The Journal of Korean Institute of Communications and Information Sciences '24-07 Vol.49 No.07
https://doi.org/10.7840/kics.2024.49.7.983

Pure Loyalty: Efficient and Secure Framework for NFT Loyalty Programs

Gifar Arif Haryadi◆, Muhammad Rasyid Redha Ansori*, Jae-Min Lee**, Dong-Seong Kim°

ABSTRACT

This study explores the versatile applications of blockchain technology, particularly within loyalty program frameworks, addressing challenges faced by traditional loyalty programs in trust, transparency, operational efficiency, and potential issues like double-spending and fraudulent activities. The focus is on designing a loyalty program framework and selecting suitable ERC721 libraries for batch minting, involving a meticulous evaluation of gas usage across different libraries for various scenarios. The proposed loyalty program architecture introduces the Subscription model, utilizing ERC721A, ERC721G, and ERC721Psi for batch minting, along with ERC20 for comprehensive token functionality. Incorporating SoulBound Tokens (SBTs) enhances security, preventing unauthorized transfers and potential rule violations, such as the unauthorized transfer of vouchers. IPFS facilitates off-chain storage of subscription badges for efficiency. The gas comparative analysis highlights associated costs, revealing potential advantages and areas for improvement. Future work includes further smart contract optimization and the development of a decentralized application (DApp), extending the practical implications of the proposed loyalty program framework.

Key Words : Batch Minting, IPFS, Loyalty Programs, NFT, SoulBound Token, Voucher

Ⅰ. Introduction

Blockchain technology, known for its decentralized and transparent characteristics, has found applications beyond its initial use in cryptocurrencies, influencing various sectors significantly. In the media sector, Ethereum's blockchain has been utilized for copyright protection, enabling decentralized music sharing and efficient licensing fee management through smart contracts. This application is demonstrated by the Hash-Based Audio Detection System (HADES)[1]. In finance, blockchain technology facilitates the conversion of cryptocurrency into digital tokens for offline use, as seen with Pure Wallet (PW)[2], showcasing its versatility and broad impact.

The evolution of loyalty programs, driven by the need to address issues related to trust, transparency, double-spending, and fraud inherent in traditional systems, has led to the development of Pure Loyalty. This framework employs Non-Fungible Tokens (NFTs) to enhance loyalty programs, addressing common inefficiencies and fraud. By utilizing innovative batch minting and issuing non-transferable vouchers, Pure Loyalty significantly improves security and engagement within the loyalty ecosystem. It tackles challenges such as fraudulent activities, low redemption rates, and complex program management, thereby offering substantial benefits to both businesses

※ This research was supported by Kumoh National Institute of Technology (2022)
◆ First Author : Kumoh National Institute of Technology, Department of IT Convergence Engineering, gieworld@kumoh.ac.kr, 학생회원
° Corresponding Author : Kumoh National Institute of Technology, Department of IT Convergence Engineering, dskim@kumoh.ac.kr, 종신회원
* NS Lab Co., Ltd., rasyidred@nslab.tech, 정회원
** Kumoh National Institute of Technology, Department of IT Convergence Engineering, ljmpaul@kumoh.ac.kr, 종신회원
논문번호 : 202403-046-0-SE, Received February 29, 2024; Revised March 28, 2024; Accepted March 28, 2024

and consumers[3-5].

TokenLink and other studies have identified significant limitations in current loyalty programs, such as privacy concerns, lack of interoperability, and challenges in managing loyalty points. Pure Loyalty addresses these issues by introducing a secure, transparent exchange mechanism powered by smart contracts to boost program participation and engagement. This strategy reduces fraud and inefficiency, leading to a more inclusive and interactive loyalty program landscape, thereby greatly enhancing the value and appeal of these programs [6,7].

