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Design and Implementation of a Microtransaction System Using the Lightning Network for Financial Inclusion in Developing Countries

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Abstract

Bitcoin has gained widespread acceptance within the cryptocurrency community, and the Lightning network, an innovative and scalable extension of Bitcoin, is demonstrating remarkable advancements in electronic payments. The Lightning network addresses the historical criticisms of Bitcoin by facilitating rapid transfers at reduced costs, addressing scalability concerns. However, despite its potential, integrating the Lightning network into diverse systems has proven challenging due to inherent system heterogeneity. This study seeks to overcome these challenges by contributing to the effective implementation of a micropayment system, specifically targeting microtransactions involving individuals outside developing countries, with a focus on the diaspora regularly transferring money to their loved ones. Our objective is to establish a decentralized microtransaction system in Burkina Faso, within the broader context of pursuing monetary independence. We have developed and implemented a prototype microtransaction system, leveraging a transfer application that combines the Lightning network blockchain and mobile money. This unique solution not only integrates local African currencies but also enables direct payments for services and goods at local establishments, fostering economic inclusivity and financial autonomy.

Keywords

Micropayment, Lightning Network, Mobile Money

1. Introduction

1.1. Background and Problem Statement

The substantial financial support from the African Diaspora plays a pivotal role

in driving the economic development of numerous countries on the continent. Remittances to Africa constitute a noteworthy portion of the Gross Domestic Product (GDP) in several nations, contributing significantly to the enhancement of living standards and the stimulation of economic growth [1]. These monetary transfers not only directly benefit the recipients but also foster local investment and the establishment of businesses, thereby fortifying the economic infrastructure of the countries. Despite the undeniable value of this contribution, the efficiency of money transfer systems to Africa encounters considerable obstacles. The diversity of currencies, the volatility of exchange rates and the imposition of high fees [2]-[4] on international transfers further impede the smooth flow of these financial transactions. In the face of these challenges, the emergence of cryptocurrencies presents a promising avenue for potential solutions [3] [5]-[8]. Cryptocurrencies, with their decentralized nature and capacity to transcend national borders, offer an opportunity to streamline international money transfers [9]. They hold the potential to reduce transaction costs, expedite transfer processes, and circumvent the exchange rate fluctuations commonly associated with traditional systems.

1.2. Objectives of the Study

In response to the identified challenges, this paper seeks to address a fundamental research question: What factors can enhance the operationalization of microtransactions to Africa, leveraging the blockchain Lightning Network layer? The primary objective of this research is to establish a decentralized microtransaction system in Burkina Faso, situated within an evolving landscape that emphasizes the pursuit of monetary independence. This undertaking has enabled the development of a functional microtransactions system, seamlessly integrating the Lightning Network with mobile money technologies.

1.3. Contributions of the Work

This work makes significant contributions by introducing an innovative microtransaction system in Burkina Faso, integrating the Lightning Network [10] and mobile money technologies [11] [12]. The system utilizing blockchain [13], fosters financial inclusion [3] [14] by allowing direct payments in local African currencies, thereby promoting economic empowerment and entrepreneurship. Beyond its technical innovation, the research contributes to the pursuit of monetary independence in Burkina Faso, strengthening the economic infrastructure and mitigating challenges associated with traditional money transfer systems. The decentralized nature of cryptocurrencies, exemplified by the Lightning Network, offers potential solutions to issues such as high fees, regulatory complexities, and exchange rate fluctuations. Ultimately, this work empowers local communities, facilitates efficient remittance flows from the African Diaspora, and demonstrates the transformative potential of blockchain technology in fostering economic development.

2. Literature Review

2.1. Financial Inclusion in Developing Countries

In the realm of financial inclusion in developing countries, insights from various authors shed light on the substantial impact of mobile money. According to D. Victor [11], mobile money covers over 70% of the population, with providers increasingly incorporating blockchain technology to enhance security and transparency while introducing novel services. The synthesis of mobile money and blockchain, as highlighted by Victor, not only showcases improved security features but also opens avenues for financial inclusion and innovation. Additionally, Djamchid Assadi and Anaïs Cudi [12] conducted a comprehensive study on microfinance and M-Banking services, revealing their role in expanding access to mobile financial services for the unbanked in both developed and developing countries. Their findings emphasize the potential of such initiatives to reduce transaction costs and increase financial accessibility for underserved populations.

