The Investigation of Layer 2 Blockchain Technologies for Decentralized Applications

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Abstract: Layer 2 blockchain technology plays a pivotal role in enhancing the scalability and efficiency of existing blockchain frameworks. It acts as a crucial layer atop base blockchains, enabling rapid, cost-effective transactions crucial for Decentralized Applications (DApps) while preserving the security and decentralization of the primary blockchain. This review dives deep into the realm of Layer 2 blockchain technologies, shedding light on their significant role in the development and operation of DApps. It kicks off with a thorough exposition of the conceptual underpinnings of Layer 2 solutions, paving the way for a detailed examination of specific implementations across major blockchain platforms like Bitcoin and Ethereum. The paper explores how the most recent advancements in Layer 2 technologies are revolutionizing DApps, offering a balanced discussion of both the benefits and constraints these technologies bring to the table. A notable aspect of the paper is its focus on the distinct strategies employed by different platforms in integrating Layer 2 solutions. Furthermore, it provides illustrative examples of various DApps that have reaped the rewards of Layer 2 technologies, thus underscoring their wide-ranging applicability and immense potential in elevating the performance and user experience of decentralized systems. The paper wraps up with a forward-looking perspective, envisioning the future trajectory of Layer 2 technologies. Efficient cross-chain interactions, state-of-the-art privacy enhancements, and smart contract execution optimization are some of the technologies that will further revolutionize the blockchain.

1 INTRODUCTION

Blockchain technology has been hailed as a transformative force for decentralization in digital transactions. The inception of Layer 1 blockchains brought forth a new paradigm of trustless and secure transactions. However, with the expansion of Decentralized Applications (DApps), the demands on blockchain infrastructure have increased, exposing the limitations in scalability and throughput. Layer 2 technologies are engineered to surmount these challenges by building atop the foundational Layer 1 to enable scalable, efficient, and cost-effective transactions, which deserves more attention.

Gangwal et al. (2023) discuss each Layer 2 protocol class in detail and elucidate their respective approaches, salient features, requirements, etc. Jourenko et al. (2019) categorize the protocols related to cryptocurrency Layer 2 scalability and discuss their advantages and disadvantages. In addition to Channels, Sidechains, Rollups, Cross Chains, or Hybrid Solutions like Arbitrum, and other technologies that increase the transaction throughput and scalability of a blockchain network (Miller et al. 2019, Tochner et al. 2019, Back et al. 2014, Belchior et al. 2021, Teutsch & Reitwießner 2019, Kalodner et al. 2019), Xu et al. (2023) present a new Layer 2 blockchain called W3Chain, which is promising to deliver high Transactions Per Second (TPS) while defeating the scalability trilemma of a public blockchain. The Layer 2 Atomic Cross-Blockchain Function Calls (LTACFC) protocol is designed to enable composable programming across Ethereum blockchains, which allows for inter-contract and inter-blockchain function calls to be synchronous and atomic (Robinson & Ramesh 2020). With the development of Layer 2 technology, DApps have gained a wider range of application scenarios. These applications include Decentralized Finance (DeFi), gaming, artwork and Non-homogenized Tokens (NFTs), supply chain management, etc. (Sunny et al. 2022). Layer 2 solutions enable these applications to run faster and more efficiently while reducing transaction costs. Xu et al. (2022) introduce L2chain,

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a layer-2 blockchain framework designed to scale DApp transactions while maintaining a concise on-chain state digest for integrity. A great number of DApps use Layer 2 technology to increase transaction speeds and reduce costs, especially on highly congested and expensive blockchains such as Ethereum. Rana et al. (2023) propose a decentralized model for using smart contracts to safeguard digital evidence to overcome these issues and analyze how the model is used in actual legal systems, law enforcement organizations, and digital forensics investigations. Rafaj et al. (2023) propose a DeFi gaming platform that leverages the benefits of layer 2 solutions to reduce gas fees and improve user experience. Kucheriya et al. (2023) introduce the project as an NFT-based game that runs on the Polygon network (Matic Mumbai Test-net) on layer 2 of the Ethereum Blockchain and is powered by decentralized Chain link Oracles. Chishti et al. (2023) propose an instant account settlement process for a roll-up-based layer-2 blockchain framework that business service providers can apply in a metaverse ecosystem for performing micro-transactions. Singularity DAO is a Layer 2 DeFi solution by Singularity NET enhancing funding for blockchain projects through AI and tokenomics, improving token liquidity (IntelligentHQ 2020). The Polygon's integration with Life DeFi Wallet boosts transaction speed and security, lowers fees and allows access to Polygon's decentralized apps (SyndiGate Media Inc 2023).

