BLOCKCHAIN FOR WASTE MANAGEMENT IN SMART CITIES

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ABSTRACT

The combination of new topics and emerging technologies allows researchers to define new processes and models. The new requirements consider the definition of modular and scalable approaches to society and the environment. Smart City is an important topic to focus on. The use of emerging technologies allows smart cities to develop new processes to improve services offered by different actors, industries, or governments. Smart cities were born to improve the quality of life of citizens. To reach this goal, various approaches have been proposed, but they lack a common interface to allow each stakeholder to communicate easily and quickly. This paper presents an architecture proposal to overcome the real limitations of smart cities: it uses blockchain technology as a distributed database to allow everyone to join the network and feel part of the community. Blockchain can improve process development for smart cities. Scalability is thanks to the context-aware approach: applications do not need to know about the back-end implementation, they only need to adapt to the interface. With blockchain, it is possible to collect data anonymously to perform some statistical analysis, to ensure security in the city, and to access public records to ensure the origin of products and energy.

Keywords: - ***Blockchain, Data Analytics, West Management, Machine Learning, Data Science, Security, Smart Cities.***

1. INTRODUCTION

The rise of new technologies defines new and improved software processes. Architecture modeling is the first step to customizing a process based on specific needs defined by functional and non-functional requirements. To create a solid and scalable system, it is necessary to design some innovative approaches during the architecture definition. Among various innovative topics in software engineering, we focus on improving smart cities. The trend of smart cities is constantly growing, as new and emerging technologies help its spread. The goal of a smart city is to improve the quality of life of citizens and simplify and make operations more efficient. For a smart city to be desirable, the network should be reliable and high-performance; moreover, data privacy and encryption should be guaranteed, and the concept of trust should be a solid foundation for the whole process.

A typical problem in the development of smart cities is modularity: new applications must be contextualized and developed with this smart city in mind. In fact, there are no standards and guidelines that can be adapted to every smart city.

Our proposal is based on the use of Blockchain technology to improve our ability to develop, manage, and apply new software and system applications for smart cities. To illustrate the main goal of this paper, let's consider a sample scenario: suppose we were to develop a system that provides smart city services, using a single distributed database to allow citizens to access information about the city. Traditional cities can become smart without using new systems, but simply by connecting to existing and distributed databases used by other smart cities. Thus, as shown in Fig. 1, a smart city participant must have a single interface to collect various data and use the database; that is, the object's interface and implementation can change independently because they are separated from each other. The implementation can be implemented only once and be compatible with every other smart city that implements the proposed interface.

The paper is organized as follows: Part II presents some characteristics of Blockchain technology and presents some state-of-the-art analysis to understand the benefits and research directions of Blockchain applied to smart cities. Part III discusses the purpose of this paper. Section IV shows the design of a scalable architecture that connects each smart city actor to the blockchain using a common interface, along with some thoughts on the various applications of such a system. Finally, Section V concludes the work.

2. CHARACTERISTICS OF BLOCKCHAIN

Blockchain technology belongs to Distributed Ledger Technologies (DLTs): born in 2008 thanks to Satoshi Nakamoto [1], it can be conceived as a distributed database where information is stored in blocks. Each block is connected to the previous and the following thanks to cryptographic (hashing) functions. The main features of blockchain are suggested below to better understand its peculiarities.

• **Decentralization:** all transactions in the blockchain are entered and verified through a consensus protocol, then replicated among all nodes participating in the network. In this way, there is no need for a central authority (i.e. a bank in financial terms) to store all transaction data.

