A survey on cloud-based solutions for cloud manufacturing

N.C. Brintha*
Department of Computer Science,
Kalasalingam Institute of Technology,
Anand Nagar, Krishnan Koil – 629001, India
Email: brinthachris_2k@yahoo.co.in
*Corresponding author

Shajulin Benedict
HPC CLoud Research Laboratory,
St. Xaviers Catholic College of Engineering,
Chunkankadai, India
Email: shajulin@sxccce.edu.in

Abstract: Cloud computing is becoming an emerging technology that is changing the traditional industry and enterprises to do their work in a new way using dynamically scalable, virtualised heterogeneous resources over the internet. Nowadays, cloud manufacturing is evolving as a new technology that transforms the traditional manufacturing business model to effective reconfigurable production lines, allows effective load balancing to dynamic customer demands and reduces the time to market. In cloud manufacturing, the resources that are geographically distributed across several sectors are incorporated as cloud-based services and they are provided to users in a centralised manner. The resources can be provisioned to the users of cloud as pay as you go model depending on the user requirements.

Keywords: cloud computing; cloud manufacturing; optimisation; architecture.


Biographical notes: N.C. Brintha graduated from C.S.I Institute of Technology, Tamilnadu. She received her ME in Computer Science and Engineering from AKCE under Anna University affiliation. Currently, she is working as an Assistant Professor in Kalasalingam Institute of Technology, Krishnan Koil, Tamilnadu. Also, she is doing her research program under Anna University as part time under the guidance of Dr. Shajulin Benedict, Professor at SXCCE Research Centre of Anna University.

Shajulin Benedict did his PhD degree in the area of Grid Scheduling under Anna University, Chennai. He has published many papers in international journals. After his PhD award, he joined a research team in Germany to pursue post doctorate under the guidance of Prof. Gerndt. Currently, he is a Professor at SXCCE Research Centre of Anna University-Chennai and he is heading the HPC CLoud Research Laboratory which was established by him at his
workplace. He is also a Guest Scientist in TUM, Germany. His research interests include grid scheduling, performance analysis of parallel applications, cloud computing, and so forth.

This paper is a revised and expanded version of a paper entitled ‘A survey on cloud-based solutions for cloud manufacturing’ presented at International Conference on Advanced Materials and Manufacturing – ICAMM 2015, Cape Institute of Technology, Levenjipuram – 627114, Tirunelveli District, Tamilnadu State, India, 27–28 March 2015.

1 Introduction

In the modern trend, collaboration of services, internetworking has been identified as key concepts in business process that have the ability to change the enterprises in a worldwide manner (Xu, 2012). Manufacturing industries are changing from traditional manufacturing to IT enabled smart technologies in order to increase the productivity, reduce life cycle costs and to reduce the time to market. Cloud computing (CC) provides on demand computing (Xu, 2012) resources with increased reliability, security, availability and scalability in a geographically distributed and heterogeneous environment (Huang et al., 2013). The National Institute of Standards and Technology (NIST) (Mell and Grance, 2009) defines CC as “cloud computing serves as a distributed environment which offers ubiquitous, convenient, on-demand access using network to a shared collection of dynamically configurable computing resources (Mell and Grance, 2009) (e.g., networks, servers, storage, applications, and services). These resources can be allocated or released with less management effort and provider interaction”.

The global worldwide market is subjected to chaotic demands and customers normally demand high quality products with reduced cost and shorter delivery times. Since in manufacturing sector, jobs are diverse and demands are high, manufacturing can be accompanied using cloud related technologies to meet the growing demands of the customer.

The concept using the terminology cloud manufacturing (CM) was proposed by Wu et al. (2014) in 2014 who introduced the concept of migration towards manufacturing with cloud resources. Using the definition proposed by NIST CM in similar to CC refers to a client-based manufacturing model through which manufacturing resources are provisioned to the user based on their demands (Wu et al., 2014; Zhang et al., 2012a). This is done in order to generate a temporary, reconfigurable production lines to improve efficiency, optimal resource sharing, reduce product lifecycle costs, efficient load balancing and on demand resource allocation (Zhang et al., 2010; Wu et al., 2012, 2013b).

