Enabling offline payments in an online world

Scalability

Researched and written by

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Lipis Advisors is a leading strategy consultancy specializing in the payment sector. Lipis Advisors staff are experts on payment systems, services, and strategy, as well as the underlying technologies that support payment infrastructures. Lipis Advisors advises on all forms of payments, including ACH payments, real-time payments, card payments, cheques, mobile payments, online payments, and RTGS/wire payments.

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About Crunchfish

Crunchfish is a deep tech company developing a Digital Cash platform for Banks, Payment Services and CBDC implementations and Gesture Interaction technology for AR/VR and automotive industry. Crunchfish are listed on Nasdaq First North Growth Market since 2016, with headquarters in Malmö, Sweden and with a subsidiary in India.

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AUGMENTING PAYMENTS

Crunchfish have the bold ambition to take a global leadership position within payment technology

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INTRODUCTION

With the increase in smartphone penetration, the growth in e-commerce, and the increased adoption of online banking over the past decade, payment digitalization has rapidly accelerated. The BIS reported that digital payment volumes reached their highest levels ever in 2021 for both advanced and emerging market economies.[1] Consumers have a plethora of digital payment options at their fingertips, with ever-increasing demand for products and services that are instant, user-friendly, convenient, and contactless. Recent trends driving a shift away from cash are likely to persist over the medium term, and exploration and implementation of Central Bank Digital Currencies (CBDCs) are on the rise. Machine-to-machine payments and micropayments are likely to take off in the next 5-10 years. In this environment, payment system operators are faced with the need to improve operational readiness and capacity to future-proof the next generation of retail payment systems.

Designing scalable and future-proofed payment systems that can handle significant increases in usage in a sustainable and cost-efficient manner is of crucial importance to payment system operators.[2] The COVID-19 pandemic demonstrated how sudden increases in volume can occur, and maintaining performance in the face of unexpected volume surges is crucial to maintaining user trust in payment systems. Improving scalability is about more than processing an increased volume of transactions while maintaining the same level of efficiency, however. It is also about designing a highly usable system that is interoperable, flexible to change, sustainable, and inclusive. While cash has always been accessible and can work as a backup option if systems are down or access to the internet is unreliable, this will not necessarily continue to be the case moving forward. In cashless markets like Sweden, this has already become an issue with the recognition that greater resilience of digital payment systems is needed.

In this paper, we consider offline functionality as an innovative tool to enhance payment system scalability. First, we discuss how scalability requirements have evolved over time as the nature of payment systems and the technology supporting them have advanced. Second, we explore how new thinking around scalable payment systems is required, given user demands and payment trends that are likely to manifest in the future. Third, we consider how offline functionality can be used as a tool to improve the scalability of future payment systems. We conclude by highlighting the aspects of offline payment system design that will influence its impact.

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1 https://www.bis.org/statistics/payment_stats/commentary2301.pdf

2 https://www.fisglobal.com/-/media/fisglobal/files/PDF/report/The-Imperative-for-Laying-New-Payment-Rails-Report.pdf?sc_lang=de-DE

THE CONCEPT OF SCALABILITY HAS EVOLVED OVER TIME

In the context of today's digital payment systems, scalability is often understood as the ability of a system to support increases in value, volume, or reach while still maintaining the efficiency of the service. It is typically measured in terms of how many transactions a system can process per second as volume increases, ultimately leading to higher performance, processing volume, and throughput. However, the concept of scalability has evolved considerably over time as payment systems themselves have transformed.

In the early days of banking and payment systems pre-1960s, transactions were largely manual, with bank clerks recording transactions in physical ledgers. Scalability was limited by the number of transactions that could be physically processed in a day. In the 1960s-80s, batch processing systems were introduced as computing power and network technology advanced. Transactions were collected over a period of time, and then processed all at once. While this increased the scalability significantly over manual systems, it still had limitations due to delays caused by the batching process.