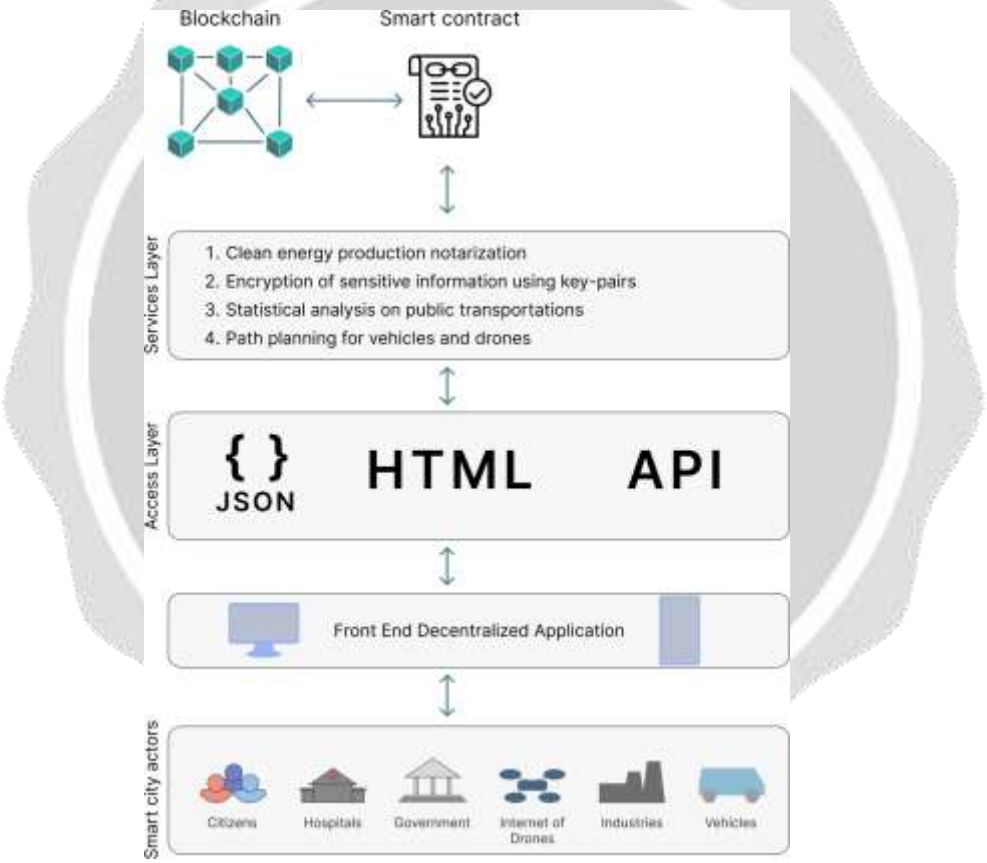

Fig. 1. Layers of the system showing a single interface in the access layer

• **Immutability:** transactions in the blockchain are stored in blocks. Each block contains its hash and the previous block's hash, creating a chain that is immutable, causing any change to a block to affect all subsequent blocks. An attacker cannot change the information of block N without changing all blocks N+1, N+2,..., M, where M is the total number of blocks in the chain. This change is computationally intensive, so it cannot be done in a short time.

• **Transparency:** the only way to update the ledger is to reach a consensus of the majority of network nodes. All changes are publicly visible: this ensures transparency and security.

• **Traceability:** immutability and transparency features make it easy to track all transactions on the blockchain.

In this way, each transaction can be traced back to its origin.

• **Trustless:** in blockchain, it is possible to make transactions between unknown parties even if they do not trust each other. Due to the absence of a central authority, it is possible to trust the validity of a transaction without knowing who was involved in it.

3.LITERATURE REVIEW

Various reviews show the role of Blockchain in smart cities, some focusing on smart healthcare, smart transportation, and supply chains [2]. They also emphasize the combination of blockchain and other technologies such as the Internet of Things and machine learning [3]. Blockchain can help smart cities become more sustainable due to its special features: a) it is immutable, so any information added to the chain cannot be modified, b) it is anonymous, which means that anyone can join the network without worrying about privacy, c) it is trustworthy, even if people don't know each other.

The authors of the article [4] focus their research on Blockchain smart contracts in the field of smart real estate. They propose a conceptual framework for adopting such a theme in smart cities. The real estate process becomes more impressive and user-friendly in line with the requirements of Industry 4.0.