Given the rapid progress of Layer 2 technology, examining the intricacies of it, including a comprehensive overview of its operational mechanisms, is pivotal for an understanding of its application in DApps. This article will elucidate which DApps are most amenable to which Layer 2 solutions, while assessing the advantages and limitations of these technologies, which is instrumental for developers and industry experts in making informed decisions regarding the optimal technology for specific applications. The rest of the paper is structured as follows. Section 2 of this paper describes the broad framework and technical development of Blockchain Layer 2 Solutions. Section 3 introduces and discusses Dapps that have adopted Blockchain Layer 2 technology.

2 BLOCKCHAIN LAYER 2 SOLUTIONS

2.1 Framework of Layer 2 and Latest Algorithms

Layer 2 refers to a set of off-chain solutions built on top of the main net to increase transaction throughput without sacrificing decentralization or security. Layer 2 builds on top of Layer 1 and can be extended in a variety of ways without having to change the underlying blockchain protocol. These include channels, sidechains, rollups, cross-chain technologies, hybrid solutions, etc. Notary Schemes, Blockchain of Blockchains, Bisection Protocols, and Trusted Execution Environments are various specialized technologies designed to improve the transaction throughput and scalability of blockchain networks. These techniques are used in different ways to reduce the burden on the main chain or to improve the efficiency of cross-chain interactions. Based on the recent review (Gangwal et al. 2023), this paper aims to further analyze in detail the new layer2 technologies arising from 2021 to 2023. To be more specific, three aspects including Bitcoin (BTC) Layer 2 solution, Ethereum (ETH) Layer 2 solution and some other blockchain Layer 2 solutions will be considered.

Sahoo et al. (2023) present a privacy-preserving solution for secure payment channel rebalancing in layer-2 blockchain networks, improving balance management and preventing transaction failures using the enhanced HTLC protocol. In another study, Yee et al. (2022) explore the nuances of blockchain finality, distinguishing between different types of finality and emphasizing the importance of transaction order finality in system states. Massimo (2023) evaluates the impact of rollup scaling solutions on Ethereum's layer-2 ecosystem, while Neiheiser et al. (2023) examine the practical limitations of Ethereum's Layer-2. Hong et al. (2022) introduce PYRAMID, a layered sharding blockchain system that enhances scalability and cross-shard transaction efficiency, showing significant improvements in transaction throughput, especially in complex cross-shard transactions.

2.2 BTC Layer 2 Solutions

Bitcoin was designed with the goals of security and decentralization in mind and does not support smart contracts and DApps like Ethereum does. Nonetheless, several projects and protocols attempt to

implement some DApps-like functionality on Bitcoin, often by building a second layer of protocols on top of Bitcoin. For example, by using the Bitcoin Lightning Network, it is possible to implement faster, lower-cost payment channels that are not DApps in the traditional sense. The Lightning Network is the earliest and most viable Layer 2 in the crypto world. BTC's Lightning Network does not go onto the main network for day-to-day transactions, thus saving on costly Gas, and if both parties believe they will no longer be able to transact, they can send a message to the main network to make the transaction. When they believe they will no longer trade, they can initiate a withdrawal command to the mainnet, the signature of which proves to the BTC mainnet the authenticity of a series of transactions between the two parties off the mainnet.

Lightning Network (LN) is a layer-2 protocol that enables fast Bitcoin transaction processing. However, it only works well for peer-to-peer micro-payments, namely, small-amount payments between individual parties. Wang et al. (2023) propose an LN-based framework for both peer-to-peer and customer-to-business payments, the Business-oriented Layer-2 Network (BLN). With BLN, Bitcoin transaction processing scales much better. Their experimental results indicate that BLN outperforms LN in terms of transaction failure rate, transaction fee, and processing time.

The 2021 Bitcoin Taproot upgrade introduced Schnorr signatures (Schnorr 1991, Maxwell 2019, Cragg et al. 2015) and MAST contracts (Kim et al. 2018), enhancing Bitcoin's cross-chain decentralization. Schnorr signatures, more efficient than elliptic curve signatures, enable clustering of up to 1,000 addresses to manage the same asset, improving privacy and reducing data load. This breakthrough surpasses Bitcoin's previous 15 re-multi signature limit, allowing for fully decentralized signature management. MAST contracts, using Merkle trees, encrypt complex scripts whose components don't overlap. These contracts, similar to smart contracts, require only relevant script disclosure for transactions, simplifying and securing operations.

