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A Novel Architecture for Cognitive Internet of Things

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Abstract

Internet of Things (IoT) represents the extension and evolution of the Internet, which has great potential and prospects for modern intelligent service and applications. However the current IoT is still based on traditional static architectures and models by our deep investigation. It lacks enough intelligence and cannot comply with the increasing application performance requirements. By integrating cognition into IoT, we present a new concept of Cognitive Internet of Things (CIoT) and its corresponding intelligent architecture. CIoT consists of Protocol Plane, Cognitive Plane and Control Plane modules and involves some novel designed models such as layer protocol stack, three-layer cognitive rings. Based on the proposed CIoT, we finally develop an actual application system to address the transportation and dispatching for ready-mixed concrete. The statistical results show that the new dispatching pattern with CIoT can achieve higher efficiency of transportation and dispatching with lower oil consumption than traditional dispatching pattern.

Keywords: *Cognitive Internet of Things, Cognition, Decision-making, Cooperation, Business Process Logic*

1. Introduction

THE, term Internet of Things (IoT) has first been used byBill Gates in 1995 [1]. MIT promoted the early development of IoT: 1) MIT proposed to give each good a unique numbering based on radio frequency identification (RFID) to realize unique identification in 1998; 2) MIT founded the Center for Automatic Identification Technology (Auto ID Center), proposed the concept of Electronic Product Code (EPC), and established RFID system in 1999 [2]. Subsequently, some famous universities including Cambridge University, Keio University and St Gallen University, joined into researches on EPC, and some international companies including IBM, Intel, and Microsoft declared to supported or joined into those researches [3]. The results of early researches have mainly been used for good's identification to realize automatic management. At this point, the early concept of IoT is rather narrow.

In 2005, the International Telecommunication Union (ITU) released ITU Internet Report 2005 and recommended the concept of IoT. According to ITU report, The IoT can realize the interconnection of thing to thing, which depends on sensors and other equipments. The core of IoT is to achieve interconnection, exchange of information, and communication between things. The definition and scope of IoT have changed and its coverage has been greatly expanded [4].

However, it has not been widely taken notice by academe society before 2009. The CEO of IBM proposed the idea of "smarter planet" which consists of the IoT. US President Obama positively responded to the idea of "smarter planet" and promoted it as a national developing strategy. In August 2009, Chinese Premier Jiabao Wen put forward the concept of "Sensing China", which made the IoT become the national strategy of

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China. Besides, other countries have been carrying out the strategic plans for the development of IoT, for example, the I-Japan strategy 2015 of Japan, the U-Korea strategy of South Korea, and the IoT strategic research roadmap of EU. Thus, the policies of those countries give the world wide concern on the researches and applications for IoT.

In order to catch up with the pace of application, researches related to IoT were widely concerned by academe, especially in IoT architecture, service offering and business processes model. Now, the IoT is proverbially applied in the field of modern service, such as healthcare, smart environments, personal and social, entertainment, transportation and logistics [5-8]. Certainly, it also has wide prospects for future application, such as robot taxi, city information model, and enhanced game room [5]. Usually there is simple decision-making mechanism in IoT for many applications to alleviate or eliminate manual intervention. With the development of application requirement, the intelligence of IoT has been emphasized more and more. After a thorough investigation on the architectures and models of IoT, we believed that the intelligence still cannot satisfy the need of application. Therefore, we proposed a new concept of ***Cognitive Internet of Things(CIoT)*** through integrating cognition into IoT. A CIoT is an IoT with cognitive capability which is integrated to promote performance and achieve intelligence. CIoT can apperceive current business types and network conditions, analyze the perceived information based on the prior knowledge, make intelligent decisions, and perform adaptive and control actions, which aims to maximize network performance and meet the application requirement.

For a new concept, people usually think about two questions: 1) which model we can use to describe it? A model is a formal abstraction of an objective thing and indicates that human has deep cognition about this thing. A descriptive model leads to a further theoretical research on every element of the model and directs the technology activities and engineering practices which produce the new thing; 2) which sites it should be placed in the existing human activity system? Namely, whether there are proper application sites for the new concept or not, because application requirement will deep promote development of objective thing or technology.

This paper focuses on the modeling of CIoT architecture to find a new research idea for IoT as well as an application which be introduced to validate the proposed architecture and indicate that our work will have far broad application prospect and great scientific significance. The remainder of this paper is organized as follows: in section 2, the related work is summarized; in section 3, we propose the architecture for CIoT and explicate it in detail; in section 4, we present an application using the proposed architecture and analyze the application effects; finally, we conclude this paper in section 5.

2. Related Work

As stated above, architecture is the basis for a new kind of network, which guides the technology activities and engineering practices. Thus, researches orienting to IoT architecture have been widely concerned.

Through analyzing the technical framework of the Internet and the logical layer architecture of the Telecommunication Management Network, a new five-layer architecture of IoT was established which is helpful to understand the essence of the IoT [9]. Combining with the EPC global standards, a working model of three-layer for IoT was presented, which consist of the sensing layer, network layer and application layer. Some pressing issues were disused to further promote the practical application of the IoT's architecture, such as the smart nodes optimization, information security and data processing [10]. In [11] a hierarchy of architecture with increasing levels of real-world awareness and interactivity is introduced. In particular, the activity-, policy-, and process aware smart objects are described and how the respective architectural abstractions support increasingly complex application is demonstrated. In those literatures, the architectures of IoT were constructed utilizing traditional layered/hierarchic approach which is applied to Internet. No matter three-layer or five-layer, the diversity between IoT and Internet has not been deep considered in those architectures. So, the architectures cannot meet the applications of IoT ideally.