Over subsequent decades, payment systems moved towards real-time processing, allowing for immediate transaction processing. During this time, scalability improved significantly but was still limited by the processing power of computer systems and network capacity. With the emergence of distributed systems beginning in the early 2000s, where processing is shared across multiple systems or servers, scalability improved dramatically by allowing for load balancing and redundancy. The adoption of cloud technology also allowed payment processors to take advantage of virtually unlimited computing resources, providing unprecedented scalability.

Most recently, Bitcoin and other cryptocurrencies introduced distributed ledger systems. While the Bitcoin blockchain and other cryptocurrency systems initially struggled with scalability, the development of "Layer 2" solutions like the Lightning Network for Bitcoin in 2018 and later the phased launch of Ethereum 2.0 beginning in 2020, aimed at increasing transaction throughput. More recently, innovative ways of enhancing scalability through offline functionality have been developed, with UPI Lite and HDFC Bank's 'Offlinepay' in India relevant examples.[3]

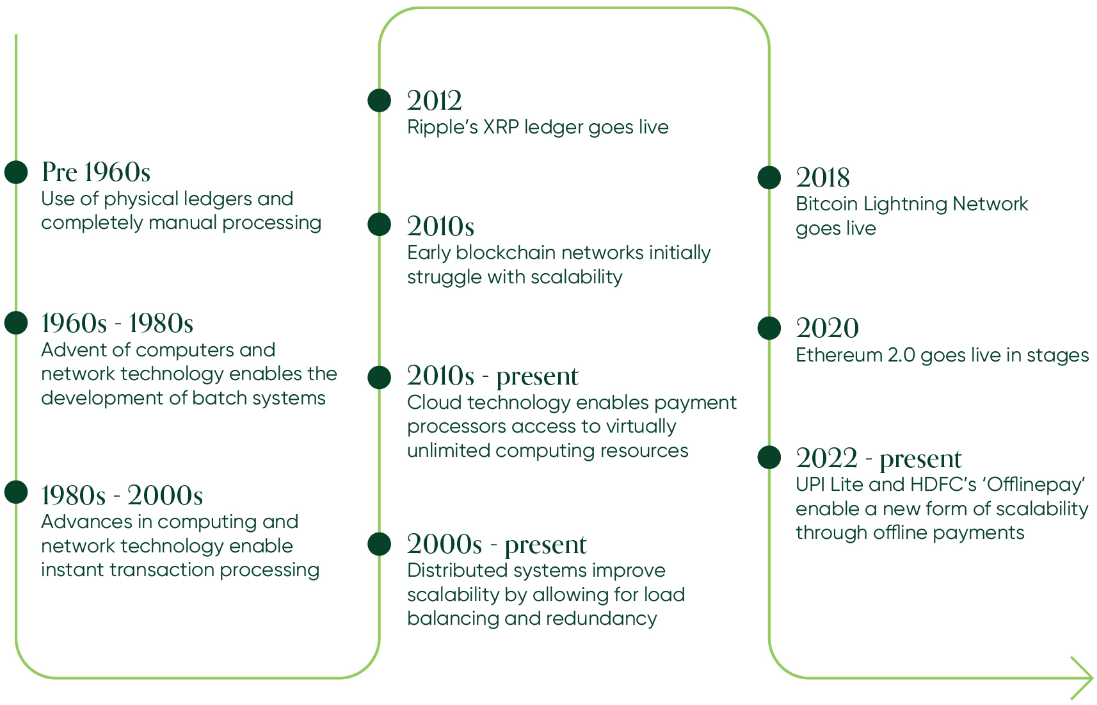

Figure 1 Scalability timeline: pre-1960s to the present

Source: Author's elaboration

[3] https://www.npci.org.in/what-we-do/upi-lite/product-overview and https://www.thehindubusinessline.com/money-and-banking/hdfc-bank-debuts-its-offline-app-heres-how-it-works/article66508236.ece

