Harmonic-Aware Scheduling For Fixed-Priority Real-Time Systems

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Abstract -This paper discusses a semi-partitioned fixed priority scheduling of sporadic tasks on identical multi-processors based on Rate Monotonic scheduling. A well known fixed-priority algorithm is the rate-monotonic algorithm. This algorithm assigns priorities on their periods: shorter the period, higher the priority. The rate of a task is the inverse of its period. Hence, the higher is the rate, higher its priority. Performed work deals with the following. First, we use the harmonic property for a task set. Harmonic property means task with periods being integer multiples of each other that has been widely studied on uniprocessor system. We developed one example with harmonic property in semi-partitioned scheduling. Two semi-partitioned approaches are developed. The first scheduling approach-1 for the tasks with utilization factor of each task no more than 0.5. The second one, scheduling approach-2, is developed for more general task sets, i.e. the utilization factor of each task is no more than 1.

Index Terms- harmonic, real-time semi-partitioned scheduling, fixed priority, RMS.

I. INTRODUCTION

Systems are referred to as real-time when their correct behaviour depends not only on the correctness of operations which they perform but also by their accomplished time. Nowadays, these system present in a vast variety of embedded systems such as automotive/avionic control system, military applications and environmental monitoring systems.

A real Time System (RTS) is a computer-controlled mechanism in which there are strict timing constraints on the computer's actions. In other words, the correctness of the system depends not only on the logical computational result, but also on the time at which the results are produced. Such systems can be simple like alarm clock or can be the most complex systems built. Real-time systems are classified in two categories: soft and hard. Hard-Real-Time system, which must meet its deadline, otherwise it will create undesirable damage or a fatal error to the system. Soft-Real-Time System has an associated deadline that is desirable but not mandatory, it still o schedule and complete the task even if it has passed its deadline. It is considered hard if it can guarantee that a certain event will always be carried out in less than a specific time and failure to respond to the event may cause a catastrophe, which is intolerable. The important part of such a system is the scheduling algorithm that decides on the timing, preemption, and resuming of requests.

Liu and Layland discovered the famous utilization bound N $(2^{1/2}-1)$ for fixed priority scheduling on uniprocessor in the 1970's [1]. The purpose of utilization bound is to test the scheduling of real time task sets with simple and practical way. Utilization bound can also be used as a metric to evaluate the quality of scheduling algorithms. A hard real-time system must execute a set of concurrent real-time tasks in such a way that all time-critical tasks meet their specific deadlines. Every task needs computational and data resources for job completion. The scheduling problem is concerned with the allocation of the resources to satisfy the timing constraints.

In multi-core processor platforms, there are various processors available upon which these jobs may execute. In uniprocessor platforms, there is exactly one shared processor available. Two approaches traditionally considered for scheduling algorithms are Rate monotonic Scheduling (RMS) and earliest Deadline First (EDF) scheduling, which have been proven to be optimal for uniprocessor scheduling [2]. Hence when the problem comes towards multi-core platforms, these uniprocessor scheduling algorithms are no longer optimal [3] because in multi-cores systems, there is need to decide where to execute a real- time task.

There have been large numbers of researches published on real-time scheduling for multi-core systems [4-8]. These scheduling algorithms consist of two parts [9, 10]: the partitioned approach (e.g. [4]) and the global (or non-partitioned) approach (e.g. [5]). In the partitioned scheduling approach, each task is assigned to a processor beforehand at runtime each task can only execute on this particular processor. All instances from the same task will be executed solely on that particular processor. In the global scheduling approach, each real-time task is assigned to available processor at run time. Both approaches have their own advantages and disadvantages, and none of them dominates the other in terms of schedulability [9].

