Research Journal of Applied Sciences, Engineering and Technology 4(20): 3891-3895, 2012
ISSN: 2040-7467

Submitted: December 18, 2011 Accepted: April 20, 2012 Published: October 15, 2012

A Scheduling Algorithm Based on Communication Delay for Wireless Network Control System

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Abstract: In this study, a scheduling algorithm based on communication delay is proposed. This scheduling algorithm can tolerate delay of periodic communication tasks in wireless network control system. It resolves real-time problem of periodic communication tasks in wireless network control system and partly reduces overtime phenomenon of periodic communication tasks caused by delay in wireless network. At the same time, the nonlinear programming model is built for solving scheduling timetable based on the proposed scheduling algorithm. Finally, the performance of the proposed scheduling algorithm is evaluated by an application example. The statistics results show that it is more effective than traditional scheduling algorithms in wireless network control system.

Keywords: Communication delay, real-time, scheduling algorithm, wireless network control system

INTRODUCTION

There has been an increasing need of real-time and reliability for automated factories, multi-robot cooperation system and industry control system (Mourikis and Roumeliotis, 2006). For example, an automated factory is usually composed of several workgroup, each of which contains so many devices such as robots, sensors, transport equipments and so on. All devices in a workgroup are connected via a local area network. Multiple workgroups are connected by network too. The system monitors and controls manufacturing equipment by a number of cooperating tasks and these tasks communicate with each other via the underlying network in industrial network control system. The scheduling algorithm may provide real-time and predictable scheduling timetable for communication tasks (Ching and Shin, 1995).

Since wireless channels are prone to transmission errors caused by channel outages and interference, the requirements of real-time and reliability are more likely to be jeopardized than wired channel in industry control system. This is one of the key issues to be resolved in wireless network control system (Willig *et al.*, 2005). The above problem can be resolved in two aspects generally. On the one hand, the robustness of wireless techniques must be improved on the industrial environment by designing protocols and mechanisms at physical, data link and network layers. On the other hand, at the industrial network control system level, those adverse effects can be (partially) compensated by designing real-time scheduling algorithms (Khalgui *et al.*, 2006).

In this study, the scheduling algorithm for wireless network control system is discussed. We present scheduling algorithm based on communication delay. This scheduling algorithm can tolerate delay of periodic communication tasks in wireless network control system. Meanwhile, we proposed the nonlinear programming model for solving scheduling timetable based on the proposed scheduling algorithms. Finally, an example shows the scheduling process of periodic communication tasks and FB tasks. It shows the performance of the GTD for the wireless network control system. It is more effective than traditional scheduling algorithm in wireless network control system. The study will be useful to engineer and researchers for the design of scheduling mechanism.

SCHEDULING ALGORITHM FOR INDUSTRIAL NETWORK CONTROL SYSTEM

The industrial network control system is a distributed real-time control system, it requires real-time scheduling algorithm to solve the scheduling of FB (function block) tasks and communication tasks. The communication tasks are non-preemptive in the industrial network control system. That is, a communication task once started and it must be finished (Khalgui *et al.*, 2006).

Many scholars have already done a lot of work for non-preemptive and real-time scheduling. Xu and Parnas, (1990) proposed scheduling algorithm with task constraints for multi-processor. This method solve multi-processor scheduling problem, but it did not consider that communication tasks will impact on tasks scheduling in different processors.

Peng *et al.*, (1997) considered different communication tasks in different processors, and studied tasks scheduling for communication tasks and FB tasks

(Lu, 2005). But they assumed that communication tasks and FB tasks have a fixed delay. Tovar (Cabral *et al.*, 2006) detailed tasks scheduling of the fieldbus control system in first and he did many pioneering work. The tasks scheduling of single segment will be looked as tasks scheduling of a single processor in scheduling algorithm. The scheduling algorithm assumes that cycles of all communication tasks are independent. However, FB tasks need communicate with each other by communication tasks in industrial network control system. So the communication tasks will be often constrained by execution order of FB tasks.

Zhou *et al.* (2001) proposed compact scheduling algorithm based on union scheduling policy and this is traditional scheduling algorithm. Its scheduling policy is combining of the periodic communication tasks scheduling and FB tasks scheduling. At first, function block and periodic communication will be looked as homogeneous real-time tasks and they are considered the order of tasks. The traditional scheduling algorithm makes every job completed as early as possible. After the previous task is finished, the next task is executed immediately. Of course, the release time of next task can not pass the finish time of previous task. Meanwhile, the deadline of previous task can not be delayed to release time of the next task. This method guarantees a certain execution order of periodic communication tasks and FB tasks and effectively improves the channel utilization, reduces fragmentation of communication channel, provides more channel time for the non-periodic communication tasks.

