Theta Mainnet 4.0

Introducing Theta Metachain to Power Web3 Businesses

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The Vision for Web3 Businesses

Web3 promises to be a revolutionary technology and a decentralized approach to next-generation application development. However, the vision for Web3 businesses is far broader than just a set of tools and technologies. Just like the advent of the Internet in the late 1990s revolutionized how people around the world communicate and interact with each other, new online models emerged at that time that completely displaced existing businesses. Case in point, Blockbuster at its peak in 2004 employed over 80,000 people with nearly 10,000 physical

stores as the largest home movie and video rental service. A small outfit, Netflix, began experimenting with mail-order service in the early 2000s and by 2007 introduced one of the first streaming media and video-on-demand services. Netflix eventually put Blockbuster out of business because it completely changed the business model and the economics of video rental services.

Web3 tools and technologies today are like the Internet in the early 2000s. They will enable a new category of media, entertainment and Metaverse businesses to emerge built on a new set of business economics and models that are community-first, decentralized and controlled by creators, IP holders and users themselves -- not the platform. Whereas existing Web2 businesses capture 80% of the value created by their platforms in the form of corporate profits, leaving only 10% to creators/IP holders and 10% to users, new Web3 businesses can thrive and scale by 10x and keep 20% of the value created to themselves. In the end, they're still 200% more successful and have the potential to completely displace today's Web2 businesses. This is the vision for Theta's upcoming Mainnet 4.0 - to enable Web3 businesses in media, entertainment and the metaverse to scale to 10x today's platforms.

Theta Network continues to be the leading next-generation video, media and entertainment blockchain since the launch of Mainnet 1.0 in 2019, backed by global enterprise validator partners including Google, Samsung, Sony, Creative Artists Agency (CAA), Binance, Blockchain Ventures, DHVC and gumi. Strategic corporate investors in Theta Labs include Samsung NEXT, Sony Innovation Fund, Bertelsmann Digital Media Investments (BDMI), CAA, and Silicon Valley VCs including DCM and Sierra Ventures.

Theta Mainnet 4.0 along with the Theta Metachain SDK is estimated to launch on Testnet on October 1, 2022 with a target general release on December 1, 2022.

Media and Entertainment Segments Ripe for Disruption

Below are some media and entertainment business segments that are ripe for disruption. Existing platforms must adapt and embrace Web3 models to survive or will be displaced by emerging Web3 equivalents.

1. **Video content platforms**

    a. **Subscription-based streaming businesses** (Netflix, Disney+, Hulu+) are beginning to stagnate with low user growth and increased churn rate. Saturation and alternatives have driven consumers to re-think charging $20/month on their credit cards. A Web3 equivalent would leverage Theta's video focused edge computing infrastructure and ThetaVideoAPI to lower the massive costs of video encoding, storage and delivery to multiple devices including mobile, web, smart TVs, set top boxes and more. Users are rewarded for watching and sharing their video with others in the network participating in Theta's P2P network. New and

unique business models could embrace NFTs and ThetaPass as a way for users to own their annual or lifetime subscription, and be able to resell them at any time.

b. **Free ad supported video services** (Youtube, Twitch, Tubi, PlutoTV) are becoming more popular and beginning to cannibalize subscription services as they drive more value to end-users. However, they are also struggling with lower user engagement, retention and the ease to switch to competing services. New Web3 equivalents can vastly decrease their costs to encode, store and distribute video through Theta's decentralized peer-to-peer model, and shift this value to users. Implementing community-based TNT-20 token governance models can give users a say in how best to extend their services and features. Users become vested in the long-term success of their business.

c. **Transactional, pay-per-view models** (Amazon Prime, other OTT services) are becoming more important given the new post-COVID world where some blockbuster movie openings, for example, are shifting to online only or theater-and-online simultaneous launch. Web3 business models present a whole set of opportunities where transactional customers can be converted to lifetime customers of the IP and brand. By watching, sharing and supporting the first in a movie franchise, all secured by Theta patented NFT-based Digital Rights Management (DRM), users can be airdropped commemorative NFTs which grant them offline benefits and engagement to the next movie in the series. Completing the entire franchise NFT collection could give them access to behind-the-scenes, meet and greets, and participation in future movies. More importantly, Web3 models can easily implement smart contracts on Theta's EVM-compatible blockchain offering transparency and immediate royalty payments to creators and IP holders. Traditionally this process has been opaque, reliant on the distribution platforms for accuracy and taking up to 180 days to receive payments.

2. **Ticketing and live events platforms** (Ticketmaster, LiveNation, Eventbrite) today are fraught with illegitimate secondary market sales, fraud and bot networks that purchase up to 60% of the tickets from primary sales leaving the end consumer paying many times the original ticket price. These businesses and their associated supply chains are ripe for disruption starting with replacing physical and digital tickets with Theta NFTs and ThetaPass that can be traced, tracked and transparently managed. Original IP holders can now be compensated for a portion of each secondary ticket sold, all tracked and seamlessly implemented via smart contracts on the Theta blockchain, and fraudulent middle-man are cut out.

3. **Movie studios and production houses** (Universal Pictures, Warner Bros, Paramount, Lionsgate) are quite traditional with little business change in the last few decades. Emerging studios and Indie filmmakers have experimented with innovative funding, production and post-production marketing models. However, Web3 initiatives could

unlock a whole new value chain where original IP and creators can reap much greater rewards than the traditional 10-15%. Starting with seed funding, fractional ownership Theta TNT-20 tokens can be sold at the early stages of a project to raise funds for production. Token owners can be entitled to a percentage of gross or net profits, similar to how movie stars can negotiate “first dollar gross” backend deals. Beyond this, leveraging ThetaPass as virtual tickets to online premieres powered by Theta P2P streaming and ThetaVideoApi.com platform enables viewers to earn more rewards that can be utilized for merchandising, products and other services.

4. **Local sports teams** (MLB, NBA, NFL, NHL) have traditionally relied on two main sources of revenues, namely ticket sales and broadcast rights. A next-gen Web3 business model for sports teams could incorporate team fan tokens where holders of these TNT-20 tokens can participate in the governance and vote on various stadium and team business decisions, including stadium improvements, logos and jerseys, ticket pricing, sponsorships and more. Fans can also stake or hold tokens to earn various VIP and membership benefits that grants them unique one-of-a-kind collectibles and merchandise. In addition to local television and cable broadcast, local teams can launch new Web3 streaming apps that leverage Theta P2P video infrastructure and enable fans to earn even more benefits by watching more games, which in turn increases sponsorship opportunities.

5. **Content and website hosting services** (Amazon, Google, GoDaddy, Squarespace) are mostly centralized platforms with content caching servers located at various major metropolitan geographic locations. A Web3 distributed content hosting service could be 3-5x more cost effective by leveraging Theta’s global edge network and EdgeStore capabilities. Content can be cached and delivered to end-users much closer than traditional hosting providers points-of-presence (POP), and be highly distributed and replicated across the network. This enables new pricing models that can accomodate for peak traffic and leverage under-utilized resources from major telecom operators and network providers.

6. **Emerging metaverse platforms** (Decentraland, Sandbox, Roblox) are already embracing Web3 and distributed ledger technologies. These virtual spaces open up a whole world of opportunities to transform today’s approach to online interaction, communication and collaboration. Most of these platforms could support open Web3 toolsets to enable anyone in the community to build and expand their virtual worlds, including Theta’s video and media API interfaces. The future of metaverse platforms will be largely driven by social interactions powered by video, audio and other rich media formats.

Web3 Business Models Drive New Economics

The Web3 business examples above can fundamentally disrupt today's media, entertainment and emerging metaverse industry. In order to be successful, these next-generation Web3 versions of Netflix, Youtube, Amazon, Google, Ticketmaster and Universal Pictures will need to embrace key design attributes to reinvent their business economics:

1. **Decentralized governance and key decision making** -- Web3 models should enable all stakeholders including the end-user community to have a say in the direction of the business, platform features and other key strategic decisions. This can be achieved by implementing new Theta TNT-20 governance tokens, for example, that can be staked and an interface to vote on protocol changes and off-chain/offline business decisions based on a fair, proportional token ownership model.

