kraken INTELLIGENCE
ORDO AB CRYPTO

The Lightning Network

Bitcoin's evolution to medium of exchange

March 2022

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1.

Introduction

Blockchains, by design, are difficult to scale. They require storage of entire transaction ledgers and real-time validation of new records across a highly distributed network of nodes. As an analogy, picture a world where computers need to store every email ever sent while confirming the authenticity of new e-mails before they ship off to their destination. Scalability is just one factor within the "blockchain trilemma," or a series of tradeoffs between scalability, decentralization, and the security of a blockchain network. Optimizing for scalability, for example, often requires a blockchain to deprioritize decentralization or security. This challenge applies to all blockchain protocols, including Bitcoin.

Developers worldwide have taken action to scale transaction throughput on the Bitcoin protocol over many years. Notably, these developers take it upon themselves to challenge conventional thinking and introduce features that do not compromise the decentralization and security of the network. In fact, many of these changes actually strengthen these core principles. One of these features is the Lightning Network, a "Layer 2" protocol for scaling and speeding up transactions settled on a blockchain. The Lightning Network protocol complements the Bitcoin protocol while circumventing its limitations to deliver instant, near-free, and final Bitcoin payments.

Accessing Bitcoin through Lightning requires nothing more than a mobile phone, allowing billions of people to join the decentralized economy. Lightning empowers market participants worldwide with immense opportunities in emerging markets like El Salvador. With 70% of the adult population in El Salvador unbanked, Lightning improves upon equality of opportunity as it significantly increases financial inclusion.[1]

Reflecting on its history, Lightning has been slow to satisfy the early excitement since launching in 2018. Over the last several years, the protocol was in beta, catering to technical development communities focused on niche applications like wallets and point-of-sale terminals. While Lightning remains fairly nascent, user adoption has picked up materially since late-2020, and the protocol is now making BTC more accessible to people worldwide. Despite its nascency, Lightning is on the brink of bringing BTC to billions of unbanked individuals, allowing them to achieve financial sovereignty coupled with utmost privacy. In this deep dive, Kraken Intelligence provides an overview of the Lightning protocol, its historical background, technical design, and the state of the network.

2.

What is the Lightning Network?

There has been significant hype brewing around the potential of blockchain technology for nearly a decade-and-a-half. Some market participants contend that decentralized blockchains are always better than centralized databases. These arguments rest on claims that blockchains improve on multiple societal themes. These themes range from the monetary system to supply chains and even the ownership of digital copyright. However, the truth is more complex. While it seems the crypto space is reaching an inflection point in establishing the native transaction rails of the Internet, a lot of improvements are still required for cryptoassets to support a global audience, particularly with respect to scalability.

The Bitcoin On-Chain Scalability Problem: Blockchains Are Inherently Inefficient

Decentralized blockchains and centralized databases primarily differ on access, censorship resistance, and immutability. In particular, a well functioning blockchain network does not allow for the adjustment of records in the ledger history. These differences require decentralized blockchains to constantly form consensus among a highly distributed set of nodes, an effort that isn't required by centralized database design. For this reason, centralized systems such as VISA can reportedly handle upwards of 24,000 transactions per second (TPS), while Bitcoin manages roughly 7 TPS.[2] In short, there are significant tradeoffs between decentralized systems and centralized systems. There is no one-size-fits-all solution.

These scalability issues are concerning because, as the world's leading cryptoasset, BTC plays a vital role as a means of transacting value. While anyone is free to hold, send, and receive BTC and benefit from a codified monetary schema, the low transaction throughput of the blockchain does not meet the standards to become a global, peer-to-peer medium of exchange on its own. This conflicts with the titled philosophy in the seminal whitepaper, Bitcoin: A Peer-to-Peer Electronic Cash System. Currently, Bitcoin faces the following significant limitations:

- **Transaction Throughput**—The Bitcoin protocol supports approximately 7 TPS. Furthermore, miners introduce Bitcoin blocks every 10 minutes, on average, meaning users cannot confidently settle BTC transfers instantly.
- **Fees**—Block space is limited and network fees required to include a transaction in a block may fluctuate wildly based on demand for block space.
- **Network Congestion**—Variable block times and heightened network use can result in transaction backlogs, which delay settlement confirmations.

