Gate Research

A Comprehensive Look At Web3 Cross-Chain Services

Leading Protocols, Innovations, and Challenges

Abstract

- Cross-chain solutions can be categorized into three major types based on the method of message verification: native verification, external verification, and local verification. Among them, external verification verifies cross-chain messages by introducing a group of external verifiers (witnesses) that are independent of both the source chain and the destination chain. Representative protocols include LayerZero, Wormhole, and Axelar, which are currently the mainstream choices.

- Mainstream cross-chain standard protocols such as LayerZero, Wormhole, and Axelar provide essential infrastructure for the cross-chain market. LayerZero is complex yet flexible, Wormhole is minimalist yet powerful, supporting efficient and secure cross-chain message transmission, while Axelar focuses on expanding cross-chain interoperability. These protocols each have advantages in terms of security, flexibility, and connection design.

- Chain abstraction simplifies the cross-chain transaction process for users by establishing a ”cross-chain relay station,” improving the user experience. Projects such as Particle Network and UniversalX are working in this area. A similar concept, intent-based transactions, can be seen as a personalized ”on-demand pickup assistant.” It is more user-centric, enabling cross-chain execution of user intentions through declarative constraints and solver networks. Projects like dappOS and Anoma have demonstrated significant potential in this regard.

- Integrating AI and cross-chain technology brings new opportunities to the cross-chain sector. For example, Wormhole’ s standardized API and low-latency features support AI agents in obtaining multi-chain data in real time and triggering cross-chain operations. This can potentially drive new models such as cross-chain liquidity mining and multi-chain AI strategy subscriptions, forming a full-chain economic network centered around AI Agents.

Topic Tags:

Gate Research, Blockchain, Chain Abstraction, Technology, Macroeconomics

Gate Research: A Comprehensive Look at Web3 Cross-Chain Services - Leading Protocols, Innovations, and Challenges

Introduction

The blockchain landscape in 2025 is expanding at an unprecedented pace. Back in 2018—the so-called ”Year of Public Chains”—there were fewer than 100 active blockchains, and DeFi had barely amassed a few million dollars in Total Value Locked (TVL). Fast forward to March 5, 2025, and the numbers tell a different story: 367 active blockchains now support over $314 billion in on-chain assets, with DeFi protocols collectively securing more than $124 billion in locked value. [1] [2]

Such figures undoubtedly reflect the vibrant vitality of the crypto-economic ecosystem. However, beneath this prosperity, a deeper structural transformation is unfolding: the demand for cross-chain interactions is rapidly reshaping the fundamental logic of Web3.

A recent case vividly illustrates the urgency of this trend. Between January 18–19 this year—just two days before former U.S. President Donald Trump launched the meme token $TRUMP, triggering a short-term frenzy both within and outside the crypto community—the cross-chain protocol Wormhole processed over $400 million worth of Solana-based asset transfers. [3] This phenomenon is not an isolated event but a microcosm of the industry’s shift toward multi-chain collaboration—users are no longer satisfied with a single chain’s efficiency and functional limitations; instead, they seek to break barriers, enable free asset flow, and achieve seamless value integration.

Against this backdrop, cross-chain technology has become a key infrastructure for unlocking value loops. Given the fragmented state of the blockchain world, what new technologies and products can solve cross-chain communication and interoperability challenges? How can they break down blockchain silos and fully integrate Web3 with both on-chain and off-chain worlds? This article delves into these questions.

It is worth noting that, unlike traditional articles, this piece will not focus heavily on historical backgrounds, technical details, or token market capitalizations. Instead, it will zero in on the core categories of cross-chain services, innovative directions, and representative protocols. Other aspects will be briefly mentioned, and readers are encouraged to refer to additional reports for a more comprehensive view.

1 Overview of the Cross-Chain Sector

1.1 Market Background of Cross-Chain Demand

In the Web2 era, the internet achieved seamless communication between servers through unified protocols such as HTTP and TCP/IP, allowing users to switch freely between different websites and enjoy a smooth online experience. However, in the Web3 era, interoperability between blockchains has yet to reach this level.

Due to differences in technical architecture, consensus mechanisms, and governance models, blockchains remain isolated, creating severe fragmentation that limits interoperability and asset liquidity across ecosystems. In response to this, various cross-chain services have emerged.

In summary, cross-chain technology refers to technical solutions that enable interoperability between different blockchain networks. The core principle is to establish trusted bridges between chains and use smart contracts or relay mechanisms to verify and execute cross-chain transactions. This technology enables secure exchange and transfer of data and assets between blockchains, overcoming the limitations imposed by blockchain silos.

According to a report by Research Nester, the blockchain interoperability market is expected to reach $8.48 billion by the end of 2037, with a projected compound annual growth rate (CAGR) of 27.1% between 2025 and 2037. [4]

1.2 Categories of Cross-Chain Solutions

According to the analytical framework proposed by Arjun Bhuptani, founder of the cross-chain protocol Connext, cross-chain solutions can be classified into three categories based on their message verification methods: Externally Verified, Natively Verified, Locally Verified. [5]

Externally Verified (External Validation): External validation achieves cross-chain message verification by introducing a set of external verifiers (witnesses) independent of both the source chain and the destination chain. These verifiers reach consensus through mechanisms such as multi-party computation (MPC), oracle networks, or threshold multi-signatures, and users must trust their honesty.

There are various implementations of external verification, including:

- PoA-based (Proof of Authority): Multichain, Wormhole
- PoS-based (Proof of Stake): Axelar, Hyperlane
- Oracle-based: LayerZero

Overall, this approach has low implementation costs and strong multi-chain adaptability, making it the most widely used solution today and the primary focus of this article. However, because it introduces a new trust assumption, security vulnerabilities exist. For instance, in 2022, Wormhole lost 120,000 ETH due to a signature exploit. [6]

Natively Verified (Native Validation): Native validation is a trust-minimized cross-chain solution where the destination chain deploys a light node (light client) contract of the source chain to directly verify the authenticity of messages sent from the source chain.

The specific process involves:

1. Deploying a light node of the source chain on the destination chain’ s virtual machine.
2. Using the light node contract to verify transactions via block headers and Simplified Payment Verification (SPV) proofs.
3. Relayers transmit block header information and ensure at least one honest relayer exists, or users manually submit transactions.

This approach offers the highest level of security but comes with high costs and low development flexibility, making it suitable for homogeneous blockchains (those with high state machine similarity), such as: Cosmos IBC, Near RainbowBridge, Ethereum Layer 2 Rollups. Since this category has limited applicability, it is not the focus of this article.

Locally Verified (Local Validation): Local validation is a peer-to-peer verification method where only the direct participants of a cross-chain interaction (counterparties) verify the message, without relying on third parties or global validators.

The process works as follows:

1. A liquidity network functions as a router, where validators hold liquidity pools, mutually verify transactions, and facilitate atomic swaps.
2. The mechanism uses lock/unlock mechanisms and dispute resolution to ensure data security.

This category requires no trust assumptions and includes solutions like Connext. However, its functionality is limited, and its applicability is narrow—mainly supporting simple swaps. As such, this article will not focus on this category.

1.3 Market Data

1.3.1 Externally Verified Cross-Chain Solutions Dominate the Market

According to data from chainspot.io and DefiLlama, as of February 20, 2025, there are currently up to 131 cross-chain bridges in the market, with a monthly transaction volume of $23 billion. [7] [8]

Specifically, the cross-chain bridges with the highest transaction volumes over the past seven days are LayerZero, Circle CCTP (a stablecoin USDC cross-chain bridge supported by Wormhole), Stargate (supported by LayerZero), Hyperliquid, Wormhole, and deBridge. All of these utilize the external verification technology solutions mentioned earlier.

Among them, LayerZero supports up to 75 blockchains (note: the actual number should be 120, possibly due to statistical limitations), consistently leading in both the number of cross-chain transactions and transaction amounts, corresponding to its token ZRO having the highest Fully Diluted Valuation (FDV) in this sector. Circle CCTP, developed in collaboration between stablecoin issuer Circle and Wormhole, supports only five chains but has a transaction volume second only to LayerZero due to the huge demand for USDC. IBC supports 85 blockchains, including Axelar, though this is limited to the Cosmos ecosystem; given the current dominance of Ethereum and Solana, its transaction volume is not very large.

Figure 1: Top Cross-Chain Bridges by Transaction Volume in the Past 7 Days

	Name	Chains	1d Change	24h Volume	7d Volume	1m Volume	24h # of Txs
1	Circle CCTP		-7.01%	$58.07m	$528.89m	$4.589b	6035
2	Stargate	+9	-27.40%	$35.68m	$309.81m	$1.664b	37142
3	Wormhole	+19	-20.61%	$21.71m	$278.42m	$2.418b	9643
4	Hyperliquid		-49.11%	$21.62m	$325.4m	$3.346b	4853
5	deBridge	+3	-63.99%	$15.06m	$247.71m	$1.615b	5595
6	Across	+3	-42.93%	$13.81m	$191.54m	$1.278b	41181
7	IBC	+85	-31.11%	$12.89m	$70.43m	$924.37m	38140
8	Allbridge Core		+786%	$9.2m	$16.62m	$91.79m	1071
9	yBridge by xSynic Net...	+16	+3220%	$5.7m	$7.07m	$32.07m	276
10	Orbiter Finance	+34	-62.11%	$5.2m	$48.11m	$277.85m	14245
11	Polygon PoS Bridge		+113%	$4.99m	$37.67m	$217.31m	387
12	Core Bitcoin Bridge		+103%	$3.48m	$22.92m	$91.01m	30
13	Base Bridge		-13.56%	$3.09m	$23.73m	$110.93m	123