Blockchain can help the development of a smart city [5] in terms of both performance and security. The distributed nature of this technology makes architectures more scalable and with fewer points of failure: as soon as one node is active, the entire network is up and running. Data sharing takes this approach: education, healthcare, and buildings can communicate using a single common interface. Artificial intelligence intervenes in data management and analysis [6]: deep learning techniques can enrich green energy production [7], [8], while neural networks can improve road management [9].

Blockchain's traceability characteristics are useful for waste management [10] through notarized documentation, legal compliance, and fleet management. It is also useful with respect to public emergency services [11]: it can help security personnel manage various anomalies, from fires to crimes. A current summary is presented in Table I. The analysis of these publications brings some open challenges: a) Sustainability is an important aspect of the topic of Blockchain applied to smart cities. It is the furthest research topic from most analyses [3]. b) A unified interface to blockchain is needed to create a bridge between different actors in a smart city and one common distributed database. c) Security and privacy should be emphasized [12]: Blockchain preserves privacy and ensures that only authorized nodes have access to sensitive information. d) The costs of deploying a complete Blockchain network in a smart city are not yet known. It is difficult to predict the costs of deploying blockchain in a smart city [2]. e) Regulations are needed for proper information sharing: smart contracts can be useful in this topic.

4. OUR VISION

We envision a scenario where Blockchain underpins smart city processes. Each process can be easily added to the system thanks to a common interface that includes every aspect of the city. Information can be exchanged using the JSON format, so communication between the front-end decentralized application and the blockchain is contextual. Blockchain technology has the potential to play an important role in the development of smart cities. It can provide a number of benefits in many areas:

TABLE I

Paper	**Publication year**	**Topic**
xie2019survey [2]	2019	Survey on the literature in evolving Blockchain technology applied to smart cities
rejeb2022blockchain [3]	2022	Trends and Research Directions for Blockchain

		Ap-applied to smart cities
ullah2021conceptual [4]	2021	Usage of smart contracts in a smart real estate environment
shari2022state [5]	2022	Survey of Blockchain applications for data management in smart cities
sharma2021sustainable [6]	2021	Integration of Blockchain and Artificial Intelligence for sustainable smart cities
ahmad2021blockchain [10]	2021	Usage of Blockchain for waste management in smart cities
kumar2022best [11]	2022	Protection of life and properties from fire damage in smart cities using Blockchain
ghazal2022securing [12]	2022	Protection of smart cities using Blockchain as a distributed database

STATE OF THE ART ANALYSIS

• Supply chain management: Blockchain can be used to track goods and materials through the supply chain, increasing transparency and reducing the risk of fraud.

• Sustainability: Blockchain can be used to manage and monitor the use of renewable energy. A sustainable smart city can be achieved if actors reduce their carbon footprint and promote green approaches.

• Authentication and identification: Blockchain can be used to verify identity in a secure and decentralized manner, making it easier for citizens to access services and engage in civic life.

• Public Records: Blockchain can be used to store and manage public records such as real estate titles or licenses.

• Transportation: Blockchain can be used to manage and monitor public transportation usage, helping cities optimize their transportation systems and reduce traffic congestion. On the transport side, Blockchain can be used to gather information to improve journeys, waiting times, and overall services.

Overall, blockchain's role in smart city governance is to improve various aspects, from sustainability (i.e. no notarization of clean energy production) to anti-hijacking (i.e. guaranteeing a bus or taxi route, creating statistical analysis for the public). transportation, passenger identification). The ultimate goal is to improve the quality of life of citizens.