Bitcoin's Lightning Network aims to solve these scalability limitations through the introduction of the Lightning Network, which promises instant and inexpensive transactions at a rate of millions of TPS.[3]

Lightning Network Overview

The Layer 2 (L2) Lightning Network complements Bitcoin's blockchain to enable "off-chain" transactions, or transactions between parties not recorded initially on the blockchain. L2 transfers occur via an independent network of nodes connected by peer-to-peer payment channels anchored to the Bitcoin blockchain. By bringing transactions off-chain, users can conduct low-cost, near-instant payments routed across a trustless L2 network via connected Lightning nodes. Because this design ensures that payment channels inherit the security of the underlying Bitcoin blockchain, or the "Layer 1" (L1)

network, users can confidently take advantage of the instant, off-chain settlements. Notably, Lightning is an overlay network powered by Bitcoin smart contracts rather than an independent blockchain. Lightning does not introduce a new token and shares a similar value system as Bitcoin: decentralization, permissionless, censorship resistance, and open source.

Using conventional Bitcoin multi-signature (multisig) smart contracts, the Lightning protocol allows users to open payment channels with other users. Users transact peer-to-peer in these off-chain channels without broadcasting every transaction to the Bitcoin blockchain. This is how Lightning promises near-instant and near-zero fee transactions. Users can confidently transact on Lightning due to the immutability of these off-chain transactions and the ability to "close" their payment channel on the Bitcoin blockchain, which results in complete finality of their settlements. In other words, Lightning sidesteps the scalability challenge of the Bitcoin blockchain by taking transaction metadata off of the L1 blockchain until a user wishes to finally settle their balances. Though Lightning is intended to advance the adoption of day-to-day BTC payments, opening payment channels introduces several other benefits.

For instance, the LN enables micropayments as small as a fraction of a penny. Micropayments on the L1 Bitcoin network are infeasible because transaction fees often exceed the transaction amount itself. Instead, other micropayment solutions required users to hold funds with third-party custodians. Lightning enables instant micropayments without requiring users to take counterparty risk with a centralized custodian.

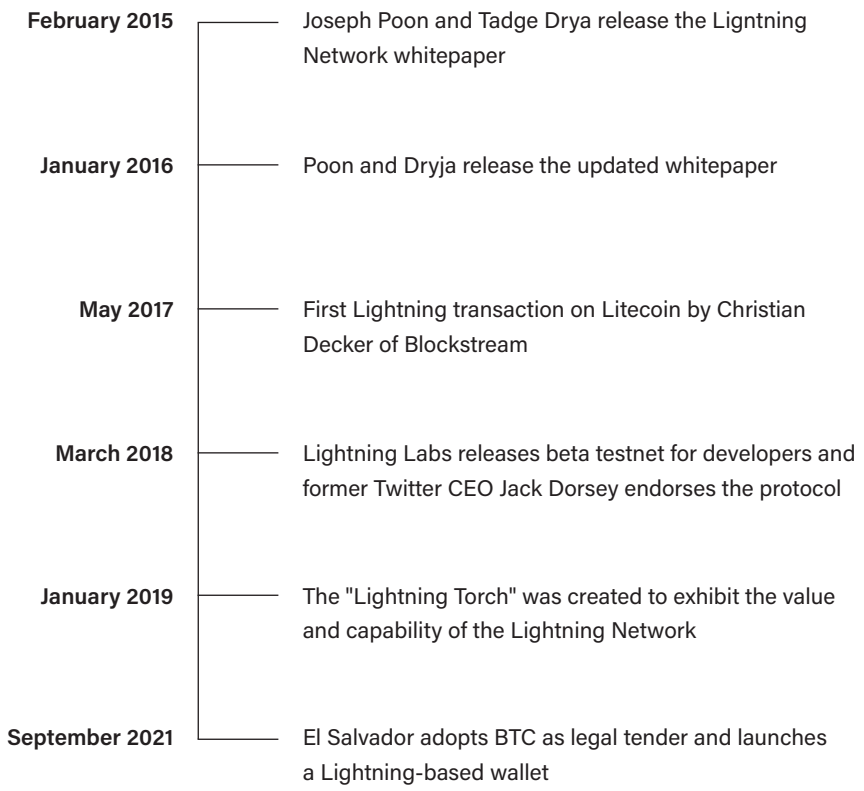
Lightning also introduces greater transaction privacy, particularly with the latest **Taproot upgrade**. Previously, Bitcoin on-chain analysts were able to identify the opening and closing of Lightning payment channels because the metadata reveals smart contract transactions that include various public keys and signatures. Now, Taproot-enabled Lightning channels allow users to open and close payment channels while appearing as standard, single-signature BTC transactions. This makes it challenging for individuals to associate payment channels with transacting users on the network.

