Fidelity DIGITAL ASSETS℠

The Lightning Network:

EXPANDING BITCOIN USE CASES

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In collaboration with

VOLTAGE

Introduction

The Lightning Network was originally created in 2016 and has been described as a "payment scaling layer" on the Bitcoin network. While the Lightning Network fully launched in 2018 with the intent to enhance transaction speed and reduce costs, it was not until 2024 that its adoption gained momentum. Today, Lightning payments are now integrated into large U.S.-based exchanges such as Kraken and Coinbase.[1,2]

This report aims to provide a high-level status update on the growth and adoption of the Lightning Network while also exploring how it delivers on its creators' original vision of a fast and cost-effective payment network. The metrics we analyze provide insights into channels, capacity, payments, fees, and more, which help to project the future growth of the Lightning Network. We collaborated with Voltage, a leading Lightning Network payment provider, to gather these insights and combined publicly available data with anonymized proprietary data supplied by their team.

Publicly available metrics include the number of public nodes, public channels, and public channel capacity. However, these figures only represent a partial view of the network because nodes and channels can be kept private. Key metrics for measuring the Lightning Network's success—such as transaction counts, transaction volumes, and fee rates—are only visible to the node operator. By collaborating with Voltage, we can provide readers with a glimpse into some of these private metrics to better analyze the overall growth of the network.

Key Takeaways:

- More businesses integrated the Lightning Network in 2024 than years past—a trend we expect to continue throughout 2025.
- The Lightning Network is showing signs of maturity. Smaller, less efficient channels deployed between 2018–2020 are closing in favor of larger, more streamlined channels.
- Total average capacity of public Lightning Network channels has grown, increasing the probability of payment success as payment sizes increase.
- A well-optimized participant in the Lightning Network can see transaction fees as low as 0% and payment completion times of less than half a second.
- A shift is occurring in favor of fewer, larger well-connected nodes as opposed to many smaller nodes.
- The Lightning Network is delivering on the promise of being the most efficient way to transact in the digital asset ecosystem.
- Lightning can be viewed as a yield-bearing network that does not require users to give up control of their bitcoin.

Introduction to VOLTAGE

Voltage is a leading Lightning Payment Provider, simplifying Bitcoin and Lightning adoption for businesses. Through an easy-to-use API, Voltage removes complexity, equipping companies with the tools and support they need to thrive when adopting instant, cheap payments. Voltage is the longest-running infrastructure provider for the Lightning Network.

What Is Lightning?

The Lightning Network is a payments protocol built on the Bitcoin network. It was proposed in 2016 to increase payment scaling, privacy, and provide near-instant transaction throughput with negligible fees without compromising on Bitcoin's fundamental properties.[3]

Development of the Lightning Network accelerated once the Bitcoin SegWit upgrade was introduced in 2017. It was launched on Mainnet shortly after with multiple interoperable implementations.

Lightning does not require a unique token as it operates with bitcoin. Channels between parties allow off-chain transactions to happen between a wider array of parties, avoiding both on-chain block confirmation time and fees associated with traditional Bitcoin transactions. The Lightning Network permits permissionless unilateral exits as a part of the protocol.

In other words, any participant in a Lightning channel may close the channel and reclaim their capital as on-chain bitcoin at any time without third-party permission. Transactions can be routed in the network to direct channel partners or to any other node in the network by leveraging other node's payment channels. Using additional channels is known as "hops" in a payment.

The Lightning Network's unique approach of utilizing Bitcoin's native token, rather than creating its own, presents a compelling opportunity for non-custodial yield generation. This design enables users to maintain full control over their capital while earning fees by facilitating payment routing on the network.

Consequently, Lightning can be viewed not just as a payment channel network, but also as a yield-bearing network. This offers users the potential for returns without relinquishing custody of their capital.

Status of the Lightning Network

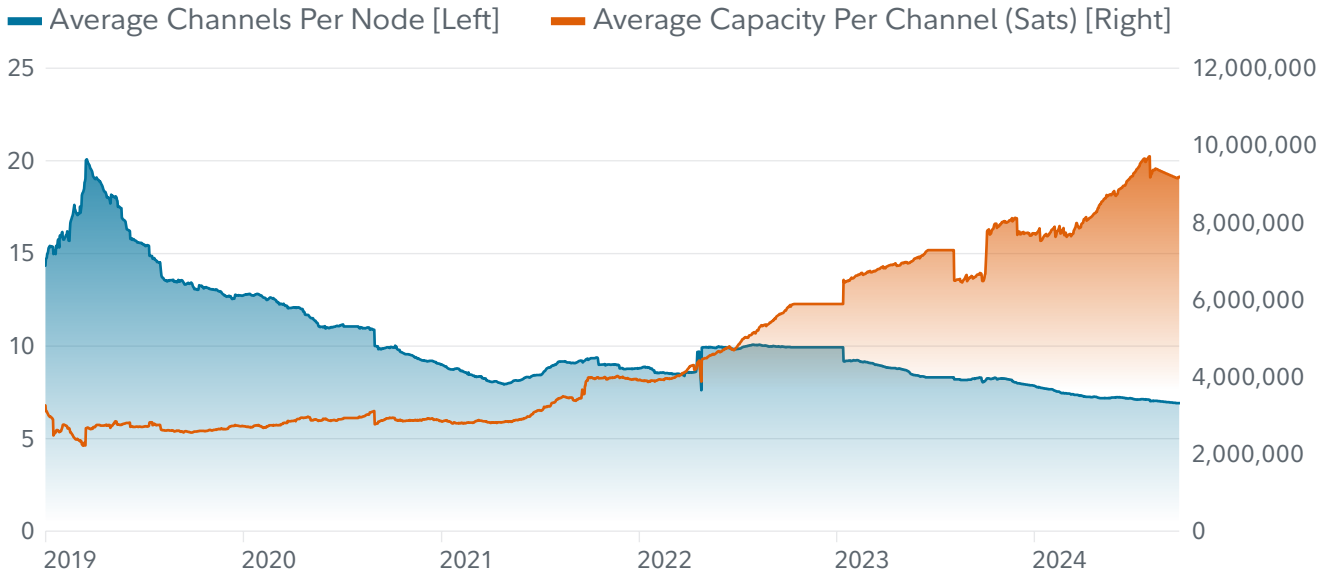
A snapshot from September 2024 demonstrates several areas of growth within the Lightning Network over the last four years (2020–2024).

