Implementation and Evaluation of a Point-Of-Sale Payment System Using Bitcoin Lightning

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ABSTRACT

Cryptocurrencies have the potential to improve financial inclusion. However, the technology is complex to understand and difficult to use. Human-Computer-Interaction (HCI) can play a vital role in improving accessibility by identifying and overcoming challenges that hold users back. However, most HCI studies have focused only on Bitcoin and Ethereum so far. Newer blockchains promise transaction speeds comparable to traditional payment systems, enabling the use of cryptocurrencies as a medium of exchange for everyday transactions. To explore the viability of cryptocurrency-based point-of-sale solutions through a human-centered lens, we used Bitcoin Lightning to implement a payment system and evaluated it in a mixed-methods study. Our results show that Bitcoin Lightning is a usable alternative to traditional solutions and that friction aggregates at the interface to existing payment systems, i.e. when purchasing Bitcoin. We discuss qualitative insights and derive implications for deploying cryptocurrencies as payment solutions.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Applied computing** → **Digital cash**.

KEYWORDS

blockchain, cryptocurrency, bitcoin, bitcoin lightning, point-of-sale, pos, payment study

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1 INTRODUCTION

Cryptocurrencies have gained growing interest in the last years [11] and are increasingly pushing into the mainstream. Recent industry reports indicate that more than 300 million people own cryptocurrencies [9] and adoption rates are to continue as fast as early Internet user growth [8]. While previously often understood as investment opportunity [1, 16, 29], the introduction of Bitcoin as legal tender in El Salvador has paved the way for cryptocurrencies to be used as a medium of exchange [41]. Despite this growth cryptocurrencies are not without critique. The high energy-demand of proof-of-work blockchains has become a point of recent discussions [10, 18] and cryptocurrencies are still perceived as an opaque and technically complex topic that is connected to many misconceptions and confusion.

The Human-Computer-Interaction (HCI) community has recognized its responsibility in making the technology accessible to all users by helping to overcome technical obstacles that would otherwise exclude people with less technical experience from participating in the growing crypto-economy [3, 14, 15]. HCI researchers have set out to identify and address human-centered challenges connected to cryptocurrency and blockchain systems (e.g. [1, 14, 46]). While cryptocurrencies are shown to be hard to understand [28] and difficult to use [15, 45, 46], the existing research body also seems to lack behind current developments in industry [17]. To date, the majority of HCI research focuses on Bitcoin [31] and Ethereum [5], whose technical architectures are constrained by comparably slow transaction speeds or high transaction fees. For example, one block on the Bitcoin blockchain takes on average 10 minutes to be mined [31], making it rather impractical for point-of-sale use cases. Newer layer-1 blockchains, like Solana [48], or layer-2 solutions, like Bitcoin Lighting [34] or Polygon [33], promise to improve these technical limitations by providing transaction settlements at near real time speeds and low transaction costs. These new systems thus provide properties comparable to traditional payment networks, while at the same time offering the advantages of an open ecosystem for anyone to participate in and build on top of it.

However, they yet have to find their way into HCI research. To our knowledge, there are no studies available implementing these state-of-the-art cryptocurrency payment systems to evaluate them for point-of-sale use cases. This leaves a gap in understanding whether these systems deliver on their promises and are a viable alternative to established payment systems. With this work we close the gap: We implemented a point-of-sale system on top of the Bitcoin Lightning network and evaluated it in a mixed method study during which N=31 participants conducted 202 payments using the system.

Our analysis shows that Bitcoin Lightning worked well as a payment settlement layer, and users perceived the usability of the system as satisfactory during use. We identified a stark contrast in the perceived ease-of-use between the setup and initial configuration of wallets and the continued use during the study. Using the system was perceived as relatively easy. However, during setup procedure, in particular purchasing Bitcoin and charging the Lightning wallet were points of struggle for many new users. These results hint at the importance of improving the initial user experience at the interface between existing payment systems and cryptocurrencies. We conclude with a discussion of adoption consideration for using and Bitcoin Lightning as settlement layer for point-of-sale cryptocurrency systems.

Contribution Statement: This paper makes two main contributions: We present (1) a reference implementation for a point-of-sale system integrating Bitcoin Lightning as settlement layer, and (2) contribute an empirical evaluation of the system through a user-centered lens. Based on these results we discuss current limitations and implications for cryptocurrency-based payment systems.

2 BACKGROUND & RELATED WORK

Bitcoin was introduced in 2008 as "*peer-to-peer electronic cash*" [31]. While it has exhibited remarkable growth over the past decade, its adoption was driven primarily by its use as an investment and store of value, not as a means of transaction. While users would like to use it as a form of payment [15], merchants accepting cryptocurrency have remained scarce.

2.1 Cryptocurrency in HCI

In recent years, the Human-Computer-Interaction community has taken interest in understanding how users perceive and use cryptocurrencies. Scholars explored the motivation and perceptions of users [15, 26] and non-users [19, 44] alike to understand how cryptocurrencies are being used. Froehlich et al. report that while users are motivated by financial interests, they would also like to use it for purchases but lack opportunities to do so [16]. Additionally, usability issues [1, 15, 45, 46] seem to hold back the adoption of cryptocurrencies: Across studies they are described to be complicated to understand and get started with [3, 15], subject to misconceptions [28], slow in transaction speed [15, 22, 38], and expensive in fees [46]. Many of the issues highlighted by existing research – particularly slow transactions and high transaction fees – have been addressed by more recent projects, such as Solana [48], Polygon [33], or Bitcoin Lightning [34] at a technical level. These improvements offer an opportunity to revisit the question of whether cryptocurrencies can become a viable alternative to existing payment systems. Especially, the recent introduction of Bitcoin as legal tender in El Salvador [41] shows the relevance of the subject and draws open questions for the adoption of cryptocurrencies for everyday payments. While HCI literature indicates the usability of Bitcoin is worse than those of credit cards [3], adoption in El Salvador appears to progress nonetheless. Unfortunately, verified reports from El Salvador are sparse and little is known about the real usability of systems built on Bitcoin Lightning.

While an emerging body of research reports on the usability of cryptocurrencies and cryptocurrency wallets brings forward valuable insights [1–3, 14–16, 20, 22–25, 30, 36, 46], these studies are not without limitations. Existing studies investigating the usability of purchasing goods with Bitcoin [3, 15] are limited to a laboratory context. For example, Alshamsi and Andras compare the usability of Bitcoin with the usability of credit cards in an between-subject setup with 22 cryptocurrency beginners and 33 credit card users [3]. Froehlich et al. explore the challenges of first-time cryptocurrencies users in-depth while making a purchase in an online shop with Bitcoin [15]. In either case, the short observation period provides little insight in whether cryptocurrencies would be viable for everyday payments as repeated interaction with any system may get easier as users become familiar with it over time.

