Design of multi-agent based cloud integrated manufacturing system (CIMS) for new product development

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Abstract

Manufacturing industry has seen rapid changes in the last decade. Unprecedented growth of web and internet technologies has revolutionized the manufacturing industry from local to global competitive industry. Customer demand for customized and high quality product with lower cost and shorter life cycle has increased. In this agile environment, manufacturing industry need to be competitive, innovative, inter operative and collaborative to meet the changing demands of customer while maintaining productivity. Traditional manufacturing execution systems (MES), supply chain management (SCM) and enterprise resource planning (ERP) are built upon rigid architecture that can't respond fully in dynamic environment. In these circumstances, the challenge is to develop an integrated solution that is intelligent, agile, robust and have the potential to meet environmental and customer demands. Keeping the above issue in mind in this article, a multi-agent based cloud integrated manufacturing systems (CIMS) for new product development has been proposed. The introduction of cloud computing technology, with its versatile models of deployment makes inter and intra original equipment manufacturer (OEM) business processes smooth. Simultaneously, the cloud computing environment with agents will make OEM intelligent, robust, modular, decentralized, and scalable with wider information visibility across partners. This will further help industry to develop a collaborative manufacturing network in long run.

1. Introduction

Manufacturing enterprises are the major wealth generator for any economy (CMV, 1998). They contribute heavily in increasing GDP of any country. European commission vision report for manufacturing sector 2020 (EC, 2004) have depicted that there are 26 million enterprises operational in European Union (EU), out of which 10% are related to manufacturing. These manufacturing enterprises contribute 22% of EU gross product. This shows the importance of manufacturing in emerging and global competitive market. Currently, in order to cope up with the market trends, different methods and technologies has been adopted by manufacturing enterprises to improve their productivity and competence. Global market trend in the last decade have moved towards customers demanding mass customization, high quality product in lesser price and shorter life cycle. This trend made manufacturing enterprises more complex with parallel information and physical flows of material to satisfy customers. This complexity raises uncertainty amongst enterprises (Manuj and Mentzer, 2008).

In order to be responsive to the global market trends manufacturing enterprises can no longer survive standalone. They have to be integrated, collaborative, responsive, flexible and reconfigurable to meet the market needs to be competitive and agile (Paulo Leita, 2009)
Information and communication technology (ICT) helps in agile manufacturing by providing collaboration among partners, suppliers and also information sharing by process integration (Wu and Angelis, 2007). However, conventional legacy IT systems lack real time adaptability

and collaboration among partners (Akkermans et al.,2003).Cloud Computing Technology (CCT) which is a new growing technology could be used to integrate and collaborate suppliers with minimum resources. CCT is a simple and cost effective solution. The concept of IT efficiency in CCT is very simple. The resources are allocated over the cloud by use of Internet. These resources are accessible from anywhere. CCT is a cost economical solution that can be implemented and deployed easily with small upfront investment (Sean et al., 2011).CCT versatile deployment models makethe information visible to all stakeholders. Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) are the examples of servicemodels. Web-centric technologies like java, Extensible Markeup Language (XML) could be used to make SaaS in order to connect manufacturing enterprise resources. XML is a good choice for data exchange in CCT.

Multi-agent system (MAS) is a state of the art modelling technology for development of open, collaborative and intelligent software agents. MAS is used over the cloud to create distributed manufacturing systems with intelligence to address the problem of manufacturing design and collaboration. An agent is a software entity which is autonomous to meet its own design objectives intelligently and when working in a collaborative environment then overall objective by communication and coordination with other agents (Matthews et. al, 2007).Currently manufacturing execution systems (MES), enterprise resource planning (ERP) and supply chain systems (SCM) are not fully integrated and collaborative. The individual working of these systems makes the coordination and integration difficult. Unified coordination, collaboration is required to achieve the global goals of manufacturing.CCT with its features of hardware cost reduction, process cost reduction, and easy adoption with various deployment models makes it an ideal choice to reach global market. Keeping in view these attributes CCT is used as a base model in this paper. Multi-agent system (MAS) based cloud framework is proposed for new product development which forms a conceptual basis for facilitating collaboration across OEM.

