산업융합연구 제21권 제8호 pp. 51-58, 2023
ISSN 2635-8875 / e-ISSN 2672-0124
DOI : https://doi.org/10.22678/JIC.2023.21.8.051

A Scalability based Energy Model for Sustainability of Blockchain Networks

Seung Hyun Jeon[1], Bokrae Jung[2*]
[1]Professor, Dept. of Computer Engineering, Daejeon University
[2]Professor, Dept. of Information Communication Engineering, Sunkyul University

블록체인 네트워크의 지속 가능성을 위한 확장성 기반 에너지 모델

전승현[1], 정복래[2*]
[1]대전대학교 컴퓨터공학과 교수, [2]성결대학교 정보통신공학과 교수

Abstract Blockchains have recently struggled to design for the ideal distributed trust networks by solving scalability trilemma. However, local conflicts between some countries lead to imbalance on energy distribution. Besides, blockchain networks (e.g., Bitcoin) currently consume enormous energy for transaction and mining. The existing data volume based trust model evaluated an increasing blockchain size better than Lubin's trust model in scalability trilemma. In this paper, we propose a scalability based energy model to evaluate sustainability for blockchain networks, considering energy consumption for transaction, time duration, and the blockchain size of growing blockchain networks. Through the rigorous numerical analysis, we compare the proposed scalability based energy model with the existing model for the satisfaction and optimal blockchain size. Thus, the scalability based energy model will provide an assessment tool to choose the proper blockchain networks to solve scalability trilemma problem and prove sustainability.

Key Words : Blockchain networks, Sustainability, Blockchain size, Energy model, Scalability trilemma

요 약 최근 블록체인은 트릴레마를 해결하기 위해 이상적인 분산 신뢰 네트워크를 설계하려고 노력했다. 그러나 일부 국가 간 분쟁으로 에너지 분배의 불균형이 발생했고, 현재 비트코인과 같은 블록체인 네트워크가 거래와 채굴을 위해 엄청난 에너지를 소비하고 있다. 기존 연구인 데이터 볼륨 기반 신뢰 모델은 루빈 방식의 신뢰 모델보다 증가하는 블록체인 크기를 더 잘 평가했다. 본 논문에서는 성장하는 블록체인 네트워크의 존속시간, 블록체인 크기 및 거래를 위해 소모된 에너지를 고려하여 블록체인 네트워크의 지속 가능성을 평가하는 확장성 기반 에너지 모델을 제안한다. 또한 수학적 분석을 통해 제안 모델과 기존 모델에 대한 만족도와 최적의 블록체인 크기를 비교한다. 그러므로 제안된 확장성 기반 에너지 모델은 트릴레마를 해결하고 지속 가능성을 검증하는 적절한 블록체인 네트워크를 선택할 수 있는 평가 툴을 제공할 것이다.

키워드 : 블록체인 네트워크, 지속 가능성, 블록체인 크기, 에너지 모델, 블록체인 트릴레마

*Corresponding Author : Bokrae Jung(brjung@sungkyul.ac.kr)
Received June 23, 2023 Revised July 13, 2023
Accepted August 20, 2023 Published August 28, 2023

1. Introduction

Many blockchain networks have recently been released as new trust infrastructure for peer-to-peer digital asset trading. However, all peers still feel difficulty in having the same right for mining and their rewards in ideally distributed networks. Vitalik Buterin initially introduces scalability trilemma, which has 3 kinds of serious problems as follows: decentralization, security, and scalability[1,2]. In other words, there exist few blockchain networks to completely solve the scalability trilemma. Meanwhile, Joseph Lubin[3] proposed a decentralization based trust model to evaluate blockchain networks. However, because the Lubin's trust model was not sufficiently considered for a scalability issue, we presented a data volume based trust model[4]. Continuously increased blockchain scale will finally drop reliability and performance of transaction in blockchain networks.

