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Research Article

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Intelligent Monitoring Network Construction based on the utilization of the Internet of Things (IoT) in the Metallurgical Coking Process

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Abstract: With the development of the Internet of Things (IoT), a new and important research direction is possible using IoT to solve the problems of information and intelligence in the metallurgical industry. This paper proposes an intelligent monitoring network based on networking technology and uses the coking process as the research object. The construction of a coking process intelligence monitoring network should focus on the formation of a perception layer network and build on a ZigBee mesh clustered network. Moreover, it also puts forward a network routing establishment and data transmission mechanism. This study provides an effective reference for the wide application of the IoT in the intelligent management and monitoring of the metallurgical process.

Keywords: Internet of Things, Coking process, Intelligent Monitoring Network, ZigBee mesh Clustered Network

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1 Introduction

With the aim of integrating "information technology and industrialization", information and intelligence have become the main development direction of the metallurgical industry [1–3]. At the same time, the IoT, cloud computing, and other emerging technologies bring new opportunities for the information construction of the metallurgical industry. The IoT is a kind of network which can achieve intelligent recognition, positioning, tracking, monitoring and management. Technologies such as Radio Frequency Identification (RFID), infrared sensors, global positioning systems (GPS), laser scanners, and information sensing allow devices to be connected to the Internet for communication and the exchange of information [4, 5].

With the continuous development of the IoT , it becomes an inevitable trend to apply IoT in metallurgical industry to improve future development. Many large-scale iron and steel groups have explored possible applications which manage logistics within the metallurgical industry appear relatively promising. Baosteel Group used wireless communication and IoT technology to transform the production in a factory, which could help the enterprise achieve accurate and real-time site control and management. They began to construct an iron and steel logistics management system and equipment management system based on IoT [6].

The Beijing Shougang Automation Information Technology Co., Ltd constructed an iron and steel logistics visual tracking and monitoring system based on 3G(The 3rd Generation Telecommunication), GPS(Global Position System), GSM(Global System for Mobile Communications), RFID and other technologies [7]. One particular problem concerned furnace numbers which could not be tracked with the existing system. Zhao Tiehua *et al.* proposed the use of a RFID to achieve axis dynamic coding and a logistics tracking scheme. They also addressed an existing safety issue [8]. Shi Hesheng and others proposed a design method using a multi-sensor network metallurgical production safety monitoring platform based on the

IoT [9]. Maanshan Iron and Steel Group adopted RFID technology to construct an intelligent access control system, attendance system, canteen dining, and consumer management system, etc.[10].

In conclusion, at present the application and construction of the IoT is mostly for certain aspects of the industrial process, which only focuses on the periphery of the metallurgical industry. Currently, there is no complete metallurgical automation network and management service platform based on the IoT. In particular, there is no intelligent management and monitoring for the metallurgical process based on the IoT. At present, management use the traditional way or a centralized monitoring management system based on fieldbus technology [11, 12]. Wireless networks, sensor networks, and Bluetooth technology, etc., are only some potential research areas which could be part of the proposed coking process's monitoring network.

This paper first constructs a metallurgy automation management platform and selects the metallurgical coking process to construct a coking process monitoring network based on the IoT. Aiming at field data sense of a sensing layer, we construct a clustered mesh network based on ZigBee, and put forward a network data transmission mechanism based on AODV routing which can achieve automation and intelligence management for the coking process.

2 Intelligent Motoring Network Construction of the Metallurgical Process based on IoT

2.1 Overall structure of the metallurgical monitoring network

Metallurgical process management includes coking process management, sintering process management, ironmaking process management, steelmaking process management, hot-rolled steel process management, cold-rolled process management, and post-process management, etc. The whole metallurgical production process is a complex system and which includes physical and chemical reaction activities. At the same time, the comprehensive system also involves the exchange of energy, momentum, and matter, which means the metallurgical production process has characteristics such as a complicated mechanism, multi-parameters, strong coupling, and a large time lag, etc. The effective way to improve the benefits to the industry is to construct an automation management and monitoring system for every process. This will reduce human intervention by the use of a sensing device which can obtain accurate data at various stages and achieve more accurate feedback. This is the main method to be employed in the proposed wireless monitoring network.