History of the Lightning Network

Though Lightning has come a long way over the past 7 years of development and adoption, the network still has significant room to grow and mature. In this section, we will discuss the history of the Lightning Network and the various feature changes that have sustained adoption growth and technical robustness. The following timeline aims to summarize Lightning's development and adoption milestones since Bitcoin's inception to better understand where Lightning stands in the bigger picture, though readers should note that the portion of history relating to Bitcoin itself is used to provide broader context.

Figure 1

Brief Timeline of the Lightning Network



Source: Kraken Intelligence[4,5,6,7,8,9]

History of the Lightning Network

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2009: Satoshi Nakamoto's Payment Channels

Payment channels, a fundamental building block of the Lightning Network, are arguably as old as the first Bitcoin software released by Satoshi Nakamoto on January 3, 2009. Bitcoin version 0.1 included a rough draft of code that would let users update a transaction before it was confirmed.[10]

While this code was a rough draft, Satoshi went into further detail to describe how payment channels could work in private communication with former bitcoinj developer Mike Hearn.[11] Still, Satoshi's design for payment channels was not entirely trustless because it permitted users to collude with miners to confirm old channel states and cheat transacting counterparties in the channel. In other words, one party could collude with a miner to confirm a non-final version of a transaction, claiming more BTC than the channel balance would allow them to and stealing funds from the other counterparty.

2011–2014: Payment Channels Take Baby Steps

In July 2011, shortly after Satoshi's disappearance from the Bitcoin project, bitcointalk.org user "hashcoin" proposed a two-tier payment channel requiring participants to exchange several partially signed multisig transactions and transactions. Hashcoin's solution aimed

to make payment channels resistant against miner collusion attacks, ensuring that if one channel participant disappeared, the other could claim all the funds in the payment channel after a certain amount of time passed.[12] However, this design was not perfect because they could only work unilaterally, meaning that "Bob" could pay "Alice," but "Alice" could not pay "Bob" via the same channel.

Many iterations of this idea emerged from the Bitcoin community throughout the following years from Christian Decker, Corné Plooy, Meni Rosenfeld, Alex Akselrod, Jeremy Spillman, Roger Wattenhofer, and more.[13,14,15,16,17] Lightning Labs engineer Akselrod made the next breakthrough in 2014 when he proposed the first bi-directional payment channel. However, developers never implemented this solution in Bitcoin's code.

2015: Release of the Lightning Network Whitepaper

Researchers Joseph Poon and Tadge Dryja originally envisioned the Lightning Network in a February 2015 rough draft whitepaper, version 0.5, to solve Bitcoin's scaling restrictions. In the draft, Poon and Dryja outlined,

> *"The blockchain as a payment platform, by itself, cannot cover the world's commerce anytime in the near future. If each node in the bitcoin network must know about every single transaction that occurs globally, that may create a significant drag on the ability for the network to encompass all global financial transactions [...] If Bitcoin is to replace all electronic payments in the future, not just Visa, as currently implemented it can only achieve a small portion of that, or at best, scale with extreme centralization of a few capital-intensive Bitcoin nodes and miners."*[18]

While the researchers published the whitepaper as a work in progress at the time, the proposed use of Hashed Timelock Contracts (HTLCs) for routing payments over multiple channels turned out to be the best solution to date. Later that month, Poon and Dryja presented at the SF Bitcoin Devs Seminar in the first public presentation of the Lightning Network.