CAPITAL EFFICIENCY

We can see a clear picture of both capital efficiency and network efficiency when viewing the public channels per node and capacity per channel. In the early stages of the Lightning Network—during which the community acknowledged its more experimental nature—node runners were quick to open new channels but with a low capacity. This was likely due to the risks associated with losing funds and experimentation around connecting to other nodes across the network.

In the years since, average capacity (in bitcoin) has grown by 118%, while the average channels per node fell 30%. This shift highlights the network's growing efficiency, allowing more funds to be transferred using fewer channels. It also reflects users' increasing trust in the Lightning Network's stability and a deeper understanding of its potential benefits.

Capital Efficiency Growth



Source: Fidelity Digital Assets Research via bitcoinvisuals.com, 09/23/24.

CAPACITY PER CHANNEL

The average capacity of peer-to-peer Lightning channels has grown by 214% over the last four years. The 90th percentile sits above this average, increasing 50% since 2020. This rightly skewed data could be alluding to a larger subset of much higher capacity channels, presumably controlled by a few central entities.

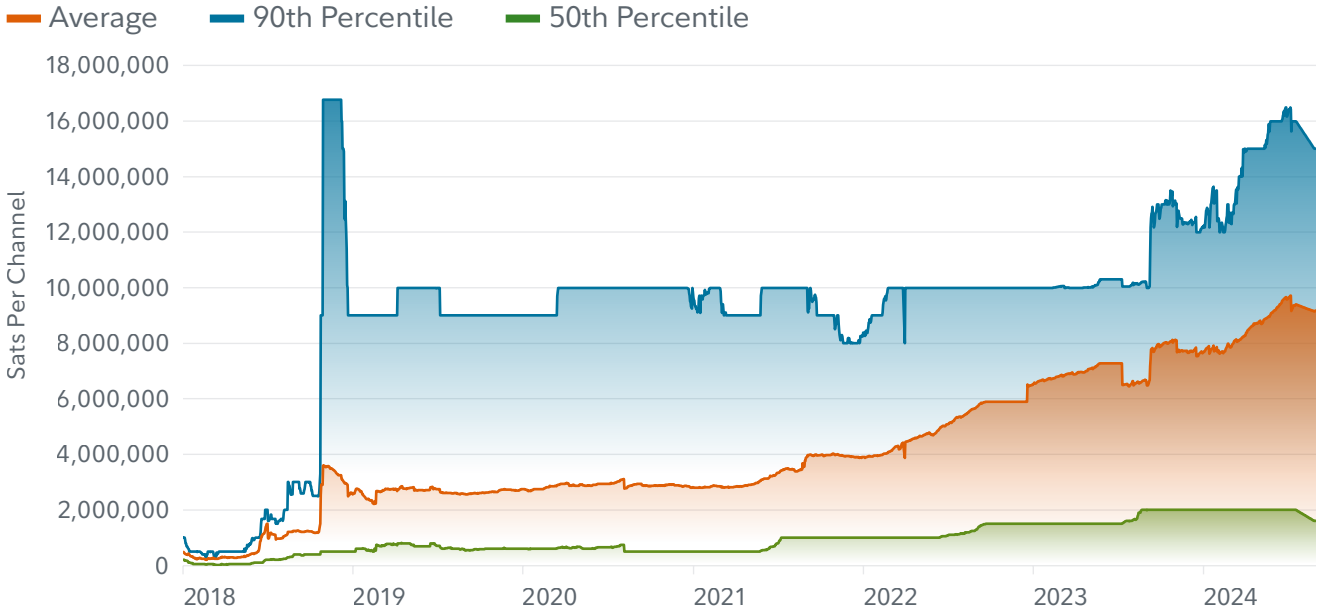
For example, Voltage, a leading Lightning infrastructure provider for businesses and enterprises, has determined that its clients have an average channel size of 7.2 million satoshis (0.072 BTC), with some channels being as large as one billion satoshis (10 BTC).

Large channel capacity ensures a higher success rate for sending and receiving higher value payments. As payments are sent and received, both sides of the channel's liquidity can be efficiently utilized.

With an average capacity of nine million satoshis, users can send roughly $9,000 through the channel at the current exchange rate as of January 2025. Assuming most daily payments fall well below this threshold, a channel of this size—when opened with a well-connected peer—could facilitate thousands to millions of individual payments indefinitely.

The Lightning Network also uses multi-path payments (MPP), allowing a single payment to split up into several smaller payments across multiple channels. This significantly increases the upper bound of maximum payment sizes. Comparatively, on-chain Bitcoin transactions are not limited by an upper bound of bitcoin sent.

Lightning: Capacity Per Channel



Source: Fidelity Digital Assets Research via bitcoinvisuals.com, 09/23/24.

CAPACITY PER NODE

Voltage supplied a portion of its dataset, which mirrors publicly available metrics. From June 2021 to October 2024, Voltage grew its average capacity by approximately 251%, while its average channels increased from 11.6 to 13.3. This increase in capacity can be attributed to growth in both the company and the network. However, it is interesting that the average channels per node also increased.