Nevertheless, vitalization of electric vehicle markets and advance in artificial intelligence continue to accelerate energy consumption globally. Besides, mining and transaction for blockchain networks have impact on hugely increasing energy consumption. Some countries' conflicts in Eastern Europe have recently led to imbalance on energy distribution. Accordingly, these conflicts disrupt the spread of renewable energy and then obstructs the growth of blockchain networks due to enormous energy consumption. In addition, these issues may cause increasing electric charge globally. Thus, the trustable solution on evaluating sustainability of blockchain networks, considering throughput and storage in blockchain scalability and energy consumption for transaction should be required. However, there are few energy models to access sustainability on energy consumption of blockchain networks.

In this paper, we propose a scalability based energy model that maximizes satisfaction of blockchain sustainability and minimizes energy consumption of transaction for increasing blockchain sizes based on Lubin's trust model[3]. To solve the blockchain sustainability problem with scalability trilemma, we design a well-defined utility function and the optimal blockchain size and satisfaction for popular blockchain networks are presented. Finally, through the existing Lubin's trust model[3] and the proposed scalability based energy model between popular blockchain networks are compared, we evaluate that Dogecoin (DOGE) is the most sustainable blockchain, which is different with the result of the previous works due to not considering energy of transaction.

2. Literature on Blockchain Sustainability

Recently, we have much interested in how long a certain blockchain network survives among floods of cryptocurrencies. In addition, according to increasing energy consumption for advanced technologies on prevalent machine learning, blockchain networks, and increasing electricity price from local conflicts, we focus on blockchain networks for sustainable operation. Now we explain two issues for blockchain sustainability.

2.1 Scalability of Blockchain Networks

First of all, scalability in blockchain networks should consider many aspects as follows[1]: throughput, storage, cost, and latency. However, the recent advance on blockchain networks has focused on the only throughput (e.g., transaction per second). If the performance of transaction is high advanced, the demand of storage in blockchain networks increases due to many transactions[2,5]. The reduction of block data mitigates the pressure of the total nodes in blockchain networks. Thus, the throughput and storage of blockchain networks should consider maintaining blockchain networks together. We mentioned a trust model related to storage of scalability in the previous work[4].

2.2 Energy of Blockchain Networks

Bitcoin (BTC) is a pioneer blockchain network on trading digital assets among peers. However, handicaps of BTC have relatively long transaction time and consumes much massive CO2 on mining[6]. In addition, energy consumption and CO2 emission are more inconceivable than VISA of as of July 2021[7]. Energy consumption per transaction as well as scalability in blockchain sustainability are much important.

While, Ethereum (ETH) recently changed its proof of work (PoW) into a proof of stake (PoS) for the blockchain sustainability, and PoS based Ethereum (ETH2) is now working[8]. However, we only considered the initial version of ETH before merging the original blockchain network into ETH2 on September 15, 2022[8,9], because the time duration to evaluate ETH2 as a new blockchain is not sufficient. Besides, even though energy consumption of ETH2 is much lower than that of DOGE[7], PoS based transactions have not accumulated for a long time.

Recently, Lasla *et al.*[10] proposed a Green-POW, which designs an energy-efficient consensus algorithm to reduce mining's energy consumption about 50%. Tezos with a PoS based consensus algorithm like ETH2 recently reduced energy efficiency of transaction almost 70%[11]. However, these transactions are not prevalent for time duration.

Thus, energy consumption on transaction within scalability trilemma[1] for blockchain sustainability should be considered[12].

In Forbes advisor[13], 4 solutions to reduce energy consumption of blockchain networks were proposed.

First, by transfer to sustainable renewable energy on mining, portion of green energy gradually increases. In fact, because global energy crisis by local conflicts happened and supply shortages subsequently led to increasing electricity price, changing flow into green energy is not still easy[14]. Unfortunately, energy policy to overcome climate crisis is temporarily affected. Thus, current energy shortages and increasing electricity price should be considered to choose sustainable blockchain networks.

Second, PoS based blockchain networks like ETH2 can reduce energy waste. The newly merged ETH can reduce energy consumption as much as almost a thousand times, compared with the original blockchain[7]. Thus, ETH2 may become one of sustainable blockchain networks.

Third, pre-mining, which is not mined for transaction and reward, is considered such as Ripple. However, even though energy consumption for transaction is dramatically low[15], Ripple is not sufficiently secure in scalability trilemma, considering a DQ index[16]. Thus, Ripple is not compared with the conventional blockchain networks in this paper.

