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LAYER 2 ECOSYSTEM OF THE ETHEREUM BLOCKCHAIN

Oleksandra Belz*, Candidate of Economic Sciences,
Associate Professor at the Department of Information Systems in Management
Ivan Franko National University of Lviv

**ORCID 0000-0001-7462-8501*

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Introduction. Decentralisation, scalability and security are the key characteristics of any blockchain network. Decentralisation involves the distribution of control and power among the participants in a network. This is one of the key benefits of blockchain technology. It allows for the avoidance of vulnerabilities inherent in centralised systems and ensures security. Security is the ability of a network to resist attack and ensure the reliability and integrity of transactions. Scalability is related to a network's ability to process large amounts of information quickly and efficiently. However, it is difficult for blockchains to achieve optimal levels of all three properties simultaneously. Increasing the level of one property usually leads to a weakening of another. This is known as the blockchain trilemma. Solving this trilemma requires a constant search for new technologies and solutions that attempt to strike a balance between decentralisation, scalability and security.

There are several ways to solve the blockchain trilemma. These include so-called Layer 1 and Layer 2 solutions [1].

The main methods for solving the blockchain trilemma at Layer 1 are optimising consensus protocols, developing efficient transaction grouping algorithms, implementing smart contracts with reduced computational costs, improving transaction processing mechanisms, and developing sharding protocols (dividing blockchains into smaller ones that manage specific data segments).

Specific methods of addressing the blockchain trilemma at Layer 2 include sidechains, state channels, nested blockchains and rollups. A sidechain is a separate blockchain that operates in parallel to the main blockchain, but has its own set of rules and consensus. A state channel is a mechanism that allows two or more participants to interact through an off-chain transaction that is stored offline, or outside the main blockchain. This process includes opening a channel, executing transactions and closing the channel. Nested blockchains are a system of blockchains where each blockchain can have its own subchains or branches. Rollups is a method where transaction data is stored in a rollup chain and the transactions themselves are executed in a data availability chain.

Analysis of recent research and publications. In today's scientific literature, considerable attention is paid to the study of the Layer 2 ecosystem of the Ethereum blockchain. For example, [2] examines the impact of Layer 2 projects on the main Ethereum blockchain. The research [3] describes the cryptographic technology zk-SNARK and its impact on the scalability of the blockchain. In [4], the internal structure of Ethereum is analysed. In addition, the advantages and disadvantages of the current Ethereum specification are evaluated

and the transaction throughput of the current Ethereum implementation is investigated. In [5], the possibilities of the Web3 ecosystem and the security challenges are analysed.

In a post dated October 31, 2023 [6], Ethereum co-founder Vitalik Buterin says that Ethereum has expanded rapidly during the year. In addition, Layer 2 projects are becoming more diverse. This trend is expected to continue. In the article, Vitalik Buterin offers the following simplified classification scheme of the Ethereum Layer 2 ecosystem, based on a certain level of security.

Rollup. Calculation is confirmed by fraud proofs or zk-SNARKs. Data is stored on Layer 1. This technology allows assets to be recovered at Layer 1 in all cases.

Validium. Calculation is confirmed via zk-SNARKs (cannot use fraud proofing). Data is stored on a server or other separate system. Using this technology, assets may be lost due to lack of access to data, but they are not stolen.

Disconnected. Transactions are executed in a separate chain. Trust in this ecosystem is the only guarantee of the safety of funds when using this technology.

Despite a large number of specialised studies, no work provides non-technical users with a sound basis for making decisions on the choice of Ethereum Layer 2 blockchain projects. The market offers a wide range of Layer 2 projects with different technical approaches and features. Selecting the most appropriate project is critical, as each has advantages and limitations. In addition, many Layer 2 projects use complex technical concepts such as zero-knowledge proofs, distributed computing, cryptographic protocols and more. Understanding and evaluating these concepts may require a deep understanding of cryptography, distributed systems, network economics, and related areas. A lack of understanding of the technical aspects can lead to the risk of choosing an insecure project. In addition, some Layer 2 projects may have high transaction fees or require a lot of resources to use.

