On-Line Real-Time Task Scheduling on Partitionable Multiprocessors

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Abstract

Multiprocesssor systems have emerged as an important computing means for real-time applications and have received increasing attention than before. However, until now, little research has been done on the problem of on-line scheduling of parallel tasks with deadlines in partitionable multiprocessor systems. In this paper, we propose a new on-line scheduling algorithm, called Deferred Earliest Deadline First (DEDF) for such systems. The main idea of the DEDF algorithm is to defer the scheduling as late as possible, so that a set of jobs is scheduled at a time instead of one at a time. For processor allocation using DEDF, we have introduced a new concept - Available Time Window (ATW). By using ATW, the system utilization can be improved and thereby enabling the system to meet the deadline of more number of tasks. Simulation results for a hypercube indicate that the DEDF algorithm performs significantly better than the earlier proposed Buddy/RT and Stacking algorithms for a wide range of workloads.

1 Introduction

A real-time system is a system in which correctness of the computation depends not only on the logical correctness of the execution, but also on the timeliness of producing results. To function correctly, it must produce a correct result within a specified time, called deadline. The system is considered failed if the time constraints are not met.

Scheduling of aperiodic tasks on real-time systems is one of the most difficult problems in the design of real-time systems. Aperiodic tasks have random arrival time. Due to their unpredictable nature in terms of arrival time and service demand, it is very difficult to design real-time systems that have a high guaranteed rate of servicing aperiodic tasks successfully. It is often desirable to schedule tasks in a prioritized manner in order to meet the deadline of the most important tasks. The characteristics of the aperiodic tasks are not known a priori and the scheduling decisions are made upon their arrival. Thus arises the need for on-line scheduling of tasks. The functionality of the on-line scheduler can be described as follows. When a new job arrives, its service demand (execution time and subcube size) and deadline are made known to the on-line scheduler. The scheduler then decides whether the new job along with all the old jobs can finish their execution before their respective deadlines. If it is not possible then the scheduler tries to accommodate as many jobs as possible based on the specified allocation algorithms and task priorities. The jobs that cannot be serviced before its deadline are not accepted by the system. The scheduler must make decision dynamically and quickly so as to have a high ratio of job acceptance and low scheduling overhead.

Multiprocessor system are emerging as potential candidates for use in real-time applications [9]. Hypercubes and mesh-connected multiprocessors are well-suited for use as real-time control units due to their high scalability, reliability and throughput. An additional advantage of these system is their ability to be partitioned into subsystems each of which can be allocated to a different job. An efficient scheduling algorithm is required for allocating multiple jobs on a partitionable real-time multiprocessors. Dynamic scheduling of real-time tasks on partitionable multiprocessor systems is an ongoing and active research area. Determination of an optimal scheduling or allocation scheme is known to be an NP-hard problem [7, 9]. In this paper, we propose a new on-line scheduling scheme for hypercube-based real-time multiprocessor system.

The on-line scheduling scheme proposed in this paper is called Deferred Earliest Deadline First (DEDF) algorithm. The main idea of DEDF is deferring the scheduling as late as possible so that the scheduler schedules a set of jobs instead of one at a time. Scheduling a set of jobs reduces fragmentation and preemption of tasks as compared to scheduling one job after another. However, it must be ensured that the tasks meet their deadline. The DEDF scheme works as follows. Whenever tasks arrive at the system, they are enqueued in a job arrival queue. A few triggering conditions are predetermined that initiate the scheduling. If the scheduling is successful then the set of newly arrived jobs are allocated to the system and are guaranteed for completion, otherwise optionally the scheduler does preemptive scheduling for all the jobs in the system. The process is repeated whenever the triggering conditions are met. We have also introduced a new concept of Available Time Window (ATW) for processor allocation using the DEDF algo-

rithm. ATW of a processor is defined as the available time interval for which that processor is available for use. The system utilization is improved by using the ATW for processor allocation. Both of the new ideas, deferred scheduling and ATW, helps in improving the performance of real-time scheduling in partitionable multiprocessors.

Due to the nature of heuristic algorithms and the complexity of multiprocessor scheduling process, it is difficult to develop a reasonably accurate analytical model for performance evaluation. We have evaluated the performance of the proposed algorithm by means of simulation. Job miss ratio and work miss ratio are two parameters that are used as performance measures for the real-time scheduling algorithms. The results indicate that the proposed DEDF algorithm has a significantly lower job/work miss ratio when compared with the previously proposed Buddy/RT and Stacking algorithms [1].

The remainder of this paper is organized as follows. In Section 2, we describe the related works about on-line scheduling algorithms for real-time tasks on partionable multiprocessors. The proposed DEDF algorithm is discussed in Section 3. The simulation platform and the results are presented in Section 4, followed by the concluding remarks in Section 5.