NEW THINKING AROUND SCALABILITY IS NOW REQUIRED

Until now, today's retail payment systems have been highly resilient in the face of surges in volume and technology has evolved to support their needs. Large global card networks can typically process tens of thousands of transactions per second, while closed-loop payment platforms such as Alipay in China can handle several hundred thousand transactions per second on peak days for e-commerce purchases.[4] As payment systems increasingly move toward instant settlement, this level of performance becomes more challenging to maintain. The Bank of England estimated that for a potential digital pound, a throughput of approximately 30,000 transactions per second would be needed, and that confirmation and settlement in under one second might also need to be achieved.[5] Moreover, with machine-to-machine payments on the horizon and payment models based on micropayments becoming increasingly prevalent, future payment systems should ideally be capable of handling millions of transactions per second with near-zero latency and instant settlement. Achieving this would require a significant breakthrough in innovation with respect to performance and cost limitations or require significant trade-offs with respect to security.[6]

Over the last several years, the industry's thinking around scalability has also become much deeper and more nuanced. Scalability is now understood in a much broader sense and is about more than just transaction throughput. Rather, it includes important areas of payment system design such as interoperability, ease of onboarding, flexibility to change, sustainability, usability, and inclusivity. Each of these areas and their impact on scalability are summarized at a high level below.

INTEROPERABILITY

An interoperable payment system can be rolled out and implemented with minimal effort, limiting infrastructure and transaction costs. It can easily expand reach to achieve positive network effects.[7]

EASE OF ONBOARDING

While the user onboarding process can often be complex and varies depending on the type of payment, the form factor used, as well as relevant KYC/AML requirements, the onboarding process for users should be seamless and not result in unreasonable delays.

FLEXIBILITY TO CHANGE

A scalable payment system should be designed to evolve with the changing needs of users and the market, which result in minimal or reasonable costs to users.

SUSTAINABILITY

Sustainability considerations have become an increasingly relevant consideration with respect to scalable payment system design, i.e., how much reusable technology resources can be utilized, and whether they may rely on software or physical hardware components.

USABILITY

A payment system with high usability is critical to achieving widespread acceptance, as ease of use determines the system's ability to retain existing and attract new users.

INCLUSIVITY

All scalable payment systems should be inclusive and accessible to everyone, but this is a particularly important feature for systems such as Central Bank Digital Currencies (CBDCs), which aspire to be as universally accessible as cash. The costs to participants of participating in the payment system should not increase because of increased volume, usage, or reach.

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4 https://www.visa.co.uk/dam/VCOM/download/corporate/media/visanet-technology/aboutvisafactsheet.pdf and https://cashpaymentnews.com/news/2022/mar/03/overview-chinas-progress-its-e-cny-pilot/
5 https://www.bankofengland.co.uk/-/media/boe/files/paper/2023/the-digital-pound-consultation-working-paper.pdf
6 https://thefintechtimes.com/guardtime-digital-payments-have-a-scalability-problem/
7 Positive network effects refer to situations where the value that the payment rail provides to its users increases as it gains more users.

OFFLINE FUNCTIONALITY AS A TOOL TO ENHANCE SCALABILITY

For the foreseeable future, scalability will remain a key consideration for payment system operators as the need for fast, inclusive, reliable, and cost-effective transaction processing continues to grow. Until now, efforts to improve scalability have focused on enhancing the performance of online systems and databases. For token-based payment systems based on distributed ledgers, rollups/layer-2 solutions and sidechains have been developed and implemented. In contrast, account-based systems based on conventional ledger technology are highly scalable by design but may face risks from a 'single point of failure.' [8]

An innovative tool for enhancing scalability that has yet to be explored deeply by the market is offline functionality. Offline payments enable transactions to occur outside of online ledger systems, potentially reducing the burden on the back-end payment infrastructure while providing additional benefits such as improved convenience, resilience, and trust. In the future, if payment systems such as CBDCs enable transactions involving very small amounts, their scalability requirements may exceed that of current payment systems. Offline payments, which involve conducting transactions outside of the ledger systems and offering an alternative processing route, could be a viable solution to address scalability challenges.