Recently a multi-core scheduling approach [4, 5, 11-13] i.e. is called semi-partitioned scheduling approach for the purpose of improving schedulability with succeeding the advantage of partitioned scheduling as much as possible. In semi-partitioned scheduling, most tasks are assigned to one particular processors to reduce runtime overhead, and a few tasks are split into several subtasks to be assigned on the different processors. Semi- partitioned approach has been shown to be sound and practical in the real implementation

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and theoretically, have the greatest achievement compared to the global and the partitioned approaches [2, 14, 15]. According to the prior work, a class of semi-partitioned scheduling offers a significant improvement on schedulability, as compared to a class of partitioned

scheduling, with less preemptions and migrations than a class of global scheduling. However, little work has studied on fixed priority algorithms.

II. PROBLEM FORMULATIONS

This section discusses the formulation of problem. The problem of semi-partitioned scheduling of sporadic tasks on multi-core platform based on RMS policy.

A. Problem model:

We consider a multi-processor platform consisting of M processor i.e. $P = \{P_1, P_2, ...P_M\}$.

A task set $T = \{t_1, t_2...t_N\}$ consist of N sporadic tasks. Each task t_i is characterized by a tuple (e_i, p_i) ,where e_i is the worst-case execution time of t_i and p_i is the minimum interarrival time between any two consecutive requests of t_i. p_i is also called period of t_i.
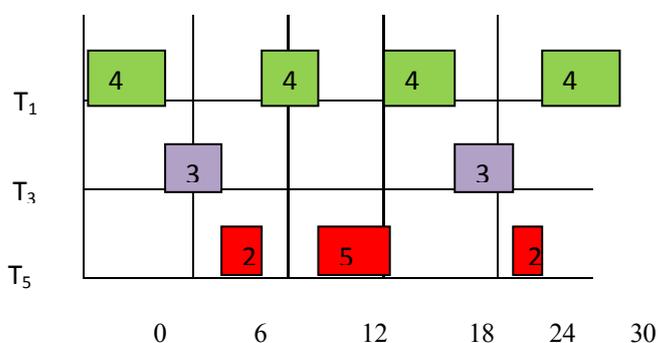
We make some assumptions:

1) The deadline of each task is identical to its period;
2) T is sorted with decreasing priority order, i.e. task t_i has higher priority than t_j if i<j
3) We use RMS strategy to assign the priorities: task with shorter periods have higher priority.
4) The utilization of a task set is less than or equal to Liu&Layland bound.

B. Example:

A task set with five real-time tasks and their scheduling is shown in Table 1 and Figure 1 respectively.

Table 1: A task set with five real-time tasks

T_i	e_i	p_i	u_i
1	4	9	0.44
2	6	10	0.6
3	3	18	0.16
4	2	20	0.1
5	15	30	0.5

(a) Processor 1

The utilization factor of a task t_i is denoted as u_i where

$$u_i = \frac{e_i}{p_i} \qquad (1)$$

The total utilization of a task set T is denoted as U (T) where
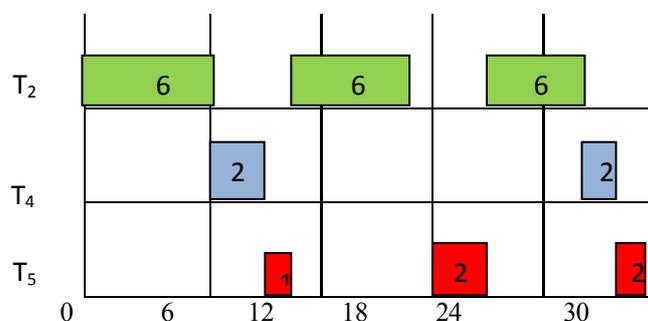
$$U(T) = \sum_{t_i \in T} u_i \qquad (2)$$

The system utilization of task set T on a multi-core platform with M processors is denoted as $U_M(T)$, where

$$U_M(T) = \frac{U(T)}{M} \qquad (3)$$

Liu and Layland [5] showed that a task set T can be feasibly scheduled by RMS on a uniprocessor if

$$U(T) \leq \theta(N) = N(2^{1/N} - 1). \qquad (4)$$

Θ (N) is also traditionally referred to as the Liu&Layland bound.

