SatLayer: Multi-Chain Security with BTC Restaking and Bitcoin-Validated Services

The SatLayer Protocol

June 2, 2025

Abstract

We introduce SatLayer, a protocol that forms the new economic layer for Bitcoin. SatLayer makes Bitcoin fully programmable through restaking and, as a result, boosts Bitcoin's liquidity efficiency and transforms it into the gold standard that the new decentralized economy is built upon. In this paper, we describe the high level architecture of SatLayer, including the various smart contracts via which it is implemented, the interactions between the different types of parties that act in the SatLayer ecosystem, and the core security and economic properties that SatLayer aims to guarantee. The initial version of SatLayer is built upon Babylon, a Bitcoin-backed Proof-of-Stake ledger, and allows developers of decentralized applications to directly tap into Bitcoin's capital. SatLayer introduces the concept of Bitcoin-Validated Services (BVS), which are applications economically secured by Bitcoin. SatLayer introduces the concept of Bitcoin -Validated Services (BVS), which are applications economically secured by Bitcoin. SatLayer enables Babylon stakeholders to opt in to secure BVSs in an accountable manner, such that if a stakeholder who opts in to secure a BVS misbehaves, in a slashable manner well-defined by the BVS, then the stakeholder's Bitcoin's are slashed.

To illustrate the potential of the SatLayer's protocol, we describe and plan to build two flagship Bitcoin Validated Services, an on-chain Bitcoin-backed prime brokerage and a yield-bearing Bitcoin-backed insurance protocol.

1 Introduction

Bitcoin [Nak08] launched a new paradigm of financial services, based on decentralized infrastructure. To this day, Bitcoin remains the leading cryptocurrency, in terms of market capitalization, and is underpinned by a robust blockchain-based distributed ledger. However, despite its resilience and strong security guarantees, Bitcoin's limited programmability restricts the deployment of generic applications. Although this limitation was overcome by systems that enable smart contract programming, such as Ethereum [W$^+$14], these systems' economic resilience is typically far weaker than Bitcoin's.[1]

[1]For reference, as of March 2025, Ethereum was the second largest cryptocurrency, with market capitalization that exceeded $230B, at a time when Bitcoin's market capitalization was $1.6T. (Source: CoinMarketCap)

Recent years have seen increased efforts that aim to tap into Bitcoin's significant, yet mostly idle, capital. The main ideas are to use Bitcoin's capital in (i) DeFi applications, and (ii) to provide full smart contract capabilities backed by Bitcoin security guarantees. In particular, Babylon [TTG+23, Tea23] allows Bitcoin owners to secure any Proof-of-Stake (PoS) chain against forking in a fully trust-minimized and non-custodial way. Importantly, the participants are fully accountable for their actions and their staked bitcoins are slashable if the participants misbehave by signing two blocks at the same height. However, double signing protection is the only Bitcoin-backed security guarantee that Babylon provides. Thus, many applications such as oracles, lending markets, decentralized exchanges, insurance applications, prime brokerages, and others cannot be secured by Babylon.

A practical solution to this problem is "restaking" protocols. These protocols offer consensus layer maintainers the ability to opt in to validating decentralized applications and other novel use cases.[2] In this setting, the participants grant the ability to the restaking protocol to impose more nuanced, fully programmable, slashing conditions, which are implemented by the application that the participants opt in to secure. In other words, participants are now accountable for their actions both in running the consensus protocol and in maintaining the decentralized application that is supported by the restaking protocol. If a participant misbehaves in either of the two domains, they are penalized by having their stake slashed.

Distributed ledgers that use PoS, either native (Ethereum) or via external staking (Babylon Genesis), offer the infrastructure on top of which decentralized applications can be built. Notably, although the infrastructure itself is secured by the ledger token's capital, the applications themselves only inherit the ledger's security, but not economic, guarantees. For example, various decentralized applications that offer lending, oracles, or similar services implement their own tokens in order to provide incentives for their users, manage governance, etc. In these cases, even if the ledger on top of which an application is built is economically secure, the application itself may not have such guarantees, e.g., if its own token's capitalization is low. This issue is particularly significant for bootstrapping new applications, that is keeping them secure and stable long enough to accumulate enough capital to support their own tokens.

Combining the above two ideas, i.e., enabling restaking of staked Bitcoin, is a powerful tool. SatLayer addresses exactly this concern by building a restaking layer on top of Babylon. SatLayer both turns Bitcoin into a yield-bearing asset and boosts its liquidity efficiency by enabling it to underpin any decentralized application or infrastructure. Two examples of such applications which we describe here are a DeFi prime brokerage, in which restaked Bitcoin acts as collateral to unlock faster settlement for liquidity-requiring operations across crypto ecosystems, and a Bitcoin-backed insurance protocol, in which restaked Bitcoin can be slashed to payout insurance claims and accrues yield from insurance premiums.

[2] Consensus layer maintainers are participants who stake their assets to participate in Proof of Stake (PoS).

Contributions

BTC as the Security Asset. The main contribution of SatLayer is utilizing Bitcoin as its foundational crypto-economic security asset. Contrary to most restaking protocols that depend on Ethereum, SatLayer enables Bitcoin holders to actively participate in the maintenance and security of decentralized applications, while also generating yields and further reinforcing the network's trust model. Through Bitcoin Validated Services (BVSs), SatLayer strengthens decentralized applications' security by anchoring validations in Bitcoin's established stability and security. This approach effectively reduces reliance on both centralized trust assumptions and cryptocurrency assets with less capital depth than Bitcoin.

Cross-Chain Compatibility. SatLayer integrates seamlessly with multiple blockchain ecosystems, including Ethereum Virtual Machine (EVM), Cosmos, MoveVM, and Solana Virtual Machine (SVM). Therefore, it reduces the architectural complexity of migrating to its system and enhances user and developer experience across different blockchain ecosystems. In practice, SatLayer's design is centered on Babylon, where its main contracts are deployed, while also having "client" smart contracts deployed on external blockchains. These clients communicate with the core (Babylon) contracts via reliable communication protocols, which ensure dependable cross-chain interactions, secure data transfer, and low latency.