Despite facing scalability and transaction cost challenges, blockchain-based loyalty programs on Ethereum benefit from decentralized security and the use of smart contracts. Features like universal earn-and-burn functionality distinguish these programs, offering transparency, security, and interoperability. By addressing issues such as low redemption rates and complex management, blockchain technology simplifies partnership complexities, enhances participant interactions, ensures privacy, and maintains competitiveness and transparency. This leads to reduced inefficiencies, lower costs, and improved customer experiences. Examples from companies like MercadoLibre, Rakuten Group, FootballNet, and Singapore Airlines highlight the benefits, including enhanced interoperability, system modernization, and better customer experiences.

Key contributions of this paper include:

- Introducing the Pure Loyalty framework, an NFT-based loyalty program system utilizing a subscription model and designed to advance loyalty programs through blockchain technology.
- Utilizing ERC721-based libraries for batch minting, along with ERC20 tokens and Soul-Bound Tokens (SBTs), and integrating these with the InterPlanetary File System (IPFS) for secure off-chain storage, significantly enhances the efficiency and engagement of the program at a reduced cost.
- Evaluation of gas usage and security analysis using static analysis tools to optimize the framework for cost-effectiveness, scalability, and to ensure reliability against vulnerabilities.

The paper is structured as follows. Related works are presented in Section II. Section III elaborates on the proposed solution. Section IV outlines the experimental setup and results. Finally, Section V summarizes the key of this paper.

Ⅱ. Related Works

Study in [8] introduced ERC721A, enabling batch minting of multiple NFTs in a single transaction and incorporating SBT for enhanced security. However, this paper lacks a detailed technical analysis of the ERC721A or SBT implementations. Research in [9] mentioned ERC721A as a more cost-effective solution for batch NFT minting in IoT device authentication and data storage, quantifying gas cost savings compared to ERC721 for various batch sizes. It is important to note that this paper did not delve into the implementation of SBTs.

Table 1 provides a detailed overview, with each study exploring different existing of blockchain loyalty programs across various categories. Study in [10] implemented of a Raft-based multi-host blockchain network using Hyperledger Fabric for performance testing, accompanied by the development of a user interface for customer inquiries about loyalty point transactions. However, security evaluation was lacking. Another study in [11] introduced a unified loyalty system for retailers and customers utilizing blockchain to reward eco-friendly purchases, enhancing interest in sustainable products. While empowering users and improving transparency, this paper did not delve into specific token standards and security evaluations.

In paper [12], a blockchain-based loyalty program using NFTs to boost brand loyalty in agribusiness was proposed. Leveraging the Ethereum network, ERC721 standard, and IPFS, this research established a secure and transparent customer reward system. Santos et al.[13] addressed the integration of multiple loyalty programs of different types on a single platform, introducing meta-transactions for enhanced privacy. Nevertheless, these papers lacked detailed gas and

Table 1. Comparison Between Proposed Solution and Related Work

Study	Blockchain Network	Token Standards	Gas Evaluation	Security Evaluation	Storage Mechanism	Implementation	System Features
[10]	Hyperledger Fabric	No	Not specified	Not specified	On - Chain	Yes	Call auction mechanism
[11]	Algorand	No	Minimal	Not specified	On - Chain	Yes	Pseudonymous model of identities(anonymization)
[12]	Ethereum	ERC721	Not specified	Not specified	IPFS	No	Personalized NFT strategies
[13]	Polygon	ERC-1155	Not specified	Not specified	IPFS	Yes	Meta transaction, multiple token
[14]	Ethereum	ERC20	Yes	Not specified	On - Chain	Yes	Privacy transaction
Proposed scheme	Ethereum	ERC20, ERC721A/G/Psi	Yes	Yes	IPFS	Yes	Batch Minting, Subscription model

security evaluations. Finally, Hinarejos et al.[14] introduced a multi-merchant blockchain-based promotional point scheme, allowing for point transfers among customers while upholding privacy and data confidentiality. Although the paper included a gas evaluation, a security assessment was notably absent.

