

A Framework for Cognitive Internet of Things based on Blockchain

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Abstract— *Internet of Things, cognitive systems, and blockchain technology* are three fields which have created numerous revolutions in software development. It seems that a combination among these fields may results in emerging a high potential and interesting field. Therefore, in this paper, we propose a framework for *Internet of Things* based on *cognitive systems* and *blockchain technology*. To the best of our knowledge, there is no framework for *Internet of Things* based on *cognitive systems* and *blockchain*. In order to study the applicability of the proposed framework, a recommender system based on the proposed framework is suggested. Since the proposed framework is novel, the suggested recommender system is novel. The suggested recommender system is compared with the existing recommender systems. The results show that the suggested recommender system has several benefits which are not available in the existing recommender systems.

Keywords—component; *Internet of Things (IoT)*, *Blockchain Technology*, *Cognitive System*, *Recommender Systems*.

I. INTRODUCTION

Recently, numerous revolutions have been occurred based on *Internet of Things*, *cognitive systems*, and *blockchain*. Fig. 1 shows all combinations among the mentioned fields. In the rest of this section, all possible combinations among the mentioned fields are studied.

In the next three paragraphs, we give small descriptions for each field independently.

Internet of Things(IoT): The term '*Internet of Things*' was coined by Kevin Ashton in 1999 [1]. The *IoT* is the interconnection of devices in a global range. In these systems, not only computers are interconnected, but also all things on the earth can be connected. In *IoT*, the 'things' can include anything from a smart-brush to an airplane control system. But each thing is consisting of some type of sensors (such as heartbeat sensor, temperature sensor, light sensor, motion

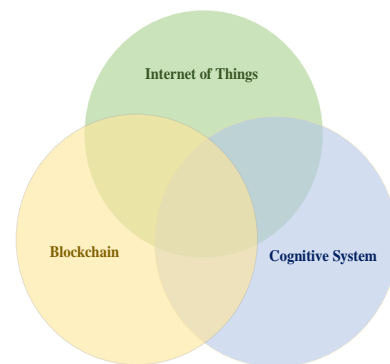


Figure 1. *Cognitive systems, Internet of Things, and Blockchain*

sensor, etc.) or actuators (such as heart-shock, sound, motors, etc.). The other parts of the *IoT* systems include the computing resources and the communication medium [1-6].

Cognitive system: The *cognitive system* continuously learns from its interaction with its environment including data, people, and situation and then improves its learning and reasoning capabilities. These systems tries to transfer the thinking capabilities of humans to machines [7]. These systems were used to define modern frameworks for managing computer networks such as those reported in [8-12].

Blockchain technology: the *blockchain technology* refers to a continuously growing list of records, called blocks. The cryptography is used to link and secure the blocks. In order to manage these systems in distributed manner, the technology of peer-to-peer networks are used. The potential of *blockchain technology* was highlighted by a digital currency called Bitcoin. This type of digital currency is managed by automated consensus among networked users. From a technical point of view, Bitcoin is digital currency that is

transacted via the internet in a decentralized trustless system using a public ledger called the *blockchain*. The technology of *blockchain* could be the next major disruptive technology and worldwide computing paradigm [13-18].

Now, the possible combinations among the mentioned fields are studied as bellow.

- **Cognitive systems and IoT:** combinations between cognitive systems and *IoT* have been reported in the literature [19-27]. Note that, *Cognitive Internet of Things* refer to new powerful systems. In these systems, the *cognitive system* is used to efficiently manage the *Internet of Things*. It is obvious that because of distributed and dynamic nature of *IoT*, selecting or designing an appropriate *cognitive system* for them is a challenging problem.
- **Cognitive systems and blockchain technology:** because of distributed nature of *blockchain* based technology, the management of these systems is very challenging. The *cognitive systems* are used to mitigate the challenges in management of these systems. Recently, some combination among these fields are reported in [28, 29].
- **IoT and blockchain technology:** The *IoT* creates a bridge toward the future of payment systems. *Blockchain technology* provides faster product innovations and integration with the *IoT* [30-32].
- **IoT based on cognitive systems and blockchain technology:** There are huge numbers of *things* and transaction in every moment of evolution of *IoT* based application. In *IoT* based *blockchain*, the *blockchain* enable micro-payment functionality between *things*, through light cryptocurrencies and smart contracts. Therefore, combination between *IoT* and *blockchain* leading to creation a system with high ration of changes during its evolution. Therefore, a system obtained from combination between *IoT* and *blockchain* should be equipped with a smart management mechanism such as those used in designing cognitive systems.

