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ORIGINAL ARTICLE

Quality of service optimization in wireless transmission of industrial Internet of Things for intelligent manufacturing

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Abstract

Based on the requirements of industrial Internet of Things in intelligent manufacturing environment, the layered architecture, cross-layer optimization protocol, and key technologies of universal converter for heterogeneous networks of industrial Internet of Things are analyzed. A new architecture of two-layer distributed hybrid industrial Internet of Things is proposed, which combines the advantages of star network and mesh network. In the orthogonal frequency division multiple access (OFDMA)–based relay system, in order to satisfy the quality of service (QoS) requirement and ensure the maximum throughput of the system while ensuring user fairness, a resource allocation algorithm oriented to quality of service (QoS) is proposed. Firstly, according to the waiting delay of the user in the queue and the requirement of the user for the rate, the delay priority factor and the rate priority factor are introduced to calculate the priority of the user, and then, the dynamic resource scheduling and allocation are carried out on the backhaul link and the access link respectively. The simulation results show that the new algorithm has low packet loss rate, better meets GBR requirements, and can achieve high system throughput and fairness.

Keywords Quality of service · Wireless transmission · Industrial Internet of Things · Intelligent manufacturing

1 Introduction

At present, intelligent manufacturing is also facing severe challenges such as too high power of canvassing, low production efficiency, low utilization of raw materials, and relatively backward service level, which seriously affect the market competitiveness and influence of manufacturing enterprises [1, 2]. As a new technology of manufacturing informatization, Manufacturing-Material Federation (MFU) is a new technology of manufacturing mode and information service mode in modern manufacturing industry. It can promote advanced manufacturing production mode, increase added value of products, and accelerate transformation and upgrading [3, 4]. To reduce production costs and energy consumption and promote the development of manufacturing industry towards globalization, informatization, intellectualization, and greening manufacturing Internet of Things (IOT) technology is also an important way to enhance enterprise's independent innovation ability, enhance enterprise's management and service levels, promote the transformation of manufacturing industry from production-oriented manufacturing to service-oriented manufacturing, and provide an important technical support for enterprises to seize the high-end value chain [5]. It greatly enhances the competitiveness of enterprises. We propose an Internet of Things (IOT) architecture for complex manufacturing process, which integrates perception, real-time transmission, pervasive computing, precise control, and trusted services, to achieve automatic dynamic acquisition of multi-source objects in the manufacturing process, dynamic manufacturing information in heterogeneous multi-hop networks reliable transmission, massive intelligent processing of large-scale multi-source dynamic data streams, precise control of manufacturing production process, and credible and efficient services for diverse application requirements; and ultimately achieve multi-objective process optimization and system energy saving [6].

Intelligent Manufacturing Internet of Things (IMIOT) technology optimizes the scheduling of manufacturing process by constructing the Internet of Things (IOT) network, and realizes the deep integration of manufacturing physical process and information system, thus promoting advanced manufacturing production mode, increasing added value of products, accelerating transformation and upgrading, reducing production costs, reducing energy consumption, and

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promoting manufacturing industry to become globalized and credible [7]. The direction of informatization, intellectualization, and greening is developing. At present, the traditional manufacturing industry is facing severe challenges such as high labor cost, low production efficiency, low utilization of raw materials, large energy consumption, and relatively backward service level, which seriously affect the market competitiveness and influence of manufacturing enterprises [8]. As a new technology of manufacturing informatization, the technology of Manufacturing-Material Federation is a new technology of manufacturing mode and information service mode in modern manufacturing industry. It can give birth to advanced production mode of intelligent manufacturing industry. On the basis of traditional industrial network, heterogeneous networks such as the Internet, wireless sensor network, and fieldbus network are integrated [9]. The networks with perceptive capabilities, such as terminals, mobile communications, cloud computing mode, and real-time communication, are called industrial products [10]. At present, industrial Internet of Things (IOT) has become a research and development hotspot. The research of industrial Internet of Things (IOT) is an important aspect to realize the IOT in an advanced manufacturing environment. In view of the special requirements of intelligent manufacturing environment, such as real time, reliability, and giving full play to the respective advantages of wired and wireless, it is particularly necessary to study the key technologies of industrial Internet of Things [11]. In reference [12], a multi-user sub-carrier pairing and power allocation algorithm based on quality of service (QoS) guarantee and proportional fairness is proposed, but the existence of direct users is not considered in the first hop network. In reference [13], in LTE-A relay network, a two-hop maximum weight delay priority algorithm is adopted. For relay users, the delay threshold of each hop link is set to half of the total delay threshold [5]. The contributions are shown as follows: (1) build the industrial IOT network, (2) transfer the QoS for users to the QoS work for IOT network, (3) propose a resource allocation algorithm oriented to quality of service.