Note: Cross-chain compatibility is a feature that will be implemented in subsequent versions of SatLayer. In the first version, all assets and logic will be hosted and implemented on Babylon Genesis in CosmWasm.

2 The SatLayer Framework

SatLayer expands Bitcoin's value proposition by connecting its native crypto-economic guarantees to the security of external decentralized applications. In this section we outline the different components that form SatLayer's ecosystem and infrastructure.

2.1 Participant Roles

The SatLayer ecosystem involves three key participant roles: (i) BVS developers; (ii) Bitcoin restakers; (iii) node operators. Naturally, a party may act in one or more of these roles at the same time.

BVS developers

BVS developers create the decentralized services that are secured via SatLayer's Bitcoin restaking functionality. These services are essentially a combination of off-chain node software and smart contract-based Dapps (decentralized applications) that are deployed on top of a blockchain supported by SatLayer.[3] Consequently, BVS developers can launch their applications or infrastructure on a

[3]SatLayer's first version will support Babylon Genesis, whereas subsequent versions will support additional blockchains including EVM Blockchains, Sui, Solana, etc.

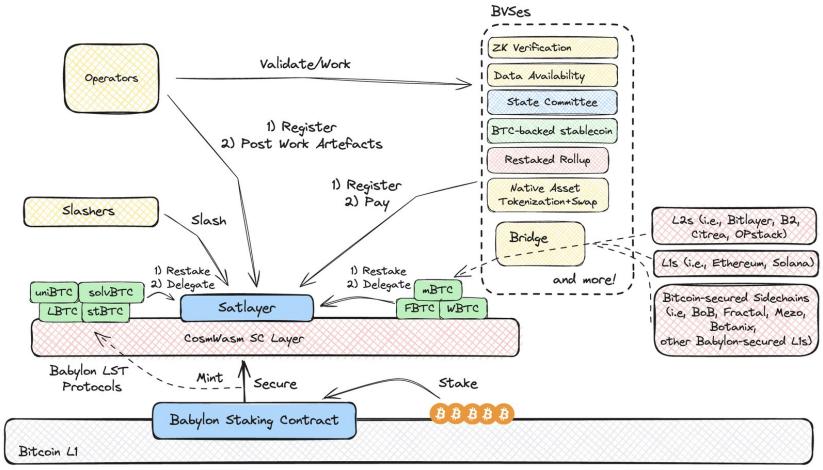

Figure 1: Diagram of the different roles in SatLayer's V1 ecosystem. SatLayer itself inherits the security guarantees of Bitcoin through Babylon Genesis, and provides a platform for tokenized BTC to be restaked and used to secure arbitrary sets of off-chain services called Bitcoin Validated Services (BVSs). Operators validate these BVSs and receive rewards for their work and can be punished via slashing if they misbehave.

blockchain that suits their functionality and performance needs and enhances their security with Bitcoin staking via SatLayer.

Bitcoin Restakers

Bitcoin restakers are parties that own bitcoins, or Bitcoin-pegged assets (e.g., wrapped Bitcoin or Bitcoin liquid staking tokens), and want to use them as restaking collateral in SatLayer. Restakers participate by depositing their tokens into SatLayer's smart contracts. Information about restaked collateral assets and balances across all chains is relayed to the Babylon-based core contracts which coordinate the protocol's operation. In practice, this data transfer is done by bridging the deposit information from the (chain that hosts the) client contract to the core contracts. The system enables the Bitcoin restakers to delegate their stake to operators (see below). These restakers are incentivized by receiving rewards in exchange for the usage of their tokens in securing BVSs. However, they also undertake the risk of operating correctly, since misbehavior in a provable manner can lead to their tokens getting slashed by the SatLayer protocol. For this reason, it is crucial to delegate the stake to a trustworthy and reliable operator.

Node Operators

Node operators participate in the maintenance of BVSs, manage off-chain computations, ensure security, and fulfill operational responsibilities. In essence, node operators are responsible for executing the off-chain logic of BVSs, maintaining their on-chain state, and ensuring the correct execution of the BVS,

including submitting proofs of misbehavior that enforce slashing of deviating operators or other slashing conditions (e.g., programmatic payouts). Operators can have stake delegated to them by Bitcoin restakers, which represents their weight in the system as well as their trustworthiness. Operators with more stake may weigh heavier when it comes to decision-making, e.g., if a BVS requires a majority of its operators to agree on a certain operation. An operator with more stake also may stand to lose more in case of misbehavior that leads to slashing. Therefore, Bitcoin restakers may opt to delegate their stake to operators that also contribute high amounts of stake on their own, i.e., have more "skin in the game".

2.2 Architecture

SatLayer employs a modular architecture in order to separate restaking, slashing, reward distribution, and BVS-specific logic. Briefly, SatLayer's core logic is implemented in WebAssembly (WASM)-based smart contracts on Babylon Genesis. This enables bitcoins which are staked to secure Babylon Genesis to be restaked as Liquid Staked Tokens (LSTs) in SatLayer. SatLayer's specialized smart contracts on external blockchains act as clients, enabling cross-chain data transfers. Finally, SatLayer operators run nodes, in order to manage data processing, event listening, and on-chain state of BVSs.

In more detail, SatLayer's infrastructure comprises the following components.

Smart Contracts

SatLayer's contracts consist of the core contracts, deployed on Babylon Genesis, and "client" contracts deployed on external blockchains.

The core contracts are implemented in Cosmos WebAssembly (CosmWasm) and coordinate the interactions between BVS applications, node operators, and restakers. In essence, the primary role of these contracts is managing the staking and slashing of the bitcoins that support the system.

The client contracts are deployed on blockchains like Ethereum, Sui, etc. These specialized contracts handle the deposits of Bitcoin-pegged assets in SatLayer and the interactions with BVSs deployed on these blockchains. For example, a party that has Bitcoin-pegged assets on Ethereum, such as wrapped BTC, can deposit their assets on the SatLayer client contract that is deployed on Ethereum. Data regarding these deposits is relayed to SatLayer's core contracts, which are deployed on Babylon Genesis, so that the party can delegate their restaked collateral to operators. If the operator that manages this stake misbehaves in a provable manner, then the assets, which are staked on the Ethereum client contract, are slashed. Otherwise, the party can withdraw these assets after a period of time, alongside possible rewards that they have accrued over time.