There is one work reported in [33] in which there fields: *cognitive systems*, *blockchain*, and *IoT* are combined which each other. It is obvious that combination among these fields bring a new approach in computer sciences. In other hand, no general framework is reported in the literature to utilize the mentioned fields simultaneously. The study and implementation in [33] is very dependent on IBM Watson and other products of this company. Another drawback of this work is that it does not support fully distributed computation required by cryptocurrencies such as bitcoin.

In this paper, we propose a general framework for cognitive *IoT* based on *blockchain*. Then, a recommender system is suggested using the proposed framework. Since the

proposed framework is novel, the suggested recommender system is novel. The structure of this paper is described as follow. In section 2, the proposed framework is described. In section 3, the case study details and comparison are given. Conclusion is given in Section 4.

II. THE PROPOSED FRAMEWORK

In this section, we present a framework for *IoT* based on *cognitive systems* and *blockchain technology*. The structure of the proposed framework is given in Fig. 2. This framework consists of three layers: *Requirement Layer*, *Cognitive Process Layer*, and *Things Management Layer*. In the *Thing Management Layer* of this framework, the elements of *IoT* are combined with *blockchain technology*. Note that, the combination between *IoT* and *blockchain technology* creates many management problems which should be solved by *cognitive systems*. It is obvious that, distributed, dynamic, and large-scale characteristics of a system obtained from combination between *IoT* and *blockchain technology* leading to emigrating difficult management problem which cannot be solved by traditional or non-smart solutions. In the proposed framework, the *cognitive process layer* is in charge of managing the system by solving management problems of the *Thing Management Layer*. The details of each layer are given in the rest of this section. Note that, we borrowed some concepts from framework of the cognitive networks introduced by [10, 23, 34].

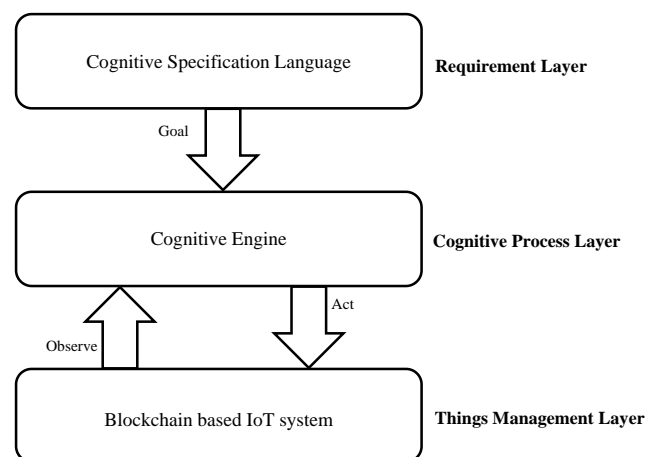


Figure 2. A framework for *Cognitive Internet of Things* on *blockchain*

A. Requirement Layer

In the requirement layer, the goal and behavior of the network can be described by a *Cognitive Specification Language (CSL)*. This language is used to fill a file called configuration file. This file is shared among those entities which manage the configurations of the *IoT*. It should be noted that, changing the goals in the requirements layer leading to changing the optimizing functions in the cognitive process layer. The goals of the systems are determined by some commands obtained from the *voice (or speech)*, *command line*, or any type of direct interaction between users and the

system. Some features of the goals which can be determined by the following elements.

- Service Type
- Payment Type
- Smart Contract Type
- Sensor Type
- Actuators Type

The above elements can be used in commands. The commands can be also used to tune the system. The commands can be fetched from outside of the framework. several approach considering distributed nature of *IoT* for sharing the configuration things are suggested as below.

- **Centralized algorithm:** In this algorithm, the last version of the configuration file is stored in one well-known server.
- **Semi-centralized algorithm:** In this algorithm, multiple servers are incharge of managing the configuration file in the *IoT*.
- **Fully-distributed algorithm:** In this algorithm, each thing periodically download the last version of the configuration file from its neighboring things.