2.2. Mobile wallet

Mobile money refers to the use of cell phones to carry out financial transactions, such as sending and receiving money, paying bills and purchasing goods and services. It is widely used in many developing countries where traditional banking services are not widely available. We have explored authors who have carried out studies on mobile money. We present a summary of their studies in **Table 1**:

Table 1. Summary of work on the coin purse system.

Djamchid Assadi, Anaïs Cudi [12] 2011	The financial inclusion potential of mobile banking. An exploratory study	
	Issue: Microfinance and the introduction of M-Banking services to unbanked populations in developed and developing countries	Benefit: Access to financial services for the unbanked via cell phones and lower transaction costs.
Dibia Victor [11] 2014	On the user-centric Evolution of Mobile Money Technologies in Developing Nations: Success and Lessons	
	Issue: Review of the evolution of mobile wallets in developing countries through key players	Contribution: More than 70% of the population is covered by mobile money.

Among the authors explored, D. Victor [11] argues that over 70% of the population is covered by mobile money. According to him, in some cases, mobile money providers are integrating blockchain technology into their platforms to create new services and improve security and transparency. Overall, it emerges that the coexistence of mobile money and blockchain can create new opportunities for financial inclusion and innovation. Djamchid Assadi, Anaïs Cudi [12], have conducted an exploratory study on microfinance and the introduction of M-Banking services to unbanked populations in developed and developing countries,

where they contribute to increasing access to mobile financial services for the unbanked and lowering transaction costs.

2.3. Banking and Blockchain

Our review of the literature on banking and blockchain gives us a very interesting overview of the various works that have been published:

- assessing the integration of blockchain in the banking system

Many authors have conducted studies on the integration of blockchain into the banking system. Among them, L. Cocco [14] and Osmani [3] have posed the problem of high banking transaction costs, lengthy banking procedures linked to the long chain of actors that must intervene, as well as the security and trust issues facing the banking sector. Osmani [3] goes further by phasing the assumptions related to the integration of blockchain into the banking system and highlighting the different possibilities, the integration approach to be followed as well as the existing limitations related to Table 2.

Table 2. Evaluation, advantages and limitations of hypotheses for integrating blockchain into the banking system [3].

Hypothesis	Evaluation	Approach	Limits
Lower costs and shorter treatment times	Yes	-Eliminating intermediaries	Need for greater commitment from all parties to this technology Exciting transaction costs
Increased safety	Yes	-Use of cryptographic algorithms Multiple computers working constantly to guarantee network security (mining)	Risk of network corruption if 51% of network computers are corrupted Technology often perceived as volatile
Increased confidence	Yes	Distributed system	Difficulties arising from trial-and-error regulation in this area

- work in the field of Blockchain applied to finance

Other authors have made significant contributions on the application of blockchain in the banking sector. We present a summary of our readings in Table 3.

Table 3 presents articles that address the use of Blockchain technology in the banking sector. The various authors identify a specific problem related to the banking industry and propose solutions based on Blockchain technology. The first article, by Mark Buitenhek [15] focuses on improving settlements, payments and identity services through smart contracts. Smart contracts are self-executing computer programs that automatically transfer digital assets when predefined conditions are met. This solution can help speed up settlement and payment processes, while improving transaction security. The second reference, by Tejal Shah, Shailak Jani [16], explores the applications of Blockchain technology in banking transaction security. The authors propose an exploratory study to

Table 3. Summary of work in the field of blockchain applied to finance.

Mark Buitenhek [15] 2016	Understanding and applying Blockchain technology in banking: Evolution or revolution?	
	Issue: Improving settlements, payments and identity services	Contribution: smart contract system
Tejal Shah, Shailak Jani [16] 2018	Applications of Blockchain Technology in Banking Finance	
	Issue: Banking transaction security	Contribution: Exploratory study
Seybou Sakho [13] 2019	Improving Banking Transactions Using Blockchain Technology	
	Problem: Solutions to problems of trust, latency, high costs, data theft.	Contribution: system using the Hyperledger blockchain,
Mouad Zouina [17] 2019	Towards a distributed token-based payment system using blockchain technology	
	Issue: Preventing identity theft using payment cards (PAN, CVV)	Contribution: Mobile application Combining banks and blockchains
B. Patel and S. Li [9] 2020	The role of blockchain in banking Future prospects for cross-border payments	
	Problem: Blockchain as a means of setting up consortia of financial institutions.	Contribution: Exploratory study