Some researchers devote to establish architectures of IoT based on the Social Network. Through mapping information, objects and persons which are the major macro elements of human society to Internet, IoT and Social Network, a platform was proposed to cluster the Internet, IoT and Social Network together and promote the development of IoT [12]. Based on the notion of social relationships among objects, a novel paradigm of Social Internet of Things (SIoT) was proposed and a preliminary architecture for the implementation of SIoT was presented [13]. In [14], a future IoT architecture was considered in two aspects: Unit IoT and Ubiquitous IoT. Ubiquitous IoT refers to the global IoT or the integration for multiple Unit IoT with ubiquitous characters. Oriented to special applications, the architecture of Unit IoT was built from man like neural network model. And the architecture of Ubiquitous IoT employs the social organization framework model. Those architectures based on the Social Network are helpful to interpret the relationship between IoT and reality world, but there are still many problems to be resolved before applied.

IoT can be considered as an application extension of Internet. So, the architectures based on Internet look like more reasonable and are paid attention by many researchers. In order to integrate real-world devices to Web, the possible integration methods, in particular how the Representational State Transfer (REST) principles can be applied to embedded devices, were discussed and applied to Sun SPOT platform [15]. In [16], a Web of Things (WoT) architecture and best practices based on the REST principles were described. It makes smart things become an integral part of Web and easier to build upon. Web IoT, a novel web application framework based on Google Web Toolkit, provides users with simple methods for integrating smart things, and enhances the interaction between humans and things or among things [17]. A novel architecture of Sensor Networks for All-IP World (SNAIL) includes a complete IP adaptation method and four significant network protocols: mobility, web enablement, time synchronization, and security. The feasibility and interoperability of the proposed approach were confirmed by the implementation of SNAIL platform [18]. Besides, cognition and decision-making are introduced into IoT applications to improve the intelligence, such as smart community system [6], Health and safety system [11], and other system [7-8].

Cognition has become popular research focuses since Doctor Mitola presented the concept of cognitive radio. Intelligent networks have greatly interested the researchers, and large numbers of achievements have been attained, which greatly promoted the evolution of network intelligence, for example cognitive network [19-20], bio-inspired network [21], autonomic computing system [22-23], and multi-agent network [24]. In this paper, we marry cognitive networks and IoT to present the concept of CIoT, and establish the architecture and models of CIoT. In order to validate the feasibility, we apply the architecture and models to an actual system and analyze the application effect.

3. CIoT Architecture

3.1. Basic Topology and Concepts for CIoT

The concept of IoT includes three meanings. The first is that its core and basis are the Internet and it is a kind of extension of the Internet. The second is that the terminals in IoT are applied to any things that are connected each other by wire or wireless communication through RFID, GPS, laser scanner, infrared sensor and other sensors. The third is that there is a business process flow corresponding to a given application. In our research, we integrate cognition into IoT and present a new concept of CIoT. Besides the three meanings stated above, the concept of CIoT is assigned a new implication namely the intelligence. Cognition can impenetrate any parts of IoT and acts as an important role for a given application. In order to achieve above discussed aims, we propose three important components in CIoT. The figure 1 illustrate CIoT's sketch map of topology.

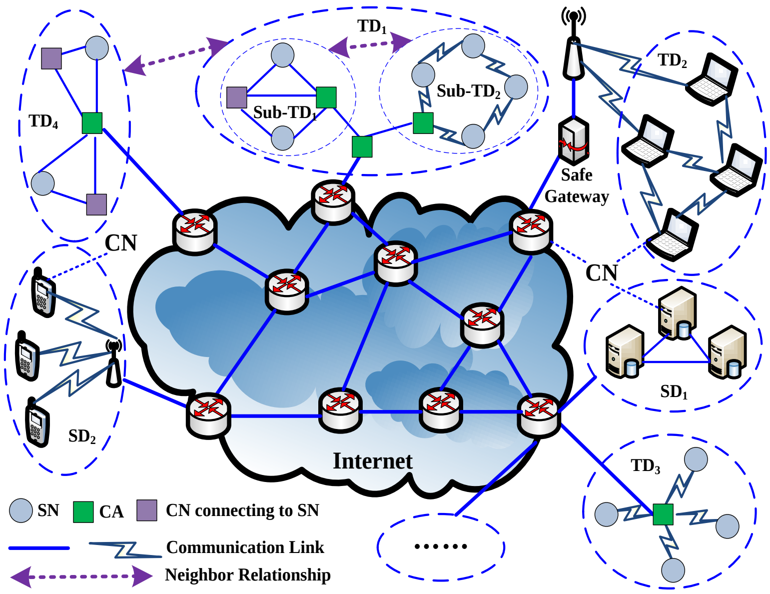

Figure 1. Sketch Map of topology for CIoT

3.1.1. Things Domain: CIoT are grouped into Things Domains (TDs), which are defined as $TD_1, TD_2, TD_3, \cdots, TD_n$ .TDs are high coupled and relatively independent. Each thing with RFID, GPS and various sensors can be regarded as a node in TD. Generally, for an application of CIoT, there is at least one TD. If necessary, a TD can be divided into several Sub-TDs. For example, we can think of the things of a plant as a TD, thus, the things of each workshop can be thought as a Sub-TD (e.g. TD_1, Sub-TD_1 and Sub-TD_2 shown in Fig. 1). The nodes could be divided into two types: Cognitive Nodes (CNs) and Simple Nodes (SNs) according to the capability of nodes. Sub-TD_1

Definition 1: CN refers to the node which has the ability to autonomously perform intelligent actions according to acquired information and prior knowledge, such as perception information merging, routing, and business process decision-making.