A. Clean energy production

Smart buildings must be energy efficient and incorporate clean energy generation technologies. There are different ways to achieve this goal: a) solar panels can be installed on the roof of a building to capture sunlight and generate electricity, b) wind turbines can convert wind speed into electricity, c) storage systems such as batteries can store excess clean energy produced during times of low consumption. Blockchain technology can support clean energy production in several ways:

a) can monitor and verify energy production to ensure the sustainability of the building; b) can help with energy trading, notarizing transactions between a building with enough energy in storage and a building with less energy than required; c) can help people understand whether a building is truly sustainable and green (i.e. shows the carbon footprint of the building), thus enabling people to choose and prefer smarter and more efficient buildings.

B. Encryption of Sensitive Information

On the citizen side, information should be encrypted to ensure privacy and anonymity. The encryption process can be both symmetric and asymmetric. In this proposal, we follow an asymmetric key encryption scheme that uses a key pair that is already present in every Blockchain architecture. This way, anyone can encrypt any message using the recipient's public key, guaranteeing that only the recipient can decrypt the message using their private key.

In the case of public service requests, it is possible to use smart contracts to make the process safe and transparent. The authentication and request process is shown in Fig. 2.

1) A citizen requests a service from an institution (i.e. proof of residence). The request is managed by a smart contract. It is also possible to directly upload documents to the Interplanetary File System (IPFS) [13], but due to the lack of regulations and laws, we have decided to let institutions store sensitive documents.

2) The smart contract together with the institution authenticates the citizen and ensures that the required certificate can be obtained.

3) The smart contract requires a document from the institution.

4) The institution returns the requested service using the same smart contract.

5) The citizen receives the requested service or document. The process is transparent, secure, and fast thanks to the intervention of a smart contract.

C. Statistical analysis

Using a distributed database like Blockchain allows people to read public records that are stored on the chain and accessible to anyone. This data is stored anonymously, which means that any information can be related to the public key (wallet), but there is no way to link this wallet to a person. In this way, the data can be used to perform certain statistical analyses in order to understand how to improve the services offered to citizens. Public transport can easily understand if the offer is lacking and improve it because it knows exactly where to act.

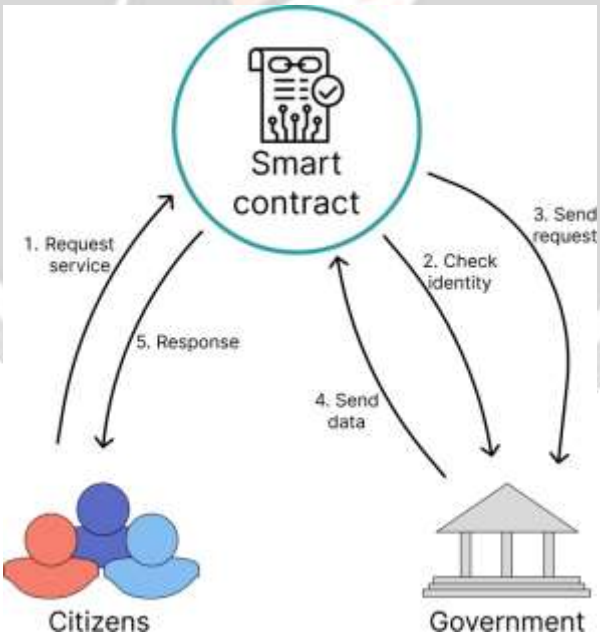

Fig. 2. Sample process for a citizen requesting a service to governmentinstitutions

D. Trip planning

The process of determining one optimal route for a vehicle to travel from one location to another is defined as route planning. This approach can be used to avoid traffic congestion in smart cities [14] or to respond quickly in case of disasters [15]. Route planning can be used for vehicles, drones and people. Blockchain technology makes it possible

to avoid hijacking: various approaches have been proposed in the Internet of Drones (IoD) domain [16]–[18]. They all share a common point of view: every time the drone approaches a new point of interest (PoI), it writes a new piece of information on the Blockchain to notarize its position. In this way, any hijacking attempt can be identified in a short time. The same approach can be considered for Autonomous Guided Vehicles (AGVs) in a smart city: AGVs can read from the Blockchain where to go, then create an optimal route and notarize the arrival time. This information may be further used for statistical analysis as highlighted above.