Gate Research, Data from: DefiLlama

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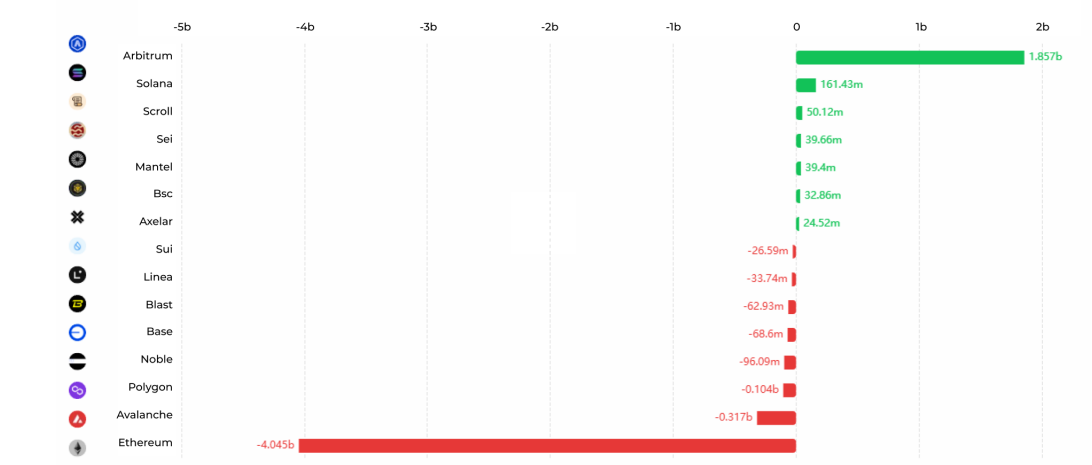
These cross-chain bridges often leverage various cross-chain technology solutions mentioned below; some of these cross-chain standard protocols are even stepping into the spotlight by launching their own official bridges.

1.3.2 Capital Flows Between Blockchains Correspond to the Prosperity of High-Traffic Chains like Solana

Currently, various cross-chain bridge products support connections to 195 blockchains. Regarding monthly cross-chain data corresponding to blockchain networks, Ethereum, Avalanche, and Polygon rank top three in capital outflows, while the highest net inflows are into Arbitrum, Solana, and Scroll. The flow of cross-chain funds indicates the recent prosperity of the Arbitrum and Solana ecosystems amid continuous capital inflows. The chart below reflects data from the past month; observing long-term trends requires dynamic analysis.

Figure 2: Ranking of Cross-Chain Capital Flows Across Blockchain Networks



Gate Research, Data from: DefiLlama

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1.3.3 requent Security Incidents in Cross-Chain Bridges, But a Downward Trend Over the Years

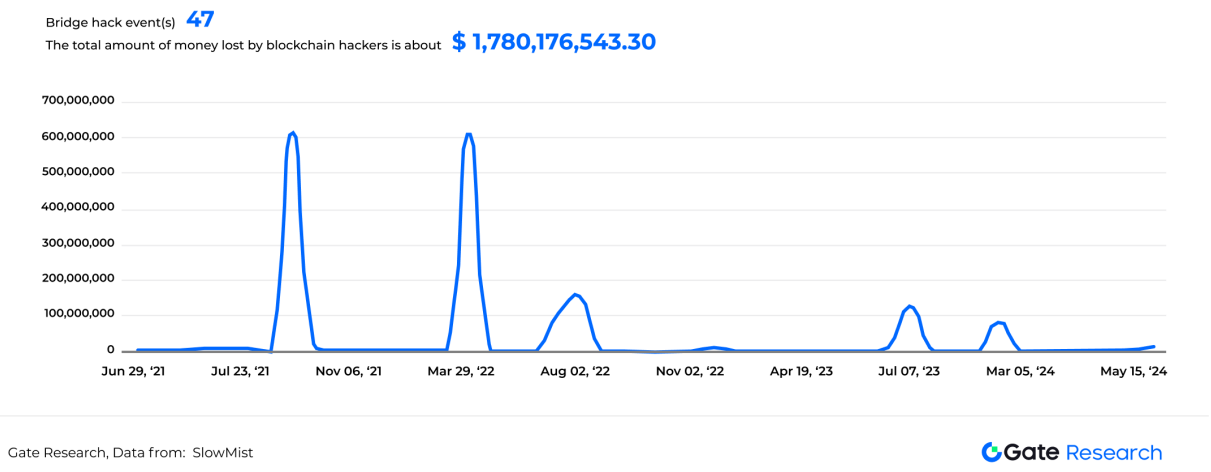
Cross-chain bridge technology enhances asset liquidity and utilization across different chains. Still, it inherently carries security risks due to the complexity of component integration, reliance on centralized components or specific verification mechanisms, and the attractiveness of large assets to hackers.

The types of vulnerabilities in these bridge attacks are diverse, including:

- **Smart Contract Vulnerabilities**: These typically involve verification logic errors or authorization issues, such as the contract vulnerabilities in Wormhole and Nomad Bridge, which constitute the majority.
- **Private Key Leaks**: Many bridges use multisig or validator mechanisms; if private keys are leaked, hackers can extract funds unauthorizedly through social engineering or insider threats, as seen in Orbit Chain's $81.5 million loss in 2024.
- **Oracle Manipulation**: Some bridges rely on external data; if the oracle is manipulated, it may lead to erroneous transactions.
- **Centralization Risks**: Some bridges are custodial, holding user assets centrally, making them ideal targets for hackers. For example, at the end of 2023, Orbit Chain's bridge was hacked, resulting in an $81.5 million loss. [9]
- **Lack of Standardization**: The architectures of cross-chain bridges vary, lacking unified standards, increasing the difficulty of security audits.

According to incomplete statistics from SlowMist, since June 20, 2021, there have been 47 publicly recorded cross-chain bridge hacking incidents, with losses exceeding $1.7 billion. Cross-chain projects are evidently struggling to cope with state-level hacking attacks, such as those from North Korea. [10]

Figure 3: Records of Cross-Chain Bridge Hacking Incidents Over the Past 4 Years



Gate Research, Data from: SlowMist

Gate Research

With the further development and integration of chain abstraction (to be mentioned below), AI, etc., cross-chain services may reduce costs and risks through more security measures (such as multi-chain verification and AI monitoring), potentially alleviating challenges related to transparency and user trust.

2 Mainstream Cross-Chain Solutions

Since 2023, various cross-chain protocols have made significant progress in terms of security, interoperability, and compatibility. LayerZero, Wormhole, and Axelar, the three dominant interoperability standard protocols, have consistently held over 80% of the market share. However, these are not the only ultimate solutions. Emerging innovations such as chain abstraction, intent-based systems, and aggregation layers have gained traction as new approaches resulting from a mix of different cross-chain strategies.

As shown in the figure below, referring to the classification framework proposed by SoSo Value column author @kyxoan17, there are currently four major approaches supporting cross-chain operations. [11]

Interoperability Standards: These are protocols that facilitate communication and interaction

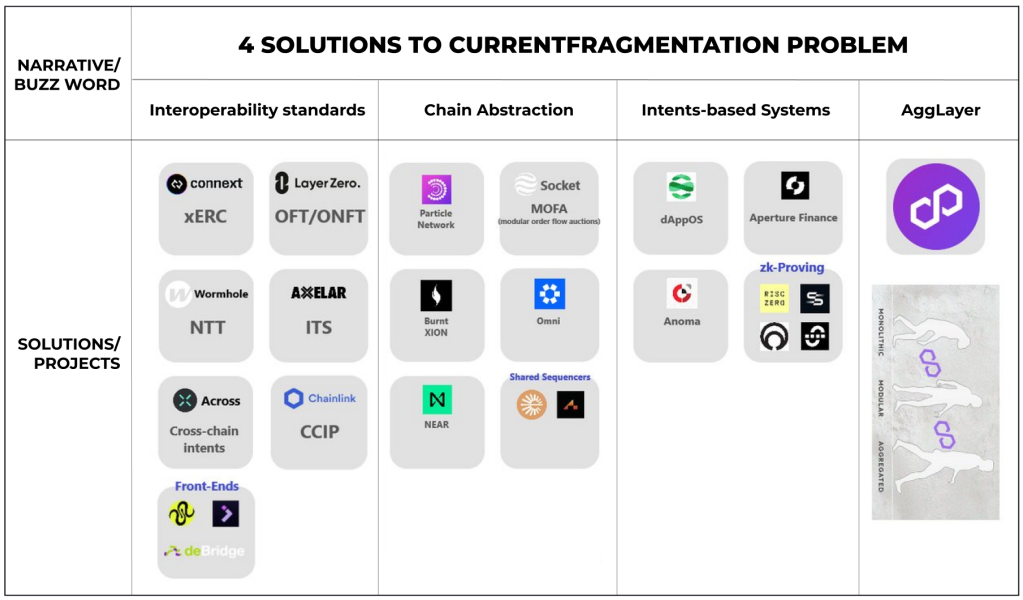
between different blockchains. Representative projects include LayerZero, Wormhole, and Axelar.

Chain Abstraction: This refers to middleware or tool components that simplify blockchain applications and services by removing friction in user experience (UX) and technical processes. Representative projects include Particle Network and Near.

Intent-Based Systems: These allow users to outsource their desired on-chain tasks to third-party ”solvers,” which interact directly with the network and protocols on their behalf. Representative projects include dAppOS and Anoma.

Chain Aggregation: This approach constructs a unified liquidity network and near-infinite scalability within a single-chain architecture, enabling instant atomic transactions. A representative project in this category is Polygon PoS’ s Agglayer.

Figure 4: Four Common Cross-Chain Interoperability Technologies



Gate Research, Data from: SoSo Value

Gate Research

It is important to note that this classification is meant to enhance understanding and is not exhaustive. Additionally, there is overlap between these categories. However, this does not prevent us from analyzing and understanding the broader landscape. We will explore these innovative cross-chain solutions using this classification in the following sections. Section 5 will go beyond technology to discuss new cross-chain narratives and emerging trends.