CN possesses higher process capability than SN. It acts as decision-making role and establishes the communication between any parts of CIoT. In generally, CNs include computers, servers, routers and other intelligent devices.

Definition 2: SN refers to the node without intelligence and having less process capability than CN. The concept of SN is opposite to the CN.

There are different numbers of CNs in different TDs and maybe only one CN in a TD under special circumstances. If a TD includes multiple CNs, two or more CNs can cooperate to enhance capability according to requirements. Furthermore, two or more TDs can also cooperate if necessary. For example, two workshops of a plant cooperate for one work.

Definition 3: For an application orienting far broad network environment, the cooperation should relate to two or more CNs/TDs, which is called Multi-x Cooperation.

Definition 4: For Multi-x Cooperation, the specific CNs selected to carry out cooperative assignments in a TD are called Cognitive Agents (CAs).

Definition 5: Two TDs with directly cooperative relationship are reciprocally called neighbors, and two TDs with indirectly cooperative relationship in virtue of other TDs are reciprocally called extended neighbors. For example, both TD_1 and TD_4 and Sub-TD_1 and Sub-TD_2 can be called neighbors.

3.1.2. Internet: IoT is a ubiquitous network building on Internet, and its core and basis is the Internet. So, the Internet is still the core and basis of the CIoT. The Internet devotes to the effective transmission of massive information in CIoT.

3.1.3. Servers Domain: For a given application, TDs can apperceive the raw information, but without the capability to deal with it. The information will be sent to server running special routines to be processed. Generally, servers for an application are coupled and fault-tolerance, so, we call them Server Domain (SD). Sometimes, SD may be only an ordinary computer or an intelligent control terminal.

3.2. Patterns of Business Process Logic

Application innovation is the core and basis of IoT development. Therefore, business process logic is very important to CIoT, because there is corresponding business process logic for each application. Generally speaking, there are three kinds of patterns for business process logic, namely Local Control Pattern (LCP), Remote Control Pattern (RCP) and Remote Server Pattern (RSP), which are shown in Fig. 2.

The LCP is the simplest business process logic and is shown in Fig. 2(a). Without the Internet, the CN in a TD receives information from SNs, and sends back the results of decision-making by wire or wireless communication to implement business process logic. The RCP is shown in Fig. 2(b). The CN in a TD receives information from SNs, merges and sends the information to a remote intelligent device (e.g. phone, computer) through Internet, then, receives feedback commands from the remote device and performs the results of decision-making. The remote intelligent device receives information from CN and sends back the results of decision-making to implement business process logic. For example, we can send a command to turn on an air-conditioner by intelligent phone before getting to smart home. The RSP is shown in Fig. 2(c). The functions of CN are same as RCP. The servers of business process receive information from CNs, then, make decision and send the results to CNs to implement business process logic.

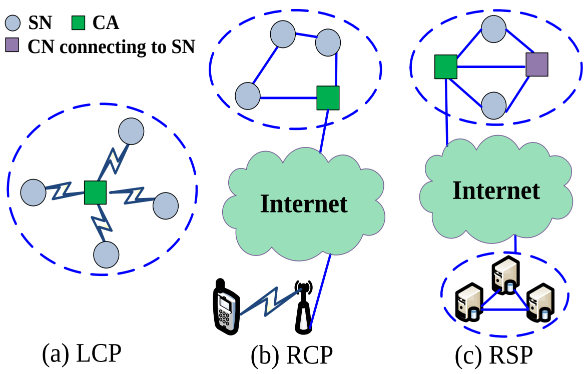

Figure 2. Three Patterns for Business Process Logic

3.3. CIoT's Architecture and Models

Network architecture is the foundations of networks. Based on the CIoT topology, patterns of business process logic and investigations on current proverbial IoT's architectures, we propose a novel three-dimensional CIoT architecture by integrating cognition into IoT.

The three-dimensional architecture is made up of three planes, Protocol Plane, Cognitive Plane and Control Plane, which are shown in Fig. 3. The Protocol Plane is constructed based on the traditional layer architecture. The Cognitive Plane performs the work related to cognition, such as information perception, data analyzing, and decision-making, and generates the commands of actions. The control plane controls the CNs to implement the commands and accomplish the business process logic. Each plane consists of some models, which are respectively discussed as follows.

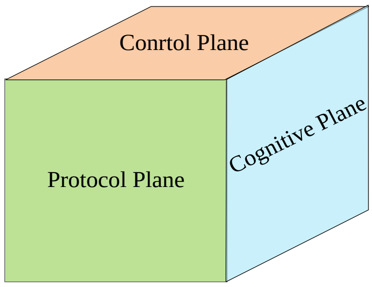

Figure 3. Three-dimensional Architecture for CIoT

3.3.1 Protocol Plane: We add new layer protocol stacks into the traditional layer architecture in CIoT. The new layer protocol stack is shown in Figure 4. The functions of each layer are illustrated as follows.

- Information Perception Layer (IPL): its functions mainly are to collect information, capture and identify things.
- Near Field Interconnection Layer (NFIL): It establishes a transmission channel between SNs and CNs. Its functions mainly are to send data collected from SNs to CNs, or send control commands from CNs to SNs.
- Network Access Layer (NAL): It provides multiform network access and uniform communication platform for CIoT's applications, such as data, voice, and video. Its aim is to support ubiquitous access.
- Network Layer (NL): It is based on the existing communication technology and the Internet. Its functions mainly are to transmit data packets, which is same as the functions of IP layer in TCP/IP protocol.
- Transport Layer (TL): It is also based on the existing communication technology and the Internet. It resolves the reliability of end-to-end and the order receipt of data packets, which is same as the functions of transport layer in TCP/IP protocol.
- Intelligent Service Layer (ISL): It is an interface between CIoT and users (including people, organizations and other systems). It is combined with the industry needs and realizes the intelligent application. The business process logic is very important part of ISL.
- Cross-layer Perception (CLP): It deploys in CNs and collects the network condition information which is provided to Cognitive Plane to support decision-making and optimize network performance.