2 Preliminaries

Two major aspects of processor management in multiprocessor systems are processor allocation and job scheduling. In a real time system, the processor allocation is concerned with the selection of processors on which the tasks will execute and the time when the allocated jobs start their execution. The job scheduler decides the order in which jobs are considered for processor allocation. Several schemes for processor allocation for non-real-time parallel tasks have been proposed including buddy, single and multiple gray code, free list, MSS, tree collapsing PC-graph [6]. The scheduling schemes proposed for non-real time systems include scan [5], lazy [6], and reservation schemes [10]. However, the work reported on on-line scheduling of real-time tasks on partitionable multiprocessors have been limited. Hong and Leung have proposed an on-line scheduling algorithm for real-time tasks with one common deadline [3].

2.1 On-Line Task Scheduling

A job J_i is characterized by its time of arrival A_i; its execution time E_i; its deadline D_i; and Dim_i, the dimension of the subcube required by the job. We assume that all these parameters are made known to the scheduler when the job arrives. A job set K consists of k independent jobs to be scheduled. Job set K is feasible on an n-dimensional hypercube if there is a preemptive schedule for the jobs in K such that each job J_i is executed in its execution interval $[A_i, D_i]$. Such a schedule is called a feasible schedule. Job scheduling algorithms based on simple heuristics such as Earliest Deadline First (EDF) and Minimum Laxity First (MLF) are often used in uniprocessor systems

[7]. Under EDF, jobs are scheduled in ascending order according to their deadlines. The job with the earliest deadline gets the highest priority. A scheduler based on MLF, on the other hand, schedules the jobs in ascending order according to their laxities, where laxity of a job is the time difference between the current time and the Latest Start Time (LST) of the job. The LST of a job is the latest time by which the job must be started in order to be finished before its deadline. It has been shown that EDF and MLF are optimal for uniprocessor systems with independent preemptable tasks [7]. While these heuristics are suitable for uniprocessor systems, they are not feasible for multiprocessor systems due to the large search space of the feasible schedules.

2.2 Related Scheduling Algorithms for Real-Time Partitionable Multiprocessors

In this subsection, we describe the two on-line scheduling algorithms proposed so far for real-time partitionable multiprocessors.

The Buddy/RT processor allocation algorithm for real-time systems proposed by Babbar and Krueger [1] is an extension of the buddy scheme proposed earlier for memory systems and processor allocations [2]. The basic idea is to include an additional restriction - *time*, while doing allocation. The Earliest Available Time (EAT) of a processor is defined as the earliest time at which that processor will become available for allocation. A processor's EAT is equal to the finish time of the latest job scheduled on that processor or the current time, whichever is higher. Instead of an array of bits (as used in the conventional buddy system), an array of EATs is used in the Buddy/RT scheme. An entry in the array of EATs indicates the time at which the corresponding processor will be available. The Buddy/RT algorithm has two phases where the second phase is optional. All the jobs are tried for scheduling on their arrival based on the FCFS discipline. For a job J_i, requesting a subcube of dimension k within a hypercube of dimension n, the Buddy/RT algorithm tries to find the smallest integer j, $0 \leq j \leq 2^{n-k} - 1$, such that all the processors in the subcube $\{j2^k, (j+1)2^k - 1\}$ have EATs earlier than the LST of job J_i, and allocates these processors to job J_i. If no such j exists, no subcube can complete job J_i before its deadline. In this case, the scheduler fails in the first phase.

The decision to go to the second phase is based on the amount of time available before the LST of all the jobs. If the available time is more than the worst-case execution time of the second phase, the second phase is initiated, otherwise the job is rejected. In the second phase, the scheduler tries to reschedule all the jobs - both the currently allocated ones and the newly arrived one.

Coalesces and splits while using Buddy/RT algorithm increases the fragmentation and thereby limits the performance. Coalesces lead to *holes* in the schedule and splits hurt the ability to schedule future jobs which need larger subcubes. The objective of the

Stacking algorithm is to avoid this weakness of the Buddy/RT algorithm. The Stacking algorithm tries to minimize fragmentation by avoiding unnecessary coalesces and splits of subcubes [1]. The approach used by the Stacking algorithm is to stack equal-sized jobs. Instead of choosing the first available subcube that allows for the job deadline to be met, the Stacking algorithm chooses the earliest available subcube that allows the deadline to be met from among those that require the least number of splits or coalesces. The Stacking algorithm also has two phases as that of the Buddy/RT algorithm. The scheduler also needs to determine whether it can get into the second phase. In [1], the authors have shown that stacking performs better than that of the Buddy/RT algorithm.