3 Mainstream Cross-Chain Standard Protocols

Solutions such as LayerZero, Wormhole, and Axelar provide fundamental building blocks for the cross-chain market infrastructure. In some cases, they even serve as underlying components for approaches like chain abstraction, intent-based systems, and aggregation layers.

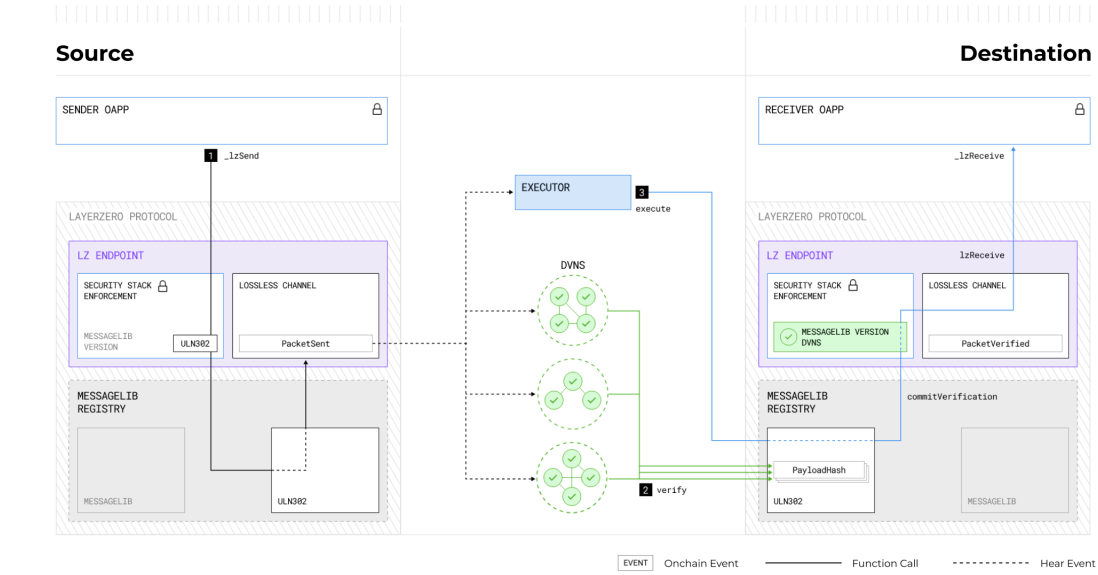
3.1 LayerZero: A Lightweight and Flexible Cross-Chain Interoperability Protocol

LayerZero is an immutable, censorship-resistant, and permissionless modular smart contract protocol that enables anyone on a blockchain to send, verify, and execute messages on supported target networks. Its core strengths lie in its robust cross-chain communication capabilities and high flexibility.

LayerZero ensures cross-chain communication validity through two independent entities:

- Oracle: Reads block headers from one chain and transmits them to another chain to verify the validity of transactions on the source chain.
- Relayer: Retrieves proofs of specified transactions and ensures that messages are delivered correctly.

Figure 5: LayerZero Cross-Chain Workflow



Gate Research, Data from: LayerZero

Gate Research

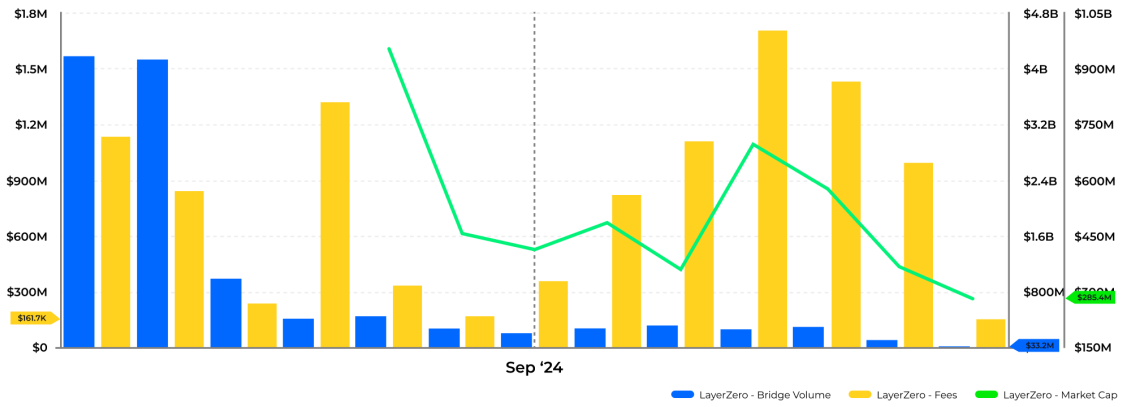
Additionally, LayerZero introduces an Ultra Light Node (ULN) mechanism, which leverages block headers and transaction proofs to validate cross-chain transactions and messages. This enhances security while reducing costs.

However, LayerZero’s complexity also presents certain challenges. Due to its intricate underlying mechanisms, its scalability is somewhat limited, and developers and users may require additional time and effort to understand and utilize it fully.

2Since 2025, LayerZero has:

- Launched QMDB, a high-performance verifiable database.
- Partnered with the TON blockchain to improve cross-chain functionalities.
- Made a strategic investment in Plume Network, an RWA-focused Layer 1 platform, to expand its real-world asset (RWA) tokenization initiatives.

Figure 6: LayerZero Transaction Volume, Fees, and ZRO Token Market Value



Gate Research, Data from: Artemis

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According to LayerZero’s official website, the protocol has connected over 120 blockchains and 300 dApps, processed approximately 138 million cross-chain messages, and facilitated over $50 billion in bridged value. [12]

From the data: In June 2024, when LayerZero launched its ZRO token airdrop, over 1.4 million unique wallet addresses interacted with the protocol. However, after community backlash over the airdrop event, activity plummeted, with current transaction volume and active addresses down to just 10% of their peak levels. [13] Compared to Wormhole and Axelar, which will be discussed later, LayerZero leads in total message volume and network support. It has also

been catching up in total bridged value, highlighting its growing advantage within the broader cross-chain ecosystem.

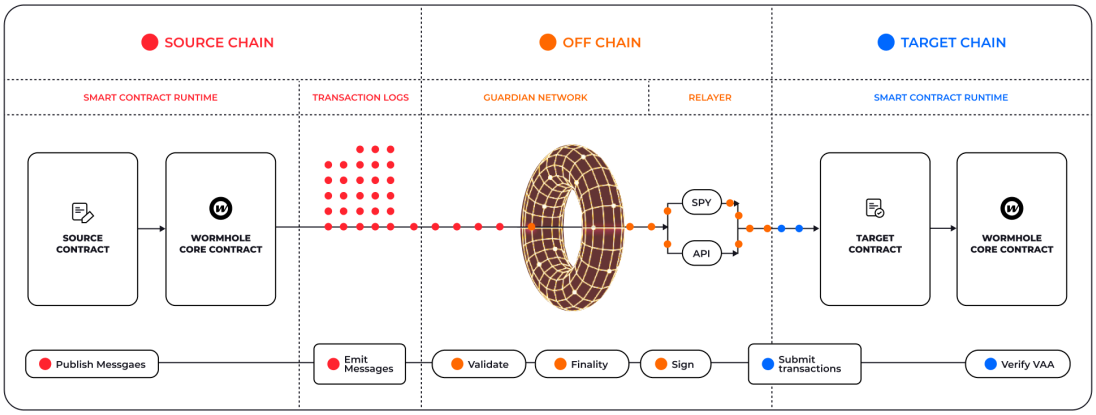
3.2 Wormhole: A Minimalist Yet Powerful Cross-Chain Messaging Protocol

Compared to LayerZero, Wormhole follows a minimalist approach. It focuses on providing an efficient and secure cross-chain messaging service, supporting the cross-chain transfer of various assets and data.

Initially, Wormhole was designed as a token bridge between Ethereum and Solana. However, it has since evolved into a general-purpose messaging protocol. It employs a modular toolkit, leveraging components such as emitters, core contracts, and transaction logs to enable and verify multi-chain messaging.

The core architecture of Wormhole is based on the Proof of Authority (PoA) mechanism, with 19 trusted entities known as Guardians. These validators are responsible for verifying the authenticity and validity of cross-chain messages between the source and destination chains. This approach allows Wormhole to ensure security while maintaining high efficiency in cross-chain communication.