2. **Incentive model for end-users** -- in the new Web3 economy, end-users are not only consumers of the business service but also participate in the infrastructure to power the service. For example, in Theta's video-focused edge computing infrastructure, community members run edge nodes that provide ingest, transcoding, storage and delivery of the video data but these same users can also use the business service. When they watch video and other content, share their excess bandwidth leveraging Theta's peer-to-peer technology, they earn rewards and tokens. These token rewards can then provide ongoing utility and benefits to holders to drive long-term engagement for the business.

3. **Transparent, immediate value to IP holders/influencers** -- by implementing key royalty, revenue share and payment tracking on Theta's EVM-compatible blockchain and smart contracts, for example, Web3 businesses can drive immediate, auditable and unambiguous value to IP holders, content owners and influencers. Today's media businesses are opaque and rely on revenue and profit reporting by highly centralized distribution platforms. This raises confidence and trust issues and leads to royalty payments which are often delayed by 6 months or more.

4. **Decentralized infrastructure to power media, video and content delivery** -- the ThetaVideoAPI platform enables anyone from a small creator to large video platforms to implement video support into their website and apps without the need to invest or worry about cloud infrastructure, video encoding/transcoding software, data storage, content delivery networks, etc. Emerging Web3 businesses in media and entertainment can launch their services in a fraction of the time, and be able to scale their business without skyrocketing infrastructure costs. Theta's growing edge node network shifts the cost structure from the video platforms to benefit the operators of the edge nodes.

5. **Distributed technology that enables for 10x scaling** -- next-generation Web3 versions of Netflix, Youtube or Ticketmaster have the opportunity to scale today's user base by 10x by reinventing the business economics to benefit end-users and IP holders. In order to power these businesses with 10s-100s millions of users each requires a horizontally scalable, customizable blockchain to their business needs where each has effectively unlimited transactional throughput and sub-second block finalization time, without impacting one another's network. This gives rise to the concept of a "Metachain" and "subchains" forming a network of interconnected blockchains with predictable, isolated smart contract execution environment, not affected by other Dapps.

6. **Permissionless, extendable platform to developers and community** -- emerging Web3 models have the opportunity to open their platform to third-party developers and the community to build on and enhance, completely permissionless. This means anyone with a set of open source tools and APIs can participate in the development and add value to the platform. Theta's new Metachain and subchain design enables this permissionless approach to extending Web3 business models.

The Need for a Network of Interconnected "Subchains"

In short, next-generation Web3 platforms, Dapps, and large enterprises will want to retain control over the economic incentives, fees, and tokenomics of the blockchain they use, and not be restricted and limited to today's standard L1 chains. L1 chains act as a public utility/public good, which is great for governance and fairness purposes at the macro level, but in many ways they are much more difficult for an individual entity or enterprise to use. For example, many financial institutions have criticized that the available transaction capacity on Ethereum is being taken up by NFT-based games, and instead opt for private blockchains.

Each platform or Web3 business can have their own subchain that is highly customizable, and effectively have their own uncongested chain structured to their needs, but unlike a private blockchain it comes with the transparency, security, and credibility of a public blockchain. Similarly, media and entertainment companies can implement their own dedicated subchains with all the Web3 tools they require for video, compute and storage, and with capacity solely for their platform and users, rather than be forced to share with others and competitors. And with a native governance token tailored to their subchain, it allows access and governance to reside with the appropriate stakeholders in their ecosystem, not those of totally unrelated entities.

In this white paper and as a core focus of Theta Mainnet 4.0, we introduce the Theta Metachain - a network of interconnected subchains, a "chain of chains".

Technical/Design feature	User benefit
Subchain operator can scale with any number of subchains	Transaction throughput remains available for specific entity, not crowded out by others
Subchain operator chooses subchain parameters	Blockchain environment and fee structure can be customized to fit specific needs and governance
Subchain operator governs their subchain via their own TNT20 governance token	Access and governance remains with key stakeholders of entity, not distributed or shared with unrelated or competitive businesses

Table 1. Theta Metachain design features and associated user benefits

Mainnet 4.0 Release Schedule

Figure 1 below is a high level overview of how the Theta Metachain is seamlessly integrated with the Theta video infrastructure comprising the Theta edge network, ThetaVideoAPI interface and NFT-based DRM for media ownership and identity management. For more details, refer to the last section of this white paper [“Video focused Web3 Edge Computing Infrastructure”](#).

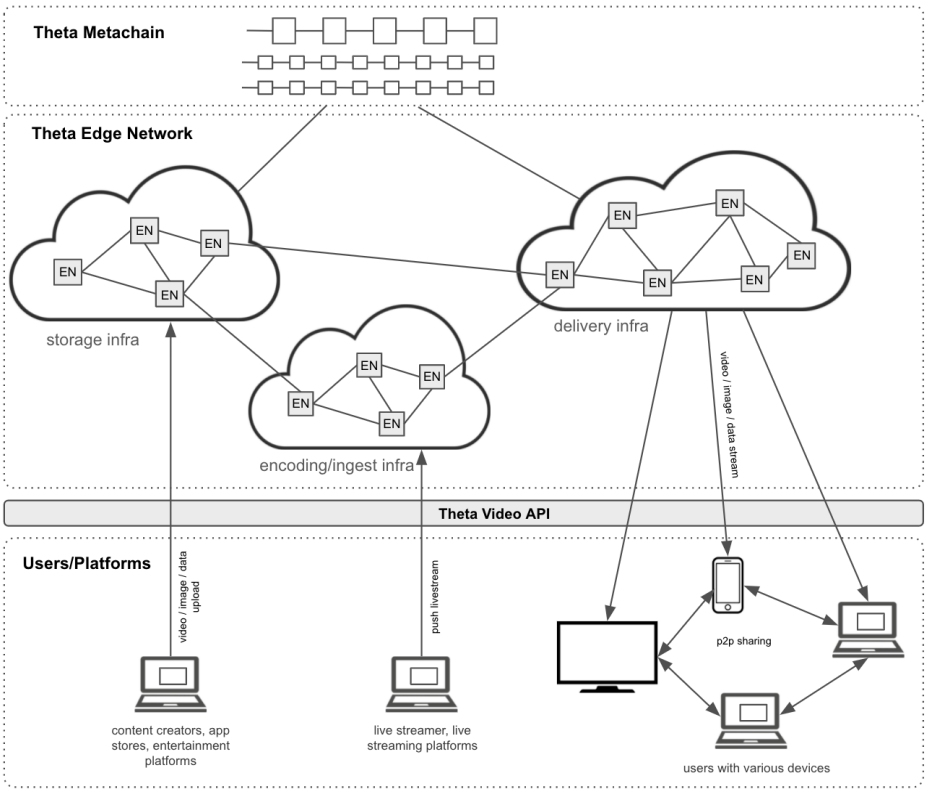

Figure 1. High level overview of Theta Metachain and the Theta video infrastructure.

Following is the product roadmap for the remainder of the year leading into the release of Theta Mainnet 4.0 and the Theta Metachain SDK on December 1, 2022. In addition to the Metachain, the Theta video infrastructure is a key component of tools made available to emerging Web3 businesses and existing media, entertainment and metaverse platforms looking to embrace Web3 economics.

- **Theta Metachain**
  - Testnet target launch: Oct 1, 2022
  - Mainnet target release: Dec 1, 2022 along with Theta Metachain SDK

- **Theta Video Infrastructure**
  - NFT-based digital rights management (DRM): Q2 2022
  - ThetaVideoAPI
    - Advanced Analytics: Q3 2022
    - Live streaming support: Q3 2022 (Beta)
  - Theta Edge Network
    - Elite edge node VOD encoding: Q2 2022
    - Elite edge node storage (EdgeStore): Q4 2022 (Beta)

Theta Metachain

Background

Theta has consistently been an early pioneer in new blockchain innovations, from deployment of Theta's Layer 2 Resource-Oriented Offchain Micropayment Pool in 2018, to the launch of the Proof of Stake Theta mainnet in 2019, to the unique multilevel-BFT consensus implementation added in 2020, and to full EVM-compatibility achieved in 2021. However blockchain technology continues to evolve at a rapid pace, and the rise of Web3 business models drives the need to innovate and extend Theta's core blockchain and protocol.