This paper comprehensively uses IoT technology, intelligent sensing, recognition technology and pervasive computing, as well as a ubiquitous network, etc. to construct a monitoring network for the metallurgical process in order to achieve data acquisition, processing, transmission and intelligent control. A metallurgical process monitoring network structure based on the IoT is a three-layer structure, as shown in Figure 1.

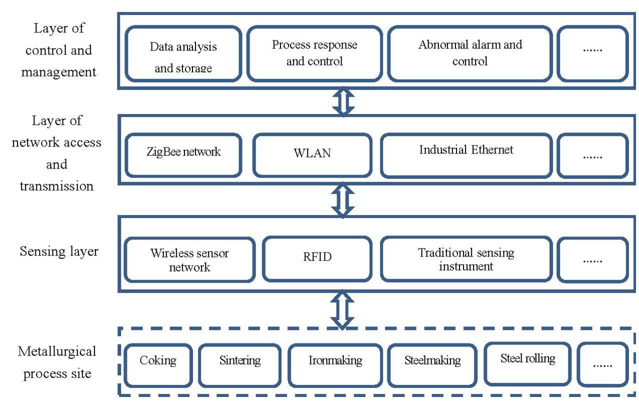

Figure 1: Metallurgical Process Monitoring Network Structure based on IoT

The first layer is the sensing layer. According to actual situations in the metallurgical environment, there may need to be wired sensor deployments in some places. Therefore, a sensor network mixing wired and wireless sensors will be deployed. The wireless sensor nodes are used to form a wireless sensor network of the metallurgical production process, which can collect relevant data of the metallurgical production process. The second layer is a network access and transmission layer, which is designed to transmit preprocessed field sensor data to the monitoring center, according to the metallurgical process situation using Industrial Ethernet, Wi-Fi, ZigBee, etc., for network access and data transmission. The third layer is the application layer, namely, the metallurgical process management, control and service layer. The main task is to to achieve real-time response based on site data, control and decision-making in the metallurgical process, such as metallurgical data storage and analysis, process response and control, as well as abnormal alarms, etc.

2.2 Property of sensor network monitoring

The site information required to be obtained in the coking process includes process information and resource information. The process information mainly includes process parameters of coking production, such as gas flow rate, gas pressure, flue suction, blower speed, the opening of various valves, coke pushing time and coaling time, etc.; Resource information mainly includes the coke oven's body state and coking material, equipment state, including flue temperature, gas collector pressure and coal quality, etc., and every team's coke quality, yield and the energy consumption of coking, etc. must be obtained every day. The monitoring indicators of each sub-process in the coking process are shown in Table 1.

According to the monitoring target subdivision can be further described with more specific monitoring properties, including monitoring properties of comprehensive production target, coke quality index, actual monitoring properties of comprehensive production target, local optimization goal setting, working process of coke oven, gas gathering process of coke oven, and heating and combustion process of coke oven. The description of sub-process monitoring indicators and their relationship is as shown in Figure 2.

Table 1: Description of sub-process monitoring indicators

Sub-process	Description of sub-process monitoring indicators
Heating and combustion process of coke oven	Serial number, date, team, furnace number, combustion chamber number, machine side flue temperature, coke side flue temperature
Working process of coke oven	Serial number, date, team, furnace number, coking chamber number, coaling time, coke pushing time, coke feeding time, coaling capacity, coke pushing current
Gas gathering process of coke oven	Serial number, date, time, furnace number, gas collector pressure
Coke quality monitoring	Date, furnace number, crushing strength, abrasion resistance, moisture, ash, sulfur
Synthesis process	Serial number, date, time, furnace number, machine side blast furnace gas flow rate, coke side blast furnace gas flow rate, machine side mixed gas flow rate, coke side mixed gas flow rate, machine side flue suction, coke side flue suction

2.3 Construction of the Monitoring Network for the Coking Process

2.3.1 The Design of the sensing layer

From the analysis of monitoring properties of the coking process in section 2.2 we can conclude that during the coking process the production state from coke oven heating and the combustion process mainly includes flue temperature, coke quality, and gas consumption, etc. The production state from the gas collector pressure control process

