Non Fungible Tokens: A review

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***Abstract*—Non Fungible Tokens (NFTs) are among the most promising technologies that have emerged in recent years. NFTs enable the efficient verification and ownership management of digital assets and therefore, offer the means to secure them. NFT is similar to blockchain that was first used by the cryptocurrency and then by numerous other technologies. At first, the NFT concept attracted the attention of the digital art community. However, NFT has the potential to enable a plethora of different applications and scenarios. We present a review of the NFT technology. We describe the basic components of NFTs and how NFTs work. Then, we present and discuss the different applications of the NFTs. Finally, we discuss various challenges that the NFT technology must address in the future.**

***Index Terms*—Non Fungible Tokens, Blockchain, Metaverse, Security, smart contract**

I. Introduction

In the last two decades, we have witnessed numerous major technological advances which have revolutionized the way we do business, communicate, travel, educate, provide healthcare services and many other daily tasks. Non Fungible Tokens (NFT) are without a doubt a major technological revolution in the last few years because it seriously disrupts the notion of property. A NFT is a digital asset that can represent numerous objects such as art pieces (digital paintings, photos, music, video), tickets, and so on. For example, at the time of writing this paper (September 2022), the artist *Damien Hirst* surprised the art world with his new project coined "The currency"[1] where among 10000 paintings sold, the artist will burn 4851 following the choice of the buyers that want to keep only a digital version in the form of a NFT. The current NFT market cap is $16.8 Billion worth, with a +6.2% change in the last 24 hours (September 9th)[2]. In fact, NFT sales are continuously increasing. According to the *Jefferies* report [1], the NFT industry will hit a valuation of $80 billion by 2025.

Technically, a Non Fungible Token is a digital property certificate that is secured through a blockchain. More precisely, NFT is like cryptocurrency because both rely on the same underlying technology which is blockchain. However, first, NFTs are implementable only on blockchains that implement smart contracts. Indeed, NFT was initially implemented on Ethereum via the Ethereum Improvement Proposals (EIP)-721[3] and then developed in EIP-1155 [4]. Although most NFTs rely on the Ethereum blockchain, a few alternatives such as Solana[5] and Polygon[6] have appeared in recent years. Solana has attracted a lot of interest recently which keeps growing exponentially. Second, cryptocurrency uses standard/fungible tokens. That is, tokens of the same cryptocurrency have the same value and are indistinguishable and interchangeable. However, a NFT is unique and cannot be replaced equivalently by another NFT. This uniqueness allows the identification of digital assets. That is, using the characteristics of NFTs and smart contracts, a person can prove the existence and ownership of digital assets [2]. Moreover, the owner of a NFT can earn royalties each time of a successful trade on any NFT market or by peer-to-peer exchange [2].

II. How it works?

As stated earlier, NFTs rely on blockchain technology which implements smart contracts. A blockchain is a distributed ledger that maintains a permanent and tamper-proof record of transactional data. A blockchain is completely decentralized by relying on a peer-to-peer network. More precisely, each node of the network maintains a copy of the ledger to prevent a single point of failure. All copies are updated and validated simultaneously [3]. *Clack et al.* [4] define a smart contract as an automatable and enforceable agreement. Automatable is achieved via computers, although some parts may require human input and control and, enforceable either by legal enforcement of rights and obligations or via tamper-proof execution of computer code. *Wang et al.* [2] defines smart contracts as what enable unfamiliar parties and decentralized participants to conduct fair exchanges without a trusted third party in order to build applications in a fully decentralized approach. Therefore, in a Blockchain/NFT context, a smart contract can be defined as code scripts that are designed to execute certain tasks once pre-defined conditions are met. These scripts typically, although not necessarily, run on distributed ledgers (e.g., blockchains). Relying on a blockchain provides a NFT numerous security and function features which include verifiability, transparent execution, availability,

[1]https://opensea.io/collection/thecurrency
[2]https://www.coingecko.com/en/nft
[3]https://eips.ethereum.org/EIPS/eip-721
[4]https://eips.ethereum.org/EIPS/eip-1155
[5]https://solana.com/solana-whitepaper.pdf
[6]https://polygon.technology

tamper-resistance, usability, atomicity, tradability, traceability, and many others.