understand how Blockchain can help enhance transaction security and prevent fraud. The third reference, by Seybou Sakho [13], focuses on improving banking transactions by solving the problems of trust, latency, high fees and data theft. The author proposes using Hyperledger Blockchain technology to create a decentralized and secure solution for banking transactions. The fourth, by Mouad Zouina [17], suggests a mobile application to prevent identity theft during card payments using a Blockchain-based tokenization solution. Tokenization involves replacing sensitive data, such as credit card numbers, with unique tokens that are securely stored on the Blockchain. Finally, B. Patel and S. Li [9] discuss the role of the Blockchain in cross-border payments and suggest an exploratory study to understand how Blockchain technology can facilitate collaboration between financial institutions. In sum, all the articles propose relevant solutions for improving the efficiency of banking processes using Blockchain technology. It should be noted that some authors propose more concrete solutions than others, but all the authors suggest food for thought for companies wishing to take advantage of Blockchain technology in the banking sector.

- work on centralized and decentralized Blockchain-based finance platforms

Following on from the applications of blockchain techniques in banking, several decentralized finance platforms making extensive use of blockchain and offering services similar to banks have emerged. They are transparent, as all transactions are recorded on a public register accessible to all. They also offer a high degree of confidentiality, as users can carry out anonymous transactions without

revealing their identity. We have explored publications by authors on decentralized finance platforms or DEFI. Some authors have juxtaposed them with centralized finance platforms or CEFIs to better conduct their exposure. Table 4 summarizes their study:

Table 4. Summary of work on Blockchain-based centralized and decentralized finance platforms.

Kaihua Qin *et al.* [18] 2021	CeFi vs. DeFi—Comparing Centralized to Decentralized Finance	
	Issue: Analysis of the legal, technical, economic and technological differences between CeFi and DéFi.	Contribution: CeFi, DéFi or hybrid classification decision tree,
Urshila Ravindran [19] 2021	A Secure Blockchain based Finance Application	
	Issue: Monetary transaction system for lending, borrowing and repayment of loan proceeds	Contribution: DigiLoan, Ethereum Blockchain
Ghoggali Brahim el Khalil [20] 2020	Banking Credit System Based on Blockchain Technology	
	Problem: Blockchain application for bank account credit management.	Contribution: Improvement of the bank credit system
Xuheng Lin, Ronghua Xu, Yu Chen [21] 2019	A Blockchain-enabled Decentralized Time Banking for a New Social Value System	
	Problem: Building a time-of-service exchange application (dapp)	Contribution: Ganache, Metamask, social value
Palina Tolmach [22] 2021	Formal Analysis of Composable DeFi Protocols	
	Problem: Proposal for a formal algebraic process technique that models DéFi protocols compositionally.	Contribution: DéFi protocols studied: Curve and Compound

Table 4 shows references that focus on the use of blockchain in centralized and decentralized finance. Kaihua Qin *et al.* [18] compare the CeFi and DeFi models, and propose a decision tree to rank them. Urshila Ravindran [19] presents a secure blockchain-based application for monetary lending and borrowing transactions. Ghoggali Brahim El Khalil [20] proposes a blockchain-based solution for bank credit management. Finally, Palina Tolmach [22] proposes a formal technique for compositionally modeling DeFi protocols to improve their security and reliability. Overall, these articles present a variety of effective solutions to current problems in finance and banking using blockchain technology.

- work on blockchain security

The security aspect of blockchain through mining processes and data security techniques is crucial to our research. The authors' contributions in this area are summarized in Table 5.

The references in this section address blockchain security issues. Suman Ghimire [23] deals with the analysis of Bitcoin's mining costs, algorithms and processes, and highlights the increasing complexity of mining this cryptocurrency. The paper by

Table 5. Summary of work on blockchain security.