Bitcoin Validated Service (BVS)

The introduction of Bitcoin Validated Services (BVSs) is the major contribution of SatLayer. A BVS is a decentralized service that is *accountably* secured by Bitcoin stake. In essence, the cryptoeconomic security of a BVS is supported by

the value of Bitcoin and increases as more Bitcoin participates in the BVS's operation. BVSs are deployed by developers either on Babylon Genesis or external blockchains which are supported by SatLayer's client contracts. A BVS defines the application logic of the service, including, crucially, specific slashing conditions. These conditions describe which deviations by the service's operators should be penalized.

For example, consider a BVS that implements a data oracle which is deployed on Babylon Genesis and provides information about Ethereum-based events. This BVS is maintained by a set of SatLayer operators, who are responsible for providing smart contract data (i.e., price feeds) to interested parties. If an operator misbehaves, e.g., by providing incorrect data , then they should be penalized for this deviation. In our example, the BVS should define how this misbehavior can be identified and when the penalization, that is the slashing of the bad operator's stake, is enforced. For instance, the BVS could require operators or service managers to regularly submit proofs of data existence (or non-existence). In this case, these proofs would need to be resolved on Babylon Genesis (i.e., via an Ethereum light client) and subsequently used to initiate slashing events or distribute rewards to operators. Alternatively, the BVS could require that a majority of its operators support the event's submission or, contrarily, its dispute; in that case, rewards and penalization can be enforced as long as this majority of operators is honest.

Operators

The final element of SatLayer concerns the operators. Operators run specialized software for each BVS they validate that monitors on-chain and off-chain events and executes necessary computations for BVS functioning. In essence, the correctness of the operator computation is backed by the restaked Bitcoin delegated to those operators. Importantly, these components may interact with multiple different blockchains, e.g., to monitor events in one and submit data to another.

Following the above oracle BVS example, an operator would need to connect to both Ethereum and Babylon Genesis. Specifically, the operator needs to listen for the Ethereum events corresponding to the data the oracle provides. After listening to such an event, the operator should submit it to the (Babylon Genesis-based) BVS contract. Consequently, the operator needs to operate (or connect to) an Ethereum full node, in order to observe the chain and collect the events, as well as operate a Babylon client, in order to submit new events. Additionally, the operator may need to transform the event in a manner compliant with the BVS's requirements. All of these operations, from the event collection to its processing and then its submission, are conducted off-chain.

2.3 Operational Workflow

SatLayer defines clear and structured workflows involving all ecosystem components and participants. Following, we present the workflows of the following core SatLayer operations: (i) vault creation and registration (ii) BVS maintenance and execution (iii) BVS rewards and slashing

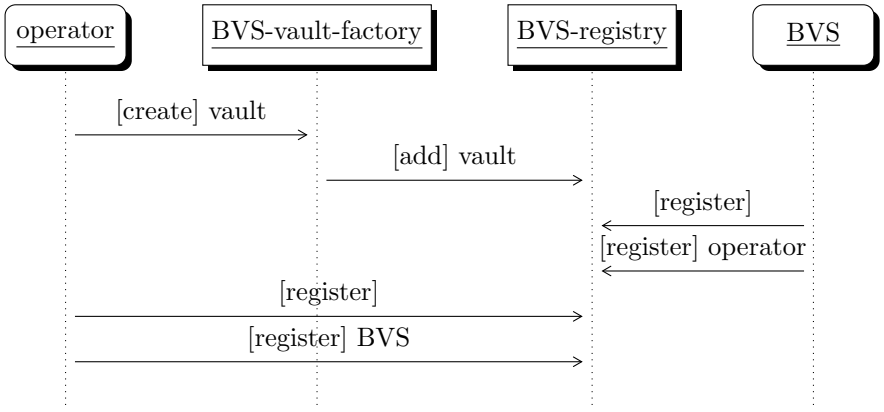

Figure 2: Workflow of initializing an operator and registering an operator to validate a Bitcoin Validated Service (BVS).

Vault Creation and Registration

Bitcoin restaking via SatLayer is comprised of the following main stages (cf. Figure 2).

Interested node operators must first deploy a vault via the BVS-vault-factory[4] and register in the BVS-registry[5]. The address which the operator used to deploy the vault is registered in the BVS-registry. The vault itself enables Bitcoin holders to deposit Bitcoin collateral, effectively restaking it and delegating it to the owning operator. The BVS registry is responsible for maintaining the records of operators and BVSs and which ones are connected to each other.

BVSs which want to make use of Bitcoin security must also register their on-chain footprint on the BVS-registry. In essence, a BVS registers an EOA address that it controls in the bvs-registry, then registers the operator they wish to work with. The operator then opts into the BVS in the registry, creating bilateral opt-in. Both the operator and the BVS can choose to terminate the relationship at any time[6]. The on-chain interactions of the BVS represents a supported token (e.g., Bitcoin, native Babylon or other supported tokens) used to validate one or more BVSs. Note that if the tokens are BTC-pegged assets on non-Babylon Genesis chains, then these assets are controlled by the Babylon-hosted SatLayer core contracts via secure bridging protocols.

Every BVS-vault's stake is delegated to the operator which owns that vault. Bitcoin holders wishing to generate yield from bitcoin restaking simply have to deposit to the vault of their chosen operatorIn effect, users delegate their strategy shares to registered operators and receive rewards, corresponding to their delegate's performance, or get slashed if the delegate misbehaves.

At this point, the operator can choose how to distribute their stake (both own and delegated) among running Bitcoin Validated Services (BVSs). We will describe in more detail the registration and execution of BVSs in the following paragraphs.

