants only have limited influence on them. Other central parties include mining pools which provide a large portion of computational resources in the Bitcoin ecosystem, but "if these pools colluded to acquire more than 50 percent of computing power share, they could effectively control all transactions, for example, preventing certain transactions' execution, approving a specific set of transactions, or approving double-spending

transactions" (Gervais et al. 2014b). To overcome this limitation, Ben-Sasson et al. (2014) and El Defrawy and Lampkins (2014) propose new currencies scheme with stronger cryptographic methods and more sustainable decentralization.

A different stream of Bitcoin ecosystem's research is about mining hardware and their development. Because mining is a resource consuming process, new types of hash calculating hardware have emerged. Taylor (2013) describes four phases of hardware development. In the first phase, the Bitcoin mining was based on CPU, which were replaced by graphical processor units (GPU) in the second phase. The third phase started mid 2011 with the introduction of field programmable gate arrays (FPGA) for Bitcoin mining. These FPGA were stepping-stone for the fourth phase, the introduction of application-specific integrated circuits (ASIC) providing a higher cost and energy efficiency. Malone and O'Dwyer calculated that "the entire Bitcoin mining network is on par with Ireland for electricity consumption" (2014).

Methods and processes can be used to support other services as well. Kitahara et al. (2014) describe a concept digital rights management based on the Bitcoin protocol. Bitcoin can be used as deposit to secure cloud computing applications (Szefer and Lee 2013) and can help to establish a data market with automated data sensors (Wörner and Bomhard 2014).

Research on the ecosystem layer leans towards a behavioral perspective (Hevner et al. 2004). All introductory papers (like Grier 2014) are based on archival data analysis, although not all sources are clearly referenced in this type of paper. Archival data analysis is also used by Gervais et al. (2014b) and Stokes (2012) with a stronger scientific rigor. A different research method used is quantitative data analysis (e.g. Glaser et al. 2014). Taylor's (2013) work about the hardware development relies on case study research. More design-science oriented papers used experiments (van den Hooff et al. 2014) or a conceptual approach (Szefer and Lee 2013).

Some papers, like Christin (2013), discuss the ethics of their research, suggesting that researching illegal activities like money laundering and platforms selling illicit goods might stimulate further usage and activate new users. In addition, analyzing data from those activities might have unintended consequences for users. Researchers must be aware of these consequences and consider strategies to mitigate the risk. One strategy described by Christin (2013) and Moser et al. (2013) are proposals of intervention strategies (e.g. blacklisting of Bitcoins) which prevent further illegal activities in the Bitcoin ecosystem.

Cryptocurrency Research and its Link to IS Research

The papers discussed above, while discussing phenomena that are IT-enabled, never link the phenomena to IS research. Nor has cryptocurrency research drawn much attention from major IS conferences and journals. The question therefore remains: Are cryptocurrencies a potential research area for IS research?

From a general view, IS research is typically based on a core subject or phenomenon, such as an IT artifact (Banville and Landry 1989, Orlikowski and Iacono 2001). For cryptocurrency research, this core artifact could be the cryptocurrencies' protocol or the peer-to-peer network or both. In addition, IS research has "a research focus on the rich phenomena that emerge whenever the technological and the social come into contact with, react to, and transform each other" (Lee 1999). Further, rich phenomena based on the intertwining of technological artifacts and social context can be found in cryptocurrencies. Just a few examples range from the open source development of the cryptocurrency protocol to fast transaction support for e-Commerce to new services and business models based on the cryptocurrencies' protocol and network. From a general view, it is justified to say that research about cryptocurrencies belongs to Information Systems Research. A stronger consideration of cryptocurrencies in IS would also enlarge the diversity of the discipline (Benbasat and Weber 1996, Robey 1996).

In order to illustrate the potential that cryptocurrency research has for IS research, I have linked the three broad fields of examination in previous research to specific AIS SIGs and tracks from AMCIS, ECIS, ICIS and HICSS. This has been done with reference to keywords of the article, the text itself and the research background of the authors. This illustration therefore serves as a starting point for the inclusion of cryptocurrency research into IS research, while also showing just how untapped this new and emergent phenomenon is.

Protocol Layer

Papers researching the protocol layer may raise interest for the communities of SIG on Information Security (SIGSEC) and of the SIG on E-Business (SIGeBIZ). Most of reviewed paper in this layer have a technical approach and construct an IT artifact. Papers like Bentov et al. (2014) and Kumaresan and Bentov (2014) analyze "system vulnerabilities and risk exposure" (Siponen et al. 2015) and present solutions to cope with these risk exposures. Other papers (e.g. Andrychowicz et al. 2014, Jayasinghe et al. 2014) discuss "technologies to facilitate negotiations and auctions" (Shaw et al. 2015) or support "Internet-based procurement and sales" (Shaw et al. 2015).

Network Layer

Most of the papers in the network layer can be linked to SIGSEC and SIGeBIZ. Authors like Bamert et al. (2013), Gervais et al. (2014a) and Singh et al. (2013) research SPV clients that allow e-Commerce transactions on smart devices. Others analyze privacy and anonymity in the Bitcoin network (e.g. Biryukov et al. 2014 and Reid and Harrigan 2011) and describe methods to re-establish privacy in Bitcoin transactions (Bissias et al. 2014). These papers could have the chance to be accepted for *AMCIS 2015 - Information Systems Security and Privacy (SIGSEC) Track* organized by SIGSEC. The paper from Anish Dev (2014) can be linked to the SIG Services (SIGSVC) community, as the author researches collaborative mining methods and contributes to "Service and crowd-sourcing or micro-tasking" (Böhmman 2014). Only for Luo et al. (2013), it was not possible to align an IS research area.