2.3 ETH Layer 2 Solutions

Unlike Bitcoin, which focuses on its role as a digital gold and store of value and adopts a more conservative upgrade strategy to ensure the stability and security of the network, Ethereum has an active community of developers, with several developers who can build a variety of complex decentralized applications on it and experiment with and research Layer 2 solutions, scaling technologies. Ethernet adopts a flexible scaling mechanism, which provides more opportunities for Ethernet to realize Layer 2, thus realizing the vision of higher throughput and lower transaction costs. Ethernet's Layer 2 solution utilizes a variety of technologies, some of the common ones include Optimistic Rollup, zk-rollup, Plasma, State Channels, Sidechains and others.

Optimistic Rollup and ZK-Rollup are two blockchain scaling technologies that both aim to improve the throughput and scalability of the blockchain, but differ in their implementation methods and characteristics. Optimistic Rollup implements a sidechain on the Ethereum blockchain that assumes all transactions are valid unless proven wrong. This hypothetical verification approach reduces the need for immediate computation and allows for higher throughput. The advantages are higher throughput and good compatibility with Ethereum. Because of the optimistic assumption, it can process more transactions. Easy integration with the existing Ethereum ecosystem and smart contracts. Depends on the security of the Ethereum main chain. The downside is that if fraud occurs, it takes a while to submit and confirm proof of fraud, which can lead to delays and additional transaction costs. And need to rely on the main chain to ensure the availability of data.

ZK-Rollup uses Zero-Knowledge Proofs to prove the validity of all sidechain transactions, rather than assuming they are valid, as Optimistic Rollup does. This means that every transaction needs to be verified in real-time. It offers instant transaction final certainty, higher security, and data availability. Thanks to the use of zero-knowledge proof, transactions can be determined quickly without a long window of challenge. Zero-knowledge proofs provide strong security. Since every transaction is verified, data availability is guaranteed. The disadvantage is that the calculation needs are high and there are compatibility problems. Generating zero-knowledge proofs requires a lot of computing resources. Integration with existing smart contracts and the Ethereum ecosystem is more complex. The cost of developing and deploying ZK-Rollup technology is relatively high.

Optimism, Arbitrum, Scroll, StarkNet, Polygon zkEVM, zkSync Era, Blast, Linea, Manta Pacific, Metis, zkFair, Ola, and Lumoz (formerly opside) are all Layer 2 extension solutions. This is mainly achieved by using Optimistic Rollups or ZK-Rollups technology.

2.4 Layer 2 Solutions for Other Blockchains

In addition to Ether, DApps and their respective layer 2 solutions exist on many other blockchain platforms.

Binance Smart Chain (BSC) is a blockchain with a multi-chain structure that allows assets to be transferred between BSC and other compatible blockchains. BSC supports the Ethereum Virtual Machine (EVM), which is similar to Ether, so many of Ether's Layer 2 solutions can also be used on BSC. In addition, BSC itself has high transaction speeds and low costs, and Solana is a high-performance blockchain that already has a high Transactions Per Second (TPS) of its own. Although Solana is different from Ether, it is designed to provide high throughput. It also supports Layer 2 solutions in its ecosystem, such as Serum, etc.

NEAR Protocol is a blockchain platform designed to provide developer-friendly smart contracts and high performance. While NEAR already has high performance on its own, it also supports Layer 2 technologies such as stateful channels, etc. Avalanche enables interoperability between different subnets through its Snowflake Protocol, which supports broader cross-chain communication. avalanche supports the creation of customized subnets on which users can implement high-performance Layer 2 solutions.

Harmony is a blockchain platform dedicated to delivering high-performance and low-cost transactions. It supports both on-chain and off-chain optimization. polka dot is a heterogeneous multi-chain architecture that facilitates cross-chain communication and asset transfers by enabling connectivity between different blockchains through Relay Chain and Parachains.

