Blockchain, State-of-the-Art and Future Trends

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Abstract

The rapid technology evolution and the future challenges demand us to adopt increasingly cutting-edge and up-to-date technological tools. In this perspective, Blockchain technology is revolutionizing countless areas of our daily lives. In this paper, we present a non exhaustive list on the state of the art about Blockchain technology in multiple application fields, both from an industry and business perspective and from a consumer one. We will also present a dedicated focus on the frictions between distributed ledgers and data protection regulations crossing all these areas.

Keywords

Blockchain, Smart Contract, Distributed Ledger, Data Protection, GDPR.

1. Introduction

If we had to give a definition of blockchain we could quote the World Bank which uses the following words: *Blockchain*, a particular type of DLT (Distributed Ledger Technology), uses cryptographic and algorithmic methods to create and verify a continuously growing, append-only data structure that takes the form of a chain of so-called 'transaction blocks' – the blockchain – which serves the function of a ledger [1, 2]. Unlike current corporate and government databases where data is stored in one place (centralized), the blockchain is composed of a digital network of globally dispersed computers, called nodes that record data and transaction history. The nodes are also responsible for validating and storing all transactions since the database was created. Since the system is decentralized, most nodes must reach a common agreement. If a node wants to make an update of its own, the other nodes must vote on this decision to ensure that the update is legitimate and secure. Once this is done, the system updates the records to the most recent and agreed updates on all nodes simultaneously. This process of voting on a node is known as "consensus" [3, 4]. Compared to a distributed database where nodes are part of a single organization, so we can say that they trust each other, Distributed Ledger Technology (DLT) is based on a digital data structure where nodes cannot trust each other, so data is only stored within nodes following agreement and specific rules (consensus). According to these rules, there is therefore no need for a central system to act as a guarantor. The blockchain is a particular distributed ledger made up of an unbroken chain of blocks, each linked to the previous one. The blocks are composed of a number of transactions that are encrypted and validated by all nodes.

The pandemic we are currently experiencing, although it still weighs heavily on our society, has undoubtedly accelerated the development of more digital and integrated processes. Therefore, many companies are accelerating their efforts to provide services that are more and more adapted to a population of smart business users but more generally, to provide reliable and efficient services through online and new technologies.

In recent years we have seen great innovation and developments in technologies related to Artificial Intelligence [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16], Big Data [17, 18, 19, 20, 21], People and Objects Geolocation [22, 23], as well as Cloud Computing [24, 25, 26], Quantum Computing [27], Super Computing [28], Cellular and Satellite Networks [29, 30, 31], and so on.

The blockchain [32] technology sector has also accelerated, with 59% more projects and 80% fewer announcements. This is in contrast to previous years and shows how the focus is shifting towards a more mature use of blockchain and a significant reduction in initial hype [33]. Indeed, the data shows that around 47% of projects are based on existing platforms. The most active countries are the United States, China and Japan, followed by Australia and South Korea. Initially, the blockchain was mainly used in finance, today only 59% of projects are linked to it, the remaining percentage is related to multiple other areas ranging from agriculture to healthcare, via art, the pharmaceutical industry, government institutions, the education sector, logistics and utilities, to name a few.

This article, after presenting the advantages of blockchain technology and the use of smart contracts, illustrates an

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overview, far from being exhaustive, of the main application areas of blockchain. Moreover, an in-depth analysis will focus on issues related to the regulation on personal data protection, a problem that involves transversally all areas where it is possible to apply blockchain technology.

The paper is structured as follows: in section II, we talk about related works, what is blockchain, how it works and what are the advantages compared to the use of distributed databases; in section III, we outline the features of blockchain, what smart contracts are and describe the main application areas; section IV analyzes the difficult relationship between blockchain and the legislation on personal data protection. Finally, in section V we summarize our work, draw conclusions, and outline possible future studies.

2. Related work

In this section, we will describe what a blockchain is, how it works and what its most important uses are. We also illustrate why the blockchain, despite being a distributed database, overcomes its limitations and expands its potential and use.

