Cognitive Internet of Things: Concepts and Application Example

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Abstract
Internet of Things (IoT) is a heterogeneous, mixed and uncertain ubiquitous network, the application prospect of which is extensive in the field of modern intelligent service. Having done a deep investigation on the discrepancies between service offering and application requirement, we believed that current IoT lacks enough intelligence and cannot achieve the expected increasing applications' performance. By integrating intelligent thought into IoT, we presented a new concept of Cognitive Internet of Things (CIoT) in this paper. CIoT can apperceive current network conditions, analyze the perceived knowledge, make intelligent decisions, and perform adaptive actions, which aim to maximize network performance. We modeled the CIoT network topology and designed cognition-process-related technologies, analyzed the payoffs of cooperative cognition based on game theory, which illustrates those novel designs can endows IoT with intelligence and fully improve system's performance. Finally, an application example was introduced based on the concept of CIoT.
Keywords: *Cognitive Internet of Things; Cognition; Cross-layer; Muiti-domain; Cooperation.*

1. Introduction

As a booming network, the Internet of Things (IoT) is proverbially applied in the field of modern intelligent service, such as ecological protection, energy conservation & emission reduction, food security, etc. In order to catch up with the pace of application, researches related to IoT were widely concerned by academe, especially in network architecture, service offering and intelligent features.

In the field of architecture, Social Network architectures were paid close attention to by researchers. Several distinctive architectures were achieved[1-2], some of which could satisfy the need of heterogeneous terminals, generous identifications, network interconnection and object position, and obtain the high robustness and stability simultaneously. Oriented to the special application environment, the diverse network architectures and corresponding protocols were proposed to provide ubiquitous services and access modes, as well as to achieve flexibility and scalability[3-4]. By analyzing the defects of TCP/IP protocols, a hierarchical architecture was obtained to meet specific circumstances [5].

Those achievements established the basic network architecture for IoT, though the corresponding international standard was still not constituted. With the development of further researches, functional and ministrant characteristics of IoT became explicit gradually. After a thorough investigation on the discrepancies between service offering and application requirement, we believed that the intelligence still cannot satisfy the need of application. Therefore, we proposed the concept of ***Cognitive Internet of Things (CIoT)*** through integrating intelligent thought into IoT. A CIoT is an IoT with cognitive and cooperative mechanisms which are integrated to promote performance and achieve intelligence. CIoT can apperceive current network conditions, analyze the perceived knowledge, make intelligent decisions, and perform adaptive actions, which aim to maximize network performance. In the cognitive process, the multi-domain cooperation can increase network capacity and the machine learning can enhance the intelligence for future.

In recent years, cognition and cooperation have become popular research focuses. Since Doctor Mitola presented the concept of cognitive radio[6], cognitive radio network[7-8] and cognitive network[9-11] have greatly interested the researchers, and large numbers of achievements have been attained, which greatly promoted the evolution of network intelligence. In those researches, the cooperative thought was often adopted to address intelligence and performance for asynchronous network[12], multi-user network[13], multi-agent network[14], autonomous multi-hop networks[15], bio-inspired network[16], autonomic computing system[17-18] and other networks[19]. Besides, cross-layer design[20] and game theory[21] were introduced to improve efficiency and optimize performance.

Those literatures accelerated the development of network intelligence. However, few researchers oriented to the intelligence of IoT. This paper focuses on the modeling and design of cognitive process for CIoT to find a new research idea. Our work will have far broader application prospect and great scientific significance.

2. System Models

Our researches build on the network topology of CIoT whose sketch map is shown in Fig. 1. It includes core network and various access network domains. The core network is mainly made up of access router, wireless router, transmission router, etc. The access network domains include cognitive nodes, simple nodes and various terminals. The meanings of some components are illustrated as follows.

2.1 Basic Concepts

Autonomous Domain (AD): it is an access network domain with autonomy and one of the following features.

- A high coupled and relative independent domain;
- A domain with distinct geographical feature;
- A network for organization, company, enterprise, etc;
- Specially, autonomic devices in core network.

If necessary, an AD can be divided into several Sub-ADs. For example, we can think of the campus network as an AD. Thus, the networks of institutes and departments can be thought of as Sub-ADs.

Cognitive Node: it also called **Cognitive Element (CE)**, refers a node which has the ability to autonomously optimize network performance according to current conditions.

Simple Node (SN): it refers to a node without intelligence, which is relative to the cognitive node.