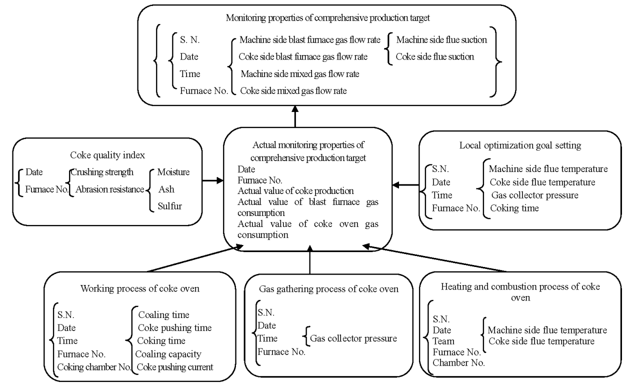

Figure 2: Monitoring Properties of Sensor Network

mainly includes pressure and valve opening, etc. The production state from the coke oven production planning and scheduling process is mainly furnace number and coaling capacity field data. Therefore, the sensor nodes used to collect side real-time production data mainly include temperature sensor, pressure sensor, position sensor, embedded clock, RFID reader, etc. The RFID reader can exist independently, or be integrated with sensor nodes. At the same time, various operation vehicles, coke oven, blast furnace, coking chamber and combustion chamber, etc., are equipped with RFID tags to allow real-time access to relevant information, such as furnace number, coking chamber number, combustion chamber number, and operation vehicle numbers, etc. The sensor nodes can form a sensor network by themselves.

Management and the control server send the scheduling target to the coke oven operation planning and scheduling system wirelessly. It sends the target flue temperature to the heating and combustion process control system, and sends gas collector pressure settings to the gas collector pressure control system. The sensor network system collects the real-time production data from three main production processes, namely coke oven heating and combustion process, coke oven gas collection process, and coke oven operation process.

2.3.2 Construction of a process monitoring network

The main task of the sensor network is to collect relevant production information from production sites and transmit it to the upper control center through the network. At the same time, the network receives the issued coke pushing schedule and control instructions. The coke oven operation plan and scheduling system mainly collects site coaling capacity, vehicle location, coke pushing furnace number, and coke pushing current, etc. The main concerns are the coke pushing furnace number and coaling furnace number, etc. The coking process sensing and monitoring network construction is shown in Figure 3.

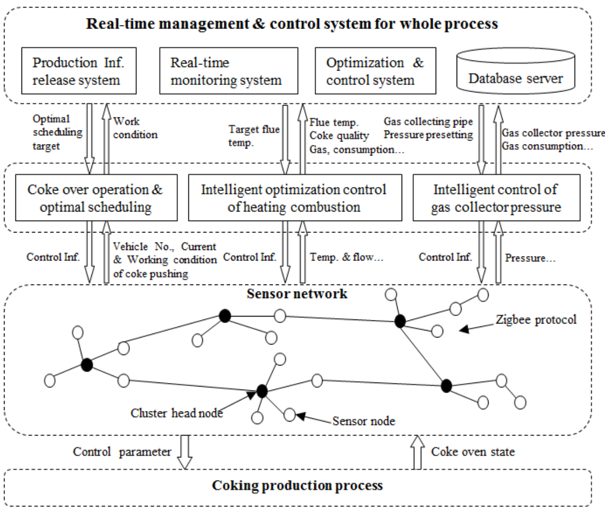

Figure 3: Coking Process Sensing and Monitoring Network Construction

The sensor network is constructed by ZigBee and IEEE 802.15.4, which uses a clustering structure to achieve hierarchical sensing and the processing of site information of the coking process. The communication between the sensor network and upper layer can be completed utilizing a WiFi gateway or current Industrial Ethernet.