3 Deferred Earliest Deadline First (DEDF) Scheduling

Although Buddy/RT and Stacking algorithms have good subcube allocation ability, they have several shortcomings. First, since they schedule the job as soon as it arrives, the scheduling overhead is high. This is even worse when they get into the second phase. Second, in the allocation scheme, whenever they find a free subcube or a subcube which has the EAT earlier than the LST of the newly arrived job, they scheduled the new job on that subcube. This kind of greedy scheme could create holes and splits that affect the later allocations. Third, the use of EAT may leave a subcube idling while jobs of the corresponding size are being rejected. The idling time may be enough for the completion of the rejected jobs. This problem is discussed in the form of an example in the following subsection. The proposed DEDF algorithm avoids all these weaknesses.

3.1 DEDF Algorithm

The main idea of the DEDF algorithm is the deferment of the scheduling as late as possible, so that the scheduler schedules a set of jobs as opposed to a single job as is done while using the Buddy/RT and Stacking algorithms. By providing more number of jobs to be scheduled, we can have an optimal allocation for a specific set within the available system constraints. This idea has been motivated by the fact that, for the feasible job sets, the static (or off-line) real-time scheduling can be optimal, in which the characteristics of all the tasks are known a priori. Thus, the static real-time scheduling can be performed on a given set of jobs to improve the performance of on-line scheduling.

In DEDF, the scheduler will not start the scheduling until some triggering conditions are met. Determination of the triggering conditions is very important and must be selected carefully. There are two important factors that are taken into consideration while deciding the triggering conditions. These are Latest Start Time(LST) of jobs to be scheduled and the length of the queue for the arriving jobs. We assume that the system has a queue called Arrival Queue (AQ) for all arriving real-time jobs. The scheduler defers the scheduling as long as every job in the AQ has enough slack time to its LST. It may not be wise to wait exactly until the minimum LST of all jobs to trigger the scheduling process as there may not be any free subcube available at that time. If the minimum LST of all jobs is L_t (=min{LST}), and the average subcube hold time (service time) of the jobs is S_t, then the triggering time t_{start} is equal to the maximum of {current time, $L_t - S_t$}. The heuristic behind this selection of time is that if there are no available subcubes, then a subcube is most likely to be available after the average hold time. Simulations are conducted to validate the heuristics and have shown good results for a variety of workload conditions.

The scheduling is also triggered when the AQ is full. In a practical implementation, the AQ can accommodate finite number of jobs. So we need to schedule as many jobs as we can (if not all) as soon as the AQ is full. If one of these two conditions (i.e., LST or length of AQ) is met, the scheduler starts to schedule the jobs waiting in the AQ.

For processor allocation with DEDF scheduling algorithm, we have introduced a new concept of the Available Time Window (ATW). ATW of a subcube is defined as the available time interval at which that subcube is available for use. An available time interval is represented by the bottom of the ATW and the top of the ATW. The bottom of a ATW is the time at which the subcube starts to idle, and the top of a ATW is the time at which the subcube starts to run the next reserved job. If there is(are) no reserved job(s) for that subcube, the top of the ATW is said to be open. A subcube could have multiple intervals when it is available for use resulting in multiple ATWs. In such cases, the multiple ATWs are maintained as a linked list and all of them are checked for possible allocations. The DEDF scheduler allocates processors for a job based on the ATW. We have shown in Section 4 that the ability of available subcube recognition of our algorithm is much better than that of Buddy/RT and Stacking that use EAT for processor allocation. Furthermore, the use of ATW guarantees that a subcube will not idle when jobs of the same size are being rejected and could have been completed during the idling time.

As in the case of Buddy/RT and Stacking, DEDF also consists of two phases in which the second phase is optional. By increasing the number of successful schedules in the first phase, the number of preemptions can be reduced. The scheduling process in the first phase of the DEDF algorithm is discussed as follows.

The scheduling of new jobs are deferred until one of the triggering conditions is met. In the first phase, the scheduler tries to schedule all new jobs in the AQ in the order of their deadline, i.e., Earliest Deadline First (EDF). Once a new job is ready to be scheduled, the scheduler performs processor allocation for that job based on the ATW. If it finds an appropriate subcube, it is either allocated or reserved for the job. It should be noted that several jobs can reserve the same busy subcube as long as their deadlines can be met. This scenario is different from the non-real-time parallel task allocation. If the scheduler does not find the required subcube, it is said to have failed in the first

Table 1: A Sample Job Set.