Suman Ghimire [23] 2019	Analysis of Bitcoin Cryptocurrency and Its Mining Techniques	
	Issue: Cost, algorithm and mining process	Contribution: Increasing complexity of Bitcoin mining
Taotao Wang *et al.* [24] 2019	When Blockchain Meets AI: Optimal Mining Strategy Achieved by Machine Learning	
	Problem: Optimal mining strategy using AI methods	Contribution: Multidimensional RL mining algorithm
Caitlin Lustig [25] 2018	Algorithmic Authority of the Bitcoin Blockchain	
	Issue: Assessing trust in open source and decentralized systems: Bitcoin vs. centralized and enterprise software	Contribution: Secure decentralized system
Mansoor Anwar Ahmed [26] 2021	Decentralized computer systems	
	Issue: Bitcoin as a catalyst for crime, and remedial solutions	Contribution: Continuous improvement of consensus algorithms
Gavin Wood [27] 2014	Ethereum: A Secure Decentralized Generalised Transaction Ledger	
	Issues: Ethereum implementation problems and future obstacles	Contribution: Blockchain security
Ardit Dika [28] 2017	Ethereum Smart Contracts: Security Vulnerabilities and Security Tools	
	Issue: Provide a taxonomy of known security issues and inspect the security code analysis tools used to identify these vulnerabilities.	Contribution: SmartCheck, Oyente

Taotao Wang *et al.* [24] explores the use of AI to optimize the mining strategy, proposing a multidimensional RL mining algorithm. Caitlin Lustig [25] evaluates trust in Bitcoin's open source and decentralized system, compared with centralized and enterprise software. This article makes a contribution by highlighting the advantages of the secure decentralized system. Mansoor Anwar Ahmed [26] looks at Bitcoin's role in crime and proposes remedial solutions by improving consensus algorithms. Gavin Wood [27] looks at Ethereum's implementation issues and future hurdles to overcome, highlighting the importance of blockchain security. Finally, Ardit Dika [28] examines security vulnerabilities in Ethereum smart contracts, providing a taxonomy of known issues and inspecting the security code analysis tools used to identify these vulnerabilities. It proposes concrete solutions for improving smart contract security. Overall, these references highlight the challenges and opportunities associated with blockchain security, and propose innovative solutions to address these challenges.

- work on Blockchain adoption and regulations

Blockchain is being increasingly adopted in a variety of industries, and many companies are using it to improve their processes and security. However, regulation of blockchain varies by country and region. Several authors have shared their

findings on blockchain adoption and regulation. We summarize their contributions in Table 6:

Table 6. Summary of work on adoption and regulations around Blockchain.

Irni Eliana Khairuddin [29] 2019	Understanding and Designing for Trust in Bitcoin Blockchain	
	Problem: Explore trust between people and Bitcoin technology	Contribution: High number of dishonest Bitcoin users
Caitlin Lustig [25] 2018	Algorithmic Authority of the Bitcoin Blockchain	
	Problem: Assessing trust in open source and decentralized systems	Contribution: Comparison between Bitcoin and centralized and enterprise software
Wanda Presthusa *et al.* [30] 2017	Motivations and Barriers for End-User Adoption of Bitcoin as Digital Currency	
	Issue: Motivations and barriers to Bitcoin use	Contribution: Motivations: curiosity and love of technology. Barrier: stability, safety
Robby Houben, Alexander Snyers [31] 2018	Cryptocurrencies and blockchain: Legal context and implications for financial crime, money laundering and tax evasion	
	Issue: Use of cryptocurrencies for financial crime, money laundering and tax evasion	Input: Policy recommendations for future EU standards
Mansoor Anwar Ahmed [26] 2021	Decentralized computer systems	
	Issue: Bitcoin as a catalyst for crime, and remedial solutions	Contribution: Robust Round Robin (RRR) and Cambium consensus algorithms

Table 6 presents references that focus on adoption and regulations around Blockchain. Each of these articles addresses a specific issue and makes different contributions. Irni Eliana Khairuddin [29] focuses on trust between people and Bitcoin technology. She examines the problem of dishonest Bitcoin users and proposes solutions to strengthen trust in this technology. Caitlin Lustig [25] looks at the algorithmic authority of the Bitcoin blockchain. He evaluates trust in an open source, decentralized system like Bitcoin by comparing it to centralized, enterprise software. Wanda Presthusa *et al.* [30], examine the motivations and barriers to the adoption of Bitcoin as a digital currency. The authors highlight motivations such as curiosity and a love of technology, as well as barriers related to stability and security. Robby Houben *et al.* [31], focus on the use of cryptocurrencies for financial crime, money laundering and tax evasion. The authors propose policy recommendations for future EU standards to combat these problems. Finally, Mansoor Anwar Ahmed [25] examines decentralized computer systems and their relationship with Bitcoin. The author examines how Bitcoin can be used to catalyze crime and proposes consensus algorithms to remedy this situation. Overall, the table presents relevant topics related to Bitcoin and blockchain, including trust,

algorithmic authority, motivations and barriers to adoption, financial crime, and solutions to remedy this situation.

