Blockchain Technology: A Framework for Endless Applications

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***Abstract*—Over the last decade, Blockchain Technology has evolved from being a peer-to-peer implementation of digital currency into a framework for numerous applications. That is, blockchain is widely recognized as the technology behind cryptocurrencies such as Bitcoin, but recent research indicates that it can be exploited way more than that. Among the most notable characteristics of the Blockchain Technology are system decentralization, data immutability, transaction transparency, and user privacy. Thus, it becomes apparent that it can significantly benefit many consumer applications, where trust and security are crucial aspects of the implementation. In this paper, we review and present, in a tutorial manner, blockchain's fundamental postulates and characteristics, and we introduce a novel point of view, where we visualize a layered representation of the blockchain infrastructure, so as to analyze it as a framework. Thinking of Blockchain Technology as a framework may assist consumers to better understand its capabilities and limitations. Additionally, we review emerging blockchain-based applications that span across many different scientific fields. We also discuss the relative merits and restrictions. Namely, we have identified applications in finance, smart contracts, internet of things, e-voting systems, storage and data protection, reputation systems, healthcare, and transportation, indicating that the Blockchain Technology is becoming a framework for endless applications.**

BLOCKCHAIN TECHNOLOGY (BT) has been rapidly evolving over the last few years, transforming itself from a secure digital currency structure to a highly adaptable distributed system [1], [2]. The idea of blockchain was initially introduced in 2008, by Satoshi Nakamoto, a researcher who implemented one of the most famous digital cryptocurrencies known as bitcoin [3]. Since then, a great variety of cryptocurrencies has emerged, such as Ethereum, Litecoin, Zcash, Dash and Monero, to name but a few. Through

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the BT, a decentralized network is created, where users can make transactions in a peer-to-peer (P2P) way, eliminating the need for a central trusted node. Additionally, BT uses cryptographic techniques, in order to validate the transactions, rendering it secure and ideal for applications like digital currencies, where security is of vital importance. Finally, the information stored in the Blockchain network is tamperproof and transparent by design. BT can be fine-tuned to benefit a variety of applications, when there is a need for it's advantageous characteristics [4].

While cryptocurrencies apply immediately to those unique characteristics, offered by the BT, recent research indicates that there are numerous applications that can take advantage of the BT. Plethora of applications that spans across different industries, such as the Internet of Things (IoT), healthcare, and transportation. Therefore, as more and more industries take an interest in the blockchain, the BT can revolutionize the consumer applications and the user experience by becoming the underlying technology in almost every modern application.

In order to have a better understanding of the ways that the BT can transform the industry, a brief description of the blockchain functionality will be presented in the following section.

BLOCKCHAIN BASIC FUNCTIONALITY

Blockchain is an innovative method of storing and exchanging information over the internet, while ensuring security and trust among the users. In blockchain the information is stored in chunks called blocks [5]. In this section, blockchain's basic functionality will be explained by presenting its unique characteristics and analyzing the structure of the blocks, from which blockchain is composed.

Blockchain Features

The BT offers four (4) significant features: Decentralization, transparency, immutability and privacy. The blockchain basic functionality is best described by analyzing those four (4) features:

1) Decentralization

Since blockchain was originally designed for a digital currency implementation, data in the blockchain are stored in the form of transactions. However, blockchain acts as a decentralized ledger, where users perform their transactions in a P2P way, thus there is no need for a central trusted node to validate the transactions.

2) Transparency

Every user in the network can validate new transactions by checking the transaction history, which is transparent and publicly accessible [5]. A copy of the complete blockchain is shared with every user participating in the network.

3) Privacy

While transaction history is traceable and transparent, the real identity of the blockchain users is hidden. BT makes use of pseudonyms, in order to maintain user privacy. A pseudonym in the blockchain is an address that characterizes every user and is used to perform transactions among them. While a pseudonym is a user identifier, no information about the actual user's identity is publicly visible.