We identified two projects concerning the use of cryptocurrency for point-of-sale use cases – interestingly enough, both pertaining to coffee. Eskandari et al. deployed an early version of a Bitcoin sales terminal in a coffee shop in 2014 [12] and Tallyn et al. explored notions of machine autonomy with a Bitcoin-enabled coffee machine in an office context [35, 42]. While Eskandari et al.'s work takes a software engineering perspective and presents the requirement engineering process as well as lessons learned, they do not report on users' perceptions of the systems. They define usability (user-friendly, time-efficient, fair exchange rates, availability), deployability (low cost to run, enabling branching), and privacy (no information leakage, maintaining payee's privacy, maintaining payer's privacy, confidential payment lists) as core requirements. To avoid the average block time of 10 minutes, their system accepts 0-confirmation transactions instead of waiting until the transaction is included in the blockchain. While this allows to facilitate point-of-sale transactions with Bitcoin without waiting, it effectively makes the system susceptible to attacks through double-spending [13]. Tallyn et al.'s work, on the other hand, is interesting as it goes into depth, exploring machine autonomy during a 1-month field study in office environments. The focus of their work, however, lies less on using Bitcoin as payment infrastructure, but on the influence of machine autonomy on everyday activities in shared community spaces. From a technical view, they do not specify how they address the slow transaction times of the Bitcoin blockchain [35, 42].

2.2 Bitcoin Lightning

Bitcoin Lightning [34] is a payment protocol built on top of the Bitcoin network that settles transactions through a network of bi-directional payment channels. This offers several advantages over Bitcoin without compromising security the same way accepting 0-confirmation transaction would: near instant transaction speed, low transaction costs, and a significantly higher throughput [34]. It is particularly interesting in the context of point-of-sale payment systems as it provides an infrastructure layer that fulfills the core requirements. To our knowledge, there is no research in the HCI field exploring the use of Bitcoin Lightning.

From a technical perspective[1] Bitcoin Lightning can be described as a payment channel network built on top Bitcoin [47]. This architecture, in essence, allows participating nodes to carry out any number of transaction off-chain. Only the initial transaction to create a payment channel and the final transaction to close it are written to the blockchain [34].

The simplest element of the Lightning network is a payment channel between two Lightning nodes. Any two nodes can open a channel by committing an initial amount of Bitcoin to the channel. The initial creation of the channel is stored on the Bitcoin blockchain in the form of a special multi-signature transaction. By doing so, both parties can now send each other transactions by updating their balances and committing new transactions. Newer transactions invalidate previous ones. If the channel is closed – either bilaterally or unilaterally – the latest transaction is written back to the blockchain and reimburses the final balances to the respective owners [34, 47]. To make a payment between any two nodes in the network, it must be routed through a series of payment channels. For this, the Lightning network broadcasts all known channels between nodes. In contrast to Bitcoin, transactions cannot be sent directly to the receiving node. Instead, the receiver first needs to generate an invoice, which is valid for only a limited amount of time. The sender then determines a valid route through the network and a chain of payments is created. The sent transaction is secured by a cryptographic secret contained in the invoice. Only once the transaction reaches its final destination, can the participating channels finalize their channel transactions and redeem their funds [34, 47].

Bitcoin Lightning's design goals emphasize fast transactions at low cost. In practice, however, the network's typology plays a significant role on whether these promises can be met. With the Lightning network launching into Beta in 2018 and growing increasingly fast since then [21], first empirical research is emerging: Based on a longitudinal measurement study, Zabka et al. find that channel endpoints rarely cheat and behave fair. At the same time, the majority of channels in the Lightning network appears to be inactive [49]. Waugh et al. attempted to investigate the network's availability and reliability to route transactions in practice. In late 2019 they conducted a series of payments to different nodes within the network using amounts equivalent to USD 0.01 to USD 100. They report that while routes to almost all nodes can be constructed, routing payments in practice "*fail much too often, in particular when sending larger payments in excess of USD 50*" [47].

2.3 Summary

In the context of this paper, we build on several learnings from previous work. There is an emerging body of HCI research surrounding cryptocurrencies. However, there are only few studies exploring its use as a payment system. Those studies have focused only on Bitcoin so far. Over the past years cryptocurrency projects improving over the original design of Bitcoin have started to reach maturity, promising to solve many of the challenges described in literature (i.e. high fees, slow transactions). Bitcoin Lightning is one such protocol aimed at enabling low-cost and near instant transactions through an off-chain payment channel network. On paper, this makes Bitcoin Lightning an ideal payment layer for everyday point-of-sale transactions. However, we lack empirical evidence in how far these promises can be met in practice. The goal of this paper is to fill this gap by building a functional point-of-sale system with Bitcoin Lightning and evaluating it in a real-world context.

3 IMPLEMENTATION: PAYMENT SYSTEM

In this section we present design considerations, the architectural approach, and the implemented point-of-sale system.

3.1 Design Rationale

Our overarching rationale for building the system was to understand in how far Bitcoin Lighting is a viable option to be used as underlying payment layer for everyday point-of-sale transactions. The system described in the following could be equally realized by integrating existing proprietary payment providers such as PayPal[2] or Stripe[3]. The unique advantage cryptocurrency-based systems may offer in the future is their open ecosystem: Open systems that allow equal participation of people without restriction are beneficial to closed proprietary systems as they enable competition and innovation. Therefore, our goal in implementing a payment system with Bitcoin Lightning is not to directly compare it with existing more mature alternatives. Instead, we want to explore whether core properties of Bitcoin Lightning offer an acceptable experience to users when deployed as a functional point-of-sale system. With this objective in mind, we prioritized the use of state-of-the-art services and libraries during the implementation. The developed system should thus reflect a realistic deployment merchants can hope to achieve with service providers available at the moment.

3.2 Actors & Use Cases

Payment systems are typically used by two actors facilitating a transaction to exchange goods. Our system includes two actors: The CUSTOMER is interested in making a purchase. The MERCHANT interested in selling goods. We distinguish three use cases for how Bitcoin Lightning may be used during a checkout process: (1) in an online environment, (2) during a checkout process in a traditional brick-and-mortar store, and (3) during a self-service checkout process, such as vending machines. Table 1 details the different use cases and their flow of events.

3.3 Requirements

From the described use cases, we derive several functional and non-functional requirements. These requirements describe the envisioned behavior of the system, independent of its actual implementation [4].