2017: The Segregated Witness (SegWit) Soft Fork Upgrade

When publishing Lightning's whitepaper, transaction malleability was considered a significant challenge. Bitcoin's transaction malleability problem allowed anyone to change a BTC transaction's unique ID (TXID) before confirmation on the blockchain. While this was not a threat to the Bitcoin blockchain for native transactions, it allowed bad actors to fictitiously suggest the original transaction, identified by the TXID, did not take place, tricking third parties like crypto exchanges or a Lightning channel. In theory, this could allow a bad actor to effectively steal funds from a counterparty by requiring them to post another transaction to replace the "failed," original transaction.

For an exchange, an attacker would make a withdrawal request, prompting the exchange to process the requested withdrawal and save the transaction ID (TXID) in their database. The attacker would then modify the transaction ID and resubmit another transaction with a different TXID, which is also mined on the blockchain. The exchange never detects that the original withdrawal was successfully confirmed on the network because the attacker modified the TXID. Effectively, the attacker double spends their exchange balance by leveraging a weakness on the exchange's internal database management.

In the case of Lightning, two users must sign a 2-of-2 multisig "funding transaction" before opening a channel. If Bitcoin nodes broadcast the funding transaction before both parties signed the multisig transaction, one of the channel's counterparties could modify the transaction to make the double-signed transaction invalid and allow the bad actor to steal funds from their counterparty.

The 2017 Segregated Witness (SegWit) soft fork on the Bitcoin blockchain eliminated transaction malleability, a fundamental precondition for implementing Lightning.

2018: Lightning's Official Launch

On March 15, 2018, Lightning officially went live for more technical users in a Beta phase on Bitcoin mainnet through the release of LND 0.4-beta by Lightning Labs.[19]

2019: The Lightning Torch

In January 2019, pseudonymous Twitter personality Hodlonaut sent ₿0.001 (or 100,000 satoshis) to a trusted Lightning wallet where each recipient added 10,000 **satoshis** ($0.34 at the time) to send to the next trusted recipient.[20] The goal of the "lightning torch" was to kickstart a game-like promotional test of the network. Many saw the exercise as an effective showcase for how seamlessly users could send Lightning payments worldwide at a time when Lightning was early in its infancy and rarely used.

The "torch" was transferred a total of 292 times, including to the likes of former Twitter CEO Jack Dorsey, Lightning Labs CEO Elizabeth Stark, and Kraken Lead Bitcoin Strategist Pierre Rochard, before reaching the 4,390,000 satoshis (₿0.0439) hard-coded limit to how large the torch could become. The final payment of the lightning torch on April 13, 2019 of 4,290,000 satoshis ($217.78 at the time) went to Bitcoin Venezuela, a non-profit organization promoting Bitcoin in Venezuela.

2021: El Salvador Adopts BTC as Tender and Releases a Lightning Wallet

At the Bitcoin 2021 conference in Miami on June 5, 2021, Salvadoran President Nayib Bukele, a tech-savvy millennial, announced plans to legalize BTC as tender and integrate it into the country's economy via Lightning.[21] Bukele suggested that legalizing BTC as tender would spur investment in the country, and help the roughly 70% of Salvadoran adults who cannot access traditional financial services.[22] To advance adoption, President Bukele promised $30 of BTC for each user of the country's preferred LN-based wallet provider, Chivo, and the government pledged a $150 million fund to facilitate transactions between USD and BTC.[23] Less than a month later, President Bukele announced on October 1, 2021, that 2.7 million Salvadorans had already signed up for the Lightning-based Chivo wallet.[24]

Layer 1: The Bitcoin Blockchain

Equipped with surface-level knowledge of the LN and its history, readers should familiarize themselves with the Bitcoin base layer's accounting method before diving further into the technicalities of Lightning. For readers that already have a fundamental understanding of Bitcoin's unspent transaction output (UTXO) model, feel free to skip this section to "Layer 2: Lightning Network Channels" on page 15.