Based on the requirements of industrial Internet of Things in intelligent manufacturing environment, the layered architecture, cross-layer optimization protocol, and key technologies of universal converter for heterogeneous networks of industrial Internet of Things are analyzed. A new architecture of two-layer distributed hybrid industrial Internet of Things is proposed, which combines the advantages of star network and mesh network. Then, with the routing control of network layer, an industrial Internet of Things protocol stack with reliable physical layer, real-time MAC layer, and adaptive network layer is designed. Through a generic conversion architecture that can integrate multiple wirelesses and wired heterogeneous network protocols, flexible configuration of equipment conversion scheduling module for different networks can realize seamless access of multiple wired and wireless terminal nodes. Finally, by building the measurement and control platform of the industrial Internet of Things, the protocol conversion and control cycle test of the heterogeneous integrated system are carried out. In the orthogonal frequency division multiple access (OFDMA)–based relay system, in order to satisfy the quality of service (QoS) requirement and ensure the maximum throughput of the system while ensuring user fairness, a resource allocation algorithm oriented to quality of service (QoS) is proposed. Firstly, according to the waiting delay of the user in the queue and the requirement of the user for the rate, the delay priority factor and the rate priority factor are introduced to calculate the priority of the user, and then, the dynamic resource scheduling and allocation are carried out on the backhaul link and the access link respectively. The simulation results show that the new algorithm has low packet loss rate, better meets GBR requirements, and can achieve high system throughput and fairness.

The rest of this paper is organized as follows. Section 2 discusses industrial Internet of Things architecture model for intelligent manufacturing, followed by resource allocation algorithms based on QoS guarantee for wireless transmission in industrial Internet of Things designed in Section 3. Section 4 shows the simulation experimental results, and Section 5 concludes the paper with summary and future research directions.

2 Industrial Internet of Things architecture model for intelligent manufacturing

2.1 Architecture of the intelligent manufacturing–oriented industrial Internet of Things

The core goal of the manufacturing Internet of Things is to realize mutual inductance and interoperability of various manufacturing resources, to achieve real-time data acquisition and accurate tracking of process state, and to realize the online real-time monitoring of production process optimization management and production service process with the support of scientific decision-making [14]. Based on the above objectives, we propose and design architecture of the Intelligent Manufacturing Internet of Things (IMIOT) as shown in Fig. 1. The architecture consists of five parts: reliable perception layer, real-time transport layer, pervasive computing layer, service and application layer. In this way, the deep integration of physical process and information process in manufacturing industry is realized. As we can see from Fig. 1,

(1) Perception layer: Reliable perception layer, sensors, and other multi-source perception technologies, aiming at real-time, accurate, and reliable acquisition of multi-source data of hybrid process for complex objects such as materials, production equipment, production process, and products in the whole manufacturing process. Through