[4] `https://github.com/satlayer/satlayer-bvs/tree/main/crates/bvs-vault-factory`
[5] `https://github.com/satlayer/satlayer-bvs/tree/main/crates/bvs-registry`
[6] But the unbonding time must be large enough to prevent economic attacks

Finally, when a party no longer wants to participate in staking, they withdraw their deposited assets, along with any rewards that they accrued from their participation in SatLayer. This is done by calling the relevant withdrawal operations of the BVS-vault contract.

Finally, bitcoin holders who wish to generate yield on their BTC can deposit it in the SatLayer vaults.

BVS Execution and Maintenance

A major requirement for SatLayer's ecosystem success is a thriving and diversified set of Bitcoin Validated Services (BVSs). The services are deployed as a combination of off- and on-chain components on any of the chains supported by SatLayer; for the purposes of this description, we assume that it is deployed on Babylon (cf. Figure 3).

Once an operator and a BVS have mutually opted in, a feedback loop emerges where each member of the system performs specific tasks in order to keep the BVS functioning properly. The distinction between this and other crypto-economic systems is that the operator is guaranteed to behave honestly due to the Bitcoin that has been restaked it.

The main task of node operators is executing the off-chain logic of a BVS, submitting the results of the relevant tasks, and validating the correctness of other operations. BVS developers are free to define the output of their tasks as they deem fit.

The execution of the BVS's logic is done via tasks, which are submitted by the BVS's clients. Each operator of the service monitors the BVS for newly submitted tasks. When a new task is submitted, as a function call to the BVS contract, the operator collects the task's parameters and performs the necessary computations. The results of these computations are collected by the aggregator (off-chain) module, which publishes them on the BVS contract. Some BVSs may have the operators directly submit results and forgo the aggregator module.

Finally, the BVS is responsible for defining the validation of the submitted results, based on well-defined correctness criteria. For example, it might require a submission of a non-interactive short proof of execution correctness (e.g., SNARK). Alternatively, it could require all operators to input the same result and, in case of dispute, perform a bisection game between the two disagreeing operators to identify which of them misbehaved and in which exact step of the operation.[7] In the most straightforward case, the BVS can assume that a majority of its operators (e.g., weighted by stake) is honest and accept the result that the majority agrees upon. Naturally, each of these alternatives comes with different correctness assumptions and guarantees, so both the BVS developers and operators should carefully explore which approach is the best for each service.

[7] Running a bisection game assumes that the task's operations can be expressed as an ordered list of deterministic sub-tasks, each of which can be easily verified by the contract. In this case, each operator can submit the intermediate states (after performing each sub-task) in a Merkle tree and, in case of disagreement, the two parties find the first leaf (that is sub-task) of difference and validate which of the two is correct.

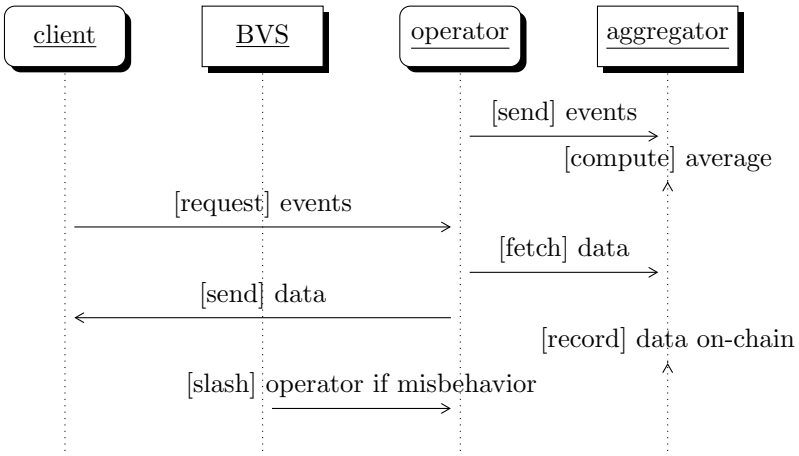

Figure 3: Example workflow of a BVS that implements an EVM oracle, where the user requests the events emitted by a given EVM smart contract. The operator fetches the events from an aggregator node as well as providing its latest measurements. The aggregate data is returned to the user, and the individual measurements are stored so that operators can be slashed if they misbehave.

Rewards and Slashing

Users that participate in the SatLayer protocol, either directly as node operators or by delegating their bitcoins, earn restaking rewards. The calculation and distribution of these rewards is the responsibility of the BVS and proceeds as follows (Figure 4).

After the completion of one or more operations, the BVS's manager computes the amount of rewards that should be given to each participating node operator. The rewards are formatted as a Merkle tree, which encodes how many tokens each address should receive. Following, the BVS's manager submits the Merkle tree's root to the BVS-rewards contract, along with the total amount of rewards that will be distributed.

Eventually, each node operator can claim their rewards by calling the BVS-rewards contract. Specifically, they submit a Merkle inclusion proof for their address and amount of rewards that need to be claimed. The contract validates the proof with respect to the submitted Merkle tree's root and then sends the claimed rewards to the operator.

Note: The BVS itself is trusted to disperse rewards correctly. In particular, it is trusted to compute each operator's and stakers' rewards, construct the Merkle tree, and submit its root on-chain.

Finally, SatLayer enables accountability of operators in the form of *slashing*. In particular, when an operator misbehaves, they may be penalized by forfeiting part or all of their assets, as follows. However, BVSs can define their slashing conditions programmatically, and may slash operators for conditions other than misbehavior.

