Carbon-Neutral Distributed Ledger

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***Abstract*-- This work introduces a carbon-neutral approach for Distributed Ledger. With computationally intensive consensus models creating exceptional levels of wasted energy worldwide, it is crucial that distributed ledger technology progresses in a direction that alleviates this trend. This work offers both a novel consensus model and a user incentive that departs from the usage of computational processes for consensus. This work considers the need for longevity of distributed ledger and reflects the desires of the different user archetypes engaged in the recent upswing of cryptocurrency. We anticipate that some users engage for investment or growth speculation, some engage for transactional purposes, and others engage for analytics and transaction verification. We introduce a sustainable distributed ledger that provides engagement considerations for each archetype while eliminating wasteful side effects of computational proof-of-work algorithms.**

The incentive for contribution included for this novel distributed ledger is based on participation over time. This work shows the ability to incentivize each of the archetypes aligned for the purpose of maintaining ledger data and transactions over time. In the model introduced, the key user engagement focus is redirected from computational waste found in current cryptocurrencies to a model that incentivizes constant uptime to receive tokens released for use over time. In addition, we demonstrate that current incentive models which result in global energy waste are converted to a user incentive where all rewards are aligned to maintain continually available data storage.

***Index Terms*— Blockchains, Distributed Ledger, Consensus Algorithms, Carbon emissions, Carbon-Neutral, Decay Algorithm, Proof of Work, Synchronous-Trust Consensus Model, User Incentive.**

I. INTRODUCTION

IN this publication, we introduce results from ongoing work that originated from an applied research project for Distributed Ledger Technology (DLT). The described incentive model is based on the systems-engineering evaluation and re-design of the models utilized in first-generation blockchain [1], [2]. The research approach identified the various archetypes of users which engage with Proof of Work (PoW) blockchains, which we will refer to as Legacy DLT. Included in these archetypes are the following user bases A) idealistic or novelty users, B) user engagement for investment or growth speculation, C) users engaged for transactional use, D) users engaged for analytics and transaction verification, and E) a new class of users of carbon-neutral blockchain. While the motivation for engagement of each user archetype serves a different purpose, each requires a uniform focus for a successful incentive model.

Analysis of the user engagement for Legacy DLTs is contrasted with the benefit each user receives for participating and compared against how each examined incentive model enables longevity of the DLT platform. The resultant analysis is applied to possible alternate configurations for enhanced incentive models absent the adverse impacts of side effects experienced in Legacy DLTs.

A. User Engagement

Archetype-A Users engage for ideological reasons or for the novelty aspects of early DLT. These users express social reform of economic structures as a major driver [3]. This category of user is incentivized by the prospects of the technology to impact social constructs and the ability to create trustless exchanges.

Archetype-B Users are speculatively engaged users who have greatly expanded to include, in the last year, what may be considered Mainstreet users [4]. This user engages for the monetary value posed by the incentive model inherent in the technology.

Archetype-C Users engaged for transactional use are more often the archetype alienated from Legacy DLT use. As Legacy DLT token cost is driven higher with speculation, an adverse impact is inflicted on this user archetype [5]. Promoting the engagement of Archetype-C users is the principal objective of the proposed incentive model, as are many third generations of DLT proposals and designs.

Archetype-D Users are involved with Legacy DLT for analytics and transaction verification and often can be seen as the new third-party service providers. In first-generation cryptocurrency applications, Archetype-D users often represent financial institutions [6].

Archetype-E Users are a new class of users for the described Carbon-Neutral DLT.

B. Side effects of Incentive Models

Our analysis of consensus models in relation to defined user Architype engagement results in identifiable use patterns aligning with three identifiable portions of the Transaction Lifecycle Segments (TLS) as follows: 1) initiation and algorithmic proofs, 2) contract execution, enforcement, and

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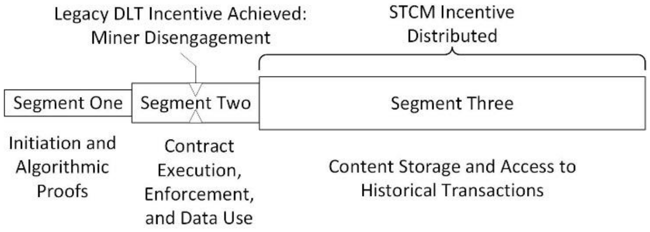
data use, and 3) content storage and access to historical transactions [6]. Incentives for Legacy DLT are different in each of these TLS and in relationship to each of the user archetypes. Several adverse side effects also manifest as a component of these incentives and the growth of users engaged in seeking the DLT rewards.

