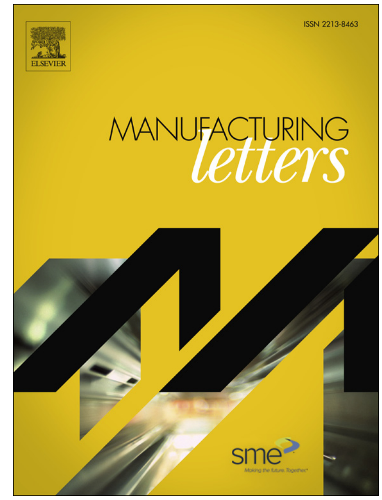
Accepted Manuscript



Letters

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PII: S2213-8463(15)00021-8
DOI: http://dx.doi.org/10.1016/j.mfglet.2015.12.001
Reference: MFGLET 71

To appear in: *Manufacturing Letters*

Received Date: 14 October 2015
Accepted Date: 22 December 2015

Please cite this article as: C. Yang, W. Shen, T. Lin, X. Wang, IoT-enabled Dynamic Service Selection across Multiple Manufacturing Clouds, *Manufacturing Letters* (2015), doi: http://dx.doi.org/10.1016/j.mfglet.2015.12.001

IoT-enabled Dynamic Service Selection across Multiple Manufacturing Clouds

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***Abstract*—Cloud Manufacturing can manage mass manufacturing resources and capabilities, and provide them as services via the Internet. Undoubtedly, multiple manufacturing clouds (MCs) will have extremely abundant services in terms of function, price, reliability, location, etc. Selecting and using services from multiple MCs is a natural evolution in the best interests of service consumers. On the other side, various uncertainties in today's highly-dynamic business environment can easily disrupt manufacturing activities, rendering original schedules obsolete. However, little work has been done to take advantages of abundant services from MCs and to effectively deal with uncertainties. To address this requirement, we propose a dynamic Service Selection (SS) method across multiple MCs. The proposed method uses IoT's real-time sensing ability on service execution, Big-Data's knowledge extraction ability on services in MCs, and event-driven dynamic SS optimization to deal with disturbances from users and service market and to continuously adjust SS to be more effective and efficient.**

Keywords-Service Selection; Uncertainty; Multiple Manufacturing Clouds; Cloud Manufacturing; Internet of Things; Big Data.

I. INTRODUCTION

Cloud manufacturing (CMfg) adopts and extends the concept of cloud computing to make mass Manufacturing Resources and Capabilities (MR/Cs) more widely accessible to users through the Internet [1]. Significant research efforts have been made to analyze the connotation and system architectures, and develop enabling technologies of CMfg [2]. However, the scope of most current research has been limited in a single manufacturing cloud (MC) [2]. The integration of multiple MCs is critical as a MC only has relatively limited MR/Cs and can only provide limited services in terms of location, function, price, reliability, etc. Selecting and using services from multiple MCs is a natural evolution, which will provide more options to customers for complementary capabilities. The ability to manage and use manufacturing services has direct relation to the success or failure of manufacturers (service consumers) facing increasingly fierce global competitions [3] [4].

Under the CMfg environment, there are still technical challenges when consumers need to use multiple services (from MCs) in certain sequence to optimally fulfill their complex manufacturing tasks. Those multiple services for a complex task form a composite service. Most work in the literature evaluates the overall QoS of composite services based on the QoS of their underlying component services, to perform optimal Service-Selection (SS). Complicated service composition modes are usually translated into simple equivalent sequence ones to get the overall QoS [5] [6], but such methods are static and do not consider the factors from the implementation aspect. More comprehensive performance evaluation metrics of SS have been proposed by synthetically considering key performance indicators from business, service and implementation aspects [7]. However, these methods cannot deal with inevitable, unexpected disruptions during the service execution, which may turn the original plan obsolete [8]. Little effort has been made to leverage abundant services hosted in MCs to eliminate such effects. Some efforts in the cloud computing research literature also tried to solve SS issues in multi-cloud environments [9]. However, they do not consider material flows, which are crucial in CMfg and affect SS decisions.

Uncertainty theory is usually leveraged to address uncertainties (by improving the robustness of schedules) during the problem formulation stage (the beginning stage)[10]. However, this is not enough when practical disruptions occur, leading to deviations from the initial schedule. At least, the schedule will become less effective and adjustments are needed with consideration of ample services from MCs. The Internet of Things (IoT), which can provide real-time information about manufacturing objects and processes, presents an exciting opportunity to narrow the gap between the decision and the service execution. Big Data (BD) adopted in CMfg can fulfill its function to help gain more knowledge about the services and the service market of MCs, for example using structured and unstructured reviews about services. Thus IoT and multi-MC will elicit a new dynamic SS paradigm to fulfill user tasks in an effective and efficient manner.