Before talking about blockchain, it is essential to introduce distributed systems [34] as the core of any blockchain is composed of a distributed and decentralized system. A distributed system is made up of two or more nodes (computers connected to each other via telematics) that collaborate simultaneously for a common goal, giving the perception to the end user that they are one system. An example is represented by the well-known e-commerce platform Amazon that is based on a large distributed system but users see it as a single, coherent platform. In a distributed system, all nodes are able to exchange information directly, without the necessity of a centralized element acting as a director. The main objective of a distributed system is to ensure fault tolerance and efficiently manage the communication and exchange of data and information between nodes. In fact, even if some nodes of the network should be unreachable, the system as a whole will be able to provide the service for which it was designed, without interruption and without providing disservice. When a database uses distributed technology to manage information of interest to stakeholders, it is referred to as a distributed database or distributed ledger (also called distributed ledger technology or DLT).

A distributed ledger is a ledger where data is entered, updated and controlled in a distributed manner among users, without the need for a central governing body. In this new scenario, data is stored in the ledger only when a consensus has been reached between the parties involved. Subsequently, this data is time stamped and a unique encrypted signature is assigned to each transaction. Each party involved in maintaining the ledger has its own local copy of the ledger and contributes to the maintenance of the distributed network by providing computing power and storage. All records in the ledger are searchable by nodes in the network and all information contained therein is verified and auditable. In summary, a distributed ledger can be viewed as a database whose data is replicated, shared, synchronized, and geographically distributed across multiple nodes in a network that communicate and collaborate via specific consensus and workload-sharing protocols.

Although the technology used for distributed ledgers and the blockchain share the same conceptual origin and have the same purposes, they are not exactly the same thing. The blockchain is as a particular distributed ledger with a distinct set of features and operational processes that give it significant value. Unlike distributed ledger, blockchain bundles transactions into blocks protecting them against tampering with powerful cryptographic systems, moreover each block is sequentially linked to all other blocks in the chain. These blocks, once inserted into the chain, are immutable and can be used to reconstruct the history of all the data within the blockchain. In addition, there is a consensus system (e.g. Proof of Work - POW or Proof of Stake - POS) to determine how new blocks should be added to the blockchain.

The most famous use of the blockchain is the technology behind bitcoins [32]. In this case, the blockchain records currency transactions, which is the transfer of currency from one wallet to another. This is just one of the potential applications of the technology, in fact, blockchains are useful in many other fields both industrial and tertiary and for many other types of recordings that go far beyond simple financial transactions. They can be used for all information that needs to be recorded in an immutable way such as health data in medical records, contracts, property transfers, purchase of goods and services and much more.

3. Blockchain: the concrete benefits and most promising applications

In this chapter, we are going to outline the main features of blockchain technology, pointing out its positive sides and possible fields of application. In fact, in the last few years, analysts have hypothesized that a large part of the industries could benefit more or less strikingly from the use of distributed ledger in general and blockchain in particular.

There are several cases of commercial use of blockchain, with transactions that are automatically verified and organized by a decentralized platform that does not require the supervision of a central entity or subject, while en-

suring resistance to tampering and fraud.

In the second part of this chapter, we will present a (non-exhaustive) list of some of the ways through which companies - large and small - are looking to harness the power of blockchain technologies.

3.1. Blockchain benefits

In the previous chapter, we briefly introduced what blockchain is and some of its main features. Now we focus on the "why", i.e. why we are hearing more and more about it and the benefits that block- chain can provide to businesses and private citizens. What has acted as a catalyst, determining its diffusion, has been the innovative concept of the Internet of Value [35]. This term refers to the use of the Internet as a means of transferring and storing values of all kinds, not just currencies and securities, but also intellectual property, music, art, scientific results, etc. In this context, Blockchain plays an essential role since it guarantees, for this purpose, several important advantages, including:

1. `Efficiency`: the exchange of values takes place in "near" real time.
2. `Decentralization`: This is perhaps the most important concept of a blockchain, as there is no need for a third party or intermediary to vouch for the validation of transactions and information entered into the distributed database. In fact, a consensus mechanism shared and accepted by all nodes in the network is used to validate transactions and blocks. For this reason, the Blockchain is defined as a trustless system.
3. `Distributed Structure`: Since the data is replicated on all nodes of the network and geographically dispersed across the globe, the system is highly resistant to failure or cyber-attacks. Since each node has a copy of the entire database, there is no single point of failure and any damage to a peer in the network does not affect the overall system operation, unlike in centralized systems where a cyber-attack or a data center blackout can interrupt the service of an entire system. This redundancy gives the entire network high availability and reliability.
4. `Transparency`: The data contained in the blockchain are available to all nodes of the network and in the case of public networks, they are also freely available to anyone who accesses the network, while not actively contributing to the subsistence of the system. This feature provides the blockchain with the peculiarity of being transparent and therefore trust towards the system is guaranteed by this feature.
5. `Unalterability`: Once the data has been written in the blockchain, it is extremely difficult to modify it as this would involve a huge expenditure of computing power. If, for example, you wanted to modify a transaction that was written 10 blocks ago, a hacker would have to modify and recalculate all 10 blocks or cut the chain and invalidate the next 9 blocks. This is, in reality, an almost impossible practice to implement on many blockchains.
6. `Highly secured structure by design`: All blockchain transactions are encrypted so it gives the network high integrity.
7. `Programmability`: instructions can be included within blocks that trigger specific actions when certain conditions occur.
8. `Incontestability`: the decision to validate a piece of information is not taken only by a node, but through a secure consensus-gathering mechanism within the network, making it particularly difficult to contest the choice made by the most.

3.2. Promising applications of blockchain

From what has been said so far, it is clear that the listed benefits are closely related to the world of finance and everything that surrounds it. In fact, initially, the Blockchain was used to certify transactions between people. Nowadays, anyone has already heard terms like Bitcoin[32], Cryptocurrency, Ethereum [36, 37], smart contract [38], etc. In recent years, however, the areas of application of the Blockchain have multiplied, going to affect sectors such as: logistics, public administration, food chain, health care, telecommunications, insurance and so on.

Despite the great ferment, the technologies are not yet fully mature and there are still few concrete applications. The flip side of the coin is that there are still huge opportunities to be exploited: only 37% of large companies and 20% of Italian SMEs are familiar with these technologies. Less than 2% of large and 1% of small companies have started projects [39]. Internationally, in 2019, there were 488 blockchain and distributed ledger projects launched worldwide, up 56% from 2018, bringing the total to 1,045 over the last 4 years. But of these only 158 are implementations, of which just 47 are already operational, the rest are experiments or Proof of Concept, while as many as 330 are just announcements. Despite the pandemic we are experiencing, the growth of blockchain-based technologies has not seen any slowdown. On the contrary, there has been significant growth. Out of 1,242 initiatives surveyed from 2016 to 2020 [40], there are 267 initiatives launched in the last twelve months at the international level by companies and public administrations, which include 70 announcements and 197 concrete projects (of which 83 are operational, the rest experiments or proof of concept). Compared to 2019, concrete projects grew by 59%, while announcements dropped by 80%, a sign of

a market that is moving away from media hype to focus on more operational initiatives; 47% of cases mapped in 2020 use existing platforms, a sign that operators' focus is shifting more toward application development and less on creating new platforms.

In this context, almost all the projects currently in use, in the development and design phase cannot disregard the presence of smart contracts, i.e. computer-based contracts that allow the full exploitation of the potential of the blockchain.

In the next section, we explain what smart contracts are and why they are so important in the innovative context that blockchain brings.

While in the next one we will indicate a list of applications and examples of Blockchain use, certainly not exhaustive but enough to understand the enormous affect that this technology is having and will have, from now on all of us.