The Unspent Transaction Output (UTXO) Model

Bitcoin utilizes the Unspent Transaction Output (UTXO) model to account for the distribution of coins among users. At its core, each UTXO is a quantity of BTC linked by an address to a private key. Bitcoin transactions consist of inputs and outputs; inputs refer to UTXOs consumed by a transaction (i.e., UTXOs spent), while outputs are the UTXOs created by a transaction (i.e., UTXOs received). A digital signature—the result of cryptographically applying a private key to data that proves UTXO ownership without exposing the private key—is required to unlock and spend UTXOs. Because only unused outputs can work as inputs to a transaction, users can only spend UTXOs once. If someone were to try to use a previously spent output in another transaction, nodes would reject the transaction.

Moreover, UTXOs are not spent partially under any circumstances. It is helpful to think of UTXOs as a receipt that shows the balance amount or change in a given transaction. For example, imagine Bob wants to buy a cup of coffee that costs $3. Because $3 bills do not exist, the purchaser can pay with a $5 bill, or several bills that add up to $3 (e.g., paying three $1 bills). UTXOs function in a similar way in that users must always spend them in their entirety.

If Bob wanted to purchase that coffee with BTC, it would cost him roughly 6,800 satoshis, or ₿0.00006833 (~$3). Now imagine Bob's wallet only has a single UTXO that contains 7,000 satoshis. In this case, Bob would spend the full 7,000 satoshis in the UTXO, creating one output with 6,800 satoshis to the seller's address, and a second output with 200 satoshis to a change address, owned by the buyer. However, if that purchaser had various UTXOs of 1,000 satoshis, 5,000 satoshis, and 800 satoshis, all three UTXOs would be used as the inputs of the transaction. The protocol would then add up the inputs in this transaction to a single UTXO containing 6,800 satoshis.

Example of a Standard Bitcoin Transaction:

1. Bob owes his local cafe 6,800 satoshis for a coffee.
2. The cafe sends Bob an address from their wallet to receive payment.
3. Bob creates a digital signature using his private key to unlock and send 6,800 satoshis from UTXOs associated with his wallet to the cafe's address.
4. Assuming Bob's wallet only has two UTXOs containing 6,000 satoshis and 1,000 satoshis, he would spend both UTXOs as the transaction's inputs.
5. The transaction creates two UTXOs as unused outputs: a UTXO associated with 6,800 satoshis goes to the cafe's wallet, and a UTXO worth 200 satoshis is sent back to Bob as change.

Layer 2: The Lightning Network

Payment Channels

Lightning's accounting method differs from the Bitcoin base layer's UTXO-based model by utilizing something called "state channels." Payment channels were the first type of state channel, using off-chain interactions to modify ownership of locked BTC to allow for "off-chain payments." A payment channel, the primary building block of the entire L2 network, is a bi-directional payment connection between two Lightning nodes.

Opening a channel between two people or more on the Lightning network begins with sending an on-chain transaction. This initial funding transaction creates the channel that both parties control. They can then use this channel to send BTC between themselves instantly, with near-zero fees and without needing to broadcast every transaction to the base layer of the Bitcoin blockchain. Either party can settle on the Bitcoin blockchain and close the channel at any time. When the channel is closed and settled on the base layer blockchain, the funds are sent to each party according to the channel's transfer history, which is summarized in its entirety as a single transaction on the Bitcoin blockchain.

The direct payment channel between the two parties can also become part of the larger Lightning Network. If two parties are not directly connected via a payment channel, transactions between these two parties can take advantage of the Lightning Network via interconnected pathways. In this case, Lightning nodes search for the best route to complete the transaction and execute against that route. For instance, Bob wants to send funds to Alice but doesn't have an open channel with her. However, both Bob and Alice have their own channels open with Mary. In this scenario, Bob could route the payment to Alice through their mutual connection with Mary without needing to open a new channel directly between Bob and Alice.