Figure: Transaction Lifecycle Segments



1) Wasteful PoW Mining

Archetype-B users of Legacy DLT are widely engaged with continuously running computational proof-of-work algorithms, also called mining, to compete to solve mathematical problems in what is essentially a worldwide lottery. The impact of this mining in 2021 for bitcoin alone consumes enough energy to be considered the twenty-first largest economy globally [7]. This use of resources is consumed only for the first and second TLS, where it is applied solely to the production of consensus. Many researchers consider the side effect of wasted energy during consensus as unsustainable [8].

2) Institutional Dependency

Over time, the growth of the overall number of blocks for Legacy DLTs remains an unchecked parameter as there is no limit to the size or current plan for the end of life of legacy operations. Archetype-A users are opting to discontinue to maintain independent ledgers, thus relying more on Archetype-D such as banks and operators of large mining pools for users for access to historical transaction records as the growth of the overall ledger continues [6]. This exit of Archetype-A users manifests because Legacy DLT models do not incentivize maintaining historical records. As a result, Archetype-A users have shifted to become Archetype-B users capitalizing on the existing incentive and adding to the global e-waste dilemma. This also results in another side effect of increasing dependence on these new institutional third parties in contrast to the identified initial aim of distributed ledger to eliminate institutional dependency [1].

The overall impact of the trend gradually pushes toward the institutionalization of DLT technology. The dilemma of mismatch of reward is addressed in “On the Wisdom of Rewarding A While Hoping for B,” as the expected outcome of Legacy DLT is in opposition to the reward set up by the legacy consensus model [9].

3) Cost Overrun

Many industries are exploring the capabilities of peer-to-peer transactions, and many announcements for programs have appeared consistently in the news and as the subject of legislation [3]. However, the engagement of Archetype-C users exhibits inverse elasticity with transaction price. As prices for Legacy DLT tokens have risen, this value increases the cost per transaction. At an elastic intolerance point, these pricing fluctuations cause entire use cases to become cost-prohibitive [10]. This side effect of Legacy DLT incentive models shows an inverse impact as Archetype-C users disengage proportionally as cost increases.

C. SCTM: Carbon-Neutral Incentive

The three adverse side effects of Legacy DLT are addressed by the "Synchronous Trust Consensus Model" (STCM) with a new approach to consensus [11]. At its core, this novel consensus model provides a solution to the mismatch found in Legacy DLT, where it aligns the reward to meet the needs for longevity. The SCTM provides a reward structure to users during the third TLS, which aligns with the intended needs of maintaining transactions over time [9].

SCTM contrasts with Legacy DLT incentive structures that do not incentivize storing the ledger transactions for historical record usage. The SCTM shifts the incentive for user engagement by rewarding tokens for persistent storage during the third TLS. Archetype-E users achieve a single SCTM reward token named Phyli in exchange for storing a single transaction for another peer ledger. Each peer ledger must pay one Phyli for storing each transaction created; thus, Archetype-E users are incentivized now by Archetype-C users to maintain longevity and continued operations.

In Legacy DLT incentives, the computational proof provides a rarity aspect such that tokens are awarded in competition with all other participating nodes [1], [2]. A similar element incorporated into the SCTM restricts awarded Phyli tokens so that they are not made readily available but earned by continued participation throughout the third TLS. To support this participation accumulation, SCTM provides a trust score contained in the consensus blocks, used as a comparison value enabling a method for tracking proper participation. The increase of trust score by a peer ledger is achieved based on maintaining continued synchronicity of consensus operations [12].

