Waterfall: Salto Collazo. Tokenomics

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***Abstract*—This article describes the core principles of the economic policy integrated into the Waterfall DAG (Directed Acyclic Graph) based system design. The main aim is to create a favorable environment incentivizing the positive behavior of each network participant and the system as a whole. Economic leverages ensure general equilibrium, to provide an optimal data replication ratio and affordable transaction fees.**

***Keywords*—tokenomics, incentive system, distributed protocol, transaction fee, directed acyclic graph, blockchain.**

I. INTRODUCTION

A. *Problem Statement*

Blockchain is an emerging decentralized technology transforming modern society and businesses due to its transparency, immutability, tamper-proof safety of data, tolerance of various types of attacks, and logic consistency [1, 2]. However, for many enterprise-class applications, blockchain technologies are not acceptable due to poor system performance and high transaction fees.

DAG technology can be considered the next generation of blockchain, owing to its optimized validation mechanism, high scalability, efficient provenance, support for the Internet of Things (IoT), and multiparty involvement [3-5]. In particular, DAG-based architecture can provide the necessary crucial features for the development of diverse decentralized finance (DeFi) services, including payment systems and non-fungible tokens (NFTs) [6, 7], electronic medical screening systems [8], new solutions in the energy [9] and real estate [10] sectors, identity document [11] and e-voting [12] services, etc.

To succeed, such an approach demands the development of ad-hoc economics of a high-speed and scalable decentralized storage system that can guarantee low-cost transaction fees. This work addresses the core economic principles integrated into the Waterfall DAG-based protocol [13], and its ability to meet these requirements.

B. *Waterfall Platform Overview*

Waterfall is a highly-scalable smart contract platform for the development of varied decentralized applications (Dapps). The distributed protocol is based on DAG technology, with fast finality Proof-of-Stake (PoS) consensus [14]. The Waterfall platform relies on the Coordinating and Sharding networks achieving high transaction throughput due to parallelized block production. The DAG structure facilitates scalability, which is one of the main challenges of decentralized technologies. Each network Worker also consists of two parts, a Coordinator and a Validator, presenting itself in the corresponding networks.

The timeline is divided into slots, epochs, and eras. The Coordinating network maintains the register of Validators, and also assigns block producers, committee members, and leaders in each slot at the epoch's beginning. Moreover, this network contains information about the approved blocks created on the Sharding network. An honest producer accompanies its created block with links to all known tip-blocks of the DAG. At the same time, the linearization (ordering) and finalization of the distributed ledger are performed in the Coordinating network, increasing overall security and synchronization.

The Waterfall platform inherits and improves the most promising features of Ethereum 2.0 [15]. A native coin serves as a main network digital asset that provides transferring of transactions, running of smart contracts, governance voting, and auxiliary token creation, to form an ecosystem with the prospect of synergistic interaction of all its elements. However, the DAG structure forces us to modify well-known tokenomics mechanisms and to find new approaches to empower this decentralized system with economic leverages that enable its sustainable development. At the time of writing the work, the Waterfall platform is implemented as a test network that operates on 64 t3.small instances of Amazon EC2.

C. *Tokenomic Goals*

Tokenomics is an ad-hoc mini economics of decentralized systems that uses inner coins or tokens to incentivize specific behavior of all participants (users, investors, traders, coin founders, developers, etc), taking into account their interests [16]. It is meant to serve the community by incentivizing positive actions and punishing malicious ones, as well as

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effectively using existing resources and integrating new ones. Tokenomics should be integrated into the system design to drive node behavior and the system as a whole. A balanced model can provide a favorable environment for the provision of a wide spectrum of affordable services within the framework of a public decentralized network.

Waterfall tokenomics has a few special goals. Firstly, to create economic conditions for expanding the network to a size that provides an optimal data replication ratio and the maximum speed of transaction propagation (edge networking). In addition, economic leverages have to encourage fast finality [17], which is a key feature for supporting payment systems and Dapps.