The paper is organized as follows. Section 2 presents a brief literature review for multi-agent based manufacturing systems and cloud computing technology. Section 3 explains the problem environment in manufacturing. Section 4 & 5 explains the proposed layered architecture for CIMS. Finally, this paper concludes in Section 6 with brief conclusion.

2. Literature Review

Manufacturing industry of 21st century has seen rapid changes because of global competition. New and emerging technologies have helped in reaching the global and competitive market. As a result the strategies in manufacturing industry have to show competitiveness in new product development, innovation and customization. New manufacturing systems should have to be integrated, responsive and intelligent which primarily focus on cost, quality and delivery. Nevertheless, the knowledge of global market, demands of customers, environment, sustainability which plays a pivotal role is also important in manufacturing industry. Integration of manufacturing systems and supply chain systems in reaching the global market has received attention of researchers in the last decade. Related to this topic, several researchers have conducted research on collaborative and integrated systems. Various methodologies are adopted like game theory with multi-agent simulation, Nash equilibrium, soft computing technologies as genetic algorithm (Moyaux et al.,2004; Nagarajan and Sosic, 2008).

Managing and controlling the manufacturing enterprise activities for product development, planning, monitoring progress, assembling and inspection is done with various algorithms (Baker, 1998). Cohen and Lee (1998) have discussed and developed an integrated

model for material supply, production and distribution process. Global production and distribution is discussed by Arntzen et al (1995) by adopting resource allocation models. Global competitive and volatile market can't survive on traditional and centralized manufacturing and supply chain systems. Distributed paradigm in which collaboration is there among all stakeholders is of paramount importance. Multi-agent system (MAS) principle is widely reviewed and discussed in literature by researchers for distributed and intelligent manufacturing. MAS concept has been derived from Distributed Artificial Intelligence (DAI). It is a decentralized approach in which parallel activities are executed with autonomy called agents. The agent concept is not a new concept (Russel and Norving, 1995; Ferber, 1999; Woolbridge, 2002).Paulo Leita, 2009) gave definition of agents as ''An autonomous component that represents physical or logical objects in the system, capable to act in order to achieve its goals, and being able to interact with other agents, when it does not possess knowledge and skills to reach alone its objectives''.

MAS is ideal for coordination, integration of manufacturing and supply chain systems having high level of uncertainty (Lou et al., 2004). The salient features of MAS are:

- **Autonomy:** agents are aware of their objectives and they work independently without human interaction to achieve their goal (Jennings and Woodbridge, 1995)
- **Social interaction:** agent communication language (ACL) helps agents to communicate with other agents and humans (Moyaux and Chaib-draa, 2006)
- **Reactive:** agents can assess the environmental changes and can respond for changes (Parunak, 1999)
- **Pro-active:** agents look at the environmental changes and initiate action in response (Moyaux and Chaib-draa, 2006)

MAS is well suited to solve the problems of design, implementation, distributed manufacturing, decentralization and modularity in a global context (Parunak et al., 1998; Akkermans et al., 2003, Luis et al., 2011; Toshiya Kaihara., 2003; Uday et al., 2006; Wei-Shuo et al., 2008; O.M. Akanle et al., 2008; Vipul et al., 2009; Michael et al., 2010; Kamil et al., 2012; Zhou et al., 2013). Interaction among agents by ACL helps in solving problems independently in volatile scenarios where it is difficult and hard to foresee. Lu and Wang (2007) discusses that MAS helps in taking timely decisions for reconfiguration in global prospective for manufacturing. Learning capabilities of MAS helps in inter and intra enterprise collaboration in a cost effective manner (Swaminathan et al., 1998).