However, the communication errors of wireless channel are frequently multiple in industrial environments. The communication errors of cable channels are rare, the FB tasks and communication tasks can not be looked as homogeneity. This condition does not hold. So we proposed a scheduling algorithm based on communication delay. This scheduling algorithm can tolerate delay of periodic communication tasks in wireless network control system.

SCHEDULING ALGORITHM BASED ON COMMUNICATION DELAY

The wireless channel influences the design of scheduling algorithm in wireless network control system. Some of the existing scheduling algorithms/models disagree with the characteristics of wireless technology (Wei and Yu, 2003; Ma *et al.*, 2004; Franco and Silva, 2005; Park and Cho, 2010). They face serious degradation question in wireless network control system. That is to say, the requirements of real-time and reliability aren't satisfied. Therefore, traditional scheduling mechanism for wired network control system must be improved. This study proposes a scheduling algorithm based on communication delay. This scheduling algorithm can tolerate delay of periodic communication tasks and adapts to characteristics of wireless communication in industrial network control system.

Concept definition: In this study, we regard field device and communication channel as processor. Field device deals with FB tasks and communication channel transmits messages (deals with communication tasks). It is obvious that a task is a basic executed unit in a control loop. In another word, a control loop is composed of so many tasks with order constraints.

In order to express the scheduling algorithm, some basic concepts are as follow: Ma *et al*. (2004).

Definition 1: Periodic task: Generating information at regular intervals.

Definition 2: Non-periodic task: Generating information at irregular intervals.

Definition 3: The macro cycle of tasks: The least common multiple of all tasks periodic.

Definition 4: The relaxation time of task: The allowed waiting time of maximum in buffer or queue.

Definition 5: Task timeout: If finishing time of task exceeds its absolute deadline, this is called task timeout.

Definition 6: Job: It is a set of tasks in a control loop.

Scheduling mechanism: The basic ideal of the scheduling algorithm based on communication delay is as follows: In consideration of the instability of wireless channel, we use different scheduling policies for scheduling of FB tasks and periodic communication tasks respectively. The traditional scheduling mechanism is used to schedule FB tasks, while the scheduling of periodic communication tasks adopts an opposite scheduling policy. A periodic communication task is early scheduled at the beginning of release time of task and the next task can not be scheduled until absolute deadline time of the periodic communication task. It possibly reserves longer processing time for a periodic communication task. At the same time, we make use of redundant data path in wireless network to make up the instability of wireless channel. All communication tasks of different piconets are allocated in the macro cycle. Accordingly, the communication capacity is widened in wireless network control system.

To realize the above scheduling algorithm, we defines $R[i][j]$, $C[i][j]$ and $D[i][j]$ to, respectively represent first release time, execution time and deadline of task j on job i. $S[i][q][j]$ and $F[i][q][j]$ are adopted to save start time and finish time of task j on job i in the q^{th} micro cycle. The pseudocode description of scheduling algorithm is as follows:

```
Sort_job(job[i]);
// sorting job[i] according to their priorities.
for p = 1 to k
//processing scheduling tasks in piconet p.
{for i = 1 to m
// processing job[i].
{if the job[i] utilize piconet p then
{time = 0;
n[i] = macrocycle/T[i];
 // job[i] should be executed n[i] times in a macrocycle.
Sort_ task(task[i][j]);
// sorting task[i][j] in job[i] according to their release time R[i][j] from j to (fp[i]+ cp[i]).
for q = 1 to n[i]
 // seting the qth micro cycle schedule for job[i].
{for j = 1 to (fp[i]+ cp[i])
 // j is index of a task in job[i].if task[i][j]is a communication task then
{for t = time to (R[i][j]+(q-1)* T[i])
Idle;
S[i][q][j] = R[i][j] + (q -1)* T[i];
// seting start time of task[i][j] in the qth micro cycle.
time = S[i][q][j]+(C[i][j]+(q -1)* T[i]);
if (time>(D[i][j] + (q-1)* T[i]) then
{startup overtime process;
}
else
//reserving maximal scheduling time.
{for t = time to (D[i][j] + (q-1)* T[i])
Idle;
F[i][q][j] = (D[i][j] + (q-1)* T[i]);
// F[i][q][j] is preassigned finish time of task[i][j] in the qth micro cycle.
time = (D[i][j] + (q-1)* T[i]);
}
}
else
// task[i][j]is a FB task.
{process on compact mode.
}
}
} // for q = 1.
} // for i = 1.
} // for p = 1.
```