Wang et al. [2] identified two design approaches for the NFT paradigm: (1) building NFTs from the initiator, and then selling them to the buyer (e.g., CryptoPunks[7]) and (2) setting a NFT template, and every user can create their unique NFT (personalized) above the template (e.g., Loot[8]). However, both design approaches follow the same operation mode during their execution on the blockchain.

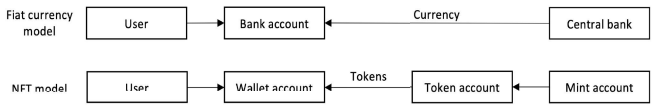

Fig. 1. Comparison of the fiat currency model and the NFT model

Figure 1 describes an analogy between the fiat currency model and the NFT model. In the fiat currency model, the central bank (e.g., European Central Bank, Federal Reserve Bank) is responsible for the currency creation. The currency is provided to users via their bank accounts. This model is similar to how tokens are represented in NFT ecosystems. In other words, a token is a decentralized currency that exists in the blockchain. As there exist different fiat currencies created by different banks, there exist different token types. A mint account mints tokens and the NFT system users can own tokens via token accounts. More precisely, the NFT ecosystem users interact with their token account through a wallet account which is a software associated with a cryptographic key-pair. Moreover, a wallet account can be associated with multiple token accounts for different mint accounts or for the same mint account. In analogy a person can have multiple accounts for the same currency or different accounts for different currencies. When a sender needs to send transactions toward a given wallet account, he/she does not need to specify for which token account it is intended for because all token accounts share the same public key. However, a specific program (e.g., Program Derived Addresses (PDA) in Solana based NFT systems) determines to which token account a transaction must be sent, relying on the wallet account and the mint account.

Figure 2 describes the structure of a NFT system. The diagram highlights the data available at each account level [5]. Next we focus on the most important fields of each of the accounts described in Figure 2. (1) For the mint account, the *Mint authority* field represents the account that can mint more tokens. The mint authority can revoke its own right, hence, making the mint account immutable (i.e., the number of tokens will not increase). The *Supply field* describes the number of valid tokens in the system. The *Decimals* field describes the divisibility of the tokens minted. A value *Decimal = 0* means that the token cannot be divided into smaller units for trading. (2) For the token account, the *Amount* field describes the number of tokens available in the account. It is worth noting how the token account keeps track of both the mint account through the *Mint* field and the wallet account through the *Owner* field. Consequently, we can define a NFT as a mint account with zero decimals and whose supply is one and will never exceed one because the mint authority revokes its mint account's right to mint more tokens immediately after minting the first one.

The mint account and the token account are also associated with a "Metadata account". The role of this account is to add metadata to the NFT. Figure 2 shows the main fields and data that this account handles. The *Key* field authenticates the metadata account. The *Update authority* indicates the account that can update the metadata account. The *Name* field shows the on-chain name of the NFT. The *Creators* field represents an array of creators and their share of the royalties. For each of these creators, the *Verified* attribute ensures that a creator signs the NFT to prove his/her authenticity. The *Is mutable* field shows if the on-chain metadata of the NFT can be modified or not. We can also note how the *Metadata account* keeps track of both the *Mint account* and the *Token account* through the *Mint* field. Finally, the *URI* field is one of the most important fields because it describes the Uniform Resource Identifier (URI) that points to a JavaScript Object Notation (JSON) object off-chain. The off-chain JSON object allows to store more data related to the NFT. For example, it contains a *Name* and *Description* fields. But most importantly, it contains an *Image* field, which contains a URI to download the digital asset [5].

As we have described above, there are two metadata storages. The rationale behind this design is mainly: (1) the cost, because storing data on-chain is costly. The storage size of an NFT metadata is variable according to the NFT. Therefore, to limit this cost, the off-chain storage option is available. We can store the digital asset (the NFT painting, video, ticket or other) on another blockchain (e.g., some of the Solana based NFT systems use Arweave[9]) or on an off-chain storage like a cloud computing solution. (2) the flexibility, because storing data on-chain is permanent, and if the NFT's metadata needs update (if *Is Mutable = True*) it will not be possible with the on-chain storage. The same issue arises with the digital asset's storage. For example, if the NFT represents a baby cat that gradually grows into an adult cat, the JSON metadata associated to this NFT must include these gradual changes as well as for the image field itself (e.g., each time the owner opens his/her wallet a new image of the cat appears). For these reasons, an off-chain storage is needed. The main drawback of this design is security. More precisely, if the data is not stored on a blockchain, an attacker can tamper with the storage and therefore tamper with the NFT itself (e.g., the image stored).