Theta's vision is to create the premiere blockchain for all media creators, from small to mid-sized video platforms, to global entertainment enterprises, to the individual amateur creator. A one-size-fits-all format won't suffice especially for large entertainment platforms that demand their own custom blockchain environment. A solution is needed that is orders of magnitude more scalable, more flexible and customizable to different use cases, and permissionless so that any entity or person can take advantage of these benefits. The Theta Metachain is our solution to these challenges.

Overall Architecture

The **Theta Metachain** is an interconnected network of blockchains, a “chain of chains”. The goal is to allow permissionless horizontal scaling of the Theta blockchain network in order to achieve potentially ***unlimited*** transactional throughput, and 1-2 seconds, or even ***subsecond*** block finalization time.

Metachain Topology

The Theta Metachain consists of one “**main chain**” and an unlimited number of “**subchains**”. Just as “meta-” as a prefix refers to something that transcends or is more comprehensive than the subject, ex. metaphysics describing what exists beyond physics, Theta Metachain refers to an overarching “main chain” above many purpose-specific “subchains”. The “main chain” in this case refers to the existing Theta mainnet. Theta will offer an easy-to-use SDK that developers can quickly use to launch a subchain and plug it into the main chain. Since each subchain can execute transactions independently, this provides a viable path to infinitely scale the processing capacity of the Metachain. The process of creating a subchain is permissionless, meaning that anyone can register and launch a subchain. No approval from Theta Labs is required.

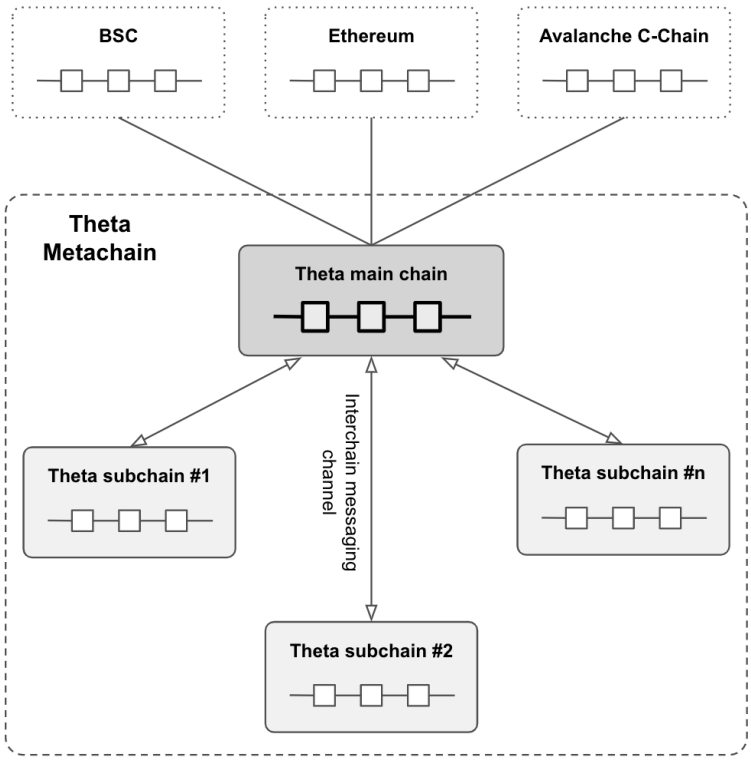

Figure 2. Theta Metachain topology, with cross-chain asset transfer supported between the main chain and subchains, as well as external blockchains such as BSC, Ethereum, and Avalanche C-Chain.

One important feature of the Theta Metachain is "**uniformity**" – the main chain and all the subchains are EVM compatible, and can thus provide a unified programming interface to DApp developers. Similar to the main chain, each subchain is powered by two tokens, a gas token and a governance token. TFUEL will be used as the gas token on all subchains. Note that the gas fee structure is customizable for each individual subchain. This means gas costs on the subchain could be made substantially lower than on the main chain. Each individual subchain will have its own governance token, which can implement an inflationary issuance model, for example, to incentivize validators to secure the subchains. The **subchain governance token** is not a native token on the subchain, but rather a TNT20 token on the Theta main chain and hence improves subchain security. For example, even if the majority of the validators of a subchain are compromised, its governance token holders can still exercise their governance right on the fully functioning main chain to contain the damages and/or penalize the attackers.

The introduction of subchains and the Theta Main chain concept **does not change or degrade the existing tokenomics of Theta blockchain in any way**. **On the contrary, subchains actually increase the utility and demand for both THETA and TFUEL.** In particular, THETA tokens are required as collateral for any subchain, and subchains ultimately rely on the main chain to maintain their security and integrity, which makes THETA staked on the main chain more important than ever. Additionally, TFUEL continues to be required as the gas token for all on-chain transactions, whether on main chain or a subchain. Any issuance of TNT20 governance tokens for subchains is used only on that particular subchain, and does not overlap in usage with THETA or TFUEL.

The subchain SDK will implement a built-in **interchain messaging channel** which connects the subchains and the main chain, and thus allows crypto assets like TNT20/721 tokens to flow freely across the chains. To achieve design simplicity, by default two subchains may not communicate directly with each other, instead crypto assets transfers between two subchains need to go through the main chain. Figure 2 shows the star-shaped topology with communication channels connecting the main chain and the subchains, as well as external blockchains such as Ethereum, BSC, and Avalanche. Note that this topology is similar to that of the Ethereum L2 rollup scaling solution. In fact, initially implemented as a multi-chain solution, the Theta Metachain can be extended into a zk-rollup by adding a few gadgets. Such an extension can achieve a higher level of security guarantees. More on this in later sections.

Note that this framework does not specify the exact design of the subchain consensus mechanism. Such flexibility allows different consensus protocols customized for specific use cases. For example, one subchain could adopt a permissionless proof-of-stake based consensus algorithm, while another subchain runs a permissioned proof-of-authority consensus protocol tailored for corporate environments.

Figure 3 shows the reference implementation of a subchain. Each subchain node is running inside a container along with a main chain node. With this setup, through the main chain node RPC interface, a subchain node can obtain main chain information in real time, including the latest block height, the registrar contract status, etc. In particular, the subchain validator can detect the governance token staking happening on the main chain in real time and update the validator set properly. This arrangement also facilitates cross-chain asset transfers, as detailed in the “Interchain Messaging Channel” section later. This architecture is scalable and decentralized and can support an arbitrary number of subchains.