It should be noted that the network's DAG structure adds few possible kinds of attacks in comparison with classic blockchains. In turn, tokenomics should promote appropriate protection, in close collaboration with the technical network design.

The tokenomics model is implemented as a set of business regulations recorded in the software that cover the full range of required features. All economic rules are enforced automatically, and are fully transparent and available to the public, making the platform more robust while also enhancing trust. Moreover, there should be mechanisms for dynamically adapting specific rules, depending on the changing situation. Such an approach allows for self-sustainability of network behavior throughout its entire lifecycle, ensuring general economic equilibrium, and providing for orderly development in accordance with the goals of the network functioning, which is a crucial challenge of this work.

II. Related Works

Typically, consensus protocols and the technical designs of decentralized networks do not describe the economic basis of their functioning, e.g., how fair nodes could be incentivized and malicious nodes penalized [18]. However, operation of a public network is impossible without an economic model, which is often implemented as a separate formal subsystem [19, 20]. The development of tokenomics models is a challenge, which involves game theory researchers as well [21]. A tight integration of all network components is necessary for successfully achieving its goals. Moreover, the problem of fair transaction fees has recently become acute, and is widely discussed among the community of blockchain researchers and enthusiasts (e.g. [22, 23]).

The evolution of economic blockchain models began with PoW (Proof-of-Work) decentralized networks like Bitcoin, Ethereum 1.0, etc (e.g. [16, 24, 25]). They have a relatively simple economy compared to modern PoS (Proof-of-Stake) models, which can potentially better ensure network maintenance [26]. Nowadays, various economic PoS mechanisms are widely developed, due in particular to Ethereum's transition to a PoS model 2.0 [15], to satisfy modern demands. In addition, there are a few approaches that integrate economic logic into the BFT (Byzantine Fault Tolerant) consensus to provide a general equilibrium of the internal economy for sustainable functioning, in accordance with certain goals (e.g. [27, 28]).

Analysis of related works revealed that the main challenges of the considered decentralized systems are to decrease transaction costs, increase the number of transactions per unit of time, and reduce the finalization time. A detailed overview of contemporary tokenomics development prospects and key trends can be found, e.g., in the Messari's report for 2022 [6].

III. Macrotokenomics

The economical functioning of the decentralized Waterfall platform as a whole, without singling out particular features and interactions of individual participants, is considered in this chapter. The governance and core principles of network economic policy are described, as well as their influence on global interactions of community groups, the stability of cryptocurrency rates, the inflation and deflation processes, etc. The high-level system design and coin flows are depicted in Fig. 1 and discussed in greater detail below.

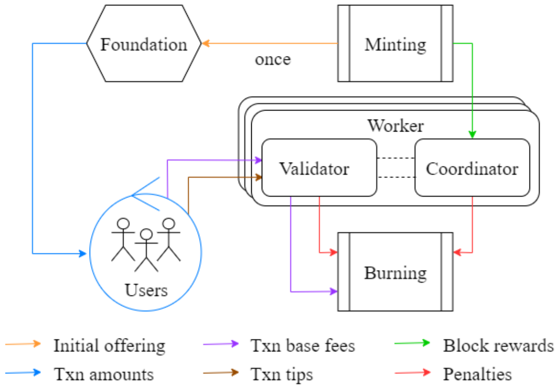

Fig. 1. The Waterfall tokenomics high-level design.

A. Pre-mining Stage

The initial coin distribution is one of the key elements of system security, at least while the network is still relatively young. For that reason, N_0 Workers with fixed stakes divided into nodes (sets of Workers having a shared ledger and an IP address) can be created at the start. Let the stake equal s coins per Worker, and an increase in the total staked amount occurs only through an increase in the number of Workers.