Payment Routing Via Hash Time-Locked Contracts (HTLCs)

While the above example demonstrates a bi-directional payments channel, global payment networks require more complexity. For this reason, the LN uses a technique called Hash Time-Locked Contracts (HTLCs) to allow payments to go through a path of payment channels rather than establishing a direct payment channel to every other person on the network.[25]

These types of smart contracts use a hash verification (i.e., hashlock) and a time expiration verification (i.e., timelock) to ensure payment security, enabling LN users to create payments with a specific "expiration date." Hashlocks restrict the spending of a UTXO until a specified piece of data is publicly revealed, allowing users to route payments via third parties without any risk that the third parties will take the payments

1. The cafe would generate a random number, run it through the SHA-256 hashing function to compress it, and share the hashed result with Alice.
2. Alice uses her payment channel with Bob to pay him 6,000 satoshis for a coffee, including the hash the cafe gave her to the payment and an extra condition requiring Bob to provide the data used to produce that hash to claim the payment.
3. Bob uses his payment channel to the cafe to pay the business 6,000 satoshis, and Bob adds a copy of the same condition that Alice put on the payment she gave Bob.
4. The cafe has the original data used to produce the hash, or the "pre-image", so the cafe can use it to finalize his payment and fully receive the payment from Bob. By doing so, the cafe necessarily makes the pre-image available to Bob.
5. Bob uses the pre-image to finalize his payment from Alice.

3.

Lightning Network Adoption

In this section, the team measures Lightning Network adoption by analyzing the growth of several key metrics, including total channel capacity, the number of nodes, and the number of channels. Per figure 2, Lightning has seen consistent growth year-over-year since inception, except for average channel size and average capacity per node. However, the data illustrates that the Lightning Network's growth has accelerated in recent years. Lightning usage has been on a steep upwards trajectory since late-2020, growing parabolically in September 2021 corresponding with the introduction of BTC as legal tender in El Salvador. Still, public metrics do not describe the full extent of Lightning adoption because of the number of users in the Lightning ecosystem utilizing private channels.

Figure 2

Lightning Network Overview

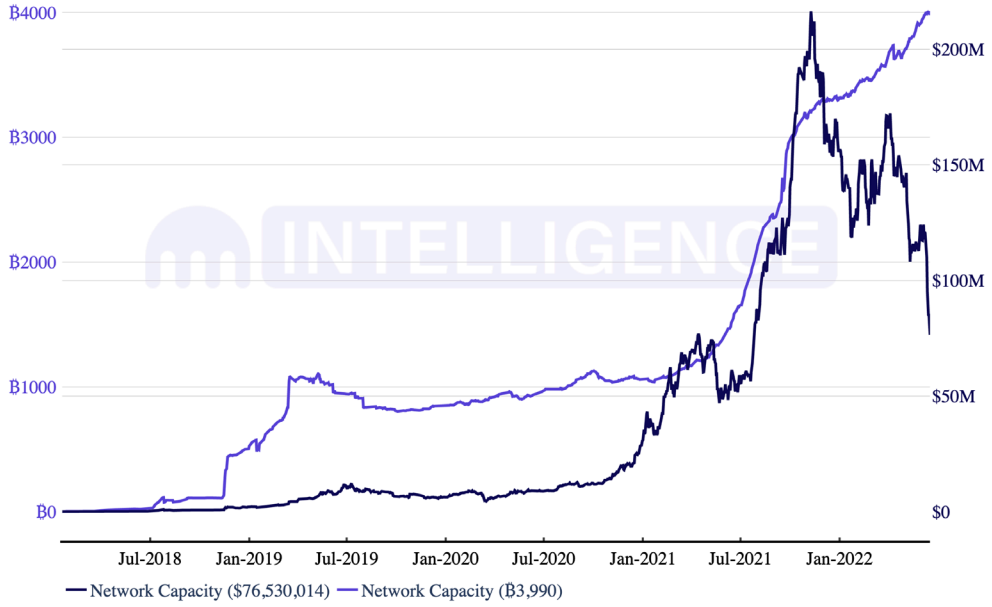
	Network Capacity		Node Count		Channel Count		Avg. Channel Size		Avg. Capacity Per Node	
	January	YoY Delta	January	YoY Delta	January	YoY Delta	January	YoY Delta	January	YoY Delta
2018	$14.2K	-	54	-	105	-	$135	-	$263	-
2019	$1.9M	12,962%	2,592	4,700%	19,391	18,368%	$96	-29%	$715	172%
2020	$7.5M	305%	4,977	92%	31,650	63%	$237	148%	$1,508	111%
2021	$38.3M	410%	8,482	70%	37,040	17%	$1,035	336%	$4,517.8	200%
2022	$76.5M	100%	16,940	100%	83,808	126%	$913	-12%	$4,517.7	-0.002%