Multi-agent systems have been adopted in multitude of domains: negotiation in supply chain (Chen et al., 2004), interaction among manufacturing enterprise, customers and suppliers (Stone and Veloso, 1997), production and control processes in manufacturing (Caridi and Cavalieri,2004), coordination of E-commerce and web based supply chain system in supply chains (Ghiassi and Spera, 2003), inventory and demand forecasting (Beamon , 1998), formation of virtual enterprises for order fulfilment (Li and Fong, 2003; Choy and Lee, 2002; S.A. Petersen et al., 2001), supply chain management tool for scheduling and order allocation (Bo and Zhiming, 2003), global project scheduling (Wang et al., 2001), MASCOT tool for coordinated planning and scheduling in supply chain (Sadeh et al., 1999), dynamically changing mechanism for planning and coordination (Labarthe et al., 2007), supply chain automation model for coordination among supplier and subcontractors (Min and Bjornsson, 2000), CIIMPLEX framework for integrated manufacturing (Peng et al., 1998,1999), coordination across enterprises (Kwon and Lee, 2002), MetaMorph II integrated manufacturing, supplier and customer architecture (Shen and Norrie,1998), AARIA distributed manufacturing architecture for customer orders (Baker et al., 1997).Most of the MAS either in supply chain or in integrated

manufacturing systems coordinate in a closedenvironment with fixed number of entities (Sadeh et al., 2001). These MAS does not help in reaching complex global manufacturing operations in a real-time manner (Chen et al., 1999).This means that MAS should be dynamic enough to work in agile environment with collaboration (CPFR, 2013).

Globally integrated manufacturing system is the need of today in which all stakeholders should have easier access to real time information availability. Despite all the efforts of designing MAS in manufacturing, still full integration is far to be reached. Small and medium enterprises (SME) in manufacturing are having isolated systems.Small and medium-size enterprises (SMEs) contribute significantly on the economic development of any country. In developing countries SMEs represent approximately 45% of employment and approximately 33% of GDP (Peer et al., 2014). Despite being the potential part of economy they are not able to meet up with growing demand of global manufacturing industry. In order to reach the global market these manufacturing SMEs need to have some platform or architecture to reach the global market and meet the requirements of OEM in an integrated way

Cloud Computing Technology (CCT), which is a new growing technology, seems to be an ideal choice for integration of SMEs with OEM. CCT works as a platform that provides manufacturing SMEs connectivity to the global manufacturing market by use of cloud. Manufacturing SMEs need to have internet connectivity at their premises and be part of OEM private cloud. The major reason for SMEs to use CCT is hardware cost reduction, processing cost reduction and ability to reach the big global manufacturing market. Cloud computing technology has already started impacting big enterprise businesses and penetrated many areas from banks, automobile sector, education, logistics, wholesale, retail and health care. CT is a simple and cost effective solution. The concept of IT efficiency in CCT is actually managing computing resources efficiently. CCT is not just cost effective – it is also a computational tool which could be deployed and scaled rapidly, thus reducing the need for huge upfront investment in enterprise IT (Sean et al., 2011).CCT improves performance in the form of better information visibility. The key features of CCT are cost reduction, improved agility, resource management and greater flexibility (Lin et al, 2012). Various service models like Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) can be adopted by enterprises to cater the needs for global presence.

Different deployment models i.e. public cloud, private cloud and hybrid cloud as shown in fig. 1 makes the adoption easier for SMEs.**Public cloud** is a cloud usually maintained by third party service provider e.g. Google, Amazon via the Internet. It is cost economical solution to deploy IT solution/infrastructure by pay as you go concept. Google Apps is an example of a public cloud that is used by many organizations of all sizes (Sean et al, 2011).**Private cloud** is a cloud that is owned by big organizations which provides them greater control over their own cloud infrastructure, and is often suitable for larger installations. A **hybrid cloud** is a combination of a public and private cloud where non-critical information is outsourced to the public cloud, while mission critical services and confidential business data are kept within the control of the organization (Sean et al, 2011).

CCT have three service delivery models i.e. Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). Service-oriented architecture (SOA), which is an international standard, is used to deliver services. SaaS is an application that is hosted over the internet and delivered to customers as a service. Service providers like Google Office, Salesforce, CRM, NetSuite etc. Provides software maintenance and support associated with the application. PaaS provides a computing platform i.e. networks, servers, storage and other services. Consumer installs their software on the computing platforms and has flexibility of

software deployment and configuration settings. Examples are Facebook F8, Google App Engine, Joyent, Azure, Salesforge App Exchange etc. IaaS provides storage, network capacity, and other computing resources on rent basis. Customer uses the infrastructure to deploy their service and software. They can manage or control the OS, storage, apps and network components. Examples of IaaS are OpSource, Blizzard, terremark, Gogrid etc.

