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A Survey of Artificial Intelligence Driven Blockchain Technology: Blockchain Intelligence

Naim Ajlouni
Department of Software Engineering
İstanbul Aydın University
İstanbul, Turkey
naimajlouni@aydin.edu.tr

Adem Özyavaş
Department of Computer Engineering
Istanbul Aydın University
İstanbul, Turkey
ademozyavas@aydin.edu.tr

Mustafa Takaoğlu
Department of Computer Engineering
Istanbul Aydın University
İstanbul, Turkey
mustafatakaoglu@aydin.edu.tr

***Abstract*— This work looks at the literature on the interaction and possible collaboration areas between the blockchain technology and artificial intelligence (AI) that can benefit both. Blockchain has gained considerable popularity because of cryptocurrencies and has been one of the centers of interest and research recently. Like any other technology, it brings its own buzzwords such as smart contracts, proof of work, and consensus algorithm together with their shortcomings which AI can help with. Similarly, blockchain technology can provide the reliable and quality data that AI algorithms need for more accurate results.**

Keywords—blokchain technology, artificial intelligence, smart contracts, distributed ledger technology, blockchain intelligence.

I. INTRODUCTION

Technological developments affecting humanity have always been the result of an accumulation of knowledge that transformed the way we carry out our daily activities. Many innovations, from the evolution of computing to the use of the internet have taken a similar path of evolution. Artificial intelligence which started in 1950s has now been mingled with blockchain and cryptocurrencies [1], which are widely discussed today, have a similar history. Merkle trees, started in the 1970s [5] and widely accepted as the foundation of blockchain, form the digest of all the transactions in a block. The impact of new technologies in our lives may be hard to predict. To some the idea of blockchain and the way it has the potential to transform the way we go about daily activities is revolutionary. Now artificial intelligence can help the blockchain technology to take its accomplishments even further by providing the tools where blockchain technology falls. Short. It is probable that in the next few decades, we will witness many innovations that both technologies can bring to our lives. It is of great importance that study subjects with such great potential are maintained under the same roof.

Blockchain technology in the simplest terms is a data center [4]. The most important feature of blockchain systems from the perspective of artificial intelligence is that it can provide the reliable and high quality data that artificial intelligence algorithms crucially depend on for accurate predictions. At the same time, artificial intelligence can help the blockchain technology with the structural problems that it faces. Therefore, the purpose of this study is to focus on the symbiosis of both technologies and look into the effects of such a work together. The fact that blockchain technology has the potential and been used outside of the financial applications today and the fact that artificial intelligence algorithms are used behind the scenes in many applications could be an indication that blockchain and artificial intelligence hybrid solutions will appear more in the near future.

The concept of Blockchain Intelligence [71] has already been mentioned in some studies. Blockchain systems have been added as a layer in software systems to benefit from the advantages brought by the blockchain technology. As opposed to blockchain's integration into the system as a layer after the system is developed, new systems will have the blockchain intelligence integrated in the system while it is being conceptualized.

The flow of our study is planned as follows: First, a detailed blockchain technology introduction is made in the second part. In the third part, artificial intelligence is summarized with the emphasis of both technologies' support for each other. In the fourth chapter, blockchain intelligence is detailed and introduced through an example.

II. BLOCKCHAIN TECHNOLOGY

Bitcoin, which is based on blockchain technology, was introduced in 2008 by Satoshi Nakamoto [1]. After bitcoin, blockchain technology has become a popular subject that has been widely studied both by private sector companies and academicians [2][3].

Blockchain architecture was proposed by Stuart Haber and W. Scott Stornetta in 1991 [4]. From a historical perspective, the roots of technology appear when Ralph C. Merkle proposed the Merkle tree in the late 1970s [5]. In 1990, the first encryption money for electronic payments was used and names as e-Cash. Further evolution and improvements of the mixed chain concept were introduced in the 1994 in an article by Neil Haller with S / KEY, a mixed chain for Unix login [6]. In 2002, Adam Back proposed a hashcash [7][8], a blockchain-based electronic currency, with a proof-of-compromise algorithm with many of the features of Bitcoin, and was referred to by Nakamoto as Bitcoin's reference study [9].