B. Things Management Layer

This layer provides required information for the cognitive process layer and then operates on manageable elements of the systems. Fig. 3. shown the structure of this layer. The more detailed explanation of each unit is given in the rest of this section.

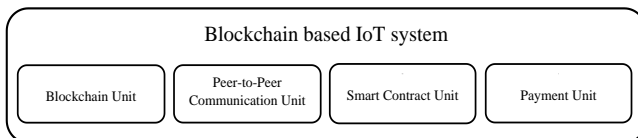


Figure 3. Things Management Layer

This layer contains four units described as bellow.

- **Blockchain unit:** this unit in charge of managing required information in one or multiple *blockchains*. In this unit, every type of blockchain (such as Healthcare [35], insurance [36], banking [37] and etc.) may be used. This unit has three sub-unit *blockchain of things*, *blockchain of microservices* and *blockchain of smart contracts*. For example, the information of *microservices* used by the system are indexed in the *blockchain of microservices* and the information of *smart contracts* used by the system are indexed in the *blockchain of smart contracts*.
- **Peer-to-Peer communication unit:** This element facilitates the communication and data exchange among *things* using peer-to-peer networking technology. This element also supports the management issues related to the other unit called *blockchain of things*.

- **Smart contract unit:** this element provides the required functions for using the smart contracts defined in the system. Note that, the codes of smart contracts are stored by the *blockchain unit* in a *blockchain* [18]. The cognitive engine is in charge of tuning and using the smart contract unit considering the goal of the system.
- **Payment unit:** this unit supports the payment process in cooperation with *cognitive process layer* and other units of the *thing manager layer* in the system. This unit also manages the information about the wallets of the users. It should be noted that the type of coins of the users should be managed in this unit. In other word, the payment manager unit must be able to communicate with the platform of every type of coins. According to Table 1, each coin has been defined on a platform and each platform has been designed for an issue. Among them three coins such as *Bitcoin*, *Ethereum*, and *IoTA* have been designed for the *IoT* [32, 38, 39].

TABLE I. IOT ON THE BLOCKCHAIN COINS

Coin	Goal
Bitcoin	Innovative payment network and a new kind of money
Ethereum	Decentralized platform that runs smart contracts
Ripple	Provide one frictionless experience to send money globally.
Stellar	A platform that connects banks, payments systems, and people. Integrate to move money quickly, reliably, and at almost no cost.
IoTA	Enables companies to explore new business-2-business models by making every technological resource a potential service to be traded on an open.
MONERO	A secure, private, and untraceable cryptocurrency.
ICON	Comprised of various institutions ranging from: financial institutions, insurance companies, hospitals, universities and more.
Golem	Creates a decentralized sharing economy of computing power and supplies software developers with a flexible, reliable and cheap source of computing power.
Dentcoin	The first Blockchain concept designed for the Global Dental Industry.

C. Cognitive Process Layer

In this layer, the *cognitive engine* observes the information about system and then executes appropriate algorithms for managing the system. This layer considers the goals of the system that are specified in requirement layer. In this layer several types of engines may be designated which are described as bellow.

- An engine for finding the goals of the system by interpreting the configuration file. In this engine, machine translation algorithms may be applied to extract the goals. Watson [40] can be used in this unit.

- An engine for managing the complexities related to smart contracts. Many smart contracts can be implemented in the system and the cognitive engine should be able to manage them.
- An engine for managing the complexities related to payment process.
- An engine for managing the knowledge and memory of the used by the management algorithms.
- An engine for managing peer-to-peer communication and *blockchain*.
- An engine for intrusion detection.

In all of above types, the information about the *things* are shared among the engines.

During implementation of the *Cognitive Process Layer*, several decisions making should be made which some of them are explained as below.

- Decision about selecting the goal of the cognitive engine that determines which engine should be designated.
- Decision about selecting *blockchain* technology for the *things* considering the goal of the cognitive engine.
- Decision about selecting smart contract which can be used in the cognitive engine.
- Decision about selecting appropriate learning mechanism considering the characteristics of the cognitive engine. For distributed and dynamic types of cognitive engine, an artificial intelligence technique which can use distributed information about *block chain* is a good candidate.
- Since, human may not be able to resist against harmful actions of the *cognitive engine*, designing a safe *cognitive engine* may be required.

Because of distributed nature of *IoT*, the cognitive engine can be implemented using one of the following methods.

