frontiers | Frontiers in Blockchain

TYPE Original Research
PUBLISHED 07 January 2025
DOI 10.3389/fbloc.2024.1388832

OPEN ACCESS

EDITED BY
Kazi Sohag,
Ural Federal University, Russia

REVIEWED BY
Wolfgang Lohmann,
Randstad Digital Germany AG, Germany
Anupama Mishra,
Swami Rama Himalayan University, India

*CORRESPONDENCE
Yan Zhou,
kgu521@kyonggi.ac.kr

RECEIVED 20 February 2024
ACCEPTED 29 November 2024
PUBLISHED 07 January 2025

CITATION
Shi Q and Zhou Y (2025) Application of blockchain technology in digital music copyright management: a case study of VNT chain platform.
Front. Blockchain 7:1388832.
doi: 10.3389/fbloc.2024.1388832

Application of blockchain technology in digital music copyright management: a case study of VNT chain platform

Qilong Shi[1] and Yan Zhou[2]*

[1]School of Music, Anshan Normal University, Anshan, Liaoning, China, [2]Department of Global Music, Graduate School, Kyonggi University, Suwon, Republic of Korea

Introduction: This paper presents the design and development of a digital music copyright management system, built on the VNT Chain blockchain platform. The system aims to enhance copyright proof and evidence storage, verify the originality of music copyrights, and facilitate secure copyright transactions.

Methods: The system leverages blockchain technology for data integrity and immutability, utilizes the Shazam algorithm to verify music originality, and employs smart contracts to secure transactions. It is composed of six functional modules: user management, copyright registration, copyright trading, infringement monitoring, evidence storage, and music ecology. The system uses blockchain, the InterPlanetary File System (IPFS), and MySQL to manage various business data requirements.

Results: Experimental results show that the registration time for each music piece increased by approximately 1.9 s. Additionally, the average feature fingerprint data for each music piece stored on IPFS consumed about 8 MB, which aligns with the expected system performance criteria.

Discussion: The system meets performance expectations, offering secure and efficient copyright registration and evidence storage. The use of blockchain and IPFS provides a scalable, reliable solution for managing digital music copyrights.

KEYWORDS

music copyright, blockchain, Shazam algorithm, music ecology, interplanetary file system (IPFS)

1 Introduction

In the digital era, digital product copyright issues have emerged, particularly in the music industry disseminated online. Digital copyright refers to the rights of creators to store, reproduce, and distribute their digital works online. Copyright may be acquired automatically or through registration according to Chinese Copyright Law. (National Copyright Administration of the People's Republic of China, 2020). The Chinese digital music industry faces challenges like copyright identification, infringement monitoring, evidence collection, and royalty distribution. Despite blockchain technology attempts, challenges remain (He et al., 2022)

This paper presents a novel approach to managing digital music copyright using the VNT Chain platform. The system integrates blockchain technology, the Shazam algorithm for music fingerprinting, and smart contracts to automate copyright transactions and manage copyrights. This combination addresses long-standing industry challenges and introduces a token-based incentive mechanism to encourage the growth of a vibrant music ecosystem. The primary technologies utilized in the design and construction of the digital music copyright management system include blockchain technology, InterPlanetary File System (IPFS), the Shazam algorithm, and smart contracts. These technologies are leveraged to address industry challenges, such as copyright identification, infringement monitoring, evidence collection, and royalty distribution. The paper discusses these technologies in detail, reviews blockchain research in digital copyright, and introduces the VNT Chain platform's capabilities. (Zhang et al., 2020; Zheng et al., 2017; Cachin, 2016; Savelyev, 2018; Aldweesh, 2024).

In view of this, this paper proposes an end-to-end music copyright management system based on blockchain. The innovations are reflected in: 1) covering six modules for the lifecycle management of music assets, connecting various links in the music industry; 2) adopting a layered architecture of "Blockchain + IPFS + database" to ensure data immutability and traceability while taking into account the availability of the system; 3) designing an improved Shazam music fingerprint extraction and matching algorithm to achieve fast and accurate copyright confirmation on-chain; 4) introducing a token incentive mechanism to effectively mobilize the enthusiasm of all participants and build a virtuous music ecosystem. The token mechanism is crucial for encouraging user participation and engagement. Tokens are earned as rewards for promoting music, supporting crowdfunding projects, and participating in revenue sharing. These tokens are not merely transactional but form the backbone of the music ecosystem, ensuring that users actively contribute to and support music creation.

2 Methods

2.1 Key technical

This section outlines the core technologies used in the digital music copyright management system, each contributing distinct functionalities essential for secure and efficient copyright management.

2.1.1 Blockchain technology

Blockchain ensures tamper-proof and traceable data, which is ideal for judicial evidence. It creates a secure and transparent record of all transactions and data entries, ensuring that once data is recorded, it cannot be altered without detection. In our system, blockchain technology is used to store user information, copyright details, transaction records, and evidence of copyright disputes on the VNT Chain platform. While the system currently utilizes the VNT Chain platform for its security and low-latency features, it is designed to be technology-agnostic. The modular architecture allows for easy migration to other blockchain platforms should the VNT platform become obsolete. The VNT Chain platform was selected for its high transaction throughput[1], low-latency processing[2], and robust security features[3], which make it particularly suitable for managing digital music copyright. These features ensure that copyright transactions are handled quickly and securely, and that all records are immutable and transparent. Additionally, VNT Chain supports smart contracts that automate key processes such as copyright registration and music sales, enhancing the efficiency and reliability of the system. Similarly, IPFS is currently used for decentralized storage of music fingerprints and large data files, but it can be replaced by other decentralized storage solutions if required (Kshetri and Voas, 2018; Tamilselvan, 2024; Frattolillo, 2024; Zhang and Li, 2019; Chen et al., 2019; Yao et al., 2018; Zheng et al., 2018).