Blockchain is a distributed digital ledger technology that every node contains a copy of all transaction records that make up on the blockchain system [10][11]. The blockchain that gains a distributed structure thanks to the sharing of transaction records with all nodes avoids the problem of being the target of cyber-attacks faced by centralized systems [12][13]. Besides, the blockchain systems enable peer-to-peer transactions, which eliminates the possibility of a third party being an intermediary [14][15]. System' nodes see all transactions making blockchain-based systems attain transparency [16].

Cryptology [17] is the basis of the blockchain [18]. The system consists of blocks [19]. Each block has a cryptological hash function [20]. These hash functions connect all end-to-end blocks as a chain [21]. The first block created is called the genesis block. The characteristics of the chain are prescribed in the genesis block, and all operations that are performed are written to the ledger in one direction [22]. A transaction approved by the nodes cannot be modified. When a block changes, the system throws that block out of the chain. This way, blockchain systems are tamper-proof [23]. Blockchain technology is a supportive technology meaning that it can be used to support other existing technologies. For this reason,

blockchain technology is currently being adapted in many areas [24].

A. Characteristics of Blockchain Technology

Each blockchain system has the following common characteristics.

Distributed and sustainable: As the nodes forming the system are spread all over the world, a distributed system is obtained, unlike central data servers [25][26]. Also, there is no vital information or piece of code in the nodes to maintain the system. Thus, blockchain systems are sustainable systems.

Secure: Cryptological hash functions [27] for example SHA256 and consensus protocols, explained in next sections, Merkle hash three and digital signatures [28] are all there to increase the security of the data which stored in the blocks [29].

Private: The information of users who make transactions in blockchain systems as a node is not shared with the public. Furthermore, in private and hybrid blockchain systems [30], transaction records are not visible to everyone and are only accessible by permissioned nodes ensuring blockchain systems' privacy [31].

Indelible: In order for a transaction to register in the blockchain system, all nodes must approve. Information that is approved and written to the blockchain becomes definite and cannot be modified [32]. In other words, it is not possible to modify or delete a transaction that has been written to the block [33].

Transparent and auditable: Nodes forming the blockchain have access to the system and could see all the transactions performed [34]. This makes the blockchain systems transparent and auditable [35].

Consensus-based: A consensus algorithm can be defined as the mechanism used by a blockchain network to reach an agreement. There are many consensus algorithms and each has some advantages and disadvantages based on the needs of the system in which they are used [36]. Algorithms such as PBFT-based, Stellar, Ripple, Proof-of-Work (PoW), Proof-of-Stake (PoS), Threshold Relay, Proof-of-Authority (PoA), Proof-of-Burn (PoB), Proof-of-Elapsed Time (PoET) are consensus algorithm examples [37].

B. Public and Private Blockchains

Public (Permissionless) Blockchains: It is a blockchain type owned by popular crypto coins such as Bitcoin [38] and Ethereum [39]. There is no limit to access and transaction. The participant joins the system and becomes part of it [40]. Because of this, the system has a distributed structure. In public blockchains, all nodes are synchronized with each other. When the established chain grows in time, the processing speed decreases with the increasing number of blocks, and hence the increase in the amount of energy consumed. As opposed to Private Blockchain, public blockchain systems allow users to monitor system events [41].

Private (Permissioned or Consortium) Blockchain: In private blockchains, access must authenticated [42] hence allowing only registered nodes [43]. Decision-making nodes are determined among the nodes granted access to the system, and the transactions are approved accordingly by registered nodes [44].

C. Blockchain Structure

The blockchain structure consists of nodes of distributed architecture [45] and which are granted access to the structure that has records of all the transactions that took place in the blockchain system [46]. The data of the transactions performed in blockchain systems are stored in blocks of the chain [47].