To address the above problems, an IoT-enabled integration framework is proposed to support dynamic service selection (SS) across multiple MCs. Under such framework, critical events to trigger dynamic SS are analyzed, and an event-driven process of dynamic SS is presented to capture underlying uncertainties and exploit abundant services to optimally fulfill user tasks.

II. MC Broker for Dynamic Service Selection

To enable optimal SS over multiple MCs, the concept of cloud service brokerage [11] is introduced into CMfg as the MC broker. The MC broker can combine and integrate multiple services from MCs to support users' goals. Thus it should has knowledge about user tasks, service offerings in MCs, SS schedules and status of service execution. As indicated in Fig. 1, it mainly consists of Big Data Platform (BDP), Virtual Resource Manager (VRM) and adaptors for different MCs. The BDP enables Big Data acquisition, integration and cleaning, storage, processing and visualization to extract information or knowledge for optimal decision-making, e.g., task decomposition and SS. The VRM provides a uniform management interface of services from MCs, via the adaptors to translate between generic management operations and provider(MC)-specific APIs. IoT infrastructure can sense the real-time state of service execution to increase the visibility of task progress. The sensed critical events should trigger the dynamic SS process to optimize the original SS plan in time, i.e., the MC broker should have the intelligence to react to various uncertainties from the service marketplace and user side. This will make task execution systems (composite services) agile and efficient to implement user tasks.

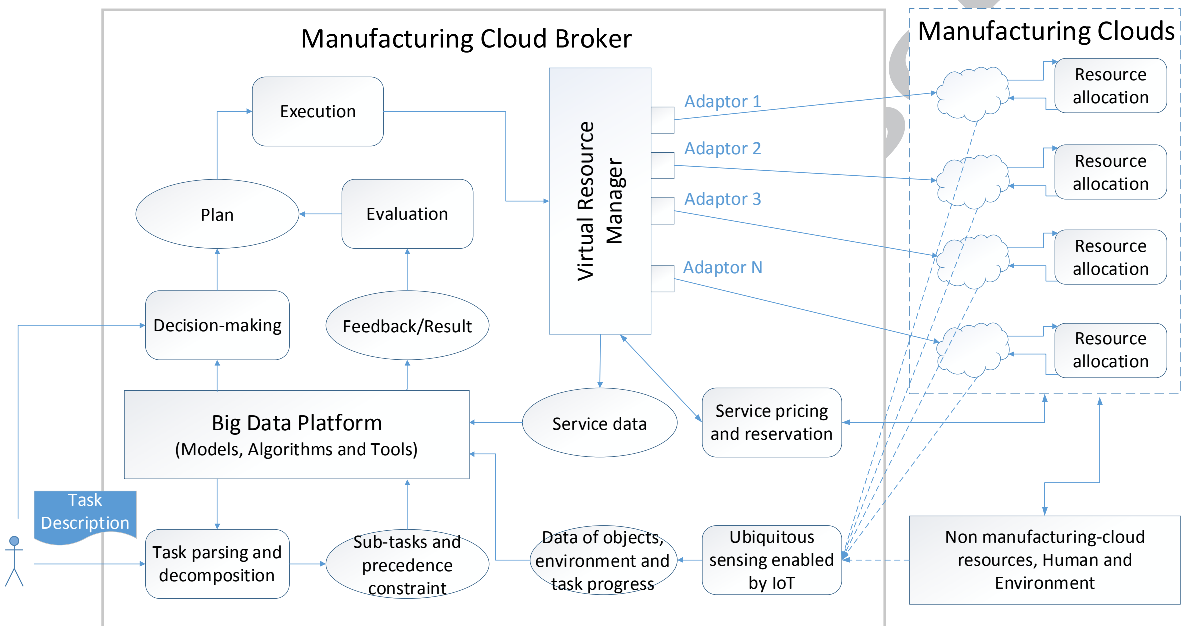

Figure 1. A framework of the MC broker for dynamic service selection

III. EVENT-DRIVEN DYNAMIC SERVICE SELECTION

Potential critical changes come from two both the marketplace and service customers, which will disrupt the original plan. Those changes which comprise uncertainties in manufacturing processes should be considered to optimize task execution.

