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Swarm Intelligence for Perception Layer Design of Internet of Things

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Abstract

Internet of Things is the extension and expansion of Internet from the virtual world to the real world, in which a large number of resource-constrained devices are used to collaborative perception, and it identifies objects and gathers information in the case of no centralized control, no global model. However, the swarm intelligence can take advantage of many simple autonomous individuals to exhibit complex emergent behaviors. In this paper, the characteristics and commonality of perception layer and swarm intelligence were analyzed firstly, and then the architecture of smart individual, self-organization modeling, swarm behavior emergence pattern were analyzed and designed. Finally, intelligentization for perception layer was achieved on the support of middleware.

***Keywords**: Internet of Things, Perception Layer, Swarm Intelligence, Middleware*

1. Introduction

The main Internet of Things (IoT) is the extension and expansion of Internet from the virtual world to the real world. It collects real-time information of any need to monitor, connect, interact with the object or process through a variety of information sensing devices, such as sensors, radio frequency identification (RFID) technology, global positioning systems, infrared sensors, laser scanners, gas sensors and other devices and technology, and then accesses to the existing networks to build a network information system to cover everyone and everything in the world [1]. The basic functions of the Internet is to achieve information exchange and sharing between people, while the IoT is more emphasis on persons and things, things and things, and their connections with the network to facilitate identification, management and control.

The IoT achieves seamlessly connection between the physical worlds with the information world. It is not an entirely new network, but on the basis of the existing telecommunications network, the internet, the next generation network, as well as a number of industry-specific networks, by adding some new network capabilities to bring about desired service. People can access IoT and enjoy the service anytime and anywhere via appropriate terminal equipment in the case of no awareness of the network existence [2]. Therefore, the innate character of IoT is the integration of the physical world and the digital world, to provide people with information acquisition, transmission, storage, fusion, and use of services, which requires three characteristics of IoT, overall sensing, reliable transmission, intelligent processing [3]:

(1) **Overall sensing**. The information of environment and objects, including the user's location, surrounding environment, physical condition, emotional, temperature, humidity, and user service experience, network status, are collected anytime and anywhere by RFID, sensor, 1D/2D code, mobile robot.

(2) **Reliable transmission**. The information of environment and objects are processed by network integration, business integration, and terminal integration of a variety of wired network, wireless network, and real-time and accurate transfer to the IoT users.

(3) **Intelligent processing**. The massive amounts of data and information are analyzed and processed by cloud computing, fuzzy recognition and other intelligent computing methods to apply and control environment and objects intelligently.

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The value of IoT is to let objects also have "wisdom" to achieve communication between persons and things, things and things, and its character is the superposition by perception, interconnection and intelligence [4]. Therefore, the architecture of IoT is roughly divided into three levels, the bottom layer is the perception layer to acquire information, and the second layer is the transmission layer for data communication, then the top layer is industry application layer [5], as shown in Figure. 1.