It is helpful to frame our understanding of offline payments in this context using what is generally referred to as the "scalability trilemma." [9] It describes how decentralized networks such as distributed ledgers strive to possess three essential attributes: decentralization, security, and scalability.[10] The trilemma highlights the challenge of achieving optimal levels of all three properties simultaneously. Typically, enhancing one aspect comes at the expense of weakening another. In other words, as efforts are made to increase scalability, it often leads to a compromise in terms of decentralization or security. Achieving the right balance between the three elements is how the scalability trilemma can be best understood.

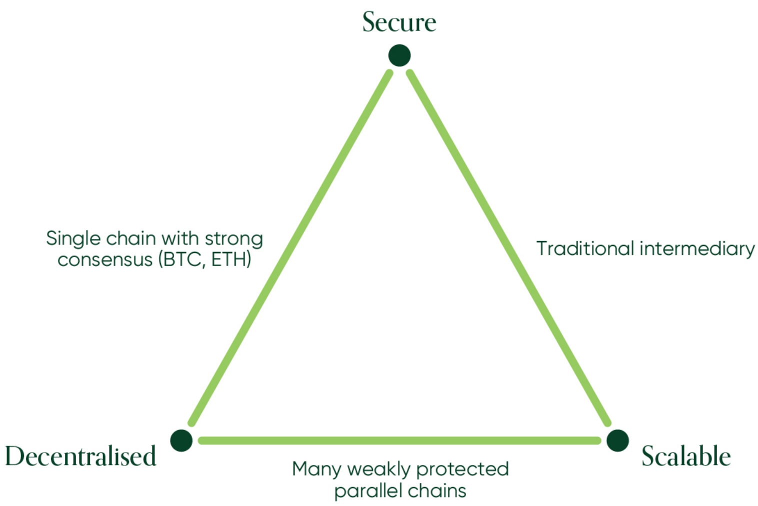

Figure 2 Scalability trilemma — Source: BIS

Offline payments may vary according to "who" is offline, i.e., whether it is the payer, an intermediary, or the back-end infrastructure. Enabling the payer to be offline offers unique benefits from the perspective of wider access, availability, and increased convenience. In normal retail environments, offline payments in which the payer is offline can help manage queues by

[8] https://www.ibm.com/docs/en/zos/2.3.0?topic=data-what-is-single-point-failure
[9] https://cvj.ch/en/education/basics/the-blockchain-trilemma/
[10] https://vitalik.ca/general/2021/04/07/sharding.html

speeding up the transaction process. Processing transactions offline in this way can also reduce costs related to data transmission and online transaction processing. These savings can make it more feasible to scale the system, especially in low-margin, high-volume scenarios. However, it can also result in greater security challenges, hence the need to consider the different benefits and risks.

Offline systems offer several benefits to online systems from the perspective of scalability, though these vary depending on a few aspects, such as whether there is a connection with the online ledger at the time of the offline payment. Some models for offline payments where the payer is not connected to the internet may rely on telecom connectivity to connect to the online ledger at the time of payment. Another offline use case has been developed by the UPI Lite service in India, where the payer's bank is offline at the time of the payment. Other forms of offline payments may occur completely away from the online ledger.[11] Interacting with the online ledger at the time of payment allows for greater security; however, it leads to a more centralized design and does not offer scalability benefits in the form of offloading volume.

Figure 3 Models for offline payments

Source: Author's elaboration

If there is no interaction with the online ledger at the time of payment, the trade-offs between decentralization, security, and scalability will differ depending on the time gap between settlement and synchronization with the online ledger. The BIS has classified the "degree of offline" into the following three types, each of which is progressively more secure, due to greater interaction with the online ledger:

[11] https://www.crunchfish.com/wp-content/uploads/2023/01/Lipisadvisors_WP1_offlinepayments.pdf

FULLY OFFLINE

The payer and payee can complete consecutive payments without ever needing to connect to a ledger system. The value exchanged is instantly transferred to the payee, enabling them to use the funds immediately without requiring any online final settlement. Both the payer and payee can remain fully offline without any time limitations.