3.3.1 Functional Requirements. We identify several functional requirements describing the system regarding the interactions with its surrounding environment, including the user [4].

[1]For an in-depth description of the technical architecture and the cryptographic mechanisms of the Lightning network, please refer to the original whitepaper by Poon and Dryja [34] and consult the resources on https://lightning.network/ (last-accessed: 2022-04-21).

[2]https://paypal.com/ (last-accessed: 2022-04-05)

[3]https://stripe.com/ (last-accessed: 2022-04-21)

Table 1: Use cases for Bitcoin Lightning for different types of checkout experiences.

Online Checkout	**Offline Checkout**	**Offline Self-Service Checkout**
Customer	Customer, Merchant	Customer
1. The customer opens the website of an online shop and adds one or several products to the basket.	1. The customer selects one or several products in the shop and brings them to the checkout counter.	1. The customer scans a QR code with their smartphone to open the website and adds one or several products to the basket.
2. The customer starts the checkout procedure, enters their shipping address, and selects Bitcoin Lightning as method of payment.	2. The merchant registers each product and, once completed, uses the wallet that is integrated in the shop system to generate a Lightning invoice.	2. The customer reviews the products in the basket, confirms the selection, and is presented with a Bitcoin Lightning invoice encoded in a URL.
3. The customer is presented with a Bitcoin Lightning invoice on the website and uses their mobile wallet to scan the QR code of the invoice.	3. The customer reviews whether the products were accounted for correctly, opens their wallet, scans the QR code of the invoice, and confirms the transaction.	3. The customer clicks on the URL to open their wallet or copies the invoice manually and then opens the wallet. After reviewing the transaction, they confirm it.
4. The customer confirms the transaction in the wallet. After a few seconds, the wallet and website show a confirmation.	4. After a few seconds, the customer and the merchant receive a confirmation of the transaction in their respective wallets.	4. After waiting a few seconds, the customer is presented a confirmation of the success of the transaction in their wallet.
5. The website redirects to a new page showing an order confirmation.	5. The customer takes their purchase and leaves.	5. The customer takes their purchase and leaves.

Notes. The entry condition for all three use cases is that both customer and merchant have a configured Bitcoin Lightning wallet with sufficient funds.

- **FR1: Inventory Management**. The system should provide a way for the merchant to add, remove, and keep track of their inventory of products.
- **FR2: Order Management**. The system should provide a way for the merchant to keep track of the orders made by customers and which status the orders are in.
- **FR3: Analytics and Reporting**. The system should provide the merchant with a way to analyze past sales.
- **FR4: Storefront Interface**. The system should provide an interface for customers to interact with / select products.
- **FR5: Transaction Processing**. The system should provide a way for merchants to issue Bitcoin Lightning invoices, to process incoming transactions, and associate them with orders.
- **FR6: Bookkeeping**. The system should provide a way to keep track of transactions for bookkeeping.
- **FR7: Wallet and Key Management**. The system should provide a way for the merchant to manage their wallet and their private keys.
- **FR8: Currency Conversion**. The system should provide the merchant with a way to convert cryptocurrency into fiat currency.
- **FR9: Payout**. The system should provide the merchant with a way to pay out their revenue to the traditional finance system, such as bank accounts.
- **FR10: Mobile Wallet**. The system should provide the customer with a way to pay with Bitcoin Lightning.

3.3.2 *Non-Functional Requirements.*

We additionally identify non-functional requirements that further "*describe aspects of the system that are not directly related to the functional behavior of the system*" [4] and contribute to the quality perceived by the user [7].

- **NFR 1: Security**. The systems should provide adequate security measures to both the merchant and the customer. Private keys should be stored encrypted. The system should provide ways to back up or recover keys.
- **NFR 2: Privacy**. The system should maintain the privacy of both the merchant and the customer. Transactions should not be visible to anyone who is not involved in them.
- **NFR 3: Usability**. The system should provide a usability comparable to existing point-of-sale system. Two aspects crucial to achieve this are affordable fees and near-instant transaction speeds. Additionally, the interaction flow during payment should be simple and quick to complete.
- **NFR 4: Availability**. The system should be able to process transactions without any major interruptions.

3.4 System Overview

Based on the functional requirements and the overall use cases, we decompose the system into four major subsystems with clearly defined responsibilities and interfaces: the shop system, the payment processor, the customer's mobile cryptocurrency wallet, and Bitcoin Lightning as settlement layer. Figure 1 provides a high-level overview of the subsystems and their interaction.

Shop System: The shop system bundles all functionality related to the management of products and the interaction between merchant and customer (FR1 - FR4). Merchants keep track of their inventory, manage outstanding orders, and review their order history. To customers, it provides a storefront to select products and initiate the checkout process.

Payment Processor: The payment processor bundles all functionality related to the processing and management of transactions (NFR5 - NFR9). It provides an interface to the shop system to initiate the payment process for an order, return the status of the respective transaction, and keeps a ledger of past transactions. Specific to Bitcoin Lightning, it provides an abstraction layer to deal with key management (NFR1) and the interaction with the Bitcoin Lightning network, such as the generation of invoices for specific orders. Additionally, it provides services for conversion of cryptocurrency to fiat currency and to transfer available funds to traditional bank accounts.

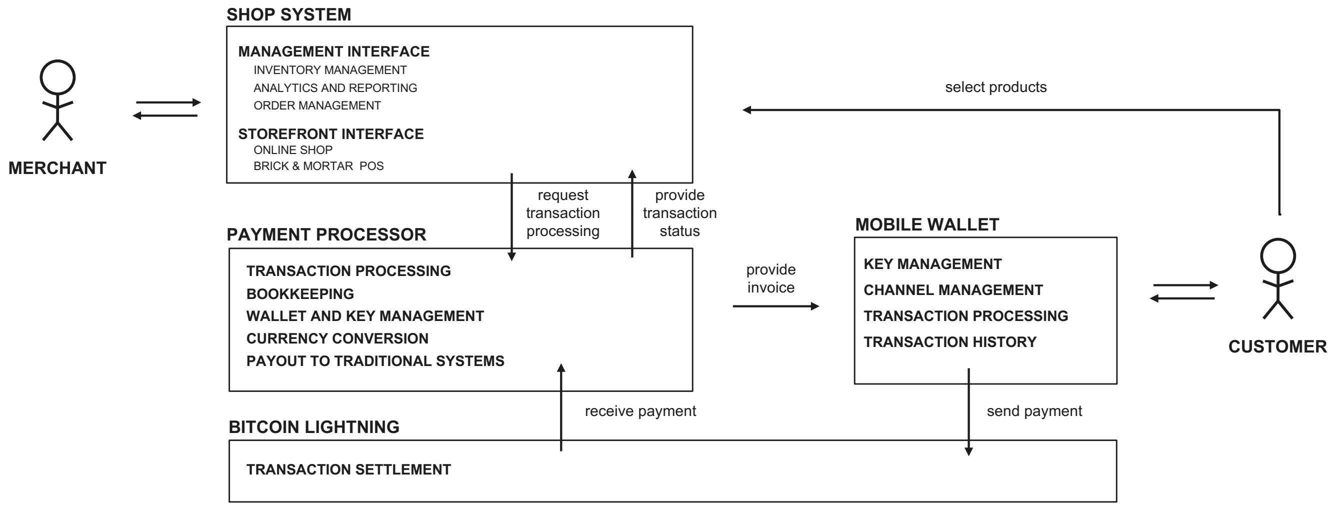

Figure 1: An overview of the subsystems.