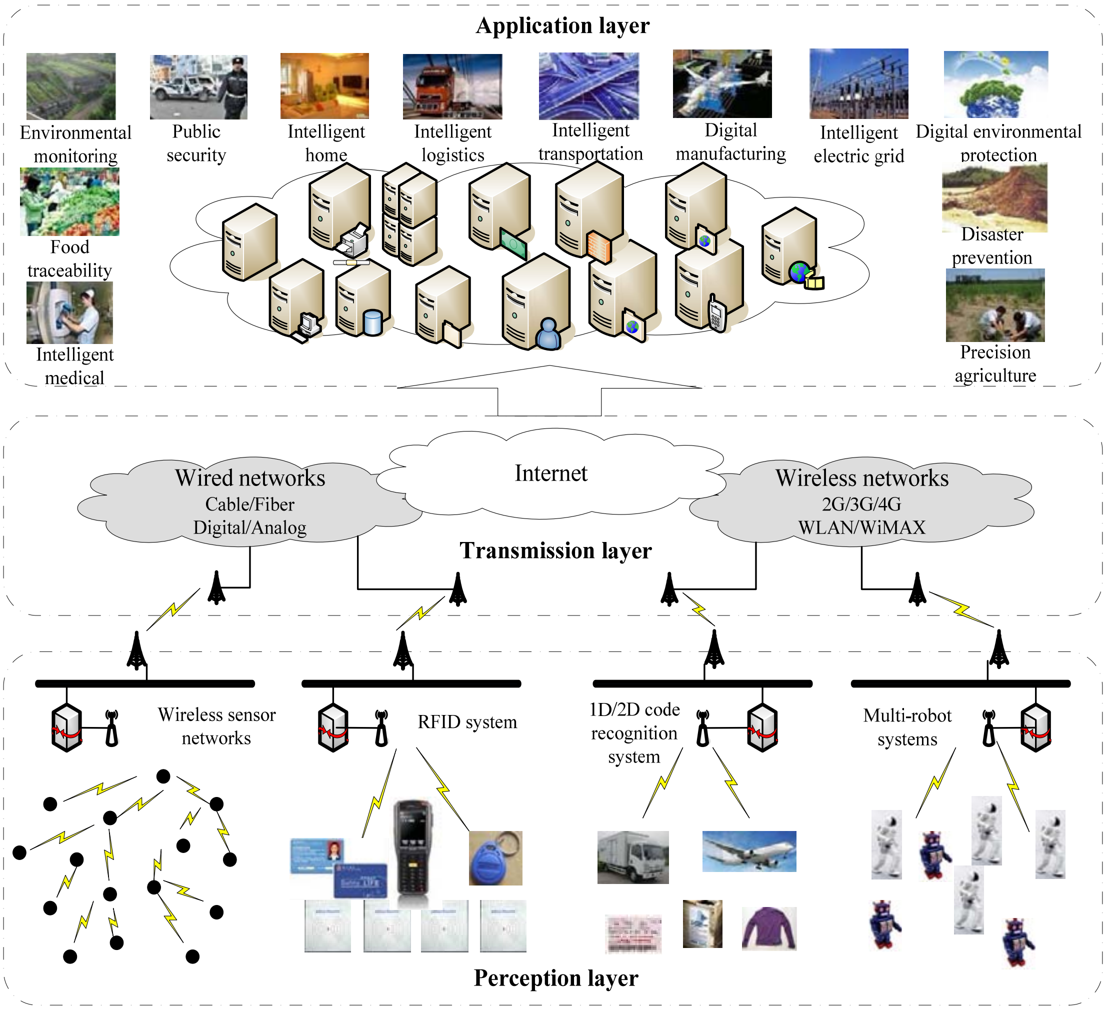

Figure 1. The architecture of Internet of Things

2. The Proposed Method
2.1. Perception Layer

In the architecture of IoT, the three layers can be analogized: the perception layer is equivalent to the human skin and facial features; the transmission layer is equivalent to the body's nerve center and brain; the application layer is equivalent to the social division of labor. As skin and facial features of IoT, the perception layer is responsible for object recognition and collection information, and mainly solves the issue of data acquisition from the physical world. The perception layer is the basis of the development and application of IoT, and has core competencies for overall sensing as a very important role. Therefore, the IoT without perception layer does not make any sense, and can not even be called IoT.

The perception layer of IoT contains massive objects what integrate information processing devices, and have certain of autonomy, bears and processes giant mass sensing information, accommodates a variety of access mode and communication mode to achieve closed-loop process from sensing, processing to control. If all sensing information is uploaded to the users for centralized processing, the transmission of massive amounts of information brings tremendous pressure on the communication; moreover it is redundancy, inefficiency. Therefore, making up of intelligent swarm and then achieving multi-node collaborative work of perception layer is great significance through local interactive.

Multi-node collaborative work in the perception layer of IoT has the following advantages:

(1) Making full use of the principle of locality, business diameter of IoT can effectively shorten, and it coverage the procedure from sensing, transmission, processing and intelligent decision to control, thereby reducing energy consumption and improve efficiency.

(2) Playing distributed architecture advantages of IoT, the single point of control, single bottleneck and single point of failure are eliminated, and scalability, flexibility, robustness are enhanced.

At the same time, by introducing the autonomous objects integrated information device, common structure node of perception layer can be designed, what is conducive to bulk produce generic and reusable components and technology, and this is the essential characteristic of the information industry mainstream products.

2.2. Swarm Intelligence

In the nature world of many groups of organisms, such as ants, bees, birds, fishes, there is no coordinator to coordinate the large number of autonomous individuals, but the entire system presents coordination and orderly state. These gregarious creatures have their survival strategy by cooperate with each other, in which each individual in the group performs only one or a limited number of actions, and makes several simple reactions against external conditions. These seemingly awkward individual behaviors make the swarm composed by them to do extremely efficient action, and even show some thinking.