There are different numbers of CEs in different ADs, maybe only one under the special circumstances. If there are multi CEs in an AD, two or more CEs can cooperate according to requirements.

Multi-domain Cooperation (MDC): for an application oriented to far broader network environment, the cooperative process of two or more ADs is called MDC.

Cognitive Agent (CA): for a MDC, it refers the specific CEs selected from each domain to carry out cooperative assignments. There is different number of CAs in different domains, maybe only one.

Neighbor: Two ADs with directly cooperative relationship are reciprocally called neighbors, and two ADs with cooperative relationship in virtue of other ADs are reciprocally called extended neighbors.

In CIoT, without artificial interventions, ADs divided, CAs selected and multi-domain cooperated are implemented autonomously. Some models based on Fig. 1 are given as follows.

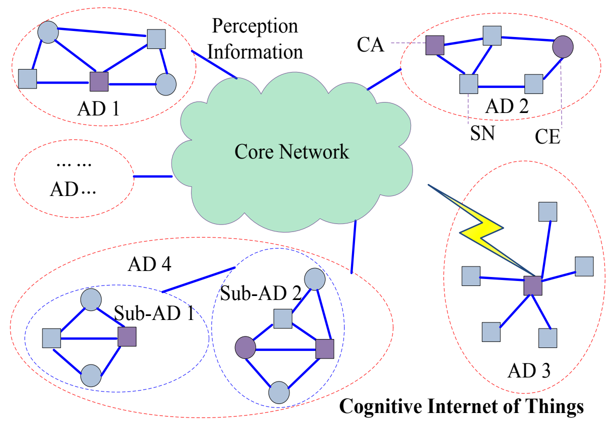

Fig. 1 Sketch map of topology for CIoT.

2.2 Neighbor relationship matrix for ADs

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

$$\overline{R_{n\times n}} = \begin{pmatrix} \overline{R_{11}} & \overline{R_{12}} & \overline{R_{1\cdots}} & \overline{R_{1n}} \\ \overline{R_{21}} & \overline{R_{22}} & \overline{R_{2\cdots}} & \overline{R_{2n}} \\ \overline{R_{\cdots 1}} & \overline{R_{\cdots 2}} & \overline{R_{\cdots\cdots}} & \overline{R_{\cdots n}} \\ \overline{R_{n1}} & \overline{R_{n2}} & \overline{R_{n\cdots}} & \overline{R_{nn}} \end{pmatrix} \quad (1)$$

In (1) $\overline{R_{n\times n}}$, if $\overline{R_{n\times n}} = \overline{0}$, $\overline{R_{ij}}$ is a zero vector, which expresses that AD$_j$ is not a neighbor of AD$_i$. If $\overline{R_{n\times n}} \neq \overline{0}$, $\overline{R_{ij}}$ is a k-dimensional vector $\overline{R_{ij}} = [r_1, r_2, \cdots, r_m, \cdots, r_k]$, a component r_m of which expresses that the neighbor r_m of AD$_j$ is the extended neighbor of AD$_i$. Subscript k denotes the number that neighbors (or extended neighbors) of AD$_j$ is extended neighbors of AD$_i$.

Performing matrix transformation on (1), we can obtain a sub-matrix (2). If (2) meets (3), $\overline{A}$ is called tight neighbor matrix. If any one of cooperative ADs is in $\overline{A}$, the cooperation within $\overline{A}$ will be considered priorly. Analogously, if (2) meets (4), $\overline{A}$ is called non-neighbor matrix. If any one of cooperative ADs is in $\overline{A}$, the cooperation within $\overline{A}$ will not be considered.

$$\overline{A}=\begin{pmatrix} \overline{A_{11}} & \overline{A_{12}} & \overline{A_{1\cdots}} & \overline{A_{1t}} \\ \overline{A_{21}} & \overline{A_{22}} & \overline{A_{2\cdots}} & \overline{A_{2t}} \\ \overline{A_{\cdots 1}} & \overline{A_{\cdots 2}} & \overline{A_{\cdots\cdots}} & \overline{A_{\cdots t}} \\ \overline{A_{s1}} & \overline{A_{s2}} & \overline{A_{s\cdots}} & \overline{A_{st}} \end{pmatrix} \quad (2)$$