4) Immutability

Each transaction is digitally signed by both the sending and the receiving party to ensure security. When a transaction is performed, it is broadcasted to the network for validation. After validating the new transactions, they are timestamped and grouped in “blocks”. These blocks are then validated by the majority of the users in the blockchain network, following the instructions introduced by a consensus protocol. The act of validating a new block via such a protocol is called mining. A lot of different consensus protocols have been proposed, such as Proof of Work (POW), Proof of Stake (POS), Proof of Authority (POA) etc [5]. Each block has a unique digital signature, and is linked to the previous block, creating a permanent chain of blocks. The so-called digital signature of the block is actually a unique hashed value, containing some important information about the block. More specifically, it contains the hashed value of the previous block, a Merkle tree of the transactions included in the block, and a special purposed number called “nonce”, which is used during by the consensus protocol during the block mining. Any change in the contents of a block will change its hashed ID, rendering the following blocks invalid and thus breaking the chain.

Block Structure

As the name implies, Blockchain is a chain of blocks. Blocks of information bonded with each other

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to create an immutable log. Figure 1 presents a high-level overview of the blockchain functionality and the structure of each block in the chain.

Each block consists of the block header and the block main body. The header includes:

- *The block version*—A number indicating the data structure and the blockchain rules.
- *The nonce*—An arbitrary number used by the miners when a new block hash value is calculated.
- *A Timestamp*—A global timestamp. The current time measured in seconds since January 1, 1970.
- *The hash value*—The hash value of the previous block.
- *A merkle root*—The root hash of a merkle tree made of the block's hashed transactions.
- *A target value*—This value defines the difficulty of the mining process. It is a dynamically adjustable number that defines the number of zeros (0) that every calculated hash value must begin with, in order to be considered valid.

The body of the block consists of all the included transactions. Every transaction in the block is hashed, and the results are hashed again in pairs, creating a hash tree, as shown in Figure 1.

BLOCKCHAIN AS A FRAMEWORK

Having described the BT key features and basic functionality, we can now discuss how blockchain can serve as a framework for various applications. There have been some attempts to analyze the BT as a set of layers [6], [7], [8], and we believe that discrete layers are the best way to describe blockchain as a framework, since they provide a clean representation of the underlying technology. Therefore, in this section, we visualized blockchain as a framework consisting of four (4) layers, as presented in Figure 2. We consider these layers (network, consensus mechanism, access, and application layer) essential for every application that needs to take advantage of the blockchain infrastructure. In the rest of this section we will describe the aforementioned layers, and we will briefly present how they enclose blockchain's key features.

Network layer

In the Network layer, a distributed network architecture needs to be implemented. In the blockchain the selected architecture is a peer-to-peer (P2P) network. The users in a P2P network can share their computational resources or exchange data without the need of a centralized administrative node. New users can easily join the network and the removal of a user does not interrupt the network's functionality. Every user, who is part of the network, acts as both a server and a client [9]. In a blockchain system every user is a node of such a P2P network.

Consensus mechanism layer

One of the blockchain's key features is the data immutability. As discussed in the previous section, to ensure this immutability, the blockchain users need to have a way to agree on a transaction's authenticity. To achieve that, a consensus protocol is implemented in this layer. There is a plethora of consensus protocols that have been used in BT, such as POW, POS, POA etc [5]. The consensus mechanism plays a vital role in the blockchain architecture, since the selected protocol will have a significant impact on the system's overall performance, speed, security, energy consumption, scalability etc.

Access layer

From a network perspective, the blockchain network can be accessed from any user willing to be part of the system. However, Access in a blockchain system can be furtherly managed in this layer. Depending to the system's access setup, the blockchain can be characterized as either public, private or hybrid [10], [11]. In public blockchain systems there are no special permissions, and anyone is able to become a part of the network, and read the complete transaction history, which is publicly available, in order to ensure transparency. In private blockchain systems, the access is moderated by a central node or a company. In certain occasions, such as banking or medical records applications, the access to the network needs to be private. This option offers enhanced security and privacy features, but it sacrifices the decentralization, since a central node is needed to administer access rights [12]. Finally, there are systems where the access can be either public or private, but the consensus is decided among a selected subset of nodes. Those systems are called hybrid or consortium blockchains. Thus, based on the application needs, this layer will define the mandatory access rights.