Cosmos is an ecosystem with an autonomous blockchain whose Inter-Blockchain Communication (IBC) protocol makes it possible for different blockchains to communicate with each other. Cosmos is an ecosystem of autonomous blockchains with the IBC protocol that enables different blockchains to communicate and exchange value with each other. Polkadot and Cosmos are two platforms that implement cross-chain technology, allowing interactions and asset transfers between different blockchain networks. By spreading the load across different blockchains, these platforms can speed up transaction processing. Cross-chain transactions allow users to utilize blockchains with lower fees, and by connecting multiple blockchains, these platforms increase the capacity and flexibility of the overall network.

3 APPLICATIONS AND DISCUSSION

Decentralized applications are applications based on blockchain technology that run on a decentralized network rather than a single server. DApps have a wide range of applications in several domains, and Layer 2 technology plays a key role in improving efficiency and scalability in these applications.

Fig. 1, Fig. 2 and Fig. 3 respectively introduce layer2 technology and corresponding DApps used in Bitcoin, Ethereum, and other blockchains. First, the main layer2 technology is introduced, then the new layer2 technology derived from the main layer2 technology is introduced, and then the corresponding dapps are analyzed. Some of the new layer2 technologies are still in the development and proposal stages and have not been widely accepted or implemented by the community. While some of the technologies mentioned in Fig. 2 were primarily developed for Ethereum, the concepts and frameworks of some technologies can be extended to other blockchains. Because there are too many platforms and dapps involved in zk rollups, the part about zk rollups in Fig. 2 has been simplified.

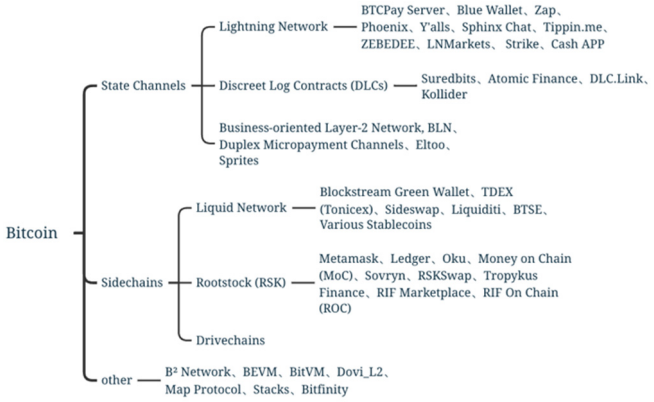

Figure 1: Layer2 technology and DApps used in Bitcoin (Picture credit: Original).

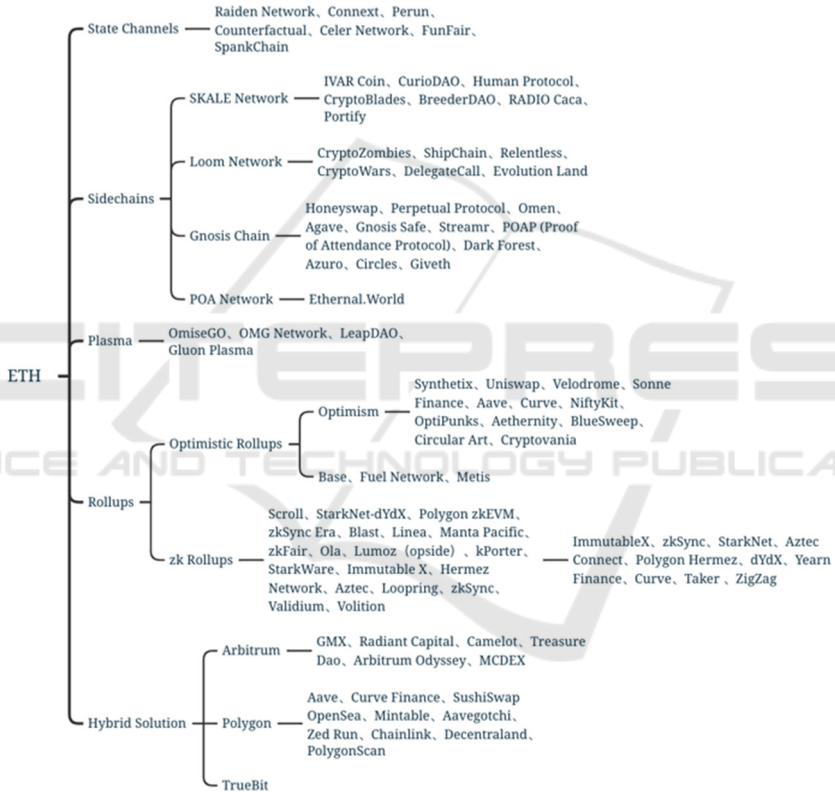

Figure 2: Layer2 technology and DApps used in Ethereum (Picture credit: Original).