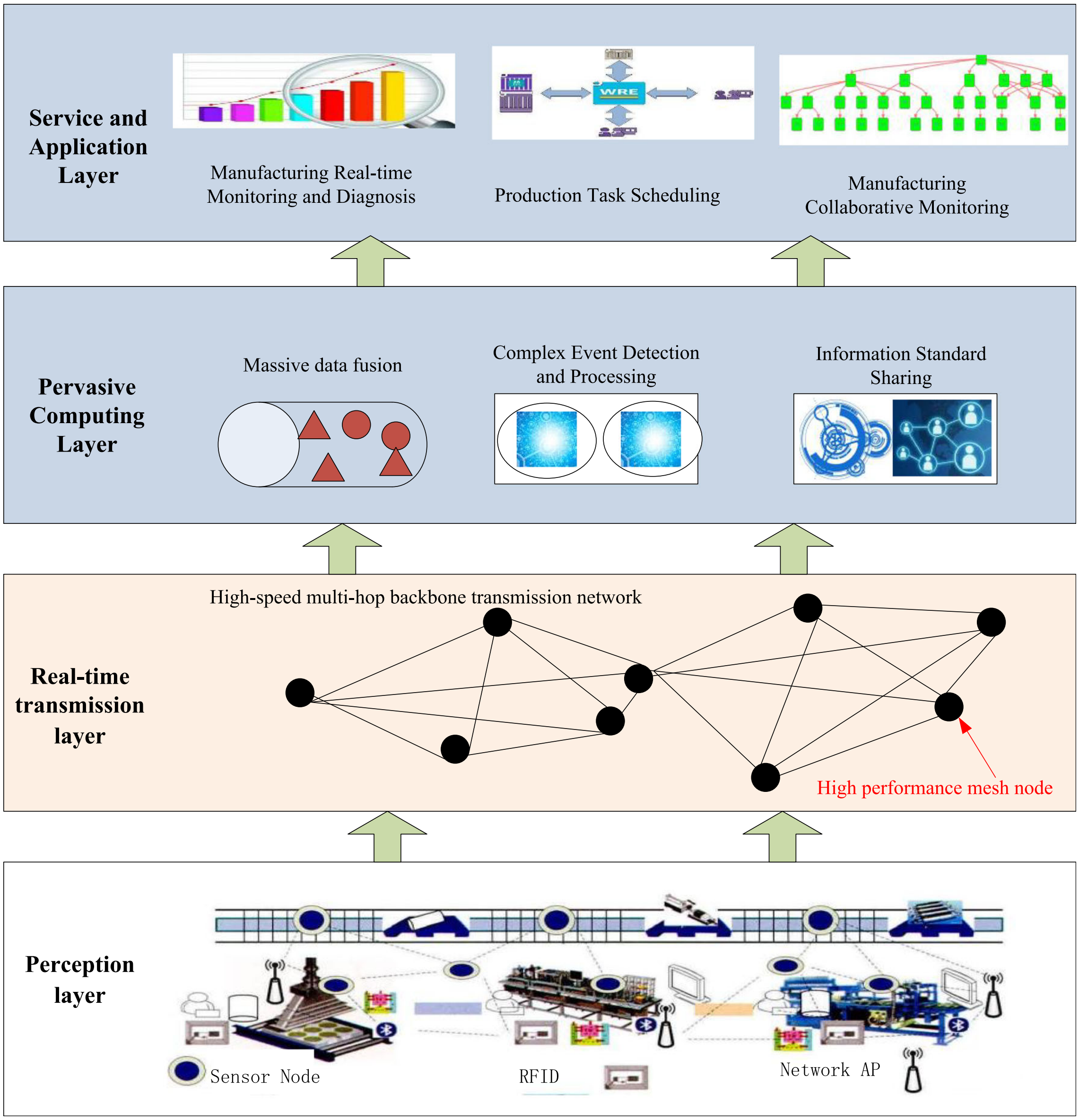

Fig. 1 Industrial Internet of Things architecture model for intelligent manufacturing

multi-node cooperative perception and scheduling optimization mechanism for dynamic uncertain process, a unified description model and method of multi-source heterogeneous perception data are constructed to provide data basis for precise control and information service of manufacturing process.

(2) Real-time transmission layer uses large-scale wireless multi-hop network with dynamic and fast self-networking characteristics as its main data transmission network, and realizes interconnection and integration with existing networks such as industrial fieldbus and industrial Ethernet to support complex dynamic manufacturing resources anytime, anywhere. Ubiquitous access, while meeting the specific QoS transmission requirements of different types of business data in large-scale heterogeneous hybrid networks, provides real-time and reliable transmission services for all kinds of sensing information and upper system control commands in heterogeneous transmission network environment. And the mesh node structure of wireless network can improve the efficiency of data transmission, which is important part for real-time network.

(3) Pervasive computing layer achieves efficient integration and intelligent processing of massive multi-source real-time data streams through distributed embedded and server counting. It can provide users with computing services anytime, anywhere and provide reliable decision-making and support for upper services. Depending on distributed computing unit, perception layer and transmission layer can realize simple data

fusion or compression for all kinds of production data collected, realize redundancy and complementarily of information processing, and reduce data capacity and its unreliability. Intelligent analysis and processing of large-scale multi-source real-time data streams can be carried out by relying on high-performance computing units, which mainly includes reducing the amount of data and its uncertainty, extracting comprehensible and interesting events from large-scale multi-source dynamic data streams, and generating a large number of large-scale multi-source real-time data streams.

(4) On the basis of massive off-line and online data and knowledge, various advanced control strategies and technologies are synthetically utilized to achieve precise control of the whole process of complex industrial manufacturing under the environment of manufacturing-in-object, so as to achieve the most comprehensive energy consumption and production efficiency of production equipment and process. Optimal state, so as to achieve manufacturing process optimization, production efficiency improvement, and system energy saving.

2.2 Multi-layer collaborative topology architecture for manufacturing Internet of Things

In view of the topological characteristics of the MAFTU transmission network [15], in order to realize the multi-dimensional QoS (throughput, delay, service differentiation, congestion, reliability) requirements of multi-service dynamic large data flow transmission, a new type of high-performance MAFTU with multi-service support, high bandwidth, low latency, low energy consumption, high coverage, and high processing capacity is needed. Transmission network focuses on the realization of flexible, scalable, and stable integration of heterogeneous manufacturing network, and the design of a network protocol mechanism to guarantee multi-dimensional quality of service requirements for data transmission [16, 17].

Between different access systems, manufacturing the Internet of Things (IOT) requires horizontal communication between the same network and vertical communication between different networks [18]. A manufacturing-object-link transmission network with vertical layered topology can be constructed as shown in Fig. 2. The backbone transmission network consists of a high-speed multi-hop transmission network constructed by a high-performance wireless Mesh router, which supports wireless ubiquitous access to sensors, controllers/actuators, RFID readers, industrial instruments, and video monitoring devices, and has data fusion and video compression functions; at the same time, it supports seamless cutting of mobile nodes. In other words, industrial fieldbus can be interconnected with wireless Mesh backbone transmission network through access gateway. The lower layer is the terminal access layer, which supports multi-hop communication. It can provide redundant multi-hop links for some broken communication links and extend the network coverage of wireless Mesh routers.

In the manufacturing Internet of Things (IOT) network, various terminals are distributed on a large scale. Through the terminal access layer clustering optimization mathematical programming model, various terminals are managed efficiently to achieve stable, fast and low energy consumption sensing data transmission.

3 Resource allocation algorithms based on QoS guarantee for wireless transmission in industrial Internet of Things

3.1 Introduction of delay priority factor and rate priority factor

In traditional cellular systems, there are many classical resource allocation algorithms and improved algorithms based on them. The priority expression of M-LWDF algorithm is:

$$P_k(t) = a_k \times W_k(t) \times \frac{r_k(t)}{R_k(t)} \tag{1}$$

$P_k(t)$ represents the priority of industrial Internet component k at time t, and $W_k(t)$ is the packet-to-head HOL (head of line) packet delay of component k at the beginning of time t slot; $a_k = -\log(\delta_k)/\tau_k$, δ_k denotes acceptable packet loss rate for networks, and τ_k is the maximum delay threshold allowed by the network; $R_k(t)$ is the actual rate that the component k achieves at time t, which is related to the channel state. The definition of $\overline{R}_k(t)$ is the same as PF algorithm, which represents the average rate of users at the current time. Representing window length with T, the update expression of $\overline{R}_k(t)$ is

$$\overline{R}_k(t) = \left(1\text{-}\frac{1}{T}\right)\overline{R}_k(t-1) + \frac{1}{T}r_k(t) \tag{2}$$

M-LWDF algorithm determines the priority value of component k according to Formula (1) and queues the priority in order from large to small. Finally, according to the ranked priority queue, wireless resources are allocated and data are transmitted. This algorithm combines the PF algorithm with the HOL packet delay. On the basis of guaranteeing fairness and high throughput, it reduces the packet loss rate of data transmission and can satisfy the QoS requirements of some delay-demanding services.