Voltage did note that some customers manage their own channels, while others rely on Voltage for channel management. This growth could potentially stem from inefficient channel management by individual users. Alternatively, it may reflect companies and enterprises utilizing Voltage to ensure the highest payment success rate possible by maintaining multiple channels with high-quality peers.

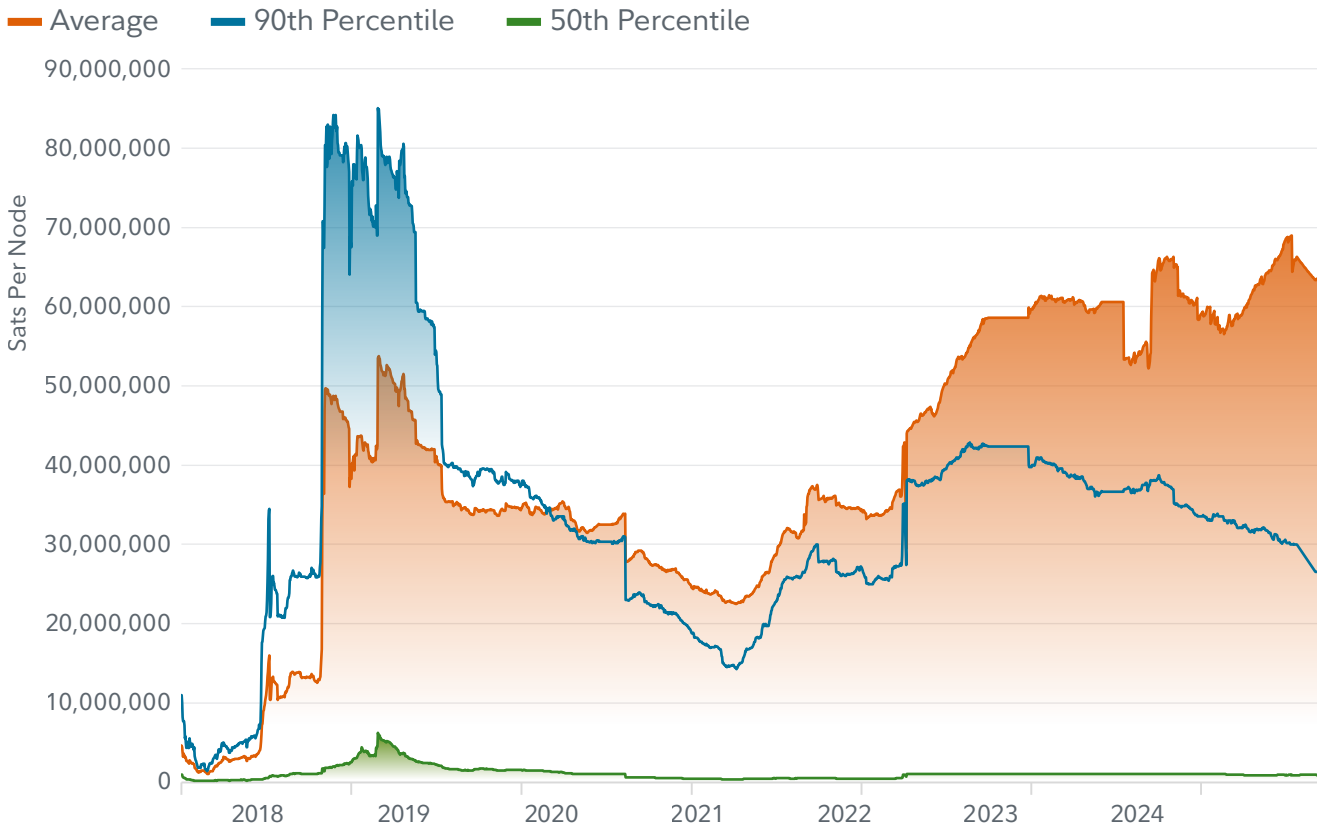
The 90th percentile of capacity per channel fell significantly below the average. This positively skewed data likely indicates the presence of central entity outliers that are elevating the overall average.

The difference in skewness coefficients between capacity per channel and capacity per node can be attributed to the distribution of liquidity. Our analysis suggests that the difference is due to "middle-class" nodes with a smaller amount of liquidity. That liquidity is spread across multiple smaller channels, aligning more closely with peer-to-peer transactions.

This indicates that fewer nodes hold the majority of the liquidity, and these nodes manage their liquidity across several channels, leading to a less skewed distribution at the node level.

In other words, while there are more channels with substantial liquidity, the network's nodes have distributed their liquidity more evenly across multiple channels.

Lightning: Capacity Per Node



Source: Fidelity Digital Assets Research via bitcoinvisuals.com, 09/23/24.