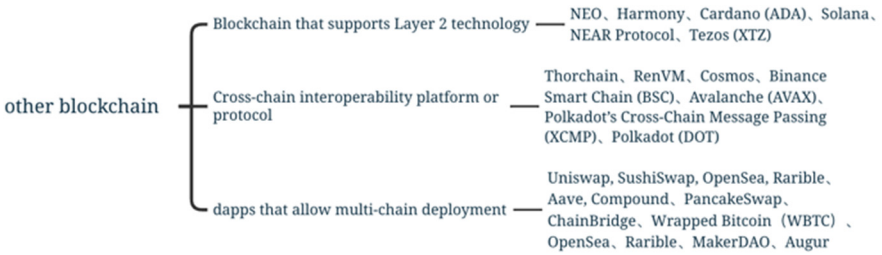

Figure 3: Layer2 technology and DApps used in other blockchain (Picture credit: Original).

3.1 Channels

State Channels allow participants to make multiple transactions outside of the blockchain and ultimately aggregate state onto the blockchain. Examples include Sprites and Trinity. Trinity is a state channel network based on the NEO blockchain designed to improve the real-time payments, low fees, and scalability of the NEO network. Sprites is an optimized state channel technology designed to reduce the amount of time that funds are locked up in the payment channel. It does this by introducing a mechanism called preimage. It is primarily used to improve payment channel networks, such as flash networks, especially when processing cross-channel payments. It reduces the complexity and fund-locking issues associated with executing payments across multiple channels, making these networks more efficient and easier to use. Payment Channels are stateful channels focused on payment scenarios. Notable networks include the Lightning Network and the Raiden Network, which is one of the best-known payment channel networks and is used by many Bitcoin payment DApps to process fast, low-cost micropayments. but is used on the Ether network and is designed to enable fast, low-fee ERC20 token transactions.

3.2 Side/Child Chains

Side and child chains enhance DApp scalability by allowing fast transactions on a parallel chain before updating the main chain. This is beneficial for large DApps needing custom blockchain parameters, especially in gaming or enterprise applications. While sidechains offer customization and reduced main chain load, their security may be lower, and integration with the main chain can be complex. Polygon (Matic) has evolved from using Plasma and state channels to implementing Layer 2 solutions like zk-Rollups and Optimistic Rollups. The SKALE Network offers a highly customizable Ethereum scaling solution through containerized virtualization. Rootstock enables DApps on the Bitcoin network, and Loom Network excels in social and gaming applications, hosting games like "CryptoZombies." The Liquid Network facilitates Bitcoin transactions with a bidirectional anchoring mechanism, converting bitcoins to Liquid Bitcoins (LBTC) on its sidechain and vice versa, aimed at accelerating transactions and enhancing privacy for financial institutions. Axie Infinity is a very popular blockchain game where players can cultivate, buy, sell and fight creatures called Axies. It originally ran on Loom Network, but later migrated to its own custom sidechain, Ronin. Although it is separate from the main Ethereum chain, it is connected to the Ethereum network via Bridge technology, allowing assets to be transferred between the two networks.

3.3 Cross Chains

Cross-chain technology enables DApps to access the functionality and assets of multiple blockchains, which is useful for building complex financial products, asset management tools, or any service that needs to utilize the features of multiple blockchains. Cross-chain technologies allow interoperability between different blockchain networks. platforms such as Polkadot and Cosmos allow developers to create DApps that can run on multiple blockchains by providing cross-chain smart contract execution. decentralized exchanges such as Uniswap, SushiSwap, and Thorchain support the exchange of assets across multiple blockchains ChainBridge, RenVM, and Polkadot's Cross-Chain Message Passing (XCMP) cross-chain bridge allows users to transfer crypto assets (such as tokens or NFTs) from one blockchain to another. This not only increases the liquidity of assets but also extends their availability. Aave, Compound users can borrow and earn interest on different blockchains. Some NFT marketplaces are expanding their functionality, OpenSea, and Rarible support buying and selling NFTs between different blockchains.