Mobile Wallet: The mobile wallet (FR10) provides the customer with the necessary functionality to manage their Bitcoin Lightning funds and make payments with them. This includes the creation of the Bitcoin Lightning wallet as well as tasks concerning key management (NFR1), channel management, transaction processing, and a history of past transactions. The customer uses their wallet to open Bitcoin Lightning invoices – i.e. by clicking on a URL or scanning a QR code – and confirming and settling them via the Bitcoin Lightning network.

Bitcoin Lightning: The Bitcoin Lightning network provides the agnostic payment layer through which transactions are routed and settled (see section 2.2). By design it provides privacy (NFR2) for the involved parties as payments are settled off-chain.

An advantage of the described architecture is that the decomposition into separate subsystems leads to high cohesion within the subsystems and low coupling between them. For example, the PAYMENT PROCESSOR provides an abstraction over the actual type of payment used to settle a transaction. This means that alternative payments beyond Bitcoin Lightning could be integrated without affecting the SHOP SYSTEM. Merchants could also decide to switch their SHOP SYSTEM while keeping their PAYMENT PROCESSOR, not affecting the transaction history and bookkeeping. The interface between the PAYMENT PROCESSOR and the customer's WALLET is provided as a standardized Bitcoin Lightning invoice. This gives customers free choice which actual wallet to use instead of being locked in to the proprietary solutions of centralized payment processors. Thus, users have the option to choose the right wallet for them, with differing degrees of self-managed to custodial options available on the market[4].

3.5 Implementation: Self-Service Checkout

We realized the described system with an **Offline Self-Service Checkout** use case (see Table 1) in mind while keeping our implementation open for future extensions. As described in our design rational, we wanted to keep the implementation close to a real-world deployment merchants can achieve with service providers available today.

Shop System: Targeting a self-service checkout use case in an offline environment, we simplified the shop system to its minimum. We printed QR codes encoding URLs redirecting to check out websites of the respective products. This approach is comparable to using QR codes to PayPal accounts to collect payments. While simple, this system fulfills the needed requirements to evaluate the overall system.

Payment Processor: We integrated Opennode[5] as Bitcoin Lightning payment processor. Opennode is one of the leading services for processing payments with Bitcoin and Bitcoin Lightning. It met the requirements we needed for the payment processing subsystem, allowed for quick integration, and future extensibility of the system as it offers a rich set of API endpoints as well as integrations to established shop systems such as Shopify[6]. Our design choice to select a payment processing service instead of running our own Bitcoin Lightning node has several reasons: First, considering our design rationale it is not realistic to assume that most merchants have the required technical knowledge or resources to deploy, manage, and integrate a full Bitcoin Lightning node on their own. The more likely scenario is that they would look for services that provide the needed functionality and plug into their shop system without much extra effort. Second, using a professional payment processing service has advantages considering the network architecture of Bitcoin Lightning. Their nodes are likely to be better connected within the

[4]The following blog article provides an overview of different architectures of contemporary Bitcoin Lightning wallets for the interested reader: https://www.veriphi.io/en/blog/lightning-wallet-architecture (last-accessed: 2022-04-21)

[5]https://www.opennode.com/ (last-accessed: 2022-04-21)
[6]https://www.shopify.com/ (last-accessed: 2022-04-21)

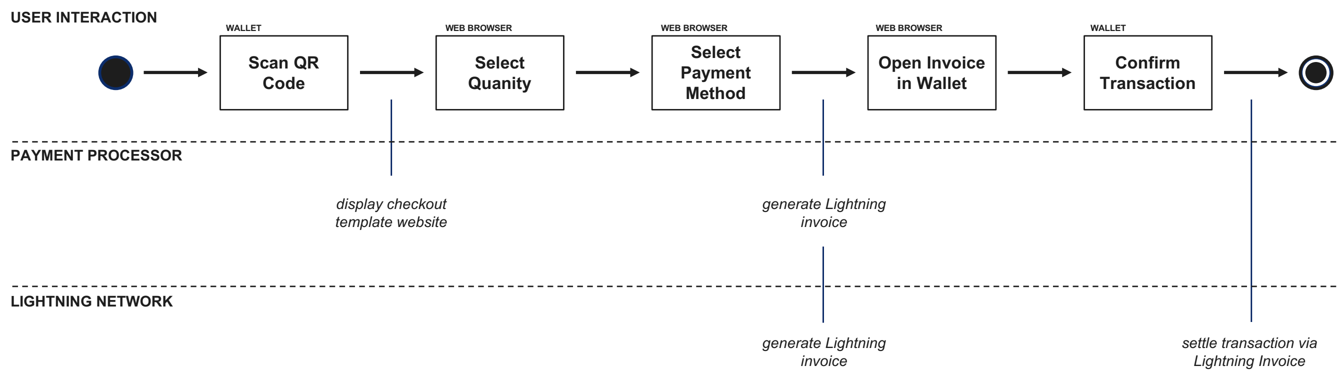

Figure 2: Interaction flow for making a purchase using the implemented payment system for the self-service checkout flow.

payment channel network and thus, we expect that transactions can be routed more reliably and more quickly.

Figure 3: Interface of the mobile Bitcoin Lightning wallet (based on bluewallet.io).

Mobile Wallet: To be able to holistically explore how users would interact with the system, we also deployed a mobile wallet. After evaluation of different open source projects, we created a fork of the popular Bitcoin Lightning wallet BlueWallet[7], and modified it to be able to collect usage logs. We were careful not to change the app interface to provide a realistic baseline of the experience users can expect today when using Bitcoin Lightning. Figure 3 provides an annotated overview of the mobile wallet interface. The modified app provided users with a non-custodial Bitcoin wallet and a custodial Bitcoin Lightning wallet. Following a similar reasoning as for choosing to use a payment processor, a custodial wallet provider is likely better connected within the Bitcoin Lightning network. Thus, it provides less risk of transactions not being able to be routed to their destination.