Based on the mentioned related studies above, this study enhances the existing blockchain-based loyalty programs, particularly by implementing batch minting and a subscription model. By incorporating batch minting, the efficiency and scalability of token generation are significantly improved, allowing for the creation of large quantities of voucher tokens with reduced gas costs. Additionally, the introduction of a subscription model adds versatility to the loyalty program, enabling users to select from various tiers based on their preferences and usage patterns. Furthermore, this study conducts a comprehensive security evaluation, addressing potential vulnerabilities and ensuring robust protection against threats such as reentrancy attack, double spending, and unauthorized access.

Ⅲ. Proposed System

3.1 Architecture

The proposed system architecture illustrated in Fig. 1 is structured with a dual-layered approach, encompassing the app and business logic layer and the infrastructure layer, to establish a resilient and

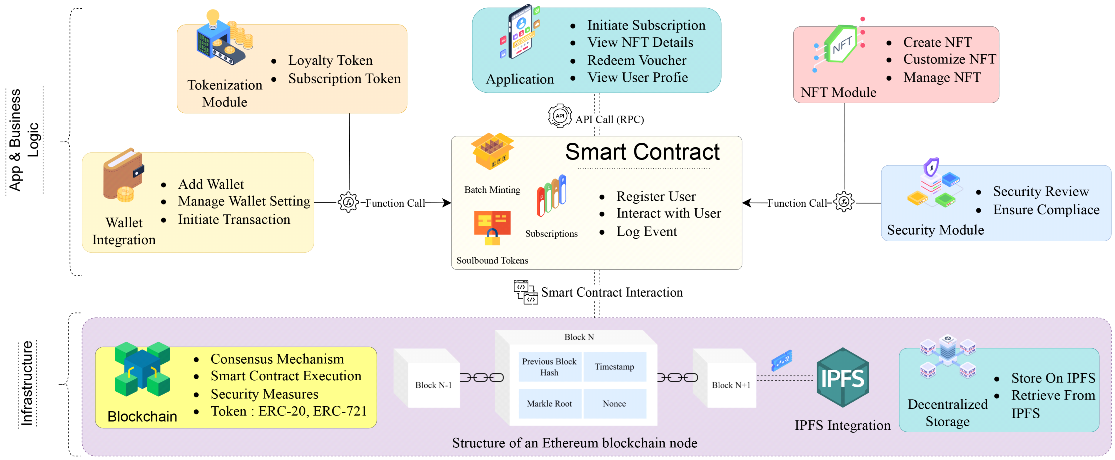

Fig. 1. The Proposed System Architecture

scalable foundation for blockchain-based loyalty programs. In the app and business logic layer, the smart contract component serves as the core engine, implementing the ERC721 standard and featuring functionalities crucial for loyalty programs, such as efficient batch minting for simultaneous token creation, integration of SBTs for enhanced security, and support for interactive subscription models.

The subscription component promotes user engagement, while the NFT module manages the lifecycle of loyalty tokens, including efficient batch minting. A dedicated security module ensures the integrity of transactions and safeguards user data with assesment tool slither, while the tokenization module facilitates the representation of loyalty rewards as tokens for broader blockchain integration. Seamless wallet integration enables users to manage their loyalty rewards effortlessly.

In the infrastructure layer, the blockchain component forms the decentralized backbone, employing the ERC721 standard and potentially integrating ERC20 tokens for additional utility. Consensus mechanisms secure transaction validity, providing a reliable and secure environment. Robust security measures are embedded at the blockchain level, following best practices to protect against potential threats. The integration of the IPFS enhances data storage, ensuring decentralization and accessibility for off-chain loyalty reward data.

3.2 ERC721 Optimization for Batch Minting

Batch minting, the simultaneous creation of multiple tokens in a single transaction, is pivotal to the system, optimizing the minting process for scalability and cost-effectiveness. This approach reflects a commitment to a resource-efficient loyalty ecosystem, reducing gas consumption and associated fees for improved user experiences.