2.1.2 IPFS (inter planetary file system)

IPFS is a protocol and network designed to create a peer-to-peer method of storing and sharing hypermedia in a distributed file system. It addresses the issue of large data storage by breaking files into smaller chunks, hashing them, and storing them across a distributed network. In our system, IPFS is used to store the digital fingerprints of music files and infringement evidence files (Zhao et al., 2019). This ensures the security and integrity of the data while making it accessible via unique Hash addresses.

2.1.3 Shazam algorithm

The Shazam algorithm is used for extracting digital fingerprints from music files. This involves creating a unique identifier for each music piece based on its acoustic features. The algorithm works by identifying and extracting key features from the audio signal, which are then hashed to create a digital fingerprint. This fingerprint is used to verify the originality of music files and to detect pirated copies. In our system, Shazam's digital fingerprinting ensures that only original works are registered and helps in monitoring and identifying potential copyright infringements.

2.1.4 Smart contracts

Smart contracts are self-executing contracts with the terms of the agreement directly written into code. They automate the process of verifying, executing, and enforcing the terms of an agreement,

1 The VNT Chain offers a high level of scalability, which is crucial for handling the volume of transactions and data expected in a system managing music copyrights. The system can process large numbers of transactions efficiently, ensuring that copyright registration, evidence storage, and transactions occur in real-time without delays

2 One of the key benefits of using VNT Chain is its low-latency processing, which is necessary to provide immediate feedback for time-sensitive operations like music confirmation and copyright protection. Users need quick confirmation of music registration, and VNT ensures that these transactions are processed almost instantly

3 Security and Immutability:The public chain architecture of VNT provides robust security through decentralized consensus mechanisms, ensuring that the data recorded on the Blockchain cannot be altered or tampered with. This immutability is critical in copyright protection, where the authenticity of ownership and transaction records must be guaranteed

TABLE 1 Explanation of critical functions.

Functions	Explanation
User Management	Smart contracts handle the registration, authentication, and management of user data
Copyright Registration	They facilitate the registration of music copyrights by verifying and recording the copyright details on the blockchain (Li et al., 2018b)
Copyright Transactions	Smart contracts automate the buying and selling of music copyrights, ensuring secure and transparent transactions
Evidence Solidification	They record and verify evidence of copyright disputes, ensuring the integrity and immutability of the evidence
Music Ecosystem Management	Smart contracts manage the interactions within the music ecosystem, including promotion, crowdfunding, and revenue sharing

TABLE 2 The details of the mechanisms.

Mechanism	Details
Automated Execution	Smart contracts automatically execute predefined conditions, reducing the risk of manual errors and ensuring consistency in transaction processing
Transparency and Immutability	All transactions conducted via smart contracts are recorded on the blockchain, providing a transparent and immutable ledger. This ensures that transaction records cannot be altered or tampered with
Security Protocols	Smart contracts are written in C language and deployed on the VNT Chain, leveraging the security features of the blockchain to protect against unauthorized access and attacks
Trustless Environmen	By eliminating the need for intermediaries, smart contracts create a trustless environment where the integrity of transactions is maintained through cryptographic algorithms and consensus mechanisms

ensuring that transactions are conducted securely and transparently without the need for intermediaries. (Li C. et al., 2018). In our system, smart contracts are used for several critical functions (Table 1): User Management, Copyright Registration, Copyright Transactions, Evidence Solidification, and Music Ecosystem Management. (Swan, 2015; Li et al., 2017).

These contracts are written in C language and deployed on the VNT Chain, enhancing the security and reliability of the system's operations.

In our system, smart contracts ensure secure and reliable transactions through several mechanisms (Table 2): Automated Execution, Transparency and Immutability, Security Protocols, and Trustless Environment.

2.2 System requirements and architecture

This section introduces the design requirements and architecture of the blockchain-based digital music copyright management system, which incorporates various modules to handle key copyright-related functions (Table 1).

2.2.1 Functional modules

The system comprises six primary modules—User Management, Copyright Registration, Copyright Transaction, Infringement Monitoring, Evidence Solidification, and Music Ecosystem. Each module addresses a specific aspect of copyright management and contributes to the integrity of the overall system.

2.2.2 Storage solutions

The system's storage layer combines blockchain, IPFS, and MySQL to balance security and efficiency. Blockchain handles critical, tamper-proof data, IPFS manages large files, and MySQL stores metadata, ensuring the system's functionality and responsiveness. Each storage solution is tailored to meet specific data needs, supporting a robust copyright management infrastructure.

2.2.3 System operations

Using a layered architecture with distinct front-end, back-end, and storage components, the system enables seamless data handling and user interactions. The back-end bridges storage with user services, utilizing smart contracts for secure operations. Meanwhile, the front-end interface, built with Vue. js and Element UI, allows users to interact smoothly with the system.

3 System design

3.1 Design of system architecture

The blockchain-based digital music copyright management system's architecture comprises three layers: front-end, back-end, and underlying storage. Each layer leverages specific technologies to ensure the system's functionality and security.

3.1.1 Underlying storage layer

The underlying storage layer of our digital music copyright management system integrates three distinct technologies—blockchain, IPFS, and MySQL—each serving specific storage needs to create a secure, efficient, and scalable infrastructure.