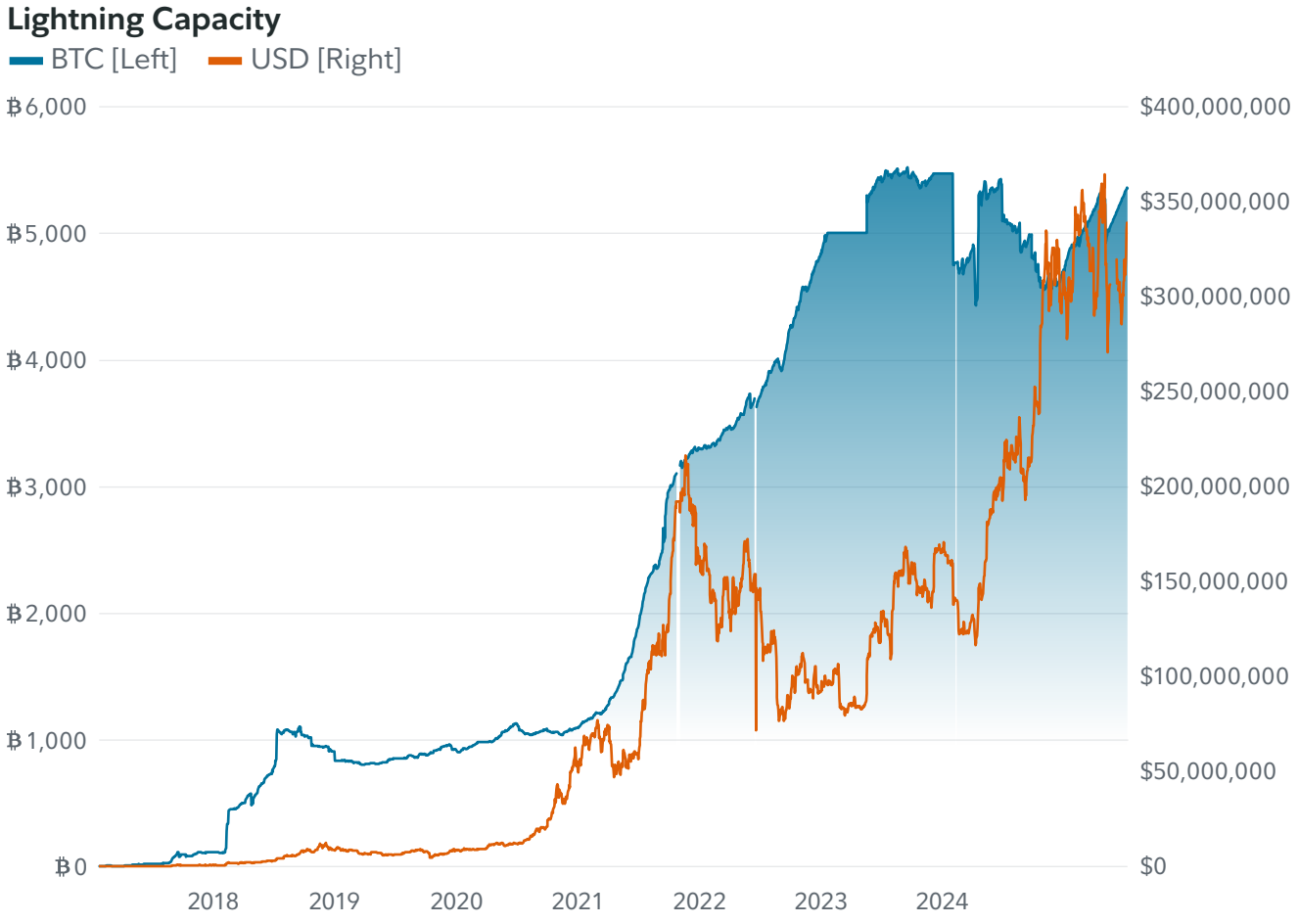
Inside this decentralized network, peer-to-peer transactions are still unlikely to require a substantial amount of liquidity. Lightning service provider (LSP) nodes would need to operate at a significantly higher capacity than an individual's node because they require the liquidity (bandwidth) to handle a plethora of user transactions. In contrast, an individually owned node would theoretically be more focused on their personal transaction amount. This difference explains why the average capacity per node is significantly higher than 90% of the network.

TOTAL LIGHTNING CAPACITY

Lightning capacity denominated in USD has increased by a substantial 2,767% since 2020—however, bitcoin's price has also increased by 504% during the same period. Given that, it would be misleading to suggest that this growth does not reflect the rise in price. Instead, this report considers the bitcoin-denominated capacity, which has grown by 384% since 2020.

While not as substantial as the USD-denominated growth, the Lightning Network's public capacity stands at 5,358.50 BTC or $509 million (with a bitcoin price of $95,000), as of January 2025.

It is worth noting that this capacity does not include private or unannounced channels, which are estimated to be just as substantial. We have seen network participants create private channels when they do not want other nodes on the network to route transactions through them. This could be a wallet service provider opening channels to their customers or two exchanges transacting with one another. The entire capacity of the Lightning Network (both public and private) is unknown.



Source: Fidelity Digital Assets Research via bitcoinvisuals.com, 09/23/24.

A Deeper Dive into Private Lightning Metrics

FEE RATES

Given that the Lightning Network is a peer-to-peer payment network and not a blockchain, the fee rates experienced in the network can vary drastically between nodes or even between payments. Across most of the digital asset ecosystem, participants are accustomed to having a global fee rate that all users must conform to. However, in the Lightning Network, each user can decide the fees they are willing to pay and deploy channels to achieve it.

This means it is possible to pay no fee whatsoever or under 0.5% fees on payments on the Lightning Network. Alternatively, if users do not have a proper channel management strategy, they could pay a high amount of fees.