2.4. Lightning Network

Building upon the imperative to address scalability challenges in blockchain technology, Joseph Poon *et al.* [10] propose the Bitcoin Lightning Network as a solution to address Bitcoin's scalability concerns, elucidating the concept of instant payments and its implementation. In parallel, Croman, Kyle, *et al.* [32] delve into the evolution of Bitcoin and Lightning transactions, providing concrete data on the scalability challenges faced. Their research reveals that while the Bitcoin blockchain processes a mere 7 transactions per second, the Lightning network can handle an impressive 1 million transactions per second. They meticulously analyze scalability issues and explore diverse solutions proposed to mitigate them. In essence, the first reference offers a specific solution, while the second provides a comprehensive overview of the evolving landscape. Together, these works underscore the critical importance of scalability for blockchain technology adoption and emphasize the necessity for innovative solutions. Beyond theoretical contributions, practical implementations on the Lightning Network have been explored and detailed in Table 7.

Table 7. Lightning Network implementations.

LN implementations	Purpose
C-lightning [33]	Follows a modular and extensible approach with strong backward compatibility. The implementation provides low-level access for individual customization and flexible use of its Lightning nodes
Lightning Network Daemon (lnd) [34]	Enables interconnectivity with other Lightning Network implementations, making it possible to connect several networks together and extend the network
Éclair/ACINQ [35] [36]	Provides an implementation library for a robust, secure and scalable node that can handle large volumes of transactions and provides a native mobile implementation of the Lightning Network
Breez [37]	Provides a full-service, non-depository platform for simple and instant bitcoin payments
Rust-Lightning and LDK (Lightning Development Kit) [38] [39]	Improve network speed and scalability, while offering advanced features for payment channel management, privacy and security.

2.5. Description of the Lightning Network-Based Microtransaction System

The Lightning Network serves as a Layer 2 scaling solution strategically constructed atop the Bitcoin blockchain, facilitating expeditious and cost-effective transactions. This is achieved through the consolidation of transactions to mitigate

costs on the Bitcoin network. In the Lightning Network, transactions operate off-chain [40], evading immediate recording on the Bitcoin blockchain. Instead, they are amalgamated within a "payment channel" established between two parties. Within this channel, the involved parties can engage in numerous transactions without incurring individual fees on the Bitcoin network for each occurrence. Only upon the closure of the payment channel is the final balance settled on the Bitcoin blockchain. This innovative approach, bundling multiple transactions into a single payment channel, allows Lightning Network users to economize on Bitcoin transaction fees, proving especially valuable during periods of heightened network congestion and increased fees. Beyond cost savings, the Lightning Network introduces advantages such as accelerated transaction times and heightened confidentiality.

3. Methodology

3.1. Methodology

The research methodology for this project follows a comprehensive approach that encompasses literature review, technology familiarization, conceptualization, and tool development. Beginning with an in-depth examination of existing literature on Bitcoin Lightning Network implementations, payment integrators, and systems incorporating local currencies, the process involves gaining a thorough understanding of technologies such as Breez and the BTCPay server. Subsequently, the conceptualization and development of a Lightning Network payment portal, seamlessly integrated with LIGUIDI CASH and local currencies, is undertaken. This includes the creation and customization of an API to facilitate communication between the portal and LIGUIDI CASH, ensuring a streamlined user experience. Prototype testing and user scenario simulations assess the practicality and effectiveness of the system, with a focus on generating invoices, conducting Lightning Network transactions, and receiving notifications. The implementation of the portal on Umbrel OS, specifically the BTCPay server, is a key step, followed by an evaluation and optimization phase based on user feedback and transaction performance. The research methodology concludes with comprehensive documentation and reporting, encapsulating the entire development process, tools used, and observed outcomes.

