2019 5th International Conference on Web Research (ICWR)

# An Architecture for Managing Internet of Things based on Cognitive Peer-to-peer Networks

Mahdi Ghorbani
Faculty of Computer and Information Technology Engineering
Qazvin Branch, Islamic Azad University
Qazvin, Iran
mahdigh13@yahoo.com

Mohammad Reza Meybodi, Ali Mohammad Saghiri
School of Computer Science, Institute for Research in Fundamental Sciences (IPM)
Tehran, Iran
mmeybodi@aut.ac.ir, a_m_saghiri@aut.ac.ir

*Abstract*—**Peer-to-peer systems are well-known patterns of distributed systems which created several revelations in designing ultra-scalable systems. Recently, these types of systems are evolved into cognitive peer-to-peer networks. Because of the distributed nature of Internet of Things (IoT), peer-to-peer systems such as blockchain can be used to design management mechanisms in IoT. Therefore, we need an architecture which facilitates the utilization of peer-to-peer systems in IoT based systems. To the best of our knowledge, there is no general architecture based on cognitive peer-to-peer networks. Therefore, in this paper, we propose an architecture for managing IoT based on cognitive peer-to-peer networks. In order to study the potential of the proposed architecture, we suggest an adaptive search mechanism and also a topology management algorithm utilizing the proposed architecture. The results show the efficiency of the suggested algorithms. The proposed architecture may facilitate a new evolution from peer-to-peer systems to thing-to-thing systems.**

***Keywords—Thing-to-Thing systems, Internet of Things(IoT), Cognitive peer-to-peer networks***

## I. INTRODUCTION

The term "Internet of Things", was first coined by Kevin Ashton at Massachusetts Institute of Technology in 1991[1]. The Internet of Things is a term used to describe a world in which objects will be able to interact with other objects by connecting to the Internet or using communication tools, share their information with each other or with humans, and a new class of capabilities, Applications, and services[2], [3]. In IoT, the 'things' can include anything from a smart-brush to an airplane control system. A world in which all the heterogeneous objects and devices are capable of addressing and hence controllable. Also, the substrate of the IOT is on wireless radio waves that allow objects, cars, and devices to communicate and coordinate remotely and using the Internet as a global platform [5-9]. From the point of view of users, the most visible impact of the IOT in the areas of intelligence, health, and well-being, health and business will be evident.

Since IoT systems are large and also dynamic, designing management algorithms for them is a challenging problem. In the last few years, this problem has become more difficult because the IoT systems have been merged into other systems such as cloud computing and social networks. It should be noted that, in a hybrid system such as IoT cloud [9-11],IoT peer-to-peer [2],[12], Cognitive IoT [59] and IoT social networks [13-16], the number of problems in designing the management algorithms of IoT systems will be increased.

In an unknown environment, cognitive systems are able to learn from past experiences and improve their decisions about its policies [18]. The cognitive systems such as cognitive radio networks, cognitive peer-to-peer networks, cognitive wireless mesh networks, cognitive mobile networks, cognitive sensor networks, and cognitive personal networks have received much attention in recent years [17-19].

The cognitive peer-to-peer networks [19] try to adaptively find an appropriate configuration for the networks. These types of networks can be used to manage thing to thing communication in IoT systems. In these systems, each thing is managed by the cognitive engine and the communication protocol is based on peer-to-peer communication paradigm. In the literature, there is no architecture for managing IoT based on cognitive peer-to-peer networking concept.

In the last decade, peer-to-peer networks are used as the infrastructure of a wide range of applications is shown in figure 1.


Fig.1. Applications of peer-to-peer networks

Some of these applications are described as bellow.

- **File sharing:** many file sharing applications utilize peer-to-peer networks. Among these applications we can refer to Torrent[20], emule

[21] and gnutella[22]. These applications don't invest in expensive servers. Therefore, many companies prefer to use them.