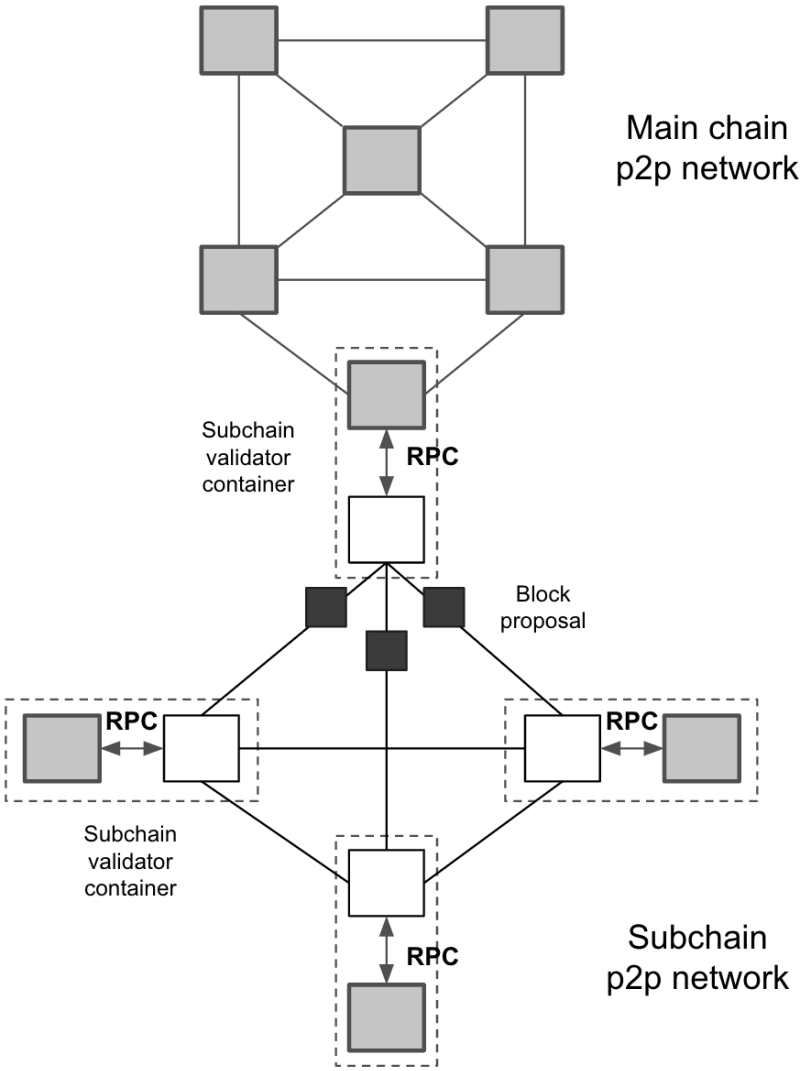

Figure 3. Theta Metachain p2p network. Each subchain validator node (white square) has an accompanying main chain node (gray square) running within the same container. Thus, a subchain validator node can interact with the main chain via local RPC calls.

Creating a New Subchain

Theta Metachain is designed to be permissionless. This means anyone can launch a new subchain. No approval from Theta Labs is needed. At a high level, creating a new subchain involves the following steps:

1. **Deposit Theta Collateral**: Subchain operators that register a new subchain must deposit a certain amount of THETA tokens to a registrar smart contract on the main chain as the collateral for the subchain. Next, for a subchain node to become a *validator candidate*, a certain amount of THETA collateral needs to be deposited to the node. The purpose of requiring THETA collateral for each individual subchain validator is to deter potential malicious subchain operators. For example, penalty mechanisms could be implemented to slash the THETA collateral if adversarial behavior is detected. The total amount of THETA collateral deposited for a subchain can serve as a "confidence measure" for the chain. There will be a minimum requirement for the THETA collateral per validator candidate. However, a subchain operator can choose to deposit more than the minimum to bolster the confidence for the chain.

2. **Subchain Validator Staking**: THETA collateral only grants a node the validator candidacy status for a subchain. To become a validator for the subchain, a sufficient amount of subchain TNT20 governance token needs to be staked to the node through a smart contract on the main chain. After the staking, the node is eligible to propose and vote for new subchain blocks when the next "dynasty" starts. A "dynasty" corresponds to a fixed number of blocks on the main chain, e.g. 500 blocks. The exact number will be determined later as we get closer to the launch. As mentioned earlier, each subchain validator needs to run an accompanying main chain RPC node. Thus, they can detect the stake deposits in real time through RPC queries, and then vote to transition to the next subchain validator set through a consensus protocol when the next dynasty starts.

3. **Launch the subchain validators**: After the initial staking, the subchain operators can launch the staked validators, which should start producing new blocks through the subchain consensus protocol. Users can now transfer their TFUEL from the main chain to the subchain and start experiencing the fast transaction confirmation and low fees enabled by the Theta Metachain technology.

4. **Subchain Validator Unstaking**: Subchain operators can also unstake and redeem their collateral. Similar to staking, unstaking is conducted through a smart contract on the main chain. Once a validator unstakes, it will be disqualified for proposing and voting for new blocks when the current dynasty ends. There is a pending period before the stake returns to the original wallet. A subchain validator or validator candidate can withdraw the Theta collateral on the main chain. Once a validator withdraws its Theta collateral, it will lose the validator and/or candidacy status when the current dynasty ends. There is a pending period before the collateral returns to the original deposit wallet. During the

pending period, if malicious behavior is reported and confirmed, the collateral could be slashed.

We will publish the exact procedure for creating a subchain on the Theta Documentation Site as we get closer to the Mainnet 4.0 launch.

Interchain Messaging Channels

We have designed an **interchain messaging channel (IMC)** protocol to facilitate crypto asset transfers between the main chain and the subchains.

As mentioned earlier, **each** subchain validator runs an accompanying main chain RPC node to interact with the main chain. With this setup, the subchain validators can monitor the main chain RPC for asset transfers from the main chain to the subchain in real time. The asset being transferred could be TFUEL, TNT20/721 tokens, or other types of digital assets. If such a transfer is detected, the next proposer is responsible for including that transaction in the new block. The other validators determine whether the transfer is legitimate by querying the main chain RPC. They subsequently cast their votes for the block based on the query results.

Conversely, whenever there is a subchain to main chain asset transfer, the next proposer is responsible for posting the cross-chain transaction to the main chain through a smart contract call. The smart contract mints the wrapped asset on the main chain when it has gathered enough evidence that the cross-chain transaction has been finalized on the subchain.

Note that the main chain needs to keep track of the subchain validator set in realtime, in order to decide if an incoming cross-chain transaction has been confirmed in the subchain. This is easy to achieve in our design, since the subchain governance token staking is handled by a smart contract deployed on the main chain (instead of the subchain).

Cross-chain asset transfer proof: Assuming the source chain implements the pipelined HotStuff consensus, a cross-chain asset transfer proof consists of the following:

- The asset locking transaction tx
- The Merkle path for tx
- The header of the block B containing tx, as well as the transaction Merkle tree root
- The headers of the child and grandchild block of B, both of which contain the quorum certificate from the current validator set. These two headers prove that block B is finalized.

To make the proofs more compact, we can consider replacing the transaction Merkle tree with KZG polynomial commitment, and using BLS signature aggregation to compress the quorum certificate. Furthermore, we can also consider turning the above into a zk-SNARK proof, depending on the cost of SNARK proof generation. zk-SNARK proof not only reduces the proof size but also the verification cost.

Comparison with Cosmos IBC: Cosmos IBC uses separate trustless relayer nodes to relay messages between the two chains. There are a few important design considerations in IBC, which introduces extra complexity:

- The relayers need to constantly upload the block headers of one chain to the other (probably should also include the validator staking/unstaking transactions which justifies validator set changes). With the headers and the proof of validator set changes, the target chain can verify whether an incoming transaction has been finalized on the source chain.
- A proper incentivization mechanism is needed for the relayers, since uploading the headers costs gas fees.
- Moreover, the uploaded headers need to be stored in the expensive smart contract storage on the target chain for cross-chain transaction validation. This has high overhead and could lead to smart contract storage explosion over time.

By comparison:

- In our design, since the subchain governance tokens are TNT20 tokens on the main chain, subchain validator set changes are naturally recorded on the main chain. Thus, validating an incoming transaction only requires a “stateless” proof. For example, the subchain validators only need to submit the tx + tx tree merkle proof + block header with two subsequent quorum certificates. The main chain smart contract verifies the proof, but doesn't need to store the proof in the state storage. Instead, as the parameters passed to the smart contract call, they can be stored in the relatively cheap block storage. This thus eliminates the need for uploading all the subchain headers to the main chain and storing them in the expensive smart contract storage, which significantly reduces the overhead.
- Since the tx validation is “stateless”, the gas cost associated with the transfer can be paid on the spot by the user that initiated the cross-chain transaction. In comparison, the relayers in Cosmos IBC need to separately pay for the gas fees when they upload the headers to the target chain.
- In our design, the subchain validators act as relayer nodes themselves. Thus, the subchain operators don’t need to maintain an extra set of nodes, which reduces operational overhead.

