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Workload-based multi-task scheduling in cloud manufacturing

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ABSTRACT

Cloud manufacturing is an emerging service-oriented business model that integrates distributed manufacturing resources, transforms them into manufacturing services, and manages the services centrally. Cloud manufacturing allows multiple users to request services at the same time by submitting their requirement tasks to a cloud manufacturing platform. The centralized management and operation of manufacturing services enable cloud manufacturing to deal with multiple manufacturing tasks in parallel. An important issue with cloud manufacturing is therefore how to optimally schedule multiple manufacturing tasks to achieve better performance of a cloud manufacturing system. Task workload provides an important basis for task scheduling in cloud manufacturing. Based on this idea, we present a cloud manufacturing multi-task scheduling model that incorporates task workload modelling and a number of other essential ingredients regarding services such as service efficiency coefficient and service quantity. Then we investigate the effects of different workload-based task scheduling methods on system performance such as total completion time and service utilization. Scenarios with or without time constraints are separately investigated in detail. Results from simulation experiments indicate that scheduling larger workload tasks with a higher priority can shorten the makespan and increase service utilization without decreasing task fulfilment quality when there is no time constraint. When time constraint is involved, the above strategy enables more tasks to be successfully fulfilled within the time constraint, and task fulfilment quality also does not deteriorate.

1. Introduction

Cloud manufacturing is a new service-oriented business model aiming for sharing and collaboration of large-scale manufacturing resources [1,2]. It realizes its objective through establishment of a common cloud manufacturing platform, which aggregates distributed manufacturing resources encompassed in the entire product life cycle, transforms them into manufacturing services, and manages them centrally [3,4]. Through centralized management and operation of services, cloud manufacturing is able to deal with multiple requirement tasks at the same time. A critical issue with cloud manufacturing is therefore how to schedule multiple tasks to achieve optimal system performance. Different from the scenario in cloud computing, task scheduling in cloud manufacturing is usually accompanied by logistics. The involvement of logistics makes the multi-task scheduling in cloud manufacturing more complicated.

Multi-task scheduling in cloud manufacturing refers to process of allocating services over time to perform a set of tasks while satisfying constraints in terms of time, cost, QoS, and service availability. Task scheduling is an intrinsic part of a cloud manufacturing system, and has a major impact on system performance. Effective task scheduling methods are capable of significantly enhancing system performance. For multi-task scheduling, scheduling objective should be achieving the overall optimization of all tasks. Multi-task scheduling requires the consideration of coupling relationships (e.g. different tasks may require the same type of services) among multiple tasks. Traditional methods for single-task scheduling may not achieve the optimal system performance under multi-task scenarios as they do not deal with all task as a whole [5–8]. Multi-task scheduling in cloud manufacturing has been considered in literature [9–11]. However, these works dealt with either only homogeneous tasks or using a different model and method. Multi-task scheduling in cloud computing has also been studied [12,13]. However, due to the fundamental differences between cloud manufacturing and cloud computing [4,14], the proposed approaches cannot be applied directly to cloud manufacturing. It is therefore necessary to explore new, effective methods for multi-task scheduling in cloud manufacturing.