Source: Kraken Intelligence, Bitcoin Visuals

The Lightning Network's capacity, the total of all publicly indexed funds in Lightning channels, has grown +277% to more than ₿3,990 since January 2021. In USD terms, this means network capacity grew by nearly +147%, or $45.5 million, to more than $76.5 million during the period. For context, from January 2018 to January 2020 network capacity grew a total of $7.5 million, but has grown by $69 million in the two years since then.

Figure 3

Lightning Network Capacity

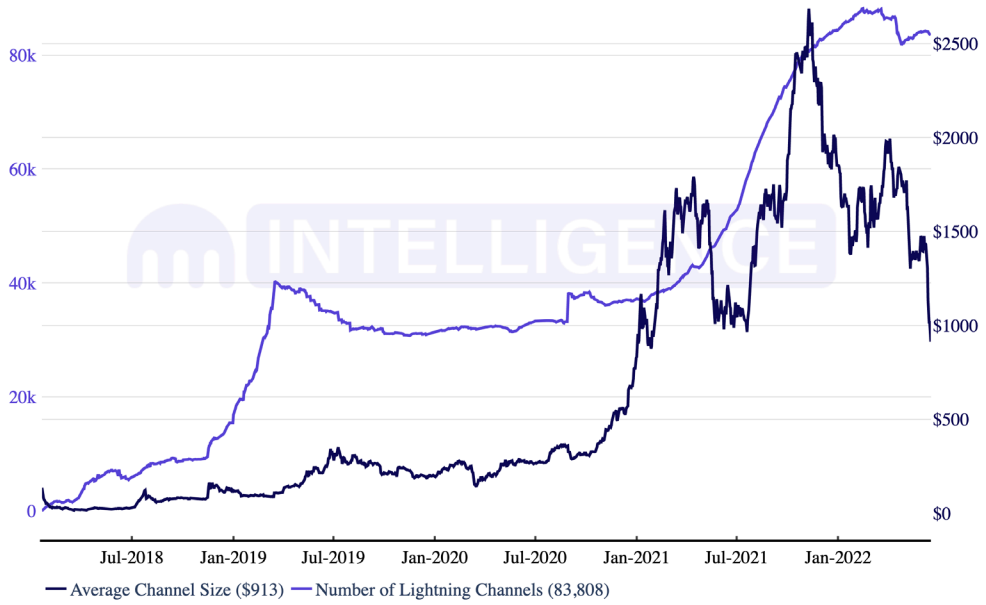


Source: Kraken Intelligence, Bitcoin Visuals

Lightning currently constitutes 83,808 channels, a +125% increase since the start of 2021. The number of channels and network capacity also implies an average channel size of nearly ₿0.0476 or around $1,000 at the time of writing. Though this figure is up +67%, the USD equivalent of average channel capacity grew +10% from roughly $832 in January 2021 to about $913 at the time of writing, accounting for BTC's depreciation.

Figure 4

Lightning Channels and Average Channel Size



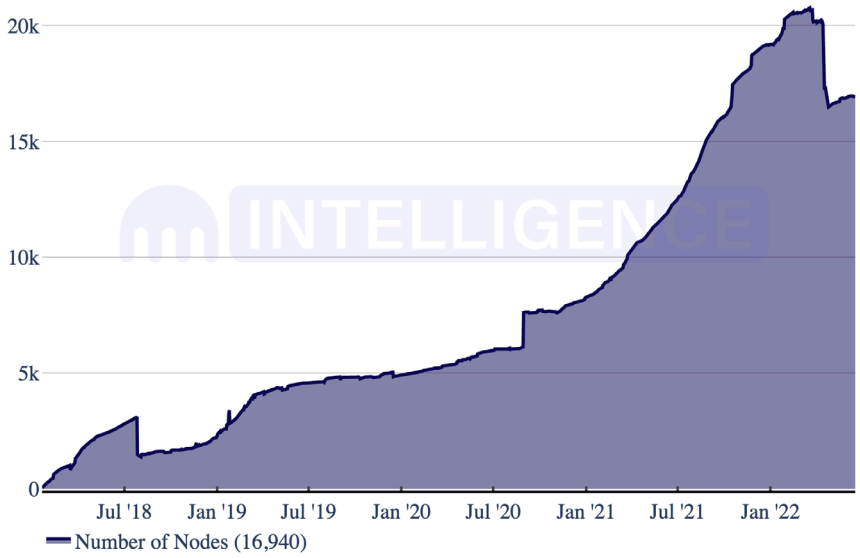
Source: Kraken Intelligence, Bitcoin Visuals