Application layer

The Application layer is the top and final layer in our view of the blockchain as a framework. All the end-user applications that are based on a blockchain

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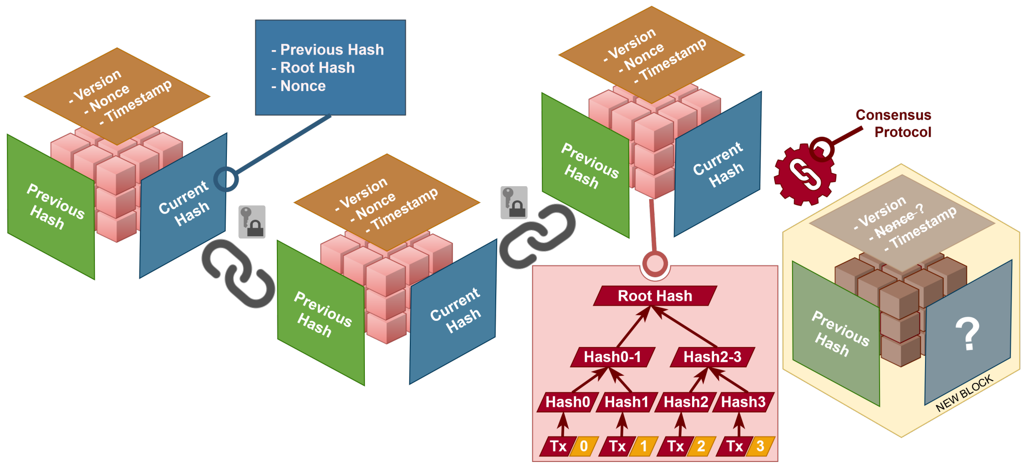

Figure 1. Blockchain's block connection example and block structure design.

infrastructure lay on this layer. The application layer also includes any Application Programing Interface (API) that provides access a blockchain system's functions. Moreover, in a blockchain system, users join the network using mobile, web, or desktop clients. Those clients are usually designed and distributed by the system's creator. Client implementations are also part of the application layer. Smart Contracts are a special kind of application, so, they can be found as standalone application within this layer, but they can also serve as an intermediate sub-layer for other applications to be built upon. Smart Contracts offer programming capabilities to a blockchain system via a kind of a scripting language and they will be discussed in more detail in the next section.

BLOCKCHAIN APPLICATIONS

In this section, we will present nine (9) different application categories that take advantage of the BT framework. Blockchain offers enhanced security and trust through the four (4) aforementioned features (Decentralization, Immutability, Transparency and Privacy). The application categories we identified are: i) smart contracts, ii) finance / commerce, iii) IoT, iv) e-voting, v) storage and data protection, vi) reputation systems, vii) healthcare, viii) transportation and ix) other. Our goal here is to highlight how each category is built on top of the BT framework and takes advantage of the BT features. Moreover, it is really important to highlight the ways the BT can benefit the end users through the various applications, since user acceptance plays a significant role in a technology's development and implementation [13].

Smart Contracts

The concept of smart contracts is not a new one. The idea was first introduced in 1997 and it concerns the creation of secure and transparent contracts that can be automatically executed among distributed nodes, eliminating the need for third parties [14]. With this said, the integration of smart contracts with the BT seems only natural. Smart contracts can be implemented on top of a blockchain decentralized network, taking advance of its in-built transparency and privacy features, while operating as a framework for other applications as well. Smart contracts are scripted procedures, written on top of a blockchain infrastructure that take user transactions as an input and automatically trigger an appropriate action as an output. Since they are based on the BT, smart contracts are tamperproof, distributed and self-operating [15].

Finance / Commerce

Applications in the finance category have already proven that can benefit a lot from the BT. The idea of blockchain has been first presented with the introduction of bitcoin in 2008 [3]. As of today, more than 1500 cryptocurrencies have been created, indicating the great potential of the BT [16].

Finance applications demand trust and traceability in order to appeal to customers. The supply chain is another great example of applications, where blockchain could be extremely valuable. Between the production of a product and the consumer, there are many intermediate steps that need to be controlled and orchestrated in a secure and trusted manner. Research has pointed out, that the BT adoption in the supply chain, could