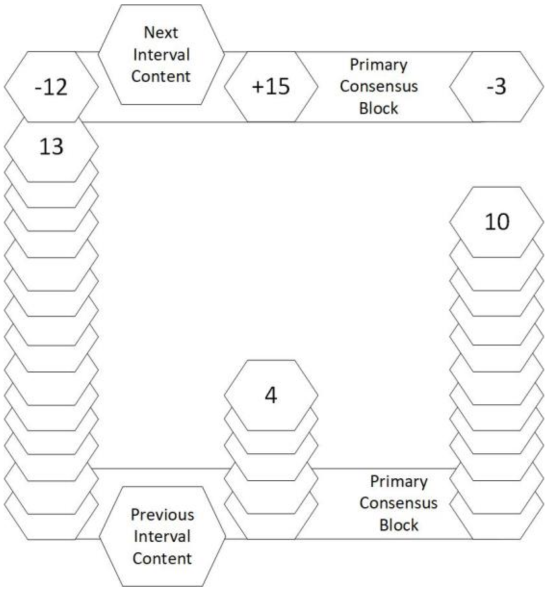
In Legacy DLT, the calculation of remaining tokens held by a node, often called Unspent Transaction Outputs (UTXO), is immutably determined by calculating all transactions back to the genesis blockchain block [1]. In contrast, the SCTM incorporates a continuous movement forward of total calculated values using Ledger Tallied Outputs (LTO). Values included in the LTO related to incentive include: 1) the current numbers of Phyli owned by the peer ledger, 2) the number of Phyli on hold, and 3) the number of Stamps owned by the peer ledger. Stamps represent the number of content blocks the peer ledger is permitted to create [11].

Placing LTO in each consensus removes the requirement to make historical calculations back to a genesis block. A period-of-value set by the incentive model then spreads out the incentive, so Archetype-E users are provided a value to maintain data throughout the entire period-of-value in the third TLS. The period-of-value is set based on needs for data, and every user archetype gains the incentive by maintaining good-behavior and valid contributions continuously.

1) Phyli Incentive

As part of the lowest of the three-level consensus model, called Primary Consensus (P*), each of the distributed nodes implements a net-zero calculation for exchange of Phyli, based on the number of blocks each has made during a synchronization period. The final calculated value is established by each node and is recorded into the LTO of each immutable consensus block. The P* calculation is depicted in Figure "Net Zero Calculation." Each peer ledgers net-zero calculation at the top is based on one Phyli received, from a Primary Synchronization List (PSL) partner, for each block it takes for storage, minus one Phyli paid to each PSL partner for each block produced and sent to that partner for storage.

Figure: Net Zero Calculation



One P interval is displayed with three participants in a PSL. The top P* block shows the calculated net sum values for each of the three peer ledgers. These are the net value of Phyli™ either transferred to or received from PSL partners over the displayed primary synchronization interval.*

2) Phyli-hold Release Incentive

Phyli tokens received during the P* Net Zero Calculations are placed on hold as part of the P* operation. For this process, the number of Phyli-hold in the LTO is increased within each peer ledger by the number of blocks made during that same P* time interval by all peer ledgers in the PSL.

Also, during the P*, a secondary process is applied to each peer's Phyli-hold balance. The release algorithm calculates the number of Phylis' to be released from the Phyli-hold balance, making them available for use by that peer.

The incentive offered by the combination of Phyli distribution and Phyli-hold release provides the ability for Archetype-E users to participate and gain incentive without requiring any outgoing payments.

Here we give a high-level description to show how Phyli-holds are released over time; for simplicity, we omit the derivation of the algorithm. The change in the hold balance at time step k is computed according to the formula

$$H_k = H_{k-1}\delta + H_n, \quad (1)$$

where H_k is the current LTO hold balance at time k, H_{k-1} is the previous LTO hold balance, δ is the decay constant which is the fraction of the holds that remain held at each P*, and Hn is the new holds to be added to the LTO balance. The hold release algorithm utilizes the trust value calculated at the time of each bridge sync [11], [12]. This raw trust is then normalized between 0 and 100, which will be used to determine the number of years it will take for the peer ledger to reach the equilibrium release state. The equilibrium release state is a condition in which, at each P*, the number of holds added to an LTO balance will be approximately equal to the number of holds released from the LTO balance. Therefore, a higher trust value will result in a faster hold release, reducing the number of years required to reach the equilibrium release state. It should also be noted that since a peer ledgers trust value is recomputed at each bridge sync and can therefore be very dynamic, the equilibrium release rate will also be dynamic. The decay constant is calculated as follows:

$$\delta = (1 - p)^{1/K}, \quad (2)$$

where K is the number of prime steps to reach a p-fraction of the equilibrium release rate.