$$\overline{A_{11}} \wedge \overline{A_{12}} \wedge \cdots \wedge \overline{A_{1t}} \wedge \overline{A_{21}} \wedge \overline{A_{22}} \wedge \cdots \wedge \overline{A_{2t}} \wedge \cdots \wedge \overline{A_{s1}} \wedge \cdots \wedge \overline{A_{st}} \neq \overline{0} \quad (3)$$

$$\overline{A_{11}} \vee \overline{A_{12}} \vee \cdots \vee \overline{A_{1t}} \vee \overline{A_{21}} \vee \overline{A_{22}} \vee \cdots \vee \overline{A_{2t}} \vee \cdots \vee \overline{A_{s1}} \vee \cdots \vee \overline{A_{st}} = \overline{0} \quad (4)$$

2.3 Network Performance Objective(NPO)

The NPO is the pilot light to adjust network macroscopically. Suppose that the NPO of CIoT is $\overline{NPO}=\left[\overline{O_1},\overline{O_2},\cdots,\overline{O_i},\cdots,\overline{O_n}\right]$, $\overline{O_i}$ denotes the local NPO for AD_i. $\overline{O_i}=\left[o_1,o_2,\cdots,o_j,\cdots,o_m\right]$ is a vector, and a component o_j expresses a sub-NPO for AD_i. Different ADs possesses different numbers and contents of NPO, and network needs to meet diverse NPO under various application circumstances. When cognition was carried out, both QoS and NPO should be considered. In some circumstances, QoS should be met priorly, and in other circumstances, NPO will be more important.

2.4 Network capability and network load

For a given domain, Network Ability (NA) refers to the capability that network can deal with business, and Network Capacity (NC) refers to the volume of business that network can accepted in a specific period of time. *NA* = [*NC*, *B*, *T*, *D*, *S*, *PLP*] is a sextet-set, *NC* denoting Network Capacity, *B* denoting bandwidth, *T* denoting throughput, *D* denoting delay, *S* denoting security level, and *PLP* denoting packet loss probability.

Network Load (NL) is the volume of business that network is taking on in a specific time. *NL* = [*NC*, *B*, *T*, *D*] is a quadruple, and the significations of *NC*, *B*, *T* and *D* are the same as in *NA*.

For a business expected to enter network, if $NA \doteq NL \succ QoS$, the business is permitted to enter network. If $NA \doteq NL \prec QoS$, the business is forbidden to enter the network, and cognition and cooperation should be performed. Here, $NA \doteq NL \succ QoS$ expresses that the network can meet the QoS of business expected to enter network, and $NA \doteq NL \prec QoS$ expresses that the network cannot meet the QoS of business expected to enter network.

3. Design of Cognitive Process

The cognition is the foundation to achieve intelligence of CIoT. For that, we proposed Three-dimensional Network Architecture (TNA), Three-layer Cognitive Rings (TCR) and cooperative mechanism. The TNA provides the basic network framework, and TCR and cooperative mechanism addresses the cognitive process.

3.1 Three-dimensional Network Architecture

Network architectures are the foundations of networks. There being no international standard, a TNA for CIoT is proposed by integrating cognitive thought into IoT based on the current proverbial architecture of IoT in international academe. It is made up of three planes, Protocol Plane (PP), Cognitive Plane (CP) and Adjusting Plane (AP), which are shown in Fig. 2. The PP includes four layers, Information Perception Layer (IPL), Network Interconnection Layer (NIL), Information Fusion Layer (IFL) and Intelligent Service Layer (ISL) by referring to traditional ISO/OSI architecture. The CP perceives current network conditions, and then performs analysis and decision-making to acquire strategies which can enhance the performance of CIoT. The AP implements adjusting actions according to the strategies generated by CP. Our research mainly focuses on CP in this paper.

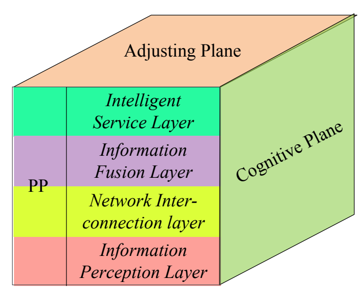

Fig. 2 Three-dimensional network architecture.

3.2 Three-layer Cognitive Rings

The functions of autonomic cognition and intelligent service are newly increased after integrating intelligent thought into IoT. The intelligent cognition is about the internal running level, and the intelligent service is about the external behavior level. Aiming at the internal running level, we propose TCR based on the OODA (Observe-Orient-Decide-Act) cognitive ring in the field of cognitive radio network, which are shown in Fig. 3.

