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ANALYSIS ON THE TMNP- SCHEDULING ALGORITHM FOR INDUSTRIAL WIRELESS NETWORK

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ABSTRACT

In order to improve real-time in industrial wireless network, the TMNP-scheduling algorithm (scheduling algorithm based on throughput maximization of non-periodic communication tasks) is proposed in this paper. The basic principles of TMNP-scheduling algorithm are analyzed, and a theory proof has been finished. The theory proof shows that TMNP-scheduling algorithm optimizes communication window debris. Compared with typical scheduling strategy of application layer in industrial control network, the TMNP-scheduling algorithm improves throughput of non-periodic communication tasks in industrial wireless network. At the same time, the nonlinear programming model is founded to generate scheduling timetable based on TMNP-scheduling algorithm. Finally, a simulation model of industrial wireless network is established. The simulation shows that TMNP-scheduling algorithm is not only effective in reducing time-out problems of periodic communication tasks, but also improving throughput of non-periodic communication tasks.

Keywords: *Performance Analysis, TMNP- scheduling Algorithm, Industrial Wireless Network*

1 INTRODUCTION

If the wireless network technology can be applied to industrial control system, it will not only enhance performance of the wireless signal transmission, but also fully consider characteristics of wireless network at system-level [1]. It is important to improve the system architecture and scheduling strategies [2] [3]. Industrial networked control system mainly assigns resources for control network, and controls scheduling for every subsystem in network. It makes the control system meet real-time [4]. So many scheduling algorithms are proposed for Industrial networked control system [5]-[7]. For example, Zou [7] proposed blend scheduling policy. This scheduling policy assumes that function block and periodic information will be looked as homogeneous real-time tasks. However, wireless network is with high bit-error-rates in industrial environments, the function block tasks and communication tasks are not looked as homogeneity. Therefore, traditional scheduling algorithm must be improved for adapting to industrial wireless network.

2 TMNP- SCHEDULING ALGORITHM

The scheduling of real-time tasks can allocate to tasks and/or resources in some way, and meet tasks requirements of time and resources [8]-[10]. In a macro cycle, when the window size is determined by periodic information, the remaining time is used for transmission of non-periodic information. Non-periodic information is transmitted in remaining time in the macro cycle. In order to express and evaluate TMNP-scheduling mechanism, the throughput of non-periodic information S is expressed as:

$$S = \frac{\sum_{i=1}^{N} \left\lfloor \frac{aw_i}{AT} \right\rfloor \times AT}{MT} \quad (1)$$

Where, N shows the number of communication window in entire macro cycle. aw_i shows the time of *No.i* remainder communication window in the macro cycle. MT shows the macro cycle of scheduling. AT shows the time used to transfer a non-periodic task (without regard to communication failure).

The basic idea of TMNP-scheduling algorithm is that, under meeting the deadline of all periodic communication tasks, we optimized scheduling

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algorithm by reducing the communication window debris. It will improve the theoretical throughput of non-periodic communication tasks. The principle is as follow:

The function block tasks and communication tasks are used different scheduling strategies in same scheduling process. The function block tasks adopt compact scheduling strategy, while the strategy of communication tasks is as follows: considering to execution time of communication task *i*, it will reserve time aw_i. When the time is over, the follow-up task will be allowed to execution. But this time can not exceed deadline of the communication task. It must ensure the value of $\sum_i^N \left\lfloor \frac{aw_i}{AT} \right\rfloor$ maximization. The communication window is reserved for every periodic communication tasks. In an industrial control system, the theory execution time of all periodic communication tasks and the cycle is given. Therefore, regardless of scheduling algorithm, the sum of synchronization window $\sum_i^N sw_i$ is constant values in scheduling timetable. At the same time, the macro cycle *MT* of scheduling timetable is constant. Because $MT = \sum_i^N sw_i + \sum_i^N aw_i$ put out:

$$\sum_i^N aw_i = \text{constant}. \quad (2)$$

Because it is constant, According to the formula (1), if it makes the throughput of non-periodic information *S* maximize, then it must assure that $\sum_i^N \left\lfloor \frac{aw_i}{AT} \right\rfloor$ is maximize. Therefore, the TMNP-scheduling algorithm may obtain to maximizing throughput of non-periodic information.