- **Video streaming:** Peer-to-peer streaming enables each peer (computer) to start a streaming process. This technology is also known as peer-to-peer television (P2PTV). Some of well-known applications of this category are Zatoo[23], PPlive[24], Tribler[25], and LiveStation[26].
- **Cloud computing:** Peer-to-peer cloud is an interesting application of peer-to-peer networks. peer-to-peer networks are merged with cloud computing to bring a scalable architecture of clouds[27].
- **Grid computing:** In a peer-to-peer grid, a peer-to-peer network for sharing computational power is used. The aim of this system is to provide easy access to large amounts of computational resources for every peer[27].
- **Messaging system:** In a peer-to-peer messaging system, large-scale, high-performance group communication is supported. Tox[28], and Ricochet[29] are two examples of peer-to-peer messaging systems.
- **Database:** Peer-to-peer database is a serverless, distributed, database. OrbitDB[30] and Barrel[31] are two examples of these systems.
- **Search engine:** A peer-to-peer search engine is a search engine where there is no central server. Faroo[32], and yacy[33] are two examples of a peer-to-peer web search engine. Recently the peer-to-peer search engine techniques have received much attention to be the infrastructure of a search engine in the Internet of Things field.
- **Storage:** peer-to-peer storage networks support storing and retrieving remote files. The clients of these systems are not aware of the real positions of the files. In another word, these networks build a distributed file system[27], [34].
- **Anonymizing:** utilizing cryptography, peer-to-peer anonymizing networks enables peer to peer communication with high anonymity. Tarzan[35], Freenet[36], and Tor[37] are three examples of these networks.
- **Insurance:** peer-to-peer insurance is a risk sharing network where a group of persons pools their premiums together to insure against a risk[38].
- **Web hosting:** in peer-to-peer web hosting, peer-to-peer networking is used to distribute access to WebPages[39].
- **Online cash system:** Bitcoin which a well-known online cash system utilizes peer-to-peer networks[40].

In a blockchain based application, these networks build peer-to-peer overlay networks over underlay networks.

In this paper, we extend the architecture reported in [19] to obtain a novel management architecture in IoT systems. In order to study the applicability of the proposed architecture, it is used to design two management algorithms for two well-known problems: resource discovery and topology management. It should be noted that the cognitive engine used in this paper is designated based on the learning process of the theory of learning automata [43], [44].

The rest of this paper is organized as follows. The related works are reviewed in Section II. Section III describes Learning Automata as reinforcement learning techniques. In section IV, our novel architecture is described. Section V describes two case studies we suggested utilizing our proposed architecture. In section VI, the simulation is presented and section VII, concludes the paper.

## II. RELATED WORKS

In this section, we briefly explain some proposed frameworks for IoT systems.

In [45], the proposed framework is designed to utilize a huge number of RDF triples in the future of IoT that supports SPARQL in different peer-to-peer systems. An architecture based on peer-to-peer systems for large-scale IoT networks in order to provide resource discovery mechanisms is proposed in [46].A11Joyn Lambda [47] is an architecture for managing the smart environment in IoT by focusing on Big data storage. The researchers in [48] proposed a framework for service discovery in IoT by analyzing some approaches such as DHT-P2P.In [49], a context-aware and locality preserving discovery framework called LOCA are proposed which is built on a distributed peer-to-peer architecture. By reviewing the above studies, it is obvious that the proposed frameworks do not have the ability to unify the algorithms of a peer-to-peer system in an aggregated architecture. It means that a general architecture for the management of the Internet of Things has not been introduced yet. As it was previously mentioned, in this paper, an architecture for managing the Internet of Things based on cognitive peer-to-peer networks[19] will be proposed.

We suggest a search algorithm and a topology management algorithm which learning automata are used to design cognitive engines. Both of these algorithms reported in [50], [51] were not designated under a general architecture.

## III. PRELIMINARIES

In this section, we present a brief overview of learning automata as the basic information for the remainder of the paper.

- **Learning Automata Theory**

A learning automata[43], [44] is an adaptive decision-making system that can improve its performance by learning how to choose the optimal action from a set of allowed actions through repeated interactions with the random environment. A learning automata has a finite set of actions and each action has a certain probability for getting rewarded by its environment. The aim is to learn to choose the optimal action through repeated interaction with the environment. If the learning algorithm is chosen properly, then the iterative process of interacting on the environment can be made to result in the selection of the optimal action.

One form of learning automata is KSALA [52] which k actions are selected instead of one action. The response of the environment is received in different methods. In the "majority of polls" method, the favorable response is when the effect of *(k/2 +1)* selected actions in the environment have the same response, otherwise, the response is unfavorable.

The interaction between the learning automata and the random environment is shown in figure 2.