Blockchain is utilized for storing critical data that requires high security and tamper-proof characteristics, such as user information, copyright details, transaction records, and evidence in copyright disputes. By leveraging the robust features of the VNT Chain

platform, which was chosen for its high security, low-latency transactions, and public chain capabilities, the system provides a secure and immutable foundation for managing and verifying copyright data. Storing information on the blockchain ensures that copyright proof and evidence remain verifiable and unalterable, providing essential legal backing (Chen and Zheng, 2018). Although VNT is not the largest blockchain platform, it is uniquely suited to the functional needs of music copyright management, allowing rapid and secure handling of transactions while maintaining transparency. Thus, the blockchain component of the system functions as the backbone of copyright verification, safeguarding vital data and ensuring the reliability of transaction records (Agyekum et al., 2019).

For large data files, such as the digital fingerprints of music files and evidence related to copyright, we use the InterPlanetary File System (IPFS). IPFS is a decentralized storage system that effectively manages large files by breaking them into smaller chunks, hashing each piece, and distributing them across a network. This method enhances data integrity and availability by preventing single points of failure and ensuring resilience in the distributed network. Each file chunk is assigned a unique Hash address, which allows fast, secure access to data and enables the system to retrieve files efficiently when needed. IPFS aligns with the system's goal of robust data management without depending on centralized storage, which can be vulnerable to data loss or manipulation (Chen and Zheng, 2018; Agyekum et al., 2019).

In addition to blockchain and IPFS, MySQL is used to manage non-critical data that requires frequent access, such as paths to locally stored music files. MySQL effectively handles metadata and pointers to files, offering quick access without burdening the blockchain or IPFS. This lightweight database ensures that the system operates smoothly by allowing fast retrieval of music file information, especially when immediate access to critical copyright details is not required. MySQL complements the storage layer by streamlining data access and enabling the system to focus on high-performance tasks, such as managing user interactions and file information, without overloading the more secure blockchain or IPFS layers.

By integrating these three storage technologies, our system efficiently manages diverse data types, balancing security, integrity, and accessibility. Each storage solution serves a unique role: blockchain provides tamper-proof security for critical data, IPFS enables reliable storage and retrieval of large files, and MySQL ensures efficient access to frequently used metadata. Together, these components create a robust and scalable infrastructure that meets the demands of digital music copyright management, supporting the needs of users, copyright holders, and the system's operational requirements.

The back-end system connects this storage layer with the front-end user interface, processing business logic and handling requests from users. It comprises both smart contract and non-smart contract implementations to optimize functionality and security. Smart contracts, written in C and deployed on the VNT Chain, are used for essential functions such as user management, copyright registration, copyright transactions, evidence recording, and the operation of the music ecosystem. By using blockchain technology, smart contracts create an immutable record of all transactions, ensuring secure, automated execution of these operations without risks of fraud or tampering (Zhang et al., 2024; Meng et al., 2018).

Meanwhile, non-smart contract components handle tasks that do not require blockchain's high security, such as monitoring copyright infringement and running algorithms like Shazam for music identification. By distributing tasks based on security requirements, the back-end system can enhance performance while maintaining a balance between security and efficiency.

3.1.2 Front-end system

The front-end system offers a user-friendly interface, enabling seamless interaction with the platform. Built with modern web technologies, it ensures a smooth user experience. The web interface is developed using Vue. js and Element UI frameworks, which create a responsive and interactive design, adapting effectively to various screen sizes and devices. For communication with the back-end, the front end relies on Axios to handle data exchange through RESTful APIs. This approach enables efficient, reliable interaction between the user interface and the back-end system, providing quick response times and smooth operational flow. The storage layer includes blockchain platforms, IPFS, and databases. Blockchain ensures tamper-proof, traceable data ideal for judicial evidence but requires digital currency for storage, thus used for crucial data only. (Pan et al., 2019; Zheng et al., 2017; Kuo and Ohno-Machado, 2017). IPFS offers distributed file storage with security features but has privacy risks due to accessible content via Hash addresses. MySQL provides easy operation and access but has higher security risks due to its centralized nature.

The back-end bridges storage and front-end, handling business logic, both smart contract and non-smart contract implementations. Smart contracts cover user management, copyright registration, transactions, evidence solidification, and music ecosystem. Non-smart contract tasks include infringement monitoring and Shazam algorithm execution.

The front-end, using Web with Vue.js and Element UI frameworks, provides user services via an interactive interface and connects to the back-end through Axios.

3.2 Functional module

This blockchain-based system for music copyright protection comprises six primary modules, each designed to fulfill specific aspects of user and copyright management. The modules include User Management, Copyright Registration, Copyright Transaction, Infringement Monitoring, Evidence Solidification, and Music Ecosystem (Figure 1). Each module plays a distinct role, ensuring efficient copyright handling, transaction management, and legal support in the music ecosystem.

3.2.1 User management

The user management module centrally manages user information, including registration, login, and personal details. This module's contract records essential user information, such as wallet address on the VNT Chain, copyright owner name, and phone number. Users first register a wallet on the VNT Chain website, obtaining a KeyStore file, password, private key, and account address, which must be securely stored. During login,

users upload their KeyStore file and password for system verification, granting access only upon successful verification. Upon first login, users complete personal information, including copyright owner name and phone number. The copyright name assists in comparing music file tags during copyright registration to verify originality, while the phone number allows timely contact if issues arise. For instance, if music fingerprint data on IPFS is damaged or if there is a content Hash discrepancy on the blockchain during music download, the user can be contacted for re-upload.

3.2.2 Copyright registration

The copyright registration module enables users to register and verify copyrights for their original music works, download copyright certificates, and retrieve original music files. Copyright information stored on the blockchain serves as proof of existence, while originality verification follows a three-stage process: (1) Content Hash Check. Verifies if the music file's content Hash already exists in the system to prevent duplicate registrations. (2) Music Tag Comparison. Checks if the music tag, embedded by the creator, aligns with the user's copyright information. This provides an initial check but isn't definitive, as tags can be modified. (3) Shazam Algorithm Verification. Extracts feature fingerprint data from a music clip and compares it to the system's fingerprint database to prevent the registration of modified copies of already-registered music.