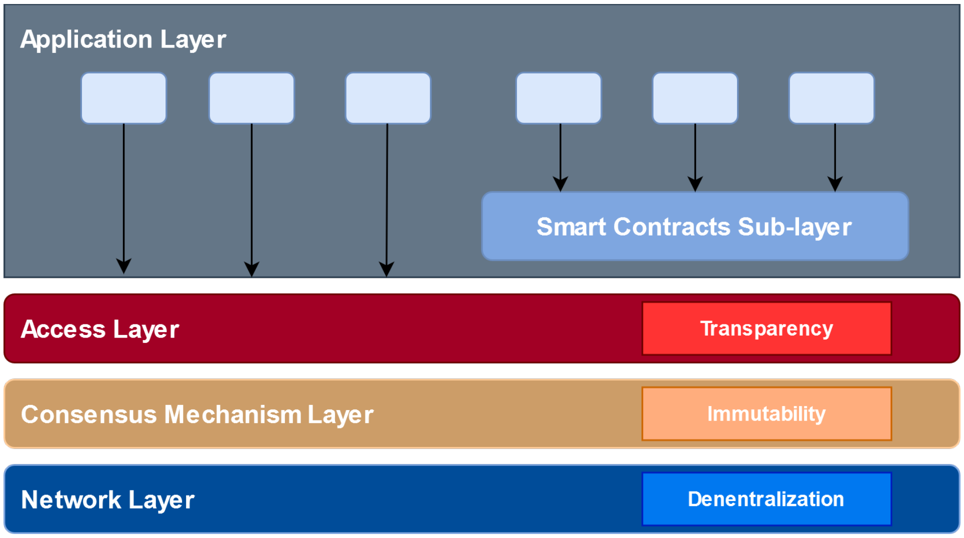

Figure 2. Blockchain as a framework, consisting of 4 layers: A) Network Layer, B) Consensus Mechanism Layer, C) Access Layer, D) Application Layer.

mitigate the paperwork, help with the identification of counterfeit products, and facilitate the product's origin tracking process [17]. Regardless the nature of the supply chain, be it an agri-food [18] or a Consumer Electronics (CE) chain [19], the distributed nature of blockchain together with its immutability and transparency, offer a unique set of tools for every customer. Users have the ability to trace the origin and the transferring of their products via simple mobile or web applications, diminishing the risk of bad quality products or price inconsistencies.

While transactions between CE manufacturers have been secured by well-defined legal frameworks, there is a higher risk of fraud in the Distributor-to-consumer (D2C) transactions, where consumers cannot always identify counterfeit products [20]. A D2C model based on smart contracts could significantly improve the consumer's security and boost their confidence when they are involved in a transaction.

Even more traditional organizations like Post Offices (POs) can benefit from the BT [21]. By implementing the BT in the POs, even people without access to a bank account, can benefit from postal services online. Moreover, an easier way of parcel tracking is created. While paying for a product, or when a parcel is scanned at different locations, the current location and status can be automatically stored in the blockchain, creating a unified permanent and transparent system for every customer.

Internet of Things

Internet of Things (IoT) is the connection and the communication of all kind of devices via private and public networks. The number of IoT devices installed worldwide is estimated to be around 26.66 billion, and they are expected to reach 75.44 billion by 2025 [22]. Given this great momentum of the IoT, consumers are getting worried about the security of IoT systems, since every home has or will have at some point an IoT device installed [23]. This security fear is not irrational. When dealing with a huge public network of low end devices, one can expect various threats, such as device unavailability, information disclosure, unauthorized access, or interrupted communication among devices [24], [25].

The distributed nature of IoT make the BT an ideal infrastructure to build on. Having each IoT device, act like a blockchain node, information can be exchanged among devices in the form of transactions, which are permanently stored in an immutable database.

Research also suggests the use of smart contracts to serve the IoT infrastructure [26]. Smart contracts are enhancing IoT capabilities, as well as strengthening the network's security and trust. With smart contracts, IoT devices may store and retrieve information about their firmware versions, as part of a secure over the air updating procedure. Additionally, smart contracts add a native billing layer in the IoT infrastructure, which can handle payments for IoT services [23]. There has already been an implementation of smart contracts for an IoT smart home application, using the Ethereum network [27]. Actually, the use cases are so many that researchers have proposed the use of blockchain as a service for IoT systems [28]. Such a model favors the sharing of data and code among IoT devices.

Since IoT devices are usually resource-constrained, some reasonable concerns may arise with the implementation of a resource-intense technology like blockchain. To address these concerns, AEchain, a variant of the proof of authentication mechanism has been proposed as a lightweight solution suitable for IoT infrastructures [29].