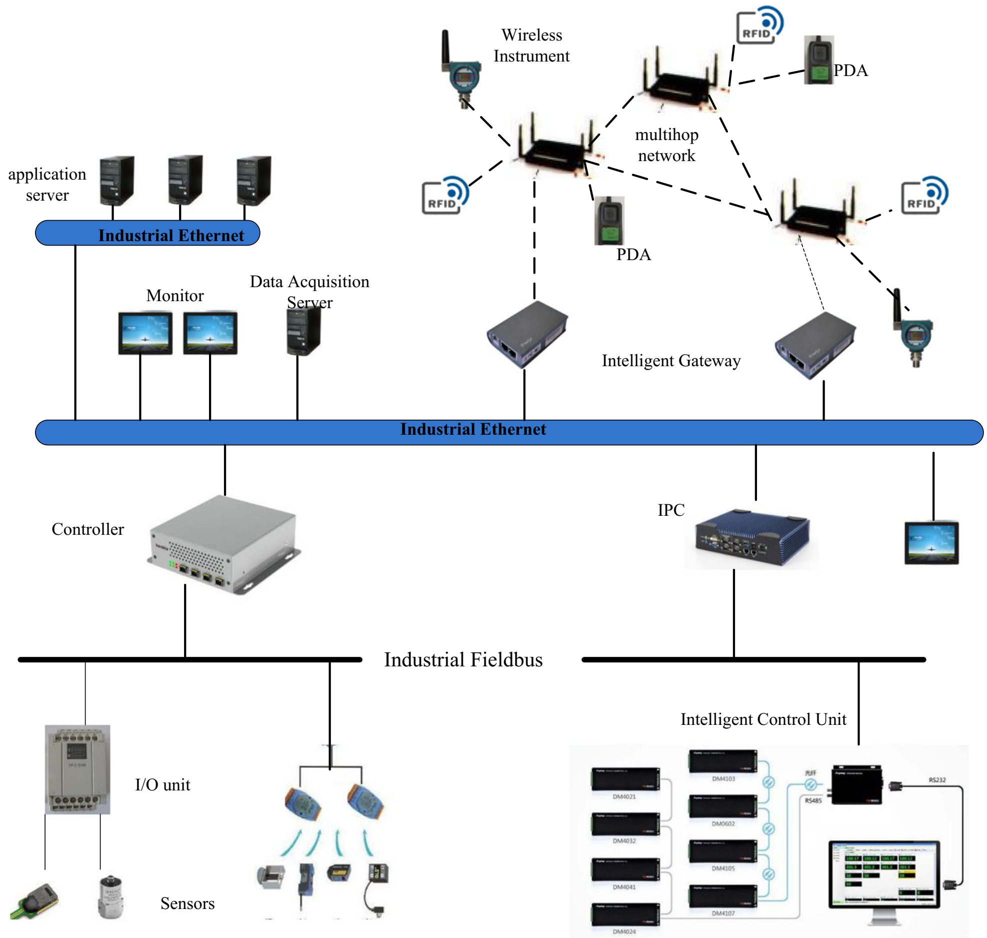

Fig. 2 Industrial Internet of Things architecture model for intelligent manufacturing

Wireless communication systems provide different QoS requirements for different services. For all real-time services, the design priority should consider their delay requirements; for GBR services, the minimum rate requirements should also be considered; for BE services, the best effort should be made to allocate resources. Therefore, on the basis of M-LWDF algorithm, the delay priority factor and rate priority factor are introduced, and the resource allocation algorithm based on service QoS guarantee–based resource allocation (QG-LWDF) is given. The priority expression of the algorithm is:

$$P_k(t) = a_k \times \frac{r_k(t)}{\overline{R}_k(t)} \left[\frac{GBR(k)}{\overline{R}_k(t)} \right]^{\alpha} e^{\beta d(k)/(D_{\max} - d_k(t))} \tag{3}$$

where $D_{\max} - d_k(t)$ is the delay priority factor of the algorithm, $\frac{GBR(k)}{\overline{R}_k(t)}$ is the rate priority factor for the algorithm, $D_{\max}$ is the maximum delay threshold that component k can withstand, and $d_k(t)$ is the packet delay value of component k buffering the queue head at time t. GBR (k) is the minimum transmission rate that component k needs to guarantee. The definition of $\overline{R}_k(t)$ is the same as that in Formula (2). The addition of rate factor can improve the priority of GBR service and meet the quality of service requirements of GBR components. When the waiting delay of data packet exceeds the delay threshold, the data packet will be discarded; when the first delay of the queue approaches the delay threshold, the priority will increase exponentially and the priority will be scheduled.