In the implementation, ERC721A by Azuki addresses high gas spent during NFT minting[15]. It employs strategic optimizations such as storage efficiency, batch minting, consistent gas costs, low transaction fees, delayed ownership assignment, and prioritized gas savings. ERC721A stands out as a thoughtful approach, delivering streamlined minting and a cost-efficient user experience.

Similarly, ERC721G by 0xInuarashi prioritizes reducing gas costs and improving efficiency in NFT operations[16]. This implementation introduces structural optimizations, SSTORE optimization, batch minting efficiency, and a single-contract batch mint and stake approach. ERC721G focuses on minimizing gas impact and efficiently handling various actions within a single transaction.

Finally, ERC721Psi, a custom implementation, optimizes batch minting and addresses scalability challenges in token transfers and metadata querying[17]. Inspired by ERC721A, ERC721Psi emphasizes batch minting efficiency, storage optimization, gas savings in token transfer, on-chain metadata querying, tamper-proof randomness, gas efficiency comparisons, scalability enhancement, and contribution to metaverse development. ERC721Psi strives to provide substantial gas savings, aligning with the broader goal of facilitating the development of the future metaverse.

3.3 SoulBound Token, IPFS, and Subscription Model

In the design of the loyalty program, SBTs play a crucial role in maintaining the integrity of memberships, serving as non-transferable NFTs that prevent unauthorized transfers and address challenges associated with traditional verification methods. These tokens, integrated strategically into the loyalty program, leverage blockchain technology to enforce non-transferability, binding each token unequivocally to its rightful owner. By leveraging the decentralized and immutable characteristics of blockchain, SBTs mitigate the risk of fraudulent activities and enhance the program's integrity, providing a transparent and secure verification process for both users and administrators[18].

Complementing the secure framework provided by SBTs, IPFS assumes a crucial role in decentralizing and efficiently storing the program's data components. As a distributed file system, IPFS hosts exclusive artwork for subscription badges, critical for differentiating memberships within the loyalty program. This strategic choice of off-chain storage addresses redundancy and scalability challenges. This dual approach, integrating SBTs for secure, non-transferable memberships and IPFS for efficient, decentralized data storage, underscores a commitment to leveraging advanced technologies to improve the loyalty program landscape, fortifying security and trust while enhancing scalability and user engagement[7].

Moving forward, the subscription model within the proposed system introduces a comprehensive scheme designed to elevate user engagement and loyalty through a multi-faceted approach (see Fig. 2). Initiated by users through purchase or reception, the smart contract orchestrates the seamless transfer of subscription costs using ERC20 tokens. Simultaneously, the smart contract engages the voucher component to batch mint redeemable vouchers, enhancing the benefits associated with the loyalty program. These vouchers serve as a mechanism to boost user participation and satisfaction within the loyalty ecosystem. Upon successful subscription, users receive the subscription badge and redeemable vouchers.

During the usage phase, users interact with the smart contract to utilize vouchers and subscription benefits. The contract, utilizing SBT, verifies active membership, monitors voucher status, and facilitates claiming for unclaimed vouchers while preventing duplicate claims.

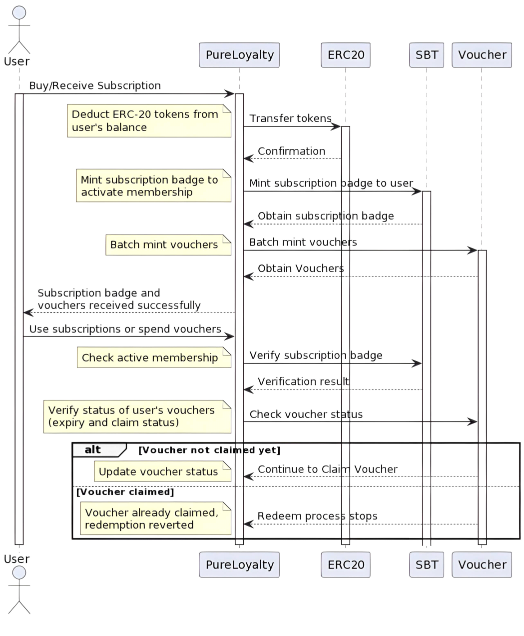

Fig. 2. Scheme of The Proposed System

3.4 Security Review Method

To ensure the integrity and robustness of the proposed loyalty program's smart contracts, we employ a comprehensive security evaluation strategy. This strategy combines manual assessment and with the help of an automated tools, notably Slither. Manual review involves a detailed examination of the smart contract code, identifying potential vulnerabilities and ensuring compliance with established best practices.