However, not all nodes in CIoT possess six layers of the protocol stack. Each part in CIoT involves different protocol stack. We respectively discuss them as follows.

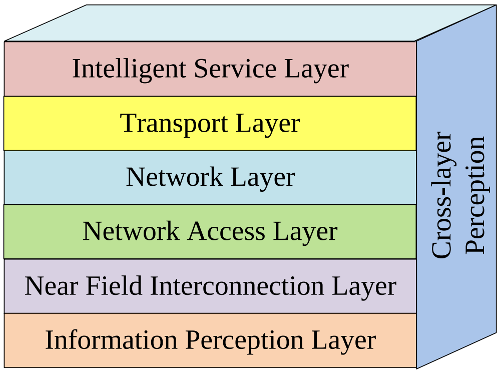

Figure 4. Layer Protocol Stack for CIoT

(1) SNs

SNs are the nodes with RFID, GPS, laser scanner, infrared sensor and other sensors. Their functions are to acquire information and transmit to CNs. Therefore, protocol stack of SNs should include IPL and NFIL, which is shown in Figure 5(a).

(2) CNs Connecting to SNs

The functions of CNs connecting to SNs mainly are to receive information from SNs, transmit business request to other CNs (e.g. servers, phones, computers.), receive feedback, and process/carry out business logic. Thus, protocol stack of CNs connecting to SNs should include NFIL, NAL, NL, TL and ISL, which is shown in Figure 5(b).

(3) Core of Internet

Internet is in charge of transmitting data packets. Thereby, the protocol stack of the core of Internet should include NAL and NL, which is shown in Figure 5(c).

(4) Servers

Servers are responsible for receiving business request from CNs, process business, and send feedback to CNs. Therefore, the protocol stack of servers should include NAL, NL, TL and ISL, which is shown in Figure 5(d).

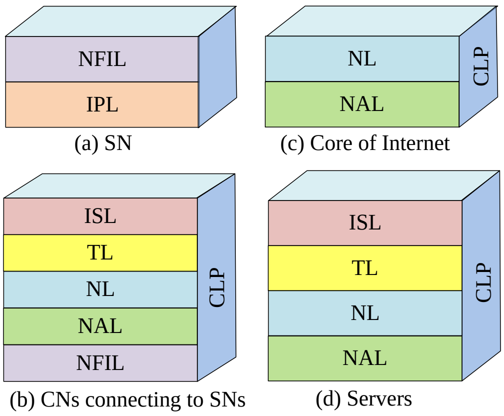

Figure 5. Layer Protocol Stack for Components of CIoT

3.3.2. Cognitive Plane: The Cognitive Plane deals with intelligence of CIoT. There are two kinds of intelligence in CIoT, network transmission and business process. We describe the process of two kinds of intelligence in a uniform model which is called three-layer cognitive rings. The model includes following important designed parts.

(1) Three-layer Cognitive Rings

Intelligence is a newly increased character after integrating cognition into IoT. We propose a uniform process model called three-layer cognitive rings to deal with intelligence. The model is based on the OODA (Observe-Orient-Decide-Act) cognitive ring in the field of cognitive radio network [20]. It is shown in Figure 6.

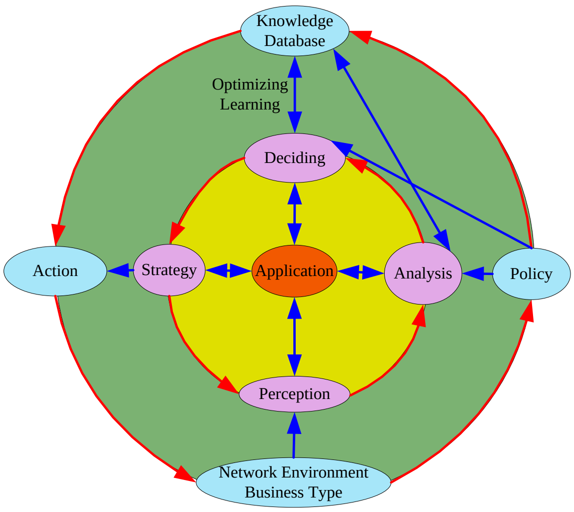

Figure 6. Three-layer Cognitive Rings Model

The model can deal with network transmission and business process in the same process. Firstly, the SNs perceive a great deal of information (network conditions or business type). Secondly, the perception information is sent to CNs to be analyzed and fused by utilizing data fusion theory and knowledge database. If local CN has no adequate capability to deal with current business, the information should be sent to higher level CN to process. Thirdly, the decision-making is performed based on the results of data fusion to generate action strategies (network adjusting command or business control commands), and machine learning theory is adopted to optimize future decision-making. In the process, knowledge database acts as a very important role. Finally, specific actions are performed according to strategies generated by decision-making. The four processes run cooperatively to achieve the application objectives referring to policies, laws, and other prescripts.

(2) Primary Decision-making Process

From the three-layer cognitive rings, we can know that the decision-making is the most important link. Therefore, orienting decision-making, we present a Primary Decision-making Process (PDP) based on the three-layer cognitive rings. The PDP is a basic component for Cognitive Plane, which is usually used to build other more complicated decision-making process and shown in Figure 7. In CIoT, each CN at least maintains a PDP. If necessary, the CN will cooperate with other CNs to acquire more valuable strategy.