For different business types, alpha and beta can take different values. For real-time business (sensor transmission and control business), take alpha = 1, beta = 1; for non-real-time business (HTTP business), take alpha = 1, beta = 0; for best-effort business (FTP business), take alpha = 0, beta = 0, that is, for real-time business (sensor transmission and control business).

$$P_k(t) = \begin{cases} a_k \times \dfrac{r_k(t)}{\overline{R}_k(t)} \left[\dfrac{GBR(k)}{\overline{R}_k(t)} \right] e^{d(k)/(D_{\max} - d_k(t))} \\ a_k \times \dfrac{r_k(t)}{\overline{R}_k(t)} \times \dfrac{GBR(k)}{\overline{R}_k(t)} \\ a_k \times \dfrac{r_k(t)}{\overline{R}_k(t)} \end{cases} \tag{4}$$

3.2 Resource scheduling and allocation in LTE-A relay system

In the design of resource scheduling and allocation model in relay scenario, user data is transmitted and stored in the buffer of base station and relay in the form of grouping. The scheduler is located at the base station and the relay. By adopting appropriate feedback mechanism, the base station can obtain complete channel state information of direct and return links. The scheduler allocates resources for relay and direct users according to different QoS requirements and channel state information, while relay allocates resources according to relay users' QoS requirements and relay QoS requirements. User channel state information schedules the users it links to. Therefore, resource scheduling and allocation in relay systems need to solve the following problems:

After reasonably estimating the resources needed by relay users in the return slot, the base station first meets the resource requirements of relay and then allocates the remaining resources to the direct transmission components to improve the overall throughput of the system. In the backhaul link, the allocation of the specific resource blocks of the direct transmission component and the relay node is completed first. A semi-static algorithm is adopted here; that is, the resource blocks of the base station side are allocated to the relay node and the direct transmission component proportionally according to the number of the relay component and the direct transmission component. The expression of the algorithm is as follows:

The number of resource blocks allocated by the direct transmission component on the return link is

$$N_d = \frac{M_d}{M_d + \sum_{r=1}^{R} M_r} N \tag{5}$$

The number of resource blocks allocated by relay nodes in the return link is:

$$N_r = \frac{M_r}{M_d + \sum_{r=1}^{R} M_r} N \tag{6}$$

where the number of resource blocks is N; N_d and N_r represent the number of resource blocks allocated to relay r and direct users respectively; M_d is the number of direct users; M_r is the number of relay users; and the number of relay users is R.

In particular, if the maximum allowable delay of the direct transmission component of the service type is $D_{\max}$ and the bit rate is $GBR\ (k)$, the parameters in Formula (5) are adjusted as follows in order to improve the priority of the relay component with the same QoS requirements as the direct transmission component, because its transmission passes through a two-hop link.

$$D_{RN} = D_{max}/2 \tag{7}$$

$$GBR_{RN} = 2GBR(k) \tag{8}$$

When the priority of relay components is calculated according to Formula (5), it is calculated according to the adjusted parameters.

As we can see from Fig. 3, in the access slot, the base station allocates resource blocks for the direct transmission components and satisfies the quality of service requirements of the direct transmission components. The relay node allocates resource blocks for the relay components and satisfies the quality of service requirements of the relay components. Each node dispatches its connected components independently. The resource allocation process of backhaul slot downlink scheduling and access slot scheduling is based on the assumption that the system has sufficient resources. When the number of remaining physical resource blocks is insufficient, the number of resource blocks required for each user's business in the scheduling queue can be calculated beforehand when resource allocation is carried out at this time. If the number of remaining resource blocks is insufficient to send current data and cannot meet the needs of current users, traversing the user set to select the user who can meet the needs of users and has the highest priority to complete the resource allocation work; if the number of remaining resource blocks does not