3.2.1. Smart contract

Nick Szabo, an American computer scientist who invented a virtual currency called "Bit Gold" in 1998, defined smart contracts as computerized transaction protocols that execute terms of a contract[38]. A modern definition of a smart contract could be formulated as follows: "A smart contract is an event-driven program, written in a specific programming language (depending on the blockchain on which it is deployed), executed on the nodes of a blockchain that produces as a result a state change of the distributed ledger on which it insists." The state change is generally represented by a transaction that changes the blockchain. When a smart contract is invoked, the expected outcome is purely deterministic based on data provided as input. Since one of the main characteristics of the blockchain is its quality of acting as a decentralized database shared among all actors that are part of the network, without the involvement of intermediaries or third parties, this peculiarity allows the smart contract to be executed without the possibility of alteration, in a certain way, saving time and money. These specialties are attracting the interest of many companies, both public and private, who are investing large amounts of capital in this sector. Currently, the best known smart contracts are those that insist on the Ethereum blockchain, but others are also emerging such as, just to name a few, EOS [41] and BSC (Binance Smart Chain) [42]. Since these blockchains are "turing complete" [1] it is possible to create highly customizable smart contracts and the areas of application can be the most varied, not only the financial field, but embracing virtually all industries. After providing a definition of smart contract let's see what smart contracts are, in more detail. A smart contract is composed of a set of instructions written in a specific programming language that run on a blockchain and represent a set of rules agreed upon by the parties involved in the project. If, at run-time, these predefined rules are followed, the smart contract executes automatically to produce the expected output. Depending on the underlying agreement, these lines of code enable both decentralized execution and verification and enforcement of the previously defined contract terms. Smart contracts allow for the exchange of anything that may have value to the parties involved, for example: money, stocks, property, etc., in a totally transparent manner, without the need for an intermediary and keeping the system free of conflicts of interest. Smart contracts do not only define the rules of the game of any agreement, they are also responsible for the automatic execution of these rules and compliance with the obligations set forth. In other words, smart contracts are automatically executed lines of code stored on a blockchain that contain predetermined and well-defined rules with no possibility of misunderstanding. In this scenario, the space for fraud is reduced and since there are no intermediaries of any kind, the costs and possible risks of conflicts of interest are also limited.

3.2.2. Blockchain applications and examples

In this section we present a review of blockchain applications, in order to understand how and where this emerging technology is playing a leading role nowadays and where we will see it gaining an increasingly relevant space in the coming years. The list below is only a part of the possible applications, and has been selected to highlight also those areas where the use of a blockchain could radically change the current scenario [2] [3].

`Banking, Finance and payments`: Financial institutions are probably the most advanced sector in terms of blockchain exploration, with initiatives capable of channeling the activity of many prominent players. Since banks and financial institutions essentially serve as repositories and secure centers for currency transfer, blockchain, as a digitized, secure, tamper-proof ledger, can ensure the same function while reducing costs and time. As an example, Switzerland's UBS [43] and Britain's Barclays [44] are already experimenting with a way to accelerate back office, money management and transfer functions using blockchain.

`Insurance`: Blockchain technology enables a wide range of options, for example for the decentralized management of an instant policy, capable of significantly lowering both complexity and activation and management costs, while also eliminating the need for intermediation. Thanks to blockchain, insurers can automate many opera-

[1] https://en.wikipedia.org/wiki/Turing_completeness

[2] https://tech4future.info/blockchain-cose-esempi-applicazioni/

[3] https://www.blockchain4innovation.it/iot/blockchain-benefici-concreti-le-applicazioni-piu-promettenti-27-settori/

tions: the premiums calculation, the system of appraisals and claims settlements, obtaining and guaranteeing the insured maximum transparency at every stage [45].

`Agrifood sector`: The food supply chain is probably one of the most complex fields of application, as the number of actors and products involved is extremely high, as is the number of relationships that are structured through the life stages of the product, from its cultivation/farming to its consumption on the table. Keeping track of everything is a huge undertaking, which the blockchain is beginning to lighten and make much more efficient, especially in terms of security and transparency for all stakeholders [46].

`Healthcare`: Healthcare institutions suffer from a chronic inability to securely share data between different platforms and institutions. Better collaboration between data providers means, in essence, a greater likelihood of making accurate diagnoses, a greater likelihood of opting for effective treatments and, more generally, an increase in the overall ability of healthcare systems to provide good care. Blockchain applied to the healthcare sector allows hospitals, payers and other healthcare facilities to share access to their networks without compromising data security and integrity. Startup Gem [4] has launched Gem Health Network, a platform based on distributed ledgers (and opensource peer-to-peer project Ethereum, in particular) combined with multi-signature and multi-factor authentication technology to create a highly secure universal data infrastructure. Tierion [5] is another startup that has developed a platform for data storage and verification in the healthcare sector.

`Pharmaceutical industry`: In the case of pharmaceuticals, the blockchain makes a decisive contribution to the supply chain, especially to avoid counterfeiting and fraud, which would otherwise be very difficult to identify, since, without a unique identifier, it is extremely difficult to recognise a genuine drug from a non-original one [47].