III. Where can NFT be applied?

The concept of Non-Fungible Tokens is not new. However, it is its application to the digital art market that has increased interests in this area lately. Before the current NFTs, it was impossible to know if a digital asset is the original one and especially if the owner is the real owner because digital assets could be copied. However, NFTs revolutionized this field by offering an irrevocable proof of property to the digital assets and products. Still, there is always the possibility of copying

[7]https://www.larvalabs.com/cryptopunks
[8]https://lootnft.io/
[9]https://www.arweave.org/

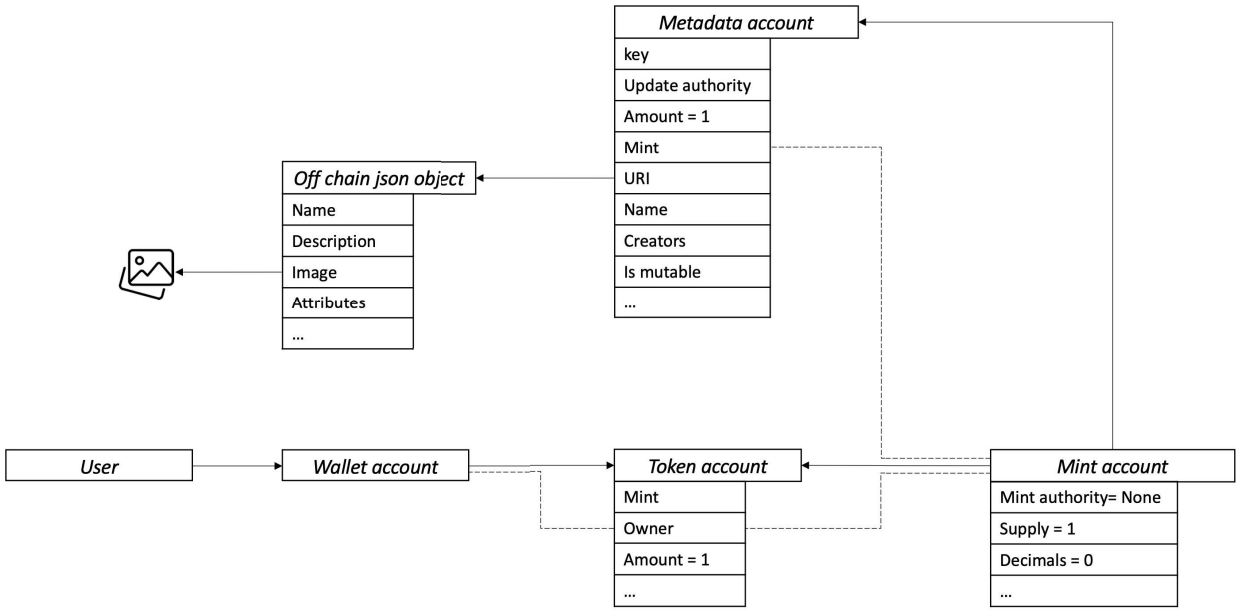

Fig. 2. Structure of a NFT system

these items. However, it is analogous to real world where we have the original item (e.g., painting) and fake copies. Even if a user copies the digital asset (i.e., image) and use it to create a new NFT, the artist's cryptographic signature and the timestamp will prove which is the original one. In short, the NFT concept helps in the protection of digital collectibles.