Generally, the total supply of tokens is not entirely available at the start. Let α be the ratio of the current supply (C) to the total staked amount $s \cdot N_0$ The value of N_0 should be set as the current optimal number of Workers, to provide an effective and secure network. A small number of Workers increases the possibility of a majority holding attack. On the other hand, a large total stake reduces free (not staked) funds in circulation that can interfere with effective work. Therefore, this ratio α is expected to be maintained, to ensure both the required amount of free funds in circulation and the most optimal number of Validators. In other words, if the current supply C is less than the total stake multiplied by $\alpha \cdot (1 - \varepsilon_1)$, a corresponding amount of coins is released; and vice versa. If the current supply C is greater than the total stake multiplied by $\alpha \cdot (1 + \varepsilon_2)$, a corresponding number of Workers is added from the funds of the Foundation. Moreover, in the first case, instead of releasing an additional coin amount, the Foundation can revoke its Workers if they were created within the framework of this protocol. This condition is checked, and the balance between the number of workers and the current coin supply is adjusted regularly with a smart contract. The following pseudocode represents this protocol.

```
float opt_ratio = alpha;
float lower_bound = opt_ratio * (1-epsilon1);
float upper_bound = opt_ratio * (1+epsilon2);
int stake_per_worker = s;
int balancing_workers = 0;
void  balance_workers_and_supply() {
    int total_stake = get_total_stake();
    int current_supply =
          get_current_supply();
    if (current_supply < total_stake *
          lower_bound){
        int need_to_reduce = (total_stake -
              current_supply / opt_ratio)/
              stake_per_worker;
        int can_reduce =
              min(balancing_workers,
                need_to_reduce);
        balancing_workers -= can_reduce;
        total_stake -= can_reduce *
          stake_per_worker;
        int tokens_to_add = total_stake *
              opt_ratio - current_supply;
        if (tokens_to_add > stake_per_worker)
            add_new_tokens(tokens_to_add);
    }else if(current_supply > total_stake *
              upper_bound){
        int need_to_add = (current_supply /
              opt_ratio - total_stake) /
              stake_per_worker;
        balancing_workers += need_to_add;
    }
}
```

The search for most optimal values of $\alpha \geq 2$, $\varepsilon_1 > 0$ and $\varepsilon_2 > 0$ for effective and secure network function is an open question and depends on certain features, such as the total and current supplies, needed free funds, security level, etc, as well as network operating goals.

B. Coin Minting

In this model of tockenomics, block production is incentivized with minted rewards for each finalized block of the Coordinating network. In other words, new coins will be issued to cover the cost of rewarding coordinators for achieving necessary security guarantees, so-called Minimum Necessary Issuance. The annualized minted amount (V) depends on the total amount of staked coins (S):

$$V = k \cdot \sqrt{S},$$

where a coefficient k will be defined below. Hence, the maximum annualized return rate (R) equals:

$$R = \frac{V}{S} = \frac{k}{\sqrt{S}}.$$

This non-linear relationship proposed in [15] means that if the amount of staked coins decreases, then the incentivization increases, and vice versa. Therefore, a balance between the volume of minted coins and network security is ensured. The coefficient k can be obtained through the desired value of R at a certain total stake

$$S = s \cdot N$$

or a certain number of Workers (N) at the current moment, since all initial stakes are uniform, although some of them may be further reduced because of penalties. In our case, the coefficient k is derived from a condition that the maximum annualized return rate equals R_0 with N_0 Workers:

$$k = R_0 \cdot \sqrt{S_0} = R_0 \cdot \sqrt{s \cdot N_0}.$$

Thus, for an arbitrary number of Workers, we have:

$$V = R_0 \cdot s \cdot \sqrt{N_0 \cdot N},$$

$$R = R_0 \cdot \sqrt{\frac{N_0}{N}}.$$

With the coin release in the early stages, the current supply C sharply increases, demanding growth of the optimal number of Workers for network security. Hence, the value of N_0 should be significantly increased as well:

$$N_0 = \frac{C}{\alpha \cdot s}.$$

The coefficient k and the annual minted amount V are recalculated appropriately until all coins are released. This will engage new Workers by increasing the minted rewards. However, if the number of Workers is too high, the network will be overpaying for security, and inflation can be detrimental to the platform's tokenomics. Therefore, the value of α should not be too low. Note that C can be approximated as the difference between the total supply and the current amount on the releasing account(s).