Job	AT	Size	ET	Deadline	LST
J_1	t	2	4	$t+4$	t
J_2	t	3	7	$t+7$	t
J_3	$t+1$	3	2	$t+8$	$t+6$
J_4	$t+2$	2	2	$t+4$	$t+2$

AT: Arrival Time; ET: Execution Time

phase. If enough time for the second phase is left, it enters the second phase. This time is decided based on the amount to time left before the LST of all the jobs (L_t). Since the second phase involves preemption, the overhead due to preemption is also taken into account while deciding whether or not to initiate the second phase. The allocation procedure of the second phase is almost the same as that of the first phase except that the job set to be scheduled includes all jobs in the system, i.e., all currently running jobs, all jobs that have reserved a subcube, and jobs in the AQ. If a feasible schedule is possible then all the jobs currently executing are preempted and the new schedule is adopted. The second phases of all the three algorithms (Buddy/RT, Stacking, and DEDF) involve preemption. Preemption of jobs has higher overhead and should be avoided as and when possible.

The effectiveness of the DEDF algorithm can be illustrated by considering an example of a sample job set as shown in Table 1. The system size is assumed to be 4-cube. Jobs J_1 and J_2 arrive at time t. Job J_3 arrives at time $t+1$ and J_4 at $t+2$. Their subcube requirement, execution time, and deadlines are indicated in Table 1. We will first analyze the scheduling performance using Buddy/RT and Stacking. Both Buddy/RT and Stacking use EAT to find an available subcube for allocation. The order of allocation is done through EDF. At time t, the AQ will have the jobs J_1 and J_2, in order. Using Buddy/RT or Stacking, the jobs J_1 and J_2 are first allocated. The EATs of the subcubes {1-4}, {5-8}, and {9-16} are updated to $t+4$, t, and $t+7$, respectively. J_3 arrives at time $t+1$ with a deadline of $t+8$. To schedule J_3 that requires a 3-cube, we need to check the EATs of the 3-subcubes existing in the system. The EAT of subcube {1-8} and {9-16} are $t+4$ and $t+7$, respectively. Thus J_3 reserves the subcube {1-8}. The EAT of all the processors in the subcube {1-8} are updated to $t+6$. The allocations and reservations at time $t+1$ are as shown in Figure 1. At time $t+2$, J_4 arrives requesting a 2-cube with a deadline of $t+4$. As the EATs of all the 2-subcubes are either $t+6$ or $t+7$, J_4 cannot be allocated in phase 1. The jobs J_1 and J_2 need to be preempted to enter phase 2 in order to accommodate J_4, if possible. In this specific case, incidentally, the second phase of Buddy/RT and Stacking will not be initiated and J_4 will be rejected. Because there is no laxity for J_4, the preemption overhead will prohibit the initiation of the second phase.

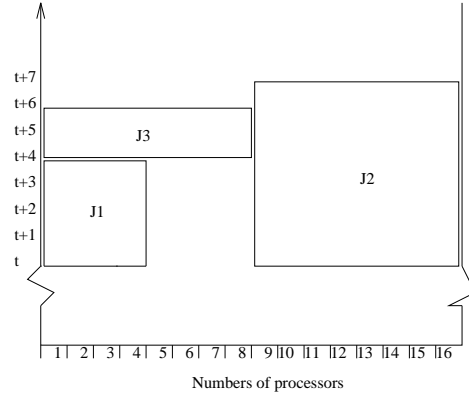When we schedule the jobs by using the DEDF al-

Figure 1: Scheduling using Buddy/RT or Stacking.

gorithm, the concept of ATW is used instead of EAT for processor allocation or reservation. We will analyze the same example with a few variations to reflect different scenarios. Consider the four jobs with their characteristics as depicted in Table 1. At time t, the DEDF scheduler is triggered as the LST of J_1 is t. The AQ has jobs J_1 and J_2. J_1 is scheduled on subcube {1-4}, J_2 in subcube {9-16}. J_3 arrives at time $t+1$. The LST of J_3 is $t+5$, so the scheduler is not triggered. J_4 arrives at time $t+2$ with a LST of $t+2$. So the scheduler is triggered at $t+2$. When the scheduler starts to schedule, it has two jobs in the AQ (J_3 and J_4). Since the DEDF scheduling algorithm schedule the job with earlier deadline first, it will schedule J_4 before J_3, even though J_3 arrived earlier. In this case, the scheduler can schedule both J_3 and J_4 successfully to meet their deadlines as shown in Figure 2. We expect this kind of situation to be more prevalent when the workload has jobs with large laxities. Using Buddy/RT or Stacking, J4 may be scheduled if we use the optional preemptive scheduling and there is enough laxity. However, by deferring scheduling, DEDF scheduling algorithm can avoid the unnecessary preemptive scheduling overhead.
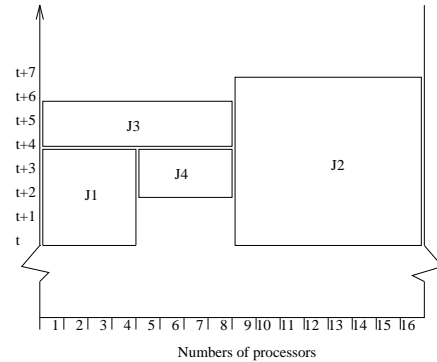

Figure 2: Scheduling using DEDF.