Figure 7: Wormhole Cross-Chain Workflow



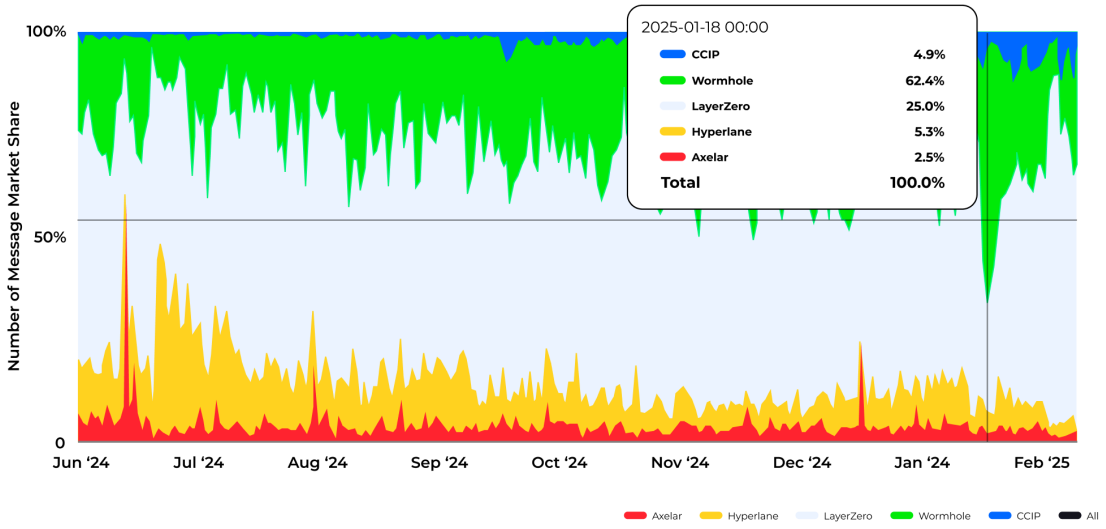
Gate Research, Data from: Wormhole

Gate Research

Wormhole has made significant advancements in cross-chain bridge security. It employs multi-signature verification and distributed validation to prevent malicious actors from taking control of

the cross-chain bridge. One notable example showcasing Wormhole's efficiency and reliability is its performance during the $TRUMP token launch on January 18. On that day, Wormhole processed $186 million in cross-chain transactions, accounting for 62.4% of total Solana-related cross-chain volume. [14]

Figure 8: Market Share of Leading Cross-Chain Protocols



Gate Research, Data from: Dune

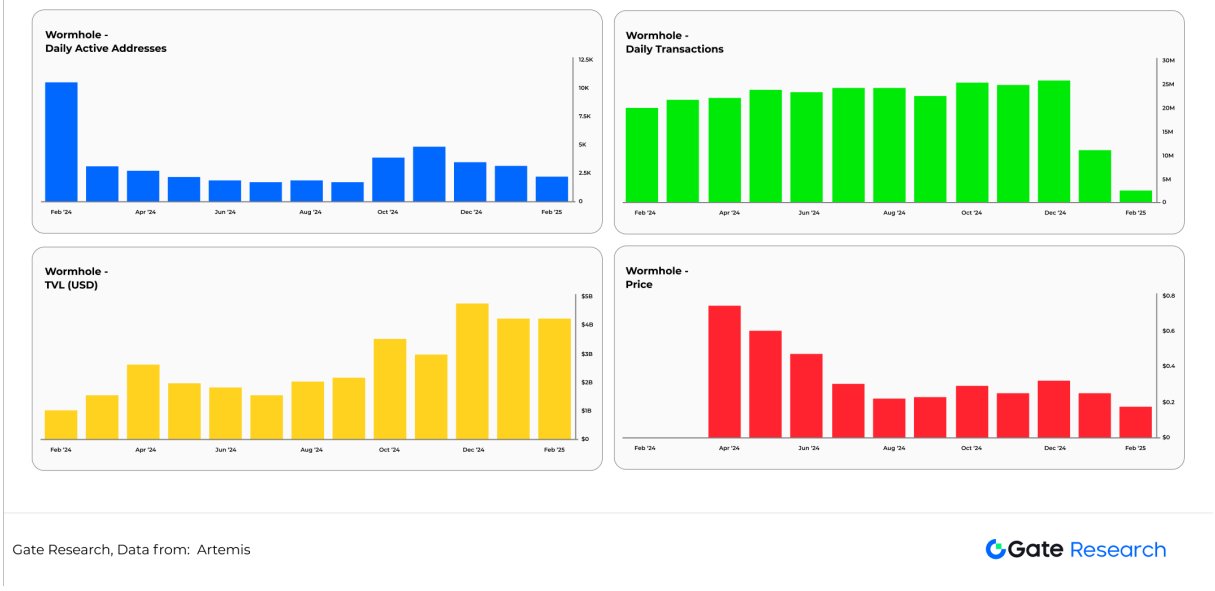
Gate Research

However, Wormhole is not without its limitations. Due to its minimalist design philosophy, it lacks some of the functionality and flexibility offered by more complex cross-chain protocols like LayerZero.

Like LayerZero, Wormhole has recently entered the Real-World Asset (RWA) space. It has partnered with Securitize, a tokenization platform backed by BlackRock, to enable seamless token transfers. Additionally, Wormhole's roadmap includes:

- Integration of Zero-Knowledge Cryptography
- Support for Hardware Accelerators
- Launch of Light Clients

Figure 9: Wormhole’s Daily Active Users, Transactions, TVL, and Token Price



According to Wormhole’s official website, the protocol currently:

- Connects over 30 blockchains
- Supports 200+ dApps
- Has facilitated more than $10 billion in asset transfers [15]

Unlike LayerZero’s broad cross-chain expansion, Wormhole adopts a ”fewer but deeper” strategy, particularly within the Solana ecosystem. Solana-based transactions account for over 50% of Wormhole’s total transaction volume. [16] As a result, Wormhole surpasses LayerZero in metrics such as Total Value Locked (TVL), Daily Active Users (DAU), and Daily Transactions (Tx Count). This reflects Wormhole’s strong positioning within the retail-heavy Solana ecosystem.

3.3 Axelar: The Pioneer of the “Interchain” Concept and the Unifier of Cross-Chain Development

Axelar is a distinctive cross-chain interoperability project that was the first to introduce the “interchain” concept on top of cross-chain and multi-chain frameworks.

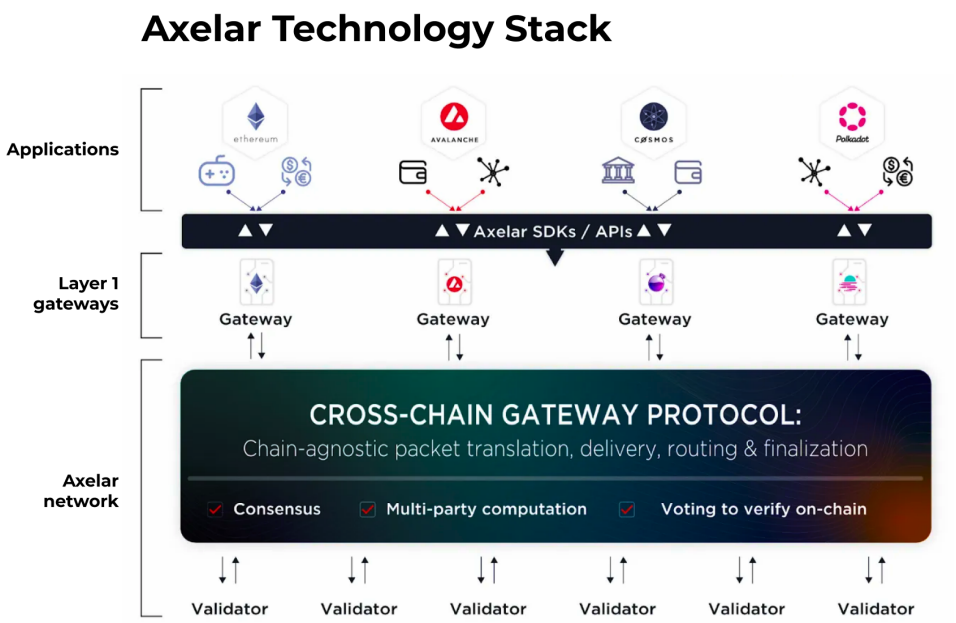
As a cross-chain interoperability layer built with the Cosmos SDK, Axelar enables a highly programmable and automated cross-chain infrastructure through three key components in its decentralized network:

– **Decentralized Network**: This is the core of Axelar, supported by a dynamic validator set responsible for network maintenance and transaction execution. Validators run the Cross-Chain Gateway Protocol (CGP), a cryptographic layer above Layer 1 blockchains. These validators execute read/write operations on gateways deployed on external chains connected to Axelar and use Proof-of-Stake (PoS) consensus to verify blockchain events.

– **Gateway Smart Contracts**: These are smart contracts deployed on the connected blockchains. Validators monitor incoming transactions on these gateways, read the transactions, and execute necessary operations through CGP.

– **Cross-Chain Gateway Protocol (CGP)**: This protocol runs on validator nodes and allows Axelar's network to interact with connected blockchains. Validators use CGP to read and write data on the gateway smart contracts, facilitating cross-chain communication and asset transfers.

Figure 10: Axelar's Cross-Chain Workflow



Gate Research, Data from: Axelar

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Like LayerZero and Wormhole, Axelar provides a developer-friendly SDK (Software Development Kit) that allows developers to deploy smart contracts and execute complex cross-chain operations easily.

Axelar enhances security through multiple defense mechanisms:

– Validator-controlled gateways: Control over gateway contracts is distributed among multiple validators using multi-party cryptographic schemes to ensure key security.

– Quadratic Voting Mechanism: To prevent validator centralization, the system requires validators to stake AXL tokens in proportion to the square of their voting power.

– Additional protective measures:
  - Frequent key rotations
  - Transaction rate limits
  - Open-source security audits

According to Axelar's official blog, recent developments continue to focus on expanding cross-chain interoperability, including:

– Advancing the Axelar Virtual Machine (AVM) as a blockchain-agnostic development platform.