[7]https://bluewallet.io/ (last-accessed: 2022-04-21)

3.6 Interaction Flow

Following the defined non-functional requirements, our aim was to create a simple and quick checkout process. Figure 2 provides an overview of the interaction flow between a CUSTOMER and the system during the checkout process. Figure 4 provides screenshots of the implemented user interfaces during the checkout process. The entire process takes five steps: The entry-point to the self-service payment is provided as a QR code linking directly to the checkout website, presenting the product. After (1) scanning the QR code, the customer (2) selects the desired quantity of the product, (3) selects the desired payment method (Bitcoin or Bitcoin Lightning), and then (4) opens the invoice in their wallet where they (5) confirm the transaction. As a consequence of the decoupled subsystem design, step 2 to 4 are completed in a web browser and only the final step is completed in the wallet of the customer. As the user walks through this checkout process, the Bitcoin Lightning invoice is generated dynamically through the PAYMENT PROCESSOR and the Bitcoin Lightning Network. The process is completed, once the transaction is settled through the Bitcoin Lightning network. One caveat, evident from the process is the need to generate the invoice dynamically. It can be generated only after the customer selected the required quantity of the product. It is not possible to provide a permanent invoice that can be reused.

4 EVALUATION

To evaluate the system, we conducted a two week-long mixed-method study in March 2022. Prior to the start, we obtained approval from the ethics board of our university (ID: EK-MIS-2020-018). 31 people participated in the study. Participants first completed a setup study comprising the initial setup of their wallets and first usage of the system, comparable to laboratory studies used in previous studies (e.g. [3, 15]). Once the system was set up, they used it over the course of two weeks to purchase drinks and coffee in an office environment. The overall goal of the evaluation was to understand whether the developed system met the requirements to be used as point-of-sales systems.

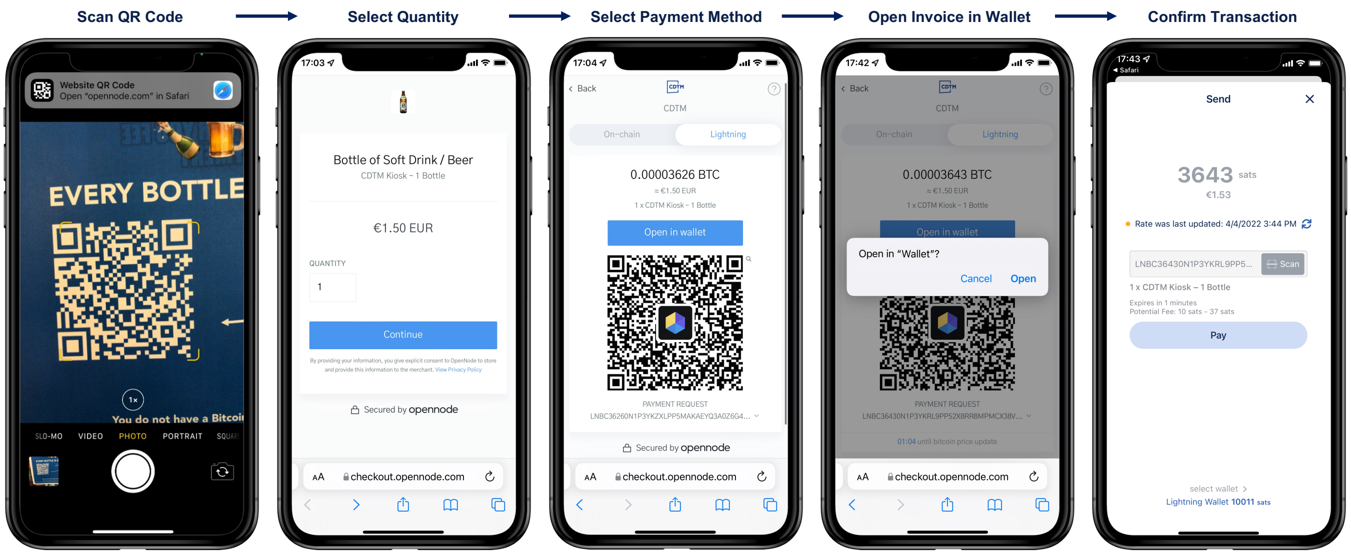

Figure 4: User interfaces for the realized interaction flow for purchasing one product for the self-service checkout.

4.1 Participants & Context

We conducted the study at a research and educational institute associated with a German university. We recruited participants from the staff and a cohort of students in the associated program. Unlike in a traditional university setting, all participants worked full time (Monday - Friday) and in presence at the institute, resembling the context one would find in typical offices spaces. We recruited in total 31 participants. The participants' educational background varied from undergraduate to postgraduate degrees in computer science and engineering (15), business administration (11) and other study backgrounds (5). Participants were between 20 and 34 (mean of 24.55) years old. 61.3% were male and 38.7% female.

4.2 Data Collection

We combined several methods to obtain a rich understanding during the evaluation. Figure 5 provides an overview of the study procedure and the collected data.

4.2.1 Methods. Throughout the study, we collected data from various sources and combined several methods to do so. During the setup study, we used an adopted think-aloud protocol. Participants were assigned in groups and recorded one another while completing the tasks and sharing their thoughts aloud. After each task we collected data with questionnaires including open and closed questions. At the end of each week, we collected additional data with questionnaires including open and closed questions. We complemented the structured data collection with ethnographic methods. We occasionally observed participants as they were using the system and inquired about their experiences. Finally, we collected usage logs from the mobile wallet and the payment processor.