Finally, carbon incentives or fees can be posed into blockchain companies, which struggle to reduce or produce CO2 emission for transaction.

In this paper, we present some penalties for energy per transaction for increasing blockchain sizes. Thus, we can evaluate sustainability of blockchain networks, which include solving scalability trilemma problem.

3. System Model

We consider energy consumption per transaction[15], which is not included at a Lubin's trust model[3] and a data volume based trust model[4]. Accordingly, we design an energy consumption model into the data volume based trust model, because energy saving is important for sustainable blockchain networks. Because we apply the same blockchain networks as the data volume based trust model[4], we can directly compare the proposed trust model with Lubin's trust model[3].

Before the scalability based energy model is proposed, we briefly introduce the conventional trust models as follows: a Lubin's trust model[3] and data volume based trust model[4].

3.1 The Existing Lubin's Trust Model

Previous researches have been focused on throughput of blockchain networks to overcome VISA transaction. However, increasing transaction speed may bring about weak decentralization of blockchain networks. Accordingly, Joseph Lubin presented a concept of a decentralization quotient (DQ), which is a measure between 0 and 1[3]. If a blockchain network is fully decentralized, it reaches at 1. For example, the DQs of BTC and ETH show the different degrees on decentralization at 0.8 and 0.7, respectively. Thus, decentralization transaction per second (DTPS) can supplement the existing assessment for blockchain networks, considering scalability trilemma[3].

In this paper, we select a Lubin's trust model[3] as a base model for sustainability of blockchain networks.

3.2 The Existing Blockchain Size based Trust Model

As the previous work[4], we briefly explain a blockchain size based trust metric (S-Trust) as follows:

$$U_{S-Trust}(x) = I_{DTPS}\,\sigma(\alpha x) - \frac{r_s}{s_b} \times \alpha x, \qquad (1)$$

where x is a blockchain size, α is a scale factor. $\sigma(\alpha x)$ is defined as a satisfaction function for αx. Using a sigmoid function[4], this presents whether blockchain users are satisfactory to increase the blockchain size. I_{DTPS} is a DTPS parameter, r_s is stale block rate (%), and s_b is average block size (KB), respectively. I_{DTPS} is defined by DQ × TPS in Table 1.

Thus, the S-Trust model[4] defines the satisfaction for TPS and valid transaction for increasing the blockchain size, and then provides the optimal blockchain size to maximize the satisfaction. With throughput of blockchain scalability, huge blockchains cause increasing the demand on more storage, which may delay to download the blockchain[1].

In this paper, we advance the S-Trust model to add the penalty of energy consumption per transaction to evaluate the sustainability among the popular blockchain networks.

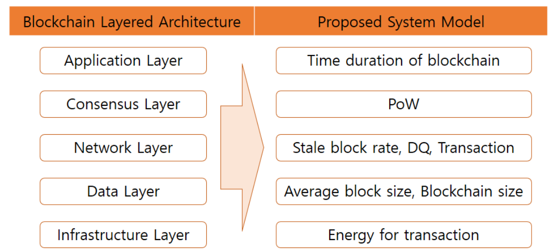


Fig. 1. The proposed system model

3.3 Proposed Scalability based Energy Model

First, we show that the features of a proposed system model are aligned with each layer of a blockchain layered architecture in Fig. 1.

Subsequently, we propose an energy model to evaluate the energy consumption of blockchain networks according to increasing a blockchain size. Here, we add an energy consumption model into the existing S-Trust as follows:

$$U(x) = U_{S-Trust}(x) - \frac{E_t N_t}{D_{bc}} \times \alpha x, \qquad (2)$$

where E_t is energy per transaction (KWh), N_t is the number of transactions, and D_{bc} is time duration (second) of blockchain networks, respectively. The proposed second term also uses the scale factor (α) of x, similar to Eq. (1). When the counts of transactions are increasing, energy consumption also increases.

Thus, the proposed scalability based energy model explains the satisfaction of the S-Trust model and energy consumption on transaction for increasing the blockchain size, considering blockchain sustainability.