Slither is a state-of-the-art static analysis tool tailored for Ethereum smart contracts[19] that is able to detect common coding pitfalls, security weaknesses, and areas for optimization. Through the integration of manual review and Slither analysis, the security of the loyalty program's smart contracts is strengthened, guaranteeing robustness and compliance.

Ⅳ. Experimental Setup and Results

4.1 Experimental Setup

The blockchain setup utilized Ethereum technology, with a smart contract written in Solidity. Subsequently, the contracts were deployed onto the Sepolia public test network. Gas consumption was directly acquired from the Sepolia test network explorer to measure the contract efficiency. Lastly, a smart contract vulnerability analysis was conducted using the static analyzer Slither to evaluate potential security risks and weaknesses.

4.2 Gas Evaluation

Table 2 provides a detailed breakdown of gas spending associated with key functions within the proposed system, specifically focusing on the batch minting libraries: ERC721A, ERC721G, and ERC721Psi. The gas usage data were extracted from each cycle scenario outlined in Fig. 2. Within the table, various functions are detailed, including

Table 2. Proposed System's Functions Gas Usage

Gas used Per Function	ERC721 Library		
	ERC721A	ERC721G	ERC721Psi
Contract Deployment	3,921,217	4,275,572	4,390,506
approve()	46,394	46,394	46,394
register() (bronze)	487,064	336,757	421,766
spendVoucher()	60,710	60,733	60,710

contract deployment, *approve*(), *register*() (using Bronze tier), and *spendVoucher*(), each associated with its respective gas values.

Contract deployment incurs varying gas cost across the ERC721 libraries. Specifically, Pure Loyalty with ERC721A as its voucher contract required 3,921,217 gas, ERC721G used 4,275,572 gas, and ERC721Psi spent 4,390,506 gas. The *approve*() function, which is ERC20 token approval for purchasing the subscription token, consistently requires 46,394 gas across all three libraries. The *register*() function for subscribing with bronze tier, exhibits differences in gas consumption, with the lowest gas usage is ERC721G at 336,757 gas, followed by ERC721Psi at 421,766 gas and ERC721A at 487,064 gas. These variations may stem from the unique features and optimizations implemented in each ERC721 library. Lastly, the *spendVoucher*() function, associated with redeeming vouchers, demonstrates relatively consistent gas used across ERC721A, ERC721G, and ERC721Psi, with 60,710, 60,733, and 60,710 gas, respectively.

4.3 Comparison of Batch Minting Libraries

Table 3 provides a comparison of gas used for different batch minting libraries within the proposed system; ERC721A, ERC721G, and ERC721Psi. Higher tiers entail greater benefits, represented by more vouchers. In this scenario, the Bronze tier creates five vouchers, while silver, gold, and platinum generate ten, fifteen, and twenty vouchers, respectively.

The comparison highlights significant variations in gas expenditure across different subscription tiers and among various ERC721 libraries. In the Bronze tier, ERC721G spends 336,757 gas, significantly less than ERC721Psi and ERC721A, which spend 487,064 and 421,766 gas, respectively. This trend persists across higher subscription levels, with ERC721G's efficiency becoming particularly evident in the Platinum tier, where it registers a gas expenditure of 709,512. In contrast, ERC721Psi and ERC721A record gas expenditures of 1,163,911 and 1,226,524, respectively. Notably, ERC721G consistently demonstrates superior cost-effectiveness, exhibiting the lowest gas expenditure across all subscription tiers, while ERC721A consistently shows the highest. This consistent performance underscores ERC721G's effectiveness in economically facilitating large batch minting operations, particularly as the demands of subscription scenarios increase.