E-Voting Systems

Traditional voting systems are based on the principle that all the officials of the voting procedure are trustworthy and have no tolerance to faults [30]. However, people do not always trust the human factor, since it seems prone to errors or corruption. On the other hand, the current implementation of e-voting systems inserts additional security risks, since those systems most of the times need to be connected to the internet in order to carry out an electronic election procedure. Moreover, the use of digital means do not increase the transparency that the end users needs to feel confident in preferring those methods [31].

Therefore, there is a need for a digital technology, capable of providing the appropriate levels of transparency, data integrity, and the voter's privacy. BT can offer the necessary levels of security and trust that an e-voting system needs.

The pseudonymity features of blockchain can secure the voters anonymity, while the blockchain transparency will enable every user to verify the accumulative results. Additionally, blockchain's immutability can ensure that the casted votes will remain intact and permanent throughout the procedure [32]. Finally, by using a combination of private and public blockchains, the network's security can be further enhanced.

Blockchain e-voting systems have already been deployed and tested for several occasions like voting in community programs in Moscow or in the South Korean province Gyeonggi-do. An Estonian tech company, LVH Group, have tried a blockchain voting system during their annual general meeting, and even the March 2018 general elections of Sierra Leone were verified by a BT e-voting system [30].

Storage and Data Protection

There are two important things to consider in a data storing application. The first thing is the data integrity and the second is the access to the data. Applications like birth and death registers, copyrights possession and land registries are based on the idea of a big continuous record. BT's immutability feature can ensure data authenticity that will remain undistorted through the time [33].

In applications like user data storing, the appropriate access management is probably the most important aspect. With the use of BT, consumers have access to their data storing and retrieval procedures, as well as the access rights management, without interfering third parties, preserving thus the consumer's privacy. Blockchain's decentralization and its transaction mechanism, which is based on digital-signatures, render it very difficult, for a malicious user to compromise the network or another user's identity [34].

An other emerging blockchain-based application is the Nonfungible token (NFT). NFTs can be used to prove ownership and authenticity of digital assets [35]. An NFT is a unique identifier which is written into a blockchain and refers to a digital asset like an image, a document, or a music track for instance. Since NFTs are stored in a blockchain they inherit all its unique features like immutability and transparency, while they can be easily transferred or sold to other users.

Reputation Systems

Reputation can be quantified in many ways. The basic principle is the calculation of a set of variables, which may be used to characterize an individual or a group of people / organizations. Reputation should be a collective metric derived by a group of people, and it should not be changeable by any individual. Additionally, reputation must not be arbitrary, but it should be proven through a series of transactions [36].

All the aforementioned requirements of a reputation system are perfectly met in a blockchain system. Blockchain builds a decentralized network, enabling multiple users to participate in the system without the need of a central management platform that can filter reputation statistics. Moreover, the BT's immutability feature makes the system trustworthy and robust.

Reputation systems are commonly used on e-commerce, or scholar platforms, and can play a significant role in a consumer's decision over a product or a service.

Researchers have tried to cross the human opinion out of the reputation equation, by implementing a binary reputation system build on the blockchain, in order to create an unbiased system [37]. A significant benefit of the BT is that new that several applications can be implemented in existing blockchain infrastructures. Researches in [38], take advantage of this aspect, by creating Kudos. A reputation and reward system for educational records, build on top of the bitcoin network.

Healthcare

There seems to be an increased interest in the BT when it comes to healthcare applications. Healthcare application can use the BT in terms of medical record storing and sharing. Medical records are really sensitive information, thus even though BT offers user anonymity, there have been worries about the patients' privacy [39]. However, blockchains decentralization and transparency characteristics, serve as an ideal infrastructure for a unified medical record sharing platform.

The need for medical data sharing has been identified by many researchers [40], [41], [42]. Patients, doctors, researchers and insurance companies, all need to access historical medical data for different reasons. BT can easily deal with such interoperability issues.

Additionally, BT can serve as an anti-fraud mechanism for healthcare systems. By storing healthcare claims in a blockchain, organizations can easily validate the claims to refrain from unnecessary benefits, and possible data breaches [43].

With a BT-based medical record, patients can access their complete medical history and even manage the access rights of their data, via mobile and web applications [40], [42]. Moreover, the idea of storing in the blockchain, real time data, obtained from wearable devices, is also explored as a possible future application [41], [39].