Ecosystem Layer

As the number of papers researching the ecosystem layer is higher, the research is more multifaceted. Again, most of the papers would raise interest in the communities of SIGeBIZ and SIGSEC. Papers like Grier (2014), Peck (2013) and van Alstyne (2014) give insights into digital currencies and might be of interest for the communities of SIGeBIZ. New services and business models in cryptocurrencies (e.g. securing cloud computing applications by using Bitcoins as deposit) might stimulate new research from the SIGSVC community. Security and risk exposure are also discussed in the reviewed papers. Selling and purchasing illicit goods using Bitcoins (Christin 2013) or money laundering (Moser et al. 2013, Stokes 2012) exemplify potential eCrimes while using Bitcoins. Cryptocurrency research can be relevant for the SIG Adoption and Diffusion of Information Technology (SIGADIT) as well. Papers like Bohr and Bashir (2014) and Glaser et al. (2014) give insights into the Bitcoin community and discuss how "individuals become aware of, decide to use, and appropriate" (Jeyaraj 2015) cryptocurrencies.

Open Research Questions

Overall it can be stated, that research about cryptocurrencies have a strong alignment to E-Business and Security, because cryptocurrencies are an example for "Internet-based payment models" (Shaw et al. 2015) using cryptographic methods to build up secure and trustful transactions. Nevertheless, a full understanding about cryptocurrencies has not been reached yet.

More investigation should also be done in the field of the influence of culture on cryptocurrencies. Although mentioned in a few papers (e.g. Bohr and Bashir 2014), the focus of the reviewed papers still lies on anonymous transactions without cultural influences (Glaser et al. 2014, Meiklejohn et al. 2013). However, due to cryptocurrencies and especially Bitcoin as a currency scheme crossing national borders, cultural issues are an important aspect nowadays. This is a possible area for future research.

New business models are not discussed in cryptocurrency research so far. Nevertheless, I see entrepreneurs who have built up their businesses around cryptocurrencies, especially Bitcoin (CoinDesk 2015b). In addition, more and more merchants accept Bitcoin as a payment method (CoinDesk 2015a). It is a possible future research area to understand the motivation of the entrepreneurs and merchant to participates, which business models they use and which approaches they use to form the ecosystem.

Cryptocurrencies present a challenge for the existing financial industries as potential clients using alternative financial tools and methods without banking support (e.g. van Alstyne 2014). Banks but also intermediaries like consultants or insurances have to change and adapt their business models to become

member of the cryptocurrency ecosystem or built up trust or alternatives to be more attractive for these potential clients (Palmer 2015). This is also a possible area for future research.

Cryptocurrencies and Bitcoin had to face extreme events and disruptions in the recent past. Examples are the lost Bitcoins from the largest Bitcoin exchanges Mt.Gox and Bitstamp, which have led to distrust in the Bitcoin ecosystem and might harm cryptocurrencies as a whole (CoinDesk 2015b). It is not clear, how and why these crisis and disruptions occur and how the users of the cryptocurrencies react to these events.

As stated above, research methods examining cryptocurrencies are oftentimes quantitative and design science oriented. The valuable results need to be complemented with qualitative methods. First approaches can be found (Taylor 2013) but a stronger inclusion of qualitative methods in the research process and mixed-methods approaches is an important future research question.

Research on cryptocurrencies, however, is not limited to the IS field of research. It might be worthwhile exploring other disciplines, such as business, law, organizational science and sociology. This could lead to an interdisciplinary field of research and lead to a fruitful enrichment of practice as well as academic. For further research, it might be also reasonable to analyze cryptocurrencies from a more sociomaterial perspective.

Conclusion

In conclusion, I argue that although cryptocurrencies have not yet reached mainstream IS research, the phenomena hold a massive potential for multifaceted research. This was shown through a discussion of the extant literature on cryptocurrencies and through linking the themes highlighted, from enhancements of the CC's protocol to methods to deanonymize network participants to researching marketplaces selling illicit goods, to IS research areas. Cryptocurrency research should be more recognized by IS research as CCs entail a core digital artifact and present a rich phenomenon based on the intertwining of technological artifacts and social contexts. Given that CC transaction ledgers are typically public, quantitative methods have thus far been used to understand underlying transaction mechanisms. However, analyzing cryptocurrencies may present a challenge for qualitative and behavioral research many participants of the CC's ecosystem are anonymous. I argue that cryptocurrencies are an alternative payment method that may replace intermediaries with cryptographic methods and should be embedded in the research areas of SIGeBIZ and SIGSEC. As research on cryptocurrencies is a new IS research field, this literature review provides a summarization, an alignment to existing IS research fields and identification of open research gaps.

Nevertheless, the literature review was limited to publications from IS research. Therefore, it remains open whether including more databases, journals and conference from other disciplines like law and sociology will further enhance the insight on CCs and Bitcoin. Synonyms for cryptocurrencies have not been used for the literature search. Their inclusion might lead to more fruitful and expansive results. Furthermore, the evaluation of the searched literature and the linkage to IS research is based on subjective interpretations of found literature and archival data. Therefore, additional discussion is needed in the future.

As a main result, this systematic literature review provides an overview and summarization of cryptocurrencies and Bitcoin and an alignment to IS research. It provides an appropriate entry point for researchers new to the field and also, a starting point for future research.

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