The first generated block is known as the genesis block [48]. The characteristics of the blockchain system to be created are prescribed in the first block and rules in this first block do not change during the lifetime of the blockchain. All the blocks after the genesis block are connected securely by cryptological methods. Also, each block has a timestamp, data, hash and previous hash value, nonce and public, and private keys [49]. Timestamp holds the time of the block created. Transactions comprise the data. The nonce is an arbitrary value and makes the blocks unique. Public and private keys are used to send data securely [50].

Blocks and Block Time: The information of transactions approved by the majority of nodes are stored in blocks. Data encoded with hash algorithms are organized as a Merkle (Hash) Tree as a fast retrieval method. All blocks are linked to each other by cryptologic hash algorithms. To link all blocks with each other hash pointers are used. Hash pointer and Merkle Tree data structure are placed in the block header [48].

In blockchain networks, the block time varies. The shorter the newly created block time, the faster the system is. For example, the Ethereum system has a block time of 15 seconds and a Bitcoin process of 10 minutes [51].

Decentralization: Today, the data centers of many advanced applications are centralized. This puts big and valuable data at the target of hackers [52]. For this reason, data security is always a significant problem. Blockchain technology enables peer-to-peer communication, public and private key usage, and hash algorithms for secure connection of the chain. Blockchain technology has a distributed architecture that deviates from being a central structure. This way, each node has become a part of this distributed system and increases the system's security [53].

Openness: In most blockchain systems, the source code is public, i.e., it is open source. Anyone can download this source code and access the system. Also, the data of the created blockchain system is open to everyone. In this way, the system becomes open and is monitored by the nodes with access rights [54].

D. Advantages and Disadvantages of Blockchain

Advantages of Blockchain: Due to the distributed structure of the blockchain, the data is not stored on a central server, thus protecting against technical malfunctions and cyber-attacks. Preventing cyber-attacks leads to the reduction of direct fraud attempts [55].

Stability is achieved in the system because the blockchain is unidirectional, a transaction approved by all nodes cannot be changed, and all changes can be monitored transparently by the access nodes [56].

The increase in the use of cryptocurrencies has enabled the possibility of reducing costs by removing third institutions or organizations through the peer-to-peer communication feature. Also, fake information sharing by financial institutions and the hidden charges applied to their customers will make customers have distrust in these companies. Use of blockchain by institutions will increase the transparency hence causing customers to trust in them [57].

Disadvantages of a Blockchain: Scalability is one of problems with the blockchain systems. Take Bitcoin for example. Bitcoin cryptocurrency is one of the applications of blockchain. As the system size, that is, the number of blocks increases, scalability has become an issue. The Bitcoin blockchain platform can handle four transactions per second, while the Ethereum blockchain platform can handle twelve transactions per second. This processing power is unacceptable compared to the Visa card system or merely Facebook's processing capacity per second [58].

Although consensus algorithms are widely studied, the weaknesses of consensus algorithms still remains unsolved.

For example, the PoW algorithm is inefficient in mining operations, and the PoS algorithm does not perform sufficiently in the process validation stage [59].

As blockchain systems' data grow with time, alternative solutions should be found in terms of data storage. Today, a blockchain system requires an average of 200 GB of storage space. The high demand for data storage that the blockchain systems need over time can become a problem [60].

Another problem is that the keys that are used as private keys used by the blockchains loss of these keys will result in the failure to reach the system. If the password is forgotten in the central data structures, there are steps to obtain a new password. Loss of private keys in distributed systems can lead to the loss of the valuable asset stored as well as the security it provides [61].

The 51% attack mentioned above poses a risk in theory. No successful 51% attack has been seen to date. However, an attack by quantum computers is likely to succeed. Therefore, it is worth noting that the 51% attack is a disadvantage. In the future, 51% attacks will no longer be a risk with the implementation of cryptology applications created with quantum calculation methods [62].