Apart from the data sharing capabilities, blockchain has embedded financing features, which can further enhance and improve medical procedures, by managing health plan or insurance payments [42].

Researchers in [40] have also implemented different kind of smart contracts, in order to handle patient-provider transactions. Ethereum-based smart contracts have been also used in [44] in order to issue and verify medical certificates. The need for digitization of medical certificates has been radically increased the last few years, and BT could play a significant role in securing the distribution and the authenticity of these documents.

Transportation

Following the trend of IoT, vehicles are also getting 'smarter' over time. Equipped with various different sensors and a networking capabilities, vehicles can obtain and exchange information via Vehicular Ad-Hoc Networks (VANETs), or the internet. With an increasing number of vehicles connected, worries about user's data protection arise [45]. BT's unique privacy features, once again render the BT an ideal framework to support vehicular networks. BT has been proposed as a layered model for Intelligent Transportation Systems (ITSs), offering privacy, decentralization and smart contracts capabilities [46]. A blockchain based communication can protect a user's real identity, while still enabling the robust transferring of valuable information, such as the road conditions or the traffic status [47]. Blockchain can also revolutionize smart parking systems. Drivers can query for available slots in parking lots and make reservations through a mobile app, while preserving their location and identity private [48].

Through the BT, vehicular networks can operate as decentralized networks, where the vehicles communicate without any central node. To enhance security and trust in the network, researchers combine reputation systems with ITSs. Vehicles with big reputation score are considered trusted and thus they are preferred to operate as a temporal central node [47], [49], [50].

Furthermore, BT can be used to create a secure and permanent log containing the complete history of every vehicular activity (vehicle conditions, past accidents, etc.) [50].

Other

In this subsection we will discuss how BT has been integrated to other emerging technological fields such as Artificial Intelligence (AI), Virtual and Augmented Reality (VR) (AR), and 6G mobile networks.

AI is a broad research area and there have been various attempts to merge AI with BT. Merging AI with BT could refer either to the use of AI to improve BT, or the use of BT to improve AI. Research has been conducted [51] to introduce blockchain as a layer in a distributed AI system, where trained models would be stored, shared and validated through a blockchain, enhancing the whole system's security. Accordingly, AI has been proposed as a way to improve a blockchain-based access control system, where AI could help detect and mitigate a malicious attack [52].

Apart from AI, BT can be used to enhance VR/AR systems. Although BT and Virtual or Augmented Reality seem to be irrelevant at first glance, research has shown great potential in the integration of BT in VR/AR applications [53]. Blockchain's transaction mechanism can serve an easy and secure way to embed in-app purchases in VR applications and games. For example, a VR concert taking place in a blockchain-based VR application can have an inherent secure way to handle the ticket purchasing and validation. Additionally, other areas like VR education has been seen to take advantage of blockchain, by using it for academic achievements verification.

Mobile networks can also benefit from BT advances. The next generation of mobile networks (6G) is a field of active research, and blockchain is being investigated as a technology that could significantly improve some emerging features of 6G [54]. Trust-based Secure Networks (TBSN), Harmonized Mobile Networks (HMN), Hyper Intelligent Networks (HIN), and Resource Efficient Networks (REN) are the four (4) key directions of 6G, where BT could be proven to be remarkably useful. BT could enable 6G trust, security and privacy throughout the network. Moreover, it could server as a layer to aggregate resources leading in a greater network of networks as envisioned in 6G. Finally, BT can be used for dynamic network slicing where it could efficiently and securely coordinate with network tenants and operators.

CONCLUSION

We have presented blockchain's basic functionality along with the key features that render it an exceptional technology for every application that needs trust and security as its main principal. Moreover, we organized and shared our view of the BT as a set of four (4) layers (network, consensus mechanism, access, and application). With this layered representation, blockchain can be easily observed as a complete and modular framework for a great variety of applications. What is more important is that the research trend strongly supports our view of the BT as the underlying technology for a great variety of applications. We identified eight (8) different application categories, which can benefit from the BT immediately and we briefly presented examples of design ideas or actual implementations of applications on each category. As more and more industries take interest in the BT, the future of the consumers might be blockchain enhanced.

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