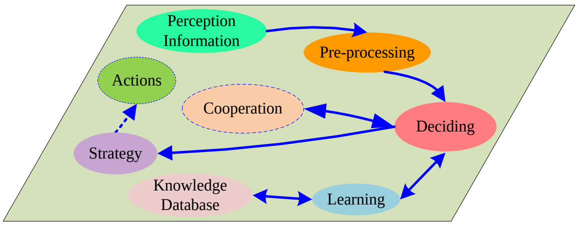

Figure 7. Primary Decision-making Process

(3) Cross-layer Decision-making Model

In the field of cognitive radio, cross-layer design is adopted to promote the efficiency of self-awareness, self-configure, self-optimal, and so on [20]. Accordingly, we introduce cross-layer into CIoT to further optimize the decision-making model of CN based on PDP. A cross-layer cognitive model for CN is acquired and shown in Fig. 8. The cross-layer decision-making model fits to resolve the intelligence of network transmission, but not the intelligence of business process.

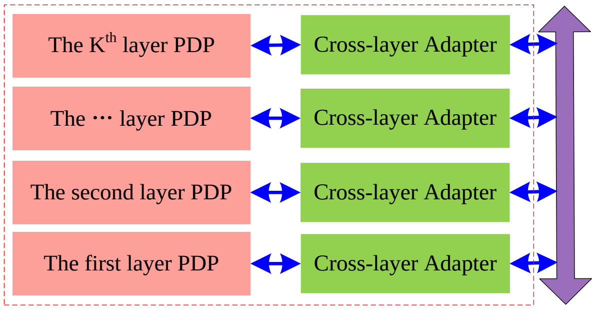

Figure 8. Cross-layer Decision-making Model

From horizontal view, there is a PDP in each layer to carry out the decision-making of relevant layer, which is connected to Cross-layer Adapter. From vertical view, the same link (e.g. Deciding in Figure 7) in PDP realize the same function. From integrated view, the cross-layer model represents a logistic CN.

Whether cross-layer is needed or not will be ascertained by Cross-layer Adapter. Supposing that the set of cross-layer states is $D=\{D_1,D_2,\ \dots,D_n\}$, each element D_i is a specific cross-layer state of K layers. If current time is t_i and cross-layer state is D_i, the cross-layer state D_j of next time t_j is determined by equation (1), and the transition matrix is shown in equation (2).

$$T_{ij}=T\left(D_j=j\,|\,D_i=i\right) \tag{1}$$

$$T=\begin{pmatrix} T_{11} & T_{12} & T_{1\cdots} & T_{1n} \\ T_{21} & T_{22} & T_{2\cdots} & T_{2n} \\ T_{\cdots 1} & T_{\cdots 2} & T_{\cdots\cdots} & T_{\cdots n} \\ T_{n1} & T_{n2} & T_{n\cdots} & T_{nn} \end{pmatrix} \tag{2}$$

(4) Cooperative Mechanism for Multi-x

Cognition has promoted the revolution from IoT to CIoT, and cooperation can improve the efficiency and intelligence of decision-making. In this section, we highlight cooperative mechanism for multi-x based on neighbor relationship matrix of TDs and game theory.

(A) Neighbor Relationship Matrix for TDs

We suppose that the set of TDs is $S=\{1,\ 2,\ ...,n\}$, and $\overline{R_{n\times n}}=\{\overline{R_{ij}}\}$ denotes the neighbor relationship matrix for TDs. Therefore,

$$\overline{R_{n\times n}}=\begin{pmatrix} \overline{R_{11}} & \overline{R_{21}} & \overline{R_{\cdots 1}} & \overline{R_{n1}} \\ \overline{R_{21}} & \overline{R_{22}} & \overline{R_{2\cdots}} & \overline{R_{2n}} \\ \overline{R_{\cdots 1}} & \overline{R_{\cdots 2}} & \overline{R_{\cdots\cdots}} & \overline{R_{\cdots n}} \\ \overline{R_{n1}} & \overline{R_{n2}} & \overline{R_{n\cdots}} & \overline{R_{nn}} \end{pmatrix} \tag{3}$$

Among $\overline{R_{n\times n}}$, if $\overline{R_{ij}}=\bar{0}$, $\overline{R_{ij}}$ is a zero vector which expresses that TD_j is not a neighbor of TD_i. If $\overline{R_{ij}}\neq\bar{0}$, $\overline{R_{ij}}$ is a k-dimensional vector $\overline{R_{ij}}=[r_1,r_2,\cdots,r_m,\cdots,r_k]$, any elements r_m of which denotes that the neighbor r_m of TD_j is the extended neighbor of TD_i. Subscript k denotes TD_j's number of neighbors who are the extended neighbors of TD_i.

Performing matrix transformation on equation (3), we can obtain a sub-matrix indicated by equation (4). For a given application, we give two decision conditions indicated by equation (4), (5) and (6): 1) If cooperation is necessary, the cooperation of those TDs which meet the equation (4) and (5) is considered priorly; 2) the cooperation of those TDs which meet the equation (4) and (6) is never considered. Here, equation (5) expresses that "logic and" of all elements for sub-matrix $\bar{A}$ is not a $\bar{0}$, and equation (6) expresses that "logic or" of all elements for sub-matrix $\bar{A}$ is a $\bar{0}$.