ZK-Rollup Extension

Readers familiar with the rollup scaling technology might have noticed that the schematic diagram of the Theta Metachain in Figure 2 resembles the topology of a rollup-based Ethereum scalability solution, where the main chain plays the role of the Ethereum L1 chain, and a subchain corresponds to an individual roll-up network. This is not a coincidence. Rather, the

Metachain is designed to have the potential to evolve into a zk-rollup-like architecture in the future by adding just a few more gadgets:

- **Validity SNARK proof**: One of the enhancements is to require that the subchains periodically submit SNARK proofs of state-transition correctness to the main chain. To be more specific, cryptographic commitment (e.g., the root hashes of the transaction and/or state trie) of the new state, as well as the cryptographic proof (e.g. a ZK-SNARK) which establishes that the new state is the consequence of applying valid transactions to the initial state are generated by the subchain validators and get written into the main chain. This significantly enhances the security, and makes attacks like rug pulls impossible, even if the adversary controls the majority of the validators of a subchain.

- **Data availability sampling with Theta EdgeStore**: First we note for a subchain with multiple validators, the validators themselves already provide a good level of data availability guarantee. This is because as long as one of these validators is honest and has the full block history (one is sufficient, majority not required), the subchain data can be made available in case of emergency. To further improve the data availability, we can require the subchains to persist their block/state data to the Theta EdgeStore network. Then, with a data availability sampling service built on top of the EdgeStore, we can provide an even better availability guarantee for the subchain data. This will further enhance the security of the Metachain. For example, even if all the validators of a subchain collude to steal user funds, they will not be able to do so since it is impossible for them to generate the validity SNARK proof. If they instead chose to disappear together to hide the subchain data, the users can still recover the subchain blocks/state from the EdgeStore-powered data availability service.

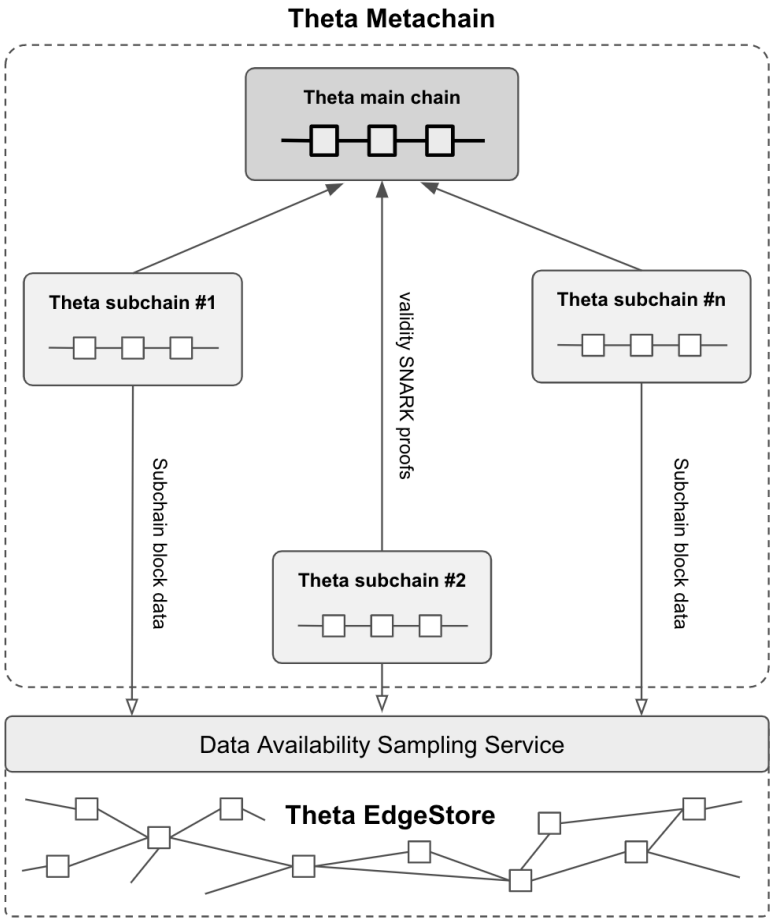

Figure 4. ZK-Rollup extension for the Theta Metachain, which can achieve full shared security.

Although the initial release may not come with the SNARK proof and data availability enhancement, we are considering the zk-rollup extension as a possible future direction for the Theta Metachain development as zero knowledge proof technology becomes more mature.

Security Analysis

Our Metachain design isolates potential security risks for each individual subchain. This is achieved by adopting a dedicated TNT20 governance token for each subchain. Readers might wonder why it is necessary to introduce subchain governance tokens instead of just using THETA. If THETA tokens were used as the governance token for a subchain, “minority stake attacks” may arise. In such attacks, the subchains that are only able to attract a relatively small amount of THETA staked could be vulnerable to attackers with a large number of THETA tokens on hand. On the contrary, attempting a 51% (or 34%) attack could be much more difficult and expensive since the attacker needs to amass a large portion of the subchain governance token.

The fact that the subchain TNT20 governance tokens are deployed on the main chain offers further security benefits. For example, the stakes of adversarial subchain validators can be slashed either automatically or through a on-chain governance process on the main chain, which helps deter potential malicious subchain validators. As another example, if the majority of the validators of a subchain are compromised, the governance token holders can quickly unstake from the breached validators to prevent them from causing further damages. This is not possible if the governance token resides on the subchain, since the malicious nodes with majority control can always reject blocks with unstaking transactions. Thus, allocating the subchain governance tokens as TNT20 tokens on the main chain effectively leverages the main chain security guarantees to improve the robustness of subchains against various attack vectors.

Furthermore, the THETA collateral for a subchain also serves as a deterrent against malicious subchain operators. Potentially, through an on-chain governance process, in addition to the TNT20 governance tokens, all or part of the Theta collateral of subchain validators can be slashed if any malicious behavior is detected.

Our interchain messaging channel design has a security model similar to that of Cosmos IBC. Unlike a typical cross-chain bridge implementation, neither Cosmos IBC nor our IMC relies on an extra set of trusted nodes to facilitate cross-chain asset transfers. Removing this extra dependency enhances the security. Cross-chain assets on a subchain are at risk only when the subchain itself is compromised.

Finally, with potential future zk-rollup enhancements, “full shared security” can be achieved where the safety of the main chain can guarantee the security of all subchains.

Comparison with Other Multichain Projects

Cosmos: Cosmos is a network connecting many independent parallel blockchains, each powered by BFT consensus algorithms like Tendermint. Developers can build custom application specific blockchains, called Zones, through the Cosmos SDK framework. These Zones connect to Hubs, which are specifically designed to connect zones together. The Cosmos network is inherently heterogeneous. Most notably, not all hubs/zones support EVM, and each zone/blockchain can have its own gas token. This may add unnecessary complexity for end users. For example, a user might need to go through multiple hops to transfer an asset, and each hop (hub/zone) may use a different gas tokens. Thus, before the transfer, a new user may have to first purchase a number of different gas tokens, leading to suboptimal user experience. In comparison, Theta Metachain features simplicity. It has a “star-like” topology, and uses TFUEL as the unified gas token. Asset transfer requires at most two hops to any destination chain including external chains like Ethereum or BSC. Also, as analyzed above, our IMC supports cross-chain transactions with much less overhead compared to Cosmos IBC. In Cosmos, a zone is secured by a set of validators governed by native tokens. Earlier in the whitepaper, we discussed the advantages of deploying subchain governance tokens on the

main chain. This design reduces the attack surface compared to the Cosmos approach. In the future, the Theta Metachain can evolve into a zk-rollup architecture which could further improve security.

