Title	先行制約付きタスクの通信遅延を考慮したマルチプロセッサスケジューリングに関する研究
Author(s)	桂，元保
Citation	
Issue Date	2000-03
Type	Thesis or Dissertation
Text version	author
URL	http://hdl.handle.net/10119/1340
Rights	
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A Study of Multiprocessor Scheduling of Tasks with Communication Delays

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February 15, 2000

Keywords: task, scheduling, multiprocessor, communication delay.

A set of tasks with precedence constraint is implemented on a multiprocessor system by assigning each task to a processing element (PE) on the system and to a control step. For processing the set of tasks quickly, it is important to find multiprocessor scheduling with minimum total processing time. In the multiprocessor scheduling considered here, all PEs have same performance, each PE can process only one task at a time, and every pair of PEs are connected by a communication link.

In conventional approach to multiprocessor scheduling, communication delays are little concerned. As a result, tasks with precedence constraint $\mathcal{T}$ are represented by a set of tasks T, a partial order on T $\prec$, and a processing time function $W : T \rightarrow \{1, 2, \cdots\}$. For tasks u and v, $u \prec v$ represents a constraint such that the process of v can not begin until completing the process of u. In the target computation model, when the number of PEs of a multiprocessor system P is m, P can process at most m tasks at a time. If control step assignment $\tau : T \rightarrow \{0, 1, 2, \cdots\}$ satisfies $\tau(v) \leq \tau(u) + W(u)$ for all u and v, $u \prec v$, and the number of tasks which satisfy $\tau(v) \leq t < \tau(v)+W(v)$ is at most m for any control step t, then it is called as scheduling of $\mathcal{T}$ onto P. The total processing time is represented by $\max_{v\in T}[\tau(v) + W(v)] - \min_{v\in T} \tau(v)$. The problem to decide whether scheduling with the total processing time at most k exists or not is the scheduling problem. This problem is known to be NP-complete. On the other hand, when we restrict the number of PEs to 2 and process time of each task to unit time, this scheduling problem can be solved in polynomial time. Also the problem can be solved in polynomial time if $\prec$ forms out-tree and process time of each task is unit time.

The performance of computers is improving rapidly with a remarkable progress in the VLSI technology in recent years. As a result, data communication delays between PEs which have ignored in previous works become significant in the total processing time.

When we incorporate communication delays into scheduling problem, a problem instance is represented by a directed acyclic graph (DAG), and two functions $W_V(v)$ and $W_A(a)$, where a set of arcs in the DAG represents precedence constraint, and $W_A(a)$ represents communication delay for data a. Several studies on scheduling problem considering communication delays have been done. Varvarigou et. al. insisted in their paper that, when an input DAG is restricted to an out-forest and $W_V(v)$ and $W_A(a)$ are restricted to unit time, there exists an approximate algorithm with the approximation difference $m-2$.

In this thesis, we proposed a heuristic method for the scheduling problem considering communication delays, where an input DAG is restricted to an out-tree and $W_V(v)$ and $W_A(a)$ are restricted to unit time. Our proposed method processes one control step to another starting with the latest control step. The input to the procedure for control step i is the out-tree which is obtained from the original out-tree by deleting vertices which are already assigned to control steps from $i+1$ to the latest control step. With respect to this out-tree, we first assign weight (priority) to each vertex in the following way. When a task (vertex) u has only one child v, $w_v = w_u + 1$. On the other hand, when u has plural children, first we select one favored child f and let the other be $c_1, c_2, \cdots, c_k$, and $w_f = w_u + 1 - \varepsilon$, $w_{c_i} = w_u + 2 - \varepsilon$, where ε is a positive real constraint which is sufficiently smaller than 1. The choice of favored child is done so that the maximum weight of f's successor w' and the maximum weight of children's successor except f w'' satisfy $w'' \leq w' - 1$. After fixing vertex weight, leaves (tasks) with higher weight are assigned to control step i. As a result of experiments, we found that proposed method always gave identical or better solution to the conventional method by Varevarigou did. While the repeated update of vertex weight is a peculiar feature of our proposed method and is expected to contribute to a good quality of solution, it makes the theoretical analysis of algorithm performance difficult. Theoretical analysis, such as the derivation of an approximation difference, is left for future work. The adaptation of our algorithm to the scheduling for general DAGs could be an interesting extension of our method.