A. Metaverse

It is true that any user can copy the NFT and use it freely in the wild Internet. However, the NFT concept can be very useful/essential in multiple fields especially the Metaverse. The early definition of Metaverse is a virtual environment parallel to the physical world wherein users interact through digital avatars [6]. However, with the emergence of technologies and concepts such as blockchain, cryptocurrency, augmented reality, and virtual reality, the Metaverse is an extension of our real world. Indeed, despite the gaming side that is more dedicated to fun, there are numerous current uses of the Metaverse in the social/economic world. The Covid pandemic has accelerated the adoption of the home office concept. Even after the Covid crisis, this practice is strongly encouraged to help with the ecological transition[10] and reduce the economic centralization around large cities thereby improving the demographic distribution. However, according to [7] collaborative work between colleagues suffers when they work remotely especially that informal chats during breaks are a boost for innovations (e.g., Google's Street View and Gmail). Moreover, remote working has an impact on workers' well-being. *Bailenson* [8] concluded that the combination of factors such as intense eye contact, lack of mobility, self-consciousness about one's own video feed, and the cognitive demands of needing to give exaggerated feedback to signal understanding, agreement or concern are responsible for what is called the "Zoom fatigue". Multiple companies (e.g., Meta Quest[11], Microsoft Mesh[12]) provide solutions to improve the worker's experience through a Metaverse office, where the coworkers interact through avatars which can be customized or as photo-realistic holograms, and/or using virtual reality. These experiences can be further enhanced by different scenarios, like for example a coworker can leave one meeting room with some design, meet other coworkers (through avatars) for an individual chat before entering into another meeting room with another design (e.g., Metapolis[13], a 30-floor VR office). The Metaverse use is not limited to gaming or to home office but can be applied to other fields. For example, online classes are rapidly gaining ground. Numerous schools and centers propose online schooling only. However, online schooling suffers from the same issues as the home office and mainly zoom fatigue as well as the lack of interaction between students. The Metaverse approach can resolve the main problems. In addition to education support, Metaverse can have more uses: auctions, online dating, job dating, concerts, trading shows, cultural exhibitions and more.

Consequently, conglomerates and governments are massively investing in the Metaverse development. *Mark Zuckerberg*, the Facebook's CEO announced the development of Meta to make Facebook evolve toward a social Metaverse[14]. The European Union (EU) also announced a project to develop

[10]The ecological transition is the process by which human societies manage their relationship with the physical environment, aiming at a more balanced and harmonious relationship regarding local and global ecosystems. One aspect of the ecological transition is the technological reconversion aimed at producing fewer polluting substances.

[11]https://www.oculus.com/workrooms/

[12]https://www.microsoft.com/en-us/mesh

[13]https://zigbang.notion.site/User-Guide-7a2dd3a17b72448b9478a526c6038c20

[14]https://www.theguardian.com/technology/video/2021/oct/28/meta-mark-zuckerberg-announces-facebooks-new-name-video

a European Metaverse [15] that has a social dimension but with mainly an economical goal in order to create ecosystems where European industrial actors can collaborate on massive projects.

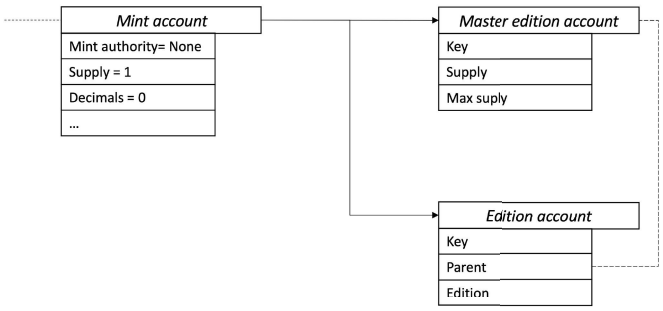

Fig. 3. Model used by Solana to duplicate NFTs

Current technological trends show that the Metaverse will be part of our everyday life. Hence regulations are needed and will be applied as it happened for past technologies. In this context, the NFT represents a key solution to boost the attractiveness, adoption, and development of the Metaverse. Indeed, in Metaverse, digital assets are used and exposed. Using NFTs, we can ensure the use of real digital assets and not fake copies which will enable a fair distribution of royalties. For instance, if some digital art is used for decoration, we can make sure to pay the owner of this NFT. Analogous to real life, it is not allowed to expose fake copies of paintings. NFT technologies allow the creation of copies. However, they represent an extension of the real NFT and are always linked to the original. Figure 3 describes the technique used by Solana to duplicate NFTs. Hence, if an owner needs to lend his/her NFT, the owner needs to create a copy linked to the original one. The French president *Emmanuel Macron*[16] announced the use of NFTs to create copies of French museums where all real buildings and art/history objects will have their NFTs in order to provide wider access to these national goods and to help promote French history, art, and culture.

