Communication-Aware Scheduling Algorithm Based on Heterogeneous Computing Systems

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Abstract. This paper proposes a new scheduling model that integrates the communication awareness into task scheduling. A scheduling algorithm is proposed for the new model, which can produce optimal schedule by serializing the communications edges. Experiment results show the significantly improved accuracy and efficiency of the new model and algorithm.

Keywords: communication aware; concurrent communication; serializing.

1 Introduction

In order to exploit the heterogeneous computing power, a lot of works have focused on solving the task scheduling problem. This problem has been shown to be NP-complete^[1]. There are several proposed algorithms dealing with the task scheduling problem in heterogeneous systems. They could be classified into a variety of categories, such as list-scheduling, clustering, duplication-based algorithms, and guided random search methods. The list-based algorithms provide good quality of schedules and their performance is comparable with other categories at a lower scheduling time. The Iso-Level Heterogeneous Allocation^[2], the Heterogeneous Earliest-Finish-Time (HEFT) and Critical-Path-on-a-Processor (CROP) techniques^[3] are all examples. However, most of the above-mentioned works have in common that they employ an idealized model of the target parallel system and don't deliberate on the impact of communication contentions. Intuition and experiments demonstrated that this model results in inaccurate and inefficient schedules^[4]. Therefore, in order to exploit the potential of parallel processing, efficient scheduling algorithms under the consideration of the communication requirements must be developed. So, CATS was proposed to schedule parallel tasks by considering the communication requirements of the applications and the network bandwidth^[5]. Sinnen investigated the incorporation of contention awareness into task scheduling by edge scheduling, which considered heterogeneous links and routing^[6].

In this paper, we propose a communication-aware scheduling that extended the classic list scheduling. The rest of paper is organized as follows. In Section 2, we introduce some definitions and preliminaries. Section 3 describes the new contention model, and investigates the integration of the awareness for the contention in task scheduling. Experimental results are presented in section 4.

2 Preliminaries

In task scheduling, the program to be scheduled is represented by a directed acyclic graph(DAG) $G=(V, E, w, c)$, where V is the set of tasks and E is the set of edges. The size of task n_i is $w(n_i)$. An edge from n_i to task n_j is expressed as e_{ij} and size of the edge is expressed as c_{ij} . Given task n_i , the set of parent tasks is denoted as $pred(n_i)$; that is, $pred(n_i)=\{n_k \mid e_{ki} \in E\}$, and the set of children tasks is denoted as $succ(n_i)$; that is $succ(n_i)=\{n_k \mid e_{ik} \in E\}$. A task n_i is called a join task if $|pred(n_i)| \geq 2$, an entry task if $|pred(n_i)|=0$, and an exit task if $|succ(n_i)|=0$.

To describe a schedule S of a DAG $G=(V, E, w, c)$, the following terms are defined: $est(n, P)$ and $ect(n, P)$ represent the earliest start time and completion time of n_i on processor P respectively, and $w(n, P)$ the execution time of node $n \in V$ on processor $P \in \mathbf{P}$. Thus, the node's earliest completion time is given by $ect(n, P)=est(n, P)+w(n, P)$. Given an edge e_{ij} , $est(e_{ij})$ and $ect(e_{ij})$ represent the earliest start time and completion time of edge e_{ij} respectively. Thus, the edge's earliest completion time is given by $ect(e_{ij})=est(e_{ij})+c_{ij}$ and $est(n_j, P) \geq ect(e_{ij})$, for $n_i, n_j \in V, e_{ij} \in E$.

3 The Proposed Algorithm

To make task scheduling contention aware, the communication edges must be serialized because communication cannot be concurrent. Thus, the awareness for communication is serialize achieved by scheduling edge.

Definition 1 (Contention Model): A target parallel system $M_{\text{contention}}=(\mathbf{P}, w, comm)$ consists of a set of possibly heterogeneous processors $\mathbf{P}$ connected by the communication network, where $comm(e_{ij}, P_{src}, P_{dst})$ denotes the communication cost of edge e_{ij} from processor P_{src} to P_{dst} .