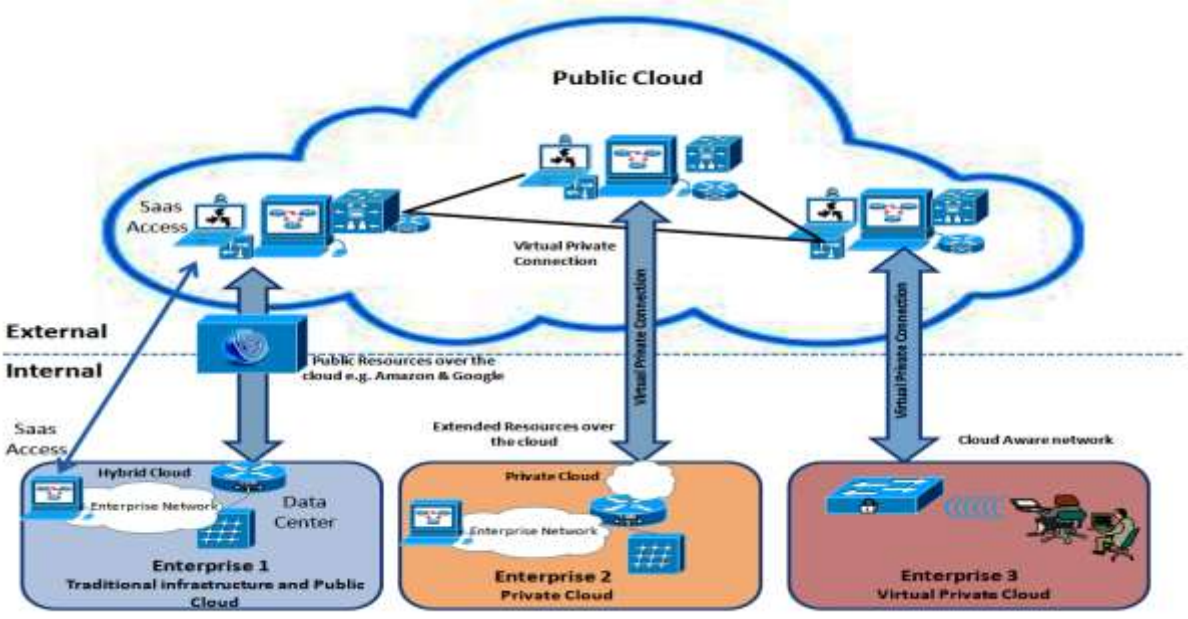

Figure 1: CCT Deployment Models

SaaS as explained earlier provides connectivity with OEM by encapsulating Service-oriented architecture (SOA). Manufacturing suppliers mostly SMEs, stakeholders and versatile departments of OEM which are located globally, gets connected with OEM by using SaaS. OEM maintains the private cloud and provides services to all stakeholders. Stakeholders simply need to have internet access at their premises to get connected with OEM private cloud infrastructure by using SaaS.Fig. 2 shows connectivity of stakeholders with OEM private cloud.

Many researchers have explored solutions for enterprise integration and some concluded that Multi-agent system (MAS) is most effective system for integration. Even till now integrated global manufacturing is somewhat hard to reach. Competition and existence of manufacturing enterprise in the global market is the dichotomy of today. In global market manufacturing and supply chain is a world-wide network of suppliers, manufacturing enterprises, distributors, retailers and finally customers for delivery of products (Fox et al., 1993). In this article multi-agent based cloud integrated manufacturing system (CIMS) as shown in fig. 2 is proposed. OEM hosts a private cloud with software agents and IT infrastructure. The resources of OEM are accessible by all the stakeholders by using SaaS.