While these steps help verify ownership, they cannot confirm absolute originality due to limitations in blockchain technology, which cannot authenticate data prior to its upload. Instead, the system offers proof of ownership at a specific time. In cases of dispute, earlier ownership evidence can support legal action. If a user illegally registers another's music, the system's immutable records can serve as evidence in defense of the original owner's rights.

Only after passing all three verification stages can users confirm ownership. At this point, they may add collaborators and set equity shares, defining revenue division. Without collaborators, the user holds full ownership. Once set, the Shazam algorithm captures the music's full fingerprint data for storage on IPFS, while copyright information is recorded on VNT Chain. The music file is saved locally and managed in MySQL for ease of access in copyright transactions and music promotion. This module also allows users to download certificates and music files.

3.2.3 Copyright transaction

The copyright transaction module enables user-to-user copyright transactions through smart contracts, with two main types: copyright transfer and usage license. In a copyright transfer, the creator permanently transfers ownership to the buyer. A usage license allows temporary profit-generating use, with three types: (1) Exclusive license. The copyright owner cannot use or license the copyright to others during the licensed period. (2) Sole license. The owner can use the copyright but cannot license it to others. (3) Ordinary license: The owner can both use and license the copyright to any third party.

To facilitate transactions, the system organizes sales according to copyright transfer and exclusive license models. The module has two functions: copyright sale and purchase. In a sale, the seller selects the music copyright, sets the sale type (transfer or license), usage time (if licensed), and sale price, then confirms. The transaction contract records this information on the VNT Chain blockchain, displaying it in the copyright store.

In a purchase, buyers browse and select music from the copyright store, where the system verifies their balance before executing the purchase. If the copyright has been crowdfunded or has collaborators, the payment is divided according to equity shares; otherwise, it goes to the owner. After purchase, users may download the music for personal enjoyment or use it for profit, such as video background music. For exclusive licenses, the system revokes user access upon license expiration.

3.2.4 Infringement monitoring

The infringement monitoring module is used to help users discover pirated music on the Internet. This module has two parts: automatic monitoring and manual monitoring. Automatic monitoring is for relatively large music websites set up within the system. After the user selects to enable the infringement monitoring function and sets the monitoring cycle, the system will crawl the music related to the user's copyrighted music on these default websites at regular intervals, and then perform similarity comparison for each crawled music. Manual monitoring is for some small websites. Users can download relevant music from these websites and upload it to the system for similarity comparison. If the music undergoing similarity comparison has high similarity with the user's copyrighted music, the system will give a prompt of suspected infringement. In the future, this system will also introduce the role of lawyers to help users further confirm whether the copyrighted music is infringed. If the music file is infringing, the user can save the comparison results and the website page information by screenshots or screen recording, and then solidify this evidence in this system to facilitate subsequent judicial rights protection.

3.2.5 Evidence solidification

The evidence solidification module can be used in combination with the infringement monitoring module. They are responsible for storing the user's rights protection evidence on the chain to facilitate subsequent judicial rights protection. First, the user needs to select the infringed copyrighted music, then can provide a text description of this infringement incident, and finally needs to upload the rights protection evidence files, such as screenshots of the website providing music downloads without authorization and the similarity comparison results of the system's infringement monitoring. After the user completes the operation, the system will store the rights protection evidence files on IPFS and store the constructed rights protection evidence information on the VNT Chain Blockchain platform. When users defend their rights through judicial means in the future, they can extract the rights protection evidence data stored on the blockchain as strong evidence for rights protection to safeguard their legitimate rights and interests. In the future, the system will introduce the roles of notary agencies and lawyers. Notary agencies are used to notarize the user's rights protection evidence, while lawyers can help users with rights protection litigation.

3.2.6 Music ecosystem

The music ecosystem module[4] supports three main activities: promoting music, raising funds for new music projects, and sharing revenue. This module encourages user participation in music promotion and crowdfunding, while also helping music creators receive financial support. This ensures continuous creativity and financial support for music creators, which exists for the prosperity of the entire music ecosystem and to help music works circulate better. The music ecosystem module can be divided into three parts: music promotion, music crowdfunding, and music ecosystem market. In music promotion, users can select the music to be promoted, and after describing the promotion task and setting the task completion amount, they can publish the music promotion demand. The system will store the music promotion information on the VNT Chain Blockchain platform and display it in the music ecosystem market. In music crowdfunding, users need to first describe the music work to be created. After setting the crowdfunding amount and the corresponding music equity ratio, they can publish the music crowdfunding demand. The system will store the crowdfunding information on the VNT Chain Blockchain platform and display it in the music ecosystem market. Ordinary users can browse the demands in the music ecosystem market. They can choose to accept promotional tasks to earn fees or accept crowdfunding demands to provide financial support for the early creation of music creators. When the copyright is traded to obtain revenue, the amount will be divided according to the equity distribution ratio. Through music promotion and crowdfunding, it can not only help promote music and let more people know about it, but also raise funds for the early creation of music creators. This can not only help platform users earn income, but also promote the enthusiasm of music creators to create, thereby bringing prosperity to the entire music industry. In order to ensure the security of music promotion and crowdfunding, all transaction information will be recorded on the VNT Chain Blockchain platform, and users can trace and view it. When certain disputes occur, the information on the blockchain can be extracted as evidence.

The system ensures music file authenticity and ownership, monitors, and prevents copyright infringements, and provides a comprehensive range of music-related services. Smart contracts written in C language using vntlib. h header file are used for most modules, enhancing security and reliability.