Even though there are several paradigm shifts CM is still in infancy (Schaefer, 2012; Bughin et al., 2010). Hence the focus of this paper will be mainly on CM. The basic cloud architecture is defined in the first half of the paper briefly. These things can be taken in to consideration for designing cloud-based applications. This paper explores the concept of manufacturing using cloud-based approaches and the manufacturing architecture. The rest of this paper in Section 3 discusses about the various optimisation algorithms that can be used to serve manufacturing cloud and Section 4 concludes the paper.
2 Cloud computing

CC provides a way to deliver the computing services through internet. The services on cloud enables the users to access the software or the hardware from the third parties, who may be at remote locations. Some common examples of such cloud-based services include storage of files, social network, webmail and other business. The information and computing resources that are distributed can be accessed easily using this cloud-based computing model.

2.1 Cloud architecture

The concept of cloud drives to the next generation data centres by deploying virtual servers. This enables the customer to access the resources and install their applications depending on their requirements without considering the location (Armbrust, 2009). The cloud architecture consists mainly of cloud resources, virtual machines, cloud programming and cloud applications (Buyya et al., 2009). The basic market oriented cloud architecture is represented in Figure 1.

Figure 1  CC architecture
A survey on cloud-based solutions for cloud manufacturing

This architecture has four main entities. They are

1. **Users/brokers** – These persons are responsible for submitting requests and getting response from cloud.

2. **Resource allocator** – These are the service providers who are responsible for providing the service. They are responsible for billing the requests, dispatching the resource, keeping track of availability of resource and monitoring the execution progress.

3. **Virtual machines** – For each physical machine multiple virtual machines are started to meet the service requests. VM’s can run applications concurrently.

4. **Physical machines** – The actual computing or processing resources are called the physical machines. They incorporate several computing servers that provide the resources that are required to meet the user demands.

Several other authors have proposed layered architecture for CC (Armbrust, 2009; Chahal et al., 2010). A new layer can be introduced in cloud that abstracts the management of different VM’s running in different cloud instead of having a unique interface for the management of the service (Belogaov et al., 2012; Meriino et al., 2010).

### 2.2 Cloud-based applications

CC has several applications because of its advantages. Some of the cloud application is represented below.

1. **Enterprise systems** – These systems are becoming complex and it requires lot of effort and cost (Wang, 2013). The best solution for enterprises is planning of the resources in an enterprise. These systems are used to deliver the operational information in a better way through knowledge management and it is recently used as a tool in various organisations (Yen et al., 2009; Chou et al., 2005). ERP on demand delivers a lot of advantages like fast deployment, predictable, time to value, flexibility, scalability and easy to upgrade (Rabay et al., 2013).

2. **Inline commerce** – This represents the exchange of products through internet. Its technical architecture includes hardware and software and another layer to hold the business transactions which is based on the technical architecture. By using CC technology, IT infrastructure costs are reduced because it provides electronic commerce which avoids the overhead incurred in renting or buying a physical resource (Qin, 2009). When cloud technology is accompanied with e-commerce it reduces cost, promotes availability, scalability and security (Armbrust et al., 2010; Abdulkader and Abualklishik, 2013).

3. **Biomedical information sharing** – informatics is the concept of applying computational and mathematical approach to analyse the biological and biochemical information. These researches are used to explore the biological information as molecules and cellular levels. Informatics using imaging focuses on tissues and organs. Recently CC is accompanied with bioinformatics to solve many limitations in this field (Stein, 2010; Langmead et al., 2009; Schatz et al., 2010). Due to the advantage of using cloud in bioinformatics Cloud Blast was first developed to solve sequence analysis problem (Matsunaga et al., 2008). There are several other projects
used for large-scale sequence processing, alignment of proper sequence, alignment, mapping of short sequences, single nucleotide polymorphism, using genome annotation to find its location and coding sequence and differential gene expression analysis based on RNA. In order to improve data processing some efforts are taken using cloud in comparative genomics (Kim et al., 2012; Kudtarkar et al., 2011) and proteomics (Halligan et al., 2009).