Swarm intelligence can be used to design algorithms or solve distributed problem from the swarm behavior of social gregarious creatures, that is, relative to the global perspective, swarm intelligence is a local control and communication mechanism. Swarm intelligence is built based on swarm emergence behavior of many simple autonomous individual what has only limited ability of the behavior and performance and does not have a centralized control mechanism. Although swarm intelligence system does not have a complete model of the environment, autonomous individuals are able to get local information from the environment and affect the environment by certain behavior. Due to the individual in such systems usually has the same architecture, the system is highly scalable, and there does not need external reorganize while the number of individual units increases or reduces in the system, what greatly enhances the flexibility, robustness and adaptability for the rapidly changing environment.

2.3. Commonality Analyses

The perception layer of IoT is composed of a large number of objects with 1D/2D or RFID tags, sensor nodes, mobile robots, etc., and each node in the monitoring area is without centralized control or global model, so the identification and information is mostly locally finite, does not mean that the overall. Meanwhile, the strictly limited resources of energy supply, storage capacity and computing power, cause afford on the complex task of perception, and then the information accuracy and precision are more or less reduced. Therefore, multi-node adaptive collaborative work in the monitoring area is needed to play the advantages of swarm, and jointly accomplish the task of object and environment monitoring, what is the basis of the IoT applications.

The perception layer of IoT and swarm intelligence has a lot of similarities, and their common characteristics are reflected in the following aspects [6]:

(1) Processing is distributed, what means there is no central processing unit, so it is better able to adapt to the changing environment, and has strong robustness. It will not affect the completion of the entire task due to the failure of one or a few individuals.

(2) It can be carried out the transmission of information and cooperation by way of short-distance communication or indirect communication, so the communication overhead increases smaller with the number increase of individuals, and it has better scalability.

(3) Each individual's ability and behavior rules are very simple, so the realization of swarm intelligence is more convenient, and it has the characteristics of simplicity.

(4) The overall intelligence of complex behavior emerges through the interaction of simple individuals, and that is self-organization.

3. Research Method

3.1. Smart Individual Design

In order to realize swarm intelligence for the perception layer of IoT, a large number of resource-constrained device nodes are mapped into gregarious individual organism with independent ability to work in the local environment, and it is called smart individual.

The smart individuals can be divided into three types [7]:

(1) **Reasoning type**. This type of smart individuals has a powerful model libraries and symbolic reasoning ability, and it can make site planning depending on the target demand.

(2) **Mapping type**. This type of smart individuals stores a lot of "event-response" couples, and directly maps an output response corresponding to the monitoring input events.

(3) **Hybrid type**. This type of smart individuals combines the above two features, not only has simple reasoning ability, but also has rapid mapping capacity.

For example, the architecture of the hybrid type smart individual is shown in Figure. 2, and the reasoning ability and mapping capacity is both provided in decision planning layer.

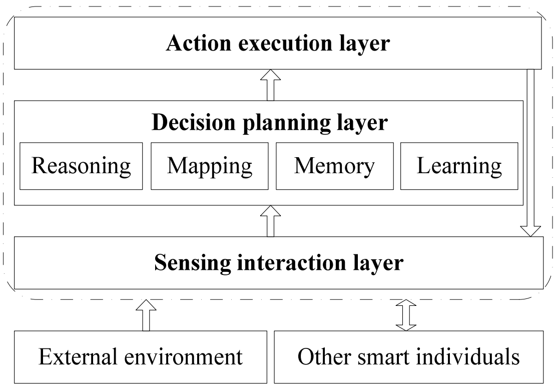

Figure 2. The architecture of the hybrid type smart individual

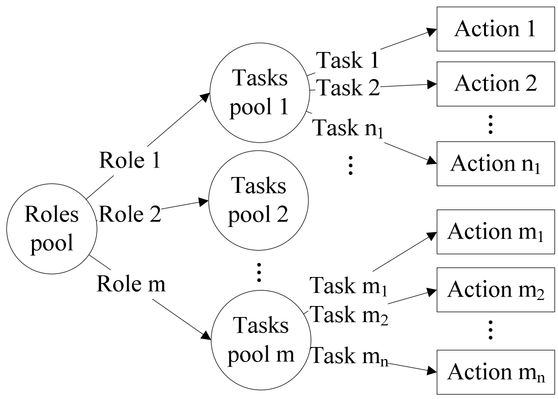

Figure 3. Self-organizing model of smart individual

The sensing interaction layer is responsible for the external environment monitoring using a variety of sensors, and shares information with other individuals by wireless communication and non-contact manners; the decision planning layer is a smart individual information processing and decision response center with symbolic reasoning, perception mapping, memory storage and evolution learning ability; the action execution layer makes timely action response for external events according to the final reasoning or mapping results of the decision planning layer.