4 Performance testing and analysis

This section evaluates the performance of the blockchain-based digital music copyright management system, focusing on key operational metrics and scalability.

4.1 System testing environment

To assess its performance, the system was tested on a setup with an Intel Core i5-7300HQ CPU, 16GB RAM, Windows 10, and VMware hosting Ubuntu 16.04. While this testing environment was selected for its backward compatibility and widespread use in development scenarios, future iterations will include tests on newer platforms such as Ubuntu 20.04 to ensure broader compatibility with modern systems. Focusing on the copyright registration module, the most resource-intensive due to its use of the Shazam algorithm, the system operates on the VNT Chain test network.

4.2 Copyright registration performance

The anticipated performance criteria for the system include ensuring that the copyright registration time for a single music piece is completed within 2 s. Additionally, the feature fingerprint data for each music piece, when stored on IPFS, should occupy no more than one-quarter of the original file size. These criteria aim to maintain both speed and efficiency in data handling and storage.

4.3 Test results and analysis

For performance testing, a 10-second audio segment is used for similarity comparison, based on the Shazam algorithm's high confidence level for such clips. The system's database requires feature fingerprint data from entire music files.

In the test, 50 internet-downloaded music files were registered individually. 45 files were successfully registered, indicating a 90% success rate. The five failed files, numbers 10, 22, 23, 25, and 27, only failed post-similarity comparison, reflecting a 100% accuracy rate in this step. Their failure was due to insufficient memory allocation for extracting feature fingerprints from their approximately 5-minute durations. This issue could be addressed by modifying system configurations to increase virtual memory and processing feature fingerprint data in batches.

4.4 Registration time analysis

Figure 2 shows the registration time for each of the 45 successfully registered music files.

In Figure 2, the slope for total registration time increases by about 1.95 s per music file, mainly due to longer similarity comparison times. Extracting feature fingerprints from 10-second segments takes about 1 s, while it takes roughly 22 s for whole files. The similarity comparison, nearly matching the total time increase, is the key factor in registration time growth. Additional time is needed for checking music file formats and converting non-compliant files, contributing to variations in processing times.

Figure 3 further details the factors increasing similarity comparison time. Analyzing Figure 3, the combined slopes of the four lines roughly equal 1.95, matching the similarity comparison time slope from Figure 2. The time increases caused by fetching IPFS addresses of feature fingerprints and sorting tens of thousands of

4 The music ecosystem module facilitates various interactions between creators and users, including music promotion, crowdfunding, and revenue-sharing. These interactions are not strictly financial but form the core of how the ecosystem operates to support and sustain music creators

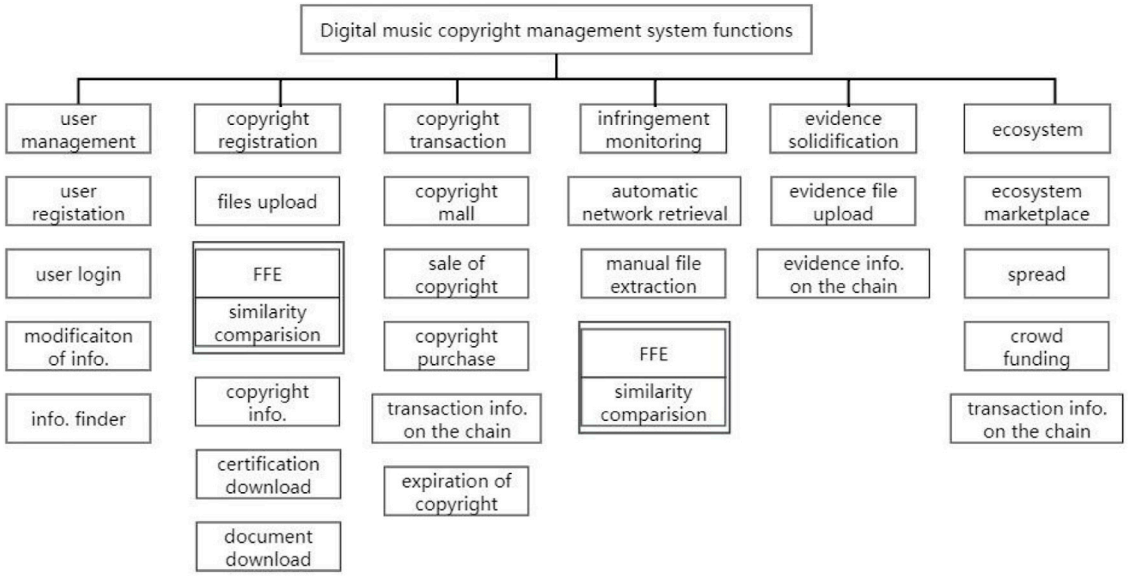

FIGURE 1
Digital music copyright management system functions

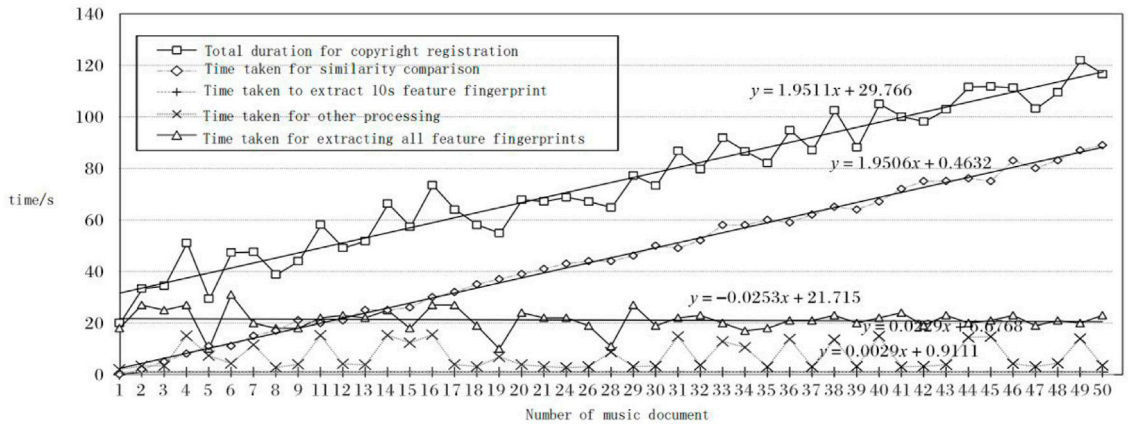

FIGURE 2
Time spent on copyright registration.