Table 3. Gas Spent for Each Batch Minting Library

Subscription Tiers	Voucher Contract Libraries		
	ERC721A	ERC721G	ERC721Psi
Bronze(5 Vouchers)	487,064	336,757	421,766
Silver(10 Vouchers)	733,557	491,615	669,154
Gold(15 Vouchers)	980,040	600,563	916,532
Platinum(20 Vouchers)	1,226,524	709,512	1,163,911

4.4 Security Assessment

Table 4 presents the security evaluation of the smart contracts within the proposed system, focusing solely on the codebase of Pure Loyalty and excluding external contracts such as Open Zeppelin and the batch minting libraries. The assessment revealed only low and informational issues. Notably, concerns arise in the timestamp comparison within voucher contracts, particularly in the *redeemVoucher*() function. However, these comparisons are aimed at verifying whether the provided voucher ID has expired.

The warning concerning the "Void Constructor in PureLoyaltyPsi" appears to arise from the absence of explicit code within the constructor function. While Slither may prompt an issue, this approach is a recognized practice for contract deployment. Therefore, despite the warning, the implementation likely adheres to established best practices, rendering the flagged issue a false positive.

Additionally, Slither detected an issue regarding costly operations within loops during the execution

Table 4. Slither Analysis Results Summary

Issue	Contract/Function Affected	Description	Severity
Timestamp Usage in Voucher Contracts	VoucherAzuki.redeemVoucher VoucherG.redeemVoucher VoucherPsi.redeemVoucher	Dangerous comparison: vouchers[voucherId].expiredTime ⇐ block.timestamp	Low
Void Constructor in PureLoyaltyPsi	PureLoyaltyPsi.constructor	Void constructor called: Ownable(msg.sender)	Low
Costly Operations Inside Loops in Voucher Contracts	VoucherAzuki.batchMint VoucherG.batchMint VoucherPsi.batchMint	Costly operation inside loop: _nextId += voucherNumTotal	Informational

of the *batchMint*() function, which is triggered when users register for the Pure Loyalty system. This function is deliberately designed to record the number of vouchers already minted and their respective owners based on the voucher ID. While Slither's warning pertains to the potential inefficiency of operations within loops, it aligns with the intended functionality in the *batchMint*().

Ⅴ. Conclusion

This research provides a thorough exploration of integrating ERC721 and ERC20 libraries into loyalty program frameworks, showcasing the transformative potential of blockchain technology in addressing traditional challenges. The comparative analysis highlights ERC721G's consistent cost-effectiveness, establishing it as a superior choice for handling batch minting across various subscription tiers. The incorporation of SBTs and the use of IPFS for off-chain storage enhance security and flexibility in loyalty program implementations.

Future works will focus on practically implementing the proposed loyalty program architecture, with deployment on the Ethereum mainnet as a central goal. Additionally, the development of a userfriendly DApp aims to offer a seamless interface for user engagement with the loyalty program. Prioritizing further smart contract optimization and user experience enhancements, ongoing efforts aim to refine the system's efficiency for successful integration into live loyalty programs. This forward-looking strategy aligns with the broader goal of translating theoretical advancements into practical, impactful solutions within the dynamic landscape of blockchain-based loyalty programs. This approach ensures the longterm viability and scalability of loyalty programs powered by blockchain technology.