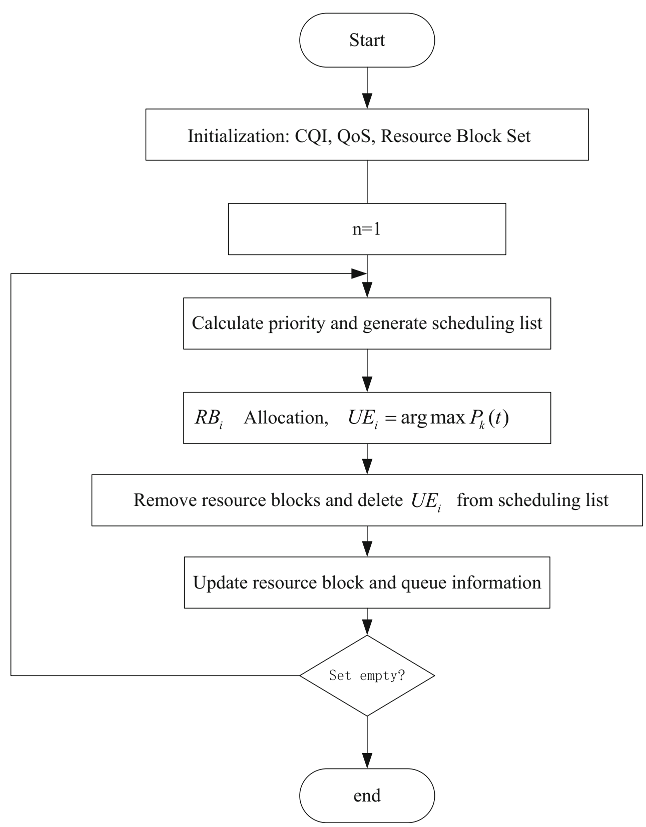

Fig. 3 Industrial Internet scheduling process based on QoS task

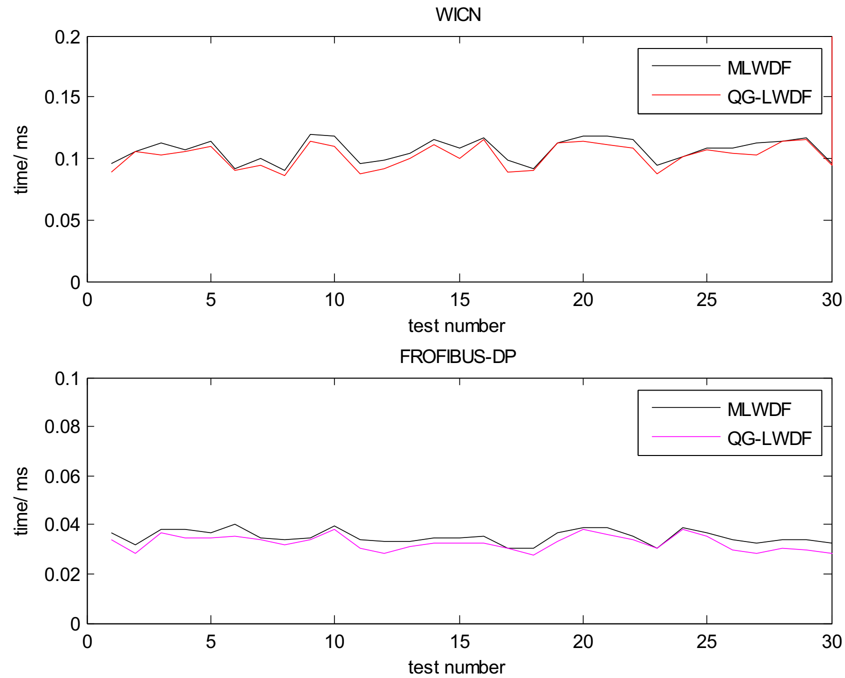

Fig. 4 Conversion time of WICN and PROFIBUS-DP protocols in gateway

meet the needs of users in the current scheduling list, the scheduling will be completed, and the next time it will be repeated.

4 Results and discussion

This section evaluates the performance of the proposed algorithm through simulation experiments. TD-LTE-A system–level simulation platform is built with the help of MATLAB software. Time-driven modeling is adopted. TTI is used as the simulation point to simulate the behavior of components and industrial Internet in real environment through dynamic system behavior. The simulation is divided into five parts: (a) initialization of LTE-A system simulation scenarios, including network topology, terminal placement, and channel modeling; (b) channel quality detection/feedback; (c) eNodeB resource scheduling and allocation; (d) data transmission in PHY layer; (e) calculation of performance indicators (such as system throughput and user fairness) and selection of three types of services, each of which has its own characteristics. An equal number of business-type components are chosen in the simulation.

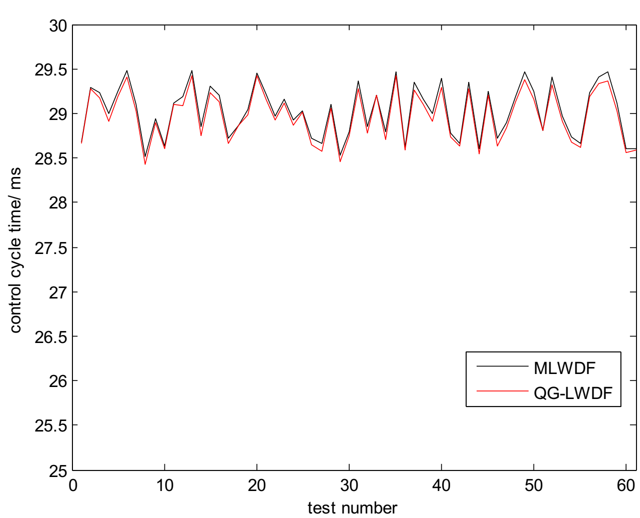

Fig. 5 Control cycle between wireless and PROFIBUS-DP networks

The proposed algorithm is compared with the two-hop MLWDF (TH-MLWDF) algorithm and the TF-QoS algorithm proposed in the literature, mainly in terms of system throughput, user fairness, packet loss rate, user proportion, and algorithm complexity to meet GBR.

4.1 Analysis of protocol conversion time and control cycle results of industrial Internet of Things

Protocol conversion time mainly tests the ability of protocol data processing in protocol gateway. The test methods are as follows: the wireless test device sends special labeled test data packets to protocol conversion gateway, and the protocol conversion gateway begins to parse and record the labeled data packets after detecting them. Receive time t1, then send the data packet to the PROFIBUS-DP data buffer according to the data mapping structure, convert the data packet of the PROFIBUS-DP network, wait for the main station to visit, record the time T2 of the conversion, then the wireless up-conversion to PROFIBUS-DP. The conversion time between WICN and PROFIBUS-DP protocols in gateway is shown in Fig. 4.