3 SOLVING SCHEDULING TIMETABLE

The scheduling algorithm of application layer may be different in the industrial network control system, but most of scheduling timetables are achieved by heuristic algorithm. The heuristic algorithm can quickly establish solution, and construct scheduling timetable. But solution has poor quality usually, or it needs to create complex heuristic rules. The TMNP-scheduling algorithm is more complex than other algorithms. It determined deadline and reserve time of every task in all segments. Taking into account deadline of all tasks, the heuristic algorithms need establish extremely complex heuristic rules. It is very difficult to establish heuristic rules. But scheduling timetable has generated in industrial network control system before the system ran. And when the system is running it is always invariant. The generation time of scheduling timetable has not been restricted. So we use the mathematical programming method to solve scheduling timetable of the TMNP-scheduling algorithm.

3.1 Problem Analysis And The Constraint Conditions

If a segment has *n* control loops in an industrial network control system, the cycle of control loop *k* is T_k. The function block tasks and communication tasks will be executed by order in every control loop. If you want to establish constraints of all function block tasks and communication tasks in this segment. Firstly, we must establish constraints of all tasks in every control loop.

Let start time of task *i* in its micro-cycle *j* be expressed by $X(j)_i$ in control loop. Let reserved time of task *i* in its micro-cycle *j* be expressed by $Y(j)_i$.

(1) When the task *i* is communication task, and it has follow-up task, start time of follow-up task is *H*:

$$\text{Constraint condition } \begin{cases} X(j)_i + Y(j)_i \le H \\ X(j)_i \ge (j-1)T_k \end{cases} \quad (3)$$

(2)When the task *i* is communication task, and it has not follow-up task:

$$\text{Constraint condition } \begin{cases} X(j)_i + Y(j)_i \le jT_k \\ X(j)_i \ge (j-1)T_k \end{cases} \quad (4)$$

(3) When the task *i* is function block task, and it has follow-up task, start time of follow-up task is *H*:

$$\text{Constraint condition } \begin{cases} X(j)_i \le H \\ X(j)_i \ge (j-1)T_k \end{cases} \quad (5)$$

(4) When the task *i* is function block task, and it has not follow-up task:

$$\text{Constraint condition } \begin{cases} X(j)_i \le jT_k \\ X(j)_i \ge (j-1)T_k \end{cases} \quad (6)$$

3.2 Establish Mathematical Programming Model

If industrial network control system has *n* tasks in a segment, including function block tasks and communication tasks. The task *i* is communication task, and start time is $x(j)_i$ in cycle *j*. The task *i* is function block task, $f(j)_i$ is start time of task *i* in cycle *j*. There has *m* control loops, the cycle of control loop *k* is T_k. T_{Macro} is macro cycle, its value is the least common multiple of T_k, $k=1,2,\dots,m$. There has *l* micro-cycle in control loop *k*, where $l=T_{Macro}/T_k$. If task *i* is communication task, $Y(j)_i$ is reserved time of task *i* in micro cycle *j*.

Based on the above analysis, we can create a nonlinear programming model to solve scheduling

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timetable of the TMNP-scheduling algorithm, and the model is as follows:

Objective function:

$$\begin{cases} \max \quad z = \prod_{i=1}^{n} \prod_{j=1}^{l} Y(j)_i \\ \max \quad z' = \sum_{i=1}^{n} \sum_{j=1}^{l} Y(j)_i \,\%\, AT \end{cases} \tag{7}$$

Constraint conditions:

$$\begin{cases} x(j)_i + Y(j)_i \le H; x(j)_i \; has \;\; follow-up \;\; task \\ x(j)_i + Y(j)_i \le jT_k; x(j)_i \; has \;\; not \;\; follow-up \;\; task \\ f(j)_i \le H; f(j)_i \; has \;\; follow-up \;\; task \\ f(j)_i \le jT_k; f(j)_i \; has \;\; not \;\; follow-up \;\; task \end{cases} \tag{8}$$