INTERMITTENTLY OFFLINE

The payer and payee can conduct a payment without connecting to a ledger system. The value exchanged is promptly transferred to the payee, allowing them to use the funds at the end of the transaction without online reconciliation. When reconciliation does occur, it could reconcile each transaction or only balance adjustments.

STAGED OFFLINE

The payer and payee can exchange value without the requirement of connecting to a ledger system. However, the value exchanged is not settled for the payee until they connect to the ledger system for online final settlement. Only after this second stage of settlement can the payee utilize the transferred funds.[12, 13] When reconciliation does occur, it could reconcile the transaction itself or only a balance adjustment.

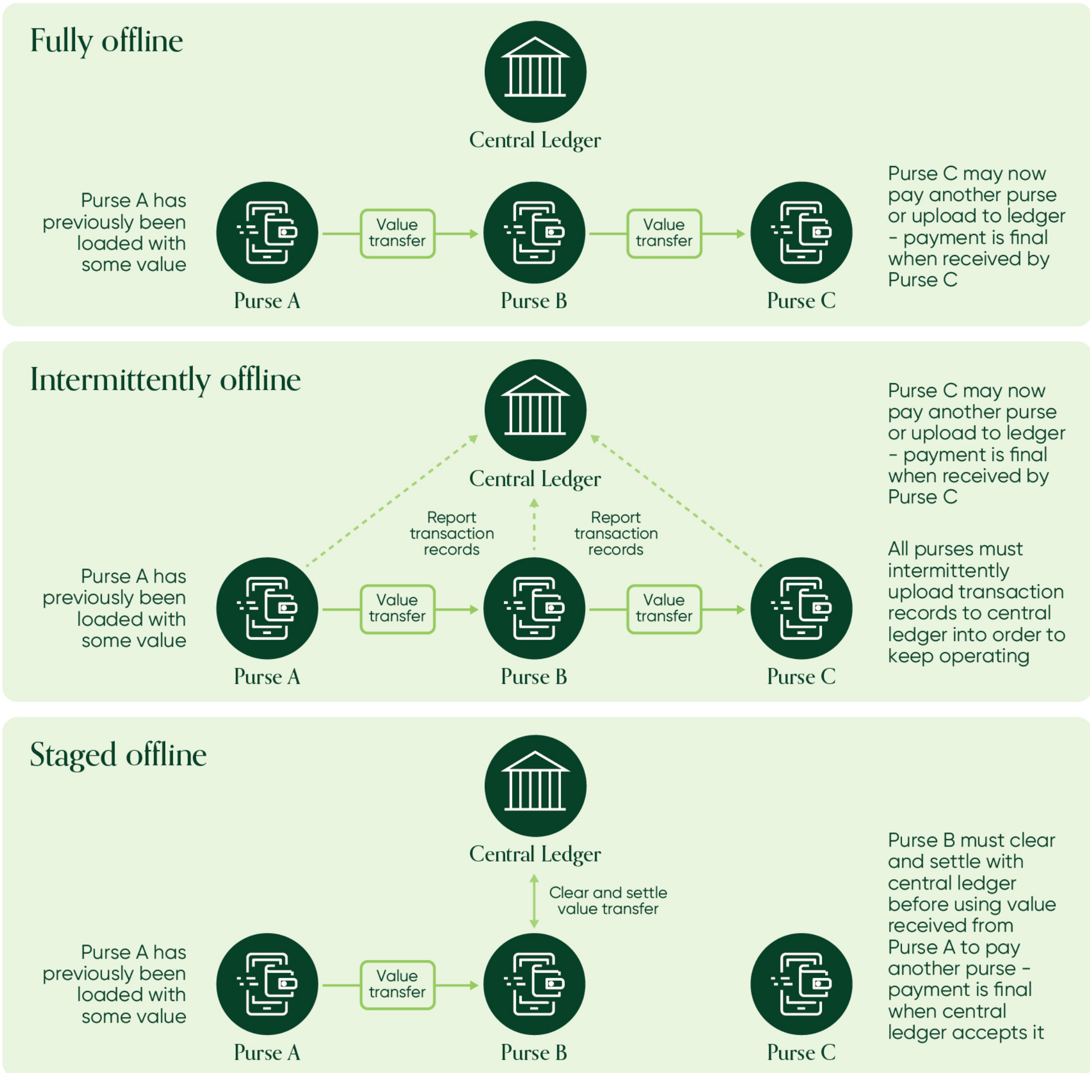

Figure 4 BIS' modes of offline payments

Source: BIS

Both fully and intermittently offline modes enable the payee to spend the value received at the end of the transfer. For illustration purposes, for both of these modes this figure shows only two transfers, the first between pursees A and B and the second between purses B and C. In practice solutions would support more than two transfers, subject to any specific limits.

[12] https://www.bis.org/publ/othp64.pdf
[13] https://www.bis.org/publ/othp64.pdf

The nature of reconciliation (e.g., transactional or balance reconciliation) also impacts the scalability benefits of offline payments.[14, 15] Processing transactions offline and later reconciling them with the online ledger reduces the burden on the network, as it allows the online ledger to process transactions at some later point in time. This aids the network in handling more transactions in high-volume situations or at times of peak demand. Without the need to communicate with a remote server for each transaction, offline transactions can be processed faster, resulting in lower latency. This speed can improve user experience and increase the number of transactions that can be handled in a given period.

In contrast, offline payments where only the balances reconcile with the online ledger could expand system scalability more significantly as fewer transactions need to be processed online. However, this could also come with increased KYC/AML risks.[16] It is crucial for payment system operators to weigh these trade-offs when they are considering the use of offline functionality to enhance system scalability. Any payment system is inherently less scalable if it results in higher rates of fraud that undermine users' trust in the system.

	Connection with online ledger at time of offline payment	No connection with online ledger at time of offline payment	Type of reconciliation with online ledger if it occurs
Decentralisation	Payer offline > payer's bank offline	Fully offline > intermittently offline > staged offline	Balance reconciliation = transactional reconciliation
Scalability	Payer offline = payer's bank offline	Fully offline > intermittently offline > staged offline	Balance reconciliation > transactional reconciliation
Security	Payer's bank offline > Payer offline	Staged offline > intermittently offline > fully offline	Transactional reconciliation > balance reconciliation

Figure 5 Summary of offline trade-offs given different models Source: Author's elaboration

Reflecting on this discussion, the below visual illustrates how the different models for offline payments vary according to their levels of decentralization, scalability, and security. Ultimately, payment system operators and central banks must uniquely consider these trade-offs and decide what type of offline model is the best approach for their market.