Finally, the strict transparency provided by blockchain architecture brings along the problem of lack of privacy. Credentials hidden by cryptology can be detected when open transaction records can be revealed. Therefore, hybrid solutions can be studied to solve the privacy problem [63].

E. *Blockchain Application Areas*

Blockchain technology can be used on banking applications, internet security, supply chain, internet of objects, insurance, personal and public transportation, online data storage, foundations and endowments, voting processes, public applications, health applications, energy management, intellectual property and copyright applications, real estate and title deeds, digital identity, smart cities, smart contracts and legal compliance examination, applications in the field of education [64].

After the introduction of the Bitcoin cryptocurrency and its attention with its success, many crypto coins are introduced and used. After bitcoin, which aims to remove central authority, cryptocurrencies have attracted attention by many central authorities, and they are trying to make their systems compatible with the blockchain. Today, many central banks are working on blockchain-based cryptocurrency and financial instruments. Besides, the applications of blockchain technology on cryptocurrency and finance are called blockchain 1.0 [4].

Smart contracts [65] are one of the most critical developments that blockchain technology brings to our lives. Smart contracts can be thought of as part of the blockchains where adds dynamicity to the system. As the name implies, smart contracts are short snippets of code. These contracts, which are developed as the solution for a unique problem, are a piece of code in the blockchain system [66]. These systems, which only get executed once the condition arises, need to be carefully optimized since they cannot be corrected after they are coded. The use of smart contracts in Blockchain technology is called Blockchain 2.0 [4].

Every day blockchain technology has been adapted to new areas of application. All non-financial application areas are called blockchain 3.0. Also, blockchain technology and artificial intelligence applications are being tested. Although not explicitly accepted by the Community, it is considered to be called artificial intelligence adaptations for Blockchain 4.0 [4].

III. ARTIFICIAL INTELLIGENCE

Artificial intelligence is building computer systems that can simulate human intelligence. All learning can only be achieved when enough and proper data exist. The data set should be of high quality, up-to-date and relevant in order to obtain the most effective results from the data to be used, rather than having a very large size. Along with the quality data obtained in this direction, the algorithm and models used must be selected correctly. In addition, the proposed artificial intelligence solution should be scalable according to new requirements.

The concept of artificial intelligence (AI) was first mentioned in the 50s. In 1956, the term of artificial intelligence was firstly announced by John McCarthy [67]. The first artificial intelligence studies were on neural networks and the idea was of a machine which can think the way a human does. The first wave of studies took place between the 1950s and the 1970s. Between 1980 and 2010, artificial intelligence studies were mostly on machine learning which is a sub field of AI. Studies after 2010 focus on another subfield of AI, the deep learning.

An examination of the literature will reveal research in General AI, Machine perception (speech recognition and computer vision), Natural Language Processing (NLP), and Robotics, Knowledge Representation and Reasoning (KRR), Pattern Recognition (PR), Machine Learning (ML), Artificial Neural Networks (ANN) and Social intelligence [68]. These research areas of artificial intelligence have many applications such as Automotive and Logistics, Retail, Healthcare, Military, Space Studies, Industry, Telecommunication, and Finance to name just a few.

A. *Possible Contributions of Blockchain Technology to Artificial Intelligence Applications*

The use of blockchain technology in artificial intelligence applications strengthens artificial intelligence applications in terms of reliability, security, transparency and trust.

Quality problems encountered in data used in artificial intelligence applications lead to low interpretability success. For this reason, the data stored in blockchain systems and collected within the framework of certain standards and whose accuracy is beyond doubt will enable artificial intelligence applications to give clearer results. In addition, blockchain technology can be a solution to privacy and trust problems, which are shown as weaknesses in artificial intelligence studies in the literature. Thanks to the fact that the data used is taken from distributed data structures and the data cannot be tampered with, the results obtained can be more reliable. In addition, privacy concerns will be eliminated in artificial intelligence applications developed with data obtained from private blockchain systems.