To illustrate the effectiveness of the ATW concept, let us assume that the scheduler is triggered at $t+1$

after the arrival of job J_3 because of the AQ becoming full. Note that the length of AQ is usually long enough to hold more than one job but just to illustrate the utility of the ATW concept we assume here that the AQ becomes full at $t+1$, and the scheduler is triggered. As J_3 requires a 3-cube, the ATW of all the 3-subcubes are checked. They are $[t+4 \rightarrow \text{open}]$ for subcube $\{1\text{-}8\}$, and $[t+7 \rightarrow \text{open}]$ for the subcube $\{9\text{-}16\}$. Thus J_3 reserves the subcube $\{1\text{-}8\}$. The ATW of all the subcubes are then updated. When J_4 arrives at time $t+2$, the scheduler is again triggered as the LST of J_4 is $t+2$. J_4 requires a 2-cube. The ATW of all the 2-subcubes in the system are $[t+6 \rightarrow \text{open}]$ for subcube $\{1\text{-}4\}$, $[t+2 \rightarrow t+4]$ and $[t+6 \rightarrow \text{open}]$ for subcube $\{5\text{-}8\}$, $[t+7 \rightarrow \text{open}]$ for subcube $\{9\text{-}12\}$, and $[t+7 \rightarrow \text{open}]$ for subcube $\{13\text{-}16\}$. Thus, J_4 is allocated to the subcube $\{5\text{-}8\}$. With the concept of EAT, the subcube $\{5\text{-}8\}$ is not used for the interval $(t+2, \ t+4)$ and J_4 would have been rejected. But using the concept of ATW, we can use the subcube $\{5\text{-}8\}$ and can execute J_4 successfully before its deadline. The difference between the concept of maintaining EAT and ATW has a significant effect on the system utilization. These situations occur frequently if the workload has jobs with relatively small laxities.

We have therefore illustrated how the two new concepts, deferred scheduling and ATW, reduces the rejection ratio of on-line real-time scheduling in partitionable multiprocessors. We have also specified how the DEDF algorithm is suitable for workload conditions of large as well as small laxities.

4 Performance Measurements

We evaluate the performance of the DEDF scheduling algorithm through simulations. For real-time systems, two useful metrics for performance evaluation are the Job Miss Ratio (JMR), which is the ratio of jobs refused to the total number of jobs that arrive at the system, and the Work Miss Ratio (WMR), which is the ratio of refused work to the offered workload. For WMR, the work requested by a job is computed as its subcube hold time multiplied by the number of processors constituting the subcube.

4.1 Workload Characterization

In our study, a Poisson job arrival process is assumed. The Poisson process has been found to model natural physical and organic processes realistically, and is commonly used to model random, independent arrivals of jobs to computer systems form an external population [4]. We assume that the subcube hold times and laxities are normally distributed. Subcube hold time is independent of subcube size. Three different distributions for the subcube dimensions are considered. They are: modified geometric distribution, the discrete uniform distribution, and a reverse geometric distribution, which is simply a mirror image of the geometric distribution. All these distribution are truncated at 0 and n-1, where n is the dimension of the hypercube. The probability mass function for the truncated modified geometric distribution is
$p(k) = \frac{p(1-p)^k}{\sum_{k=0}^{n-1} p(1-p)^k}$, where $p = \frac{1}{mean+1}$. For the dis-

crete uniform distribution, $p(k) = \frac{1}{n}$, and for reverse geometric distribution, $p(k) = \frac{p(1-p)^{n-1-k}}{\sum_{k=0}^{n-1} p(1-p)^k}$. While all subcube sizes are equally likely in the uniform distribution, the geometric distribution has a high proportion of small jobs and the reverse geometric distribution has a high proportion of large jobs. All the above mentioned assumptions and workload characteristics are also considered in previous studies [1] [8].