3) Stamp Incentive

Some Legacy DLTs have applied multiple-tier incentive structures for different types of participation. The SCTM employs a second-tier token called a Stamp which uses a similar concept as that of Ethereum's Gas. The Stamp is a transferable incentive connected to the execution of a single transaction. Stamps are linked to a Smart Contract, called a Transaction Contract (T.C.) in the Philos™ platform, and are pre-purchased before T.C. execution in exchange for Phyli.

The number of Stamps held by each peer ledger is one of the LTO values, and as with the Phyli and Phyli-hold, Stamp balances change during P*, in addition to the Net Zero Calculations. With this method, Archetype-C users can purchase or sell Stamps for varying amounts of Phyli to other Archetype-C users.

In addition, the selling of Stamps between peer ledgers effectively creates another incentive structure. Having built a business model implemented by a Transaction Contract, the Archetype-C user can effectively pre-sell Stamps to another Archetype-C operator, allowing the second user to execute a limited number of transactions utilizing their Transaction Contract.

4) Phyli Acquisition

A peer ledger can acquire Phyli from another peer ledger through an exchange sequence. Alternatively, the Philos Marketplace™ Administration Management can issue Phyli structured under a service agreement. This method of acquiring Phyli is anticipated to be used for economic controls of the entire system to manage growth and the price per Phyli set by the needs for maintaining economic stability. The initial assessment of cost is ten times for Phyli with no hold vs. a Phyli with a matching Phyli-hold. As an example, if the initial cost of a Phyli with a matching Phyli-hold is one cent, then the initial cost of a Phyli with no hold is ten cents.

5) Phyli Annihilation

Phyli is a utility token, and thus a method is provided to remove a portion of them from the system by annihilation. Phyli is removed when converted to Stamps for use to execute Transactions Contracts as defined by the Stamp Incentive.

6) *Economic Stability Incentives*

A main intent of the SCTM and constructs for the described incentive models are to maintain a widely expandable stable marketplace. To do so the value anticipated for executing a single content item must remain economically constant and remain tied to the value of data storage over the period-of-value during the third transaction lifecycle segment. This incentivization is implemented through the balance of available Phyli introduced into the Philos Marketplace™ over time by the Administration Management.

7) *Incentives Calculation*

The incentive is tallied during each consensus and placed into the LTO within the immutable consensus block. LTO calculations by each peer ledger in the synchronization list execute independently based on each peer ledger's uniform set of blocks. Verification of LTO and protection from double-spend are the purpose of the higher two levels of consensus. The calculations for consecutive P* operations are seen in Figure: "LTO Calculations." The image exhibits the LTO resultant values given the displayed set of blocks produced by each peer ledger. The Phyli value in the Next Primary Consensus Block (P* Next) is augmented by the resultant Net-Zero Calculation performed for that peer ledger.

Example: System ID (SID): 25

$$\mathrm{Phyli}_{25}^{Final} = \mathrm{Phyli}_{25}^{Initial} + \mathrm{Net} - \mathrm{Zero}_{25}$$
$$10{,}004 = 10{,}000 + (+4)$$

The Stamp value in the P* Next is reduced by the number of blocks made by that peer.

Example: System ID (SID): 25

$$\mathrm{Stamps}_{25}^{Final} = \mathrm{Stamps}_{25}^{Initial} - \mathrm{Blocks\ Created}_{25}$$
$$8{,}757 = 8{,}762 - (5)$$

The Phyli-hold value in the P* Next is adjusted based on the reduction in the number of holds calculated by the hold release algorithm and an increase by the number of blocks made by all peers in the synchronization list.

