

LIGHTNING NETWORK AS AN ALTERNATIVE PAYMENT INFRASTRUCTURE FOR SMALL AND MEDIUM-SIZED ENTERPRISES

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ABSTRACT

This paper presents the design, implementation, and economic evaluation of a payment module that enables merchants to accept Bitcoin payments through the Lightning Network using a self-hosted Bitcoin node. While the Bitcoin base layer suffers from limited throughput, relatively high transaction fees, and longer confirmation times, the Lightning Network addresses these limitations through off-chain payment channels, enabling near-instant settlement at minimal cost. The study combines a theoretical analysis of the Bitcoin protocol and the Lightning Network with a comparative evaluation of traditional payment methods and cryptocurrency-based payments. Primary data were collected from the official pricing schedules of eight payment terminal providers and six payment gateway providers operating in the Czech Republic. A full Bitcoin and Lightning Network node was deployed on an HP 260 G2 Mini platform running Umbrel, Bitcoin Core, LND, and BTCPay Server. Based on this infrastructure, a web application named Flash was developed to support payment processing and transaction management. The functionality and usability of the application were verified through pilot user testing. The results indicate that transaction costs associated with the Lightning Network are several orders of magnitude lower than those of conventional payment terminals and payment gateways while maintaining immediate settlement. Furthermore, operating a self-hosted payment infrastructure requires only a modest initial investment. The study identifies merchant technical expertise and the limited adoption of Lightning Network wallets among consumers as the principal barriers to broader deployment. The findings suggest that the Lightning Network represents a technically feasible and economically attractive payment alternative for small and medium-sized enterprises seeking to reduce transaction costs and increase payment-processing autonomy.

Keywords: Lightning Network, Bitcoin, payment infrastructure, transaction costs, decentralized payment systems, BTCPay Server, small and medium-sized enterprises, cryptocurrency payments

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1 INTRODUCTION

Cashless payment methods have been steadily increasing their share of transactions in the Czech Republic. According to the payment behavior survey conducted within the Prosperity Index project, 60% of Czech customers prefer payment cards when shopping online, while 12% choose bank transfers and 9.3% use QR-code payments (Index Prosperity, 2024). This trend is consistent with international findings demonstrating that the expansion of digital payment instruments systematically displaces cash transactions, with transaction speed and perceived security representing key determinants of payment method selection (Schuh & Stavins, 2016; Arango-Arango & Suárez-Ariza, 2020). The diversification of available payment methods is not only a matter of customer convenience but also has economic implications for merchants, who bear transaction costs associated with each cashless payment.

Traditional payment infrastructure based on card networks, payment gateways, and bank transfers combines card scheme fees, interchange fees, and margins charged by payment terminal providers. The resulting fee for a single transaction charged by a typical payment terminal provider in the Czech Republic ranges from 0.75% to 1.95% (Dotypay Fees, 2025; KB SmartPay, 2023; ČSOB START Tariff, 2022). Transaction fees charged by payment gateways range from 0.5% to 1.99% and are often supplemented by setup fees or monthly subscription charges (GoPay, 2025; Barion, 2025). Furthermore, settlement to the merchant's bank account may be delayed by one to three business days.

One of the primary motivations behind the creation of Bitcoin was the development of a payment system that does not require a trusted third party. In this framework, peer-to-peer transactions are verified through cryptographic mechanisms and a decentralized network of nodes (Nakamoto, 2008). However, the base layer of the Bitcoin blockchain exhibits several well-known limitations for everyday retail use. It processes only tens of transactions per second, maintains an average block interval of ten minutes, and transaction fees may rise to several dollars during periods of network congestion, making micropayments economically inefficient (Novák, 2023).

A response to these limitations is the Lightning Network, a second-layer solution built on top of the Bitcoin blockchain. The Lightning Network operates through shared payment channels established between pairs of nodes, where balance allocations are continuously updated while only the opening and closing of channels are recorded on the main blockchain (Antonopoulos *et al.*, 2021). As a result, transactions can be settled almost instantly with fees measured in satoshis, representing fractions of a cent. The Lightning Network is among the most advanced layer-two protocols built on blockchain infrastructure and has attracted increasing academic attention in recent years from the perspectives of security, network topology, and economic behavior (Gudgeon *et al.*, 2020; Zabka *et al.*, 2022). Empirical analyses indicate that despite a growing number of nodes and channels, actual retail adoption remains limited.