Obviously, this is a multiple objective nonlinear programming problem, if the number of tasks is more, it will solve difficultly. Of course, the scheduling timetable of TMNP-scheduling algorithm can also be used by formula $\max \quad z = \prod_{i=1}^{n} \prod_{j=1}^{l} Y(j)_i$ to solve, and calculated $Y(j)_i/AT$, if it has remaining time s, the all follow-up tasks will be moved forward up s in scheduling timetable. This way can obtain approximate scheduling timetable of TMNP-scheduling algorithm.

The model is a typical nonlinear programming model. If it has a solution, then the solution (include $x(j)_i$ and $f(j)_i$) will compose scheduling timetable of TMNP-scheduling algorithm. If it has no solution, then a set of tasks can not be scheduled.

4 EXAMPLES AND SIMULATION

A simple network control system is made of 9 wireless devices, including 14 function blocks, they consist of four jobs (control loop), and periodic communication tasks have seven. The theory execution time of every task and cycle of every job are shown in Table I. In this section, we will solve schedule timetable of TMNP-scheduling algorithm by above nonlinear programming model, and establish a simulation model.

Table I: Time Parameter of Task

Task		Theoretical Execution time (ms)	period (ms)
Job 1	AI1	10	100
	Data1	10	
	PID2	20	
	AO2	10	
Job 2	AI3	10	300
	PID3	20	
	Data3	20	
	AI4	20	
	Data2	10	
	PID5	30	
	AO5	10	
	Data4	20	
Job 3	AI6	20	200
	PID6	50	
	Data5	30	
	AO7	10	
	Data6	10	
Job 4	AI8	10	100
	Data7	10	
	PID9	50	
	AO9	20	

4.1 Simulation Model

As shown in Figure 1, the model is divided into six modules: the periodic data generating module (gen_period_packet), the non-periodic data generating module (gen_nonperiod_packet), the task queue module (task_queue), the MAC protocol module (CSMA/CA), the wireless receiving module (wireless_receiver) and the wireless transmission module (wireless_transimitter).

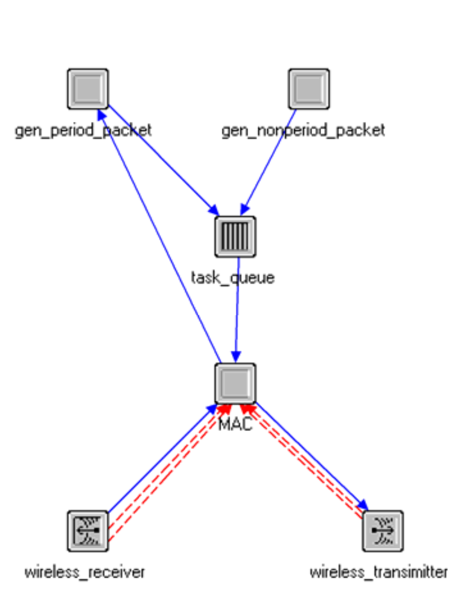

Figure 1: The Node Model

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According to the system and nonlinear programming model, we establish the network simulation model in the scope of 100m * 100m. Its main simulation parameters are shown in Table II, and other parameters of physical layer and MAC layer is default configuration.

Table 2: Main Simulation Parameters

Node type	simulation parameters	value
Device node	data size	128~512bytes
	non-periodic packet generation rate	20~40 pkts/sec
	maximum transmission rate	11M
	communication radius	100m
	working frequency	2.4~2.483GHz

4.2 Simulation Results

In five hours, periodic data will be generated according to the scheduling timetable, and the scheduling timetable is produced by above nonlinear programming model. The generating rate of non-periodic data increases from 1 to 20pkts/sec. The average overtime rate of packets is shown in Figure 2.

The simulation results show that scheduling timetable of TMNP-scheduling algorithm is more suitable for characteristics of radio channel. It reduces the overtime phenomenon of the communication tasks effectively (especially the periodic communication tasks), and improves the throughput of non-periodic communication tasks.