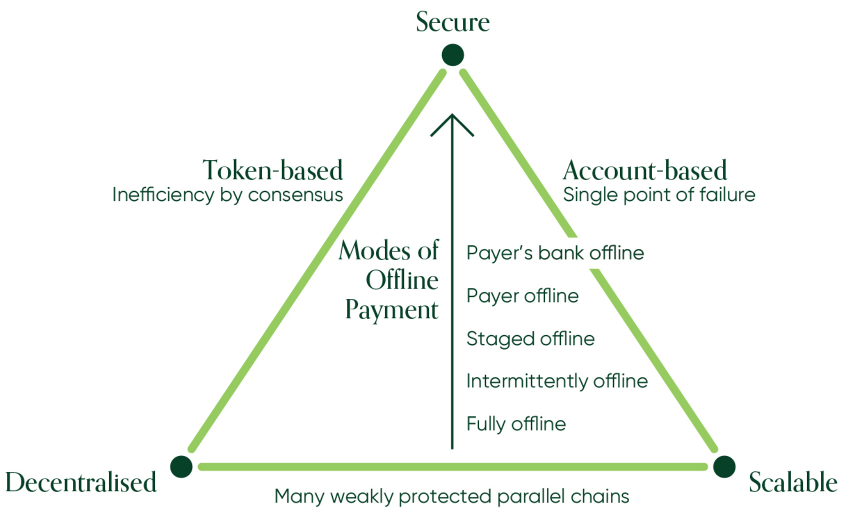

Figure 6 Summary of the scalability trilemma as applied to offline payments Source: BIS

[14] https://www.crunchfish.com/wp-content/uploads/2023/05/Lipis_WP3_Crunchfish_Enabling-offline-payments_FINAL.pdf
[15] https://www.bis.org/publ/othp64.pdf
[16] https://www.crunchfish.com/wp-content/uploads/2023/05/Lipis_WP2_Crunchfish_Enabling-offline-payments_v5.pdf

DESIGN CONSIDERATIONS FOR SCALABLE OFFLINE PAYMENT SYSTEMS

With an understanding of the scalability benefits of offline payments as well as the trade-offs, we now turn to a discussion of design considerations for enhancing the scalability of the offline payment system itself. As discussed at length in previous white papers, design choices are agnostic to the underlying payment rail (e.g., token-based, or account-based). Rather, the main design choices are instead related to the type of security protocol of the offline transaction (native layer-1 vs. non-native layer-2) as well as the trusted environment of the payer's bearer application (hardware-based vs. software-based).