Despite its evident technical advantages, the adoption of cryptocurrency payments among retail merchants remains relatively low. Empirical research identifies perceived complexity, uncertainty regarding customer behavior, and limited visibility of merchant-side benefits as the primary barriers (Jonker, 2019). From the consumer perspective, cryptocurrency holders still represent a relatively small segment of the population, and their motivations for ownership are heterogeneous, combining speculative interests with distrust of the traditional financial system (Auer & Tercero-Lucas, 2022). A specific challenge associated with the Lightning Network is the technical complexity of operating a self-hosted node, the lack of documented reference implementations of integrated payment modules, and limited awareness of the associated economic implications (Bouška, 2023). Nevertheless, operating a proprietary Bitcoin node represents a crucial prerequisite for achieving full sovereignty over payment acceptance. Without a self-hosted node, merchants remain dependent

on third-party infrastructure within the Lightning Network ecosystem, which partially undermines the primary benefits of decentralized architecture in terms of resilience and competitiveness.

In the context of small and medium-sized enterprises (SMEs), the choice of payment infrastructure acquires a significant economic dimension. Reducing transaction costs and shortening settlement times directly contribute to profit margins, particularly for businesses operating with low unit margins or high transaction volumes. The adoption of blockchain technologies in business has become an established field of research emphasizing the critical role of technical readiness and supporting infrastructure (Wamba *et al.*, 2020). Furthermore, independence from card schemes and banking intermediaries increases operational resilience against technical failures or regulatory disruptions affecting these providers.

The objective of this paper is to present a comprehensive design and reference implementation of a payment module enabling merchants to accept Bitcoin payments through the Lightning Network via their own Bitcoin node, supplemented by a quantitative comparison of transaction costs with traditional payment methods in the Czech Republic. Specifically, the paper (i) summarizes the cost structures associated with payment terminals, payment gateways, bank transfers, and cryptocurrency payments; (ii) describes the proposed system architecture integrating a Bitcoin node, LND, and BTCPay Server with a web application; and (iii) presents the results of pilot usability testing of the implemented application. The outcome is a set of recommendations for merchants considering the inclusion of Lightning Network payments within their payment portfolio.

2 METHODOLOGY AND DATA

To achieve the stated objective, an engineering design and information systems development methodology was employed, combined with a qualitative and quantitative comparison of payment methods. The research process was structured into five consecutive stages:

- (1) Deployment and configuration of a self-hosted Bitcoin node.
- (2) Deployment of a Lightning Network node and establishment of payment channels.
- (3) Requirements analysis and architectural design of the payment module.
- (4) Implementation and pilot testing of the web application.
- (5) Comparative evaluation of payment methods.

At the infrastructure level, a compact HP 260 G2 Mini desktop computer was used, equipped with an Intel Core i3-6100U processor, 16 GB DDR4 RAM, and a 1.92 TB enterprise-grade SSD (SanDisk MLC with power-loss protection and DRAM cache). The hardware platform was selected based on requirements for long-term stability, sufficient storage capacity relative to the current size of the Bitcoin blockchain (approximately 745 GB at the time of the study), and low power consumption.

The device was configured with Umbrel version 1.4.1, a specialized Linux distribution designed for operating self-hosted Bitcoin and Lightning Network nodes through containerized deployment. The Bitcoin layer was provided by the reference implementation Bitcoin Core, while the second layer was implemented using LND (Lightning Network Daemon) version 0.18.5. To generate invoices and integrate Lightning Network payments with the application, the open-source BTCPay Server platform was deployed. Within the Umbrel environment, BTCPay Server operates as a containerized service and automatically integrates with the remaining node components. The selection of LND reflects its status as the most widely deployed Lightning Network implementation in the production network (Gudgeon *et al.*, 2020).