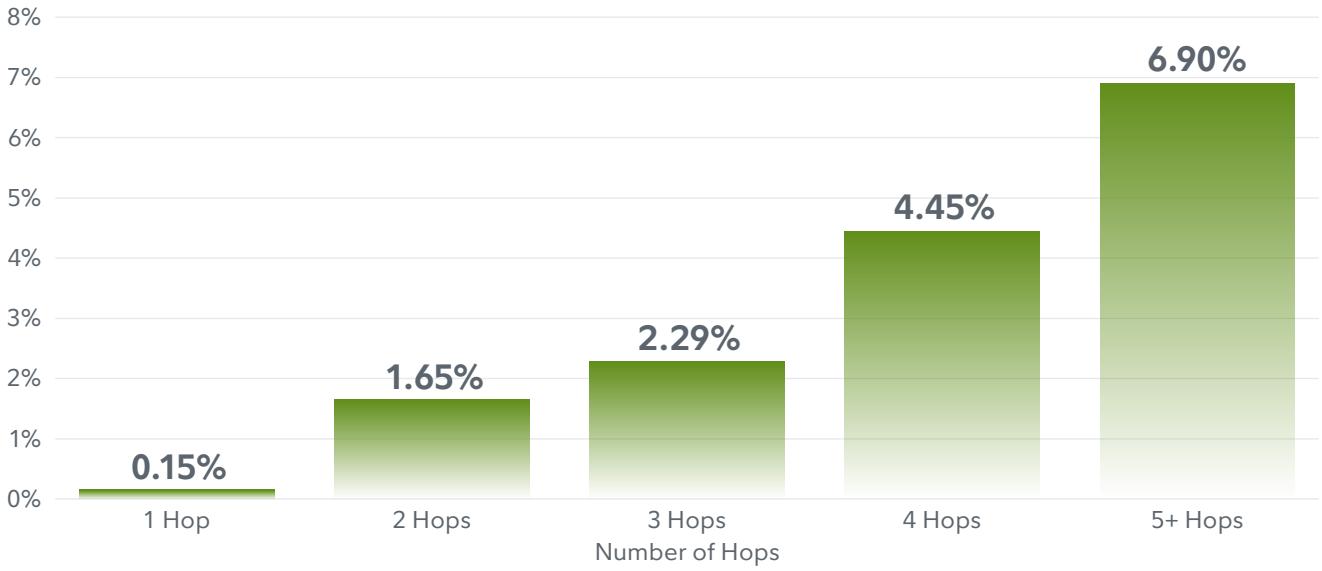
An aspect of Lightning transactions that can be attributed to fees is the number of "hops" a transaction requires to find the end address. If one was to consider the Lightning Network as a subway system, each "hop" can be compared to a rider having to get off and on to another train, paying a separate fee for each.

The payment rails in the Lightning Network are channels created between nodes. Each node sets their individual fee rate and charges the user for forwarding the transaction to the next node. The forwarding of a payment is known as a "hop."

The more hops a payment uses, the higher the fee will likely be. However, it is possible to pay no fees for a payment if you are paying directly to your channel counterparty. This is why having an effective channel strategy is key to achieving low fees.

Users must be mindful of the channels they open to ensure the fewest number of hops. Channels are becoming fewer but more substantial, indicating channel consolidation.

Average Payment Hop Fees (Voltage Sample Set)



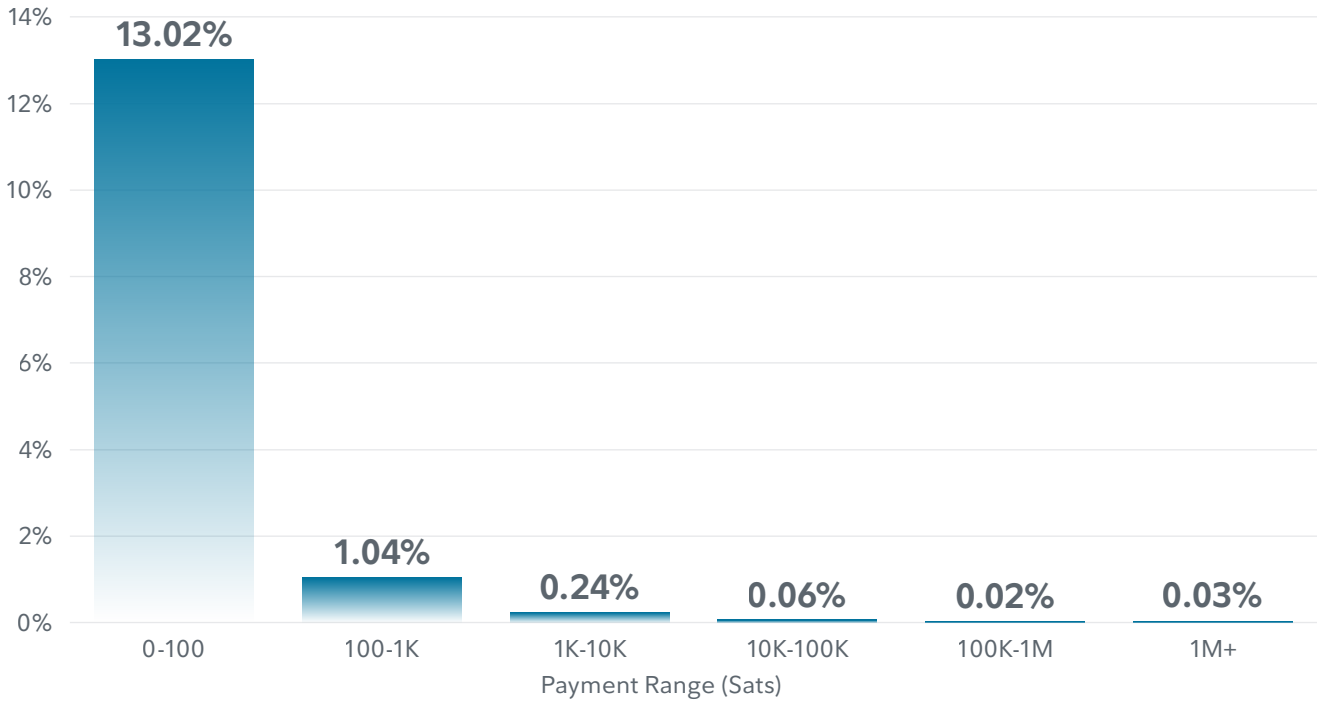
Source: Fidelity Digital Assets Research via Voltage, 10/22/24.