Firstly, the TCR perceive a great deal of heterogenous network conditions information. Secondly, the conditions information is analyzed and fused utilizing data fusion theory. Thirdly, the decision-making is performed based on the results of data fusion to achieve strategies of network behaviors, and machine learning theory is adopted to optimize future decision-making. Finally, network adjusting is executed according to strategies generated by decision-making. The four process run cooperatively to achieve the network performance objectives referring to policies, laws, and other prescripts etc.

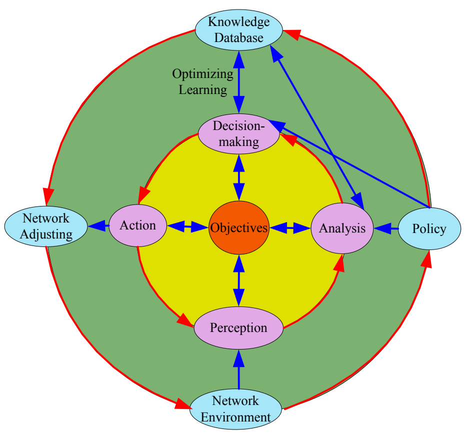

Fig. 3 Three-layer cognitive rings for CIoT.

We abstracted the TCR to acquire a Meta-Cognition (MC) which is shown in Fig. 4. In CIoT, each CE maintains at least one MC to build more intricate cognitive process. Decision-making is the most important tache in MC, which carries out decision according to normative information. If necessary, the CE will cooperate with other CEs to acquire more valuable strategy. In order to improve the intelligence for future decision, machine learning method is introduced to optimize knowledge database.

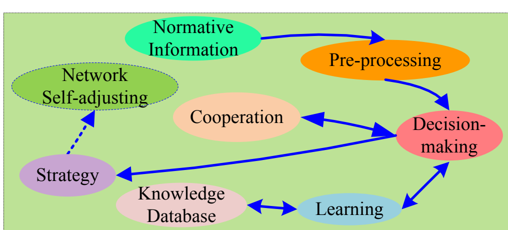

Fig. 4 Meta-Cognition.

3.3 Cooperative mechanism

Cognitions have promoted the revolution from IoT to CIoT, and cooperation can improve cognitive efficiency and network performance. In this section, we highlight cooperative mechanism through exploring cross-layer cooperation and multi-domain cooperation.

3.3.1 Cross-layer cooperation

In the field of cognitive radio, cross-layer design is adopted to promote the efficiency of self-x. Accordingly, we introduce cross-layer into ICoT to optimize the cognitive process of CE and address cooperation of cross-layer based on MC. A cross-layer cooperative model for CE is acquired and shown in Fig. 5.

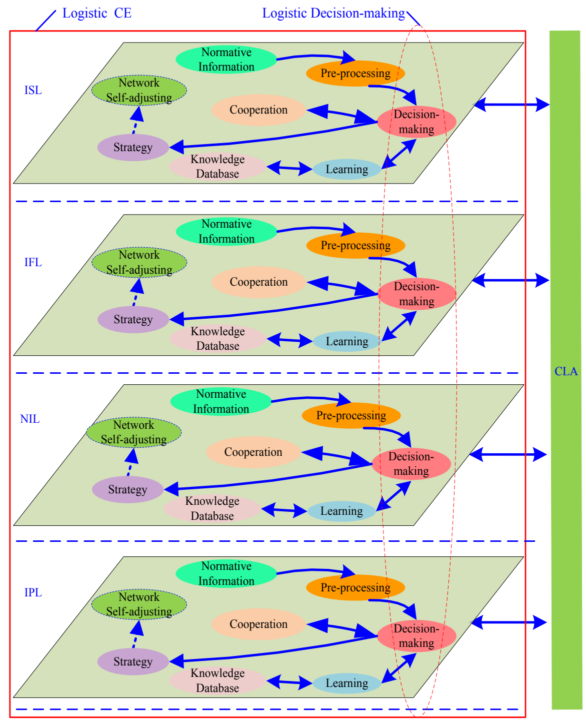

Fig. 5 Cross-layer cooperative model.

From horizontal view, there is a MC in each layer to carry out the cognition of relevant layer, which is connected to Cross-layer Adapter (CLA). From vertical view, the same taches of every MC (i.e. Decision-making) realize the same function and represent a logistic tache (i.e. logistic Decision-making). From integrated view, the cross-layer cooperation represents a logistic cognitive process of CE.