Multi-agent based technology is used for integration and adding intelligence to manufacturing. All tiers of suppliers are connected and can be registered by accessing the private cloud of OEM. SMEs don't have to invest a lot on IT infrastructure. They need to have internet connectivity infrastructure and resources connected with private cloud of OEM to have a global reach. Customer orders are the primary focus of any OEM. Proposed multi-agent based CIMS is helpful in new product development because of its integrated architecture. The architecture is able to handle variations in product development, types and demands without reconfiguration to accommodate orders with new and customized specifications.

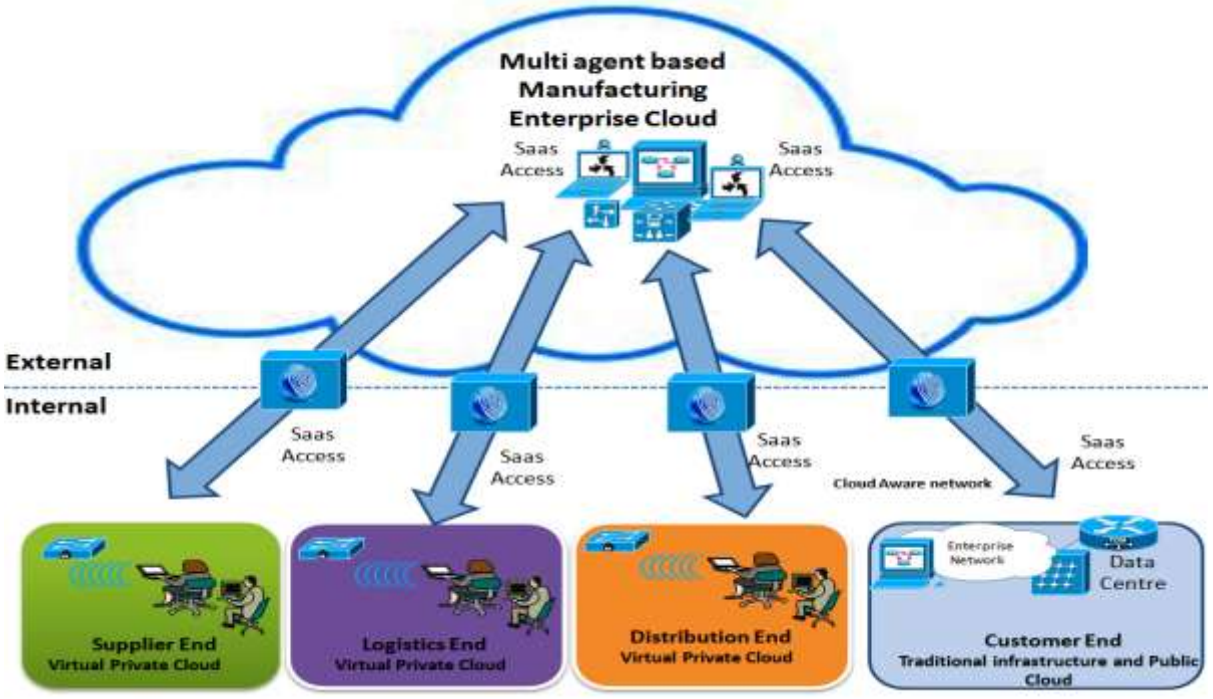

Figure 2: Multi-agent based cloud with stakeholders

New product development specifications are sent to OEM by passing through sequence of design phases. As all manufacturing suppliers are registered with private cloud of OEM so they can reply back with their best cost and delivery time in a prompt manner as shown in fig. 3. Section 8 discusses new product development scenario in detail.