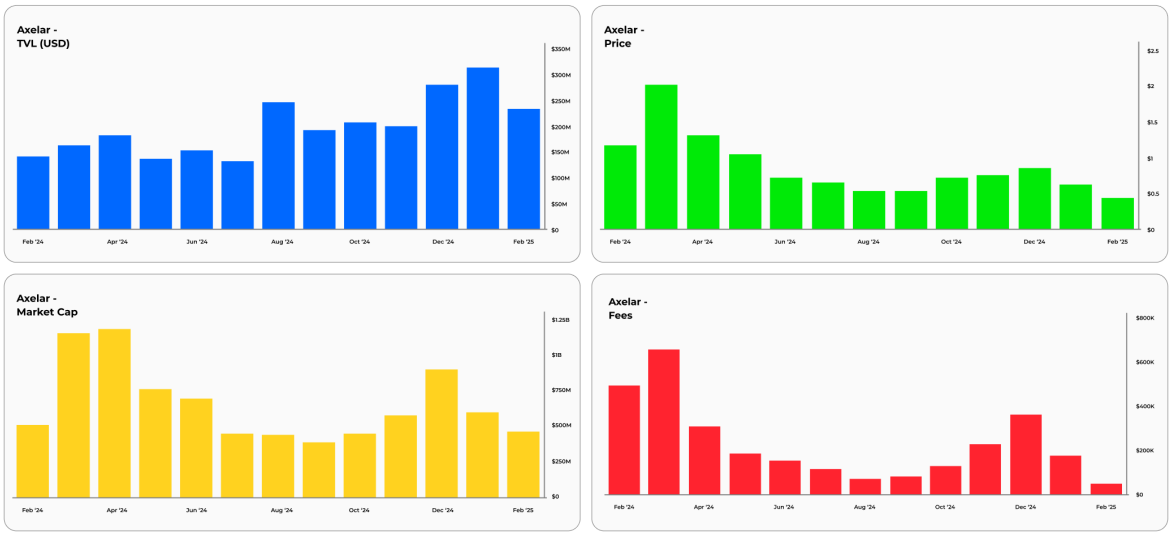
– Enhancing the Interchain Amplifier, which enables permissionless connections to arbitrary chains and seamless chain integrations.

– Improving the Interchain Token Service (ITS) to facilitate cross-chain token creation and management.

– Partnering with OpenZeppelin to develop open interoperability interfaces.

– Exploring new tokenomics models and network functionality optimizations.

Figure 11: Axelar's TVL, Token Price, Market Cap, and Fees



Gate Research, Data from: Artemis

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According to Axelar's official website, the protocol has connected 69 blockchains, operates with 75 validator nodes, and has processed approximately 1 billion cross-chain messages. However, among the three major protocols, Axelar holds the smallest market share and has already

shown signs of being surpassed by competitors such as Hyperlane and Chainlink's CCIP [17].

Compared to LayerZero's extensive multi-chain coverage and Wormhole's deep liquidity integration, Axelar primarily focuses on Cosmos and DeFi cross-chain interactions, making it a more niche solution. This limited focus weakens its overall competitiveness, a fact reflected in business metrics that align with our direct observations.

From the data:

- Since 2024, Axelar's TVL (Total Value Locked) and transaction volume have maintained a monthly growth rate of 5%-10%, but this growth has been inconsistent.
- Axelar's bridge volume and daily active users (DAU) remain below 20% of LayerZero and Wormhole's, indicating significantly lower market penetration.
- Due to its smaller user base, Axelar struggles to generate the same strong network effects as LayerZero and Wormhole, putting it at a disadvantage in attracting new projects and developers.

To close the gap, Axelar must sustain a high growth rate and expand its ecosystem to remain competitive.

Summary

In summary, LayerZero is known for its high flexibility and scalability, Wormhole is favored for its simplicity, efficiency, and security, while Axelar provides developers with great convenience through its interchain concept and unified development environment.

Feature/Protocol	LayerZero	Wormhole	Axelar
Primary Positioning	Trustless cross-chain communication protocol, primarily for cross-chain messaging	Facilitates cross-chain communication and supports cross-chain asset transfers	Cross-chain messaging, similar to LayerZero
Technical Mechanism	Uses light nodes and ultra-light nodes, achieving cross-chain communication through relayers and oracles	Minimalist architecture, triggers contract events to send messages, validated by comparing with Guardian signatures	Developed with Cosmos SDK, does not directly host EVM
Flexibility	Offers extensive configuration options, adaptable to multiple application scenarios	Allows developers to freely expand functionalities	Possibly influenced by Cosmos SDK
Connectivity Design	Peer-to-peer	Hub-and-spoke model	Hub-and-spoke model
Cross-Chain Type	Focuses more on message passing, with asset transfers handled by Stargate	Supports both asset and message cross-chain transfers	Primarily for cross-chain messaging
Security Verification	Uses a dual-layer system, separating oracles and relayers, with off-chain validation	Uses PoA mechanism (19 nodes), allowing developers to adjust consensus levels as needed, with off-chain validation	Uses DPoS mechanism (75 nodes) + quadratic voting, with on-chain validation
Ecosystem Integration	Ethereum and Layer 2 ecosystems	Solana and Ethereum ecosystems	Cosmos and Ethereum ecosystems
Market CAP	$320M	$500M	$400M
FDV	$2.9B	$1.75B	$550M

Gate Research, Data from: Gate.io

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Note:

1. Market Cap and FDV data are as of February 20, 2025, sourced from official websites and Gate.io.
2. The information in the table is based on the time of writing and may be subject to delays, incompleteness, or outdated details.

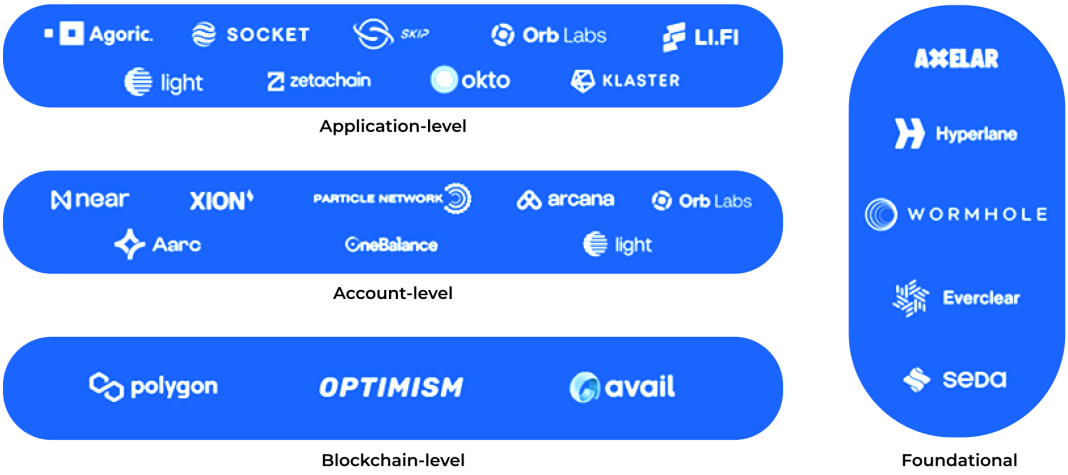
4 Emerging Cross-Chain Solutions: Chain Abstraction, Intent-Based Systems, and Aggregation Layers

4.1 Chain Abstraction

Chain Abstraction refers to separating the complexity of blockchain interactions from the end-user experience. Simply put, this means hiding the intricate operational details of blockchains from users and even developers to some extent, making it easier to build and use dApps [18].

For example, ENS (Ethereum Name Service) and CCIP (Cross-Chain Interoperability Protocol) are real-world applications of chain abstraction.

Figure 12: Technical Layers of Chain Abstraction



Gate Research, Data from: Particle Network

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Although the concept of chain abstraction was first proposed by Near's co-founder, its development was inspired by centralized exchange (CEX) cross-chain trading functionalities. The evolution of chain abstraction has progressed from wallet abstraction (supporting social accounts and multi-chain assets), to account abstraction (adopting the ERC-4337 standard), and now to chain abstraction as a whole. In other words, the "abstracted" elements have expanded beyond private keys and mnemonic phrases to include account interactions, user experience, and frontend simplifications.

In layman's terms, chain abstraction functions like a "cross-chain transit station." This special blockchain handles all cross-chain transactions and verifications while keeping users unaware of the complex technical details. Users only need to interact with this "station" instead of dealing with individual chains. This is similar to sending a package through a collection center, where you don't need to contact multiple courier companies—you just drop off the package, and the collection point handles the entire delivery process. While chain abstraction simplifies cross-chain transactions, it may also introduce inefficiencies, as all processes must go through this transit system, making some transactions slower or less flexible.

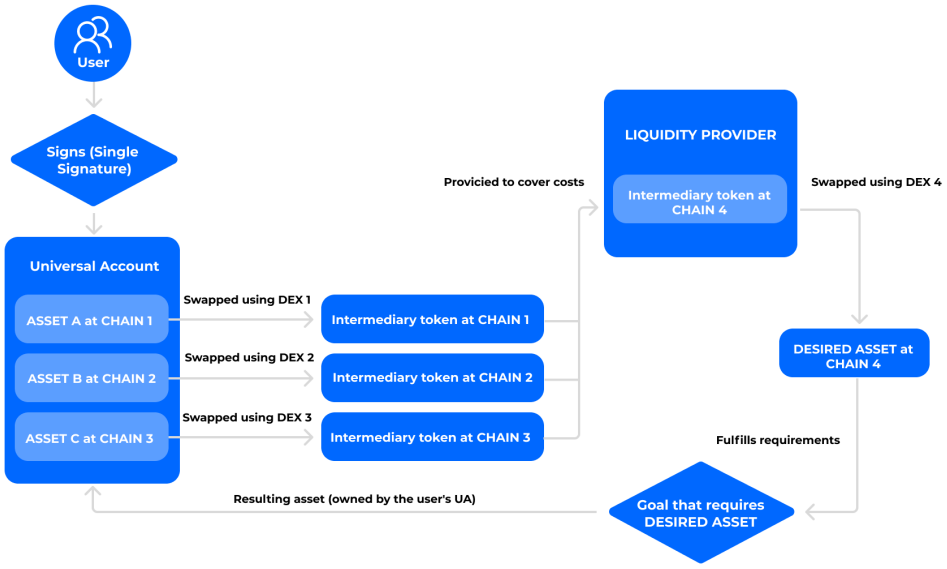
Overall, chain abstraction represents a paradigm shift—moving from a chain-centric model to a user-centric approach. This shift suggests that blockchain competition will focus more on user experience than technical superiority. As a result, Web3 adoption will accelerate as dApps evolve from product-driven to demand-driven models.

Particle Network: A Modular Layer 1 for Chain Abstraction

Particle Network is a leading project in the chain abstraction space. It encapsulates the complexities and differences between various blockchains to allow users to manage multi-chain assets and accounts within a unified interface.