3 Wireless Sensor Network Construction of Coking Processing Based on ZigBee

3.1 Construction of a mesh clustered network based on ZigBee

The last section describes the overall structure and the construction process of a coking process monitoring network. The bottom sensor network for collection of coke oven site data is constructed using ZigBee technology [13]. Based on the features of the coking process and considering sensor network energy effectiveness, this paper uses a mesh clustered network. A clustered network divides a ZigBee network into many clusters and the nodes are further divided into cluster nodes and cluster member nodes, each of which is composed of many nodes. The simplest cluster tree network is a single cluster network. If multiple neighboring clusters are connected, it can form a larger network. The coordinator can assign a node to become the cluster head of a new neighboring cluster. Similarly, new cluster heads can assign other nodes to become neighboring cluster heads and form a peer-peer network with multiple clusters. A multi-cluster network structure expands the network coverage. At the same time, it does not need communication between each terminal node and base station, so it saves many node energy.

The cluster head node can be used as a coordinator and router. It is the center of the cluster and responsible for cluster establishment, cluster data collection, and routing establishment, etc. A terminal node cannot become a cluster head, but only serve as a member of a cluster.

The member node and cluster head node can use single hop communication, and can also use multi-hop communication. This paper considers network transmission overhead and network complexity. The member node and cluster head node use single hop communication [14]. Multi-hop communication is used between the cluster and a cluster or information source and sink nodes. Member nodes are responsible for collecting site sensing data and transmitting them to cluster head nodes. The cluster head node transmits or integrates the data of member nodes, and then transmits them to the sink node. Here, the sink node acts as the ZigBee coordinator and the topological structure is shown in Figure 4.

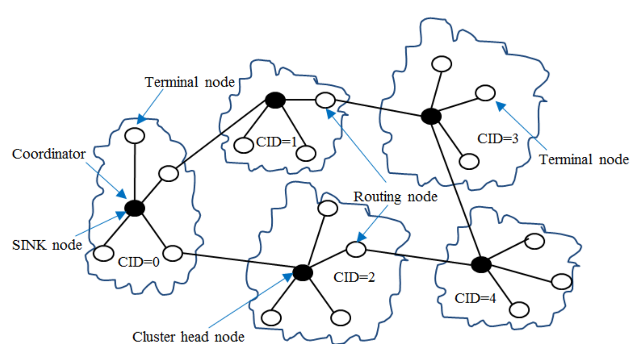

Figure 4: Topological Structure of ZigBee Mesh Clustered Network

3.2 Generation of cluster head and establishment of cluster

If the ZigBee network is divided into many clusters, it should first be considered how to generate cluster heads and establish clustering according to cluster heads. Firstly, the ZigBee coordinator is the first cluster head and sink node at the same time, responsible for collecting information and communicating with the upper layer. The rest of the cluster head nodes are generated in nodes with routing functionality. In the initial stage, the routing nodes with network depth and even number are chosen as a cluster head candidates. The number of cluster heads used in the classical setting of a usual normal clustering network as referenced is usually set at 5% of the total number of nodes.

In terms of network depth definition, the cluster head node is used as a coordination benchmark. If the depth is 0, the depth of neighboring nodes will be 1, and so on. The routing node with an even number depth sends a broadcast message RREQ(Route REQuest). The node receiving the message will respond and send a confirmation message to the source node. After receiving a confirmation message, the source node signal strength RSSI(Received Signal Strength Indicator) is compared with the preset signal strength $RSSI_{AVG}$ (the mean of the signal strength of a neighboring node and a source node which is determined by experiment in advance). If it is larger than the preset $RSSI_{AVG}$, it will add the node into the neighboring node list. Finally, according to the method employed to compare node numbers around the neighbor list, the point with the most nodes will be determined as the cluster head. The process of generation of cluster head and establishment of cluster is as shown in Figure 5.