To enable slashing for their application, a BVS must first call "enable-slashing" on the bvs-registry contract with the desired slashing parameters. The

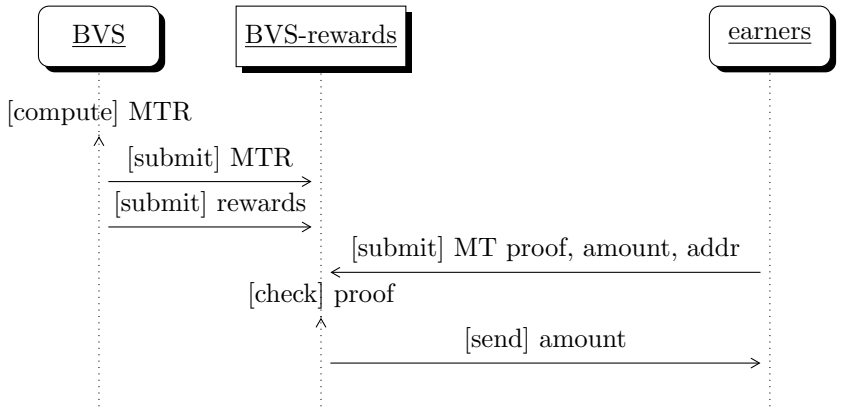

Figure 4: Workflow of rewarding earners (node operators and restakers).

operator must also opt into the slashing by calling "operator-opt-in-to-slashing".

A request for slashing is initiated by the slash initiator, which is the same entity as the BVS. The on-chain system used to initiate the slash can be as simple as an Externally Owned Account (EOA) or could be a smart contract system. The slasher sends a request slashing message to the bvs-router using the address that they registered their service with. After the request slash is sent, the operator has a grace period to submit a "cancel-slash" request. The slash initiator can choose to cancel the slash if the operator has addressed the issue (in a way defined by the service). If the operator fails to respond or responds unsatisfactorily, their funds will then be moved to a locked state. The slashed funds are then routed appropriately in a final step to those who are entitled to them.

3 Incentives

Designing a reward mechanism that aligns user and developer incentives with the intended functionality is crucial for the secure operation of the protocol. In this section we outline SatLayer's fee and reward mechanism and how rational participants are incentivized to act honestly.

3.1 Reward Program

The first option for getting rewarded is SatLayer's reward program.[8] Briefly, the program's goal is to attract Bitcoin liquidity to the system during its early stages. For this reason, early users that restake their bitcoins on SatLayer earn rewards in the form of SatLayer's Sats^2.[9]

[8] `https://docs.satlayer.xyz/partners/satlayer-rewards-for-partners`

[9] The SatLayer Sats^2 rewards program will run prior to the launch of the full protocol. More information about the program can be found at `https://docs.satlayer.xyz/restakers/sats-staker-rewards`.

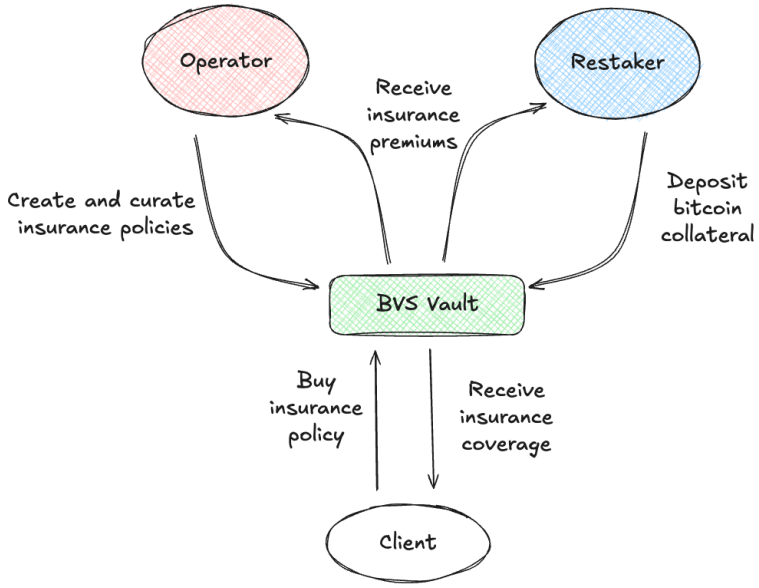

Figure 5: Example workflow of a BVS that implements an insurance protocol. Clients buy insurance from the BVS and pay a premium which is split between the operator and the vault depositors (restakers). The operator is responsible for curating a set of policies that their vault supports.

3.2 BVS Fees and Operator rewards

Deploying a BVS and using it incurs certain fees, which are awarded to the maintainers of the BVS. Each BVS defines its own reward conditions and methods for calculating distribution amounts, as well as how these rewards are distributed, e.g., in the form of the BVS's native tokens or other such assets. This freedom leads to a market for attracting BVS operators, since these participants are expected to opt for validating BVSs with a lower cost-to-reward ratio.

Example 1: Insurance Protocol Here, we describe an example of a BVS that implements a general-purpose decentralized insurance protocol. Such protocols typically take in deposits of collateral which are managed by the protocol itself or curators that underwrite insurance processes against this collateral. Insurance buyers buy policies from the protocol against this collateral and pay a premium in return. When a claim occurs, the protocol either settles the claim programmatically or manually, and pays out the claim to the insured party if valid.[10]

The key advantage of designing an insurance protocol as a SatLayer BVS is that the protocol is able to make use of restaked bitcoin as collateral, massively increasing the potential coverage capacity. In such a BVS, the operators would act as the initiators, curaters, and underwriters of various insurance policies

[10]For example, the decentralized insurance protocol Nexus Mutual has their native token (NXM) stakers vote on whether or not a claim is valid(`https://docs.nexusmutual.io/developers/Diagrams/Contracts%20Diagrams/claims-assessment`)

(e.g., liquidation protection or slashing insurance). Operators determine the parameters of each policy they curate, such as the insurance premium, the coverage capacity, and the conditions for claims verification. Claims settlement conditions can be specified per-policy to be either programmatic, in which claims are verified automatically, or vote-based, in which a pre-selected committee votes on the validity of claims. In the case of a successful claim, the operator's vault is slashed for the coverage amount which is then used to pay out the claimant.

The insurance premiums paid by the buyers are split between the operator and the vault depositors. Restakers can choose to deposit their bitcoins into an operator's vault to earn yield on their bitcoins in the form of premiums paid by the buyers of all policies which are underwritten by the vault. Correspondingly, bitcoin deposited into the vault increases the coverage capacity of the insurance policies it offers. Thus, BVS operators are incentivized to create and curate policies for their vaults which minimize the risk of claims payout and maximize the insurance premiums paid by buyers. These interactions are summarized in Figure 5.