4.2 Simulation Environment

We have simulated three different scheduling algorithms: Buddy/RT, Stacking, and DEDF with various workload conditions. The input parameters are the scheduling algorithm to be used, dimension of hypercube, observation interval, offered system load, job arrival rate, subcube size distribution, mean subcube size, standard deviation of subcube size, mean laxity, standard deviation of laxity, mean subcube holding time, and the standard deviation of holding time. The simulation outputs are the JMR and WMR, which are plotted with respect to the offered system load or the mean laxity. If λ is the job arrival rate, X is the mean subcube hold time, P is the mean number of processors in a subcube request, and N is the number of processors in the hypercube, then the offered system load is $\frac{\lambda X P}{N}$. The mean laxity is evaluated as a percentage of the mean subcube hold time.
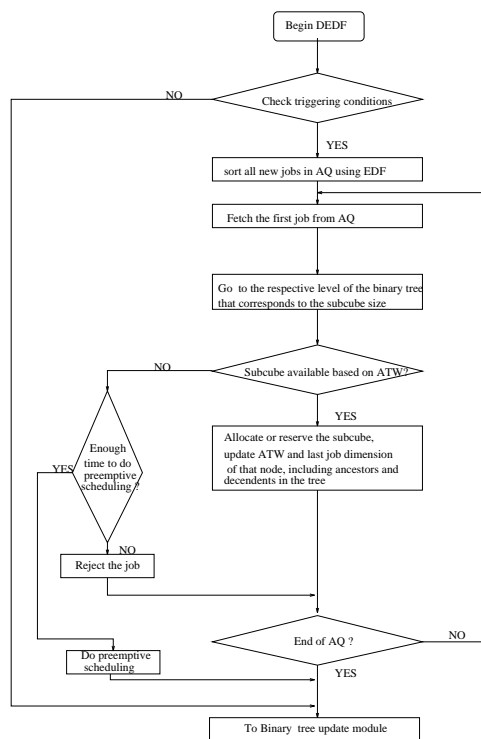

Figure 3: Flowchart of the DEDF scheduling scheme.

In our simulation, the hypercube system is represented as a binary tree. Each node in the binary tree

represents a possible subcube in the hypercube and maintains its status. The complete structure of the DEDF scheduling simulator is shown as a flowchart in Figure 3. The binary tree update module is shown in Figure 4. A predetermined preemption overhead of 2 time units is included to capture the time taken in making the rescheduling in the second phase, if necessary. A temporary binary tree is used for the scheduling of all the jobs in the system including the jobs currently running, the jobs that have reserved subcubes, and all jobs in the AQ. All jobs are sorted by EDF. If the scheduler cannot find an available subcube for a job in the second phase, the job is rejected by the system. In addition, once the scheduler starts preemptive scheduling, it does not schedule new jobs arriving after it has begun arranging the jobs based on EDF.
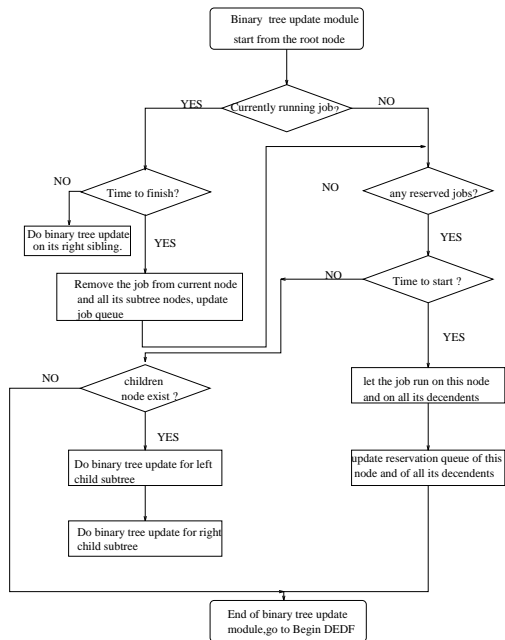
Figure 4: Flow chart of the binary tree update module.

4.3 Results and Inferences

We have computed both JMR and WMR for the system and workloads presented in this section. The trends of both these plots are observed to be the same. For the sake of brevity, we have reported only the plots of the JMR. The JMR is expressed in % and is plotted against the offered system load or the mean laxity.

Figure 5 shows the plot of job miss ratio in % with respect to the offered system load for a hypercube of dimension 8 (256 nodes). The job size distribution is considered geometric with a mean laxity of 150% of the mean service demand. It can be observed from the plot that the JMR of the DEDF is considerably less than that of Buddy/RT or stacking algorithms. We have also plotted a curve that represents the DEDF algorithm that does not uses the concept of ATW.