Whether cross-layer is needed or not will be ascertained by CLA. Suppose that the set of cross-layer states is $S = \{S_1, S_2, \ldots, S_n\}$, each component S_i is a specific cross-layer state of four layers. For example, S_i can denote the cross-layer of IPL & NIL, IFL & ISL. Besides, IPL & IFL, IPL & ISL, NIL & IFL and NIL & ISL have no cross-layer. If current time is t_i and cross-layer state is S_i, the cross-layer state S_j of next time t_j is determined by (5), and the transition matrix is shown in (6).

$$P_{ij} = P\left(S_j = j \mid S_i = i\right) \tag{5}$$

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$$P=\begin{pmatrix} P_{11} & P_{12} & P_{1\cdots} & P_{1n} \\ P_{21} & P_{22} & P_{2\cdots} & P_{2n} \\ P_{\cdots 1} & P_{\cdots 2} & P_{\cdots\cdots} & P_{\cdots n} \\ P_{n1} & P_{n2} & P_{n\cdots} & P_{nn} \end{pmatrix} \tag{6}$$

In the first instance, we divide the applications into several groups, each of which is designated a specific cooperative state of cross-layer. Therefore, the transition matrix P and transition probability P_{ij} can be acquired early. With the time passing by, payoffs of cross-layer cooperation are analyzed and assessed in virtue of machine learning. The P and P_{ij} are optimized gradually, which will meet the application requirement perfectly.

3.3.2 Multi-domain cooperation

From Fig. 1, we regard the CIoT as a group of ADs, and the relationship of Multi-domain is predigested as in Fig. 6. In a particular period of time, if one CE cannot meet the QoS of application, multi-domain cooperation will be considered in far broader network environment.

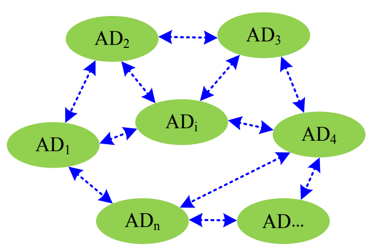

Fig. 6 Multi-domain relationship.

Suppose that the set of ADs is $D = \{1, 2, \ldots, n\}$, the power set of D is $G = \{G_1, G_2, \ldots, G_i, \ldots, G_m\} = \{\Phi, \{1\}, \{1,2\}, \ldots, \{1, 2, \ldots, n\}\}$, each element G_i of which is called a cooperative group. We think of the multi-domain cooperation as cooperative games $GAME = <D, v>$. Here, v is the mapping form $2^D = \{G_i \mid G_i \subseteq D\}$ to the set of real numbers R^D; $v(G_i)$ expresses the payoffs acquired by G_i. Besides, suppose that the expecting cooperative payoffs of $AD_j \in G_i$ is $u_j(G_i)$, the effective payoffs of every ADs can be denoted in a vector $P = (P_1, P_2, \ldots, P_t)$ which is called Payoff Vector. Here, P_i denotes the increment of NC of AD_i.

For this cooperation model, it is easy to establish a cooperative group based on game theory, but difficult to find an acceptable "solution", because there are various combinatorial modes of ADs. The maximum cooperative payoffs are our goal and discussed in next section.

4. Payoffs Analysis of MDC

In this section, we discussed how to gain the maximum payoffs based on the cooperative model narrated above.

If every domain of G_i is the same as the domains which are determined by (2) and (3), we call G_i Fixed Cooperative Group (FCG). Analogously, if every domain of G_i is the same as the domains which are determined by (2) and (4), 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 cooperation, which are called Effective Cooperative Group (ECG).