Example 2: Bitcoin-backed prime brokerage Another example of key BVS use case is a Bitcoin-backed prime brokerage. In traditional finance, prime brokerages are financial institutions that provide a range of services to their clients, including trade execution, lending, and asset custody.[11] These services are paralleled in Web3, where institutions and high net worth individuals have need of prime brokerage facilities for hedging and fast settlement of trades and liquidity-requiring activities such as bridging assets between blockchains.

SatLayer unlocks full programmability for bitcoin collateral, enabling its deep liquidity to service the prime broker needs of the crypto ecosystem. In a BVS implementing a prime brokerage, the operators would act as the prime brokers, executing client requests in return for a fee against the bitcoin collateral deposited to their vaults. These fees would be split between the operator and the vault depositors. Each operator would define the set of prime broker services they offer, as well as the conditions for executing these services (e.g., minimum trade size).

Slashing could occur for multiple reasons - if an operator does not fulfill a client's request according to predefined settlement conditions, vault assets could be slashed as punishment. Additionally, if an operator takes on risk that is not fully offset once a transaction is settled, then then vault assets would be slashed to cover the shortfall.

3.3 Handling of Slashed Assets

As seen in the above examples, the handling of slashed assets can vary depending on the BVS use case and is a key component of sound BVS design.

The first concern in terms of slashing is the level of slashed assets. Specifically, the protocol defines whether slashing of a misbehaving party is *partial*, where only part of their assets are forfeited, or full, where all assets of the party are confiscated. Since slashing is the primary mechanism for disincentivizing misbehavior, the choice between partial and full slashing, e.g., in the case of particularly serious offenses, should be carefully designed and implemented.

[11] `https://www.investopedia.com/terms/p/primebrokerage.asp`

The second question revolves around the handling of slashed assets. There are typically two options in this case. First, the slashed assets may be pooled, redistributed, or reused in ways that are beneficial for the protocol, e.g., via a robust governance protocol. Alternatively, the slashed assets may be burnt. The choice between the two options offers a tradeoff between enhanced functionality and opportunities (when repurposing) or implementation simplicity and avoiding side-effects (when burning), so the mechanism should be carefully designed and implemented.

4 Interoperability

In this section we outline SatLayer's interoperability characteristics.

4.1 Multi-Chain Connectivity

SatLayer aims to enable Bitcoin staking across diverse blockchain ecosystems. This is enabled via the bridging of Bitcoin assets from various chains to Babylon, followed by restaking them on SatLayer. Such cross-chain connectivity is implemented through robust communication protocols ensuring synchronization between Babylon and external chains and promotes state consistency.

SatLayer's deployment on Babylon Genesis acts as the control plane upon which activity from external chains (i.e., staking, slashing, BVS registration, etc.) is synchronized.

4.2 Application-Level Integration

Currently, various chains support different programming languages, execution environments, virtual machines, and accounting paradigms (e.g., UTxO vs accounts). Consequently, a service which is developed under one chain's framework may need to be migrated, or even completely redesigned, in order to be redeployed to a different chain. This increases friction for projects, leading to "siloed" settings where applications cannot leave a particular ecosystem without incurring a massive overhead for the developers.

SatLayer aims to alleviate such a transition from alternative "Application Validated Services (AVSs)" by building an interoperability layer that allows restakers and BVS developers to deposit capital and deploy their on-chain applications on any SatLayer-supported chain.

In essence, SatLayer will support an interoperability stack which enables data transfers between Babylon and external chains. This functionality allows developers to build and deploy their applications on any SatLayer-supported chain that they think best fits their application's requirements, while SatLayer handles the underlying communication and coordination of these applications from its Babylon-hosted core. This has two main benefits for developers. First, they are not forced to migrate or rewrite existing applications to a new environment. For example, a BVS written in Solidity can be deployed on Ethereum and be secured by SatLayer via its interoperability stack, instead of having to be rewritten in WASM. Second, they can choose which supported chain fits the needs of their application best. For example, a BVS that relies on Ethereum's RANDAO as a source of randomness could be deployed on Ethereum, which

supports native access to RANDAO values, instead of being deployed to a different chain and requiring transfers of the relevant RANDAO values to that chain.

5 Security and Economic Outline

SatLayer's core proposition is based on utilizing Bitcoin as a crypto-economic security asset. In this section we outline the security properties that SatLayer aims to guarantee, the assumptions that may be needed to achieve this, the points that need to be carefully considered, as well as relevant notions from the literature. Note that the formal definition of these properties and rigorous analysis of SatLayer is outside the scope of this paper.

5.1 Execution Properties

Correctness

A core property that SatLayer should guarantee is the execution correctness of the BVSs supported by the restaking process. Essentially, SatLayer should guarantee that, under a realistic set of honesty and/or rationality assumptions, a BVS which is supported by SatLayer operators outputs the correct value during its execution. For example, these assumptions could include an honest majority (in a Byzantine analysis) assumption or that all participants are rational (in a game theoretic analysis).

Correctness is not restricted to the BVSs, but also applies to the SatLayer protocol itself. For example, the protocol should ensure that its main functionalities, such as registration and removal of operators, stake registration and delegation, reward distribution, and slashing enforcement, should be correctly executed.

Availability

The second major property that SatLayer should guarantee is that the supported BVSs progress over time. In essence, SatLayer's mechanism should ensure that, under a set of assumptions as above, a BVS does not stall, observe outage, or halt altogether.

As with correctness, availability should also be guaranteed for the SatLayer protocol itself, in addition to the BVSs that it supports. Specifically, SatLayer should ensure that operators and stakers can freely join or leave the system, as well as operations such as stake delegation, reward withdrawal, or recording of slashing cannot be censored.