Hash values per fingerprint are relatively minor. Hash value matching uses a multi-process and binary search approach, with its logarithmic time complexity minimizing time increases as data grows. The most time-consuming aspect is retrieving feature fingerprint data from IPFS, taking about 1.1 s per music file's Hash address. Future optimizations in data storage and transmission are planned to reduce registration time and improve system efficiency.

4.5 Storage space efficiency

Of the 45 successfully registered music files, their feature fingerprint data on IPFS consumes about 8 MB per file, as shown in Figure 4, with the number of Hash values per fingerprint displayed in Figure 5. This storage size, though 2–3 times larger than the original music files, follows the Shazam algorithm's space-for-time trade-off, enhancing similarity comparison speed. The proposed system, compared to previous ones in Table 3, offers more comprehensive functionality, delivering end-to-end copyright services for efficient music copyright management.

4.6 System performance comparison

To evaluate the system performance, the traditional centralized music copyright management system is selected as the baseline, and the efficiency advantages of the proposed system are quantitatively evaluated from three core processes of music entry, confirmation, and infringement detection. The results are shown in Table 3. It can

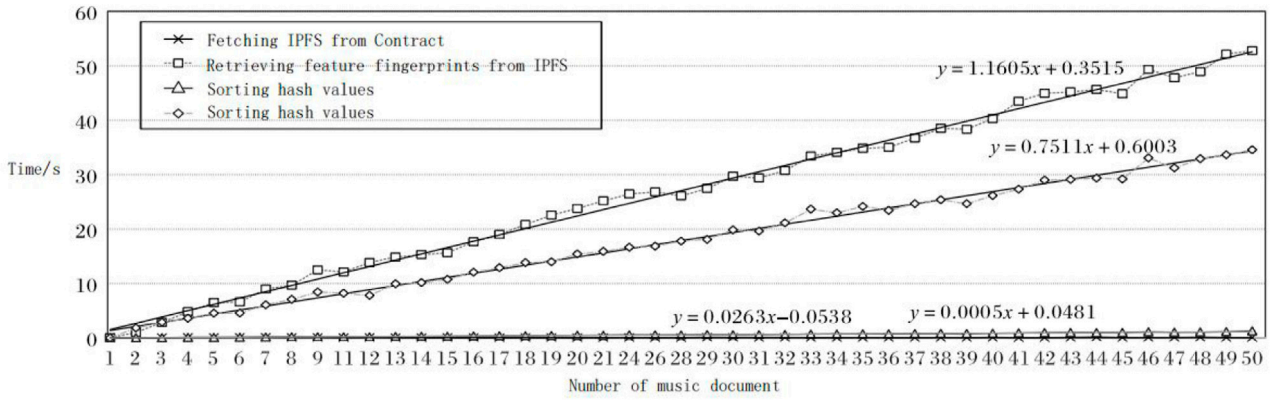

FIGURE 3
Factors of copyright registration time increase.

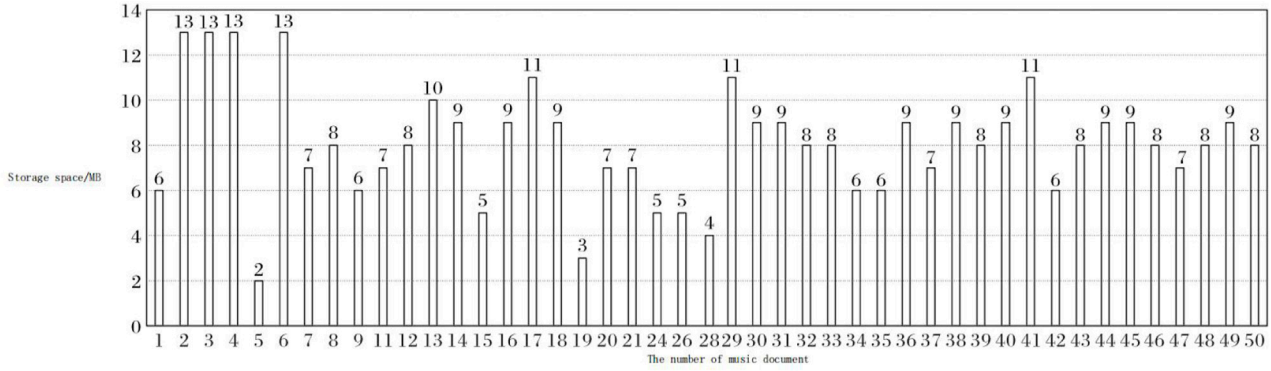

FIGURE 4
Storage space size cost by each feature fingerprint on IPFS.