In addition to the above mentioned applications there are several other applications of CC for Software Parks, distance learning etc. HPC-based cloud applications and the various performance tools that are available are discussed (Benedict, 2012, 2013). In recent days CC is accompanied with manufacturing to promote automated production lines (Li et al., 2010, 2011). Normally, manufacturing sector encompasses production-based manufacturing but the concept of cloud in manufacturing enables a drift from production-based to service-oriented manufacturing. So the remaining sections of the paper discusses about CM.

3 CC to CM

CC can be adopted in manufacturing sector due to its high scalability and flexibility in getting solutions. This reduces the cost of productivity and delivery time of manufacturing process (Wu et al., 2013a). CM moves traditional manufacturing business to networked manufacturing i.e., the geographically distributed resources can be used for manufacturing a single product (Tao et al., 2010).

The application layer of cloud interacts with the user to get the requirements which is used to produce the desired solutions. Due to sequencing and planning, numerous production lines are generated to create the desired solution (Ma et al., 2013). This production planning and sequencing of tasks can be done using automated applications. As a final process, the application layer locates the resources, manages them and allocates them to the work process.

3.1 CM architecture

In CM, the distributed manufacturing resources are encapsulated as cloud services in a centralised server (Huang et al., 2013). The CM architecture is described below using four layers. They are the layer that has the manufacturing resources, the virtualised service layer, and the globalised layer for management of resources centrally and the application layer that interacts with the user which is represented in Figure 2 (Michaloski et al., 2009; Vijayaraghavan et al., 2009).

The four layers are explained as below.

1 Manufacturing resource layer – This is a layer which encompasses the physical resources of manufacturing process like computers, servers, the design and analysis tools, software’s needed for simulation etc that is to be used for the development of product.

2 Virtual service layer – This layer provides an abstraction to the physical resources and it helps in identifying the resources (Wu et al., 2013a; Tao et al., 2010; Ma et al., 2013), virtualises them (Michaloski et al., 2009; Vijayaraghavan et al., 2009) and
packages them as CM service (Campos and Miguez, 2009; Xu and Nee, 2010; Hardwick and Loffredo, 2006).

3 Global service layer – This layer helps in allocating and reallocating resources, pricing, manages QOS and enables remote monitoring of the manufacturing resources (Huang et al., 2013; Tao et al., 2010). It is responsible for the complete operational facility of cloud.

4 Application layer – This layer is a serves as an interface between the actual customers and the cloud resources. This layer also provides the needed SLA’s to the user and promotes data portability (Rimal et al., 2011).

An important issue in manufacturing sector is to optimise the resource effectively. In order to optimise the resource there are several algorithms which is used to optimise the machining parameters.

Figure 2  CM architecture
3.2 Optimisation techniques in CM

The advantage of using CM technology has influenced many manufacturing industries, like automobile, mould, process planning in design, aerospace, electronics etc. Optimisation technology is one of the key concepts for CM operation which is used for efficient integration of manufacturing resources. In manufacturing sector, some algorithms are used to find how to allocate the machining equipment optimally to different tasks from a pool of resources. The manufacturing suppliers uses some decision making concepts to select the raw materials and components for their operation which reduces the production cost and improves the productivity in an enterprise (Xi et al., 2012). To optimally utilise the resources it is necessary to set up a mathematical model for selecting the manufacturing equipment in CM.

The main concept behind the problem of optimisation is to effectively allocate the resources to a set of jobs in such a way that it reduces the throughput time, turnaround time, waiting time, computational complexity and cost. The main target of scheduling is to maximise the resource utilisation and minimise processing time of the tasks. Some optimisation algorithms used in CM is as follows.