Its core product, Universal Accounts, enables users to maintain a single balance, address, and interaction point across multiple blockchains. To achieve this, Particle Network relies on Universal Liquidity, a fundamental atomic cross-chain exchange system that consolidates liquidity across different chains, making transactions appear as if they occur on a single network.

Figure 13: Universal Liquidity Cross-Chain Workflow



Gate Research, Data from: Particle Network

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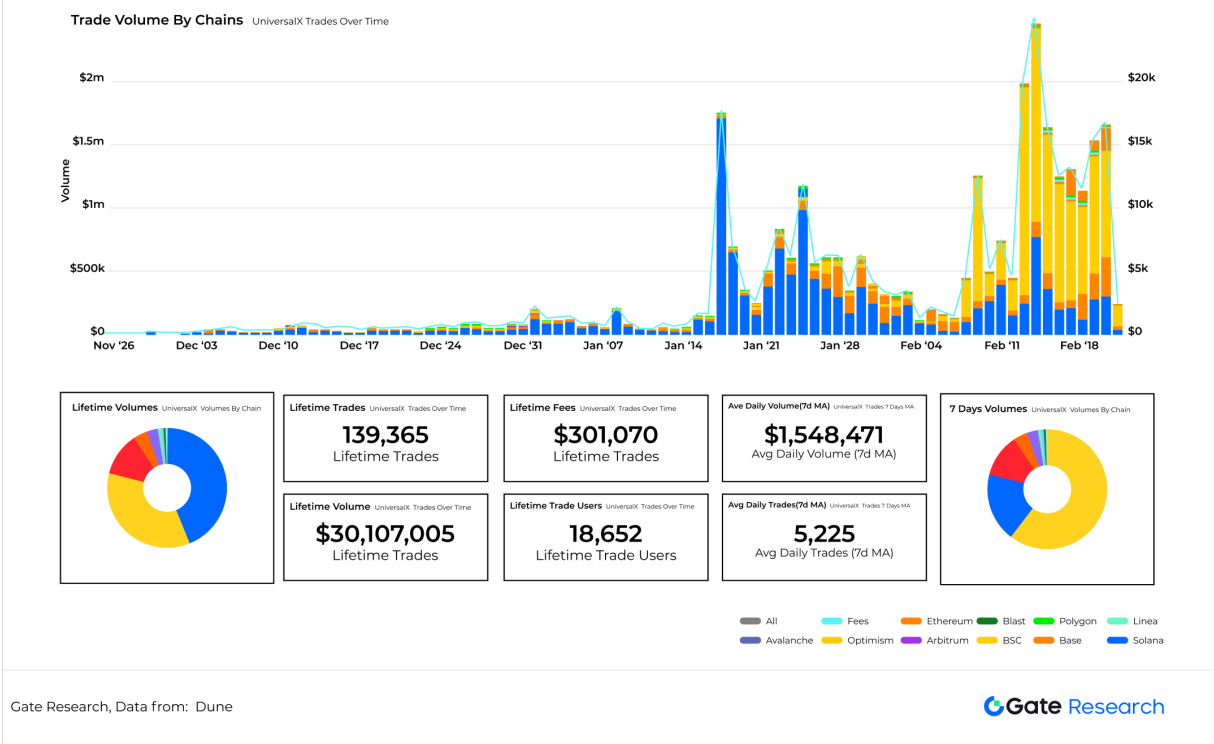
Universal Liquidity automatically swaps users' assets into "intermediate assets" (such as USDC, USDT, etc.) to seamlessly execute cross-chain transactions. These intermediate assets are then stored in liquidity pools and converted into the required tokens on the appropriate chain. Users only need to click a button (e.g., "Buy NFT" or "Swap"), and the entire process happens automatically.

According to Particle Network's official data, the network supports over 70 blockchains, with over 30 million users and 5,000 integrated dApps [19].

Figure 14: Particle Network Business Data



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The cross-chain trading platform UniversalX, developed by Particle Network, has seen accelerated growth in transaction volume and users in 2025. Following the BNB Chain ecosystem boom in February, BNB transactions on UniversalX accounted for over 60% of the total volume, surpassing the peak of 50,000 daily transactions in early January. UniversalX's daily active addresses reached 5,225, with daily transaction volumes climbing to $1.5 million, nearing the transaction levels of Wormhole, a protocol focused on high-traffic blockchain networks [20].

Near: A Comprehensive Chain Abstraction Solution

Near focuses on fully implementing chain abstraction, combining account abstraction, frontend abstraction, backend abstraction, liquidity abstraction, and data abstraction into a holistic solution.

For example, Near's account abstraction simplifies user login and transactions, allowing authentication via social accounts or biometric verification instead of traditional private key management. Additionally, the Relayer Mechanism enables users to execute transactions without holding native tokens. Users can sign transactions off-chain, while third-party relayers pay for and process the transactions, improving flexibility and user experience.

Currently, Near has introduced Meta Transactions, Chain Signatures, Intents, FastAuth (email login), Omni Bridge, and other innovations. Among them, Omni Bridge is a multi-chain asset bridge that utilizes Chain Signatures and its decentralized Multi-Party Computation (MPC) service to enable trustless cross-chain asset transfers. This new method reduces verification time from several hours to just a few minutes while significantly lowering gas fees across all supported blockchains.

4.2 Intent-Based Transactions

The Intent-Centric approach overlaps with chain abstraction in concept and technology, but intent is a more user-centered method. Paradigm first introduced the idea in June 2023 in its paper ”Intent-Based Architectures and Their Risks” [21].

According to Paradigm, Intent-Centric is a signed declarative constraint allowing users to delegate transaction creation to third parties while retaining full control over the transaction counterparties.

The core process of intent transactions involves:

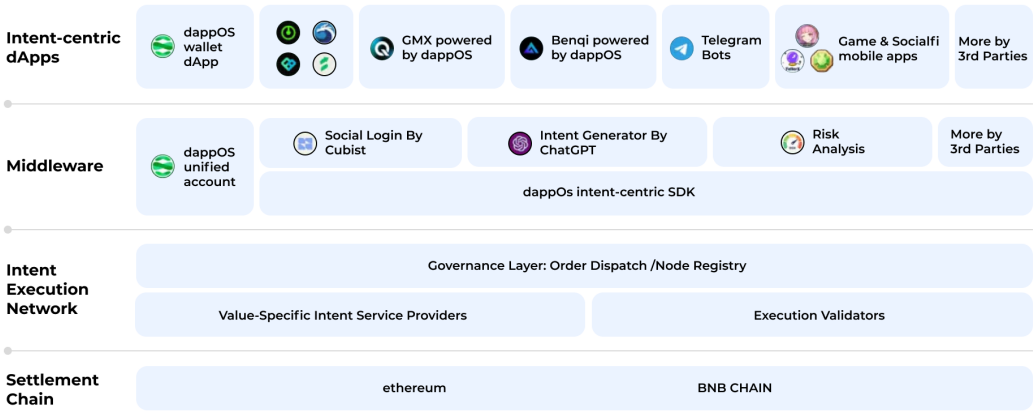
1. Users declaring the desired transaction outcome.
2. A decentralized solver network acting as a ”distributed state trading party”, matching cross-chain proofs from the target chain to the user’ s primary chain.
3. Enforcing transaction execution through proof verification on the main chain.

This approach provides outcome-based guarantees, allowing users to:

– Optimize execution states and transaction latency by selecting counterparties.

– Ensure transparency, traceability, and verifiability.

Figure 15: Intent Transaction Ecosystem Landscape



Gate Research, Data from: Web3Caff

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In simple terms, if chain abstraction is like a package collection center, then intent-centric transactions function as a personalized courier service. For example, DeFAI, a rising trend, offers greater flexibility and customization.

More importantly, intent transactions redefine blockchain interaction models. Traditional transactions require users to follow blockchain rules, whereas intent transactions shift the paradigm so blockchains adapt to users' needs. This user-driven approach could be a key breakthrough for Web3 mass adoption.

dappOS: AI-Powered Intent Engine

dappOS is a leading intent-based transaction protocol and a multi-chain intent partner of Gate Wallet. According to its latest blog post, dappOS is pioneering three key narratives: Account Abstraction → Chain Abstraction →Intent-Centric Transactions.

Built on abstracted accounts and cross-chain protocols, dappOS offers a unified multi-chain wallet and asset management solution.

AI-Powered Intent Engine:
Users simply enter a request such as "Buy BAYC at the best price," and the system automatically routes the transaction using LayerZero, Axelar, and other cross-chain protocols.

Three Key Features of dappOS:

– Asset Intent: Allows users to utilize their assets while earning passive income.

– EX Intent: Ensures users get the best trading costs when executing spot transactions.

– Intent-Based dApp Interaction: Enables seamless dApp interaction, eliminating the need for direct blockchain interaction.

For example, Perpetual Protocol, a decentralized perpetual trading protocol on Optimism, now integrates dappOS V2, allowing BNB and Polygon users to trade on Perpetual Protocol without switching networks. Users can pay gas and bridging fees using any token they choose. And traders gain full visibility into their current and past transactions.

Figure 16: dappOS V2 Intent-Based Transaction Fee Breakdown

Item	Explanation	Example
Method	Payment options (VW、EOA、ACH)	VW
GasPriceLimit	Gas payment amount	5 USDT on BSC
PriorityFee	Fees paid to nodes	1 USDT on BSC
BridgeFee	The cost of bridging	1 USDT on BSC
Token	The currency and chain of Gas Price and Priority Fee	USDT on BSC
Input	The amount and currency that need to be bridged	1000 USDC on BSC
Output	The amount and currency that needs to be received	1000 USDT on BSC

Gate Research, Data from: dappOS

Gate Research

Integrating dappOS V2 with Perpetual Protocol has introduced an advanced bidding and pricing system, allowing nodes to actively participate in the network and generate revenue from their services. This results in greater efficiency and cost savings for users, as they can select the most optimal nodes for their transactions, significantly reducing cross-chain expenses.