Example: System ID (SID): 25

$$\mathrm{Phyli\ hold}_{25}^{Mid} = \mathrm{Phyli\ hold}_{25}^{Initial} - \mathrm{Hold\ Decay}_{25}$$

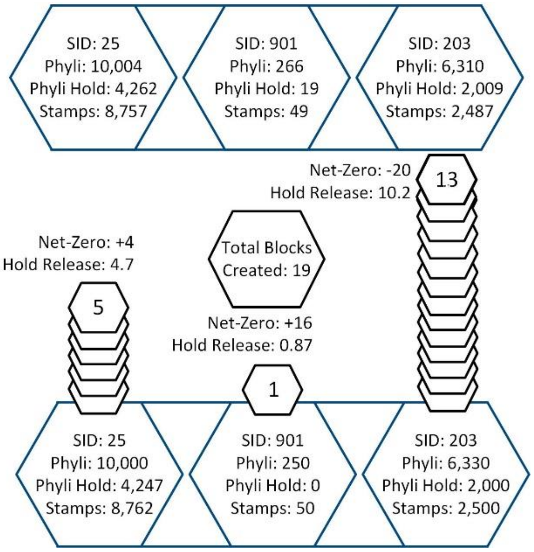
$$4{,}242.3 = 4{,}247 - 4.7$$

$$\mathrm{Phyli\ hold}_{25}^{Final} = \mathrm{Phyli\ hold}_{25}^{Mid} + \mathrm{Total\ Blocks}_{25}$$
$$4{,}261.3 = 4{,}242.3 + (19)$$

D. *Potential Global Energy Reclaimed*

With the current trend in cryptocurrency use, there is a tremendous potential to use this defined incentive model to reverse a dangerous global trend. Unfortunately, the trend continues to worsen. In January 2016, to mine one Bitcoin required 1005 kWh, while in June 2018, each mined coin cost approximately 60,461 kWh [13].

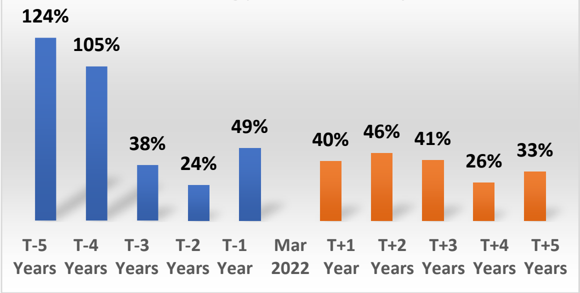
Figure: LTO Calculations



One P interval is displayed with three participants in a PSL. The calculations for the period applied within the Next P* Block are the results of calculations done for Ledger Tallied Outputs and placed into the Immutable Next P* Block.*

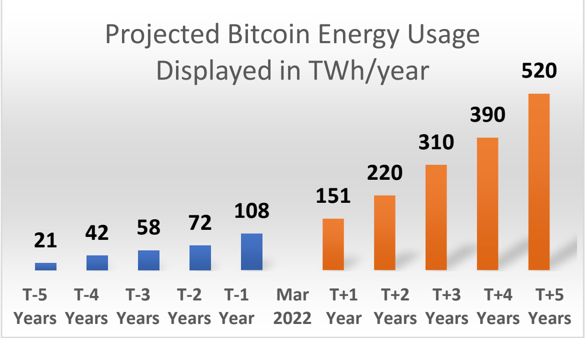
The annual best guess bitcoin energy consumption for one full year before March 2022 was 107.55 TWh, the previous year's energy consumption was 72.04 TWh [14]. The following chart shows the year-over-year increases in energy usage for the last five years [14]. Added to this chart are projections should bitcoin energy usage continue to grow in a similar but reduced trend over the next five years.

Figure: Bitcoin Energy Growth Projections



With these projected growth trends, the energy usage is shown over a five-year period in Figure "Bitcoin Energy Usage Projections." The resultant yearly energy projected consumption of 520 TWh is more than Germany, the world's ninth-largest power using country.

Figure: Bitcoin Energy Usage Projections



If the resultant change just maintained the current worldwide bitcoin power consumption, the projected cumulative savings over the next five years would be 1053 TWh, which is greater than the annual energy usage of Russia, the world's fourth-largest power using country. This amount of power usage would cost 52.6 Billion U.S. Dollars at $0.05 per kWh, creating approximately 895 Billion pounds of CO2 emissions [15].