References

[1] M. R. R. Ansori, R. N. Alief, I. S. Igboanusi, J. M. Lee, and D.-S. Kim, "HADES: Hash-based audio copy detection system for copyright protection in decentralized music sharing," *IEEE Trans. Netw. and Serv. Manag.*, vol. 20, no. 3, pp. 2845-2853, Sep. 2023. (https://doi.org/10.1109/TNSM.2023.3241610)

[2] I. S. Igboanusi, K. P. Dirgantoro, J.-M. Lee, and D.-S. Kim, "Blockchain side implementation of pure wallet (PW): An offline transaction architecture," *ICT Express*, vol. 7, no. 3, pp. 327-334, Sep. 2021. (https://doi.org/10.1016/j.icte.2021.08.004)

[3] G. A. Haryadi, M. R. R. Ansori, J.-M. Lee, and D.-S. Kim, "Efficient voucher distribution and non-transferability in NFT loyalty programs," in *Proc. Symp. KICS*, pp. 858-859, Gyeongju, South Korea, Nov. 2023.

[4] M. Yoon, "K-pop stars use NFT, fan reward systems to fight ticket scalping," (2024), Retrieved 19, Feb. 2024. from https://www.koreaherald.com/view.php?ud=20240126000423&ACE$_$SEARCH=1

[5] H. Suhagiya, H. Mistry, A. Trivedi, R. Mangrulkar, and P. Chavan, "TokenLink: A

secure loyalty point exchange system powered by smart contracts," *Int. J. Comput. and Appl.*, vol. 46, no. 3, pp. 152-166, Dec. 2024. (https://doi.org/10.1080/1206212X.2023.2293592)

[6] J. Yao, Y. Zheng, Y. Guo, et al., "A privacy preserving system for targeted coupon service," *IEEE Access*, vol. 7, pp. 120 817-120 830, Aug. 2019. (https://doi.org/10.1109/ACCESS.2019.2937669)

[7] P. M. Mohan, V. Balachandran, O. Z. Quan, J. P. Z. Xin, and D. M. Divakaran, "NFT-Merit: An NFT-based module credit management system on ethereum blockchain," *2022 IEEE Int. Conf. Teaching, Assessment and Lear. for Eng.* (*TALE*), pp. 472-476, Hung Hom, Hong Kong, Dec. 2022. (https://doi.org/10.1109/TALE54877.2022.00083)

[8] K. Ko, T. Jeong, J. Woo, and J. W.-K. Hong, "Survey on blockchain-based non-fungible tokens: History, technologies, standards, and open challenges," *Int. J. Netw. Manag.*, vol. 34, no. 1, e2245, Jul. 2024. (https://doi.org/10.1002/nem.2245)

[9] N. E. Majd and M. Sharko, "Secure and cost effective IoT authentication and data storage framework using blockchain NFT," *2023 32nd ICCCN*, pp. 1-7, Honolulu, HI, USA, Jul. 2023. (https://doi.org/10.1109/ICCCN58024.2023.10230124)

[10] S.-F. Tu, C.-S. Hsu, and Y.-T. Wu, "A loyalty system incorporated with blockchain and call auction," *J. Theoretical and Applied Electr. Commerce Res.*, vol. 17, no. 3, pp. 1107-1123, Aug. 2022. (https://doi.org/10.3390/jtaer17030056)

[11] L. Mastilak, R. Suchy, K. Kostal, and I. Kotuliak, "Blockchain-based sustainable retail loyalty program," *IEEE Access*, vol. 11, pp. 75 063-75 075, Jul. 2023. (https://doi.org/10.1109/ACCESS.2023.3296914)

[12] H. Hosseinalibeiki and M. Zaree, "A blockchain based solution to improve loyalty program with NFT in agribusiness," *J. Smart Environ. and Green Comput.*, vol. 3, no. 4, pp. 127-146, Nov. 2023. (https://doi.org/10.20517/jsegc.2023.09)

[13] A. F. Santos, J. Marinho, and J. Bernardino, "Blockchain-based loyalty management system," *Future Internet*, vol. 15, no. 5, Apr. 2023. (https://doi.org/10.3390/fi15050161)

[14] M. F. Hinarejos, J.-L. Ferrer-Gomila, and A. J. Barceló, "A secure solution for a blockchain-based consortium promotional scheme," *IEEE Access*, vol. 10, pp. 119 676-119 691, Nov. 2022. (https://doi.org/10.1109/ACCESS.2022.3221424)