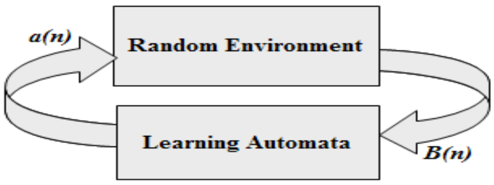


Fig.2. The relationship between learning automata and its random environment [43].

## IV. Proposed Architecture

In this section, we present an architecture for managing the Internet of Things based on cognitive peer-to-peer networks. The structure of the proposed architecture is given in figure 3. This architecture consists of three layers: Requirement Layer (RL), Cognitive Process Layer (CPL) and Things Management Layer (TML).In the requirement layer, the goal and behavior of the network are described by a Cognitive Specification Language (CSL). In the cognitive process layer, the cognitive engine observes the information about the system and then executes appropriate algorithms for managing the system. Note that, we adopted the concepts of RL and CPL from the framework of the cognitive peer-to-peer networks introduced in [19] [59].

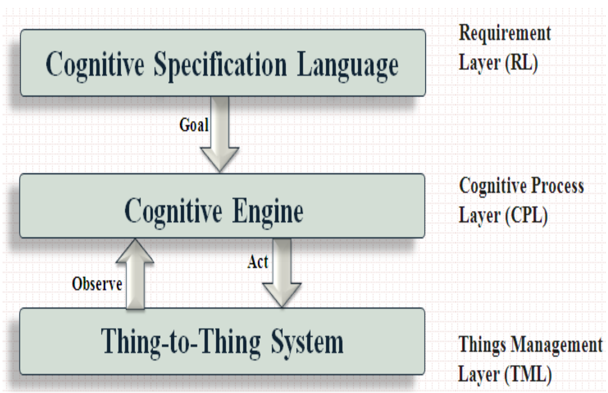


Fig.3. An Architecture for IoT based on cognitive peer-to-peer networks

- **Things Management Layer**

This layer provides required information for the cognitive process layer and then operates on manageable elements of the systems. Figure 4 is shown the structure of this layer. The more detailed explanation of each unit is given in the rest of this section.

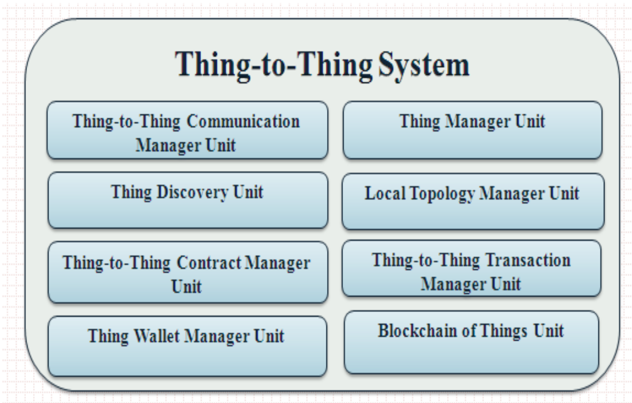


Fig.4. Things Management Layer

- **Thing-to-thing communication manager unit**: in this unit, the peer-to-peer communication protocols are provided for things.
- **Thing manager unit**: in this unit, the properties of things such as power, and protocol stack are managed.
- **Thing discovery unit**: in this unit, a set of peer-to-peer resource discovery algorithms are used to find the appropriate thing.
- **Local topology manager unit**: in this unit, a set of peer-to-peer topology manager algorithms are used to manage the topology of the things.
- **Thing-to-thing contract manager unit**: in this unit, contract among things are executed.
- **Thing-to-thing transaction manager unit**: in this unit, the economic transactions among things are executed.
- **Thing wallet manager unit**: in this unit, a wallet is defined for each thing.
- **Blockchain of Things unit**: In this unit, the hybrid blockchain is utilized for managing things. Brief descriptions about Public, private, and hybrid blockchains are given below [41].
  - **Public Blockchains**: In this type, anyone can join and participate in the network. Bitcoin is one of well-known example for public blockchain [40].
  - **Private Blockchains**: In this type, the write permissions in the system are kept centralized to one organization but Read permissions may be public or restricted. In these systems, key participators are related to the organization which manages the blockchain [42].
  - **Hybrid Blockchains**: In this type, a combination of public and private blockchains is used. This type of blockchain can be used to design

hierarchical blockchain systems for scalable systems required by IoT.