Latency, Throughput, and Necessary Delays

The analysis of SatLayer should not only focus on security but also performance. For instance, it should outline how quickly operators and stakers can join or leave the system (latency), as well as how many BVSs can be (reasonably) secured in parallel with any given set of stakers (throughput). In addition, the analysis should outline how the composition of SatLayer with other systems introduces delays that are necessary for its correct operation. For example, if

a BVS requires the bridging of data across chains, then the analysis should outline how SatLayer's latency is affected due to the need for completion of such operations. Additionally, the protocol should account for the latency of the Bitcoin blockchain, e.g., when it comes to enforcing penalties for misbehaving validators. For example, if a validator is slashed and needs to be removed from SatLayer, the performance of the system may be affected, e.g., the operation of BVSs in which the misbehaving participation operates may be delayed until the slashing is finalized on Bitcoin.

5.2 Economic Analysis

The above properties concern the execution guarantees of SatLayer. Since SatLayer's design is crypto-economic in nature, where security argumentation mostly revolves around Bitcoin's capital offerings, we now focus on the game theoretic and crypto-economic aspects of the mechanism.

Incentive Compatibility

The main focus of a game theoretic analysis should be to show that the system, which includes the protocol and the incentives' structure, is incentive compatible. In essence, the analysis would assume that all participants (cf. Section 2.1) are rational, that is they aim to maximize their utility. Typically, a party's utility is the amount of rewards that they gain from participation, possibly minus the cost of executing the protocol and/or including potential external gain from deviating from the protocol (e.g., bribes or double spending). Following, the goal is to show that, under this rationality assumption, all participants are incentivized to follow the protocol. Results of such analysis include a Nash equilibrium, where every individual party follows the protocol as long as everybody else does so, or strategy dominance, where a party follows the protocol regardless of what others do.

Note that incentive compatibility relates both to SatLayer and the BVSs themselves. In particular, if SatLayer is incentive compatible then rational operators will follow the protocol when registering a BVS, restaking, and performing protocol-related tasks like submitting slashing requests. Similarly, if a BVS is incentive compatible then rational operators will execute the tasks correctly and timely.

Operator collusion

The game theoretic analysis described above often considers parties as individuals, with each trying to maximize their own utility. However, in some cases it is reasonable to assume that parties may collude. In this case, parties form coalitions and coordinate their actions, e.g., in order to increase the coalition's aggregate utility (compared to operating on an individual basis). A goal in this case could be to show that the protocol is resilient, i.e., it is an equilibrium or dominant strategy, even in the presence of such coalitions.

Collusion principally concerns both the SatLayer and the BVS's operation. For example, if slashing is enforced via social consensus, then colluding operators may vote against a valid slashing request to avoid penalization, which should otherwise be guaranteed by SatLayer. Similarly, if some operators collude with

the BVS manager, then the latter may miscompute the reward allocation in their favor.

Accountability

A major component of the game theoretic analysis of SatLayer will be exploring its accountability guarantees. Briefly, accountability encompasses how faults are attributable and the ways in which parties are penalized for misbehaving. Accountability has been widely explored in the literature, e.g., [NTT21], so here we will outline some aspects of it and leave a thorough investigation of it for future work.

A first consideration when it comes to accountability are the limits to enforcing it in a non-interactive manner. Briefly, if a non-interactive proof of misbehavior can be created, w.r.t. to a well-defined set of rules, then accountability can be enforced deterministically at the protocol level, e.g., on the ledger itself. However, faults are not always objectively attributable.[12]

When a non-interactive proof of misbehavior cannot be created, the system needs to rely on the participation, and possibly honesty, of other parties. For example, the parties may vote on whether a misbehavior occurred and, assuming an honest (super)majority, penalize the misbehaving party without needing to produce a mathematical proof. However, an additional consideration here, beyond the need for honesty assumptions, is that faults cannot always be objectively attributed to a single party, even if the supermajority of participants is honest. For example, a fault may occur in a way that either of two parties is at fault, without being able to pinpoint which of the two.

Furthermore, a second point of discussion concerns unintentional slashing. For example, software bugs, network outages, or other unforeseen elements may hinder a (otherwise honest) party from participating in the protocol. The accountability mechanism should take into account such unintentional faults and refrain from severely penalizing parties for them, albeit still disincentivizing lack of participation.

In summary, a game theoretic analysis of the SatLayer ecosystem should explore such considerations and outline the limits of accountability in practice. Note that although SatLayer is responsible for offering the platform on which accountability is enforced, the slashing conditions and the mechanism for enforcing it are the responsibilities of the BVSs themselves. Therefore, the analysis would outline the limits of responsibility of the SatLayer protocol and the BVS and explore the interconnection between the two.

Security of Underlying Ledger

Since SatLayer's core contracts are deployed on Babylon Genesis, they inherit its security and economic guarantees. Essentially, SatLayer depends on the Babylon Genesis ledger to offer safety and liveness. If Babylon Genesis's security is compromised and one of these properties is violated, then SatLayer could also see operations censored (liveness hazard) or reversed (safety hazard). Although this is a fundamental concern, which stems from the fact that SatLayer is deployed on top of Babylon Genesis, it should be explored in terms of crypto-

[12] For example, see [Eig24, Section 1.2] for a discussion on fault categorization.

economic security. Specifically, the security of SatLayer should be analyzed as the minimum security guarantees of SatLayer itself and Babylon Genesis.

Validator Reuse and Crypto-economic Composition

Another broad area of analysis concerns the system's economic guarantees in the presence of other protocols with which it shares the validators. In the case of SatLayer this is an inherent feature, since it depends by design on the restaking of staked Bitcoin to secure multiple BVSs. However, economic composition of various systems via validator reuse can lead to exogenous shocks that, if not accounted for, could lead to breakdown of the protocol itself. Therefore, the analysis should outline the economic guarantees of the system w.r.t. its level of overcollateralization, such that if a number of operators suddenly become unavailable (e.g., due to being slashed in a different protocol in which they also participate), then the system can continue functioning properly. Such questions have been explored in the literature, e.g., [DR25], so they need to be tailored for SatLayer's needs and particularities.

Note that crypto-economic composition is a concern for both SatLayer and the BVSs. In essence, both SatLayer and the BVSs rely on reuse of external assets, namely Bitcoin, for their crypto-economic guarantees. Therefore, if an exogenous shock occurs, e.g., due to the slashing of Bitcoin stakers in other protocols, its effects could manifest on SatLayer. Similarly, if operators participate in the validation of multiple BVSs, slashing events on one BVS could affect the security of others.