4.2.2 Apparatus. Our apparatus comprised the implemented system described in section 3.5, an instruction guide for the tasks during the setup study, and several questionnaires. Table 2 provides an overview of the different measures collected with questionnaires. We collected demographic data (age, gender, educational background). We used the Single-Ease-Questionnaire (SEQ) [40] as a quantifiable measure to proxy the perceived usability of the system. Users were asked to rate on a scale from 1 (very easy) to 7 (very difficult) how they perceived the respective task (during the setup study) or using the system over the past week (in the weekly questionnaire) – i.e., "*How difficult or easy did you find using Bitcoin Lightning as payment system?*". As recommended [39], we followed with an open question asking participants "*What made you choose this number?*" to elicit qualitative insight. Similarly, we used one item out of the User Experience Questionnaire (UEQ) [27] to measure the perceived speed of the system by asking users to rate it on a scale from 1 (fast) to 7 (slow). Additionally, we collected task completion rates, the number of times participants used the

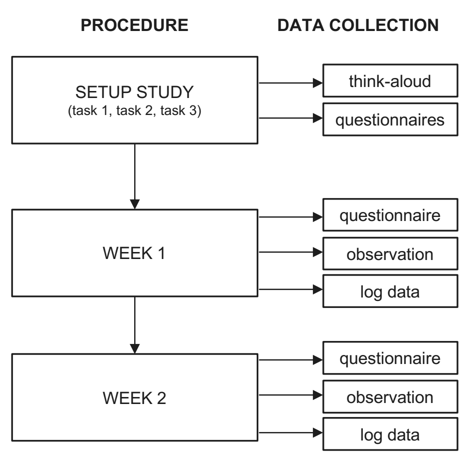

Figure 5: Overview of the study procedure and the collected data.

system over the past week, and queried for encountered problems, positive moments, and suggestions for improvement with open questions.

Table 2: Overview of the data collected with questionnaires.

		T1	T2	T3	W
demographics	multiple			•	
task completion	y/n	•	•	•	
SEQ	scale (1-7), text	•	•	•	•
fast vs slow	scale (1-7)			•	•
no. times used	number			•	•
open questions	text			•	•

4.2.3 Procedure. Our evaluation is comprised out of two phases: The initial setup study and the subsequent usage of the system over the course of two weeks. During the setup study, participants had to complete three tasks: (T1) create a bitcoin wallet and buy bitcoin, (T2) create a bitcoin lightning wallet and transfer bitcoin onto it, and (T3) make a first purchase with the wallet. Participants formed groups of two, recording each other with smartphone cameras while following a think-aloud protocol. After completion of each task, participants individually filled the respective task questionnaire. We chose these tasks because they represent the first steps users would need to take to use Bitcoin Lightning as a means of payment. After completion of all three tasks, we distributed EUR 40 in Bitcoin to the participants as compensation for participating in the study.

Over the course of the next two weeks, participants were free to purchase coffee (EUR 0.5) and an assortment of beverages (EUR 1.5) with the deployed system. At the end of each week, a questionnaire was distributed to participants to inquire about their experience.

5 RESULTS

We collected in total 116 qualitative statements, including 236 relevant coded statements. Complemented by quantitative measurements, we present the results of the evaluation of the system. Table 3 provides an overview of the quantitative metrics describing the usage behavior and the perception of the system.

Our point-of-sale system offered participants the opportunity to purchase beverages and coffee using Bitcoin Lightning as a payment method. In total 896 app sessions and 202 payments were conducted by participants over the course of the study. The majority of app session happened within the first week, whereas the majority of transactions happened in the second week. The difference in app sessions can be explained by the additional interaction needed during the setup procedure. On average, each participant made 3.0 purchases during the first week and 4.21 purchases in the second week (min=0, max=10 for both weeks).

5.1 Ease of Use

We observed a stark contrast in the perceived ease-of-use during the setup study and the subsequent use. In particular, the purchase of Bitcoin (T1) and transfer to their Bitcoin Lightning wallet (T2) was perceived as cumbersome and frustrating by many participants. In part, this is reflected in the task completion rates (c.f. T1, T2, T3) and the difference in SEQ scores (c.f. T1, T2 vs T3, W1, W2).

Table 3: Overview of the collected quantitative metrics during the evaluation.

		T1	T2	T3	W1	W2
task completion	quest.	57%	91%	95%	–	–
SEQ	quest.	3.00	3.10	2.30	2.35	2.42
fast vs slow	quest.	–	–	3.95	3.74	3.88
mean times used	quest.	–	–	–	3.00	4.21
total transactions	logs	–	–	–	86	116
total app sessions	logs	–	–	–	706	190
mean session time	logs	–	–	–	59s	34s

Notes. The high number of app sessions in W1 can be attributed to the initial setup procedure. Testing with ANOVA, the difference in SEQ scores between T1, T2, T3, W1, W2 are not statistically significant ($F(4, 110) = 1.495, p = 0.209$). Likewise, the difference in fast-slow scores between T3, W1, W2 are not statistically significant ($F(2, 64) = 0.082, p = 0.921$).

43% of participants could not complete the first task, purchasing the equivalent of EUR 40 in Bitcoin [8]. In the majority of cases, the cause was related to payments for the purchase of Bitcoin being declined by the banks or credit card issuers of the participants or issues during the Know-Your-Customer (KYC) id verification. One participant described their experience, "*The onboarding went well and was easy, until the transaction got blocked by the bank. After unblocking the credit card, we retried the transaction and the card got blocked again*". It was surprising to see that this was not an isolated issue, but affected multiple participants across several German banks. Another participant stated, "*For me, it did not work with BANK1 and BANK2 credit cards. Although the id verification process was successful, the transaction did not work. I tried it several times with no success.*" (bank names redacted). For other participants, purchasing Bitcoin was halted by the KYC process. For example, "*when trying to purchase Bitcoin, I was supposed to receive an email to confirm my identity within 60 seconds. Even several hours later, it has not arrived.*". While many participants had issues during the process and found it tedious, there were also some for whom it worked well, e.g. "*The money transfer was easily done by Apple Pay.*" or "*I have transferred coins from another wallet, so the process was very easy.*".

Looking at the ease-of-use after the setup, there was a notable decrease in perceived difficulty once participants had a set-up Bitcoin Lightning wallet. SEQ scores decreased from 3.00 and 3.10 (T1, T2) to 2.30, 2.35, and 2.42 (T3, W1, W2). The collected qualitative data and our observations back up the SEQ measures: Participants found it overall easier to use the system for payments than to initially configure and fill their wallets. For example, participants stated, "*Having the transaction go through for the first time was quite fun, especially after the boring and time-intensive setup.*", or "*After the first successful payment, it is pretty straightforward.*", or "*Once everything is set up, the payment itself is very simple and fast.*".

In addition, the collected data contained comments related to different aspects of the user experience that are not directly related

[8] If participants were not able to finish task 1 (e.g., because their credit cards were declined) we sent them the compensation for participating in Bitcoin after task 1, so they could continue the study.

to Bitcoin Lightning. Examples include the load performance of the app, the structure of the user interface, or the interaction flow during the checkout process. For example, we received comments complementing the user interface and others criticizing it to be "*not very intuitive*". While most of the reported issues in this category can be addressed by iteratively improving the system in line with design guidelines and software engineering best practices, one criticized aspect cannot without implementing an entirely different payment layer: Several participants argued that the checkout process is too complicated, involving too many redirects, and they would rather "*scan the QR code directly in the wallet and pay*". The underlying architecture of the Bitcoin Lightning network requires invoices to have an expiry date. Thus, they can only be generated dynamically once the final payment amount in known, making a static invoice for now infeasible.