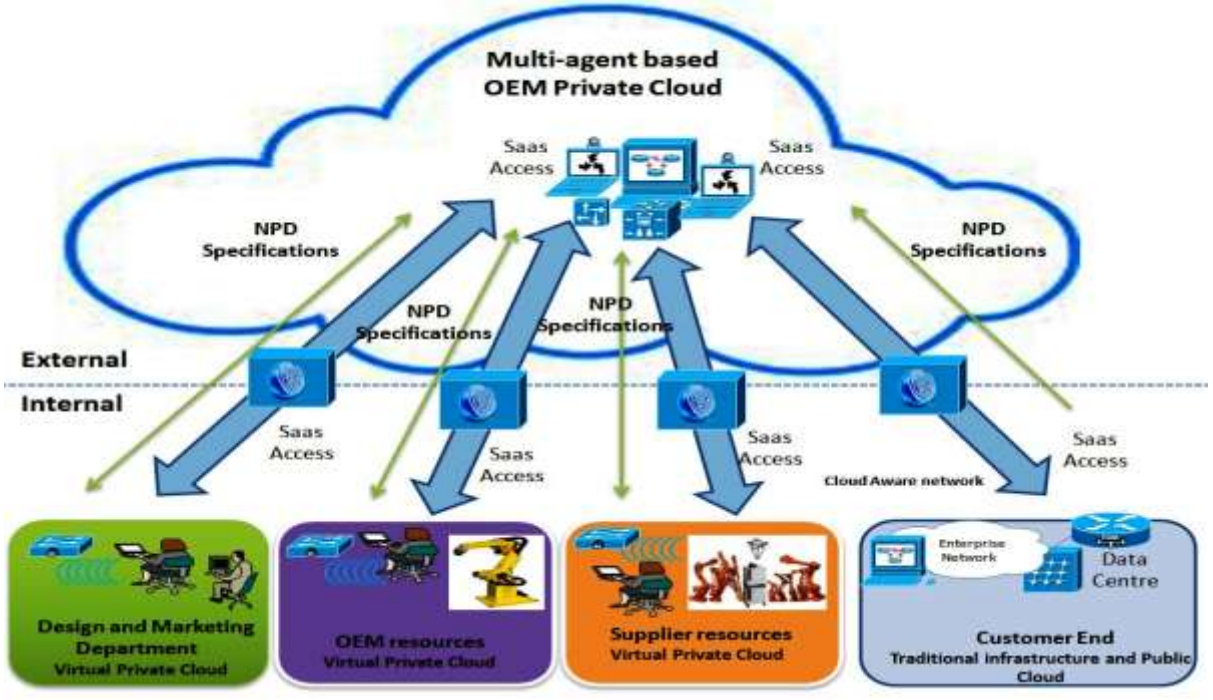

Figure 3: NPD scenario using multi-agent based CIMS

Private OEM multi-agent based CIMS is helpful in allocating resources to manufacturing suppliers after getting order from customers as shown in fig. 4.