3.2. Protocols Used for the System Implementation

Our architecture is inspired by the Breez system [37]. Breez is a Lightning wallet that facilitates the use of Bitcoin through its association with several common utility applications such as: point-of-sale, podcast player, video streaming and messaging. However, the context of this thesis, which focuses on the operationalization of microtransactions to and within Africa, requires a modification of the Breez architecture. This modification essentially concerns the transaction process and the types of services that will be associated with it.

The proposed architecture is shown in **Figure 1**.

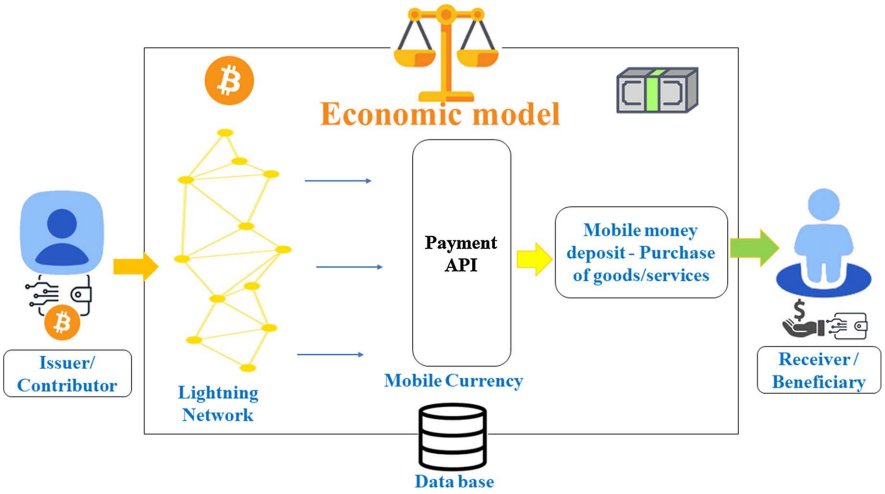

Figure 1. System architecture.

Legend for **Figure 1**:

1) represents the majority of Africans in the diaspora considered in this system as transmitters or contributors. They are the actors who trigger the system's actions.

2) represents the heart of the system. It is made up of three (03) essential parts.

2.1) Lightning network. This part enables users with Bitcoin cryptocurrencies to pay for products and services for specific recipients. The advantage of the Lightning network is that it uses the most widely adopted cryptocurrency combined with an off-chain payment system favoring minimal transaction fees. These advantages facilitate micropayments, which are a lever for financial inclusion in African society. The Lightning part of the system also has an integrated Bitcoin wallet that receives all Bitcoin transactions initiated on the platform.

2.2) represents the configuration of an integrated mobile payment system server (CashOut system). This system receives as input the transfer notification received from the bitcoin wallet, specifying the amount and other additional information supplied by the sender. This information may include the recipient's telephone number, and the service or product chosen for the recipient. On output, the server performs a transfer in local currency, either directly to the mobile deposit or to the chosen service provider. In the latter case, the final recipient, having been notified of the purchase of the product or service intended for him/her, contacts the supplier institution to benefit from the product or service which has already been purchased.

2.3) represents the business model integrated into our system. In order for the system to be functional, it is essential to have liquidity in the right amount on our mobile payment server, so as not to run out of mobile deposits. It is also essential to monitor the funds received in cryptocurrency, in view of the risk of permanent inflation recognized for cryptocurrencies. It is also essential to take into account the application of system operating charges. The economic model is therefore

made up of mathematical calculation models to provide the gauging indicated for optimum system operation.

3) represents the services available on the platform. The issuer can choose from this list the products or services he wishes to offer to the beneficiary of his choice.

4) represents the beneficiary of the system's services. He needs at least a cell phone number.

3.3. Methodology for Implementing the Prototype Application

In this system, we present an approach that significantly reduces the number of players involved in the transaction processing mechanism. The system focuses on the transfer of assets to a central platform. This platform hosts a range of products and services from which the initiator of the transfer can select to directly benefit the recipient in Africa. The proposed system enables a sender or initiator of a transfer to create a Lightning Network invoice on a dedicated web interface. He/she enters the amount of the transaction, selects the desired service, and enters the recipient's telephone number. Depending on the service, other information may be required. The web interface completes the invoice creation process by generating a QR code. The sender scans the QR code with his phone through his Lightning wallet application to proceed with payment, and may also retrieve the payment address for equipment that doesn't have a scanning system. Once payment has been made, the issuer is notified of the successful payment, and the mobile payment server is also notified of the successful Lightning transaction. This notification contains the parameters required for the subsequent mobile transaction. The mobile payment server then receives the Lightning payment notification. It is equipped with the computer code used to implement the mobile deposit. It enables part of the business model to be applied, by determining the fees to be charged and the current cryptocurrency exchange rates. Finally, the beneficiary of the system's services needs to have at least a cell phone number to receive notifications of transfers intended for him or her.