The nonlinear programming model for solving scheduling timetable: Let $Y(j)_i$ denote the reserved time of the i^{th} periodic communication task in the j^{th} micro cycle. $X(j)_i$ is the start time of the i^{th} task in the j^{th} micro cycle and let $x(m)_i$ and $y(m)_i$ denote the start time and finish time of task i in the m^{th} micro cycle.

The nonlinear programming model for solving scheduling timetable is as follows:

Objective function:

$$\max z = \prod_{i=1}^{n} \prod_{j=1}^{l} Y(j)_i \tag{1}$$

Table 1: Times parameters of tasks

Task		Execution time (ms)	Microcycle (ms)
Job 1	AI1	20	200
	Data1	10	
	PID2	50	
	AO2	20	
Job 2	AI3	30	400
	PID3	60	
	Data3	20	
	AI4	30	
	Data2	20	
	PID5	60	
	AO5	30	
	Data4	20	
Job 3	AI6	40	400
	PID6	80	
	Data5	30	
	AO7	40	
	Data6	30	
Job 4	AI8	30	200
	Data7	20	
	PID9	60	
	AO9	30	

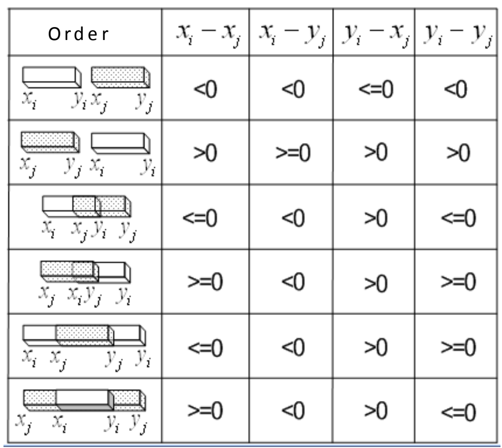

Fig. 1: The order relations of two communication tasks

Constraint condition:

- The k^{th} control loop:

$$\begin{cases} x(j)_i + Y(j)_i \le F(j)_i \\ x(j)_i + Y(j)_i \le jT_k \\ x(j)_i \ge (j-1)T_k \end{cases} \tag{2}$$

- Constraint condition of non-overlap communications tasks

According to the previous Fig. 1, we can deduce constraint condition (3):