In this paper, we address the issue of multi-task scheduling in cloud

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Nomenclature

$a_{k,u}$	Unit service amount for $s_{k,u}$
$A_{i,s}$	Quantity of $S_{i,s}$
At_k	Arriving time of T_k
AC	Average cost of all tasks
AR	Average reliability of all tasks
AT	Average completion time of all tasks
AU	Average utility of all tasks
c_l	Logistics cost for unit weight and unit distance
$c_{i,s}$	Unit cost of $S_{i,s}$
C_k	Cost of T_k
$Cap_{i,s}$	E_i's capacity for $S_{i,s}$
$Cons_{T_k}^T$	Completion time constraint of T_k
CT_k	Completion time of T_k
$d_{ii'}$	Geographical distance between E_i and $E_{i'}$
E_i	Enterprise i
I	Number of enterprises in a cloud manufacturing system
J	Number of service types in a cloud manufacturing system
K	Number of tasks in a cloud manufacturing system
l_i	Number of service types of E_i
LC_k	Logistics cost of T_k
$LC_k^{u,u+1}$	Logistics cost between $s_{k,u}$ and $s_{k,u+1}$
LT_k	Logistics time of T_k
$LT_k^{u,u+1}$	Logistics time between $s_{k,u}$ and $s_{k,u+1}$
n_k	Number of subtasks of T_k
p_δ	Probability for logistics between subtasks
Q_k	Total QoS utility of T_k
Q_k^C	Cost utility of T_k
Q_k^T	Time utility of T_k
Rel_{E_i}	Reliability of E_i's services
Rel_k	Total reliability of services for T_k
$Rel_{k,u}$	Reliability of service for $s_{k,u}$
Q_k^{Rel}	Reliability utility of T_k
$r_{k,u}$	Required service type of $s_{k,u}$
$R_{i,s}$	Type of $S_{i,s}$
$s_{k,u}$	uth subtask of T_k
$S_{i,s}$	E_i's sth type of service
SC_k	Service cost of T_k
$SC_{k,u}$	Service cost of $s_{k,u}$
ST_k	Service time of T_k
$ST_{k,u}$	Ideal service time of $s_{k,u}$
$ST'_{k,u}$	Real service time of $s_{k,u}$
t_l	Logistics time for unit distance
t_k	Required service time of T_k
$t_{k,u}$	Required service time of $s_{k,u}$
T_k	Task k
w_C	Cost preference weight
w_{Rel}	Reliability preference weight
w_{SU}	Resource utilization weight
w_T	Time preference weight
w_{TCT}	Total completion time weight
wl_k	Workload of T_k
$wl_{k,u}$	Workload of $s_{k,u}$
$W_k^{u,u+1}$	Logistics weight between $s_{k,u}$ and $s_{k,u+1}$
WT_k	Waiting time of T_k
$WT_{k,u}$	Waiting time of $s_{k,u}$
α_0=1.0	Benchmark efficiency coefficient
α_i	Efficiency coefficient of E_i's services
$\delta_k^{u,u+1}$	No logistics exists between $s_{k,u}$ and $s_{k,u+1}$ for $\delta_k^{u,u+1}$=0 and vice sersa

manufacturing based on task workload [13]. The innovations of this work are as follows. First of all, we proposed a new multi-task scheduling model for cloud manufacturing based on service composition idea and method. Some critical issues pertaining to scheduling in cloud manufacturing such as logistics are taken into account. Secondly, the proposed model incorporates novel methods for modelling task workload and service (including service quantity and efficiency) [15,16], which enables us to dynamically calculate task (or subtask) fulfilment time and service utilization [17]. More importantly, based on different workload-based task scheduling methods, we find that scheduling larger-workload tasks with a higher priority can lead to better system performance such as a shorter makespan and higher service utilization. Monte Carlo methods are employed to reveal the regularity behind the scheduling methods [9–11].

The rest of this paper is structured as follows. In Section 2, a systematic literature review and corresponding analysis are conducted. Section 3 gives an example that motivates the establishment of the current multi-task scheduling model. Section 4 elaborates on the multi-task scheduling model in detail. In Section 5, a concrete multi-task scheduling example is given. Section 6 presents the results of simulation experiments and associated analysis. And finally, Section 7 concludes this paper followed by discussions on future research.

2. Literature review

First of all, it is necessary to clarify a number of fundamental concepts such as manufacturing tasks, resources, and services. Wang et al. [18] discussed the manufacturing task semantic modelling and description in a manufacturing system. In their view, manufacturing tasks can be divided into nine categories, including design tasks, manufacturing and processing tasks, logistics and inventory tasks, etc. A manufacturing task information model consisting of static information, subtask set, relation constraint, and service/capability demand was proposed. Wang et al. [19] described customers' requirement tasks at four different levels, namely, products, parts, processing technology, and machining procedure (or process). Accordingly, manufacturing resources can be categorized into four different levels, i.e. enterprise level, workshop level, cell level, and device level [20]. The classifications above reflect the multi-level and multi-granularity characteristics of requirement tasks and resources. Liu et al. [20] proposed a multi-granularity manufacturing resource model for the multi-granularity matching between manufacturing tasks and manufacturing capabilities, as well as the approach to encapsulating manufacturing capabilities into manufacturing cloud services by extending OWL-S.

To date, a couple of works have addressed the multi-task scheduling issue in cloud manufacturing. Cheng et al. [10] dealt with multiple task-oriented virtual resource integration and optimal scheduling from the perspective of cloud manufacturing enterprises. They focused on the issue of scheduling tasks as many as possible onto a fixed amount of resources to obtain a higher profit for an enterprise under the constraint of delivery deadlines. Jian et al. [9] dealt with the scheduling of a batch of workshop production tasks with the same characteristic and production process. The research issue is that, given the production time and production cost of each task in a production process, how to schedule tasks to minimize the total cost and time. Different from the aforementioned two works where only the same type of tasks was tackled, Li et al. [11] addressed the scheduling of multiple heterogeneous tasks at the subtask level. Also, the transportation of components or products between subtasks is taken into account. To achieve the optimization objectives, all of the three works above considered resource occupancy and time division sharing. Lartigau et al. [17] discussed scheduling methodology for production services in cloud manufacturing, and proposed a framework for scheduling methodology