3.2. Self-Organization Modeling

Similar to the bee colony, ant colony of the natural world, because of the different applications of IoT, hardware heterogeneous of perception layer node, etc., the smart individual needs to play different roles, corresponding to assume different tasks, resulting in different action response. Therefore, the self-organizing model should be built on the basis of roles, tasks and actions, as shown in Figure. 3. Firstly, starting from the perception layer of IoT needs, a roles pool is built by all related roles. Then, the involved tasks of each role in the roles pool are analyzed, and these tasks constitute the role corresponding tasks pool. Finally, a series of actions for each task are developed [8].

However, bird flock and fish school is no leader in general, and each smart individual is the same role. So the isomorphic swarm can be seen as a special case of heterogeneous swarm with only one role in the roles pool.

3.3. Swarm Behavior Emergence

Complex swarm behavior can emerge on the basis of environment sensing, communication interaction, and autonomous decision-making by the smart individual of swarm within the local environment. The approaches are as follows:

(1) **Environment sensing**. Each smart individual of swarm senses environmental information of local area by its own carried sensors, and the information will be as one of basis for the decision planning, and then the similar local environment inevitably leads to a similar decision planning, which will emerge in simple swarm behavior.

(2) **Communication interaction**. Smart individual collects its neighbor information through a simple, robust local communication interaction mechanism, to extend the scope of monitoring, improve collaboration efficiency and the swarm performance. It is divided into explicit interaction and implicit interaction: the implicit interaction achieves interactive collaboration among smart individuals by sensing and impact with the environment, such as the release and detection of pheromone; and the explicit interaction achieves information transmission based on a particular communication medium by common rules and protocols [9]. Therefore, the implicit interaction has good scalability, and does not cause traffic increase rapidly when the swarm scale increases, in contrast, the explicit interaction can be more rapid and efficient transfer, exchange information between smart individuals.

(3) **Autonomous decision-making**. The decision planning is the core and key of a smart individual architecture, what is autonomous process of the overall information fusion process and thereby making the decision planning results. The process utilizes reasoning mechanisms based on local rules and conditions mapping of smart individual, and memories and learns information from the "perception -> decision -> action" process. Both parallel weighted method and serial decision tree method are the most commonly used autonomous decision-making framework [10], as shown in Figure. 4.

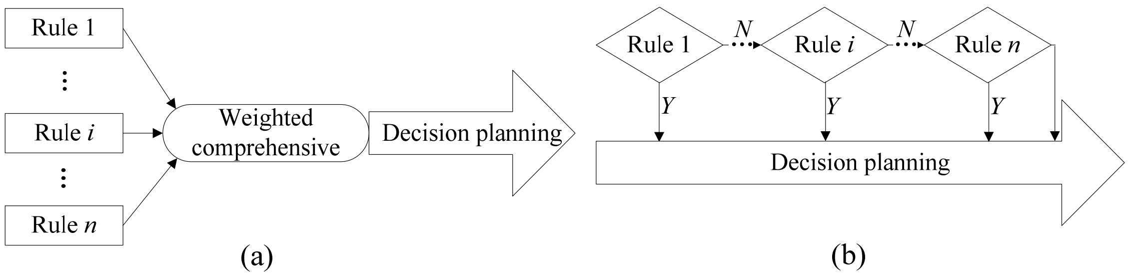

Figure 4. Autonomous decision-making framework: (a) Parallel weighted method; (b) Serial decision tree method

4. Results and Discussion

4.1. Middleware Services

Middleware for IoT is the common needs of the IoT applications in environment monitoring, interconnection and Intelligentization. Firstly, the complex and changeable application environment of IoT, the wide variety monitoring demand of environmental information, cause a lot of differences between nodes of perception layer, such as heterogeneous physical devices, etc., what needs middleware support for a common resource management platform and invocation interface. Secondly, the basis of IoT is interconnection, but, a variety of wireless communication method, a massive node deployment, flexible network topologies, etc., bring many challenges, what needs middleware to achieve reliable communication, reliable deployment and reliable management. Lastly, the superiority of IoT is information sharing and collaborative work, so, in order to solve the contradiction between the massive information and the storage capacity, the calculation ability of perception layer, middleware is needed to achieve massive data fusion, local decision planning, and intelligent cooperative scheduling [11].