In fact, the general rate R will be less, due to faults or malicious behavior of some Coordinators. However, honest Workers can get rewards of at least approximately R_0 per annum from their investments at the beginning. For example, Fig. 2 depicts the maximum annualized return rate that might be generated by stakeholders as block rewards at various numbers of Workers with $R_0 = 0.20$ and $N_0 = 8{,}192$.

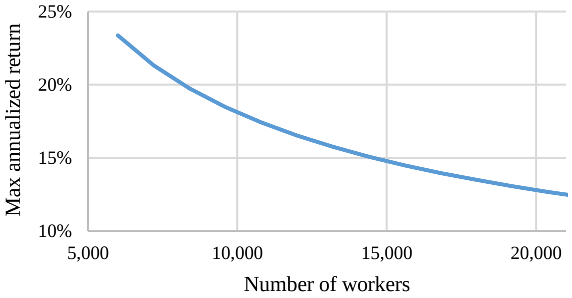

Fig. 2. The maximum annualized return rate of workers with $R_0 = 0.20$ and $N_0 = 8{,}192$.

As the number of Workers grows, the return rate decreases, but rewards might be even higher due to tips from increased network activity.

A minted reward for a produced block can be obtained by taking into account the values of the annualized minted amount and slot times. Let i-th be the slot of the Coordinating network:

$$B_i^c = \frac{60 \cdot 60 \cdot 24 \cdot 365.25}{t_i^c} ,$$

where t_i^c is its time in seconds.

Therefore, the minted reward per block is:

$$W_i^c = \frac{V}{B_i^c} .$$

Note that the sum over all slots of the Coordinating network per year (Y) equals:

$$\sum_{\forall i \in Y} W_i^c = V \cdot \sum_{\forall i \in Y} \frac{t_i^c}{60 \cdot 60 \cdot 24 \cdot 365.25} = V .$$

Further, the amount W_i^c is split among the Committee leader and members that produced i -th block in the Coordinating network.

C. Base Transaction Fee

A base transaction fee must be paid for any transaction included in a block. The mechanism of its formation is similar to how a minted reward is obtained, and also depends on the annualized minted amount. Let i-th be the slot:

$$B_i^s = \frac{60 \cdot 60 \cdot 24 \cdot 365.25 \cdot b_i}{t_i^s},$$

$$W_i^s = \frac{V}{B_i^s} ,$$

where the number of blocks per slot in the Sharding network $b_i > 1$ and t_i^s is its time in seconds.

Note that if the block number and the time slot are constants within a year, then B^s is the annual number of blocks. The sum over all slots and blocks of the Sharding network per year equals:

$$\sum_{\forall i \in Y} \sum_{j=1}^{b_i} W_i^s = V \cdot \sum_{\forall i \in Y} \frac{t_i^s}{60 \cdot 60 \cdot 24 \cdot 365.25} = V .$$

Finally, a base transaction fee in i-th slot is defined as:

$$f = \frac{G}{G_{max}} \cdot W_i^s \cdot p ,$$

where G is the needed gas amount to process that transaction, G_{max} is the total allowable gas amount per block, and p is a price multiplier. The sum of all base transaction fees over j-th block of i-th slot:

$$F_{ij} = \sum_{txns} f \leq W_i^s \cdot p .$$

For a normal transaction the ratio:

$$\frac{G}{G_{max}} = \frac{1}{10{,}000}$$

ensures quite low base fees, even for high values of the multiplier p.

Clearly, the value of W_i^s depends on the current number of Workers as well (Fig. 3).