Using the dataset from Voltage, we can see that larger Lightning transactions experienced lower fee rates. While this may seem counterintuitive, it is likely due to nodes in the network using a fixed cost or flat rate for their base fee.

In other words, nodes are size agnostic. They are assigning the same base fee for sending $5 and $1,000, then additionally a percent of payment size. At the time of writing, Lightning appears to be one of the most cost-effective protocols for sending substantial amounts of value.

However, this does not imply that transactions such as micropayments are impossible to conduct on the Lightning Network. Instead, it simply suggests that users and entities supporting this ecosystem need to be intentional when opening channels to perform that use case.

Average Payment Fee (Voltage Sample Set)



Source: Fidelity Digital Assets Research via Voltage, 10/22/24.

It is possible the Lightning Network could further entrench itself as one of the most cost-effective methods of transacting within the entire digital asset ecosystem when properly configured. This would fulfill its original intent of processing payments at a significantly lower cost compared to on-chain transactions. Users paying high fees in the Lightning Network could easily avoid doing so with proper analysis and configuration.

It is also important to consider that payments to in-demand destinations often incur higher fees. This is due to routing and fee market dynamics inherent to the network.

Through a well-connected self-hosted node, transactions that required an average of one to three hops paid a fee of 0.04%. In other words, transactions over 1,000,000 satoshis (~$1,000) have cost between $0.39 and $1.27. This fee-to-transaction settlement ratio is rare within the traditional payment processing sector and across other digital asset networks.

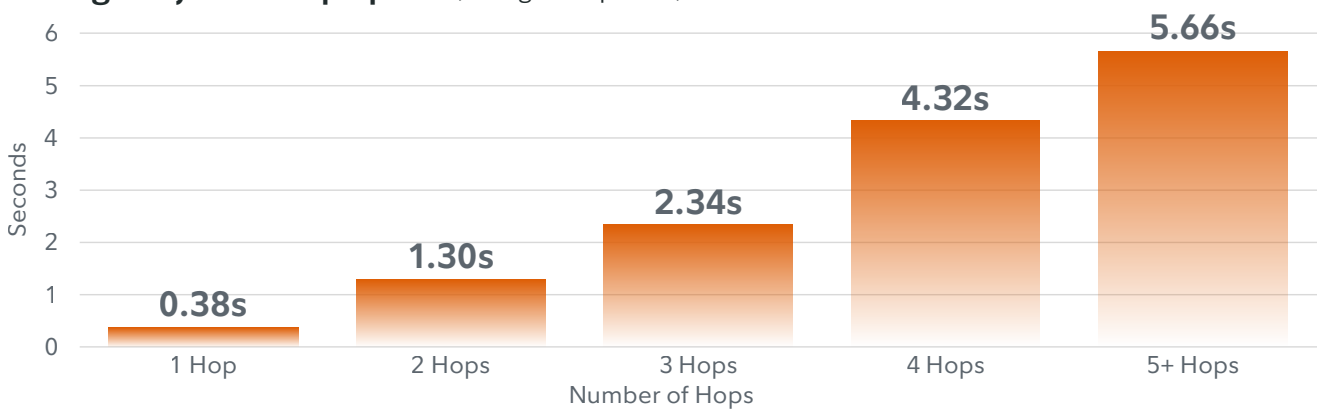
SPEED

The Lightning Network is known for its speed, as almost all payments below one million sats (0.01 BTC) finalize in less than one second. It should be noted that all data transfer speeds are limited to the speed of light by physics, even in the most ideal conditions.

We see the number of hops in a payment being the largest factor in payment completion time. Continuing our subway analogy, the more stops a payment must take, the more time it requires by nature.

A single hop payment averages a completion time of 0.38 seconds, which is notably faster than other digital asset payment mechanisms. This speed is also impacted by the connectivity of nodes, again demonstrating the importance of nodes being well-connected.

Average Payment Hop Speed (Voltage Sample Set)

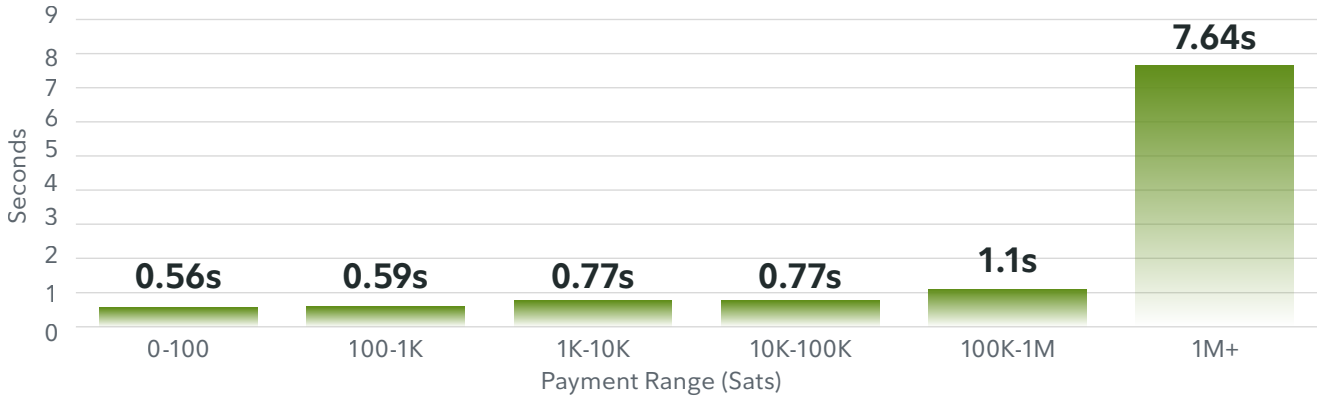


Source: Fidelity Digital Assets Research via Voltage, 10/22/24.