3.4 Rollups

Decentralized Exchanges (DEXs) Loopring utilizes zkRollups technology to reduce transaction costs and increase transaction speeds on Ether. Optimism is an Ether Layer 2 solution using Optimistic Rollups that reduces transaction costs and time and has been adopted by several Decentralized Finance (DeFi) projects. Immutable X uses zkRollups technology to provide zero gas fees and instant trading for NFT transactions for decentralized marketplaces for artwork, game items, and more. The base is a Layer 2 network built by the $20 billion market cap crypto giant Coinbase, which primarily utilizes OP Stack technology to develop Optimistic Rollups on the Ethereum network. its network node providers primarily include Blockdaemon, QuickNode and Blast, Safe Wallet, block browsers Etherscan and Blockscout, and data indexers The Graph and Covalent, etc. The base has more native projects, including Aerodrome developed by Velodrome, Seamless Protocol, and friend. tech, which have all

become leading projects of Base. become Base's leading projects. If the focus is on fast trading and high security, ZK-Rollup may be a better choice. If cost efficiency and high compatibility are valued, Optimistic Rollup may be a better fit. Development teams need to consider the volume of transactions, security requirements, cost constraints, and technical capabilities to choose the best technology for their project. Rollups are unique in that they move data processing off-chain while keeping the data committed to the main chain, combining the high efficiency of off-chain processing with the high security of the main chain. This balance is not common in other Layer 2 technologies.

3.5 Hybrid Solutions

Hybrid Layer 2 solutions offer DApps flexibility to select technologies suited for specific use cases. Arbitrum, leveraging Optimistic Rollups, increases throughput and reduces Gas fees, supporting Ethereum smart contracts and existing DApps like GMX, Radiant Capital, and Camelot. It also hosts non-DeFi projects like Treasure DAO, a casual game emphasizing creativity. TrueBit offloads intensive tasks from the blockchain, reducing computational load and transaction costs. It uses Interactive Verification, where external nodes ensure off-chain computation accuracy, featuring a gamified verification process. TrueBit is considered for applications like Golem, Dogethereum, and Livepeer, a decentralized streaming platform. Polygon integrates various Layer 2 technologies, including Plasma, state channels, zk-Rollups, and Optimistic Rollups, supporting diverse DApps like Aave Protocol, Decentral Games, Sandbox, and Uniswap v2. These applications benefit from Polygon’s high throughput and low fees. DApps choose Layer 2 solutions based on specific needs with Polygon and Optimism favored for high-throughput, low-cost DeFi and NFT platforms. Some like Axie Infinity may opt for custom sidechains for unique customization features.

4 CONCLUSION

This paper provided a comprehensive examination of Layer 2 blockchain technologies and their impact on DApps. It commenced with an introduction to the conceptual framework of Layer 2 solutions, followed by a detailed analysis of their implementations in Bitcoin, Ethereum, and other blockchain platforms. It analyzes the application of the latest Layer 2 technology solutions in DApps and also clarifies the advantages and limitations of Layer 2 technology. The exploration highlighted the unique aspects and focal points of each platform's approach to Layer 2 solutions. In the final section, this paper discussed various DApps, illustrating how Layer 2 technologies have enabled these applications to overcome traditional blockchain limitations. The diverse examples underscored the broad applicability and potential of Layer 2 solutions in enhancing the performance and usability of DApps, indicating a promising direction for the future of decentralized systems. As the blockchain landscape continues to evolve, future Layer 2 technologies will focus on enabling more efficient cross-chain interactions, integrating advanced privacy enhancements such as Proof of Zero Knowledge, and optimizing the execution efficiency and cost of smart contracts, leading to a wider range of application scenarios, stronger user privacy protection, and better performance for DApps.

REFERENCES

A. Gangwal, H. R. Gangavalli, A. Thirupathi. A survey of Layer-two blockchain protocols. Journal of Network and Computer Applications, Volume 209, 103539, ISSN 1084-8045 (2023)

M. Jourenko, K. Kurazumi, M. Larangeira, et al. Sok: A taxonomy for layer-2 scalability related protocols for cryptocurrencies. Cryptology ePrint Archive, (2019)

A. Miller, I. Bentov, S. Bakshi, R. Kumaresan, P. McCorry. Sprites and state channels: Payment networks that go faster than lightning. International Conference on Financial Cryptography and Data Security.pp.508-526 (2019)

S. Tochner, S. Schmid, A. Zohar. Hijacking routes in payment channel networks: A predictability tradeoff. arXiv preprint: 1909.06890 (2019)