On top of this infrastructure, a web application named Flash was designed and implemented. The system architecture follows a three-tier model consisting of:

- the presentation layer (frontend),
- the application layer (backend),
- the data layer.

The frontend was developed using React, with Vite serving as the build tool and Tailwind CSS providing styling functionality. The server-side application runs on Node.js using the Express framework and exposes interfaces both to the client application and to BTCPay Server. Data persistence is handled through a MySQL relational database, while user authentication is implemented using JSON Web Tokens (JWT).

The data model includes entities representing users, stores, products, categories, receipts, receipt items, price-change history, VAT rates, and currencies. The system distinguishes between two user roles: a standard user (cashier) and an administrator with extended CRUD privileges for user accounts, categories, and products.

3 RESULTS

The deployed Bitcoin node achieved full synchronization with the Bitcoin blockchain and demonstrated stable operation. The acquisition cost of the hardware solution amounted to approximately CZK 5,100, consisting of CZK 1,500 for the computer, CZK 600 for 16 GB DDR4 memory, and CZK 3,000 for the SSD storage device. The average power consumption of the system is approximately 12 W, which, at an electricity price of CZK 6.5 per kWh, corresponds to annual operating costs of approximately CZK 683. Consequently, energy consumption does not constitute a significant component of the total cost of node operation.

The software layer of the node was deployed in a complete configuration. The Bitcoin Node application, implementing Bitcoin Core, performs validation of the entire blockchain history and actively maintains peer-to-peer connections with other nodes in the network. The Lightning Node application, implementing LND version 0.18.5, provides the functionality of the second-layer payment network. During operation, two public payment channels were established. At the time of verification, balances amounted to 29,341 satoshis in the on-chain wallet and 179,670 satoshis in the Lightning Network wallet, with two active channels and five connected peers. BTCPay Server was automatically integrated with the LND node within the Umbrel environment and served as the payment gateway responsible for invoice generation and payment-status monitoring.

The implemented Flash web application supports the principal operational processes required by merchants, including order creation, selection of products from a categorized inventory, shopping-cart management, settlement through two payment methods (cash and Bitcoin Lightning Network), management of VAT rates and discounts, and receipt generation. The administrative role provides complete management of user accounts, product categories, and inventory items, including price-change history.

For Lightning Network payments, the application invokes the BTCPay Server interface, which generates an invoice containing a QR code. The customer scans the QR code and completes the payment using a Lightning Network wallet. Upon confirmation of payment receipt by BTCPay Server, the application records the transaction data in the database and generates a receipt.

Tab. 1 Multi-criteria comparison of payment methods from the merchant's perspective

Criterion	Cash	Card payment	Payment gateway	Bank transfer	QR payment	BTC	BTC LN
Payment settlement speed	★★★★★	★	★	★★★★★	★★★★★	★★★	★★★★★
Transaction fees	★★★★★	★★	★★	★★★★★	★★★★★	★★★★★	★★★★★
Technical complexity	★★★★★	★★★	★★★	★★★★	★★★★	★★★	★★★★
Security	★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Suitability for small business	★★★★★	★★★	★★★	★★★	★★★★	★★★★★	★★★★★

The key outcome of the comparative evaluation is the quantitative comparison of transaction costs presented in Table 1. The values for card payments were obtained from calculations performed using the Dotypay fee calculator for a MasterCard debit card, while the payment gateway values were based on the promotional fee rate of 1.25% published by PayU.

Tab. 2 Comparison of Merchant Transaction Costs for Selected Payment Amounts

Payment method	CZK 100	CZK 1,000	CZK 10,000	CZK 25,000	Settlement time
Cash	CZK 0	CZK 0	CZK 0	CZK 0	Immediate
Payment Card (POS Terminal)	CZK 2.33	CZK 14.65	CZK 137.86	CZK 343.21	1–3 days
Payment Gateway	CZK 1.25	CZK 12.50	CZK 125.00	CZK 312.50	1–3 days
Bank Transfer / QR Payment	CZK 0	CZK 0	CZK 0	CZK 0	Immediate to 1 day
Bitcoin (On-Chain)*	CZK 0	CZK 0	CZK 0	CZK 0	~10 minutes
Bitcoin Lightning Network	Few satoshis	Few satoshis	Tens of satoshis	Tens of satoshis	Immediate

* For on-chain Bitcoin transactions, the transaction fee is paid by the sender (customer); the merchant incurs no fee for receiving the payment.