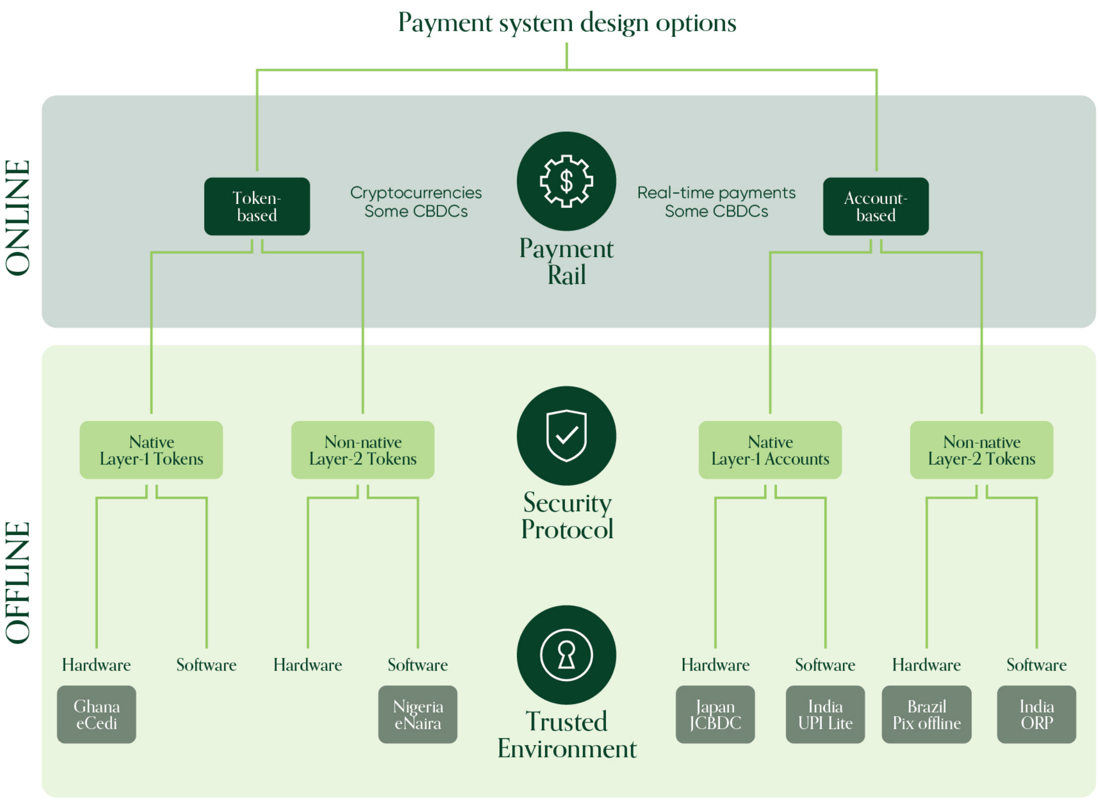

Figure 7 Payment system design options

Source: Author's elaboration

Readers of our previous papers will recall our recurring discussions on the security protocol-related design choices of native layer-1 solutions vs non-native layer-2 solutions. Scaling the payment system with a native layer 1 offline protocol will require changing the rules and mechanisms of the original payment rail directly. A layer 2 solution, on the other hand, can use an external, parallel network to facilitate transactions away from the underlying payment rails. Non-native layer 2 solutions are therefore interoperable by design, which facilitates greater scalability through ease of onboarding and reduced implementation costs for system participants.

The choice of hardware or software-based offline trusted environment can greatly impact the scalability features of offline payment systems. Hardware-based offline payment systems can typically handle a large volume of transactions without requiring an internet connection or external infrastructure. However, the production and distribution of physical devices, also known as Secure Elements (SE), can make this approach relatively more expensive to implement and maintain. Software-based trusted environments, on the other hand, do not require the distribution of physical components and may be updated more easily, resulting in lower usage costs.

Below, we summarize the potential benefits of software-based offline solutions in this context:

FLEXIBILITY TO CHANGE
Software-based solutions are often easier to upgrade as they involve updating or modifying code instead of replacing or adding physical hardware components. This enables maintenance or improvements to occur at scale without significant operational disruption.

EASE OF ONBOARDING/INTEGRATION
Software-based solutions may be easier to roll out and integrate into existing systems and databases. Ultimately this allows for streamlined onboarding and encourages usage.

COST-EFFECTIVENESS
It may be the case that the use of software-based solutions requires less upfront investment for ecosystem participants than hardware-based solutions. Upgrades and expansions can also be more cost-effective.

SUSTAINABILITY
In the long run, software solutions can be more environmentally friendly as they do not require physical materials or energy for manufacturing and transportation.

Ultimately, the choice between hardware and software-based offline solutions depends on the specific needs and circumstances of the market. Evaluating the impact of these design choices on scalability system features such as ease of onboarding, flexibility to change, energy efficiency, usability, and inclusivity, can provide some guidance on selecting the right design choices for enhanced scalability. The choice of form factors, including whether a smartphone vs. feature phone or card can be supported, is another consideration for usability and inclusivity in many emerging markets.[17] In these markets, a large proportion of users may not be able to afford smartphones or lack digital literacy. In these cases, some combination of hardware- and software-based trusted environments should be implemented to ensure true scalability.

CONCLUSION

In this paper, we provided a new perspective on how offline functionality can help support the increased scalability of digital payment systems in response to ongoing digitalization and changing user demands. Although the degree of decentralization, scalability, and security will vary depending on the specific offline model chosen, there are many potential benefits that incorporating some type of offline functionality can offer. The choice of native layer 1 and non-native layer 2 solutions, as well as hardware vs. software-based solutions, will also impact the scalability of the offline system itself, which must also be considered in the context of privacy and interoperability, as discussed in previous papers.

Looking ahead, in our next and final paper in this series, we turn to another topic highly relevant to the scalability discussion: the implementation of offline payment systems.

[17] https://www.crunchfish.com/wp-content/uploads/2023/01/Lipisadvisors_WP1_offlinepayments.pdf