5.2 Perceived Transaction Speed

We measured the perceived speed of the system by surveying participants in the questionnaires after the setup study, after week one, and after week two (1=fast, 7=slow). The mean ratings provided by participants revolved around the center of the scale, slightly tipping to the 'fast' side (T3=3.95, W1=3.74, W2=3.88). Based on the recorded usage logs, we can further see that app sessions on average took 53.86 seconds. The average session length decreased from 59.29 seconds in week one to 33.67 seconds in week two. Looking at the second week in particular, we can see that the app was used in 61% of cases to make payments: 190 app sessions resulted in 116 transactions. Our observations as well as participants comments in the weekly survey are in line with these measurements, indicating that the overall checkout process takes around 30 to 60 seconds beginning to end. With regards to whether this speed was acceptable to participants, we received both supportive and opposing comments. On the positive side, participants stated, "*It is quick and easy.*", "*It only took like 30s!*", and "*The transaction went through really quick!*". Others perceived this as too slow: "*It should be faster!*", "*It is a bit annoying that it always takes around 10 seconds for the payment to go through.*", or "*Sometimes there's a lag in the transaction, and it takes a little longer than I'd like for the payment to complete*".

One additional aspect captured during our contextual observations was a notable increase in transaction speed during the second half of week two. One participant reported, "*The app seems to work quicker, or maybe this is only a feeling after getting used to it.*". We observed that during the first week, transactions would take between 10-20 seconds to complete after an invoice was scanned and confirmed in the wallet of a user. This suddenly changed during the second week, at which point transactions across all users would take only around 4-6 seconds. This change was particularly noticeable as the user interface of the deployed mobile wallet would previously time out after about 20 seconds and ask users to check back later. After that point, the wallet provided a confirmation of the transaction's success and automatically closed the screen. This change did not go unnoticed: One participant remarked, "*Lightning transactions are now completed within seconds and a confirmation of the transaction is shown.*", and another one, "*Transactions worked smoothly, the payment process got faster.*".

5.3 Transaction Fees

Another relevant aspect for deploying point-of-sales systems affecting users' adoption are transaction fees. Overall, two types of fees were charged during the study in the current implementation: First, the payment channels involved in forwarding a transaction in the Bitcoin Lightning network can announce fees. Every channel can announce fees with a fixed component and a variable component. Consequently, the calculation of the exact network fee for a specific transaction depends on the amount transferred and the channels through which it is routed. In addition, the implemented payment processor, Opennode, charged a 1% fee for every incoming transaction. This 1% fee, however, is not visible on the customer's side, as it is deducted from the incoming payment the merchant receives. Thus, as with other cryptocurrencies, only transaction fees relating to the network have to be paid by the sender, i.e. the customer.

In line with these expectations, we observed that the full cost for transactions were slightly higher than the charged price (in EUR) due to the network fees. Typically, the price would be 1-2 cents over the purchase price, meaning 1.51 or 1.52 EUR for a drink sold at 1.5 EUR, and 0.51 or 0.52 for a drink sold at 0.5 EUR at the time of sale. Participants did not specifically complain about the size of the fee charged for transactions. However, they identified the need to pay fees as a clear disadvantage over alternative solutions. For example, one person described the fees as simply "*unpleasant*" and another one stated, "*One thing I don't like is the transaction fee, which wouldn't occur if we would simply use Paypal.*".

Bitcoin price volatility was another aspect that surfaced in our dataset. Depending on the Bitcoin-EUR exchange rate at a specific time, a different amount of Bitcoin would be charged to equal the fixed product prices in EUR. Looking at the recorded transaction data, there was a 15 point difference between the lowest (90.6%) and highest price paid for a transaction (105.6%) when compared to the mean (100%). Some participants expressed that they experienced this volatility negatively. For example, one participant said when asked whether they could imagine using Bitcoin Lightning in the future, "*The Bitcoin price would have to be more stable, I want my coffee to be the same price every day.*".

The user interface in the wallet allowed participants to view their available funds and past transactions in either Bitcoin, Satoshi[9], or Euro. If set to Euro, past transaction values were shown based on the current exchange rate, e.g. at EUR 1.52, 1.58, or 1.36, not the exchange rate at the time of purchase. From a users' perspective, it was thus not really possible to distinguish easily between the paid price and the associated transactions fees. This further irritated participants. One explained, "*It is irritating that the value of the payment in the past is changing as well. I would rather like to have a fixed amount of money, as this reduces risk for me as a user and additional stress of not knowing how much I can buy in the future.*".

5.4 Reliability

Over the entire course of the study, we observed that transactions could be successfully routed most of the time. We asked all participants to report any error messages they would receive throughout using the app when making payments. We received only one report

[9] One satoshi refers to the smallest denomination of bitcoin, equivalent to 100 millionth of a bitcoin

of a transaction failing connected to issues with the Bitcoin Lightning network, due to an (apparent) "*lack of inbound capacity of the receiver along the payment channel route*". However, by scanning the invoice again, the participant could almost immediately send their payment at the second try. However, throughout the setup study, we observed that for many participants the mobile wallet would return API Errors. These errors were not caused by the Bitcoin Lightning network, but the API of the custodial Bitcoin Lightning wallet on the user's side. If that happened for a user, their wallet would not be able to send Bitcoin Lightning transactions for around 15 minutes. One participant explained, "*I was confused by an API error that didn't allow me to transfer from bitcoin to lightning. But after some time it worked fine.*". These errors were in effect due to exceeded rate limits against the custodial wallet API, and largely subsided within the first week. While we could not pinpoint what caused the excess of the rate limit, we speculate that all deivces

"*I didn't experience technical issues last week.*"

6 FINDINGS

6.1 General Usage Behavior

Our point-of-sale system offers participants the opportunity to purchase beverages using Bitcoin Lightning as a payment method.

An assortment of 12 different bottled drinks was available in the common area fridge for all participants to access at all time. We made sure that the fridge was restocked on a daily basis and adapted the type and quantity of drinks available to the feedback of the users (weekly survey). Each bottle could be purchased for the Bitcoin Lightning equivalent of EUR 1.50. Furthermore, users could purchase coffee from a semiautomatic coffee machine also available to everyone at all time. We serviced the machine and all of its components on a regular basis and made sure that coffee beans and different kinds of milk and sugar were always available. A coffee serving could be purchased for the Bitcoin Lightning equivalent of EUR 0.50.