With the help of cryptocurrency, NFTs will revolutionize multiple areas because it offers new opportunities for economic trade. For example, there are different "open world Role-Playing Games (RPG)" where players can have interactions such as trading goods with virtual tokens created by the game. Today, they can trade NFTs with cryptocurrency that have a real value with fiat currency. The same can be applied to digital assets within a Metaverse (e.g., exhibition of digital art, digital pets or any digital asset where the visitors can trade NFTs). In fact, some of the more expensive transactions done in NFTs correspond to virtual plots of land in Metaverses, some of them costing more than $1 million USD [17]. Moreover, because NFT technology relies on blockchain, the transactions between the seller and the buyer do not need a trusted third party which allows a fair and better remuneration for creators and artists also because traditional sharing platforms (e.g., Spotify for music streaming) do not pay them fairly[18].

As a last use case of NFTs in the Metaverse, NFTs can be used as *virtual challenge coins*. In the real world, challenge coins have been used to prove membership to a group, especially in the military to prove membership to a unit. NFTs in the Metaverse can be used as *virtual challenge coins* by which users can show that they belong to a group, or that they hold some kind of certification. This use case of NFTs in the Metaverse can allow a user to demonstrate a skill even after the issuing group (or certifying company) does not exist anymore by taking advantage of the supporting infrastructure of NFTs in a blockchain.

B. Digital Twins

The NFT concept can also enable the use of digital twins. Initially, a digital twin was defined as a computational model that evolves over time to persistently represent the structure, behavior, and context of a unique physical asset (e.g., a component, a system or a process) to monitor and predict the activity of the physical asset throughout its lifecycle. Since each physical asset is unique, NFTs allow the creation of unique digital twins, making the definition of this digital twin more accurate.

C. Proof of authenticity/property

A NFT can also be used as a proof of authenticity and property for physical goods. One of the most promising areas is the luxury and jewelry in markets which sell used goods. Indeed, The global luxury resale market was worth 28 $billion in 2020 which increased to $32.61 billion in 2021, and is likely to reach $51.77 billion by 2026 [9]. Unfortunately, the rise of luxury resale has led to increased counterfeiting. It is estimated that one-fifth of all the luxury goods on social media are counterfeits which cause the luxury industry to lose $30.3 billion per year due to fake online sales[19]. NFTs bring a solution to address the sale of counterfeits. Indeed, if for each physical item, a NFT is created by the manufacturer and provided to the first buyer. This represents the unique digital extension of the luxury good. Hence, a buyer of used goods gets the physical item and the NFT which is the proof of authenticity. If a malicious seller having a real item (e.g., a bag) sells a fake item and lures the buyer through the NFT, the seller will stay with a real item but without a NFT and therefore without a proof of authenticity making it impossible to sell the item.

This special case of NFT is called Physical NFT. Physical NFTs are digital tokens tied to real-world assets. There are two parts to physical NFTs. The first part refers to the digital asset issued on a blockchain using smart contracts. The second part is the physical asset, which is often linked to a corresponding unique key/identifier, such as a Quick Response (QR) code or a Near-Field Communication (NFC) tag. This unique identifier

[15]https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_22_5525
[16]https://www.thebigwhale.io/article/macron-linnovation-et-la-prise-de-risque-font-echo-a-lhistoire-profonde-de-notre-pays
[17]https://www.exodus.com/news/top-5-virtual-land-sales/
[18]https://www.nytimes.com/2021/05/07/arts/music/streaming-music-payments.html
[19]https://mojeh.com/fashion/counterfeit-culture-could-you-be-duped-into-buying-a-fake-bag/

(shared by both types of assets) ensures that the physical asset and the associated NFT remain connected.

D. Authentication/identification/authorization

Finally, NFTs can be used as authentication tools to authenticate, identify, and authorize identities/processes. Indeed, PKI is used to create and manage digital certificates. However, because of the increase in the number and sizes of networks as well as the adoption of novel paradigms such as the Internet of Things and their usage of the web, current centralized PKIs are vulnerable to single point of failure as the network loads increase. In this context, the NFT paradigm can be used to create certificates that contain authorization and identification information. Due to the limited size of the certificates, they can even be stored on-chain. Therefore, the deploying system uses a fully decentralized authentication approach because NFT technology relies on the blockchain which is a fully decentralized technology. Other than the traditional use of certificates, that is to authenticate processes, these authentication NFTs (certificates) can be used in numerous other use cases such the authentication of avatars in the Metaverse to avoid identity spoofing, the authentication of social media accounts, digital subscriptions, membership programs and more.