## V. CASESTUDIES

In this section, two algorithms are designated based on the proposed architecture designed in the previous section. First, we focus on resource discovery algorithm and then a topology management algorithm in peer-to-peer systems is investigated.

### A. Resource Discovery Algorithm

In this subsection, we present an adaptive search algorithm which applies KSALA to train the peers in the search procedure. In our algorithm, each peer utilizes KSALA in order to select neighbors. It means that there is a table with k nodes and k probability values of locating objects based on past iterations. According to the feedback from the environment, all the probability values of the current node are updated. In figure 5, the flowchart of our search algorithm is shown. For more details, refer to [50].

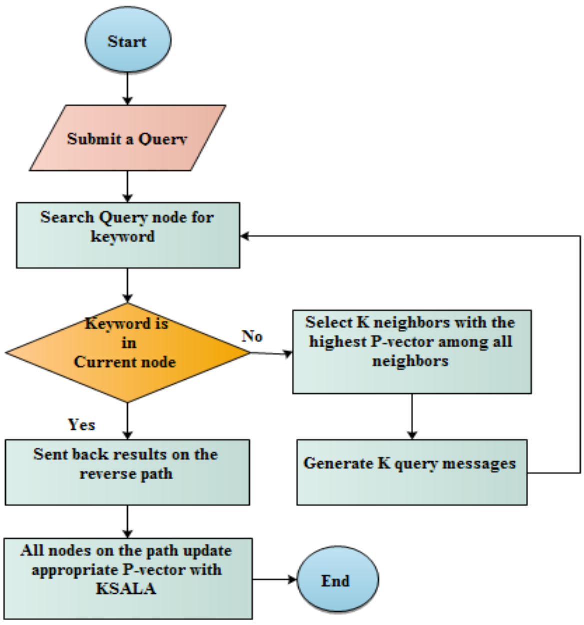


Fig.5. Flowchart of the proposed search algorithm

### B. Topology Management Algorithm

In [53], Khambatti proposes the creation of the communities using the classification based on the users' vector of interest without prioritizing the ones. We propose an adaptive topology management algorithm which each peer uses the learning automata to make a decision regarding its membership in the proposed community at different times. In order to train the peers, being or not being a member of a community is of great importance considering the existing records in the peers' table as well as the activity of the proposed community. The activity of the community means whether the community still exists in the peers' table. Figure 6 describes the phases of our algorithm. Note that, these phases are executed for each recommended group. For more details, refer to [51].

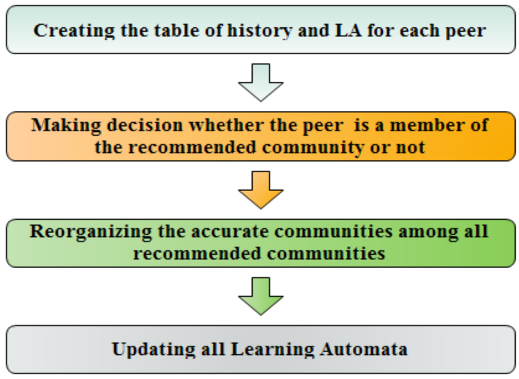


Fig.6. Phases of the proposed topology management algorithm

## VI. SIMULATION

In this section, we describe the simulation environment and present the results of the experimental evaluation of our algorithm.

Oversim simulator [60] is used for the simulation of our two proposed algorithms. Our simulation parameters are similar to [50], [51].

We performed several simulations to obtain the efficiency of our proposed search algorithm. We compare our search algorithm with k-random walks algorithm[54-56], Local Flooding with k Independent Random Walks (LFKIRW) algorithm [57] and Adaptive Probabilistic Search (APS) algorithm [58].To evaluate our proposed topology management algorithm called LATS, we compare that with Khambatti alg. to discover the number of communities selected by each peer to become a member of them and then the effect of scalability of networks is studied.

- *Hit per Query*

The number of discovered objects per query is presented in figure 7. Because in our algorithm the selected walkers always have the highest probability value, it will increase the chance of discovering objects when the query is propagated.