5. PROPOSED ARCHITECTURE

Our contribution is about designing an architecture where every player in a smart city can benefit from using Blockchain as the back end of the system. The main goal is to develop a common interface to communicate with the database so that everyone can connect to the network in a secure and fast way. Smart contracts can accept any data in JSON format: new actors just need to upload information in JSON format. The data is then managed by a contract that collects and converts it into value, uploading it to the Blockchain. In Fig. 3, an architecture showing different actors is proposed.

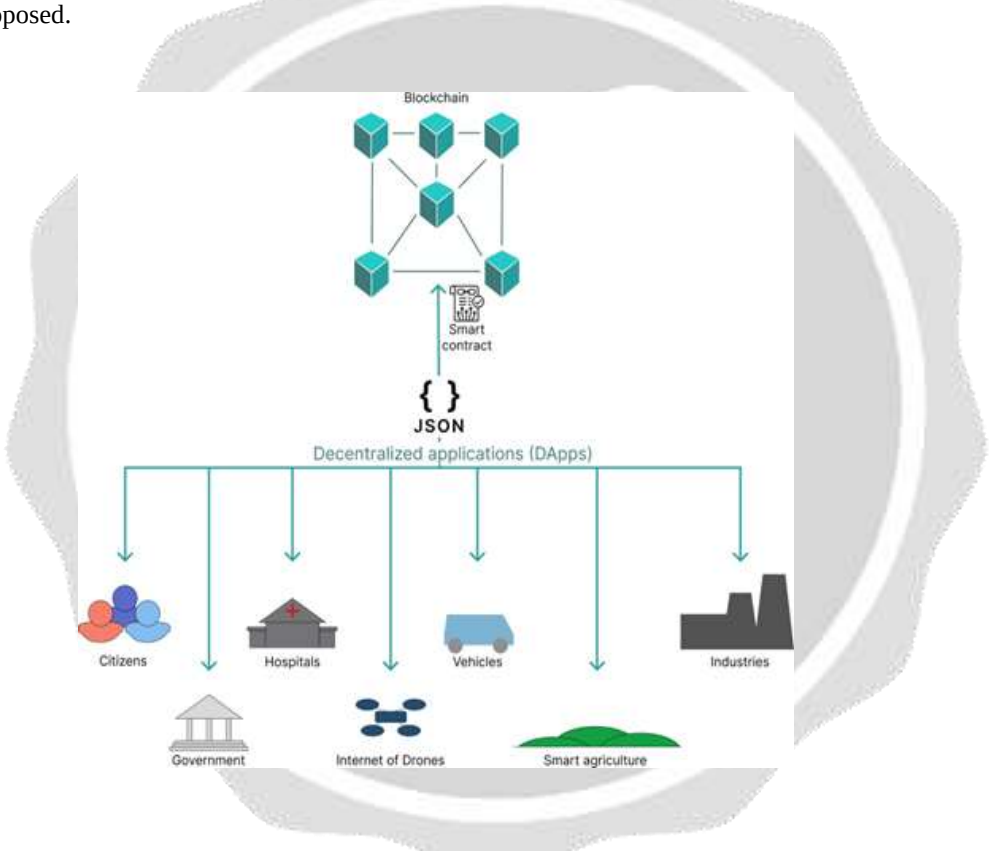

Fig. 3. Architecture of the proposed Blockchain-based smart city

In our scenario, each actor uses a decentralized application (D App) to connect to the blockchain. Daps are designed to be distributed and run on multiple nodes rather than being controlled by a single entity. Some applications of such an architecture can be summarized as follows:

• . Clean energy production. To achieve sustainability goals, clean energy production can be notarized on the Blockchain. Everyone can ensure that the energy used in the building comes from renewable sources.

• Encryption of sensitive information. Sensitive information can be encrypted using a node key pair. Autonomous shared vehicles (i.e., taxis) can use this token to authenticate passengers and ensure that only a passenger who has paid for the ride can use the vehicle.