When a communication, represented by the edge e_{ij} , is performed between two processors P_{src} and P_{dst} . Thus, the earliest completion time of e_{ij} is

$$ect(e_{ij}) = \begin{cases} ect(n_i) & \text{if } P_{src} = P_{dst} \\ ect(n_i) + comm(e_{ij}, P_{src}, P_{dst}) & \text{otherwise} \end{cases} \quad (1)$$

where $P_{src}=proc(n_i)$ and $P_{dst}=proc(n_j)$. Thus, the edge earliest completion time $ect(e_{ij})$ is now the earliest completion time of n_i plus the communication of e_{ij} from P_{src} to P_{dst} , unless the communication is local. For n_a , we claim that a chain of communications can be found as $X_a: e_{1a} \rightarrow e_{2a} \rightarrow \dots \rightarrow e_{ka}$, where $n_i \in pred(n_a)$ ($i=1..k$),

such that $est(e_{1a}) \leq est(e_{2a}) \leq \dots \leq est(e_{ka})$, i.e., $ect(n_1) \leq ect(n_2) \leq \dots \leq ect(n_k)$. We define $\Omega(e_{ia})$ as the idle communication time before the communication edge e_{ia} , is issued as $\Omega(e_{ia}) = est(e_{ia}) - ect(e_{(i-1)a})$, ($1 \leq i \leq k$). Thus, $est(n_a) = ect(n_i) + \sum_{i=1}^k \{comm(c_{ia}, P_{src}, P_{dst}) + \Omega(e_{ia})\}$.

Given task n_a , $ect(n_a)$ is determined according to its parent tasks and communication edges. If task n_a has a

single parent task n_i , then $est(n_a) = ect(n_a)$. If n_a and n_i exist different processors, the execution of n_a is delayed by $ect(n_i) + comm(e_{ia}, proc(n_i), proc(n_a))$. If n_a and n_i exist same processor, the communication time c_{ia} is negligible and n_a can start at $ect(n_i)$. If task n_a has k parent task $n_1, n_2, \dots, n_k$, where $ect(n_1) \leq ect(n_2) \leq \dots \leq ect(n_k)$. At first, because of earliest completion of n_1 , the start time of edge e_{1a} should be first scheduled to $proc(n_a)$, $ct_1(sc)$ is denoted as the completion time of scheduling the first communication. However, if the parent task n_2 cannot complete in advance, which means $ct_1(sc) = ect(n_1) + c_{1a} \leq ect(n_2)$, there is an idle time Ω_1 between them. Thus, the edge e_{2a} must be delayed by $ect(n_2)$. Next, the procedure continue to schedules the edge e_{ia} ($2 \leq i \leq k$) that satisfies the following condition: $t_s(e_{ia}) = \max(ct_{i-1}(sc), ect(n_i))$, where $ct_i(sc) = ct_{i-1}(sc) + \Omega_{i-1} + c_{ia}$ and

$$\Omega_i = \begin{cases} 0 & \text{if } ect(n_{i+1}) \leq ct_i(sc) \\ ect(n_{i+1}) - ct_i(sc) & \text{otherwise} \end{cases} \quad (2)$$

If k th edge is scheduled, $ct_k(sc)$ and $est(n_a)$ can be determined. Therefore, $est(n_a) = ct_k(sc)$. We can easily prove that $est(n_a)$ is minimal.

The best known scheduling heuristic is list scheduling. A common and usually good priority is the node's bottom level bl , which is the length of the longest path leaving the node. Recursively defined, it is

$$bl(n_i) = w(n_i) + \max_{n_j \in succ(n_i)} \{c_{ij} + bl(n_j)\} \quad (3)$$

Based on above theory and analysis, we propose an extended list scheduling algorithm that considers the communication awareness by reasonable serializing the communication edges, which is listed as below.

Algorithm List Scheduling With Communication Awareness

Input: program $G = (V, E, w, c)$ and model $M = (P, w, comm)$;

Output: A schedule with minimal completion time;

begin

Sort nodes $n \in E$ into list L , according to priority scheme bl and precedence constraints;

for $n_j \in L$ do

{ Find processor $P \in \mathbf{P}$ that allows earliest completion time of n_j ;

for each $n_i \in pred(n_j)$ in ascend order $ect(n_i)$ do

if $proc(n_i) \neq P$ then schedule e_{ij} on P ;

schedule n_j on P ;

}

end.

4 Experiment Results

This section presents experiments results to verify some aspects of the proposed contention aware scheduling. We adopt the same test methods with [6]. In each experiment, the values of these parameters are assigned from the corresponding sets given below.

$$SET_V = \{100, 200, 400, 800\}, SET_{indegree} = \{1, 2, 5, 10\} \text{ and } SET_{CCR} = \{0.1, 1, 5, 10\}.$$

Fig. 1 and Fig.2 show the average accuracy and efficiency achieved under the two models over all DAGs on parallel systems. Experimental results demonstrated the significantly improved accuracy and efficiency than classic schedule schemes.

Fig. 1. Average accuracy

Fig. 2. Average efficiency

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