Based on Eq. (2), we can define a blockchain sustainability problem[17] relating to satisfaction of increasing the blockchain size as follows:

$$x^* = \arg\max_{x>0} U(x), \tag{3}$$

where *U(x)* has a convex set[17]. Because the blockchain size (*x*) is a positive value, 1st, 2nd, and 3rd terms of Eqs. (1) and (2) are concave and affine functions, respectively.

For maximizing the scalability based energy model of (3), the derivative of *U(x)* is defined as followings:

$$\frac{\partial U(x)}{\partial x} = I_{DTPS} \frac{\partial}{\partial x}\left(\frac{e^{\alpha x}}{e^{\alpha x}+1}\right) - \frac{\alpha r_s}{s_b} - \frac{\alpha E_t N_t}{D_{bc}}. \tag{4}$$

Here, considering $\frac{\partial U(x)}{\partial x}=0$, we can find the optimal blockchain size (x^*) by the substitution that $e^{\alpha x}=t$. Thus, we can derive a quadratic equation as follows:

$$\beta t^2 + (2\beta - I_{DTPS})t + \beta = 0, \tag{5}$$

where, a refined value (β) is represented as follows:

$$\beta = \frac{r_s D_{bc} + s_b E_t N_t}{s_b D_{bc}}, \tag{6}$$

where, t is always larger than 0 due to an exponential function. Finally, t is calculated as follows:

$$t = \frac{(I_{DTPS} - 2\beta) + \sqrt{(2\beta - I_{DTPS})^2 - 4\beta^2}}{2\beta}. \tag{7}$$

Thus, the optimal blockchain size (x^*) can be calculated from Eq. (7) as follows:

$$x^* = \frac{\ln(t)}{\alpha}. \tag{8}$$

4. Numerical Results

In this section, we present the numerical analysis for the proposed scalability based energy model and the conventional Lubin's trust model[3]. We mostly assume blockchain networks and parameters used from data volume based trust model[4]. Table 1 defines the primary parameter and values in Eq. (2) for performance comparison of the proposed scalability based energy model.

Table 1. The parameters and values[4,13,18]

Items	BTC	ETH	LTC	DOGE
DQ	0.8	0.7	0.5	0.5
TPS	7	15	56	33
r_s [%]	0.41	6.8	0.273	0.619
s_b [KB]	534.8	1.5	6.11	8
N_t	711,738,687	1,476,315,700	105,523,841	82,727,411
D_{bc} [Year]	13.14	6.57	10.38	8.21
Et[KWh]	707	62.56	18.522	0.12
α	5×10^{-6}			

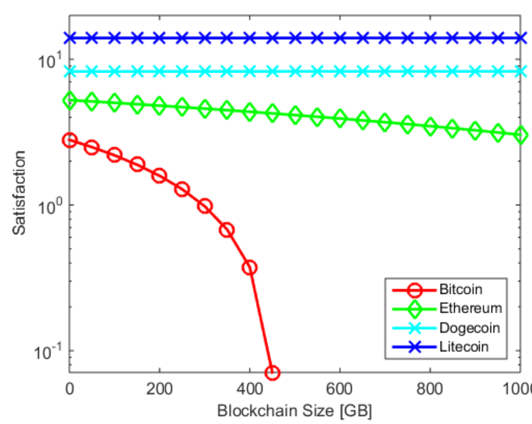


Fig. 2. Comparison among blockchain networks

Fig. 2 compares satisfaction of blockchain networks according to increasing the blockchain size. BTC and ETH are permanently decreasing because their PoWs increase their energy per transaction much. While DOGE and Litecoin (LTC) work based on a similar PoW, their energy consumption per transaction is significantly low in Table 1. Although the blockchain network of the lowest power consumption in Table 1 is DOGE, LTC shows the most satisfaction among other blockchain networks, considering the proposed scalability based energy model. Unfortunately, the satisfaction of BTC and ETH decreases for increasing blockchain sizes.