4. Results

4.1. Presentation of the Results of the Prototype Implementation

We have successfully implemented a prototype mobile money transfer application combining the Lightning network and mobile money. In a practical way, this application allows people residing in Burkina Faso to receive from anywhere in the world money transfers directly in F CFA to their mobile electronic account. The contribution of this thesis concerns the facilitation of the reception of transfers issued from any point in the world covered by the Internet. Unlike previous works, this solution integrates local African currencies and allows direct payment for services and goods in local establishments.

4.2. Analysis of the System's Performance

The evaluation of the system's performance highlights transaction costs as a

critical metric. A comparative analysis demonstrates that Lightning Network transactions incur a minimal transactivation fee of $0.002, significantly lower than traditional alternatives. For instance, Wisa charges fees ranging from 2% to 3%, Western Union imposes fees between 1.5% and 3%, and local mobile money transfers, while relatively cheaper at approximately 1.5%, are limited to specific subregions. This analysis underscores the cost-effectiveness of Lightning Network transactions, offering a competitive edge in affordability and accessibility.

Beyond cost, the Lightning Network-based system delivers a comprehensive suite of advantages. Its high scalability ensures seamless handling of increased user demand without performance degradation during peak periods. Near-instant latency facilitates real-time payments for emergency transfers and on-site purchases, enhancing user satisfaction and trust compared to traditional systems that may take hours or days to process transactions. Security is bolstered by the cryptographic safeguards of Bitcoin, reduced on-chain exposure, and enhanced privacy, ensuring secure operations even in regions with limited regulatory frameworks.

The system's interoperability bridges blockchain technology with localized monetary systems, aligning with user habits through simplified access and convenient services. This tailored design enhances relevance within African societies (Table 8).

Table 8. Cost evaluation.

Payment solution	Cost	Cost for 150 $
Lightning	0.02 $	0.002
Visa	1% to 3%	4.5
Western union	1.5% to 3%	4.5
Mobile Money	1.5%	2.5

4.3. Evaluation of User Satisfaction

Several key factors characterize the adoption of a transfer application in our African societies. Among these factors, the most essential are: transfer costs, security, functionalities that take into account African habits and the user interface of the solution. The feature comparison is shown in Figure 2. To assess user satisfaction, we compared the features of our solution with those of existing systems, focusing on the added features that set it apart. While our solution shares common features with existing systems, such as low-cost transfers, fast transactions and a payment operator portal, it introduces important innovations. These include direct payments in local establishments in Burkina Faso, support for local currencies such as the CFA franc and a microfinance/insurance contribution project. This approach ensures that the solution not only meets user expectations, but exceeds them by addressing specific needs in the local context. The evaluation methodology included usability testing and real-world scenarios to evaluate how these

added features improve the user experience. This analysis, based on a comparative approach, highlights that the extension of functionalities is a key factor in differentiating the solution and effectively meeting user needs.