It just defers the allocation and uses EAT for allocation. The curves shows that performance is also gained by only deferring the scheduling. It can be also inferred that both deferment of scheduling, and allocation using ATW have impact on reducing the miss ratio. Similar trends are also observed when the job size distribution is uniform or reverse geometric.
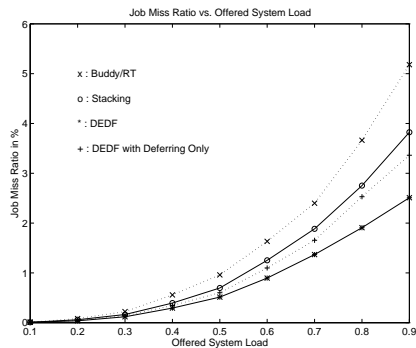

Figure 5: Job miss ratio versus offered system load. (mean subcube size = 9.36, geometric job size distribution)

The job miss ratio in % with respect to the mean laxity in % (of the subcube hold time) for an 8-dimensional hypercube is plotted in Figures 6, 7, and 8. The offered system load is assumed 0.4. The job size distribution in Figures 6, 7, and 8 are geometric, uniform, and reverse geometric, respectively. It is observed that the JMR using the DEDF scheduling in considerably lower than that of Buddy/RT and Stacking for all the distributions. For low laxities, there is not much difference between the Buddy/RT and Stacking algorithms. But the DEDF algorithm demonstrate a substantial improvement in performance from low to intermediate mean laxities. At high mean laxities, all the three algorithms have less JMR as almost all the jobs have a very high probability of being accepted due to the large laxities. It is also observed that the JMR for any given laxity is lower in case of geometric distribution as compared to the other two distributions. This is because of the more number of small-sized jobs in geometric distribution.

The performance improvement using the DEDF scheduling is between 25% to 150% compared to Buddy/RT, and in between 10% to 75% compared to the Stacking algorithm for the workload studied in this paper.

The performance of various scheduling schemes with the increase in the hypercube size is plotted in Figure 9. The curves for the job miss ratio (in %) is plotted against the hypercube dimension for uniform job size distribution. The offered system load and the mean laxity are assumed 0.4 and 150%, respectively. It is observed that the JMR of the DEDF scheduling is always lower than that of Buddy/RT and Stacking. Furthermore, the increase in JMR with the increase in the system size is slower in case of DEDF as compared to the other algorithms. Similar trends are also observed when the job size distribution is geometric
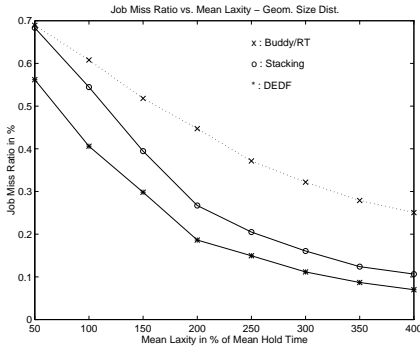
Figure 6: Job miss ratio versus mean laxity. (mean subcube size = 9.36, geometric job size distribution)
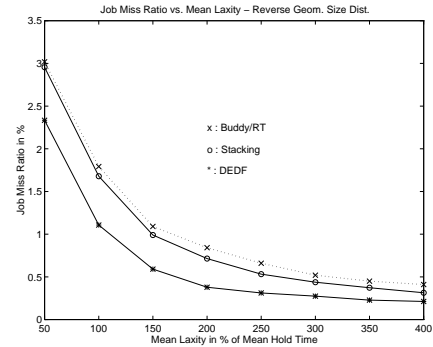

Figure 7: Job miss ratio versus mean laxity. (mean subcube size = 32, uniform job size distribution)

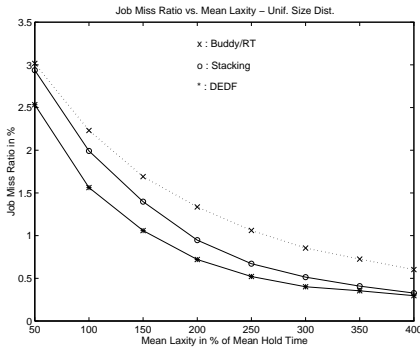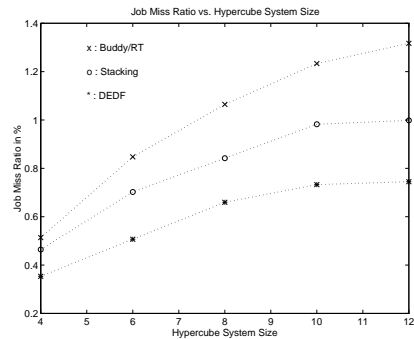Figure 8: Job miss ratio versus mean laxity. (mean subcube size = 66.67, reverse geometric job size distribution)

Figure 9: Job miss ratio versus the system size. (uniform job size distribution, offered load = 0.4, mean laxity = 150%)

or reverse geometric.

Finally, we compare the miss ratios of the jobs of different sizes for the three scheduling algorithms - Buddy/RT, Stacking, and DEDF. Figures 10, 11, and 12 reflect the relative job miss ratios of different size subcubes in an 8-cube system for the three scheduling algorithms. The job size distributions in the figures are geometric, uniform, and reverse geometric, respectively. The plots can be also read as the probability of rejection of a particular size job for each of the algorithms. For all the three distributions, it is observed that the miss ratio of the large size jobs are high, as expected. While comparing the three algorithms, it is seen that the miss ratio of the DEDF algorithm is lower than the other two algorithms for all job sizes. This observation is true for all the three job size distributions.