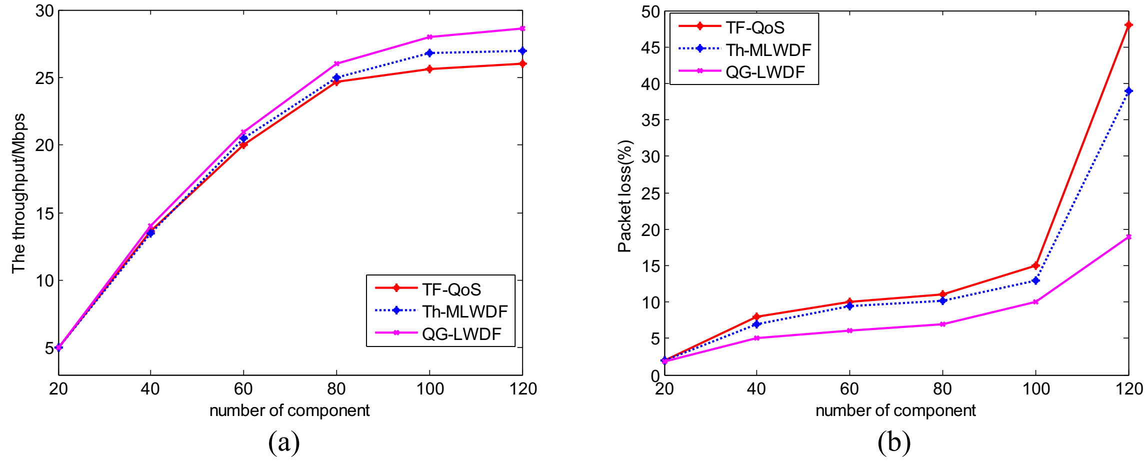

Fig. 6 Comparative analysis of system throughput and packet loss rate performance. **a** Throughput comparison. **b** Packet loss comparison

As shown in Fig. 4, the average up-conversion time is 0.04 ms and down-conversion time is 0.12 ms. The main reason why downlink conversion time is interrupted and larger than up-conversion time is that downlink interface is partially processed by SPC3 protocol chip and gateway CPU. In the case of receiving interruption, data needs to be read from SPC3 data buffer; in the case of upstream, gateway CPU does not need to do this step. It can be seen from Fig. 4 that the up-down conversion time is relatively stable and the real-time performance is very high.

The control cycle period refers to a period of 1 week for signals to be transmitted through a closed-loop control network consisting of two or more networks. In heterogeneous networked control systems, the control cycle is typically a period of data acquisition and transmission from one network's sub-nodes to another network. After processing, the controller sends the control signal to the network where the acquisition node is located.

Cycle making period is an important index for investigating real-time performance of industrial heterogeneous networked control systems. The control cycle between wireless and PROFIBUS-DP networks is shown in Fig. 5.

From the test results of Fig. 5, it can be seen that the control cycle between WICN wireless network and PROFIBUS-DP network is 29 ms, and it has high stability. Because of the complexity of industrial network system in design and use, the test results are presented. The results show that the measurement and control system based on industrial Internet meet the real-time and reliability requirements of wireless network.

4.2 Analysis of network packet loss and throughput

Network delay means that all kinds of data are transmitted through network protocols (such as TCP/IP) in network media. If the amount of information is too large and not limited, excessive network traffic will lead to slow device response and network delay. Data is transmitted in a network by

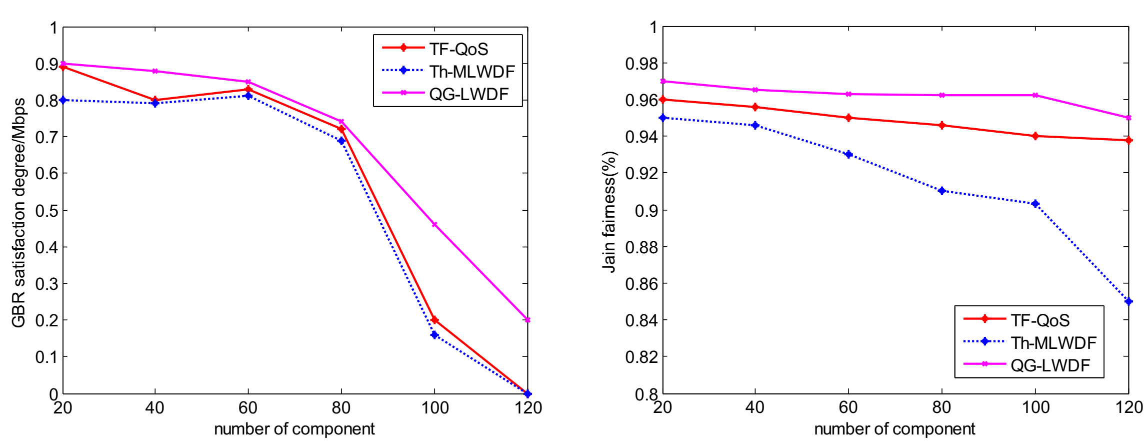

Fig. 7 Comparisons of GBR satisfaction and the Jain fairness performance. (**a**) GBR satisfaction comparison. **b** The Jain fairness performance comparison