- *Average Messages per Query*

Figure 8 shows the number of produced messages per query under four algorithms. In k-random walks algorithm, about 70% of walkers waste TTL messages. In comparison with the other algorithms, our proposed algorithm produces lower messages per query. It is due to the intelligent selection of walkers during search and accurate TTL consumption in order to deliver messages.

- *Community Discovery by a peer*

As is shown in figure 9, the community discovery percentage through LATS increases after its execution compared to the other method. This increase in the community discovery is due to the more accurate selection of the community by the peer given the calculations of the probabilities in the previous stages of the execution of the algorithm. The community discovery rate was 82% with LATS, while this value was 62% for khambatti_alg.

- *Scalability*

Figure 10, shows the effect of network size on community discovery by all peers. As is shown, increasing the number of nodes has a good effect on the success of community discovery. It means that by increasing the number of nodes, the learning rate of nodes rises and more communities are discovered according to the previous iterations.

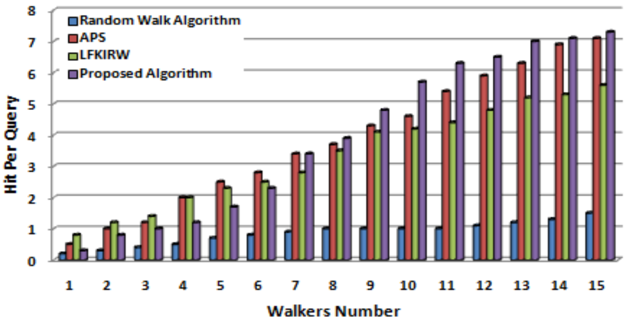


Fig.7. Number of hits per query vs. number of deployed walkers [50]

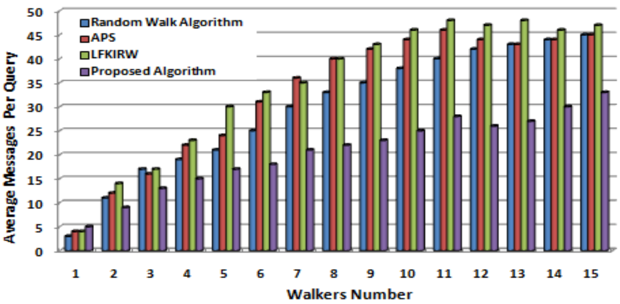


Fig.8. Message per query vs. number of deployed walkers[50]

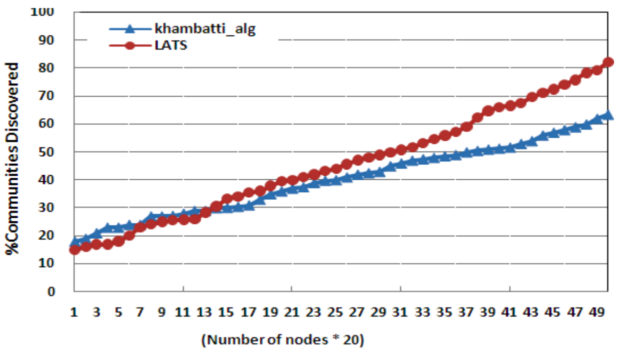


Fig.9. Rate of Communities Discovered by a peer [51]

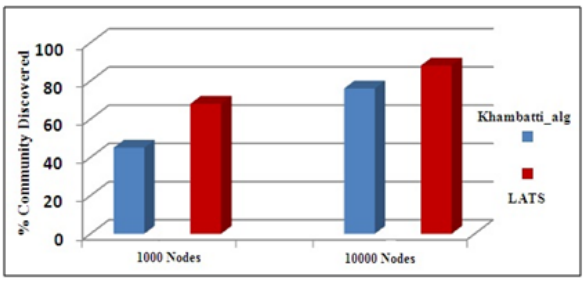


Fig.10. Scalability of network vs. Community discovery

## VII. Conclusion

In this paper, we proposed architecture for managing IoT systems based on cognitive peer-to-peer networks. In order to study the potential of the proposed architecture, it was used to design two management algorithms for two well-known problems: resource discovery and topology management. In the first algorithm, an adaptive mechanism based on learning automata for resource discovery was suggested and the second algorithm is an adaptive mechanism for topology management which uses learning automata. The proposed architecture is able to transfer one-decade knowledge of distributed systems management mechanisms of peer-to-peer systems to IoT based systems.

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