Objectives of the article. This research aims to analyse the Layer 2 ecosystem of the Ethereum blockchain, which would serve as a basis for users without deep technical knowledge to make informed decisions regarding the selection of Layer 2 blockchain projects. To achieve the research objective, it is necessary to identify the main technical concepts underlying different Layer 2 blockchain projects. It is also necessary to perform a security analysis of the projects and evaluate their popularity among users.

The following research methods were used in the article: observation, analysis, generalisation, synthesis, comparison, explanation.

The main material of the study. The dataset for this study includes material from L2BEAT, a public goods organisation focused on increasing transparency within the Ethereum blockchain [7] (data as of March 11, 2024). L2BEAT aggregates information on 45 Layer 2 scaling projects within the Ethereum blockchain and categorises them into the following types.

ZK Rollup [3; 7–10]. In ZK Rollup, transactions are processed off-chain and transaction data is then aggregated and published to the main chain in encrypted form. Zero-knowledge proofs (zk-SNARK or zk-STARK cryptographic protocols) are used to generate proofs of transaction correctness without compromising confidential information. This methodology ensures transaction privacy, security and efficiency.

Validium [3; 7–9]. This is a variant of ZK Rollup where transaction data is processed off-blockchain and only summaries of those transactions are published on the main chain. Transaction data remains private and confidential as it is not shared on the main chain. In Validium, zk-SNARK can be used to prove the correctness of aggregated transaction data. It ensures transaction privacy and security.

Optimistic Rollup [7; 8; 11; 12]. In an Optimistic Rollup, transactions are initiated and executed off-chain. The results are then grouped and transferred to the main chain. The main advantage of Optimistic Rollup is its ability to process a larger volume of transactions with lower gas costs.

Optimium [7; 8; 12]. At the time of writing, Optimium is still under development. Systems using it allow invalid state roots to be generated. Consequently, funds can be stolen if an invalid state root is presented to the system.

First of all, consider the types of projects identified by the L2BEAT team and the simplified categorisation scheme of the Ethereum Layer 2 ecosystem proposed by Vitalik Buterin. Based on the characteristics of the described types of ecosystems, ZK Rollup and Validium should be classified as Rollup, Optimistic Rollup as Validium, and Optimism as Disconnected.

For a more in-depth analysis of Layer 2 scaling projects within the Ethereum blockchain ecosystem, several indicators characterising each project type are calculated (see Table 1).

Table 1

Key performance indicators for second-tier scaling projects on the Ethereum blockchain

Metrics	Layer 2 scaling project type on the Ethereum blockchain			
	ZK Rollup	Validium	Optimistic Rollup	Optimium
Number of projects	12	9	12	12
Total value locked in escrow agreements, million USD	3821.7	625.9	29191.1	4386.9
Maximum value locked in escrow agreements, million USD	1610.0	308.0	15700.0	2320.0
Average share of the value locked in the total project cost, %.	0.92	0.19	6.38	0.97
Maximum share of the value locked in the total project cost, %.	4.23	0.81	41.04	6.08

Source: compiled by the author based on data from [7]

An important metric for evaluating Layer 2 blockchain projects in the Ethereum ecosystem is the total value locked in escrow agreements. This metric indicates the amount of assets (such as cryptocurrencies) transferred to a contract to ensure the execution of certain conditions or operations. These assets become inaccessible to the owner until the conditions specified in the contract are met. As can be seen from the data in the table, the blocked amount in escrow agreements for all Layer 2 scaling projects in the Ethereum blockchain ecosystem is 38,025.6 million USD. In 365 days, the locked value of escrow agreements for all Layer 2 scaling projects increased from 7,141.8 million USD to 38,025.6 million USD, a fivefold increase [7].

Furthermore, Optimistic Rollup scaling projects are the most popular among users of the Ethereum Layer 2 blockchain. Despite the lower level of security compared to projects such as ZK Rollup and Validium, users of Optimistic Rollup scaling projects have executed a total of six and a half times more transactions than on the more secure projects. The lower transaction costs on Optimistic Rollup projects with sufficient security can explain this fact. The second most popular scaling project is Optimium. This suggests that low cost is more important than high security for users of the Ethereum Layer 2 blockchain. Starknet stands out as the strongest player among ZK Rollup projects. Immutable X is the best of the Validium projects. Arbitrum One is popular among Optimistic Rollup projects. Manta Pacific is the best of the Optimium projects.