`Government and public administration (PA)` [48]: The introduction of blockchain in PA procedures represents one of the most interesting application areas as it will produce a real revolution in the quality of services offered to citizens. The scenario is not an easy one to implement, and there are what we might call generational barriers in terms of digital culture, not only on the part of the institutions, but above all on the part of the end users, the citizens. The blockchain could make services efficient and transparent, the request for useful data would be available almost in real time, and it would also allow the certification of authenticity, timestamping and ownership of the provided data [49]. In this field, the Department of Homeland Security (DHS) has provided a number of grants to explore innovative solutions using blockchain technology for secure digital identity management, to improve the anti-counterfeiting capabilities of digital documentation to prevent fraud and forgery [50]. In addition to reducing the number of human resources needed to deliver many services, the blockchain would also provide a huge motivational factor for civil servants, who would see the results of their work tracked in a transparent manner, including in relation to the achievement of annual performance targets.

`School and academia`: The Holbertson School of Software Engineering, based in San Francisco, California (USA), has announced that it will use blockchain technology to authenticate academic degrees and certificates [51]. Other universities have also started to implement tools based on distributed ledger technology to ensure greater transparency in the management of academic certificates. Another important benefit comes from saving time and costs associated with managing thousands of paper documents.

`Electoral voting (e-voting)` [52]: Elections require authentication of voter identity, secure storage of records and a fully transparent counting and counting process to determine the winner. Blockchains can serve as a useful tool for selecting, monitoring and counting votes while reducing attempts at electoral fraud. Follow My Vote [6] has already been used in testing during the US presidential election as an end-to-end verifiable online voting system.

`Logistics and large-scale retail trade`: Logistics is one of the privileged areas for the digitalization of processes. Thanks to blockchain, goods can be uniquely tracked during transport and storage in the warehouse, minimizing the possibility of error. This can be used by large-scale retail systems to manage the entire supply chain more safely and efficiently. This is a very interesting detail, if we consider that this technology can be easily combined with other services, such as data analysis based on artificial intelligence, which allows optimizing order processes thanks to predictive simulations [53].

`Buying and selling of goods and services`: Critical issues found in the buying and selling of movable and immovable assets include lack of transparency primarily during and after transactions, excessive reliance on paper, and possible fraud and errors in public records. Blockchain offers a way to reduce the need for paper support for recording data and thus leads to faster transactions related to contract drafting, identification of counterparties and precise details of the purchase and sale. Decentralized databases applied to this industry can help record, track and transfer e.g. land titles, title deeds, liens etc. and help ensure that documents are accurate and

[4] https://enterprise.gem.co/health/
[5] https://tierion.com/
[6] https://followmyvote.com/

verifiable. Purchasing of services can enjoy the same benefits as processes are streamlined and payments are secure and directed to those involved, without the need for intermediaries. Ubitquity [7] has developed a platform for financial institutions and mortgage companies to manage the related documents in a fully transparent manner, improving back-office administration and reducing associated costs. Visa and DocuSign [8] presented a report documenting an experiment conducted in the car leasing industry. The two used distributed ledgers to build a proof-of-concept system for a process that culminates in the leasing of a car in a completely autonomous and unrelated manner.

`Art and collecting`: NFTs (Non Fungible Tokens) [9] are literally revolutionizing the art market and beyond. The possibility of making a digital work unique has contributed to give value to goods that otherwise, due to their natural reproducibility, would have been completely devoid of it. This phenomenon has led many artists to tokenize their digital works on special platforms (SuperRare [10], Rarible [11], etc.) that regulate the market, giving the creator a royalty for each subsequent transaction. An anthology of works by the digital artist Beeple was recently auctioned at Christie's for a sum close to 70 million dollars. Collectibles are also benefiting from NFT technology as the U.S. NBA [12] is selling "top shoot" of its basketball players. Another famous example is the collection of pixel art images called Cryptopunks [13], which has currently reached staggering figures. NFTs also offer the ability to sell digital versions of some of their tangible products, thus creating entirely new markets. Gucci , has released virtual sneakers in the form of NFTs [14].