IV. NFT CHALLENGES

Despite the important evolution of NFT in recent years, there are still numerous major challenges that NFT must address to achieve a wider adoption. In this section, we highlight some open research and operational challenges.

Volatility/high price of cryptocurrency: A NFT system relies on a public blockchain, which involves costs that depends on the cryptocurrency used by the underlying blockchain system. However, cryptocurrencies are volatile. This volatility introduces two main issues: first, the volatility of the NFT value regarding to its fiat value. As an analogy, for example, a physical painting will not have a different price/value every day. Second, the volatility of smart contracts costs makes the management costs very variable. Furthermore, minting a NFT requires triggering a smart contract and uploading the metadata related to this NFT into the underlying blockchain. As a consequence, NFT-related transactions are very costly and way more expensive than simple transfer transactions [2].

According to a recent study [10], the evolution of the cryptocurrencies rates will get more stable over time. Even better, blockchain developers and community are working on regulating and stabilizing the amounts of fees related to smart contracts use[20].

Security of the digital asset/media: To avoid the high prices related to the storage on-chain, the media related to the NFT is commonly stored off-chain. However, the original off-chain file can be corrupted or lost. The technique of InterPlanetary File System (IPFS) is used in numerous NFT systems. In IPFS, only the hash of the digital media is stored on-chain and the media itself is stored off-chain. However, this technique has its limits and introduces the issue of the immutability of the media off-chain [2][11]. Even if the NFT's metadata on-chain does not change, the off-chain media could be (1) lost if the off-chain storage no longer stores it, (2) corrupted, or (3) the NFT might point to an erroneous file address. Consequently, a user cannot prove that he/she actually owns the NFT.

To provide a solution to this storage problem, the platform *Decrypt.co* recommends the use of *ipfs2arweave* services which combines IPFS with *Arweave*. *Arweave*[21] is a protocol that stores data permanently, with a single upfront fee ($0.05 per megabyte). More precisely, the protocol matches people who have hard drive storage space to spare with entities that need to store data. However, this solution does not fully guarantee the that the digital asset will not be lost because it relies on the hard drives of the common internet users, even if the data is duplicated through IPFS. In the same context *Li et al.* [12] proposed a new collaboration model for NFT data placement between blockchain and Peer-to-Peer (P2P) storage network. The P2P storage network stores content data off-chain whereas the blockchain stores the NFT metadata and helps the storage network choose the file's storage locations. To enhance the availability of data, the authors also propose a dynamic replication location strategy. However, the problem of data storage off-chain remains.

Privacy/anonymity: A blockchain user is authenticated through its public key (more precisely an address derived from the public key). This authentication ensures the anonymity of the user which is considered as one of the biggest advantages of the blockchain/cryptocurrency. However, this anonymity is not always guaranteed with NFTs. Indeed, if the address of an artist or a NFT holder is known, all his/her assets will be known. The solution of using different public keys (different accounts with one account per asset) by the same user is possible. However, this solution is not scalable.

Qin et al. [2] stated that some of the existing privacy-preserving solutions such as multi-party computation, homomorphic encryption, ring signature, and zero-knowledge proof could provide a solution to the privacy/anonymity problem. However, their high implementation costs could become an obstacle to their deployment.

Issues of the underlying technologies: The NFT technology relies on the blockchain which in turn depends on other technologies. Therefore, the NFT technology is vulnerable to the security issues of its underlying technologies. For example, recently, because of a vulnerability in Decentralized Finance (DeFi) protocol[22], which is a protocol related to smart contracts, hackers stole almost $600 million value in NFT[23].

While NFTs rely heavily on smart contracts (for the transactions function or for the wallets operations), smart contact developers are not always aware of the security risks that they can/may cause. Furthermore, there is a lack in standards, procedures and best practices related to the design/creation of

[20] https://smartereum.com/6777/buterin-expresses-concern-over-stabilizing-ethereum/

[21] www.arweave.org

[22] https://ethereum.org/en/defi/

[23] https://www.cnbc.com/2021/08/11/cryptocurrency-theft-hackers-steal-600-million-in-poly-network-hack.html

smart contracts. Moreover, developers do not have the adequate tools for testing, verifying, and auditing smart contracts efficiently [13].