Anoma: An Intent-Centric Privacy Architecture

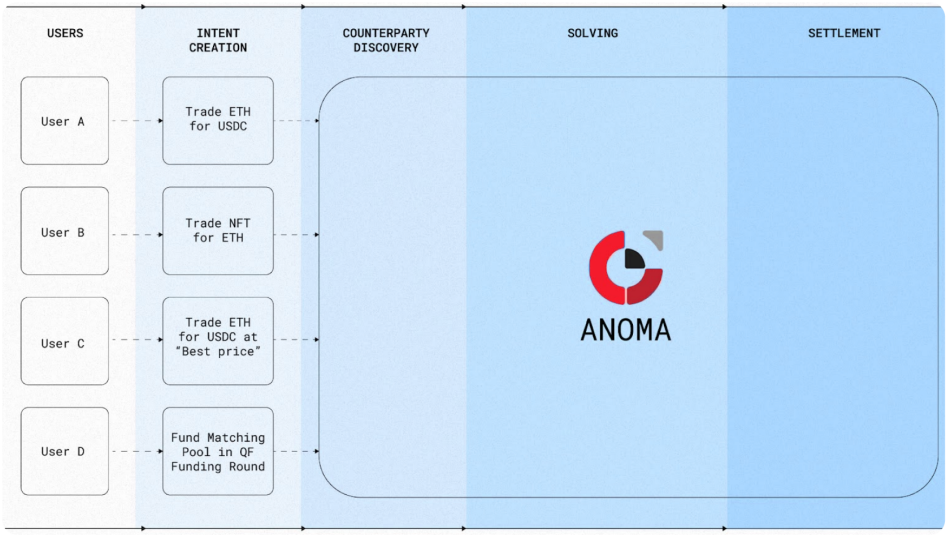
Anoma is also a popular intent-based transaction protocol that allows users to state their desired outcome simply, and the system will automatically find the optimal transaction execution path.

The core principle of Anoma Network is to use its Intent Propagation Layer and Solvers to facilitate decentralized counterparty discovery and matching while leveraging a distributed ledger for settlement.

How Anoma Works

1. Users submit intents through Anoma’s Intent Propagation Layer.
2. Solvers collect and match intents, finding counterparties that fulfill the specified conditions.
3. Once a match is found, the transaction is submitted to an encrypted mempool.
4. The consensus module sorts transactions, and the Typhon consensus algorithm updates the network state.
5. Parallel processing accelerates transaction execution.

Figure 17: Anoma Intent Transaction Workflow



Gate Research, Data from: Anoma

Gate Research

Additionally, one of Anoma’s major strengths is its ability to handle transparent, shielded, and private data, ensuring strong privacy protection for users.

Essential: A Declarative, Intent-Based Blockchain

Essential is a declarative, intent-centric Layer 2 blockchain that is deployed on Ethereum as an Optimistic Rollup.

Unlike imperative blockchains, where transactions require explicit execution, a declarative blockchain uses constraints to achieve state updates without direct execution. For users, this means seamless and predictable transaction outcomes. For developers, it reduces complexity and accelerates innovation. For the Web3 ecosystem, it offers greater scalability, lower costs, and stronger decentralization.

At its core, Essential operates on execution-free blockchain technology and a constraint-based Domain-Specific Language (DSL). This allows users to complete computations off-chain, with only fraud-proof verification conducted on-chain, thereby enhancing throughput and reducing transaction fees.

4.3 Chain Aggregation

While the previous discussions mainly focused on account-level and application-level solutions, this section explores interoperability solutions at the blockchain level. Although Cosmos' IBC protocol and Polkadot's parachain architecture have introduced early versions of a "ChaiNet" model, where blockchains function as nodes sharing security, liquidity, and computational resources for global optimization, their cross-chain adoption remains limited due to centralized relay chains and ecosystem fragmentation. Given these constraints, we focus on Agglayer, a newly launched blockchain aggregation solution.

Agglayer: Aggregating All Chain Information

Agglayer (Blockchain Aggregation Layer) was first proposed by Polygon Labs in 2024. It refers to an interoperability framework that aggregates all recognized messages across interconnected chains to construct a unified liquidity system with near-infinite scalability, resembling a single blockchain.

How Agglayer Works

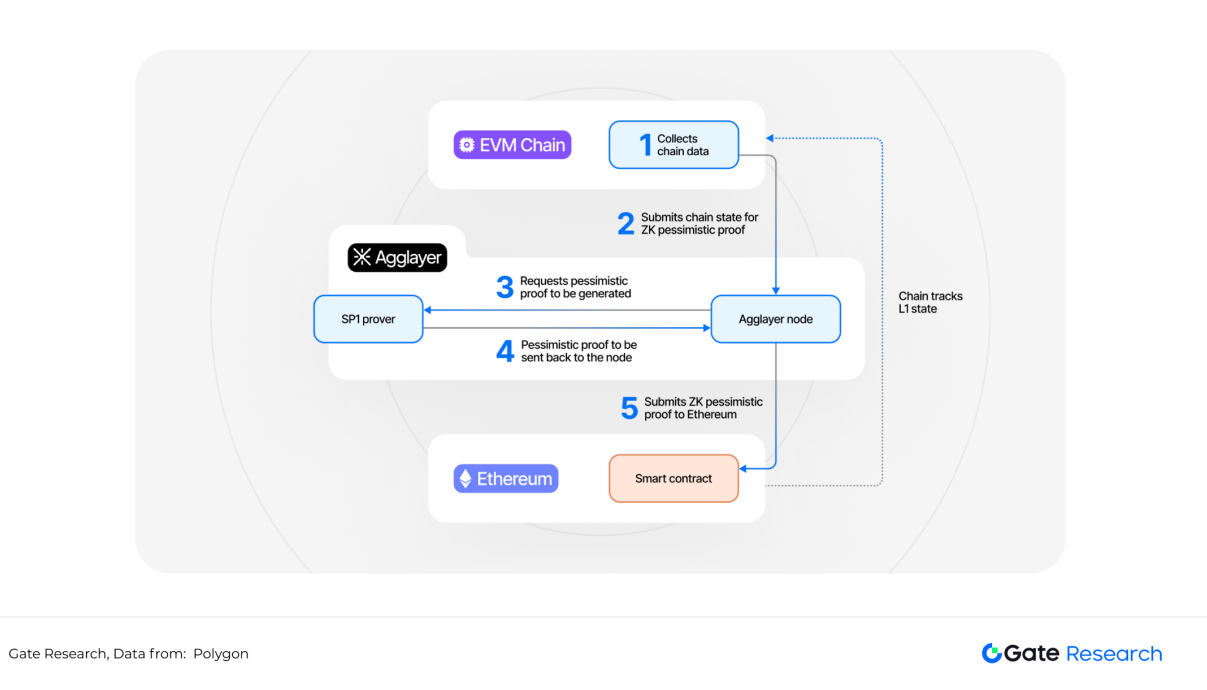
Agglayer is a lightweight interoperability framework built upon three key components:

1. Agglayer Nodes –Rust-based services responsible for validating zero-knowledge proofs.
2. Pessimistic Proofs –A new zero-knowledge proof system that went live on the mainnet in February 2025, ensuring withdrawal requests are backed by legitimate deposits.

3. Unified Bridge –Maintains data structures to facilitate cross-chain transactions, including asset transfers, message passing, and state management.

These components enable lightweight, secure, and verifiable cross-chain transactions.

Figure 18: Agglayer Cross-Chain Workflow



From a user perspective, Agglayer makes cross-chain transactions as simple and fast as browsing different websites on the Internet. Users can execute atomic cross-chain transactions in under one second without needing to frequently bridge assets, significantly improving the user experience.

Compared to LayerZero and similar protocols, Agglayer does not require complex oracle and relayer setups, reducing system complexity and potential security risks. It offers a simple and efficient framework, ultra-low latency cross-chain transactions, and strong sovereignty, making it well-suited for high-speed applications such as gaming and social networks.

From the author’ s perspective, Agglayer reveals an important trend: Cross-chain technology is evolving from a “bridging model” to an “aggregation model.” This evolution suggests that the blockchain ecosystem may gradually adopt a hub-and-spoke structure, similar to Wormhole and Axelar, where a few high-performance mainchains act as hubs, connecting numerous specialized functional blockchains.

However, compared to mainstream cross-chain protocols, Agglayer still has certain shortco-

mings regarding ecosystem maturity, heterogeneous chain support (i.e., non-EVM chains), and the level of decentralization.