• . Statistical analysis. Public transport may perform statistical analysis (i.e., preferred destination, waiting times,etc.) to improve the offer, still guaranteeing anonymity.

• Route planning. Route planning is possible to avoid hijacking. In the Internet of Drones topic, this can be a useful approach to ensure that the path followed by the drone is correct and there is no tampering [18], [19].

In addition, every actor in a smart city can feel part of the community, have easy access to any public information in the Blockchain, and exchange messages with other actors in a transparent way.

The architecture respects the requirements for building a system process with respect to modularity and scalability, thereby ensuring high performance and reliability guaranteed by the presence of Blockchain.

```
async updateDocData(ctx, id, oldData, updatedData) {
    const old_data = JSON.parse(oldData);
    const updated_data = JSON.parse(updatedData);

    const updatedDoc = {
        ...old_data,
        ...updated_data,
    };

    await ctx.stub.putState(id, Buffer.from(JSON.stringify(updatedDoc)));
    console.log(updatedDoc);
}


async addData(ctx, id, oldData, category, newData) {
    const new_data = JSON.parse(newData);
    const doc = JSON.parse(oldData);

    if (!Array.isArray(doc[category])) {
        throw new Error(`Given category is not of Array type! `);
    }
    doc[category].push(new_data);
    await ctx.stub.putState(id, Buffer.from(JSON.stringify(doc)));
}
```

Fig. 4. Context-aware smart contract supporting JSON-formatted information

A prototype is being developed to demonstrate the benefits of using a single access layer. Some context-aware smart contracts are designed to upload JSON information to the Blockchain, as suggested in Fig. 4. These smart contracts take input, perform some data validation checks, and then upload it to the Blockchain. Data is accessible to smart city actors; the loading process will generate a JSON object. A particular front-end distributed application can manage the JSON output to display the information requested by the user. The described process is shown in Fig. 5: the steps from 1.2 to 1.3 are independent of the front-end distributed application.

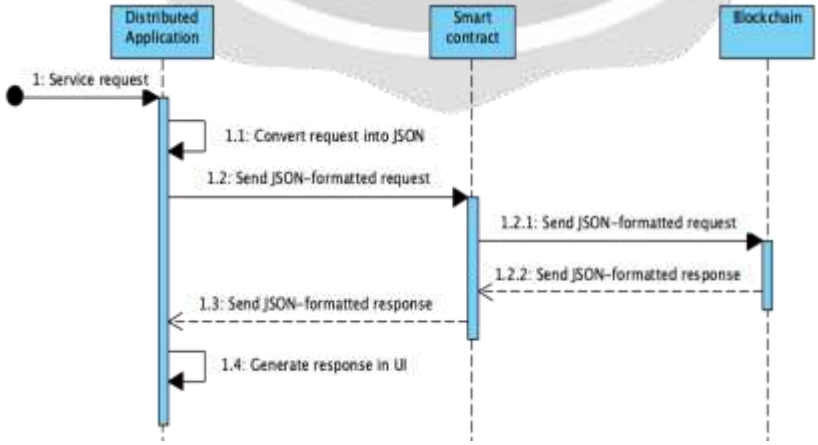

Fig. 4. Context-aware smart contract supporting JSON-formatted information

6. CONCLUSIONS

In this paper, we propose an architecture for the application of Blockchain technology in smart cities. Thanks to its properties, blockchain guarantees anonymity, optional data encryption and traceability of goods, production of clean energy and vehicles. We will show how different stakeholders can benefit from using this architecture, then make some reflections on model workflows (i.e. the process for a citizen requesting a service or document to government institutions) and process improvements. Contextual approach provides scalability and allows applications to communicate in the same way with every service proposed in the city. Future development concerns the development of a complete simulator using smart contracts to implement some smart city services to show how each actor can communicate, exchange data, and access public records.

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