In the seven-week span of the study, we sold a total amount of 732 drinks, combining bottles (60%) and coffee (40%) together. Drink consumption was relatively constant from Monday to Friday, with clear lows over the weekends (90% decrease in consumption). During workdays (Monday to Fridays) we had an average consumption of 20.14 drinks per day with no clear change between weekdays. The first week stands out with a 30% lower average consumption, which clearly reflects the adoption time of the participants.

Clearly visible on the fridge door and next to the coffee machine, we hanged a dedicated QR code for payment. Payment was not enforced in any way, hence participants managed their payment behavior themselves. Participants could use our app to scan the QR code, choose a multiple of the desired drink (bottle or coffee) and pay using the Bitcoin Lightning wallet. In the span of the seven-week study, we received a total amount of 609 payments, with an average of 1.2 drinks per payment. 90% of all transactions paid for a single drink and 10% for two or three drinks. This suggests that participants though of the system as convenient enough to portray their individual transaction instead of making bulk payments. We received an average of 16,8 payments per day, with the same deficit during the first week as reported before.

	Average	**STD**	**Min**	**Max**
Change Rate [BTC/EUR]	26,34	01,70	23,21	28,96
Transaction Fee [BTC]	00,39	00,28	00,08	3,61

Table 4: Transaction costs scaled by E-06

During the progression of the study, we had a variable change rate for Bitcoin Lightning; the maximum was achieved on March the 7th, with a decreasing tendency as the study advanced. The minimum was achieved on March the 28th (Table 4). Transaction fees varied a lot more, with an average of 3,39 E-07 BTC. We did not see any dependency on the number of transactions and the change rate of Bitcoin Lightning, suggesting that the participant's purchase behavior was independent.

6.2 System Usability

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6.3 User Perception

7 DISCUSSION

In this paper, we present the implementation of a point-of-sales system built on Bitcoin Lightning and its evaluation in a mixed-methods field study. Our evaluation shows that it worked reliably throughout the study, and users had no major problems using the system for payments once they had a configured wallet. However, it also showed that the initial process of setting up the wallet and getting started is difficult for many users. This discussion aims to reflect on these results and highlight implications for future research and practice.

7.1 System Performance

Considering the overall results collected during our evaluation, we find that the system provided an acceptable experience. Throughout the observed period, transactions were reliably settled over the Lightning network. While the transaction speed was slow-moving at the beginning of the study, its increase in the second half of week two points to the advantage of utilizing central nodes within the network to improve performance. Most users deemed the transaction fees of 1-2 cents acceptable, as only few participants complained about them. This said, all of these aspects – perceived usability, transaction fees, and transaction speed – leave room for improvement. Especially during the setup study, several problems and challenges surfaced that underline the conclusions made by previous work (e.g. [14, 15, 20]): There is a need to improve the onboarding experience of new users – an aspect where the HCI community is uniquely positioned to contribute to. Additionally, we observed that the interface to established systems like banks or identity verification providers remain a major cause of friction [15]. Upcoming regulations surrounding cryptocurrencies could both be a catalyst for addressing these issues, or lead to more restrictive measures. While the achieved transaction speed of 4-6 seconds is in itself comparable to existing systems, the interaction flow it is embedded in was perceived as complicated by users. While permanent invoices are not technically feasible for now, a recent proposal aims to change this by extending the Bitcoin Lightning protocol [37].

7.2 Adoption Considerations

Reflecting on our experience developing the system, we found that the decision of using a payment processing services made it relatively easy to integrate and accept Bitcoin Lightning payments. We argue, that merchants without much technical expertise would be able to implement such solutions, i.e. through plugins to popular shop system such as Shopify. One downside of using a service provider instead of running a dedicated Bitcoin Lightning node is that a merchant would arguably not exploit the full benefit of decentralization and would have to pay fees to the service provider. Dealing with these tradeoffs between the independence of decentralization and scale effects of using centralized services connects to the emerging phenomenon of reintermediation [17, 43] seen in many blockchain related applications. Taking a business perspective, the question for merchants remains whether accepting Bitcoin Lightning or other cryptocurrencies is economically beneficial and sustainable in the long run. As new payment solutions generally face a cold start problem [6], it remains questionable whether users are motivated to change from established solutions to Bitcoin Lightning if both choices are offered. From the customer's perspective, except for edge cases, there is little to no advantage using Bitcoin Lightning at the user experience level compared to centralized solutions. Today systems like PayPal appear to offer a better value proposition: free transactions for individuals, wide acceptance, fiat currencies without price volatility, and a buyer protection. While many of these features are not yet available, we believe that the current state of the technology allows for them to be built on top of the open ecosystem that Bitcoin Lightning (or other cryptocurrencies) offers.

7.3 Limitations and Future Work

This paper provides a first evaluation of Bitcoin Lightning for an offline point-of-sale use case. Our study is not without limitations and leaves room for future research. Our study ran for only a short time and was tested with a small basket size (typically EUR 0.5 to EUR 1.5). A benchmark study of the Lightning network [47] showed grave differences in network reliability depending on the size of a transaction. Exploring scenarios with higher item values would be interesting not only to understand the technical limitations of Bitcoin Lightning, but also whether users would expect features such as cash-backs common with many credit card providers today.

Additionally, our evaluation focused primarily on the system performance and did not explore participants' experience using Bitcoin Lightning in depth. Particularly during the adoption of new technologies, users may be motivated to engage due to more than pure functional benefits. Building on recent ethnographic research on centralized alternative currencies [32], future work may disassemble the social experiences of everyday cryptocurrency use (e.g. around trust, anonymity, decentralization, volatility and perceived environmental impact) in more detail.

Thus, there are exciting opportunities for HCI scholars to explore lived user experience during the adoption of cryptocurrency based payment systems over longer periods of time and in different contexts. Particularly the recent real-world deployment of Bitcoin-Lightning in some regions around the world offers interesting opportunities to study the use of cryptocurrencies in the field.

8 CONCLUSION

This paper presents design considerations and a reference implementation for a point-of-sale (PoS) system using Bitcoin Lightning as underlying payment layer. The evaluation of the system in a mixed methods study shows that low-value transactions can be reliably routed via the Lightning network, and users found making payments reasonably easy once they had a configured wallet. Setting up the wallet and initially acquiring Bitcoin was, however, prone to different challenges, highlighting the need to research on how to decrease entry barriers to cryptocurrencies. We examine the performance of the system with regards to ease-of-use, speed, transaction fees, and reliability and discuss implications for adoption of cryptocurrency based payment systems.

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