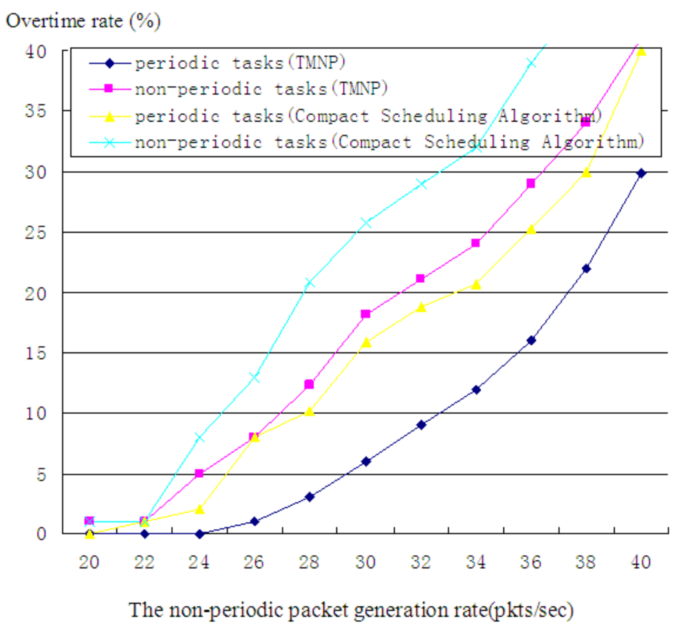

Figure 2: The Average Overtime Rate Of Packets

5 CONCLUSION

Although the network delay is reduced, the real-time of system can be improved. But if the delay is unchanged, and you may improve scheduling mechanism of tasks at high-level, the real-time can be improved too. This paper's purpose is improving real-time performance in industrial wireless network by scheduling strategy on application layer. It will provide a solution, an idea, theoretical basis or practical guidance. It is useful for research of industrial wireless network.

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REFRENCES:

[1] W. Lang, P. Zeng, "Internet of Things Technology and Application Oriented Industrial Automation", Instrument Standardization & Metrology, Vol. 1, No. 5, 2010, pp. 21-24.

[2] G. Cena, I.C.Cena, A. Valenzano, "Evaluation of Response Times in Industrial WLANs", IEEE Transactions on Industrial Informatics, Vol. 11, No. 3, 2007, pp. 191-201.

[3] C. M. Krishna,kang G. Shin.Real-time Systems.Beijing: Tsinghua University Press,2004.9.

[4] J.Xu, "Multiprocessor scheduling of processes with release times, deadlines, precedence, and exclusion relations", IEEE Transactions on Software engineering, Vol. 19, No. 3, 1993, pp. 139-154.

[5] J.M. Wassick, J. Ferrio, "Extending the resource task network for industrial applications", Computers & chemical engineering, Vol. 35, No. 10, 2011, pp. 2124-2140.

[6] L. Shaohe, Z. Weihua,W. Xiaodong, "Link scheduling in wireless networks with successive interference cancellation", Computer networks, Vol. 55, No. 6, 2011, pp. 2929-2941.

[7] Y. Yongming, X. Duan,L. Luo, "Wireless Sensor Network Time Synchronization Design for Large Generator On-Line Monitoring," Sensor Letters, Vol. 9, No. 2, 2011, pp. 1467-1471.

[8] A. Willig, "Transmission reliability in wireless industrial LANs," IEEE Transactions on Industrial informaitics, Vol. 91, No. 22, 2005, pp.173-182.

[9] D.Peng, K.G.Shin, T.K.Abdelzaher, "Assignment and scheduling communication period tasks in a distributed real-time system", IEEE Trans Software engineering, Vol.23, No.2, 1997, pp. 745-757.

[10] L. Angrisani, M. Bertocco and D. Fortin, "Experimental Study of Coexistence Issues Between IEEE 802.11b and IEEE 802.15.4 Wireless Networks", Instrumentation and Measurement, Vol.57, No. 8, 2008, pp. 1514 - 1523.