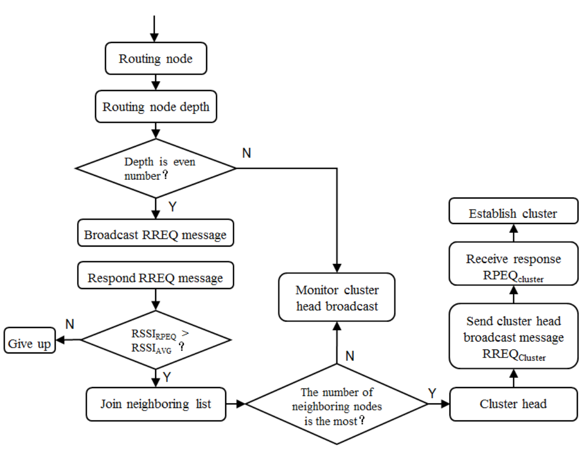

Figure 5: The process of generation of cluster head and establishment of cluster

The node selected as a cluster head broadcasts the message $RREQ_{cluster}$ announcing it has become the cluster head. The node that has received the message will send a responding $RPEQ_{cluster}$ under the condition that it is not a cluster head, and request to join the cluster. Then the cluster head will send the reply to confirm the node can join the cluster, and then the node will join the cluster. A cluster head node maintains a member list and a cluster member node maintains a cluster head node list.

The connection and networking between clusters depends mainly on non-cluster head nodes which are located in the overlapping regions of two or more clusters. These nodes connect the adjacent cluster heads together to form a multi-hop routing path.

3.3 ZigBee network data transmission mechanism

Next, we will introduce the ZigBee network data transmission mechanism within cluster and between clusters.

3.3.1 Data Transmission mechanism within cluster

Data sensing and transmission can be carried out after a cluster mesh ZigBee network has been established. For data transmission, cluster members and cluster heads use single hop communication. Therefore, there is no routing problem, but the conflict of data exchange between multiple cluster member nodes and cluster heads should be considered. In order to avoid too many cluster membernodes sending data to cluster head nodes at the same time, some algorithms use a TDMA mechanism to solve any conflict. A slot time is assigned by the cluster head node to each member node, and the member node sends data in that slot time. But the method is powerless to avoid cluster conflict between adjacent clusters. The use of CDMA can improve the concurrency of communication within cluster and between clusters. However, comparing sensor nodes, a large load is burdensome. In addition, if there is a direct single hop data transmission to the sink node, the energy consumption is too high. Therefore, the communication between the cluster head node and the sink node uses multi-hop routing, which is described in section3.3.2. The generation and establishment mechanism of a cluster scheduling list based on TDMA can be described as follows:

It is necessary to establish a scheduling access list when carrying out cluster access and data communication based on a TDMA mechanism. When clustering is initially established, the scheduling list is empty and needs to establish a scheduling access list for the cluster head node first. The common way of establishing a scheduling list is by using a cluster head to broadcast a slot time allocation packet, which contains each cluster member's ID and an assigned slot time for each member node. But this method is not targeted and may result in the slot time of each node being the same. Member nodes also have different data sizes. The larger data size may need more slot time to transmit data. However, the use of the same slot time will have the problem of unreasonable time distribution. When a cluster member node cannot transmit all data in its slot time, it will wait for the next round of slot time, which will result in a relatively long delay. Therefore, this paper uses a periodic tentative slot time allocation mechanism initiated by the cluster members.

When there is no scheduling access list and cluster member node has data to be sent, it should adopt a CSMA\CA (Carrier Sense Multiple Access with Collision Avoidance) mechanism competitive channel based on competition. If it is competing for a channel, it should send a message abstract to the cluster head node, which includes cluster member node ID and the message size that requires sending, etc. After receiving the abstract message of all member nodes, the cluster head node will assign the corresponding slot time according to the message size of each member node. Thus the cluster head node will establish a scheduling access list and broadcast the slot time assignment table for member nodes. For cluster member nodes, the message transmission capacity is a dynamic value. If it maintains a fixed slot for a long time, it will not be able to cope with the change. Therefore, a periodic scheduling access list update is used and its effectiveness passes through a time stamp record. Figure 6 shows the general structure of a schedule access list.

Node ID	Slot time segment	Total length of slot time segment	Time stamp

Figure 6: Structure of Schedule Access List

The above process will repeat periodically to complete the dynamic slot time assignment of cluster member nodes. The cluster communication process is shown in Figure 7.