(b) Processor 2

Fig. 1: Allocation fails when simply grouping harmonic

tasks and assigning them to the same processor.

Consider a two-processor platform with a task set as shown in Table1. Since T_1 and T_3 are harmonic, we can group T_1 and T_3 to one processor, i.e. Processor 1. Similarly, we can group T_2 and T_4 to the other processor, i.e. Processor 2. Since no processor can accommodate T_5 entirely, we have to split T_5 between these two processors. With this assignment, there are two problems. First, as shown in Figure 1(a), the maximum capacity that can be accommodated in Processor 1 is 9. Since the subtasks from T_5 cannot be executed concurrently on two processors, at most 5 time units from Processor 2 can be utilized by T_5 as shown in Figure 1(b). As a result, T_5 cannot complete before its deadline. Second,

in order to use all 5 time units on Processor 2, we need complicated process migration controls and synchronization mechanisms. Note that, if we assign T_1 and T_5 to one processor, and the other tasks to another processor, it is easy to verify that the schedule is feasible.

From this example, to take the advantage of harmonic relationship among tasks to improve the feasibility a critical problem is how to wisely select the task to split and to among different processors. To solve this problem, two scheduling approaches are proposed, namely, approach-1 and approach-2.

III. Scheduling approach-1

We introduce first approach i.e. Scheduling approach-1 with utilization is no more than 0.5. To improve the scheduling performance, we use the harmonic relationship in which it is not necessary that all tasks in the same task set are strictly harmonic. We always select the processor with minimal total utilization of tasks. Approach-1 assigns tasks to processors in increasing priority order. A task can be assigned to the current processor, if all tasks on current processor can meet their deadline. If a task cannot be accommodated entirely by any processor then we split task into two parts. The first part is assigned to the current processor and the second part is assigned to the next processor.

We used the worst-fit strategy. These approaches used the task splitting technique to get as high priority as possible on each processor. To split a task, we adopt a simple heuristic that assigns subtasks to the processor with the highest available capacity.

Scheduling Approach-1:

Require: utilization is less than or equal to 0.5, T= {t_1, t_2,..t_N} and *P= {P_1, P_2,....P_M}*

1: **while** there is non_full processor and an unassigned task **do**

2: t_i : the task with the lowest priority in T;

3: P_m: the processor with minimum harmonic index in *P*;

4: **if** T_{Pm} +τ_i is feasible **then**

5: $t_i \rightarrow P_m$;

6: **end if**

7: **if** P_m = the processor with the maximum capacity (greater than 0) for t_i; **then**

8: Task is assigned entirely

9: **else**

10: Split task t_i and assigned part of t_i to the processor until it is maximally utilized;

11: **end if**

12: **end while**

13: **if** there is unassigned task **then**

14: Return "Succeed if all tasks are allotted";

15: **else**

16: Return "Allocation Failed";

17: **end if**

T is the list of accommodating unassigned tasks, sorted and a multiprocessor system *P*. Approach-1 makes the assignment decision for each task through the "while" loop from line 1 to line 12. Among all unassigned tasks left in T, we select the task t_i with the lowest priority. t_i *is* assigned to the processor with the minimum harmonic index. Harmonic index i.e. to measure the harmonicity of a task sets. If this assignment fails, then split occurs. We choose the processor with the maximum execution capacity for t_i. We assigned t_i entirely since there is maximum capacity available on processor. Otherwise, we split t_i into two subtasks t_i^1 , t_i^2 and assign that part of t_i to the processor until it is maximally utilized.

IV. Scheduling approach-2

In the following, we introduce second semi-partitioned fixed-priority scheduling approach i.e. Scheduling approach-2, which is developed for general task set. Scheduling approach-2 pre-assigns exactly the heavy tasks for which pre-assigning them will not cause any tail subtask to miss deadline.

Scheduling approach-2 contains three steps:

1) First, we pre-assign the heavy tasks that satisfy a particular condition to one processor each in decreasing priority order.