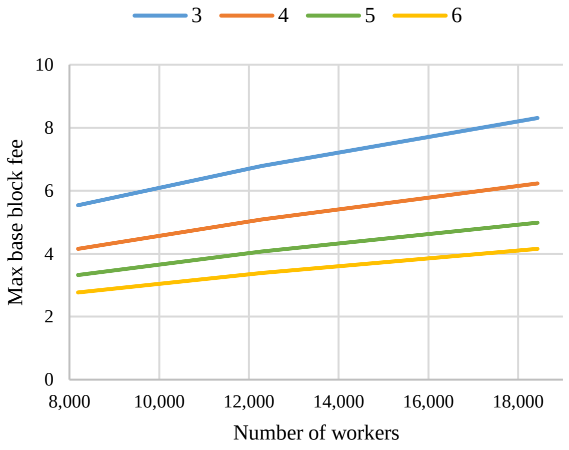

Fig. 3. The maximum base block fee (W_i^s) with $N_0 = 8{,}192$, $s = 32{,}000$ coins, $p = 1$, $t_i^s = 10$ sec, and $b_i = 3 \ldots 6$ blocks per slot.

D. Coin Burning

The process by which coins are removed from circulation to reduce their current supply is called ‘burning.’ For example, some coins can be intentionally sent to an account that can only receive them without any further withdrawal. According to EIP-1559 (Ethereum Improvement Proposal), base transaction fees are burned to improve Ethereum’s tokenomics [29], but validators get to keep tips from transactions.

As a variant, a fixed portion of each transaction fee can be burned [30]. A similar approach is applied in our economic model. The base transaction fee is split into two portions with a burning multiplier $l \in [0; 1]$:

$$f = l \cdot f + (1 - l) \cdot f .$$

The first component is burned but the second one is left to a Validator. Clearly, that $l \neq 1$ increases the total Workers’ rewards and reduces the burned coin amount. The value of l can be the same for all blocks and changed only by the network voting, or it depends on a certain block or the reputation of a block producer to incentivize it. This is an issue currently under exploration.

In addition, all penalties are burned as well. If the coin amount on a worker's account becomes less than 50% of the initial stake, then the worker loses the right to validate and produce blocks in the future. In doing so, the received rewards are not taken into account. All kinds of penalties are charged automatically in the case of a Worker's faulty behavior:

1) a Coordinator as a committee member makes a series of vote omissions;
2) a Coordinator as a committee member signs and sends conflicting messages (e.g. double voting);
3) a Coordinator as a block producer does not create a block in the Coordinating network;
4) a Coordinator as a block producer creates more than one block in the same slot of the Coordinating network;
5) a Validator creates more than one block in the same slot of the Sharding network, and those blocks are finalized in the Coordinating network;
6) a Coordinator provides invalid proof of offenses mentioned above.

These decisions are made by all Coordinators, based only on information from the coordinating ledger. A whistleblower who finds an offense records a corresponding proof in a block, when it is its turn to produce a block. Hence, there is no need for an additional network consensus. Penalties are cumulative, e.g., if three blocks are created instead of one, then the penalty is doubled. Moreover, if a committee member does not vote in i-th block, it does not receive its part of the minted reward W_i^c; if a Validator could not have time to synchronize before producing its block and refers to the old blocks, its reward can be reduced. Formally, one can say that there losses are also burned.

IV. MODEL SIMULATING

In a traditional economy, the tracking of currency issuances facilitates the provision of transparency in monitoring various financial aspects. In tokenomics, an increase and decrease in the circulation of coin supply are called inflation and deflation, respectively. The difference between minting and burning coin volumes is an important network economic characteristic that can automatically be calculated on the spot. Thus, the predetermined algorithm of the coin issuance should be properly examined and simulated in reference to specific transaction workloads that affect coin burned volumes as base transaction fees.