Source: Author's calculations based on fee schedules published by payment service providers (Dotypay, 2025; KB SmartPay, 2023; ČSOB, 2022; GoPay, 2025; Barion, 2025; PayU, 2025).

The results demonstrate that for transactions in the range of several thousand Czech crowns—typical of retail purchases—the transaction costs of card payments amount to approximately CZK 14 per transaction, whereas Lightning Network transaction costs remain several orders of magnitude lower, measured in only a few satoshis. Given that average retail profit margins are often only a few percentage points, this difference represents a meaningful component of the economic competitiveness of small businesses. For higher transaction values, the potential savings increase proportionally with transaction volume.

The multi-criteria evaluation further indicates that cash payments and the Lightning Network share the advantages of negligible fees and immediate settlement. However, they differ substantially in terms of technical complexity and customer anonymity. Card payments and payment gateways offer a high degree of convenience and broad customer acceptance but at the cost of transaction fees and reduced privacy. Bank transfers executed through QR codes represent the most cost-effective cashless option for merchants within the traditional banking infrastructure, although they do not facilitate cost-efficient operation outside the SEPA area.

Pilot usability testing of the Flash application involving five participants confirmed the comprehensibility and usability of the interface. All participants successfully completed all ten assigned tasks without external assistance. Completion times varied among participants, with more pronounced differences observed during administrative operations. Older participants generally required more time to navigate the interface. User feedback indicated a need for greater visual emphasis on inventory-management controls; however, overall usability evaluations were positive. Given the limited sample size, the findings should be interpreted as indicative results characteristic of a pilot study.

Additional evidence of growing cryptocurrency payment adoption in the Czech Republic can be found in publicly available industry data. Confirмо, a cryptocurrency payment processor, reported settlement volumes of USD 383 million in 2024, representing a year-on-year increase of 260% (Confirмо Turnover, 2025). Similarly, the Czech e-commerce retailer Alza reported cryptocurrency payment volumes of approximately CZK 201 million in 2021, corresponding to roughly 0.5% of total annual revenue (Cryptocurrency Payments on Alza.cz, 2022).

4 DISCUSSION AND CONCLUSIONS

The conducted study demonstrates that the Lightning Network operated through a self-hosted Bitcoin node represents a technically feasible and economically advantageous alternative to traditional payment infrastructures for retail transactions. For typical transactions ranging from hundreds to thousands of Czech crowns, Lightning Network transaction costs are several orders of magnitude lower than those associated with payment terminals and payment gateways, while maintaining virtually instantaneous settlement. The initial investment required for the node hardware amounts to only several thousand Czech crowns, while annual electricity costs remain in the range of a few hundred crowns. In the context of small and medium-sized enterprises, such an investment can be recovered within a relatively short period through savings on transaction fees alone.

From the perspective of the economic competitiveness of small businesses, a proprietary payment infrastructure offers three principal advantages. First, reducing marginal transaction costs improves the sustainability of business models operating with low unit profit margins, such as small cafés, bars, or other hospitality establishments, where card-payment fees may significantly reduce the gross profit generated by individual sales. Second, the immediate availability of funds,

compared to the two- or three-day settlement periods commonly associated with card-payment systems, improves operational cash flow. The importance of these two factors is consistent with empirical findings indicating that settlement speed and perceived security significantly influence payment-method selection from both the consumer and merchant perspectives (Schuh & Stavins, 2016). Third, independence from third-party infrastructure enhances operational resilience against technical failures affecting payment gateways and card-processing systems. From a sustainability perspective, it is also noteworthy that a self-hosted node does not require data-centre infrastructure and can operate efficiently on low-power hardware.