- **Centralized approach:** In this approach, the cognitive engine is implemented in one server.
- **Semi-centralized approach:** In this approach, the engines of the cognitive engine are implemented in multiple servers.
- **Fully-distributed approach:** In this approach, every *thing* has its own cognitive engine.

III. CASESTUDY AND COMPARISON

In this section, a cognitive recommender system algorithm is designated based on the proposed framework for a shopping center. The commands obtained from the user should be considered by the system is described as bellow.

- Recommend the items to the user considering history of purchases.
- Consider the healthcare profile of the user for computing the discount factor.
- Use the Bitcoin wallet for payment process.
- Use a recommendation service called X-Service recommendation.

The above commands are taken by the cognitive engine and then the required functions are issued. The algorithm of the cognitive engine is given as bellow (Fig. 4).

Algorithm <i>cognitive engine</i>	
Inputs User's commands; User's information collected by sensors.	
Notations: Smart-contract1// smart-contract 1 is based on health care information Smart-contract2// smart-contract 2 is based on shopping history X-Service// this service is uses collaborative filtering for recommendation. X-Service is bought by the uses. This service uses collaborative filtering for recommendation.	
01:	Begin
02:	Take the commands of the user;
03:	Interpret the commands to the goals of the system;
04:	Fetch smart contract considering the goals of the system; //Smart-contract1 and Smart-contract2 are fetched from Blockchain
05:	Collecting information of the sensors and then storing them by the <i>blockchain</i> unit;
06:	Call the X-Service; // X-Service provide the list of recommendations. The information of this service is available in the blockchain.
07:	Calculate the discount using Smart-contract1 and Smart-contract2;
08:	Compute the final value of payment;
09:	Execute payment process using the user selected wallet; // the selected wallet is based on Bitcoin.
10:	End

Figure 4. The cognitive engine

In the proposed algorithm, when the user enters the shopping center, his information is sensed by the sensors and saves in the blockchain. After that user's commands have been received, the cognitive engine and the corresponding services are called to interpret the commands in order to draw out the goals of the system for the user. According to the goals which have been extracted, the smart contract can be fetched and then the corresponding recommendation services can be called. After that, appropriate items can be recommended to the customer by the system. Users purchase products and then the discount has been calculated based on smart contracts. Finally, the user completes the payment process using its Bitcoin wallet information which leading to changing the account's value. Note that, according to the goals determined by the user, the smart contracts are based on user medical information and history of purchase.

Table 2 compares the suggested algorithms with other studies reported in the literature. Table 2 shows that most published articles report one of these three features. To the best of our knowledge, our work is novel (unique) and there hasn't been any prior study on designing *internet of things* based on *cognitive systems* and *blockchain* for recommender systems.

TABLE II. COMPARE WITH OTHER RECOMMENDER SYSTEMS

Reference	Blockchain based	IoT Based	Cognitive Based
Noirie et al., [2017] [41]	Not Reported	✓	Not Reported
Forestiero, (2018) [42]	Not Reported	✓	Not Reported
Kaur, (2018) [43]	Not Reported	✓	Not Reported
Hahn, (2018) [44]	Not Reported	✓	Not Reported
Bursalioglu et al., (2018) [45]	Not Reported	✓	Not Reported
Frey et al., (2016) [46]	✓	Not Reported	✓
Gholizadeh et al., (2017) [23]	Not Reported	✓	✓
Our Study	✓	✓	✓

IV. CONCLUSION AND FUTURE RESEARCH

In this paper, we proposed a framework for *Internet of Things* based on *cognitive systems* and *blockchain technology*. In this framework, the *cognitive engine* of the *cognitive process layer* observes the status of *things* from the *things management layer*. Then, the *cognitive engine* acts on actuators of the *things* and triggers an appropriate list of the *smart contracts*. In the proposed framework, various coins can be used for the payment process using peer-to-peer communication protocols. Also, we studied the applicability of the proposed framework by designing a cognitive recommender system algorithm in the shopping center. The proposed framework was compared with other existing solutions with respect to three features. To the best of our knowledge, our work is novel and there hasn't been any prior study on designing *Internet of Things* based on *cognitive systems* and *blockchain technology* for recommender systems. For future research we can apply the technologies of Web of Things in the proposed framework.

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