Let the value characterized by the occupancy of j-th block of i-th slot be:

$$r_{ij} = \frac{F_{ij}}{W_i^s \cdot p} \in (0; 1].$$

Obviously, if r_{ij} is a constant r within a year, then the annualized amount of burned coins (U) equals:

$$U = \sum_{\forall i \in Y} \sum_{j=1}^{b_i} F_{ij} \cdot l \ = \sum_{\forall i \in Y} \sum_{j=1}^{b_i} r_{ij} \cdot W_i^s \cdot p \ \cdot l = r \cdot V \cdot p \cdot l$$

or if the slot time and the number of blocks are constants within a year, then:

$$U = \sum_{\forall i \in Y} \sum_{j=1}^{b_i} r_{ij} \cdot \frac{V}{B^s} \cdot p \cdot l = r_0 \cdot V \cdot p \cdot l \, ,$$

where r_0 is the average value of r_{ij} over all blocks per year. The annualized burned amount U with $p = 1$ never exceeds the emitted amount V anyway, since $r_{ij} \leq 1$. In the future, the value of p can be changed by network voting.

The annual inflation rate can be considered as the ratio of $(V - U)$ to the current coin supply (approx. $\alpha \cdot S$). A few possible scenarios based on a different level of the block occupancy and the number of Workers are presented in Fig. 4, with $p = 1$ and $l = 1$. Obviously, there is no inflation with $r_0 \cdot p \cdot l = 1$ and the deflation process can be observed with $r_0 \cdot p \cdot l > 1$.

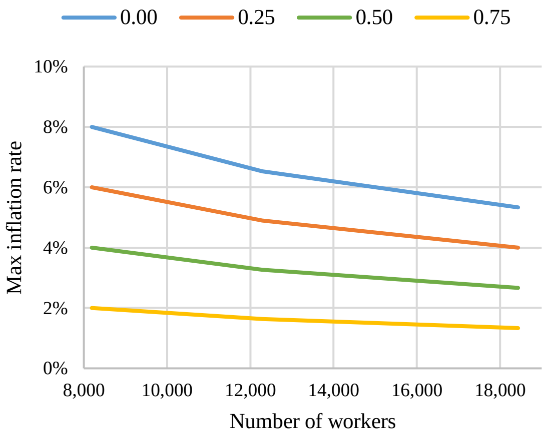

Fig. 4. The maximum annualized inflation rate depending on the average block occupancy r_0 with $\alpha = 2.5$.

The economic model can be both inflationary and deflationary, since the number of coins burned in the Sharding Network correlates with the amount minted in the Coordinating Network. Therefore, for each certain set of network specifications, structural and mathematical modeling can be applied to achieve the optimal configuration of parameters, with a determined objective function according to the chosen strategy of the platform development.

V. CONCLUSION

The Waterfall platform is a complex but effective combination of various existing and original solutions. The consistency of the individual system components and the optimization parameters of their functioning occurs due to the apparatus of tokenomics. Despite the fact that the proposed tokenomics model is developed exclusively for the Waterfall platform, the approaches and algorithms described in the work can be useful in the development of economic support systems for other decentralized systems.

The designed general model allows for achieving an economic equilibrium that takes into account the interests of all network participants and keeps transaction fees at a relatively low level, that facilitates the widespread implementation of decentralized technologies and smart contracts into enterprise-class applications. Its advantages are manifested, when servicing a large flow of transactions (thousands per second). In addition to improving reliability, economic openness promotes the digital transformation of society by adding transparency and trust. In particular, an affordable transaction fee allows the use of the platform for varied DeFi services, IoT, medical screening systems, emerging peer-to-peer energy trading, etc.

The core principles of Waterfall tokenomics are consistent with its DAG-based system design. Moreover, the dynamically adapted macroeconomic mechanisms provide for the self-sustainable and optimal performance of the platform according to the rapidly changing situation.

Future work will include researching economic interactions between a few Sharding networks, formation of transaction fees depending on the coin exchange rate, voting for some economic parameters, and simulating different incentivization strategies, as well as developing the mechanics needed for their implementation, e.g. adjusting a distribution of rewards between Workers, setting values of penalties, economic aspects of on/off-boarding procedures, etc.

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