$$\bar{A}=\begin{pmatrix} \overline{A_{11}} & \overline{A_{21}} & \overline{A_{\cdots 1}} & \overline{A_{n1}} \\ \overline{A_{21}} & \overline{A_{22}} & \overline{A_{2\cdots}} & \overline{A_{2n}} \\ \overline{A_{\cdots 1}} & \overline{A_{\cdots 2}} & \overline{A_{\cdots\cdots}} & \overline{A_{\cdots n}} \\ \overline{A_{n1}} & \overline{A_{n2}} & \overline{A_{n\cdots}} & \overline{A_{nn}} \end{pmatrix} \tag{4}$$

$$\overline{A_{11}}\wedge\overline{A_{12}}\wedge\cdots\wedge\overline{A_{1t}}\wedge\overline{A_{21}}\wedge\overline{A_{22}}\wedge\cdots\wedge\overline{A_{2t}}\wedge\cdots\wedge\overline{A_{s1}}\wedge\cdots\wedge\overline{A_{st}}\neq\bar{0} \tag{5}$$

$$\overline{A_{11}}\vee\overline{A_{12}}\vee\cdots\vee\overline{A_{1t}}\vee\overline{A_{21}}\vee\overline{A_{22}}\vee\cdots\vee\overline{A_{2t}}\vee\cdots\vee\overline{A_{s1}}\vee\cdots\vee\overline{A_{st}}=\bar{0} \tag{6}$$

(B) Cooperative Model for Multi-x

The game theory was commonly used in modeling cooperation of multi-participants [25]. In CIoT, cooperation of CNs/TDs is the very important for the business process. In this section, we address this problem based on game theory.

In a particular period of time, if one CN/TD cannot meet the requirement of application, multi-x cooperation will be considered in far broad network environment.

We assume that the set of cooperative CNs/TDs is S = {1, 2, …, n}. In order to avail discussion, we regard a CN as a special TD, so each element of S is a TD. The power set of S is G = {G_1, G_2, …, G_i, …, G_m} = {Φ, {1}, {1,2}, …, {1, 2, …, n}}. Each element G_i is called a cooperative group. For example, the TD_1 and TD_4 in Fig.1 are a cooperative group.

Based on neighbor relationship matrix, if Gi can be expressed by equation (4) and (5), we call Gi Fixed Cooperative Group (FCG); analogously, if G_i can be expressed by equation (4) and (6), we call G_i Non-Cooperative Group (NCG); in other conditions, we call G_i Dynamic Cooperative Group (DCG). Obviously, FCG and DCG are useful for our researches, and we call them Effective Cooperative Groups (ECG).

We think of the multi-x cooperation as cooperative games *GAME* = <*S*, *m*>. Here, *m* is the mapping form $2^S=\{G_i\,|\,G_i\subseteq S\}$ to the set of real numbers RS. Assuming that the expecting cooperative payoffs of $TD_j \in G_i$ is $u_j(G_i)$, the payoffs of G_i is $v(G_i)$ shown in equation (7), and system total payoffs $v(S)$ is shown in equation (8). The effective payoffs of TDs can be denoted in a vector $P = (P_1, P_2, \ldots, P_n)$ which is called Payoff Vector and shown in equation (9).

$$v(G_i)\begin{cases} < \sum_{j=1}^{t} u_j(G_i),\ G_i \in \mathrm{NCG} \\ \geq \sum_{j=1}^{t} u_j(G_i),\ G_i \in \mathrm{ECG} \\ >> \sum_{j=1}^{t} u_j(G_i),\ G_i \in \mathrm{FCG} \end{cases} \tag{7}$$

$$v(S) \geq \sum_{i=1}^{m} v(G_i) \tag{8}$$

$$P_i = \sum_{j=1}^{m} u_i(G_j) \tag{9}$$

In equations (7), (8) and (9), t denotes the number of TDs in G_i and m denotes the number of cooperative group. Element P_i denotes the increment of specific capability of TD_i.

It is difficult to find an "optimum solution", because there are various combinatorial mode and intricate logic relationship between TDs. But, it is possible to acquire an "acceptable solution" to meet the requirement of application for multi-x cooperation. Therefore, we need to establish proper ECG to achieve acceptable payoffs. Supposing that ECG = {ECG_1, ECG_2, …, ECG_u} is a set of ECGs, there is a unique function φ which can make sure of the combinatorial mode of TDs as in equation (10) and (11).

$$\varphi_i[v] = \sum_{i=1,\, j=1}^{n,u} \gamma_n(ECG_j) \times [v(ECG_j) - v(ECG_j - \{i\})] \tag{10}$$

$$\gamma_n(ECG_j) = \frac{(|ECG_j| - 1)!\ \times\ (n - |ECG_j|!)}{n!} \tag{11}$$

Among them, n denotes the number of cooperative TDs, and u denotes the number of ECG. $|ECG_j|$ denotes the number of TDs in ECG_j, $\gamma_n(ECG_j)$ expresses weighted factor of each ECG_j, and $[v(ECG_j) - v(ECG_j - \{i\})]$ can be considered as the payoffs that TD_i contributes to ECG_j. If equation (10) and (11) are met, both TDs and ECGs can obtain positive payoffs.

That is to say, the construction of perfect ECGs is the precondition to achieve "acceptable solution" for multi-x cooperation. Obviously, any one of ECGs should at least be a DCG, but it is better for a FCG. Therefore, for cooperation, we seek the cooperative relationship of multi-x from G to acquire the ECGs as perfectly as possible.

The cooperative mechanism can be used to improve the intelligence both network transmission and business process. In each circumstance, what is stated above only devotes to construct perfect ECGs and ensure that the ECGs bring positive payoffs. The cooperative approach and its algorithm should be discussed uniting specific CIoT applications.