6 Related Work

The concept of restaking has gained significant traction in recent years. Various industry projects explored different options and functionalities of restaking on different platforms, while the academic literature is analyzing the security and crypto-economic properties of such protocols. In this section we provide a brief, non-exhaustive but rather representative, list of such existing work.

Industry Projects

Using Bitcoin as the resource of a Proof-of-Stake (PoS) protocol has been explored and implemented in various systems. Babylon[13] is such a system, which uses Bitcoin as its staking asset, notably in an *accountable* manner, such that if a Babylon validator misbehaves then their bitcoins are slashed (on the Bitcoin blockchain) [TTG+23, Tea23]. BounceBit[14] uses a combination of its native token and Bitcoin, albeit the bitcoins are used indirectly since they need to be bridged (and wrapped) before being used on BounceBit. The functionality of these systems is orthogonal to SatLayer, since SatLayer can be deployed on any such protocol and inherit both its security guarantees and its supported staked assets.

EigenLayer[15] is a system that pioneered the notion of restaking on Ethereum. EigenLayer allows designers of smart contracts called Autonomous Verifiable

[13] `https://babylonlabs.io`
[14] `https://www.bouncebit.io`
[15] `https://www.eigenlayer.xyz`

Services (AVSs) to define specific correctness guarantees, such that if a (re)staker that maintains the AVS misbehaves then they face slashing of their staked assets, which can be native Ethereum, Liquid Staking Tokens (LSTs), the EIGEN token, or any ERC20 token. In effect, EigenLayer offers an analogous functionality to SatLayer, albeit limited to Ethereum (or Ethereum-based assets), whereas SatLayer focuses on Bitcoin instead.

Symbiotic[16] is a protocol that allows developers to build their own restaking implementation and operator set. In particular, Symbiotic allows anyone to create a set of validators and define collateral assets. In order to participate, stakers deposit collateral and receive asset-specific tokens, which can be used as the means of restaking and securing various applications. Notably, Symbiotic operates primarily on Ethereum, while also offering some support of Bitcoin via integration with bitcoin wrapping services. In comparison, SatLayer is primarily focused on using Bitcoin directly and, more importantly, trustlessly as its main collateral asset.

Academic Literature

Restaking has been explored to a large extent in the literature. Here we will provide only a brief overview of some important related topics, while we refer to [GVKT24] for a more in-depth exploration of the state of the art and the challenges of this line of research.

A core part of SatLayer is focused on slashing misbehaving parties. The necessity and usefulness of slashing has been widely explored in the literature. STAKESURE [DRK24] analyzes the crypto-economic safety of Proof-of-Stake (PoS) systems by comparing the profit and the cost of corrupting enough validators to launch an attack. Interestingly, it discusses how slashed funds can be allocated as insurance, such that they are used to compensate victims of attacks. In the same line of work, [BLR24] shows that slashing is not sufficient to guarantee crypto-economic security if message delays are not bounded, but can be used as a building block of a secure protocol in a synchronous network where honest parties are always active. These results demonstrate the necessity of both using and carefully designing the slashing mechanism, such that node operators are disincentivized to attack the system and slashed funds are used to further enhance its security.

The economics of restaking are explored further in [DR25]. This work explores the effects of composing restaking protocols with Layer 1 systems and the risks of reusing validators across multiple such protocols. In particular, it identifies the risks that arise for a protocol under stake shocks, when part of its validators population gets slashed due to attacks on external systems with which the protocol shares validators. To this end, the paper quantifies the level of overcollateralization needed, that is the excess between the cost and profits from an attack, such that a protocol can withstand sudden losses of (restaking) validators. The results of this work are orthogonal to the design of a restaking system like SatLayer, but nonetheless offer useful insights on the limits of its security and the risks that it may inherit, or introduce, to the protocols with which it shares validators.

[16] `https://symbiotic.fi`

7 Conclusion

This paper introduces SatLayer, a restaking protocol that forms the new economic layer for Bitcoin. SatLayer makes Bitcoin fully programmable, boosting its liquidity efficiency by enabling it to secure decentralized applications (Dapps) and infrastructure. In essence, SatLayer transforms Bitcoin into a yield-bearing asset and simultaneously unlocks its potential to elevate the trust, flexibility, and scalability of decentralized blockchain ecosystems.

SatLayer's core functionality is hosted on Babylon Genesis, a blockchain with accountable Bitcoin staking capabilities. In turn, SatLayer inherits Babylon's underlying security guarantees and enables users who stake their bitcoins, either directly on Babylon Genesis or in BTC-pegged tokens hosted on external blockchains, to restake their assets in order to maintain Bitcoin Validated Services (BVSs).

SatLayer also defines reward and slashing mechanisms. In the reward scheme, fees paid by the BVS developers and users are awarded to the BVS maintainers in order to incentivize correct and honest participation. For slashing, BVSes can specify programmatic conditions under which their operators can be slashed, either for misbehavior or for other reasons (e.g., , insurance payouts).

To illustrate the potential of SatLayer, we describe two planned flagship BVSs, an on-chain Bitcoin-backed prime brokerage and a Bitcoin-backed insurance protocol. For the former, SatLayer enables fast settlement of liquidity-demanding operations such as arbitrage and bridging across various crypto ecosystems. SatLayer restaked Bitcoin absorbs the duration risk of these operations in return for a fee. For the latter, SatLayer restaked Bitcoin is used as collateral for insurance policies such as slashing insurance or liquidation protection, and accrues yield from insurance premiums.

Finally, SatLayer enables interoperability in multiple ways. First, it allows the deployment of a BVS in any of the supported blockchains and uses a secure data transfer mechanism to coordinate these BVSs via the (Babylon Genesis-hosted) core contracts. Second, it enables the participation of holders of Bitcoin-pegged assets which live on supported blockchains, e.g., wrapped Bitcoins or alternative DeFi liquid Bitcoin-pegged tokens.

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