[15] C. Labs, "Introducing ERC721A: An improved ERC721 implementation," (2022), Retrieved 8, Mar. 2024. from http://www.azuki.com/erc721a

[16] 0xInuarashi, "ERC721G: The gas standard," (2022), Retrieved 18, Feb. 2024. from https://erc721g.gangsterallstar.com

[17] C. Lab, "ERC721Psi: A truly scalable NFT implementation for low-gas on-chain applications and randomized metadata generation," (2022), Retrieved 18, Feb., 2024. from https://mirror.xyz/ctor.xyz/zy3TUWuJFSeWyMWAucTRP45o-sVToKTrtDsUIiD_m48

[18] M. R. R. Ansori, Allwinnaldo, R. N. Alief, I. S. Igboanusi, J. M. Lee, and D.-S. Kim, "Batch minting-enabled digital certificates based on soulbound token for achievement verification," in *Proc. Symp. KICS*, pp. 1350-1351, Jeju, South Korea, 2023.

[19] J. Feist, G. Grieco, and A. Groce, "Slither: A static analysis framework for smart contracts," *2019 IEEE/ ACM 2nd Int. WETSEB*, pp. 8-15, Montreal, QC, Canada, May 2019. (https://doi.org/10.1109/WETSEB.2019.00008)

Gifar Arif Haryadi

He is currently enrolled in a Master’ s program in IT Convergence Engineering at Kumoh National Institute of Technology since 2023, he previously earned a Bachelor’s Degree in Telecommunication Engineering from Telkom University, Bandung, Indonesia, spanning 2016 to 2021. His research is focused on exploring the fields of blockchain, information security, and artificial intelligence.

[ORCID:0009-0007-1129-0727]

Muhammad Rasyid Redha Ansori

He is currently working as a researcher at NS Lab Co., Ltd. located in South Korea. He completed his Master’s degree in IT Convergence Engineering from Kumoh National Institute of Technology, South Korea in 2023, and obtained his Bachelor’s degree in Telecommunication Engineering from Telkom University, Indonesia in 2020. His research interests include blockchain, information and security, real-time systems, and machine learning.

[ORCID:0000-0002-5704-9134]

Jae-Min Lee

He received his Ph.D. degree in Electrical and Computer Engineering from Seoul National University, Seoul, Korea, in 2005. From 2005 to 2014, he worked as a Senior Engineer at Samsung Electronics, Suwon, Korea. From 2015 to 2016, he served as a Principal Engineer at Samsung Electronics. Since 2017, he has been an associate professor in the School of Electronic Engineering and the Department of IT-Convergence Engineering at Kumoh National Institute of Technology, Gyeongbuk, Korea. He is a member of IEEE. His primary research interests include smart IoT convergence applications, industrial wireless control networks, UAVs, the metaverse, and blockchain.

[ORCID:0000-0001-6885-5185]

Dong-Seong Kim

He received his Ph.D. degree in Electrical and Computer Engineering from Seoul National University, Seoul, Korea, in 2003. From 1994 to 2003, he worked as a full-time researcher at ERC-ACI at Seoul National University. From March 2003 to February 2005, he served as a postdoctoral researcher at the Wireless Network Laboratory in the School of Electrical and Computer Engineering at Cornell University, NY. Between 2007 and 2009, he was a visiting professor in the Department of Computer Science at the University of California, Davis, CA. He served as Dean of IACF from 2019 to 2022. Currently, he is the director of the KIT Convergence Research Institute and the ICT Convergence Research Center (ITRC and NRF advanced research center program), supported by the Korean government, and CEO of NSLab Co. Ltd. He is a senior member of IEEE and ACM. His primary research interests include real-time IoT, industrial wireless control networks, networked embedded systems, and blockchain.

[ORCID:0000-0002-2977-5964]