5 New Trends in the Cross-Chain Ecosystem

Although many of the innovations discussed in the previous sections are still in their early stages, the cross-chain sector has already seen several promising developments beyond just technological advancements. Below are four noteworthy trends:

5.1 AI Integration is Driving Multi-Chain Economic Networks

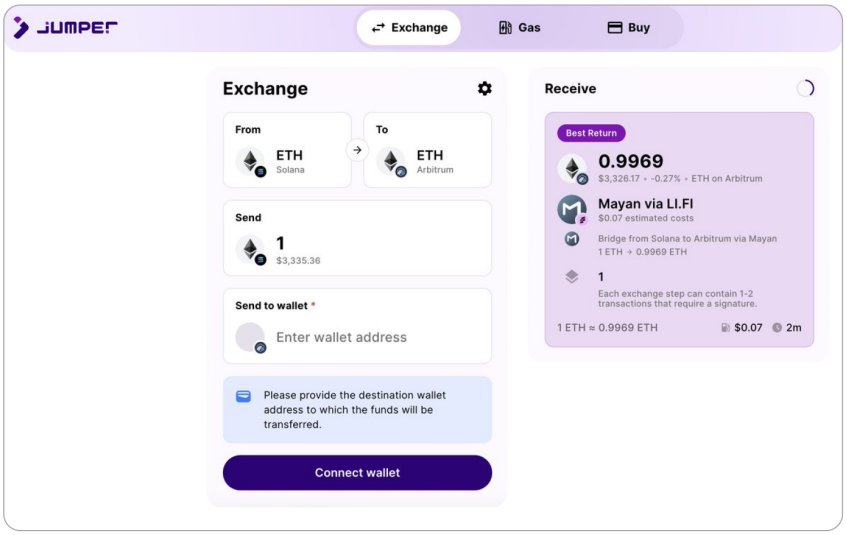
The convergence of AI and cross-chain technology is opening new opportunities for the cross-chain sector. Take Wormhole, for example—its standardized API and low-latency features allow AI agents to:

- Access real-time multi-chain liquidity data
- Identify price differences and arbitrage opportunities
- Quickly trigger cross-chain transactions
- Freely schedule asset transfers and information flows

This is accelerating the emergence of the DeFAI (DeFi + AI) model.

For instance, Jumper, a cross-chain bridge aggregator, integrates Mayan, a cross-chain auction protocol powered by Wormhole. With this setup, cross-chain swaps between Solana and Ethereum take as little as 2 minutes, requiring no manual operation or third-party website navigation, greatly simplifying user interactions and improving efficiency [22].

Figure 19: One-Click Cross-Chain Functionality in Jumper



Gate Research, Data from: Jumper

Another example is the partnership between Mayan and Solana's AI ecosystem accelerator, SendAI, which has pioneered a new DeFAI model:

- Predictive Execution –AI analyzes historical data to pre-deploy liquidity on target chains.
- Autonomous Market Making –AI monitors price disparities across 30 blockchains and executes triangular arbitrage within 10 seconds.
- Risk Control –Machine learning detects abnormal trading patterns and blocks suspicious cross-chain requests.

Additionally, AI plays an important role in cross-chain bridges' security auditing and risk prevention. By leveraging AI technology, cross-chain bridges can monitor transaction behavior in real-time, identify potential security threats and risk points, and take immediate action to protect user assets. This integration not only enhances the intelligence level of cross-chain technology but also lays a solid foundation for the sustainable development of the cross-chain sector.

5.2 Privacy Computing for Cross-Chain Privacy Protection

The integration of privacy computing technology with cross-chain services is one of the key innovation directions in the cross-chain sector.

Beyond the three major cross-chain protocols and Agglayer, several projects are actively exploring privacy-enhancing technologies:

– Merlin Chain: Uses ZK bridging technology to enable BTC-to-EVM interoperability.

– Aztec Connect: Implements ZK-based anonymous verification for cross-chain transactions.

– Polyhedra Network: Introduces zero-knowledge proof (ZKP) technology to protect privacy in cross-chain asset and data transfers.

Beyond data encryption, the author believes that one of the biggest future potentials of privacy technology lies in collaborative cross-chain data training. For example, Polyhedra's zkBridge already supports cross-chain data verification, meaning zero-knowledge proofs can aggregate on-chain activity to generate cross-chain credit scores, which could be applied in node reputation assessment and real-world asset (RWA) credit evaluation.

According to Polyhedra's official data, zkBridge has securely processed over 20 million cross-chain transactions across more than 25 blockchain networks. By leveraging privacy computing, Polyhedra has not only improved cross-chain transaction security and privacy but also enabled the seamless flow and efficient utilization of cross-chain assets and data【23】.

5.3 Compliance in Cross-Chain Transactions

As blockchain continues to integrate with the real world, regulatory frameworks may need to shift from on-chain regulation to cross-chain regulation. This transformation is a technical challenge and requires a new regulatory paradigm. The author believes that in the future, dedicated cross-chain compliance protocols may emerge to act as regulatory interfaces between blockchains.

The tokenized real-world asset (RWA) platform Ondo Finance is one of the early pioneers exploring this direction. At the first Ondo Summit in February 2025, Ondo Finance announced the launch of its Layer 1 blockchain, Ondo Chain, designed specifically for tokenized real-world assets.

Unlike traditional bridge protocols, Ondo Chain is a fully independent Layer 1 blockchain, featuring:

– Institutional participants and staked RWAs securing the network.

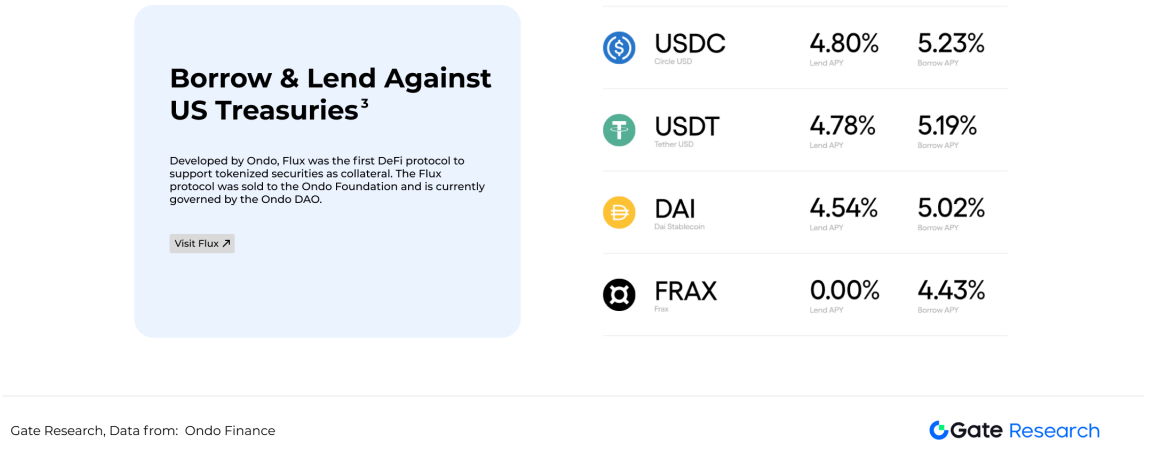
– Integration with traditional financial systems, reducing costs and latency.

– Real-time liquidity capabilities.

Additionally, Ondo Chain incorporates built-in oracle mechanisms and data isolation techniques to ensure accurate and real-time on-chain data.

According to the latest data from the official website, Ondo Finance supports 10 blockchains, with a Total Value Locked (TVL) of $678M and a maximum APY of 4.80% [24].

Figure 20: Ondo Finance Stablecoin Deposit Rates



Gate Research, Data from: Ondo Finance

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Essentially, protocols like Ondo Chain fulfill compliance requirements through KYC metadata, but this comes at the cost of user privacy. In the author’ s view, a reasonable compromise would be to use zero-knowledge proofs (ZKPs) to achieve ”compliant anonymity”—meaning on-chain behavior remains verifiable but not visible, with selective disclosure only possible under multi-institutional joint authorization. Currently, Aztec Connect’ s privacy Rollup has already implemented a similar solution, which could be adapted for cross-chain compliance scenarios.

5.4 Innovative Business Models

Beyond technical advancements and regulatory developments, cross-chain protocols explore new economic models to address challenges such as limited revenue streams and weak token utility. For example, LayerZero has proposed enabling a ”fee switch,” suggesting a $0.01 protocol fee per cross-chain message, with proceeds used to buy back and burn ZRO tokens, thereby reducing its circulating supply [25].

Additionally, some projects are exploring cross-chain governance (e.g., BitXHub) and cross-chain data sharing, among other innovative directions. These emerging models not only enrich the cross-chain ecosystem but also open up new possibilities for the future development of cross-chain technology.

6 Conclusion

From the above discussion, it is evident that the development of cross-chain solutions follows a clear ”layered evolution” trajectory: from asset interoperability (cross-chain bridges) to data interoperability (cross-chain messaging), then to experience interoperability (chain abstraction) and more efficient intent-based transactions. In the future, the focus must shift towards a deeper integration at the ecosystem level:

- Technological integration: AI, privacy computing, and regulatory security need to be deeply embedded within the protocol stack rather than simply layered on top.
- Economic restructuring: The revenue model needs to shift from transaction fees to ecosystem-wide value sharing, creating a native cross-chain economic system.
- Governance evolution: The industry must balance reputation systems and decentralized governance to resolve the tension between human-driven and algorithm-driven decision-making.

This development trajectory closely mirrors the evolution of Web2—from network connectivity to information exchange, service interoperability, and semantic interoperability.

Thus, this similarity may hint at Web3’ s future: cross-chain technology is not just about asset transfers but also logic and ecosystem interoperability, ultimately leading to seamless and autonomous blockchain interconnectivity.

Regarding the latest technological integrations, the application of privacy computing technology has significantly improved the security and confidentiality of cross-chain transactions, while the introduction of artificial intelligence (AI) has greatly enhanced operational efficiency and reduced maintenance costs. This convergence suggests that new business models may emerge in the cross-chain sector, such as cross-chain liquidity mining and multi-chain AI strategy subscription services, which could potentially lead to a fully interconnected blockchain economy centered around AI agents.

However, the development of cross-chain technology still faces numerous challenges, including security vulnerabilities, transaction delays, high fees, AI collusion risks, and immature modular architectures. In particular, the increasing frequency of cross-chain bridge security incidents in recent years has highlighted the critical need to balance security and efficiency. The fundamental challenge for the industry remains: How to enhance service efficiency and reduce costs while ensuring security?

As Internet pioneer Vinton Cerf once said: ”Science fiction does not remain fiction for long. And certainly not on the Internet.” [26] The economic value being created by cross-chain networks may very well be the key to unlocking the next billion users in Web3. We have every reason to believe that in the future, cross-chain technology will inject new energy into the sustainable development of the blockchain industry, driving blockchain innovation to new heights.

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