Polkadot: Polkadot is a blockchain protocol that connects multiple specialized blockchains into one unified network. It achieves scalability through a sharding infrastructure with multiple blockchains running in parallel, called parachains, that connect to a central chain called the Relay Chain. A small number of validators are randomly assigned to each parachain and rotate within a given time interval. With the design of Polkadot, the security of the relay chain is paramount, should that be compromised then all connected chains will also be compromised. Due to this dependency, the relay chain could become the performance bottleneck of the system. To achieve a reasonable performance, only a limited number of parachain slots (e.g. 100) is available. Due to the scarcity, parachain slots are auctioned and thus have a high cost barrier. This limits the extensibility of the Polkadot network. In comparison, Theta Metachain allows a virtually unlimited number of subchains, and thus can freely scale out horizontally. In addition, in Polkadot, each parachain is typically only secured by a limited number of validators (around 10 per parachain with a minimum of 5). Given such a small number, the chances are significantly higher of collusion between the validators assigned to a parachain. Finally, Polkadot has a relatively long finalization time (60 seconds), which is substantially longer than the 1-2 seconds or even subsecond finalization time target for the Theta subchains.

Avalanche Subnet: Avalanche subnets are highly customizable. Subnet manages its own membership and it may require that its constituent validators have certain properties, e.g. require KYC. While Avalanche is highly decentralized and supports high transaction throughput, it has a non-uniform programming interface. For example, the primary network consists of the P-chain, X-chain, C-chain, where only the C-chain supports EVM. Moreover, similar to Cosmos and Polkadot, different Avalanche subnets may use different gas tokens, leading to extra complexity for developers and users. In terms of the consensus algorithm, Avalanche's signature polling-based metastable consensus provides only probabilistic finality and requires synchronous timing (per Avalanche's whitepaper). In comparison Theta Metachain's SDK by default implements BFT consensus that guarantees deterministic finality.

All these projects are promising projects with different design trade-offs. We summarize the main differences in the following table.

	Theta Metachain	Cosmos	Polkadot	Avalanche Subnet
Scalability	Unlimited transaction throughput	Unlimited transaction throughput	Limited due to the max 100 parachains constraint	Unlimited transaction throughput
Transaction finalization time	Subchains can achieve 1-2 seconds, or even subsecond deterministic finalization	6-7 seconds, deterministic finalization	60 seconds	1-3 seconds, probabilistic finalization
Security	Each subchain has its own security. Governance token deployed on mainchain reduces attack surface. Future extension to zk-rollup will be highly secure with “full shared security”.	Each chain/zone has its own security. Cosmos plans to research into shared security with hubs validating zones.	Relay chain validates state transition for all parachains. Shared security can be achieved at the cost of scalability.	Each subnet has its own security. The subnet validators also validate the primary network.
DApp dev/user experience	More dev/user friendly. Unified program interface. EVM support across the board	Heterogeneous network, may create extra complexity for dev/user	Heterogeneous network, may create extra complexity for dev/user	Heterogeneous network, may create extra complexity for dev/user
Interoperability	All subchains are connected through the main chain via interchain messaging channels (IMC). At most two hops between any two chains. IMC has much less overhead than Cosmos IBC.	Interoperable across connected zones and hubs through IBC, but may require different gas tokens along the path, resulting in suboptimal user experience.	Interoperability is enabled between parachains through Cross-Chain Message Passing (XCMP) protocol and is also possible to connect to other systems through bridges.	Interoperability is enabled between blockchains within a subnet as well as between subnets.

Table 2. Comparison between Theta Metachain, Cosmos, Polkadot, and Avalanche Subnet

Video-Focused Web3 Edge Computing Infrastructure

Architecture Overview

Theta’s video-focused edge computing infrastructure is an essential enabler of the Web3 ecosystem powered by Theta Mainnet 4.0. The diagram below illustrates the overall architecture of the video-focused edge computing infrastructure.

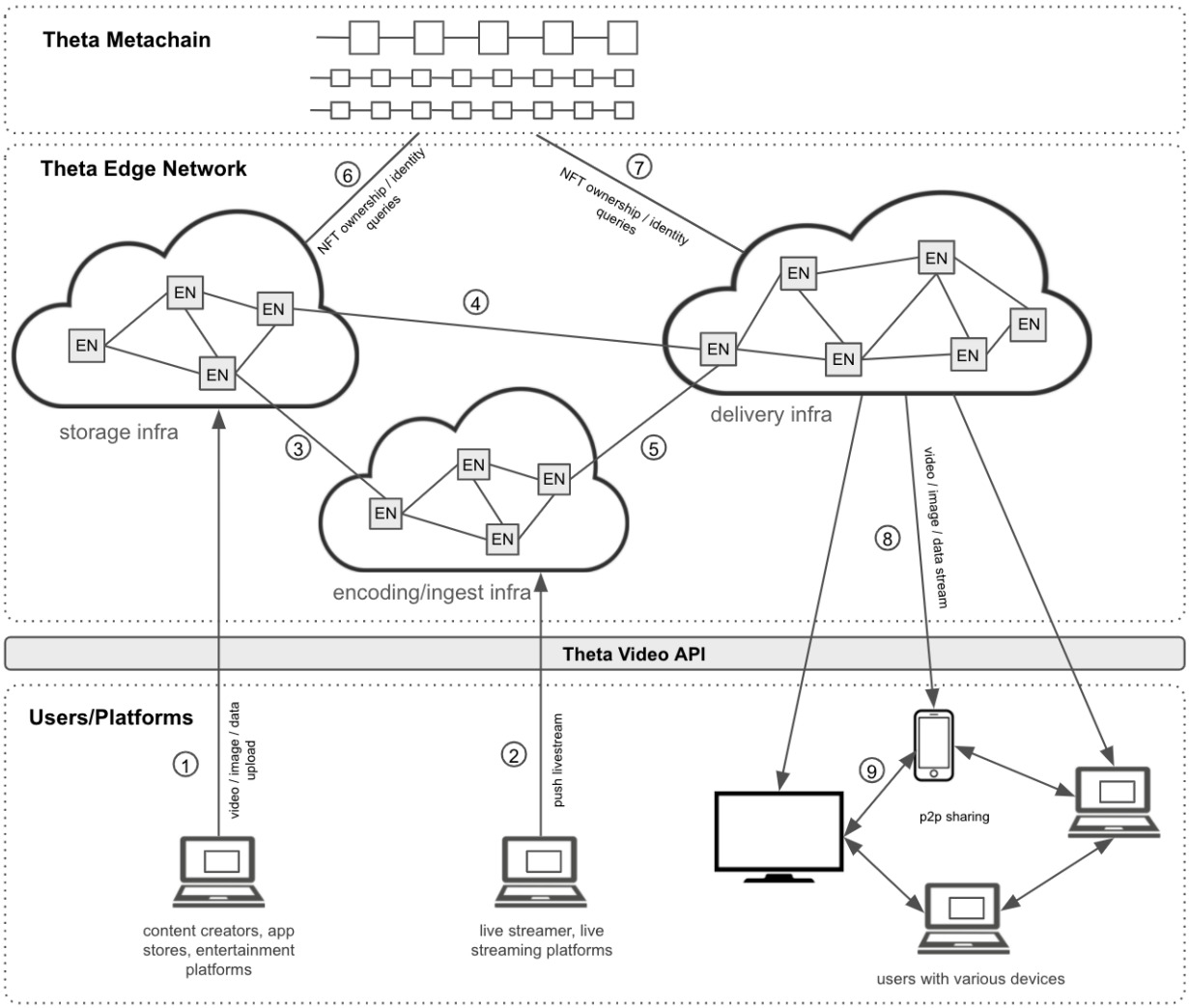

Figure 5. Diagram of the video-focused Theta edge computing infrastructure

The architecture consists of four layers:

- **Users/Platforms**: The bottom layer are the video viewers, creators, streamers, and media platform partners. They are the users of the infrastructure.
- **Theta Video API**: On top of the user layer we have the Theta Video API, a thin layer which encapsulates the functionalities of the edge network into a developer-friendly programming interface. Theta DApp developers and users interact with the edge computing infrastructure primarily through this interface.
- **Theta Edge Network**: Above the Theta Video API layer is the edge network consisting of edge nodes run by the Theta community. These edge nodes provide various functionalities, including storage, video encoding, live stream transcoding, and data delivery. Note that in the diagram, we group the edge nodes into three logical sub-networks, i.e. storage/encoding/delivery infrastructures. This is just for ease of illustration. In the actual deployment, each individual edge node is equipped with all

these capabilities. The Elite Edge Nodes will be prioritized over regular edge nodes for encoding/storage job assignments.