As of today, Layer 2 scaling projects on the Ethereum blockchain use ZK Proofs and Fraud Proofs to verify the state of the system. Fraud proofs verify the correctness of certain information without disclosing the information itself. Fraud Proofs typically rely on transaction or event verification principles, using event monitoring mechanisms to detect invalid or fraudulent actions. This may require fewer computing resources and is generally less complex to implement. Unlike ZK Proofs, Fraud Proofs detect invalid actions or transactions in distributed systems. ZK Proofs require the use of cryptographic protocols such as zk-SNARKs or zk-STARKs, which can lead to greater complexity in implementation and deployment. In addition, ZK Proofs may require more computing resources.

In terms of approaches used to detect fraud in Layer 2 scaling projects on the Ethereum blockchain, twenty projects use ZK Proof, five use Fraud Proof, and twenty do not use any state validity verification method. However, ZK Proof's systems have only locked 12% of all funds of Layer 2 scaling projects on the Ethereum blockchain. Fraud Proof's solutions have locked 41% of all funds of Layer 2 scaling projects on the Ethereum blockchain. In addition, scaling projects without fraud detection have blocked 47% of all funds of Layer 2 scaling projects on the Ethereum blockchain. The best Layer 2 scaling projects do not perform system health checks or use cheaper technology. Among such projects is Arbitrum One (Fraud Proof solution).

It is also worth noting that users of only five Layer 2 scaling projects on the Ethereum blockchain can log out in case of unwanted updates. Among these projects is Arbitrum One.

Bridges play a crucial role in the Ethereum ecosystem, facilitating the secure and efficient transfer of assets across different layers. They allow different Layer 2 solutions to seamlessly interact with each other and with the main Ethereum blockchain. This promotes the exchange of assets and data across different platforms. It also ensures access to the wide range of functionalities offered by the main Ethereum blockchain. Bridges are essential for the development of security and reliability in essential areas such as asset storage and movement.

The L2BEAT community is currently investigating thirty-six bridges [13]. As of March 11, 2024, these bridges have blocked 10,289.5 million USD in Ethereum contracts.

Messages transmitted across Layer 2 bridges in the Ethereum blockchain are verified using Destination Chain, Optimistically and Third Party techniques [13–17]. Destination Chain involves validating and confirming messages on the chain to which the token or message is directed. Optimistically involves taking an optimistic approach to verifying transactions, directly accepting them as correct if no problems or inconsistencies arise. Third Party involves the use of an independent entity to verify and validate transactions between chains, such as an auditor or trusted observer. Among the thirty-six bridges, twenty-eight use a Third Party to verify messages, four use a Destination Chain, three use an Optimistic Chain, and one uses a combination of methods.

Users of nine bridges are unable to withdraw funds if the operator engages in dishonest or malicious behaviour. As a result, such bridges are not very popular with users and account for only 2.8% of the total value of funds locked in conditional deposit contracts on Ethereum. Of these bridges, three use Optimistically's message verification techniques, while six use Third Party.

Conclusions. The research shows that the Layer 2 ecosystem within the Ethereum blockchain is currently undergoing active development, offering many scaling solutions. This provides the flexibility to choose the most appropriate option according to the developer's requirements.

Many Layer 2 scaling solutions are designed to provide security. However, within the Ethereum Layer 2 ecosystem, users prioritise price considerations. Among the scaling projects, Arbitrum One is the undisputed leader. When it comes to bridges, an important criterion is security. The best bridges offer the possibility to withdraw funds in case the operator behaves dishonestly or maliciously.