3.2.1 Multi-objective bacterial foraging optimisation

The concept of bacterial forging algorithm (BFO) was first stated by Kevin M. Passino in order to deal with the concept of optimisation in distributed environment (Passino, 2012). This is based on the foraging behaviour of bacteria named Escherichia coli (E-coli) which lives in human intestine (Dang et al., 2008). The mode of selection reduces and recovers the strategies of foraging. This algorithm reduces cost and improves efficiency (Subramanian and Padma, 2011).

3.2.1.1 Conceptual representation

Biological studies have shown that the foraging process includes four steps as shown in Figure 3 which includes swarming, reproduction and elimination-dispersal (Tang et al., 2006). The E-coli bacteria can have its movement as a 'run' which is moving in a particular direction whereas a ‘tumble’ denotes that E-coli can change its direction (Narendhar and Amudha, 2012; Panigrahi et al., 2011; Passino, 2002; Kim et al., 2007).

- Chemotaxis – This step evaluates the fitness function either in serial or parallel. This process directs the movement through a chemical stimulus through the process of swimming and tumbling (Baijal et al., 2011).

\[
\theta^i(m+1, n, l) = \theta^i(m, n, l) + \nu(i)\xi(j)
\]

where \(\nu(i)\) is the size of the step in random direction, \(\theta^i(m, n, l)\) represents the \(i^{th}\) bacterium in terms of chemotatic, reproductive and dispersal step.

- Movement can be done in two ways like swimming for a period of time in same direction or it may tumble and an alternate between the two modes of operation for the entire lifetime.
The random direction is given by

\[ \mathbf{g}(j) = \frac{\mathbf{\Delta}(i)}{\sqrt{\mathbf{\Delta}(i)^T \cdot \mathbf{\Delta}(i)}} \]  

(2)

where \( \mathbf{\Delta}(i) \) represents a vector in arbitrary direction. During the run movement of bacteria, \( \mathbf{\Delta}(i) \) remains unchanged; otherwise, \( \mathbf{\Delta}(i) \) represents a random vector whose elements lie within the range \([-1, 1]\).

- **Swarming** – This is a behaviour that is found in motile species of E-coli that represents the spatio temporal patterns which are formed in a semisolid nutrient medium (Budrene and Berg, 1995). The E-coli group can arrange themselves by taking its movement towards the nutrient gradient that is normally placed in the semisolid matrix with nutrient chemo effectors.

- **Reproduction** – The bacteria that is too weak to survive will eventually die, these bacteria normally yields a low value for the objective function. The bacteria that look healthier can survive and they are split in to two asexually and placed in the same location. This allows maintaining constant swarm size.

- **Dispersal** – During the life span of bacteria, some changes may occur gradually or suddenly which may kill the lives of some group of bacteria in a particular region which has a high collection of nutrition gradient. In some cases the all bacteria in a particular location are killed. In order to consider this situation some or group of bacteria can be terminated or liquidated and the strategy of replacement can be started in the search space (Dasgupta et al., 2009).

**Figure 3** Basic steps in BFO

![Basic steps in BFO](image)

### 3.2.1.2 Variations in BPFO

- **Dynamic bacterial foraging optimisation (DBFO)** – When the concept of bacterial foraging optimisation, is applied in dynamic situations it is called DBFA. Dynamic environments have faster convergence, so the selection process must be flexible to provide global optimum in every possible direction. It provides diversified global search but also does not compromise the local search capabilities (Yan et al., 2012; Chen et al., 2008).

- **Hybrid bacterial foraging optimisation (HBFO)** – When bacterial foraging optimisation is included along with other evolutionary or biological algorithms it becomes HBFO. For example if the behaviour of a swarm or ant is incorporated in the tumble part of BFO then it can be called as a HBFO (Narendhar and Amudha, 2012; Kim et al., 2007).
• Parallel bacterial foraging optimisation (PBFO) – This is an evolutionary soft computing tool which considers the fitness functions of all the bacteria to find the best optimum value. The fitness function evaluations can be carried out serially or in parallel (Bakwad et al., 2009).