E. Conclusion

We have proposed a novel incentive model for Distributed Ledger, where no intensive computational algorithms are used during the consensus processes and where the system could be carbon neutral. In our analysis of Legacy DLT, we identified the wasted energy spent on mining is exerted in the first and second of three segments of the overall transaction lifecycle (TLS). In order to remove the dependency on transactional proofs, a new incentive is presented, which incentivizes the storage of transactions instead of mining, which uses computationally intensive proof algorithms. The Synchronous-Trust Consensus Model, which implements this unique incentive, shifts the reward from the first two TLS as it appears in Legacy DLT applications to the third TLS in the SCTM.

The novel incentive model was discussed in relation to DLT engagement by several different archetypes of users and a workable incentive for each type of user offered. Should the techniques proposed in this paper be adopted, it could bring about a dramatic reduction of DLT-sourced carbon emissions. Changes suggested by this model could result in a reduction of projected worldwide energy usage by 1053 TWh. The resultant reduction would equate to savings of 48.9 Billion U.S. Dollars and a decrease of 895 billion pounds of CO2 emissions.

F. References

[1] S. Nakamoto, Bitcoin: A Peer-to-Peer Electronic Cash System. Satoshi Nakamoto, 2008. [Online]. Available: www.bitcoin.org

[2] V. Buterin, “A Next Generation Smart Contract & Decentralized Application Platform.” Ethereum, 2017. [Online]. Available: etherium.org

[3] Benkler, Yochai. "We cannot trust our government, so we must trust the technology." The Guardian Feb 22 (2016). www.theguardian.com.

[4] K. Grobys, S. Ahmed, and M. Sapkota, “Technical trading rules in the cryptocurrency market,” Elsevier - Finance Res. Lett., vol. 42, no. 32, Oct. 2021.

[5] K. Wang, N. Jia, C. Han, and M. Maheswaran, “A Social Accountability Framework for Computer Networks,” IEEE Commun. Soc., vol. 978-1-4244-5638–3, p. 10, 2010.

[6] C. Borio, S. Claessens, B. Cohen, D. Domanski, and H. S. Shin, BIS Quarterly Review September 2017 International banking and financial market developments. Bank for International Settlements, 2017. Accessed: Mar. 13, 2022. [Online]. Available: www.bis.org/publ/qtrpdf/r_qt1709.htm

[7] A. de Vries and C. Stoll, “Bitcoin’s growing e-waste problem,” Resour. Conserv. Recycl., vol. 175, p. 105901, 2021, doi: https://doi.org/10.1016/j.resconrec.2021.105901.

[8] B. Sutherland, “Blockchain’s First Consensus Implementation Is Unsustainable,” Elsevier, vol. 3, no. 4, pp. 917–919, Apr. 2019, doi: 10.1016.

[9] R. D. Boettger and C. R. Greer, “On the Wisdom of Rewarding A While Hoping for B,” Organ. Sci., vol. 5, no. 4, pp. 569–582, Nov. 1994.

[10] C. Gorog and T. Rossi, “BlockFrame CSU-P MJ Tracking Project Phase II.” BlockFrame Inc., Apr. 2018, [Online]. Available: https://bit.ly/3q0KBm6.

[11] C. Gorog and T. Boult, “Blockchain Synchronous Trust Consensus Model,” arXiv:2112.03692 Dec 2021

[12] P. Russell and P. Brown, “The Philos Trust Algorithm: Preventing Exploitation of Distributed Trust,” arXiv:2203.04795 Mar2022.

[13] I. Inacio, “Environmental costs related to cryptocurrency mining: ensuring that innovation does not happen at the expense of the environment.,” SSRN, May 2021, doi: 10.2139.

[14] University of Cambridge, “Cambridge Bitcoin Electricity Consumption Index,” Cambridge Bitcoin Electricity Consumption Index Methodology, Feb. 27, 2022. https://ccaf.io/cbeci/index (accessed Feb. 27, 2022).

[15] U.S. Energy Information Administration, “U.S. Energy Information Administration,” Independent Statistics & Analysis, 2022. https://www.eia.gov/ (accessed Mar. 01, 2022).

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