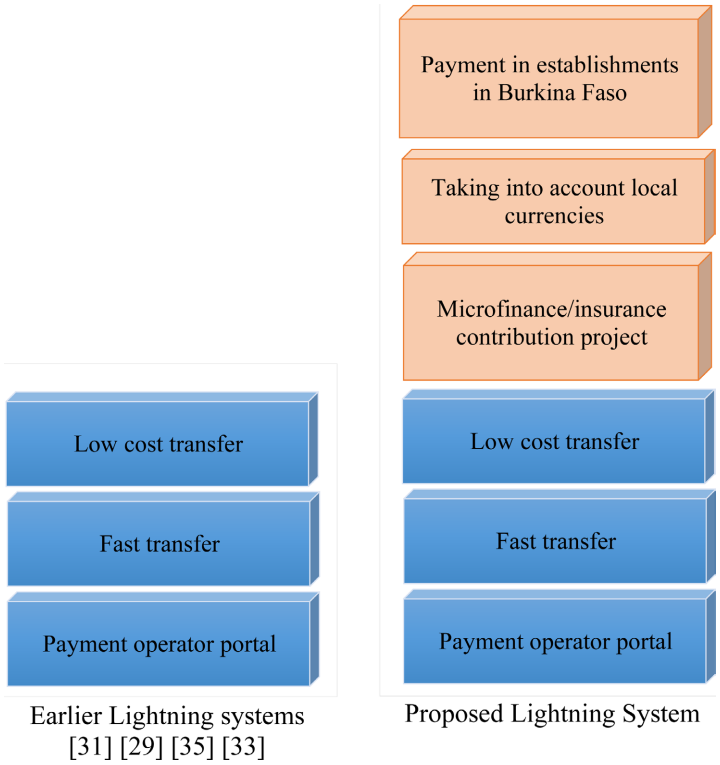

Figure 2. Lightning network feature comparison chart.

5. Discussion

5.1. Limitations of the System

The volatile nature of cryptocurrencies poses a significant challenge in the field of automated money transfer solutions. So, staying updated on cryptocurrency trends remains essential, as the field is marked by substantial fluctuations. Additionally, the system's current reliance on a prototype underscores limitations in scalability, reliability, and security, as it has not yet been tested in real-world conditions. While the prototype performs well in controlled environments, scaling to production may reveal unforeseen challenges, such as handling higher transaction volumes, ensuring compatibility with diverse local mobile systems, and managing liquidity in dynamic market conditions.

Security is a critical consideration for any financial system. Despite inheriting the robust cryptographic safeguards of the Bitcoin blockchain, the Lightning Network-based system requires further testing to address potential vulnerabilities, including payment channel attacks or price manipulation due to cryptocurrency volatility. Rigorous stress tests must assess the system's resilience against threats like denial-of-service (DDoS) attacks and fund access risks. Comprehensive evaluations are essential to understand the impact of cryptocurrencies on transactions

and to implement effective risk management strategies for users, ensuring a secure and reliable solution.

5.2. Future Directions of the System

While the prototype has demonstrated the system's effectiveness in controlled environments, future work should focus on large-scale load testing and pilot deployments to validate its scalability, reliability, and security. This involves simulating high transaction volumes, testing the system across diverse mobile environments, and evaluating its performance under network congestion. Conducting a field testing phase or a pilot project in a specific geographic area will provide critical insights into the system's behavior under real-world conditions.

Regular security audits and penetration testing are essential to identify vulnerabilities specific to blockchain technology and its integration with mobile systems. Implementing enhanced security protocols, such as advanced cryptographic measures and risk management frameworks, will ensure secure operations. Additionally, continuous monitoring and regular updates will be critical to maintaining the system's resilience against emerging threats.

5.3. Contributions to Financial Inclusion and Economic Development

We have successfully implemented a prototype mobile money transfer application combining the Lightning network and mobile money. In a practical way, this application allows people residing in Burkina Faso to receive from anywhere in the world money transfers directly in F CFA to their mobile electronic account. The contribution of this thesis concerns the facilitation of the reception of transfers issued from any point in the world covered by the Internet. Unlike previous works, this solution integrates local African currencies and allows direct payment for services and goods in local establishments.

6. Conclusions

Through this study, the implementation of a money transfer system to Africa combining the use of the Lightning network and the mobile wallet was proven through the successful integration of BTCpay server and the LIGIDICASH API in the same IT solution. In addition, relevant functionalities have been integrated into our transfer solution. These functionalities enable the initiator of the transaction to have a range of services and products which he could acquire for the benefit of the recipient in Africa. The latter system aims to solve the problem of effective social involvement of the transaction sender, as the object of the transaction is directly associated with the amount transferred.

At the end of our research, we came up with a prototype mobile money transfer application combining the Lightning Network and the mobile wallet system. In practical terms, this application enables people living in Burkina Faso to receive money transfers from anywhere in the world, directly in CFA francs into their mobile electronic account.

We are looking forward to completing the development of the mobile application and integrating the functionalities for purchasing goods and services. In addition, it is essential to keep abreast of cryptocurrency news, as this field is marked by considerable volatility.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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