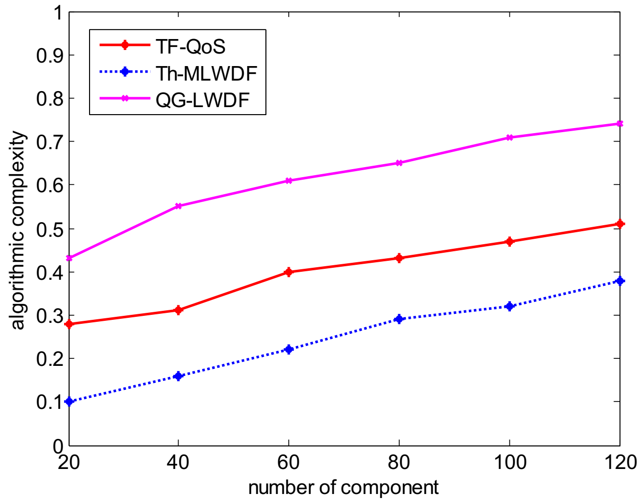

Fig. 8 Comparisons of algorithmic complexity

dividing it into data packets, each of which contains frames representing data information and providing data routing. However, when data packets propagate in general media, a small part of them will be lost due to the distance between two terminals, and most of them will reach the destination terminal. The data in the network is composed of data packets, and the processing of each data packet by the firewall consumes resources. Throughput is the maximum rate that a device can accept without frame loss. The packet loss and throughput are important indicators in the industrial IoT network.

Figure 6 shows the analysis of system throughput curve. With the increase of the number of network components, the throughput of the three algorithms has been greatly improved, which shows that the throughput of the system increases with the increase of the number of components under the condition of system bandwidth. Before the number of components is 80, the system throughput of the three algorithms is similar. Overall, compared with TH-MLWDF and TF-QoS, QG-LWDF improves system throughput to a certain extent.

Because QG-LWDF algorithm assigns higher priority to delay-sensitive users and reduces the number of packet loss, its packet loss rate performance has been improved. As shown in Fig. 6, with the increase of the number of users, the system is in a state of overload, and the packet loss rates of the three algorithms begin to increase rapidly. However, compared with TH-MLWDF and TF-QoS algorithms, the packet loss rate is still greatly reduced. This is because the delay priority factor is reasonably introduced into the priority of QG-LWDF algorithm, and the delay threshold of relay users in access slot is dynamically adjusted, so the delay requirement of real-time traffic can be well met. Figure 6 is a comparison of GBR users with the increase of users when the service type is real time. When the number of users is less than 80, the three algorithms have a high proportion of users meeting GBR needs. The number of users continues to increase, and the system is overloaded. All three algorithms can only meet some GBR needs. The performance of the proposed algorithm is similar to that of TH-MLWDF algorithm, which is superior to TF-QoS algorithm.

4.3 Analysis of GBR satisfaction degree and algorithmic complexity

In this paper, the fairness of different scheduling algorithms is compared by using the Jain fairness algorithm mechanism. The expression of the Jain fair algorithm is:

$$I_{JF} = \left(\sum_{i=1}^{n} x_i^2 \right)^2 / n \times \sum_{i=1}^{n} x_i^2 \tag{9}$$

where x_i represents the average throughput of the ith component.

The Jain fairness curves of the three algorithms are shown in Fig. 7. From the graph, we can see that the Jain fairness curves of QG-LWDF and TF-QoS algorithms are above 0.95, which shows that both can guarantee the fairness of users; while TH-MLWDF algorithm can guarantee the fairness of users when the system resources are relatively sufficient at the beginning, but with the increase of users, the wireless resources are scarce, and the fairness of users is good. It will drop rapidly.

Finally, the time complexity of the three algorithms is compared and analyzed. The average CPU execution time of the corresponding algorithm program is taken as the measure factor of the algorithm complexity. As shown in Fig. 8, the computing time increases linearly with the number of users. As can be seen from Fig. 8, the execution time of QG-LWDF algorithm is higher than that of TF-QoS algorithm and TH-MLWDF algorithm. This is because the introduction of delay control factor and rate control factor of QG-LWDF algorithm, the judgment of service type, and the pre-allocation of resource blocks increase the complexity of computation, so the proposed algorithm is complex. Sacrifices have been made in terms of complexity, but overall improvements are worthwhile relative to other performance improvements.

5 Conclusion

Based on the requirements of industrial Internet of Things in intelligent manufacturing environment, the layered architecture, cross-layer optimization protocol, and key technologies of universal converter for heterogeneous networks of industrial Internet of Things are analyzed. A new architecture of two-layer distributed hybrid industrial Internet of Things is proposed, which combines the advantages of star network and mesh network. Then, with the routing control of network layer, an industrial Internet of Things protocol stack with reliable physical layer, real-time MAC layer, and adaptive network layer is designed. Through a generic conversion architecture that can integrate multiple wirelesses and wired heterogeneous network protocols, flexible configuration of equipment conversion scheduling module for different networks can realize seamless access of multiple wired and wireless terminal nodes.

Furthermore, we propose a resource allocation algorithm to guarantee the QoS requirements based on the idea of M-LWDF algorithm. Considering the system throughput, user fairness, and QoS requirements of different services, resource scheduling and allocation are carried out in the backhaul and access slots of the relay system respectively according to the algorithm. The simulation results show that the proposed algorithm can take into account the performance of both relay users and direct users and achieve high system throughput and fairness, while ensuring the quality of service requirements of direct users and relay users.

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