3.3.3 Control Plane: Control Plane focuses on the reality problems of CIoT. There are two meanings in Control Plane. The first one relates to effective transmission of network. CIoT can generate network actions strategies (e.g. modifying protocol parameters, changing logic connection, replacing protocol) through intelligent decision-making. However, who and how to perform the strategies? It is one focus of Control Plane. The network actions strategies can be performed through configurable protocol components which can be designed based on component technology [26-27]. The further discussion for this is out of the emphasis of this paper. The second one relates to business process of CIoT application. CIoT can generate actions strategies (e.g. operation commands, control flow.). However, who and how to perform the strategies? It is another focus of Control Plane. We illuminate this issue in section 4 combining with an actual application.

4. Application Example and Analysis

In order to validate the feasibility of proposed architecture and its corresponding models, we apply them to an actual system, Ready-mixed Concrete Transportation and Dispatching System (RmCTDS). The application analysis and application prospective are also discussed in this section.

4.1 Introduction of RmCTDS

Ready-mixed concrete is a kind of special building material with some rigorous restrictions, such as raw material, recipe, production flow, time of validity (no more than 4 hours generally). Therefore, ready-mixed concrete can be regarded as a large-scale application system of CIoT in practical. It has a supply chain form raw materials (e.g. sands, gravels, concretes.) to termination products (e.g. bridge, roadway, building.). RmCTDS is a subsystem and only responsible for the transportation and dispatching of ready-mixed concrete which is transmitted by Ready-mix Truck (RmT). The sketch map of application scene for RmCTDS is shown in Figure 9. Here, A and B denote the origin of ready-mixed concrete; C, E and G denote the construction site of buildings; D denotes the construction site of overpass; and F denotes the construction site of roadway.

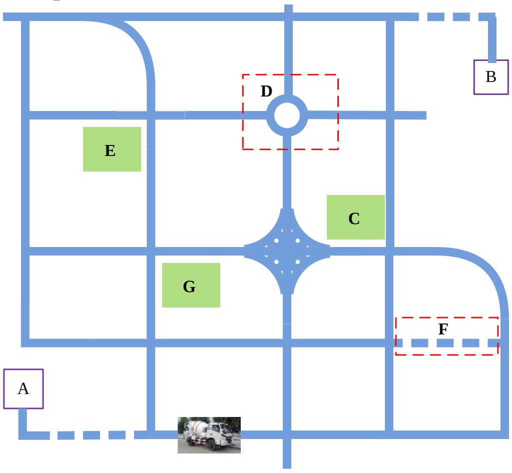

Figure 9. Sketch Map of Application Scene for RmCTDS

The RmCTDS mainly includes some components shown as follows.

- RFID: identifying RmT.
- RFID reader: reading the RFID information and sending it to server.
- GPS: acquiring position information of RmT.
- Vehicle module: integrating RFID, GPS, LCD display and GPRS, sending information from RmT to Server, receiving information from server.
- Digital scale: weighting the RmT.
- Digital scale reader: obtaining the reading of digital scale and sending it to server.
- Server: running various service routine, such as dispatching routine, path choice routine, recording routine.

The functions of RmCTDS mainly include three aspects. The first one is to dispatch RmT to carry ready-mixed concrete from origin to destination. The second one is to choose the optimal path and ensure RmT arriving at the destination as soon as possible. The last one is to save the transport records to support for quality tracking. Where, some transmission technologies are needed [28-32]. Along the flow from origin to destination, the main process steps of RmCTDS are shown as follows.

Step 1: dispatching routine generates the transport commands and sends to RmT according to order form, RmT's attributes, output, etc.

Step 2: RmT receives transport command and gets to origin to load ready-mixed concrete. The correlative information is perceived and sent to servers, such as RFID, digital scale reading, and current time.

Step 3: path choice routine acquires an optimal path (i.e. the shortest time first) based on Dijkstra algorithm according to the information received and traffic conditions obtained from the transportation department or other approaches, and sends it to RmT.

Step 4: RmT receives the path command and runs along the path. It will receive again and again the path command on the road repeatedly.

Step 5: when arriving at destination, the RmT sends the current time to server by GPRS.

Step 6: the server receives the time information and save it.

4.2 Analysis of Models for RmCTDS

We develop the RmCTDS based on the proposed architecture of CIoT. The instantiated models are discussed in details as follows.

(1) SNs

There are three types of SNs in RmCTDS. The first is RFID fixed on RmT to identify RmT. The second is digital scale to weigh the RmT. The third is GPS fixed on RmT to position RmT.

(2) CNs Connectiong to SNs

There also are three types of CNs connecting to SNs in RmCTDS. The first is RFID reader fixed on origin and destination to read RFID and send it to server. The second is digital scale reader to obtain the reading of digital scale and send it to server. The third is vehicle module to send information from RmT to server, and receive information from server.

(3) Servers

There are several servers to run dispatching routine, path choice routine, recording routine, etc. The servers are extensible along with the development of business.

(4) Pattern of Business Process Logic

The pattern of business process logic is relative simple. The CNs receive information from SNs, merges and sends the information to servers through Internet. Then, servers receive information from CNs and make decision according to business logic (dispatching, path choice, etc.), and send back the results of decision-making to CN, which is shown in Figure 10.