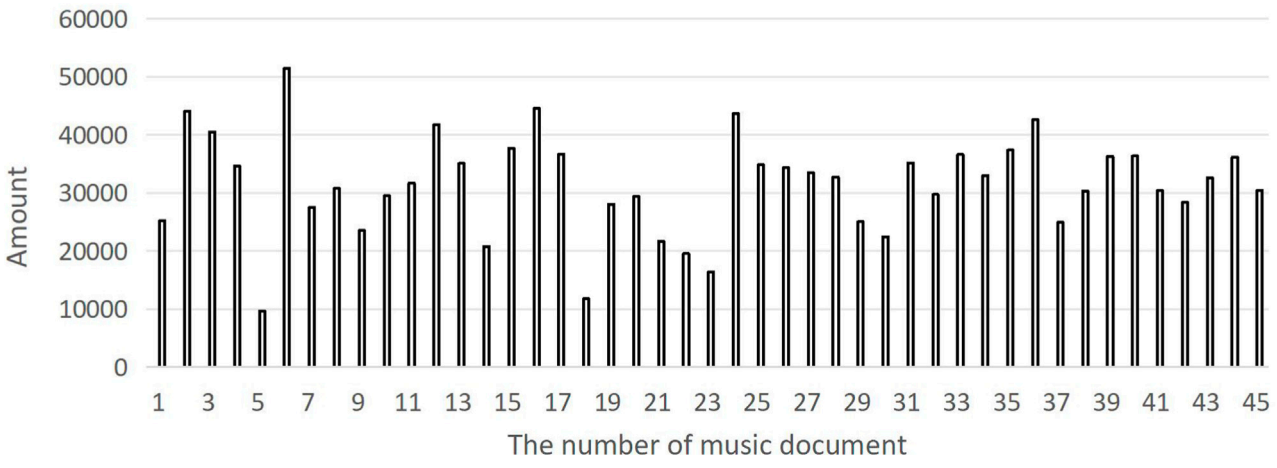

FIGURE 5
Number of Hash value in each feature fingerprint.

TABLE 3 Performance comparison of core processes in different systems.

System\Process	Music entry	Ownership confirmation	Infringement detection
Traditional System	Manual review, 1–3 days	File notarization, 3–5 days	Manual/simple scripts, 7–15 days
Proposed System	Shazam fingerprint extraction, seconds	Blockchain confirmation and evidence preservation, seconds	Shazam fingerprint matching, seconds

be seen that, benefiting from the distributed ledger and smart contract technology of blockchain, the proposed system significantly outperforms the traditional system in the copyright confirmation link, reducing the confirmation time from days to seconds. At the same time, with the help of IPFS's massive storage and Shazam's fingerprint matching algorithm, the music entry and infringement detection links also achieve performance comparable to traditional systems.

4.7 Scalability and security

Also we constructed music libraries ranging from 10,000 to 1 million entries to evaluate the system's scalability,. As the music library grew, the system's entry time remained nearly constant due to IPFS's distributed storage capabilities. Ownership confirmation and infringement detection times remained in the second range, with minor increases due to smart contract execution and the fingerprint matching algorithm. These results demonstrate that even with large-scale data, the system can maintain acceptable latency, making it suitable for widespread use in the digital music industry. Overall, even if the music scale reaches millions, the system can still complete the full process within acceptable latency. This indicates that the proposed system has the potential to support large-scale applications.

In terms of security, existing schemes have security risks such as data tampering, single point of failure, and privacy leakage. The proposed system can effectively avoid the above risks and achieve higher security by comprehensively using mechanisms such as blockchain immutability, IPFS distributed storage, and federated learning privacy protection.

5 Conclusion

With the improvement of people's living standards, more individuals are inclined towards listening to music or creating their own. However, numerous issues in the existing music copyright industry pose significant obstacles to its development. The emergence of blockchain technology provides a promising solution for music copyright management.

This paper presents an innovative design of a blockchain-based management system that covers the full lifecycle of music copyright. It systematically optimizes the storage architecture, music fingerprint extraction and confirmation algorithm, and incentive mechanism. This approach balances data security, system performance, and functional availability, offering practical solutions to many current pain points in digital music copyright management.

The system adopts a layered data storage scheme combining "on-chain and off-chain" solutions. Critical copyright information is stored on-chain to ensure data consistency and judicial credibility. Large object data and hot data are stored off-chain using IPFS and MySQL, respectively, meeting low-latency data access requirements while reducing the load on the blockchain. In the core confirmation module, the improved Shazam fingerprint extraction and matching algorithm is efficiently executed on-chain, achieving music confirmation within seconds. Additionally, through the token economy, users are incentivized to participate in music release, rating, promotion, and other activities, forming a positive cycle and building a healthy music ecosystem.

This work has important theoretical and practical significance for regulating the order of digital music copyright, protecting the legitimate rights and interests of musicians, and promoting the digital transformation and upgrading of the music industry. Future optimizations can enhance the system's consensus mechanism, storage scheme, and cross-chain interoperability. These improvements will extend the system's application to a broader range of digital copyright protection scenarios, promoting the deep integration of emerging technologies such as blockchain and artificial intelligence with copyright protection, thereby contributing to intellectual property protection in the digital economy era.

In this study, we address the problems in the current music copyright industry by developing a digital music copyright management system based on blockchain technology. The system encompasses six major functional modules that meet the majority of music copyright management needs. Furthermore, the introduction of the music ecosystem module not only motivates users to share their music works but also assists music creators in raising funds for their early-stage creations, fostering continuous creativity and the overall prosperity of the music industry. However, the system still has room for improvement, such as addressing the increasing time required for copyright registration and optimizing infringement monitoring through the integration of artificial intelligence technology. Future work will focus on further enhancing the proposed system.