Additionally, larger payments do take more time to complete. This is likely due to time required to find proper routes to send the payment. As payment sizes increase, fewer and fewer channels could facilitate the payment (in a single transaction).

Therefore, the time it takes to find the optimal route increases as channels are disqualified. This also demonstrates the importance of well-connected nodes and the need for increased channel bandwidth.

Average Payment Speed (Voltage Sample Set)



Source: Fidelity Digital Assets Research via Voltage, 10/22/24.

The Lightning Network is not limited to the traditional constraints that blockchains are because it is peer-to-peer. It can complete transactions as fast as both the "sender" and "receiver" can resolve the payment rather than when the next block is confirmed in the blockchain.

With proper configuration, payments via the Lightning Network can easily be faster than one second. This could potentially position it as a leader in the digital asset ecosystem as it relates to the amount of time it takes to complete a payment.

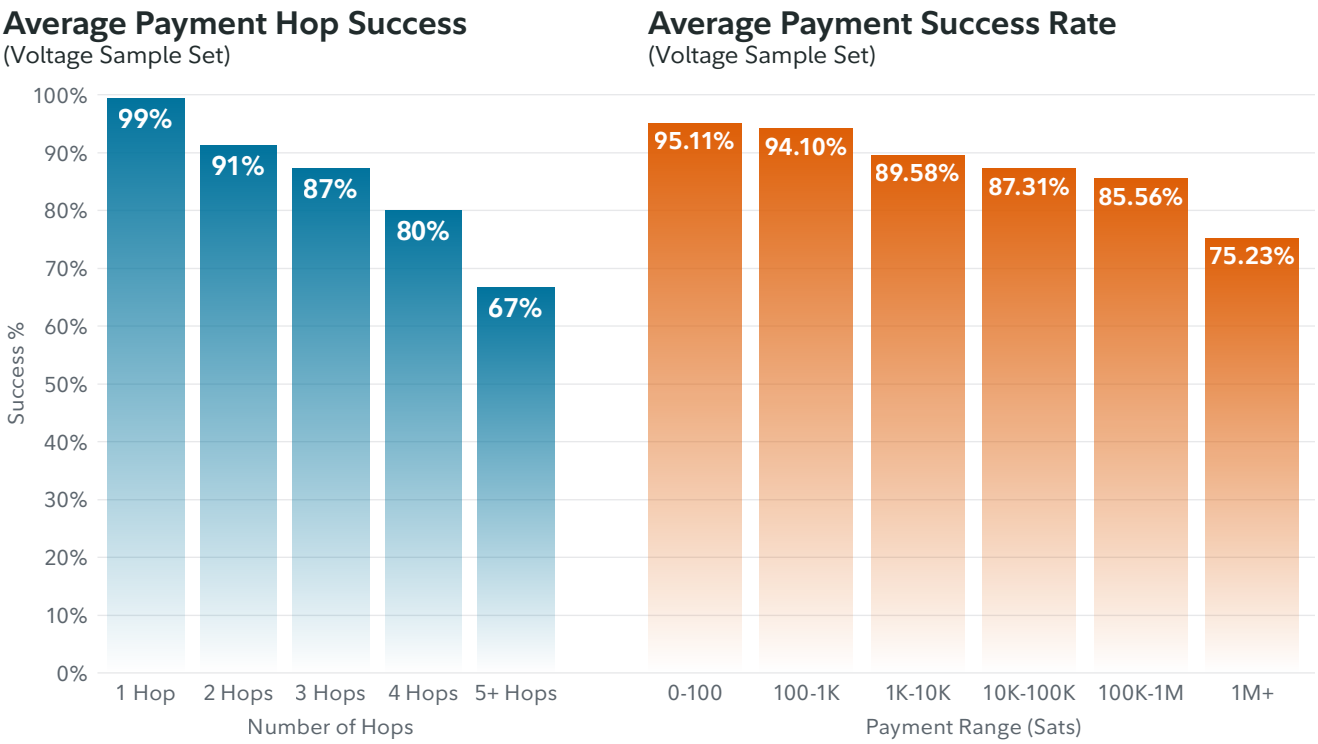
SUCCESS RATE

Our analysis suggests the biggest impact on the transaction success rate is the number of hops. The fewer hops, the greater the success rate. Transactions requiring only one hop have the highest success rate at over 99%.

As more hops are required for the payment, the likelihood of a failure increases. This underscores the importance of a well-designed channel strategy to ensure all payments are above the 99% success threshold. Each additional hop requires more node connections, which increases transaction complexity and can lead to higher latency, among other potential issues.

With each hop that is added, the success rate declines by 4–8%. This becomes particularly problematic with larger payment sizes, as fewer channels across the network can accommodate such payments.

Similar to transaction speeds and fees, the 99%+ success rate for Lightning payments is possible with proper configurations. A key factor in this rate is engineering solutions such as payment retries. With these solutions in place, we anticipate that payments on Lightning will become easier and more reliable.



Source: Fidelity Digital Assets Research via Voltage, 10/22/24.

Status of the Lightning Ecosystem

Lightning is steadily emerging as the language (protocol) of multiple layers and services using bitcoin as money. For example, Fedimint, Cashu, Nostr, and Podcast 2.0 applications all utilize the Lightning Network.

By leveraging a single payment network, these services demonstrate an interconnectedness comparable to how social platforms and messaging apps gain value through expanding their user bases. Ease of use and interoperability play a substantial role in that setup.