For example, in the study published in 2019, researchers proposed a self-testing and tracking systems for COVID19 [69]. In this study, it is aimed to process the data obtained with a blockchain-based application from health institutions using a machine learning algorithm. The point that should not be overlooked in this study is the machine learning study on the data obtained from the blockchain system. In other words, while the data is obtained through smart contracts in the blockchain system, there is no artificial intelligence applied in the data extraction.

Many study ideas are suggested in global warming, smart agriculture and other similar areas. The use of data obtained from blockchain-based distributed data structures in studies with artificial intelligence applications at the center is of great importance in this respect.

B. *Possible Contributions of Artificial Intelligence to Blockchain Technology Applications*

Blockchain is a relatively new topic of study and is on its way to become more mature and stable. Like any other new technology, it has its urgent shortcomings that need better solutions. The main issues that need to addressed in blockchain technology are high energy consumption,

scalability, security problems arising from improper development of smart contracts [70].

Especially the high energy consumption seen in the bitcoin blockchain application is a huge problem in terms of sustainability. Although the use of new alternatives proposed in consensus algorithms that can solve high energy consumption is promising. The success of artificial intelligence applications in energy consumption optimization is well known. For this reason, the contribution of artificial intelligence applications in the most optimal determination of the energy spent in the mining process, which is needed not only in the bitcoin blockchain system, but also in all similar blockchain systems, will undoubtedly be very high.

Blockchain systems are systems that cannot be intervened after they are installed and increase in size as their use increases. When the idea of bitcoin crypto money was proposed by Satoshi, solution suggestions were also shared for the problem to be encountered in scalability. Pruning of old transaction records in blockchain was proposed by Satoshi [1]. However, the same problem is encountered in many similar blockchain systems, as in the example of bitcoin, which is moving towards 350 GB. Federated Learning may be a very convenient solution method to this problem. Federated learning is a machine learning technique that trains an algorithm between multiple decentralized nodes without exchanging data. Because of this feature, it is a machine learning algorithm that is very suitable for blockchain architecture [4].

In blockchain systems, the smart contracts that we encounter in the Blockchain 2.0 process have made the blockchain systems more functional. Smart contracts are small pieces of code prepared for previously anticipated situations and automatically complete the transaction in case the condition it states is met. An overlooked flaw in smart contracts developed in blockchain systems can cause serious problems in the future. For this reason, it is of great importance that the smart contract codes are checked by an artificial intelligence algorithm and their deficiencies are detected. The platform named Oyente offers a service for Ethereum-based blockchain smart contracts. However, this service needs to be provided in all blockchain systems and the need for a developed one using artificial intelligence algorithms is undoubtedly very high.

In cases where mining is required in blockchain systems, efficiency is an important issue. Artificial intelligence applications that track and organize the working conditions of miners are needed to increase efficiency. Thanks to the solution suggestions that ensure that miners do not work in vain, energy consumption will decrease as well as faster transactions on the network.

C. *Projects on Artificial Intelligence and Blockchain Technology in the World and Turkey*

In the literature reviews we have done, there are no institutions working on or projects about artificial intelligence and blockchain technology in Turkey. For this reason, adding blockchain technology to the work of Turkish organizations working on artificial intelligence is of considerable importance.

However, there are initiatives such as DeepBrain Chain, Synapse AI, Endor, AiX, Peculium, Autonio, burs iQ, Indorse, Matrix, Neureal, BotChain, Singularity Net, Numerai, Dopamine working in this field in the world. If shared initiatives are examined, the potential of blockchain and artificial intelligence studies carried out todays will be better understood.

IV. BLOKCHAIN INTELLIGENCE

The concept of blockchain intelligence, as its name suggests, is one that involves and integrates the use of both technologies. It is aimed to obtain a more efficient system by using artificial intelligence tools for various improvements in a blockchain system while designing a new one. As briefly touched before, developing a blockchain intelligence system will help to solve many structural problems of “regular” blockchain systems. When the distributed, decentralized, anonymous, secure, transparent structure provided by blockchain technology is combined with the learning, detection, diagnosis, improvement and automation opportunities provided by artificial intelligence algorithms, the mingling process will result in more efficient blockchain systems.