- **Theta Metachain**: The top layer is the Theta Metachain. Through the Metachain's RPC interface, the edge network can interact with smart contracts deployed on the Metachain.

Hybrid Configuration Support: Our architecture is purposely designed to support a hybrid configuration that combines cloud-based infrastructures and the power of decentralized edge node network. For example, the EdgeStore decentralized storage network can work alongside AWS S3, GCP cloud storage, to achieve better robustness and fault tolerance when AWS or GCP are unable to achieve scale at optimum cost. A live stream transcoded by the decentralized ingest network is pushed to the delivery network where edge nodes and the client side p2p sharing network can further assist the streams delivered, extending the coverage to locations that are far away from the CDN points of presence (PoP) data centers. Existing CDNs like Akamai and Cloudfront can be used in conjunction with the edge network to provide more thorough coverage for users in different regions of the world. The support for hybrid configurations offers flexibility and interoperability, and thus effectively combines the best of both worlds today, but the long-term opportunity of decentralized networks and distributed ledger technologies are game changing.

Here are a few examples illustrating the potential Web3 use cases:

Example 1 - video delivery: A video content creator uploads a clip to the storage infrastructure through the Theta Video API dashboard (step ① in the diagram). The storage infrastructure could either be a decentralized storage network like Theta EdgeStore or a cloud storage like GCP cloud. Whenever the Theta encoding/ingest network detects the new upload, it assigns the transcoding jobs to one or more edge nodes, which in turn download the clip and transcode it into a stream with multiple bitrates/resolutions (step ③). Next, the edge nodes upload the stream to the delivery infrastructure consisting of the edge nodes, and potentially existing CDNs (step ⑤), and return the content creator with a playback URL on the Theta Video API dashboard. The content creator can embed the URL on his/her website. Whenever a viewer watches the video, the delivery network will find the best possible routes to deliver the stream to end viewers (steps ⑧ ⑨).

Example 2 - NFT digital asset hosting: An NFT creator uploads an image to the storage infrastructure through the Theta Video API dashboard, and pays TFUEL for the Theta EdgeStore decentralized storage backend to host it permanently (step ① in the diagram). Next, the delivery network downloads the image and replicates it across the network (step ④) to shorten the access latency for the end users (steps ⑧ ⑨). TFUEL paid by the uploader will be split by the edge nodes storing the image file.

Example 3 - Paid live stream secured by NFT-based DRM: A live streamer can put up a stream that is only viewable by paid users. This can be achieved by leveraging Theta's NFT-based DRM technology. First, the streamer issues a subscription NFT. When he creates a stream on the Theta Video API dashboard (step ① in the diagram), he can specify that only

users with a particular NFT collection in his/her Metamask wallet can watch the stream. Next, as the streamer pushes the stream into the ingest network (step ①), the ingest nodes will encrypt the stream and relay the encrypted stream to the delivery network (step ⑤). When users watch the stream on their device, they first need to connect their Metamask wallet with the video player. The delivery network queries the Theta Metachain to check if the user's wallet indeed owns the subscription NFT (step ⑦). If the NFT ownership is confirmed, the delivery network sends the user's device a decryption key (step ⑧), with which the user can decrypt and access the live stream.

Example 4 - Generic website hosting: Although our edge computing infrastructure focuses on the video delivery capability, it can host generic files and deliver generic data streams. For this use case, the website creator uploads the static files of the website to the storage infrastructure through the Theta Video API dashboard (step ① in the diagram), and pays for the storage cost in TFUEL. The files are then replicated throughout the networks to reduce download latency (step ④). Finally, the users can access the website through the Theta edge delivery network (step ⑧).

Products and Services

To fully support the above use cases, throughout the year 2022 we plan to roll out a series of Web3 tools and services. These new services include richer feature sets for Theta Video API including live streaming support, analytics, decentralized video encoding/ingest, and NFT-based digital right management. Theta EdgeStore is a critical and strategic initiative that Theta will continue to devote R&D resources to.

Theta Video API

Theta Labs released "Theta Video API" in Oct 2021, a new platform for developers that allows them to add decentralized video to any website or application without any central servers, content delivery or video hosting software. As an evolution of Theta's Web 3 vision, the move brings an easy to use API to anyone, and delivers to users a revolutionary way to stream decentralized video content with just a few lines of code.

The Theta Video API wrapped the video-focused edge computing infrastructure into a set of developer-friendly, easy-to-use APIs. Through it anyone can simply upload a video clip and the Theta Video API will return a playable link they can add a Theta-powered player to a site featuring the video clip. The ease of use means now anyone will be able to roll out decentralized video to handle delivery, and playback of their videos. Users that watch will then be able to relay video over the Theta Network on a peer-to-peer basis, fully leveraging Theta's decentralized infrastructure. This isn't simply embedding an existing video stream — any user can use Theta Video API to upload any video to their website with just a few clicks in a permissionless process.

It's simple for developers to use: a web or mobile developer posts a video file to the Theta Video API ingest endpoint and get a playable video URL in return along with a few lines of JavaScript code which enables the Theta decentralized stream delivery library.

In 2022, a set of new decentralized features will be added to Theta Video API as part of the Mainnet 4.0 release, including the following:

- **Elite Edge Node (EEN) encoding for VoD (Video on Demand)**: The initial release of Theta Video API utilizes cloud based encoding infrastructure to encode videos uploaded by users. We are now adding VoD encoding support to the edge network and plan to release a new version of EENs in Q2 2022 where edge nodes will be able to process multi-bitrate multi-resolution commercial encoding workloads and get rewarded with TFUEL.

- **Live streaming support**: The initial release of Theta Video API focused its support on on-demand video. We will expand the capabilities to live streaming in an upcoming release scheduled for Q2 2022. Live streamers and streaming platforms will be able to create a stream either on the Theta Video API dashboard or through the API interface and push it to millions of end viewers. The EENs facilitate the stream ingest, transcoding and delivery of the stream and get paid with TFUEL end-to-end.

- **Analytics dashboard**: advanced video/stream analytics will be added to the Theta Video API dashboard. Analytics data can also be retrieved from the API interface including important stats such as video playback smoothness, stream consumption, effectiveness, delivery offloads, etc. This is critical to help content creators get a sense of how well the videos were experienced by their viewers.

With these exciting features, anyone can create an entire video or live streaming platform using only Theta Video API without the need for any other video encoding, delivery, or playback providers since Theta Video API creates an end-to-end decentralized video pipeline — all-in-one, easy to use, and decentralized. Theta aims for this to significantly reduce the cost of adding media and video to any Web3 app or platform, removing barriers to entry and allowing new content types and creators to flourish. Existing video platforms can also use these services to lower their cost and improve user engagement.

NFT-based Digital Rights Management

Theta Labs has received patent application approval for USPTO Application №17/218,245, a technology developed for implementing decentralized digital rights management (DRM) via NFTs in a decentralized network. This technology has massive applications for managing rights across a number of domains including, for example, live performances, concerts, and other ticketed events that require authentication, which can now be managed via an NFT that provides true digital ownership by the user which cannot be taken from them.