Furthermore, the growth in the sheer number of Lightning nodes indicates that the network is beginning to see many new participants. Nodes saw continuous growth from 2018 to late August 2020, rising from 54 to 6,134. However, node growth has since gone parabolic, rising over +176% to 16,940 nodes at the time of writing. Lightning node

growth has proliferated so fast that there are now roughly 1,000 more Lightning nodes than Bitcoin nodes.[26] Should adoption continue to grow at this rate, the Lightning network could realize BTC's potential as a medium of exchange asset—an essential feature for global money that was previously a bottleneck for BTC going mainstream.

Figure 5

Lightning Nodes



Source: Kraken Intelligence, Bitcoin Visuals

5.

Conclusion

The Lightning Network is a protocol for scaling blockchains for a global audience. Lightning circumvents the bottlenecks of network-wide consensus by settling transactions off-chain, avoiding latency and computational redundancies that hamper blockchains. Moreover, the L2 solution tackles these scalability issues that plague blockchains without compromising security or decentralization on the L1 blockchain, effectively avoiding making any tradeoffs within the blockchain trilemma.

Lightning was first proposed 7 years ago in 2015 but did not launch until 3 years later after extensive development and testing. Though the network has been slow to pick up momentum since its launch in 2018, the Lightning Network is now posting growth in adoption and enabling BTC to serve as a medium of exchange. This is evidenced by the +176% rise in the number of nodes, +125% jump in channels, and the $45.5 million increase in network capacity. The revolutionary technology is making BTC more accessible to people worldwide, enabling market participants to send money instantly via internet-native global transactions with immense opportunities in emerging markets like El Salvador, whose population is roughly 70% unbanked. While Lightning still needs much work, it is currently solving real-world problems for the people that need it most by providing global financial access to unbanked individuals.

Footnotes

1. https://www.acuant.com/blog/the-worlds-unbanked-population/
2. https://usa.visa.com/run-your-business/small-business-tools/retail.html
3. https://www.coindesk.com/tech/2021/07/12/the-lightning-network-is-going-to-change-how-you-think-about-bitcoin/
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11. https://lists.linuxfoundation.org/pipermail/bitcoin-dev/2013-April/002417.html
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13. https://bitcointalk.org/index.php?topic=28565.0
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17. https://www.tik.ee.ethz.ch/file/716b955c130e6c703fac336ea17b1670/duplex-micropayment-channels.pdf
18. http://lightning.network/lightning-network-paper-DRAFT-0.5.pdf
19. https://blog.lightning.engineering/announcement/2018/03/15/lnd-beta.html
20. Satoshis are a tiny subunit of bitcoin. Each bitcoin is made up of 100 million satoshis.
21. https://www.cnbc.com/2021/06/05/el-salvador-becomes-the-first-country-to-adopt-bitcoin-as-legal-tender-.html
22. https://www.npr.org/2021/06/11/1005231250/el-salvador-plans-to-use-electricity-generated-from-volcanoes-to-mine-bitcoin
23. https://www.reuters.com/business/finance/el-salvador-leads-world-into-cryptocurrency-bitcoin-legal-tender-2021-09-07/
24. https://time.com/6103299/bitcoin-el-salvador-nayib-bukele/
25. https://wiki.ion.radar.tech/tech/bitcoin/hltc
26. https://bitnodes.io/

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