Interoperability: Interoperability issues are among the main obstacles to the adoption of NFTs. A NFT relies on its underlying blockchain technology. However, there exist different blockchain technologies and therefore different NFT ecosystems. Consequently, the NFT ecosystems are isolated from each other, which means that a user must first chose a NFT ecosystem and then buys/trades/sells NFTs on the same ecosystem. This hardly limits the NFT trading opportunities (e.g., a metaverse where different users trade NFTs each from a different NFT ecosystem). Although the interoperability can be ensured via a centralized trusted third party, this will make the NFT ecosystem lose its two major advantages which are the decentralization and the absence of a third party.

Another type of interoperability issue can arise when there is a need to use NFTs on existing legacy systems like for authentication/authorization. Even if NFT technology represents a promising technology and a solution to some digital property issues, it remains an emerging technology that needs to be properly integrated into the existing legacy systems to reap its full benefits. Unfortunately, not all the systems allow an easy integration of NFT concept mainly due to technological obstacles. Efficiency and cost are major considerations for the replacement of the existing systems. Therefore, it is necessary to develop efficient gateways that allow the integration of NFTs with these systems. For example, *Musamih et al.* [11] have explained how the integration of NFTs into healthcare ecosystems could be beneficial. However, healthcare ecosystems involve multiple technologies that must cooperate. Several of these technologies rely on legacy systems which makes the integration of NFTs challenging.

Belchior et al. [14] presented a holistic survey on the existing interoperability approaches for Blockchain technologies which they classify into three categories: Public Connectors, Blockchain of Blockchains, and Hybrid Connectors. They concluded that there is always a need for new, more efficient interoperability approaches.

Legal considerations: Defining a clear legal frame on worldwide decentralized technologies (e.g., cryptocurrency) has always been a challenge for authorities [11] and NFT technology is not an exception. There are different legal and policy issues related to the use/adoption of NFTs. Furthermore, each country has its own policy regarding these technologies. Consequently, different issues arise such as the Know Your Customer (KYC) data issue, cross-border transactions where a user buys/trades/sells NFTs from/in another country. Furthermore, the political/legal decisions of one country can have beneficial/disastrous consequences on the rest of the world. For example, the ban of cryptocurrency by China caused the decrease of major cryptocurrencies value (mainly Bitcoin and Ethereum) for a long time[24]

Another legal issue is related to taxable property. Generally, properties and intellectual property such as art or domain names are considered as taxable properties. However, NFT-based sales are not taxable in most of the countries which may greatly increase financial crimes through NFT trading. Therefore, in the future we must address this tax issue.

Energy consumption: It is well known that blockchain technologies consume a lot of energy. This is more relevant for blockchains that rely on the proof of concept consensus mechanism (e.g., Bitcoin). According to the International Energy Agency (IEA)[25] the crypto mining energy use is around 140 TeraWatt-hour (TWh) in 2021, which is almost half of all the data centers energy consumption (excluding the crypto mining activity). Also according to the IEA, the crypto mining energy consumption increased by 3300 % since 2015. The Bitcoin's annual carbon footprint is estimated around 50.55 Million Tonnes of carbon dioxide equivalent (Mt CO2)[26], which is an equivalent of the carbon footprint of a small country such as Hungary.

Hence, it is necessary to (1) develop and use consensus mechanisms (e.g., proof of stake) that are energy-efficient (compared to consensus mechanisms based on proof of work). And (2) to use green energy wherever possible to ensure the function of blockchains and NFT ecosystems.

In this context *Bada et al.* [15] argue the need for a green blockchain and present a framework for the development of sustainable and environment friendly Blockchain-enabled systems.

V. Conclusion

The NFT technology has enabled new concepts like the exclusive ownership and the proof of ownership of digital assets. Therefore, NFTs are paving the way for new applications and uses of digital assets.

In this paper we presented the key features of NFTs from a technical perspective to allow the reader to better understand the mechanisms behind such a technology. Then, we described the different use-case scenarios where NFTs will bring benefits. We conclude that NFT technology will foster and enable the wide development of the metaverse because it will offer the metaverse users all what they need to manage digital assets efficiently and securely. The NFT technology can also bring benefits to the authentication/authorization mechanisms and allow a decentralized identity management which will help in the design of decentralized identity management schemes to scale with the increasing growth of networks and to address the centralization issue of current architectures. Finally, we discussed the different challenges that the NFT technology must solve to allow its large adoption and make the most of this promising technology.

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