It can be argued that by deferring the scheduling, one may delay informing the rejection of a job to the user. The delay may not be acceptable for certain applications. The DEDF algorithm is thus not suitable for such applications. However, in any case, the concept of ATW can be still employed to enhance the performance of real-time scheduling. Furthermore, the concept of deferred scheduling can be employed in con-junction with Buddy/RT or Stacking algorithms to extract enhanced performance for application that are insensitive to the dealy in acceptance/rejection decisions.

5 Conclusion

A new on-line scheduling algorithm called DEDF is proposed in this paper for real-time partitionable multiprocessor. The DEDF scheduling scheme is based on heuristics and two new ideas are introduced in the algorithm. First, the scheduling of the jobs are not necessarily done as soon as they arrive, but are postponed. The scheduling starts when certain triggering conditions are met. Delayed scheduling allows us to schedule a set of tasks instead of a single one. A set of tasks is usually scheduled more efficiently compared to one-at-a-time. Second, the concept of ATW is used instead of EAT which was used in the earlier proposed scheduling algorithms. By using ATW, the utilization of the system is improved as it enables the allocation of more number of jobs. The improvement in utilization, in turn, improves the performance of the DEDF scheduling algorithm. The complexity of the DEDF algorithm is less than that of Buddy/RT and is equal to that of the Stacking algorithm. Although we have
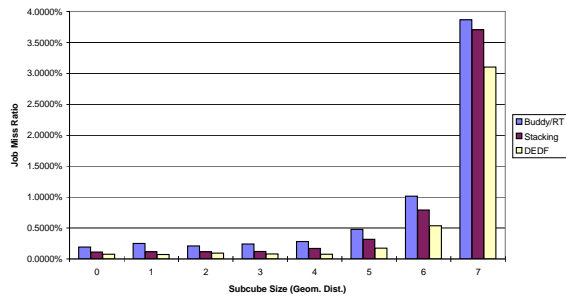
Figure 10: Job miss ratio with respect to various sub-cube sizes in an 8-cube.
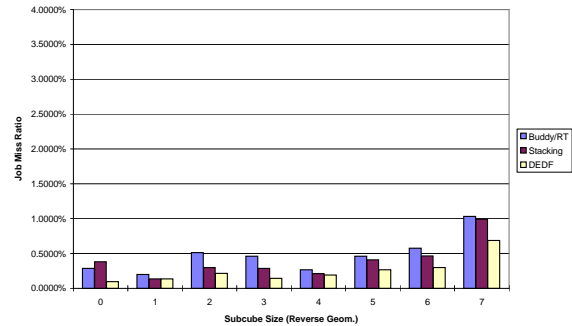(geometric job size distribution, offered load = 0.4, mean laxity = 150%)

Figure 11: Job miss ratio with respect to various sub-cube sizes in an 8-cube.
(uniform job size distribution, offered load = 0.4, mean laxity = 150%)

discussed the applicability of the DEDF algorithm for hypercube computers, it is equally well-suited for any partitionable multiprocessor.

The performance of the DEDF algorithm is evaluated through simulation. The results indicate that the job and work miss ratios of the DEDF algorithm is considerably less as compared to that of the earlier proposed Buddy/RT and Stacking scheduling algorithms. The JMR using DEDF scheduling increases relatively slower with the increase in the hypercube size. Furthermore, the JMR of different size jobs are lower using the DEDF scheduling when compared to that of the Buddy/RT or Stacking. Future work includes the consideration of additional resource and precedence dependencies while scheduling the real-time jobs. We also plan to study the effect of other allocation algorithms proposed for hypercube and mesh in conjunction with the DEDF scheduling algorithm.

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Figure 12: Job miss ratio with respect to various sub-cube sizes in an 8-cube.
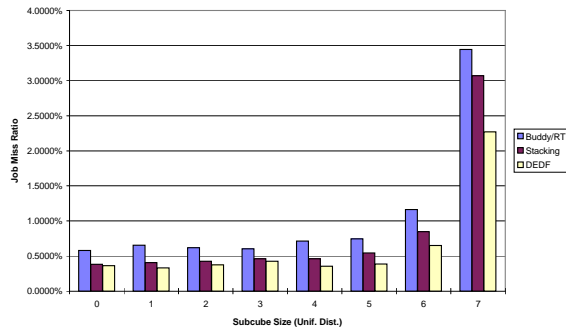(reverse geometric job size distribution, offered load = 0.4, mean laxity = 150%)