In countries where legal processes necessitate manual confirmation, blockchain serves as a complementary technology that enhances the reliability of digital copyright records. By offering verifiable timestamps and immutable records, blockchain reduces the risk of forgery and supports more efficient legal processes. The combination of blockchain and traditional legal systems can provide a more robust solution for digital copyright management.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

QS: Project administration, Writing–original draft, Writing–review and editing. YZ: Data curation, Formal

Analysis, Methodology, Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The work was supported by the Anshan Normal University [JG21CB191].

Acknowledgments

We acknowledge the use of ChatGPT-4 for language refinement and assistance in improving the clarity and quality of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Agyekum, K. O. B. O., Xia, Q., Liu, Y., Pu, H., Cobblah, C. N. A., Kusi, G. A., et al. (2019). "Digital media copyright and content protection using IPFS and blockchain," in *Proceedings of the 2019 international conference on image and graphics, LNCS* (Cham: Springer), 11903, 266–277. doi:10.1007/978-3-030-34113-8_23

Aldweesh, A. (2024). The impact of blockchain on digital content distribution: a systematic review. *Wirel. Netw.* 30 (2), 763–779. doi:10.1007/s11276-023-03524-0

Cachin, C. (2016). "Architecture of the hyperledger blockchain fabric," in *Proceedings of the 2nd workshop on scalable and resilient infrastructures for distributed ledgers*, 1–6.

Chen, W. L., and Zheng, Z. B. (2018). Blockchain data analysis: a review of status, trends, and challenges. *J. Comput. Res. Dev.* 55 (9), 1853–1870.

Chen, Z. H., Li, Q., Gan, J., Zhang, C., and Li, Z. (2019). VC Chain: an alliance audio-video copyright blockchain system. *Comput. Eng. Sci.* 41 (11), 1939–1948.

Frattolillo, F. (2024). Blockchain and smart contracts for digital copyright protection. *Future Internet* 16 (5), 169. doi:10.3390/fi16050169

He, D., Liu, Z., Yang, Q., and Ma, L. (2022). The development of digital collection platform under responsible innovation framework: a study on China's non-fungible token (NFT) industry. *J. Open Innovation Technol. Mark. Complex.* 8 (4), 203. doi:10.3390/joitmc8040203

Kshetri, N., and Voas, J. (2018). Can blockchain strengthen the internet of things? *IT Prof.* 20 (3), 68–72.

Kuo, T. T., and Ohno-Machado, L. (2017). ModelChain: decentralized privacy-preserving healthcare predictive modeling framework on private blockchain networks. *JMIR Med. Inf.* 5 (4), e46.

Li, C., Dai, B. R., Wang, H. J., and Wang, X. D. (2018a). Digital copyright protection and trading system based on blockchain technology. *Mod. Comput.* (29), 80–84.

Li, L., Zhou, S. Q., Liu, Q., and He, D. B. (2018b). Blockchain-based digital copyright trading system. *Chin. J. Netw. Inf. Secur.* 4 (7), 22–29.

Li, M., Jiang, P., Li, Y., Zhang, L., and Cai, Z. (2017). A survey on the security of blockchain systems. *Future Gener. Comput. Syst.* 107, 841–853.

Meng, Z., Morizumi, T., Miyata, S., and Kinoshita, H. (2018). "Design scheme of copyright management system based on digital watermarking and blockchain," in 2018 IEEE 42nd Annual Computer Software and Applications Conference (COMPSAC) (IEEE), 359–364. doi:10.1109/compsac.2018.10258

National Copyright Administration of the People's Republic of China (2020). Copyright law of the People's Republic of China [EB/OL]. Available at: http://www.ncac.gov.cn/chinacopyright/contents/479/17542.html.

Pan, Y., Chen, Q., and Zhang, X. (2019). "Research on the application of blockchain technology in copyright protection," in *2019 IEEE international conference on intelligence and security informatics (ISI)* (IEEE), 45–48.

Savelyev, A. (2018). Copyright in the blockchain era: promises and challenges. *Comput. Law Secur. Rev.* 34 (3), 550–561. doi:10.1016/j.clsr.2017.11.008

Swan, M. (2015). *Blockchain: blueprint for a new economy*. O'Reilly Media.

Tamilselvan, N. (2024). Blockchain-based digital rights management for enhanced content security in digital libraries. *Technol. (IJBT)* 2 (1), 1–8.

Yao, Y., Hu, C., Zhao, L., Fan, Y., and Yuan, Y. (2018). "A blockchain-based copyright protection framework for digital assets," in 2018 IEEE International Conference on Big Data and Smart Computing (BigComp) (IEEE), 609–613.

Zhang, B. Q., and Li, L. (2019). Balance of digital copyright interests based on blockchain technology. *China Publ. J.* 11, 22–25.

Zhang, Q., Wu, G., Yang, R., and Chen, J. y. (2024). Digital image copyright protection method based on blockchain and zero trust mechanism. *Multimedia Tools Appl.* 83, 77267–77302. doi:10.1007/s11042-024-18514-3

Zhang, X., Zhang, W., Xu, X., and Huang, J. (2020). A blockchain-based copyright protection framework for digital media assets. *IEEE Access* 8, 27274–27284.

Zhao, G. F., He, Y., and Zhou, J. H. (2019). Digital copyright registration technology based on blockchain. *Inf. Technol. Netw. Secur.* 38 (4), 79–83.

Zheng, Z., Xie, S., Dai, H. N., Chen, X., and Wang, H. (2017). "An overview of blockchain technology: architecture, consensus, and future trends," in IEEE International Congress on Big Data, Honolulu, HI, USA, 25-30 June 2017, 557–564. doi:10.1109/bigdatacongress.2017.85

Zheng, Z., Xie, S., Ning, H., and Hao, F. (2018). "An overview of consensus algorithms used in blockchain," in 2017 IEEE International Congress on Big Data (BigData Congress) (IEEE), 380–387.