A. Back, M. Corallo, L. Dashjr, M. Friedenbach, G. Maxwell, A. Miller, A. Poel-stra, J. Timón, P. Wuille. Enabling blockchain innovations with pegged sidechains. http://kevinriggen.com/files/sidechains.pdf (2014)

R. Belchior, A. Vasconcelos, S. Guerreiro, M. Correia. A survey on blockchain interoperability: Past, present, and future trends. ACM Comput. Surv.54(8), 1-41 (2021)

J. Teutsch, C. Reitwießner. A scalable verification solution for blockchains. arXiv preprint: 1908.04756 (2019)

H. Kalodner, S. Goldfeder, X. Chen, S.M. Weinberg, E.W. Felten. Arbitrum: Scalable, private smart contracts. USENIX Security Symposium.pp.1353-1370 (2019)

M. Xu, Q. Wang, H. Sun, et al. W3Chain: A Layer2 Blockchain Defeating the Scalability Trilemma. 2023

IEEE International Conference on Blockchain and Cryptocurrency (ICBC). IEEE, 1-9 (2023)
P. Robinson, R. Ramesh. Layer 2 Atomic Cross-Blockchain Function Calls. arXiv preprint arXiv:2005.09790 (2020)
S. F. A. Sunny, P. Hajek, M. Munk, et al. A systematic review of blockchain applications. IEEE Access, 10: 59155-59177 (2022)
Z. Xu, L. Chen. L2chain: Towards High-performance, Confidential and Secure Layer-2 Blockchain Solution for Decentralized Applications. Proceedings of the VLDB Endowment, 16(4): 986-999 (2022)
S. K. Rana, A. K. Rana, S. K. Rana, et al. Decentralized model to protect digital evidence via smart contracts using layer 2 polygon blockchain. IEEE Access (2023)
T. Rafaj, L. Mastilak, K. Kostal, et al. DeFi Gaming Platform Using the Layer 2 Benefits. 2023 33rd Conference of Open Innovations Association (FRUCT). IEEE, 236-242 (2023)
H. Kucheriya, V. Shah, H. J. Gala, et al. Dodging Turtis-NFT Gaming on Blockchain. 2023 World Conference on Communication & Computing (WCONF). IEEE, 1-6 (2023)
M. S. Chishti, A. Banerjee. Instantaneous Account Settlement in Roll-Up based Layer-2 Blockchain Framework for Metaverse Applications. 2023 IEEE International Conference on Metaverse Computing, Networking and Applications (MetaCom). IEEE, 78-85 (2023)
Introducing SingularityDAO: The Unique Layer 2 Noncustodial DeFi Solution From SingularityNET. IntelligentHQ [BLOG] (2020)
Life DeFi Wallet Integrates Polygon Blockchain to Bring Scalable User-Friendly Decentralized Applications to Its DeFi Ecosystem. In ICT Monitor Worldwide. SyndiGate Media Inc (2023)
S. S. Sahoo, M. M. Hosmane, V. K. Chaurasiya. A secure payment channel rebalancing model for layer-2 blockchain. Internet of Things, 22: 100822 (2023)
B. Yee, D. Song, P. McCorry, et al. Shades of finality and layer 2 scaling. arXiv preprint arXiv:2201.07920, (2022)
A. Renzoni. Assessing the impact of rollups scaling solutions on ethereum's layer-2 ecosystem (2023)
R. Neiheiser, G. Inácio, L. Rech, et al. Practical Limitations of Ethereum's Layer-2. IEEE Access, 11: 8651-8662 (2023)
Z. Hong, S. Guo, P. Li. Scaling blockchain via layered sharding. IEEE Journal on Selected Areas in Communications, 40(12): 3575-3588 (2022)
Y. Wang. BLN: A LAYER-2 Framework for Fast Bitcoin Transaction Processing (2023)
C. P. Schnorr. Efficient signature generation by smart cards. Journal of cryptology, 4: 161-174 (1991)
G. Maxwell, A. Poelstra, Y. Seurin, et al. Simple schnorr multi-signatures with applications to bitcoin. Designs, Codes and Cryptography, 87(9): 2139-2164 (2019)
S. M. Cragg, G. T. Beckham, N. C. Bruce, et al. Lignocellulose degradation mechanisms across the Tree of Life. Current opinion in chemical biology, 29: 108-119 (2015)
S. Kim, Y. Kwon, S. Cho. A survey of scalability solutions on blockchain. 2018 International Conference on Information and Communication Technology Convergence (ICTC). IEEE, 1204-1207 (2018)