A. Changes from Marketplace

1) Fluctuation of completion time

In order to enable just-in-time manufacturing [12], it is important to consider the fluctuations of completion time of sub-tasks. The fluctuations can be caused by breakdown of machines, expansion of productivity, new (rush) orders, cancelation of orders, etc. If the subtasks are finished in advance, then the subsequent subtasks can possibly be started earlier using available services from MCs. If the completion time of some subtasks are delayed and exceeds the scheduled start time of the next subtasks, the manufacturing plan needs to be adjusted based on available service offerings. IoT technologies such as RFID, WSNs, can substantially increase the visibility of shop floors and make the real-time capture of field data possible. Thus fluctuations of completion time can be predicted more exactly in advance or the completion event can be captured in real-time manner, to enable dynamic and efficient SS.

2) Better choices of manufacturing services

The service marketplace of MCs exhibits obvious dynamic characteristics. The changes can be categories, prices/pricing strategies or other QoS parameters. For example, surplus production capacity may be sold at discounts. New services may emerge with better QoS or disruptive functionality. Those changes can be used to get more benefits, e.g., through replacing selected services with ones that have lower prices or better QoS. In addition, more information or knowledge about the services can be acquired through historical data, and user ratings and comments with the help of BD. Such information or knowledge becomes more accurate and creditable as related data accumulates. Thus better choices of manufacturing services can be employed to improve dynamic SS.

B. Changes from Service Consumers

The changes can come from the consumer side. Many reasons can lead to revision of original tasks. Service consumers may need to revise the tasks according to changed demands, for example, requiring some processing subtasks achieved with higher machining precision. The driving force can also stem from BD, which can collect market data from various sources and extract new trends, demands or reviews of current products. Besides, real-time data of smart products enabled by IoT can elicit changes of production processes. New technologies at the consumer side can also be disruptive factors to drive the change of task decompositions. Thus current SS in CMfg should support agility and evolution of manufacturing tasks to meet rapidly changing demands.

C. Dynamic Service-selection Process

The proposed dynamic SS process is shown in Fig. 2. The critical events from both market and consumer sides should be captured to trigger the optimization of SS (dynamic SS process). The MC broker will generate new SS plans for users by taking account of the original plan and current service options in MCs. A final plan will be determined and executed according to user's decision. Through dynamic SS process (continuous adjustment of SS plans), the tasks from consumers can be executed optimally by intelligently reacting to the changing manufacturing environment.

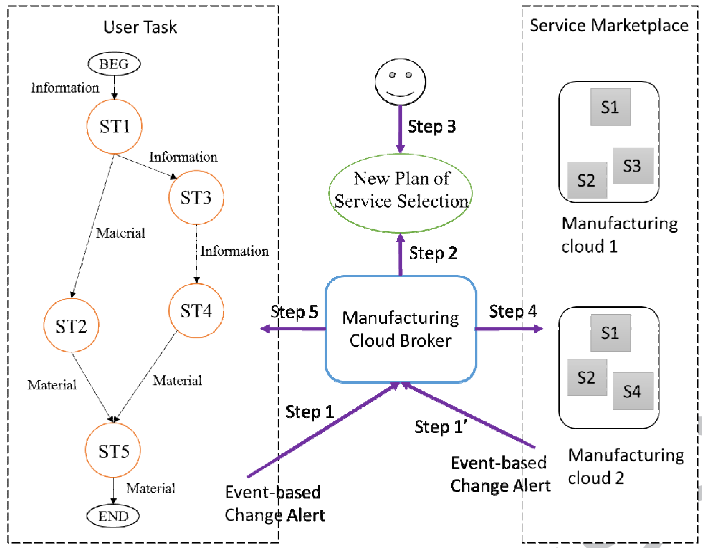

Figure 2. Dynamic service selection process in multiple manufacturing clouds

IV. CONCLUSION

Fierce competitions in the global market push companies to be more agile and react to changes quickly. The abundant services from multiple MCs have created unprecedented opportunities for enterprises to outsource their non-core business to reduce lead-time, cost, improve product quality and facilitate customization. Uncertainty problems in dynamic manufacturing environments should also be addressed to optimally fulfill user tasks. This paper introduces our preliminary investigation on the SS issue across multiple MCs. First, an IoT-enabled framework of the MC broker that can collect data about services in multiple MCs and orchestrate them to execute user tasks is proposed to support the full exploitation of abundant services. Second, considering the critical disturbance captured by IoT and changes of user tasks and service market, a new dynamic SS method is proposed to make SS more effective and efficient in uncertain manufacturing environments. As the service market of MCs is very large and highly dynamic, IoT-enabled real-time capture of disturbances and the adaptive SS method can lay solid foundation for the optimal execution of user tasks. Third, Big Data technology is employed to assist optimal-decisions on SS, e.g., extracting knowledge about service qualities or market demands. Our future work includes the formulation of dynamic SS problems, the design of intelligent optimization algorithms, and the implementation of typical applications.

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