3.2.2 Ant colony optimisation

Ant colony optimisation (ACO) is an evolutionary and heuristic concept that is based on behaviour of ants where the ants work together and converse using some pheromone trails in search of food (Dorigo et al., 2006; Jaskiran and Inderpal, 2013). An ant solves a problem iteratively by using a construction graph where edges represent the possible partial solution that the ant can take according to a probabilistic state transition rule. After selecting a partial or a complete solution, a rule to update the pheromone starts. A feedback mechanism is included in this rule to speed up convergence and to prevent premature solution stagnation. Due to the advantages of ACO various algorithms based on the ACO meta-heuristic have been applied to many difficult optimisation problems (Chiang et al., 2006).

3.2.2.1 Conceptual representation

Ants normally use two different types of pheromone for its movement. They are,

• Foraging pheromone (FP) – The ants wander in search of food. If it finds the food it returns its nest otherwise it starts in search of food till it finds it. It is used to discover the overloaded nodes. If some nodes are overloaded then scheduling must be performed to reduce the load (Chiang et al., 2006). This to find an alternative path when an ant encounters an overloaded node.
• Trailing pheromone (TP) – This pheromone is used by ant to make its path back to its nest, after it has discovered its food source. This helps to discover the under loaded nodes to implement load balancing. When a node with this constraint is found the ant tries to trace back.

The concept of ACO (Rastogi et al., 2012; Zhu et al., 2012) can be represented in Figure 4.

Figure 4 Basic steps in ACO

![Diagram of ACO process](image-url)
3.2.2.2 Variations of ACO

- Modified ant colony optimisation for load balancing (MACOLB) (Khan and Sharma, 2014) – In this concept, the ant movement is done towards both the front and rear direction. When using MACOLB throughput is maximised, response time is reduced and energy consumption is less which ultimately improves performance.

- Task matching ACO – This is used to schedule the tasks effectively and allocate resources such that the node does not get overloaded. The major goal in this is to schedule tasks effectively by reducing the time (Chiang et al., 2006).

3.2.3 Genetic algorithm

Genetic algorithm (GA) is a searching technique which provides localised search used to generate solutions to optimisation and complex search problems (Karunakar and Datta, 2007; Abdella and Marwala, 2005). This algorithm starts with an initial population and uses some genetic operators to create offspring’s. The candidates in the population compete with each other to get a solution based on the fitness function. The concept like mutation and crossover of GA is used to create new solutions from existing ones.

3.2.3.1 Variations of GA

- Interactive genetic algorithm (IGA) – IGA is useful for decision-making layer in the problem solving process and thus improves the accuracy of the partner selection by the diversification tacit knowledge of domain experts. In IGA the calculation of individual fitness value is based on the subjective evaluation of decision makers. Thus it reduces the problem of evaluation fatigue of decision making (Zhang et al., 2012b).

- Enhanced genetic algorithm (EGA) – This concept is enhanced using new fitness function based on mean and grand mean values. This optimisation is used for both job scheduling and resource scheduling. This will schedule the whole process and optimise as much as possible (Kaur et al., 2014).

There are several other optimisation algorithms for CM including artificial neural network (Maqableh et al., 2014; Pooranian et al., 2014; Heckerling et al., 2004), fuzzy logic (Abd et al., 2013; Li and Zhang, 2012; Zhang et al., 2014), particle swarm optimisation (PSO) (Pandey et al., 2010; Netjinda et al., 2012; Guo et al., 2012), bee colony optimisation (Bitam, 2012; Mizan et al., 2012), bat algorithm (Kaur and Kinger, 2014; Malakooti et al., 2013).

4 Conclusions

CM is recently becoming a paradigm for the next generation manufacturing. CM provides effective solutions to manufacturing problems. Based on the various literatures reviewed, it is found that CC can be effectively used in CM which can be helpful for manufacturing or service industries all over the world. In addition the effectiveness of cloud can be improved further by using suitable optimisation techniques for optimisation of resources in manufacturing cloud that is discussed above. Optimisation is an important
concept in CM which is reviewed using various algorithms that can be adopted to service the task effectively.

References


A survey on cloud-based solutions for cloud manufacturing