2) We do task partitioning with the remaining tasks and remaining processors using Scheduling approach-1 until all the normal processors are full.

3) The remaining tasks are allocated to the pre-assigned processors; the assignment selects one processor with lowest priority pre-assigned task to assign as many tasks as possible, until it becomes full, then select the next processor.

The main idea of scheduling approach-2 is to pre-assign each heavy task whose tail subtask might get a low priority, before partitioning other tasks, therefore these heavy tasks will not be split. If one simply pre-assign based all heavy tasks, it is still possible for some tail subtask to get a low priority level on its host processor.

In Scheduling approach-2, the pre-assignment for heavy tasks follows the same strategy as introduced in [6]. Specifically, for any heavy task t_i let PR_i^E denote the set of empty processors before t_i assignment and $\left| PR_i^E \right|$ denote the number of processors in this set. Then a heavy task t_i needs to be pre-assigned to an empty processor if

$$\sum_{j>i} u_j \le \left(\left| PR_i^E \right| -1 \right).\Theta(N)$$

There is an important difference between assigning tasks to remaining (normal) processors and to pre-assigned processors. When tasks are assigned to normal processors, the approach always selects the processor with the minimal (the same as in approach-1). In the contrast, when tasks are assigned to pre-assigned processors, always the processor at the front of PR_{pre} is selected, i.e., we assign as many tasks as possible to the processor in PR_{pre} whose pre-assigned task has the lowest priority, until it is complete.

In this approach, we use grid simulation toolkit. The GridSim toolkit allows modeling and simulation of entities in parallel and distributed computing (PDC) systems-users, applications, resources, and schedulers for design and evaluation of scheduling algorithms.

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Scheduling approach- 2:

Require: Task set: T = {t₁,t₂ ..t_N}, Multiprocessor: *PR = {P₁, P₂...P_M}*, Grid simulation.

1: Heavy tasks are pre-assigned to empty processor set denoted as PR_{Pre} ;
2: **for** i = 1 to N **do**
3:      **if** utilization is less than or equal to 0.5 and $\sum_{j>i} u_j \le \left(\left|PR_i^E\right|-1\right).\Theta\left(N\right)$ **then**
4:      tasks are assigned to the processor|;
5:      **end if**
6: **end for**
7: **while** there is non_full processor and an unassigned task **do**
8:      t_i: the task with the lowest priority in T
9:      t_j: the task with the lowest priority in T_{PRpre} ;

10:      **if t**$_i$ has higher priority than t$_j$ **then**
11:      Push *PR* (t$_j$) from PR_Pre to PR;
12:   **end if**
13:   P_m: = the processor with minimum harmonic index in PR;
14:   **if** T$_{Pm}$ +t$_i$ is feasible **then**
15:      Assign τ$_i$ to processor *PRm*;
16:      Continue;
17: **end if**
18: PR_m: the processor with maximum capacity for t$_i$ in *PR*;
19 **if** PR_m does not exist, **then** Break, **end if**
20: **if** T$_{PRm}$ +t$_i$ is feasible **then**
21:      Assign t$_i$ to processor *PRm*;
22: **else**
23:      Split task t$_i$ and assigned part of t$_i$ to the processor until it is maximally utilized;
24:   **end if**
25: **end while**
26: **if** Task is unassigned to the processor **then**
27:   Return "Succeed if all tasks are allotted";
28: **else**
29:   Return "Allocation Failed";
30: **end if**

V. Conclusion

Two approaches are developed a semi-partitioned scheduling approach for scheduling real-time sporadic tasks on multi-core platform based under RMS policy. We used harmonic property for periodic tasks. Harmonic property is task with period being integer multiples of each other. To improve the schedulability we take harmonic relationships among the tasks. Scheduling approach-1 for task sets with utilization is no more than 0.5 and scheduling approach-2 general task with utilization is no more than 1. In first approach, we used worst-fit strategy i.e. we select the processor with minimal total utilization of task that assigned to it. Since accommodate capacity is increased. In second approach, we used grid simulation toolkit.

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