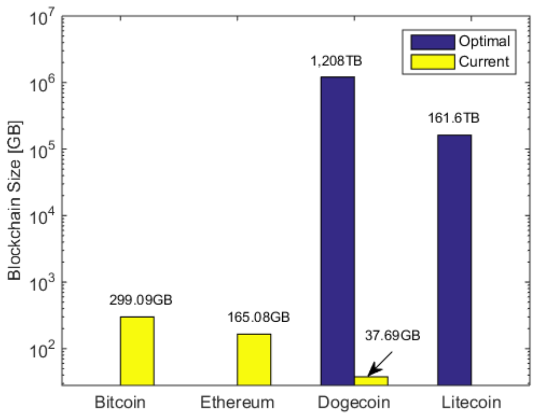


Fig. 3. The optimal and current blockchain sizes for blockchain networks

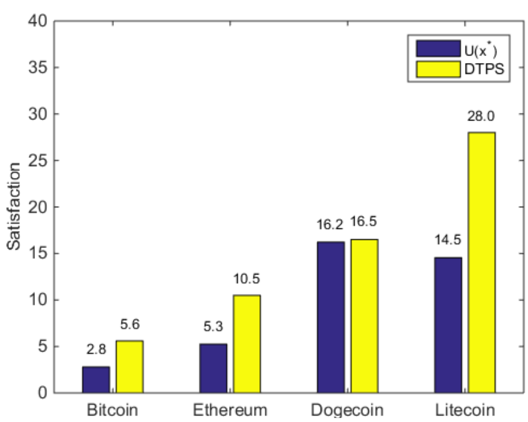


Fig. 4. Comparison between the proposed scalability based energy model and the existing Lubin's trust model

Fig. 3 shows the comparison between the current and optimal blockchain sizes. Unfortunately, BTC and ETH cannot confirm the optimal blockchain sizes, because the proposed scalability based energy models for their blockchain networks are continuously reduced and then their transactions on blockchain networks are not satisfactory. However, DOGE and LTC are sufficiently big for available blockchain sizes as 1,208 terabyte (TB) and 161.6 TB, respectively. In particular, DOGE can provide the most optimal data volume among other blockchain networks. Thus, BTC and ETH may become not sustainable blockchains, under the proposed scalability based energy model.

Fig. 4 shows the performance between the proposed scalability based energy model and the conventional Lubin's trust model[3]. The existing Lubin's trust model shows LTC is the most blockchain networks. However, the proposed scalability based energy model presents that DOGE is the most sustainable as 16.2, considering the blockchain size and energy consumption. Considering only the Lubin's trust model, LTC is significantly higher than DOGE for blockchain satisfaction. However, when the energy per transaction is additionally considered, DOGE is the best choice for sustainability. This means that the growth of DOGE can be sufficiently verified, because all transaction costs should be reduced in blockchain networks, considering that electricity consumption dramatically increases. Here, the satisfaction comparison among blockchain networks is available within each model.

Finally, the evaluation of the conventional Lubin's trust model chooses LTC. While, the proposed scalability based energy model selects DOGE. Because DOGE provides potentially the largest blockchain network, we can anticipate that the time duration of DOGE will be the longest among any blockchain networks.

5. Conclusion

We have presented a scalability based energy model to evaluate sustainability of blockchain networks, considering the blockchain size and energy consumption for transaction. The proposed scalability based energy model considers transaction based energy consumption caused by the existing data volume based trust model. Through a rigorous analysis, we show that DOGE is one of the superior blockchain networks for sustainability against the previous Lubin's trust model. The proposed scalability based energy model anticipates to well verify blockchain networks for sustainability.

REFERENCES

[1] A. Hafid, A. S. Hafid & M. Samih (2020). Scaling Blockchains: A Comprehensive Survey. *IEEE Access, 8*, 125244-125262.

[2] D. Khan, L.T. Jung, M.A. Hashmani (2021). Systematic Literature Review of Challenges in Blockchain Scalability. *Applied Science, 11*, 9372.

[3] J. Lubin (Apr. 6, 2019). *An Overview of the State of the Blockchain Ecosystem*. Decrypt(Online). https://decrypt.co/6343/an-overview-of-the-state-of-the-blockchain-ecosystem

[4] S. H. Jeon. (2020). Data Volume based Trust Metric for Blockchain Networks. *Journal of Convergence for Information Technology, 10 (10)*, 65-70.