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Oleksandra Belz, Candidate of Economic Sciences, Associate Professor at the Department of Information Systems in Management, Ivan Franko Lviv National University. **Layer 2 Ecosystem of the Ethereum Blockchain.**

This research aims to scrutinise the Layer 2 ecosystem within the Ethereum blockchain, providing a basis for informed decision-making by users with limited technical expertise when selecting Layer 2 projects. The research is based on data collected from the L2BEAT community. The article outlines the key technical concepts underlying various Layer 2 projects on the Ethereum blockchain, and describes the characteristics of projects such as ZK Rollup, Validium, Optimistic Rollup and Optimium. It juxtaposes the project types identified by the L2BEAT team with a simplified framework of the Ethereum Layer 2 ecosystem proposed by Vitalik Buterin. Ethereum blockchain Layer 2 scaling projects are audited, focusing on the indicators "total value locked in escrow agreements" and "share of value locked in total project value". The technologies used to verify the authenticity of the system state in Ethereum Blockchain Layer 2 scaling projects are explained. An analysis of fraud detection approaches in Layer2blockchainscalingprojectsisundertaken.Techniquesforvalidatingmessagestransmittedover Layer2blockchain bridges are described. An assessment of the security of the Layer 2 blockchain ecosystem is presented, along with an evaluation of the popularity of such projects among users. The study concludes that for users, pricing in the Ethereum Layer 2 blockchain ecosystem is key, with Arbitrum One emerging as the undisputed leader in scaling projects. In terms of bridges, user preference leans towards those that facilitate the withdrawal of funds in the event of dishonest or malicious behaviour by the bridge operator.

Keywords: Ethereum, blockchain, ZK Rollup, Validium, Optimistic Rollup, Optimium, blockchain state verities, ZK Proofs, Fraud Proofs, bridges, Destination Chain, Optimistically, Third Party.

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Белз Олександра Григорівна, кандидат економічних наук, доцент, доцент кафедри інформаційних систем у менеджменті Львівського національного університету імені Івана Франка. **Екосистема рівня 2 блокчейну Ethereum.**

Метою роботи є аналіз екосистеми рівня 2 блокчейну Ethereum, який був би підґрунтям для прийняття обґрунтованого та інформованого рішення щодо вибору проектів рівня 2 блокчейну Ethereum користувачами без глибоких технічних знань. Вхідними даними для даного дослідження є матеріали суспільної компанії L2beat. У статті виділено основні технічні концепції, які лежать в основі різних проектів рівня 2 блокчейну Ethereum. Описано особливості проектів типу ZK Rollup, Validium, Optimistic Rollup, Optimium. Проведено співставлення типів проектів, які виділяє команда L2beat, зі спрощеною схемою поділу екосистеми рівня 2 Ethereum, запропонованою Віталіком Бутеріним. Здійснено порівняння проектів масштабування рівня 2 блокчейну Ethereum за показниками «заблокована вартість в контрактах умовного депонування на Ethereum» та «частка заблокованих коштів у загальній вартості проекту». Виявлено, що користувачі проектів масштабування типу Optimistic Rollup виконали транзакцій на суму в шість з половиною раз більшу, ніж на безпечніших проектах типу ZK Rollup і Validium. Описано технології перевірки достовірності стану системи, які використовують проекти масштабування рівня 2 блокчейну Ethereum. Проведено аналіз проектів масштабування рівня 2 блокчейну Ethereum на предмет використання підходів до виявлення шахрайства. Виявлено, що топовими проектами масштабування рівня 2 блокчейну Ethereum є такі, які не виконують перевірку достовірності стану системи, або використовують більш дешевшу технологію (Fraud Proofs). Описано методи перевірки повідомлень, які надсилають через мости рівня 2 блокчейну Ethereum. Проведено аналіз безпеки екосистеми рівня 2 блокчейну Ethereum та оцінено популярність таких проектів серед користувачів. Сформульовано висновок, що для користувачів екосистема рівня 2 блокчейну Ethereum дуже важливе значення має ціновий фактор. Серед проектів масштабування беззаперечним лідером є Arbitrum One, який належить до проектів типу Optimistic Rollup та використовує технологію перевірки на наявність шахрайства Fraud Proofs. Щодо мостів, то користувачі надають перевагу тим, які дають змогу забрати кошти, якщо оператор моста діє недобросовісно або зловмисно.

Ключові слова: Ethereum, блокчейн, ZK Rollup, Validium, Optimistic Rollup, Optimium, достовірності стану блокчейну, ZK Proofs, Fraud Proofs, мости, Destination Chain, Optimistically, Third Party.