Beyond these examples there are many other fields of possible application of blockchain, such as: industry 4.0 [54]; electricity [55]; telecommunications [15]; notary [16]; industrial and intellectual property [17]; retail [18]; gaming [19]; charities [20] and defence [21] just to name the most famous ones.

4. Blockchain, privacy and GDPR compliance

In the chapter we analyze an issue that cuts across all applications related to blockchain technology, in fact we examine the difficult relationship and integration between blockchain technology and personal data protection.

Every action we daily perform on the network leaves a fingerprint that, if ordered chronologically, allows us to define our "life stream". Combining our "life stream" with that of all users around the globe, we can only imagine the immense amount of data that surrounds us, defined as Big Data, i.e. structured and unstructured information that needs to be aggregated and analyzed in order to be better exploited. More generally, the term Big Data refers to that set of data that is too large and complex to be analyzed with traditional application and computing software. Big data are strategic in many fields as they improve the user experience; they allow the creation of machine learning models; they provide important indications for the development and improvement of existing products; they allow the realization of predictive models that identify frauds and potential malfunctions of systems; they provide useful information to improve business procedures and finally they give a push towards innovation as they can be useful to create new products and strategies anticipating (or channeling) the desires of users. Consequently, it is of paramount importance that this growing amount of data is stored securely, tamperproof, and without the possibility of being counterfeited and altered. In this perspective, blockchain technology can be a useful ally of big data to manage the limitations just highlighted because once a data is saved within the blockchain acquires the following features: decentralized, transparent and immutable (these features have already been described in previous chapters so we will not go into them in this section). The other side of the coin is represented by the impact that this collaboration has and will have on privacy and on the right to protection and confidentiality of personal data. Fraudulent uses and data breaches involving companies and governments are increasingly frequent. In fact, the "Cambridge Analytica" scandal [56] has caused a stir, where data ideally sold for market research have instead been used, according to the investigation, to support the election campaign of the US President by a third party government. It will therefore be necessary to find a balance between current legislation (first and foremost the GDPR - General Data Protection Regulation [57, 58]), research/development and the use of these new technologies. In fact, there are

[7] https://www.ubitquity.io/
[8] https://www.docusign.com/products/blockchain
[9] https://ethereum.org/en/nft/
[10] https://superrare.com/
[11] https://rarible.com/
[12] https://nbatopshot.com/
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[20] https://academy.ivanontech.com/blog/exploring-the-blockchain-charity-sector-and-charity-projects
[21] https://eda.europa.eu/webzine/issue14/cover-story/blockchain-technology-in-defence

some obvious frictions that it is absolutely necessary to overcome with respect to the principles of Accountability, Data Protection by Design and Data Minimization, in order to make the use of these technologies compliant with European legislation. The European Parliament, having taken note of these and other doubts, has realized an important study [59], in which it suggests three policies to make blockchain projects compatible with the mandatory regulation: the interpretative regulatory orientation; the creation of conduct codes and sectorial certification systems; the promotion of multidisciplinary research [60]. Unfortunately, these indications are not yet sufficient to protect technology choices from the "sword of Damocles" represented by the GDPR, so further analysis and insights are needed, very often dropped into the individual use case. Therefore, possible solutions to specific use cases will be the subject of further research.

5. Conclusion and future works

The rapid evolution of technology and the challenges that the future poses require us to adopt increasingly cutting-edge and up-to-date technological tools. In this perspective, blockchain technology is revolutionizing countless areas of our daily lives. In this article, we initially presented what are the benefits of using blockchain; subsequently, we presented a non-exhaustive list on the state of the art and use of blockchain technology in many application fields. Like all new technologies that try to become mature, blockchain now faces the challenges of integration and coexistence with mandatory regulations. The GDPR has strengthened the protection of our personal data, profoundly changing the way organizations manage the collection, storage and transmission of personal information. Therefore, blockchain must also necessarily comply with these indications and while on one hand, it can be a tool that provides significant benefit in terms of security, reliability, transparency and immutability, on the other it has aspects that create friction and possible compliance issues. Therefore, future studies will be geared towards finding solution elements that integrate and make blockchain technology compatible with the laws of the state, especially with regard to the protection of personal data.

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