3.3.2 Data transmission mechanism between clusters

(1) Data transmission mechanism between the clusters based on AODV protocol

A multi-hop routing transmission mechanism is used for communication between clusters or from source node to sink node. In the mesh clustering network, the cluster member nodes communicate with the cluster head by single-hop, so the route discovery problem can be neglected. The cluster member nodes just send the data ac-

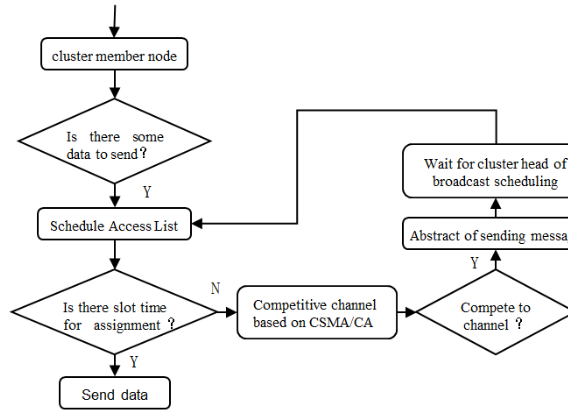

Figure 7: Cluster Communication Process

cording to the slot which is given. But the communications between the cluster heads are multi-hop route discovery process. Moreover, some non-cluster nodes also act as the route access nodes. AODV(Ad hoc On-demand Distance Vector Routing) is regarded as a typical on-demand distance vector routing protocol, mainly used in the wireless ad hoc network, to build a unicast or multicast route. AODV is highly identical to the mesh clustering network proposed in this paper. So, we choose the AODV as a basis, and give a modification that fits to our network, to implement the on-demand route discovery. The routing request process on an AODV protocol is described in reference [15].

(2) Routing discovery and transmission path formation

After receiving the routing request, the destination node will not broadcast a routing request. It first sets up a reverse path to generate a RREP that contains the latest series number and other information which is broadcasting to the source node by the way of unicast along a reverse path. After receiving the RREP, the middle node and source node will set up the routing to the destination node, and update the series number and other relevant information. After receiving the RREP, the source node will immediately set up routing and begin to transmit the data. After the routing process is completed, the source node will send its cluster head a routing confirmation packet with routing information. After receiving this packet, the cluster head will broadcast a routing update packet. While the cluster members receive this message, it will share the routing information which has been newly established by the node. The process is as shown in Figure 7. In the figure, the blue solid node is a cluster head node, the black solid node is a routing node, and the white hollow node is a terminal node. The black arrow indicates that routing discovery requests the transmission of a RREQ packet, the purple arrow indicates that routing responds with a RREP packet, the orange arrow indicates routing confirmation information broadcasted by cluster head node, and the blue arrow indicates the path from source to the destination node.

For example, when source node S wants to transmit data to destination node D, it should first broadcast a RREQ packet until it reaches the destination node. Then the destination node transmits a RREP packet response. When the source node receives the RREP response, it will transmit routing confirmation information to the cluster head node, which will broadcast routing confirmation information. So, the routing nodes of a whose cluster ID is 1 can share this routing information and finally form a path from S to D (blue arrow pointing in Figure 7), as shown in Figure 8.

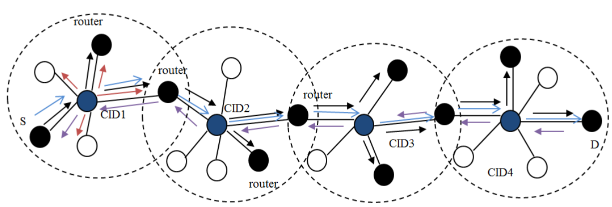

Figure 8: Routing Discovery Process

4 Conclusion

With the increasing requirements for information and intelligence in the metallurgical industry, it is an inevitable trend that new technologies, for example, the IoT and cloud computing will be used to solve related issues in this industry. At present, the IoT is mainly used in the external systems of the metallurgical industry, such as personnel management and equipment management. However, are few studies on the utilization of intelligent control in the metallurgy process. This paper is based on the exploration of this problem. We put forward a metallurgical process monitoring network model which is based on the IoT and the construction of a monitoring network of the metallurgical coking process. We focus on the research and analysis of the construction of a bottom layer sensing network involving networking, network routing, and data transmission mechanisms. The next step in this work is to carry out instance validation and analysis and further improve of the network model.

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