The middleware for IoT is carrier of smart individual architecture, self-organizing model, swarm emergence behavior, etc., and is mainly composed with the following services [12-14]:

(1) **Hardware resource management service**. It manages all hardware resources and facilities of node to provide driver and invocation interface.

(2) **Events trigger response service**. It encapsulates all of the "event-response" couples of perception layer, and the roles and tasks are hierarchical classification organized.

(3) **Application request-response service**. It implements the communication between IoT and users, including network configuration, management and information report.

(4) **Data fusion and decision-making service**. It fuses, interacts and memories information, and makes decisions independently.

(5) **Node monitoring and scheduling service**. It is the main services of the node of perception layer.

4.2. Case Study

For example, in target tracking applications of IoT, when a node discovers the target, it convenes neighbors to participate in tracking, and collects and fuses the target position information, then reports to users [15-16]. The procedure is as shown in Figure 5.

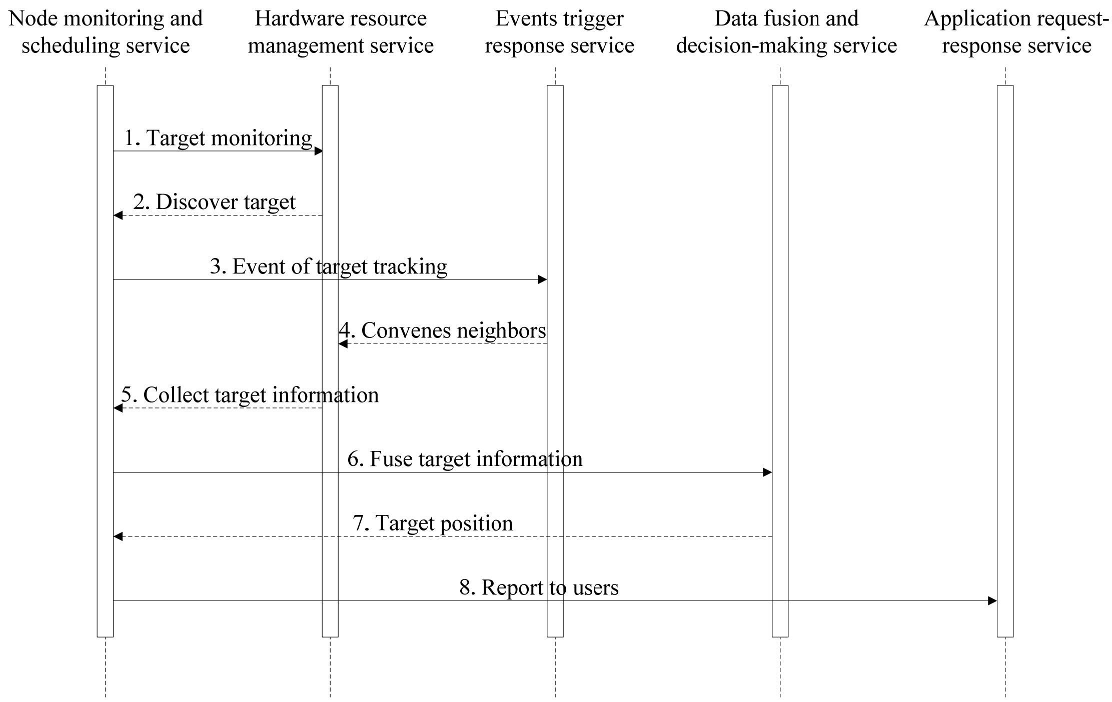

Figure 5. Procedure of middleware services in target tracking

5. Conclusion

In this paper, the swarm intelligence is introduced into perception layer application of IoT, and a large number of resource-constrained sensing device nodes are mapped into smart individual to monitor local environment, interact with neighbors, decision planning and perform appropriate action. The collaborative work mode by multi-node self-organization and swarm behavior emergence shows a certain degree of intelligence. By way of example, the procedure of middleware services is analyzed to verify feasibility of swarm intelligence for perception layer of IoT.

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