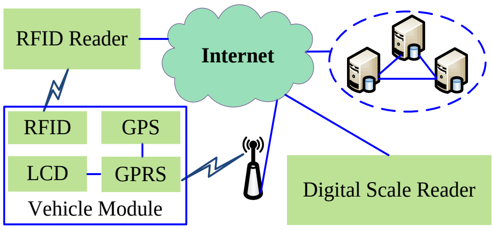

Figure 10. Business Process Logic for RmCTDS

There are two kinds of intelligent decision-making in RmCTDS, RmT dispatching and path choice. The RmT dispatching create scheduling strategies which is a vector <ID, Product ID, Weight, Origin, Destination, Loading Time, Arriving Time> according to order form, product, attributes, output, etc. Here, ID identifies RmT; Product ID identifies various kinds of ready-mixed concrete; Weight denotes load; Origin denotes A or B; Destination denotes C, D, E, F or G; Loading Time refers to the inferior limit of loading; and Arriving Time refers to the inferior limit of arriving. The intelligent decision-making algorithm, knowledge database and machine learning are used in RmT dispatching. Besides, the cooperation of origin A and B is considered in emergency situations. The path choice calculates the optimal path according to traffic conditions, origin, destination, etc. The Dijkstra algorithm, knowledge database and machine learning are used in path choice.

4.3 Performance Analysis for RmCTDS

In order to test the efficiency of RmCTDS, we respectively record the driving time, oil consumption and distance of running from A to G and from A to D 100 times in traditional dispatching pattern and in RmCTDS dispatching pattern under the close same circumstance.

The distributions of driving time are shown in Figure 11 and Figure 12. In the figures, horizontal ordinate denotes the driving time and vertical ordinate denotes the number of RmT arriving. In order to avail calculation, we regard five minutes as a statistical unit. That is to say, if the driving time is from 32.5 minutes to 37.5 minutes, we regard it as 35 minutes. It can conclude form the Figure 11 and Figure 12 that the distribution of driving time in RmCTDS dispatching pattern is more convergent than in traditional dispatching pattern.

We can deduce equation (12) to calculate the average driving time based on Figure 11 and Figure 12.

$$\overline{T} = \frac{\sum x \times y}{\sum y} \tag{12}$$

In equation (12), x denotes the driving time for RmT, y denotes the number of RmT corresponding to driving time x, and $\overline{T}$ denotes the average driving time. By calculating, the average driving time from A to G is 61.8 minutes in traditional dispatching pattern and 53.95 minutes in RmCTDS dispatching pattern, and the decline of average driving time is 12.7%; the average driving time from A to D is 71.4 minutes in traditional dispatching pattern and 61.85 minutes in RmCTDS dispatching pattern, and the decline of average driving time is 13.4%. That is to say, the driving time form origin to destination in RmCTDS dispatching pattern is less than the driving time in traditional dispatching pattern.

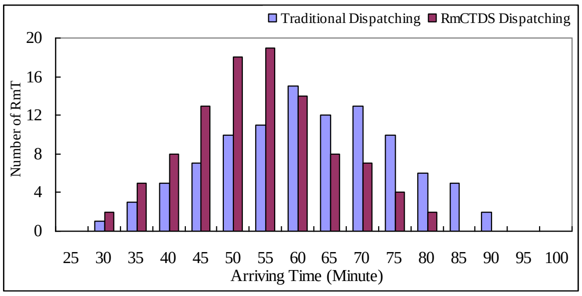

Figure 11. Distribution of Driving Time from A to G

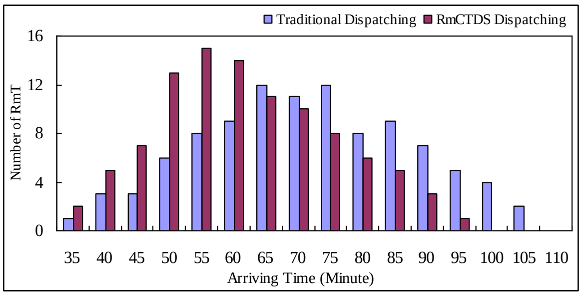

Figure 12. Distribution of Driving Time from A to D

Besides, relative to the traditional dispatching pattern, we can derive two other conclusions from the statistical data: 1) the oil consumption in RmCTDS dispatching pattern decreases 5.1% (from A to G) and 5.9% (from A to D); 2) the distance of running in RmCTDS dispatching pattern increases 9.8% (from A to G) and 10.6% (from A to D).

For RmCTDS, the experiments results show that the distance of running increases, however the oil consumption and driving time decrease. This is because that path choice is inclined to select unimpeded road, which reduces the times of RmT starting and makes RmT run smoothly. Thus, oil consumption and driving time decrease despite distance of running increasing.

4.4 Future Prospect of RmCTDS

The business process logic is essential to CIoT, and it influences the development of CIoT applications. For RmCTDS, if the business process logics are consummated and heavy overhead, we can provide a cloud-based service pattern, which can serve all companies related to ready-mixed concrete. That is to say, we can provide a kind of service pattern combing cloud computing and CIoT. Further to say, we can integrate the companies of ready-mixed concrete supplying chain, such as concrete factories, ready-mixed concrete companies, transportation companies, construction companies, developers, project management departments, into a system to provide more perfect service. It also is the future prospect of CIoT.

5. Conclusion

IoT is a heterogeneous and mixed ubiquitous network, which has been widely applied in the field of modern intelligent service. However, the current IoT significantly lacks intelligence and cannot meet the application requirement. In this paper, we address this problem through integrating cognition into IoT, and present the CIoT and its architecture and models. We introduce the design of CIoT architecture and detail the models such as layer protocol stack, three-layer cognitive rings, primary decision-making process, cross-layer decision-making model, and cooperative mechanism for multi-x. Finally, in order to validate the architecture and models of CIoT, we develop an actual application RmCTDS which shows that CIoT is very effective for applications of modern intelligent service.

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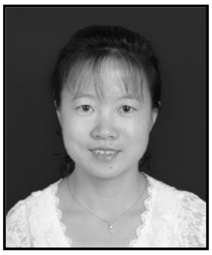

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