The total cooperative payoffs of G are shown in (7) and the Payoff Vector P is shown in (8). Formula (8) is tenable because some payoffs can be shared by ADs. The relationship between P_i and u_i is shown in (9). The differences between $v(G)$ and U are the net cooperative payoffs, which is shown in (10).

$$v(G)\begin{cases} < U = \sum_{i=1}^{m}\sum_{j=1}^{n} u_j(G_i), \text{if } (\forall G_i \in G) \in \text{NCG} \\ \geq U = \sum_{i=1}^{m}\sum_{j=1}^{n} u_j(G_i), \text{if } (\forall G_i \in G) \in \text{ECG} \\ \gg U = \sum_{i=1}^{m}\sum_{j=1}^{n} u_i(G_i), \text{if } (\forall G_i \in G) \in \text{FCG} \end{cases} \tag{7}$$

$$\sum_{i=1}^{t} P_i \geq v(G) \geq U \tag{8}$$

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

$$NP = v(G) - U \tag{10}$$

If $NP \hat{+} NA \hat{-} NL \succ QoS$, the cooperation is effective, and new applications will be allowed to enter the network. Otherwise, new applications will be prohibited to enter the network, and far broader cooperation will be considered to achieve more payoffs. Particularly, if $\forall\ G_i \in G$ is a FCG, the net cooperative payoffs are far higher than U, which is the optimal cooperative state. If $\forall\ G_i \in G$ is a NCG, the net cooperative payoffs are less than U, and therefore the cooperation will not be suggested. What's more, if cooperative payoffs meet the NPO primely, the cooperation is anticipant though maybe the local NPO of peculiar AD cannot be met.

Our research is to find an acceptable "solution" to multi-domain cooperation, which can meet the NPO and obtain the increment of NC possibly. Therefore, we need to establish Convergent Cooperative Groups (CCG) to achieve satisfactory payoffs.

Suppose that $CCG = \{CCG_1, CCG_2, \ldots, CCG_u\}$ is set of CCGs, there is a unique function φ which can make sure of the combinatorial modes of ADs as in (11) and (12).

$$\varphi_i[v] = \sum_{i=1,j=1}^{n,u} \gamma_n(CCG_j) \times [v(CCG_j) - v(CCG_j - \{i\})] \quad (11)$$

$$\gamma_n(CCG_j) = \frac{(|CCG_j|-1)! \times (n-|CCG_j|!)}{n!} \quad (12)$$

$|CCG_j|$ denotes the number of ADs in CCG_j, $\gamma_n(CCG_j)$ expresses weighted factor of each CCG_j, and $[v(CCG_j) - v(CCG_j - \{i\})]$ can be considered as the payoffs that AD_i contributes to CCG_j.

If (11) and (12) are met, both ADs and cooperative groups can obtain positive payoffs, which are described in (13) and (14).

$$\varphi_i[v] \geq v\{i\} \quad (13)$$

$$\sum_{i \in D} \varphi_i[v] \geq v\{D\} \quad (14)$$

Therefore, the construction of perfect CCGs is the precondition to achieve acceptable "solution" for multi-domain cooperation. Obviously, any one of CCGs should be an ECG, and it will be better for a FCG. For each cognitive process, we seek the cooperative relationship of multi-domain from *G* to acquire the CCGs as perfectly as possible. Simultaneously, the machine learning method should be introduced to cognitive process to optimize CCGs. The relative optimal cooperative relationship of multi-domain will be achieved, and with the time passing by, it will be more and more perfect gradually.

5. An Application Example

In order to validate the feasibility of proposed concept and its corresponding models, we apply them to an actual system, Ready-mixed Concrete Transportation and Dispatching System (RmCTDS).

5.1 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 Fig. 7. Here, A denotes the origin of ready-mixed concrete; B, C and E denote the construction site of buildings; D denotes the construction site of overpass; and F denotes the construction site of roadway.

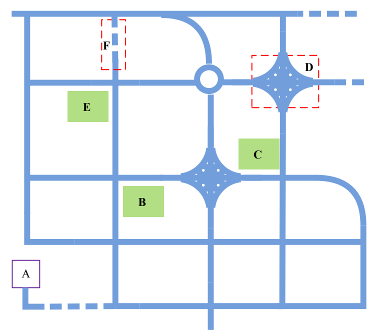

Fig. 7 Sketch map of application scene for RmCTDS.

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. 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.

5.2 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 F 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 and oil consumption are shown in Fig. 8, Fig. 9, Fig. 10 and Fig. 11, respectively.

In the Fig. 8 and Fig. 9, 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 37.5 minutes to 42.5 minutes, we regard it as 40 minutes. It can conclude form the Fig.8 and Fig.9 that the distribution of driving time in RmCTDS dispatching pattern is more convergent than in traditional dispatching pattern.