There will be significant improvements in three aspects in the systems we call blockchain intelligence. These can be expressed as smart operational maintenance of the blockchain, smart quality assurance of smart contracts, and automatic malicious behavior detection of blockchain systems [71]. Explanations on these issues are included in the titles A, B and C.

A. *Smart Operational Maintenance*

A blockchain system can be monitored using artificial intelligence and the errors that the system may encounter can be detected and maintained in advance. Data is constantly produced in all blockchain systems that are widely used today. If the system is not monitored regularly, the problems that may arise will cause very destructive results. For this reason, it is possible to keep the performance of the system in the most optimal way by constantly monitoring it with artificial intelligence and making necessary interventions.

B. *Smart Quality Assurance of Smart Contracts*

The verification of the structural accuracy of smart contracts using artificial intelligence algorithms was a requirement that we mentioned in the previous sections. However, the determination and development of smart contracts required in blockchain intelligence by the system will emerge as one of the issues we will encounter under the roof of blockchain intelligence in the future. In this way, a blockchain system will detect new smart contracts it needs and include it in the system in the most appropriate way. As it can be understood from here, changes will be possible in the structures of smart contracts used in blockchain systems. Because there is a need for alternative solutions to overcome the almost impossible problems arising from smart contracts that cannot be changed after they are introduced in the blockchain system. The most obvious solution method will be to bypass the smart contract used and define a new smart contract instead. In an environment where studies on blockchain technology are increasing, it is possible for us to encounter innovations in the above-mentioned direction.

C. *Automatic Malicious Behavior Detection*

One of the most used products of blockchain systems today is crypto money. Since the first use of Bitcoin crypto money in 2009, there have been many discussions about who used cryptocurrencies and for what purpose. Undoubtedly, it is very natural to use cryptocurrencies to finance many illegal activities due to its anonymous structure. Turkey also experienced as previously "Çiftlik Bank" fraud attempt which is prepared with the logic of the Ponzi scheme for fraudulent purposes. Unfortunately such fraud attempts are going on around the world. And finally, it is known that serious amounts of theft have been experienced using systemic errors found in some blockchain systems. Automatic malicious behavior detection systems are needed to prevent all these negativities. It is aimed to establish a system that will alert in suspicious situations encountered with an artificial intelligence that examines blockchain systems, and will detect illegal purposes, various manipulations, and attempts like Ponzi scheme [73].

D. *Blockchain Intelligence Case Study*

The use of blockchain technology in the field of health is a very interesting subject of study. The multi-stakeholder structure of the healthcare industry is in great need of technological innovations in order to facilitate the management of institutions. For this reason, many studies are carried out, including ourselves, on the application possibilities of blockchain technology in the health sector. However, the studies carried out jointly include the suggested solutions to increase data security and anonymity. Considering the possibilities of blockchain implementation in health, which blockchain intelligence will suggest, a much more complex structure emerges.