Despite these economic benefits, several significant barriers to wider adoption remain. On the merchant side, the primary obstacle continues to be technical competence. Although platforms such as Umbrel are designed to simplify deployment and management, operating a fully functional Lightning Network node—including channel balancing, channel-state backup, and liquidity management—requires a deeper understanding of the protocol or access to external technical support. This finding aligns with broader research on blockchain adoption in business environments, where technical readiness and supporting infrastructure are repeatedly identified as critical success factors (Wamba *et al.*, 2020).

Empirical research on cryptocurrency-payment adoption among merchants further suggests that perceived complexity and uncertainty regarding customer demand often outweigh purely financial incentives (Jonker, 2019). From the consumer perspective, the adoption of Lightning Network wallets remains limited. Although the availability of both custodial and non-custodial wallet solutions continues to grow, the majority of consumers have not yet interacted with this technology. Contemporary research further indicates that motivations for cryptocurrency ownership are heterogeneous and combine speculative interests with distrust of the traditional financial system. Consequently, only a subset of cryptocurrency holders is motivated to actively use digital assets for everyday payments (Auer & Tercero-Lucas, 2022).

This dual-sided adoption barrier reflects a classic network-effect problem. The economic value of accepting Lightning Network payments increases as the proportion of customers possessing compatible wallets grows, while customer incentives to use such wallets increase as merchant acceptance expands.

The limitations of the present study should be interpreted in four dimensions:

- First, the pilot usability testing involving five participants represents an exploratory validation exercise intended primarily to identify major usability issues rather than provide statistically representative measurements of user experience. A more rigorous evaluation would require a substantially larger sample size and the incorporation of standardized usability assessment instruments.
- Second, the multi-criteria comparison of payment methods combines qualitative expert evaluation with quantitative cost calculations. The subjective component of the assessment should be replaced in future research by a structured evaluation framework validated through expert-panel review.
- Third, the economic advantage of the Lightning Network was quantified primarily through transaction-fee comparisons. In real-world deployment scenarios, merchants must also consider the volatility of the Bitcoin exchange rate relative to the Czech koruna, which may introduce additional costs or risks.

Fourth, the study does not address the regulatory dimension, which is essential for production deployment in commercial environments. Furthermore, empirical analyses of Lightning Network topology indicate that network capacity is concentrated among a limited number of large nodes (Zabka *et al.*, 2022). For newly entering merchants, this implies the necessity of carefully selecting channel management and connectivity strategies.

Based on the findings presented above, several practical recommendations can be formulated:

- For merchants considering the inclusion of Lightning Network payments within their payment portfolio, a sensible initial approach is to operate a self-hosted node for low-value transactions, where transaction fees constitute a significant proportion of unit profit margins. For more advanced deployments, combining a self-hosted node with automatic conversion of cryptocurrency into fiat currency through a third-party service may reduce exposure to exchange-rate volatility while preserving the economic advantages of low transaction fees.
- For the research community, the study opens several promising avenues for future investigation, including:
 - longitudinal analyses of the actual operating costs of proprietary payment infrastructures,
 - quantitative studies of network effects in retail Lightning Network adoption,
 - comparisons of energy consumption and overall carbon footprints among alternative payment infrastructures.

Given the ongoing development of layer-two protocols (Gudgeon *et al.*, 2020), a natural continuation of this research would be a comparative analysis of the Lightning Network and competing layer-two solutions from the perspective of retail-payment applications.

4.1 Conclusion

In conclusion, the proposed and implemented reference architecture of a payment module demonstrates both the technical feasibility and the economic viability of accepting Bitcoin payments through the Lightning Network using a self-hosted Bitcoin node within a small- or medium-sized-business environment.

The principal contribution of the study lies in providing an accessible, reproducible, and well-documented implementation that lowers the entry barrier for merchants considering the integration of Lightning Network payments into their payment mix. In addition, the study offers an empirical comparison of transaction costs directly relevant to the Czech market environment.

Future research should focus on the long-term economic implications of node operation, the evolving regulatory framework governing cryptocurrency payments, and customer-side barriers to adoption. Such investigations would contribute to a more comprehensive understanding of the role that decentralized payment infrastructures may play within the broader digital-payments ecosystem.

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