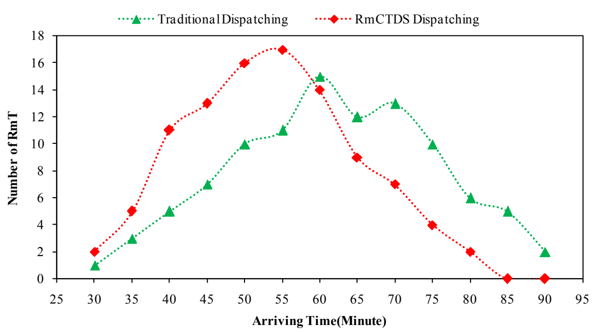

Fig. 8 Distribution of driving time from A to F.

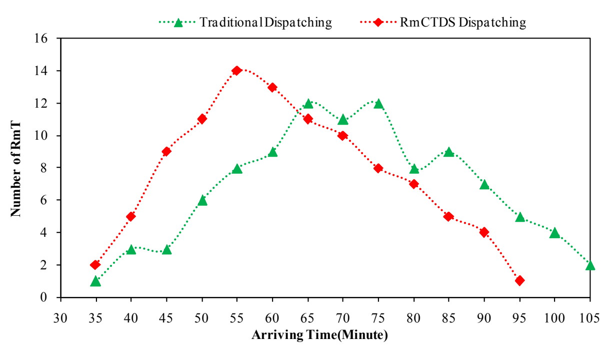

Fig. 9 Distribution of driving time from A to D.

We can deduce equation (15) to calculate the average driving time based on Fig. 8 and Fig. 9.

$$\overline{T} = \frac{\sum x \times y}{\sum y} \tag{15}$$

In equation (15), 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 F is 61.8 minutes in traditional dispatching pattern and 53.7 minutes in RmCTDS dispatching pattern, and the decline of average driving time is 13.1%; the average driving time from A to D is 71.4 minutes in traditional dispatching pattern and 62.3 minutes in RmCTDS dispatching pattern, and the decline of average driving time is 12.7%. 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.

In the Fig. 10 and Fig.11, if the oil consumption is from 9.75L minutes to 10.25L, we regard it as 10L. By calculating, the oil consumption in RmCTDS dispatching pattern decreases 7.1% (from A to F) and 7.4% (from A to D). Besides, the distance of running in RmCTDS dispatching pattern increases 9.6% (from A to F) and 9.9% (from A to D).

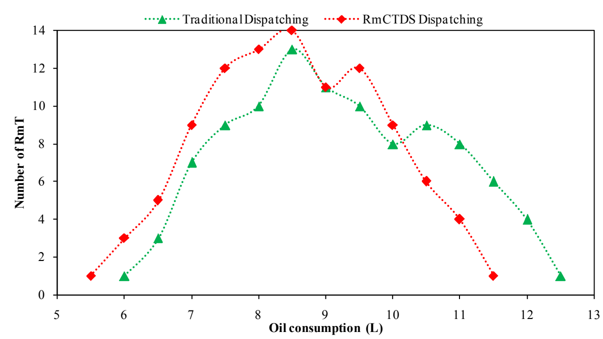

Fig. 10 Distribution of oil consumption from A to F.

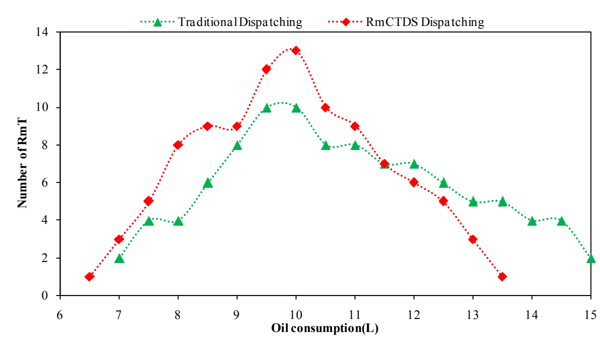

Fig. 11 Distribution of oil consumption from A to D.

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.

6. Conclusions

In this paper, we presented the concept of CIoT to address the lack of intelligence, modeled the CIoT network topology and designed cognition-process-related technologies. Our cognitive process was made up of TCR and cooperative mechanism based on proposed TNA. The cognitive process autonomicly runs and cooperative mechanism is autonomously triggered when one node cannot fulfill the cognitive assignments. Then, the payoffs of multi-domain cooperation were analyzed based on game theory, which illustrates those novel designs can endows IoT with intelligence and fully improve system's performance. Finally, we present an application example RmCTDS to validate the concept of CIoT.

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