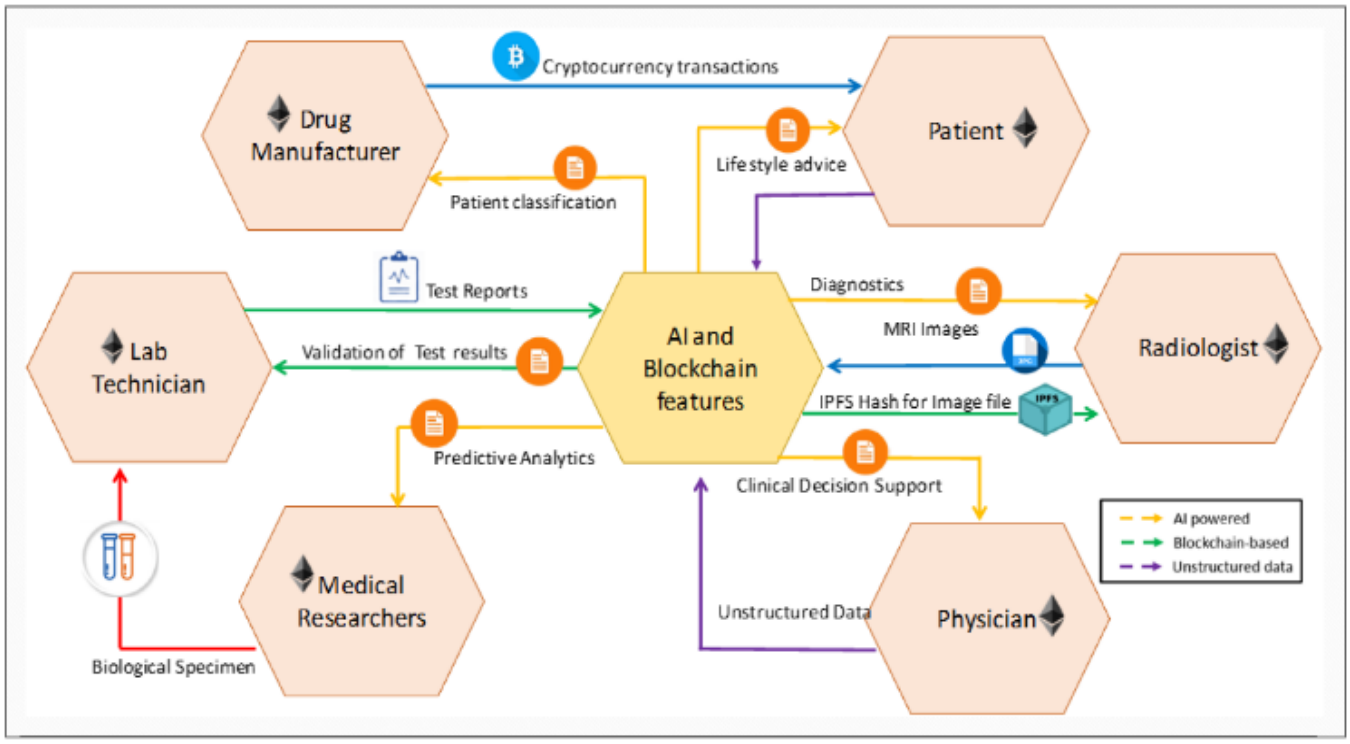

Figure 1 Blockchain Intelligence Example in Healthcare

As it can be understood from Figure 1, it is seen that the blockchain systems to be developed will have a much more dynamic and intelligent structure if the concept of blockchain intelligence begins to be used in real applications.

Also the study conducted in 2018 (It is the study where the visual shown in Figure 1 was used to our study), in a health management system proposal in which all stakeholders consist of solution suggestions developed with blockchain technology, it is recommended to use artificial intelligence with blockchain technology and add features such as analysis, diagnosis, advice, support and classification [72].

Solutions such as education, retail, government and management can be developed with the same logic as the example we shared in the field of health. As it can be understood, if the use of artificial intelligence and blockchain systems together is widespread and easy to implement, it is no exaggeration to say that an era in which blockchain intelligence will prevail is about to begin.

V. CONCLUSION

In our study, the concept of blockchain intelligence is introduced. It was stated that what can be achieved in closing the structural deficiencies of blockchain technology with artificial intelligence. Solutions that can be provided by blockchain intelligence are shared to detect structural problems encountered in smart contracts in advance. The necessity of blockchain intelligence in tracking suspicious transactions and taking necessary precautions has been shared. The necessity of blockchain intelligence has been stated to monitor blockchain systems and to detect performance problems anticipating them and taking precautions before they happen. In addition, as can be seen in the shared health example, it has been shown that the innovations provided by artificial intelligence are a very suitable method in eliminating the deficiencies needed with the distributed, secure and anonymous structure of blockchain technology.

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