[5] Q. Zhou, H. Huang, Z. Zheng & J. Bian. (2020) Solutions to Scalability of Blockchain: A Survey, *IEEE Access, 8*, pp. 16440-16455.

[6] OECD (2019). *Blockchain technologies as a digital enabler for sustainable infrastructure*. OECD iLibrary(Online). https://www.oecd-ilibrary.org/environment/blockchain-technologies-as-a-digital-enabler-for-sustainable-infrastructure_0ec26947-en

[7] V. Kohli, S. Chakravarty, V. Chamola, K. S. Sangwan & S. Zeadally (2023). An analysis of energy consumption and carbon footprints of cryptocurrencies and possible solutions. *Digital Communications and Network, 9(1)*, 79-89.

[8] Ethereum.org (2022), *What was The Merge?* The Merge(Online). https://ethereum.org/en/upgrades/merge/

[9] W. Duggan, M. Adams, F. Powell. (2022). *What Is Ethereum 2.0? Understanding The Ethereum Merge*. Forbes Advisor(Online). https://www.forbes.com/advisor/investing/cryptocurrency/what-is-ethereum-2-merge/

[10] N. Lasla, L. Al-Sahan, M. Abdallah & M. Younis (2022). Green-PoW: An energy-efficient block chain Proof-of-Work consensus algorithm, *Computer Networks, 214*, 109-118.

[11] Tezos: An Energy-Efficient Blockchain. Tezos (Online). https://tezos.com/carbon/

[12] J. Sedlmeir, H.U. Buhl, G. Fridgen & R. Keller (2020). The Energy Consumption of Blockchain Technology: Beyond Myth. *Business & Information Systems Engineering 62*, 599–608.

[13] J. Schmidt, F. Powell. (2022). *Why Does Bitcoin Use So Much Energy?* Forbes Advisor(Online). https://www.forbes.com/advisor/investing/cryptocurrency/bitcoins-energy-usage-explained

[14] E. Thomson. (2022). *6 ways Russia's invasion of Ukraine has reshaped the energy world*. World Economic Forum(Online). https://www.weforum.org/agenda/2022/11/russia-ukraine-invasion-global-energy-crisis/

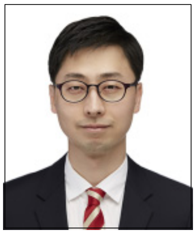
[15] *Popular cryptocurrencies: Which is the most environmentally friendly?* TRG Datacenters (Online). https://www.trgdatacenters.com/most-environment-friendly-cryptocurrencies/

[16] E. Muzzy and M. Anderson. *The Maximally Decentralized Blockchain Settlement Layer*. Consensus Research(Online). https://consensys.net/research/the-maximally-decentralized-settlement-layer/

[17] S. Boyd & L. Vandenberghe. (2004). Convex Optimization. Cambridge : Cambridge Univ. Press.

[18] A. Gervais, G. O. Karame, K. Wüst, V. Glykantzis, H. Ritzdorf & S. Čapkun. (2016, October). On the security and performance of Proof of Work blockchains. *23rd ACM Conference on Computer and Communications Security*, (pp. 3-16). New York : ACM.

전 승 현(Seung Hyun Jeon) [정회원]



• 2017년 2월 : 한국과학기술원 전기및전자공학부 (공학박사)
• 2018년 7월 : KT 융합기술원 인프라DX연구소
• 2023년 3월~현재 : 대전대학교 컴퓨터공학과 조교수

• 관심분야 : 분산망, 에너지 소모, 블록체인, 기후 위기
• E-Mail : creemur@dju.kr

정 복 래(Bokrae Jung) [정회원]

• 2010년 8월 : 한국과학기술원 정보통신공학과 (공학박사)
• 2011년 5월 : 한국전력기술(주) 원자로설계개발단 선임기술원
• 2012년 3월~현재 : 성결대학교 정보통신공학과 부교수

• 관심분야 : 광가입자망, 유·무선 통합망 기술, 그린에너지 통신망
• E-Mail : brjung@sungkyul.ac.kr