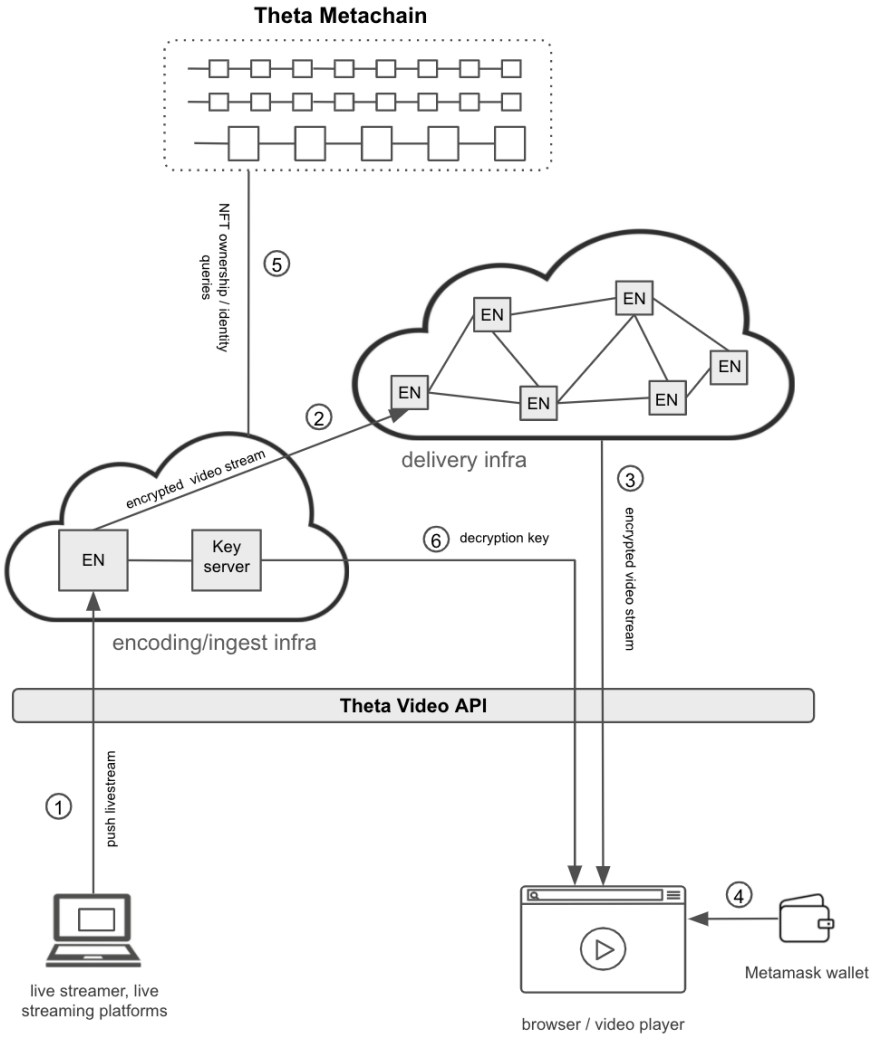

Figure 6. NFT-based Digital Right Management for live streaming

More importantly, one major friction point for content rights holders to use decentralized video streaming is concerns over their content rights being violated, as they require strong guarantee that a peer-to-peer network won't be used to infringe on their content rights or that of their artists. By using NFTs to implement decentralized DRM, Theta Network solves this issue for content rights holders in a way that does not require a centralized party to authenticate users each time data is streamed. This opens the door for global content brands to safely bring their videos, movies, and games to Theta's decentralized data and video delivery network.

We are planning on releasing an implementation of this patented DRM technology in Q2 2022. This upcoming release features interoperability with existing ingest softwares, such as Wowza and FFMPEG, and supports popular livestreaming standards such as HLS. Thus, it can be easily integrated by platform partners and independent streamers. The details of the implementation is illustrated in Figure 6 above and described below.

Streamer/Streaming platform:

- The streamer creates an NFT collection, and lists the NFTs for sale, or simply airdrops the NFTs to viewers (step ① in the diagram).
- Streamer registers a new stream through Theta Video API. On the dashboard (or through the API) he can associate the NFT collection with the stream (step ①).

Viewer:

- To watch a video stream gated by an NFT collection, a viewer first needs to purchase or acquire the NFT and transfer it to their Metamask wallet.
- When the video player loads, it will ask the viewer to connect their Metamask wallet (step ④).
- Metamask prompts the viewer to sign a randomly generated message. The signature is then uploaded to prove the viewer's wallet address.
- The key service queries the Theta Metachain with viewer's wallet address to check if the wallet indeed owns an NFT of the designated NFT collection (step ⑤).
- If the NFT ownership check passes, the key server sends the decryption key to the viewer (step ⑥), with which the video player can decode the encrypted stream (step ③).

In the example above, we describe the system implementation in the context of a livestream but the same technology applies for on-demand video.

The core innovation is the ability for the Theta decentralized delivery network to authenticate viewers via ownership of an NFT issued from a smart contract. When a viewer requests for a stream, the system can use the NFT to verify that it is a valid user/viewer of a particular data stream. If the proper NFT is presented, a data key will be provided that decrypts the data stream. This means that as a content provider, you have cryptographic proof that only the right viewers are able to view the stream — even if that data stream is accessed by an unauthorized user, they would not be able to decrypt the stream and see the underlying data without the proper NFT. This opens up a whole world of possibilities for Web3 media, entertainment and metaverse businesses to innovate and gate premium content, in a fully decentralized way.

Theta Edge Node Storage - EdgeStore

The Theta EdgeStore network aims to be an append-only, content-addressing, decentralized key/value storage network for the permanent web. The EdgeStore implements a unique technique called "flexible sharding" which can be viewed as an probabilistic extension of the Chord protocol for distributed hash tables (DHT). The EdgeStore also incorporates erasure code encoding at its core. Erasure code can greatly enhance the data availability. Even if a large percentage of EdgeStore nodes are shut off, it's highly probable that you can still recover the data from the remaining nodes.

An EdgeStore node not only stores the permanent data shards assigned to it, but also caches the popular contents locally. Therefore, in addition to providing storage capability, the network also acts as a decentralized content delivery network (dCDN) for any type of files. We foresee that a wide array of decentralized Web3 applications can be built on top of the Theta EdgeStore, including but is not limited to the following:

- Permanent storage for digital assets of NFTs including images, videos, rich media
- Data availability service for layer 2 scaling solutions such as rollups.
- Decentralized CDN for video, music, game patches, software updates, and more.
- Storage backend for general Web3 DApps, e.g. blogging sites, chat apps, decentralized app stores, decentralized Github repositories, etc.
- Storage for Metaverse digital assets, including 3D models of the characters and buildings in virtual reality worlds.
- Storage for training data sets for AI algorithms such as autonomous driving, protein folding etc.

Theta Labs released the “Alpha Preview” version of Theta EdgeStore earlier this year (here and here). The EdgeStore was released as a standalone binary in this initial version. In Q3 2022, we plan to release a gateway service for the EdgeStore Alpha and integrate it with the ThetaVideoAPI. This way users can upload videos, images, and other files to the EdgeStore Alpha network through the ThetaVideoAPI dashboard, and retrieve the files via API services. This significantly enhances end-to-end capabilities and integrates into an unified product.

As the EdgeStore technology becomes more mature and stable, we will roll out a Beta version and integrate it into the Theta Edge Node software. That will empower the Theta Edge Network to provide reliable decentralized storage and CDN services, and provide new ways for Edge Node operators to earn TFUEL for their contributions to Theta ecosystem dapps.

Summary

As applications and businesses transition into Web3, they will require customizable, high-performance blockchains to enable new business models and tools for value creation. Theta Metachain will be created to meet the needs of video platforms, ticketing companies, metaverses, and many other enterprises as they evolve to decentralized models that put value capture and data ownership back in the hands of users. By transitioning to the Metachain model enabling potentially unlimited transactional throughput and subsecond block finalization, Theta will be ready to meet the needs of applications with millions of users and transactions per day.

Each platform or Web3 business can have their own subchain that is highly customizable and comes with the transparency, security, and credibility of a public blockchain. Media and entertainment companies can implement their own dedicated subchains with all the Web3 tools

they require for video, compute and storage via Theta Video API, EdgeStore, and NFT-based DRM.

This is the vision for Theta MetaChain beginning in December 2022 - enabling emerging Web3 businesses in media, entertainment and the Metaverse to scale to 10x today's platforms.