PAYMENT SCALING

Adoption of the Lightning Network has been slow but steady. Businesses such as Coinbase, Kraken, and Strike have integrated its abilities into their core business models to enable quicker and more cost-effective payments between users. Decentralized social projects such as Nostr allow users to seamlessly send small amounts of bitcoin to each other in the form of "zaps."[4] Nostr users have sent more than 3.6 million individual zaps in the last six months.[5]

The Voltage dataset shows an almost 200% increase in payment volumes when comparing 2024 to 2023 and a notable 2,424% increase when comparing 2024 to 2022.

Another popular application born of Lightning is the streaming of bitcoin. Applications such as Fountain—commonly referred to as a Podcast 2.0 application—enable the direct payment to and from podcast creators for time listened. The amount the user sends is completely "opt in," however, this technology could be applied more broadly to any kind of payment in relation to time spent.

For example, streaming services could charge based on usage instead of a standard payment. Company payrolls could be automated and earned down to the second worked, enabling employees to realize their paycheck in real time rather than bi-weekly or monthly.

Similarly, AI agents perform tasks very frequently and will need a method of transacting between one another. Lightning is highly suitable for these kinds of transactions because of its superior speed and cost.

Additionally, projects such as ARK, another Layer 2 protocol currently in the design phase, continue to innovate alongside the Lightning Network and expand use cases beyond peer-to-peer channels. Compared to Lightning, which requires channels with liquidity on both sides, ARK introduces shared unspent transaction outputs (UTXOs), allowing users to share virtual UTXOs (vUTXOs) with a larger group instead of on a one-to-one basis.[6,7] ARK also plans to have interoperability with the Lightning Network, thereby expanding Lightning's network effects.

What's on the Horizon?

Another interesting aspect of the Lightning Network is the application of fungible and non-fungible tokens. The Taproot Assets protocol enables the issuance of digital assets outside the scope of the underlying blockchain (Bitcoin).[8]

Assets are created and embedded into bitcoin's existing dataset of UTXOs. Taproot Assets have the potential to expand Bitcoin's functionality beyond seemingly simple value transfer by enabling the transfer of all assets inscribed to the network.

However, the most notable breakthrough here lies in the combination of Taproot Assets and the Lightning Network. At its most basic level, Bitcoin is simply a decentralized ledger of "who owns what." This means bitcoin is never sent between addresses like some explanations may imply. Rather, a change in the ledger means adding a credit to one side and a debit to the other.

This distinction is important because these two protocols enable ownership of inscribed assets to be traded at "lightning" speed with a negligible cost. Stablecoins, NFTs, and real-world assets such as gold and corporate bonds could trade seamlessly between users, companies, or even countries.

As a payment rail, Lightning is one of the fastest in the world. Now, users can load it with virtually any asset. Users may even choose to use the Lightning Network over other comparatively fast alternatives because it is backed and secured by Bitcoin.

An alternative view offers the Lightning Network not as a peer-to-peer scaling technology, but instead as one for immediate and final settlement between banks and institutions. Currently, most banks are a part of an interbank settlement network such as Fedwire or SWIFT. These networks enable one- to two-day payments. However, these transactions include multiple third parties. In some cases, additional parties are needed such as a clearing house or correspondent banks.

Using the Lightning Network, banks and institutions could settle debts instantaneously and in real time, either for themselves or on behalf of clients and users. However, the "HODL" mentality, driven by expectations of increasing purchasing power, makes investors reluctant to spend bitcoin. This could impact the speed at which Lightning is adopted.

Consequently, the Lightning Network and similar technologies that promote bitcoin spending remain relatively new concepts for most users. Looking ahead, we anticipate continued growth for the Lightning Network, despite bitcoin's perception as a maturing store of value that discourages spending.

Stablecoins on Lightning are expected to address this issue. Users will benefit from the speed and low fees that the Lightning Network offers while holding a stable asset.

CONCLUSION:

Lightning Could Strengthen Bitcoin's Overall Investment Thesis

Where Layer 1 bitcoin transactions take an average of 10 minutes to settle, Lightning transactions occur at the speed of light. Lightning transactions have a negligible cost, enabling the streaming of funds. This combination enables bitcoin payments to be used for day-to-day purchases such as a cup of coffee and for a new type of digital commerce enabled by micropayments.

For Lightning to be truly effective, users need Lightning payments to work 100% of the time. Both publicly available data and Voltage's proprietary data support the thesis that Lightning is steadily improving in efficiency and growth while also expanding its use cases beyond simple one-to-one payments. Its network capacity and transaction volume have continued to increase as Lightning continues to scale.

Additionally, there is the advantage of not needing to rely on a different blockchain or token. The ability to use the native bitcoin token for transactions is highly attractive in today's digital asset ecosystem, as new protocols with obfuscated tokenomics are constantly emerging.

Lastly, we believe the Lightning Network presents a transformative opportunity for both new and existing financial institutions as well as payment service providers to gain a significant competitive advantage in the global remittance and transaction processing landscape.

This second-layer solution, built on the current most secure digital asset network, offers several key benefits that may warrant consideration from institutional entities. By adopting this technology, banks, exchanges, and payment processors may be able to position themselves at the forefront of financial innovation. Further institutional adoption could solidify Bitcoin's role in the global financial system, enhancing its long-term value proposition and investment potential.

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[1] https://blog.kraken.com/product/kraken-now-supports-instant-lightning-network-btc-transactions
[2] https://www.theblock.co/post/291662/coinbase-lightning-network-lightspark
[3] https://lightning.network/lightning-network-paper.pdf
[4] https://nostr.how/en/zaps
[5] https://stats.nostr.band/
[6] https://github.com/ark-network/ark
[7] https://ark-protocol.org/
[8] https://docs.lightning.engineering/the-lightning-network/taproot-assets/faq