$$(x(m)_i - y(n)_j)(y(m)_i - x(n)_j) \ge 0 \tag{3}$$

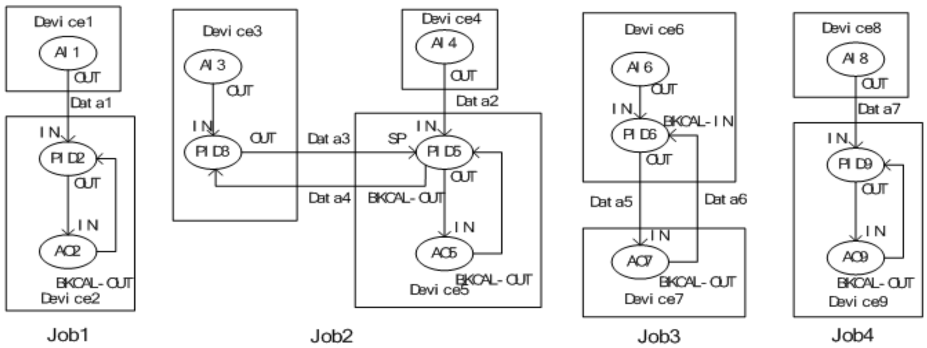

Fig. 2: A simple network control system configuration

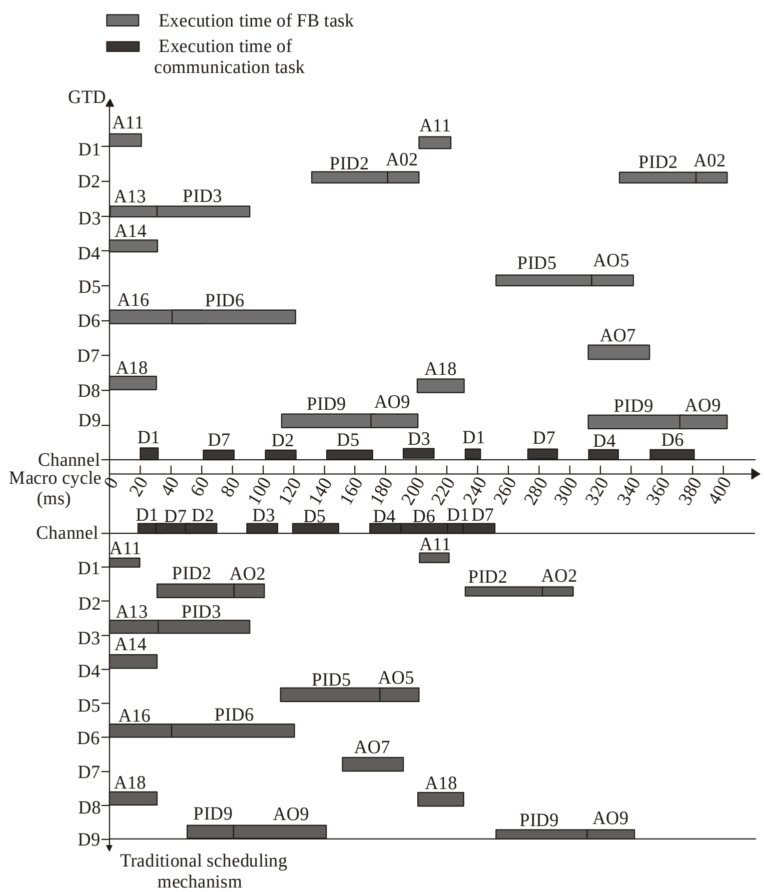

Fig. 3: The scheduling timetables

APPLICATION

A simple network control system is shown in Fig. 2. There are four independent jobs in 9 wireless devices. It consists of 14 FB tasks and 7 periodic communication tasks in the system. Table 1 shows the time parameters of all tasks. Considering the execution sequence, the scheduling timetables are constructed, respectively by scheduling algorithm based on communication Delay (GTD) and traditional mechanism. The execution time of all tasks in the system is shown in Fig. 3 From the scheduling process of all tasks in a macro cycle, the scheduling of periodic communication tasks is dispersed, but it has not gone beyond the limits of deadline.

Because all periodic communication tasks have remained time slot, when transmission errors appear, overtime phenomenon can be partially compensated in wireless channel by the remained time slot. However, the redundant time has not been left for retransmission in traditional scheduling mechanism.

Table 2: Statistics of experimental results

	FB task			Communication task			Total		
	task number	overtime task number	overtime rate (%)	task number	overtime task number	overtime rate (%)	task number	overtime task number	overtime rate (%)`
GTD	9546	641	6.71	18358	1235	6.73	27904	1876	6.72
Traditional scheduling mechanism	9651	718	7.44	18672	1843	9.87	28323	2561	9.04

The Table 2 shows that the GTD esolves real-time problem of periodic communication tasks in wireless network control system, and partly eases overtime phenomenon of periodic communication tasks caused by delay in wireless network.

CONCLUSION

Wireless technology can bring many benefits to industrial network control system. However, wireless technology have not gained widespread acceptance at the factory floor. One reason is the difficulty in achieving the real-time and successful transmission of packets by error-prone wireless channels. Owing to the problem of wireless technology in industrial network control system, the scheduling algorithm for wireless network control system is discussed in this study. We present scheduling algorithm based on communication delay. This scheduling algorithm can tolerate delay of periodic communication tasks in wireless network control system. Meanwhile, we proposed the nonlinear programming model for solving scheduling timetable based on the proposed scheduling algorithms. Finally, an example shows the scheduling process of periodic communication tasks and FB tasks. It shows the performance of the GTD for the wireless network control system. It is more effective than traditional scheduling algorithm in wireless network control system. The study will be useful to engineer and researchers for the design of scheduling mechanism.

ACKNOWLEDGMENT

This study was supported by Natural Science Foundation of Liaoning Provincial (No. 20102178) and Liaoning Provincial Office of Education Fund of China (No. 2009S078 and No. 2009B149).

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