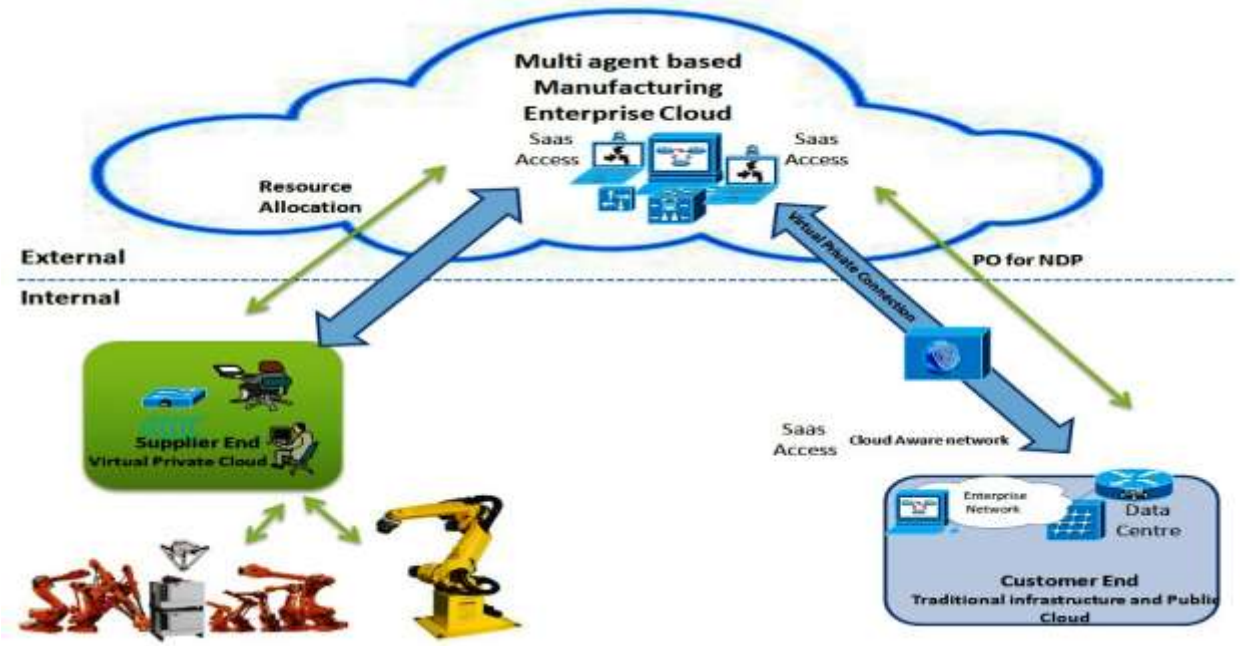

Figure 4: Multi-agent based CIMS with supplier resource connectivity with cloud

3. Problem Environment

The problem in global manufacturing environment is scarce availability of integrated manufacturing system. There is need to have an integrated systemof supply chain and manufacturing by keeping data, information and product flow in a real-time manner. In this environment integration of all stakeholders is of paramount importance. Supply chain stakeholders of OEM should be fully integrated and collaborative with manufacturing where the product is made / assembled. Global competition is striving manufacturing enterprises to have integrated solution coupled with latest technology to have global presence. Manufacturing enterprises are becoming highly complex. It involves several decisions making processes like customer enquiry for new products, customization in products, price quote for products and manufacturing enterprise intricate processes for product development. The complexity requires integration and collaboration among all stakeholders.

In this paper, an attempt has been made to propose a layered approach for multi-agent based CIMS architecture. It amalgamates the beauty of cloud-computing and multi-agents technology in manufacturing environment. In the proposed architecture, agents can work autonomously without human interaction in a collaborative way in complex manufacturing environment. The next section explains cloud based layered architecture and multi-agent based CIMS architecture for new product development.

4. Proposed Agent Based CIMS Architecture

The agent based **C**loud **I**ntegrated **M**anufacturing **S**ystem (CIMS) is based on multi-agents and cloud computing technology.Main reason of having the proposed system is that virtual enterprises and outsourcing is gaining popularity nowadays. In order to have a complete control on manufacturing system and supply chain, there is need to have an integrated system that provides real time information visibility in reaching tactical decisions.

Proposed CIMS is amulti-agent based architecture built on the concept of cloud computing technology (CCT). OEM hosts the entire infrastructure over the private cloud that provides resources and connectivity to all the stakeholders regardless of location. CIMS is made on the basis of viewpoints i.e. strategic, operational and technology. Strategic CIMS is concerned

with integration of business processes and capabilities to dynamically integrate and optimise business development. Operational CIMS is the dynamic configuration and integration of resources by using service-oriented cloud in agile and dynamic market. Technology CIMS is customisation and virtualisation of manufacturing hardware by using service-oriented cloud, software and technologies. In this paper private cloud concept is used for integration of multi-agent based manufacturing subsystem and multi-agent based supply chain subsystem. Both of these subsystems are on the private cloud of OEM. The multi-agent based manufacturing subsystem is for controlling production operations of enterprise. The availability of manufacturing subsystem from cloud provides flexibility in terms of availability of resources in agile market demand. Another multi-agent based supply chain subsystem also resides on OEM private cloud. It provides easy access to distributors, retailers and suppliers to meet the changing needs of the customers. The integration between the two subsystems creates a cloud based integrated manufacturing system (CIMS) which makes the enterprise virtually available from anywhere.

5. CIMS Layered Architecture

CIMS layered architecture is shown in fig.5. This section explains the features and characteristics of each layer.

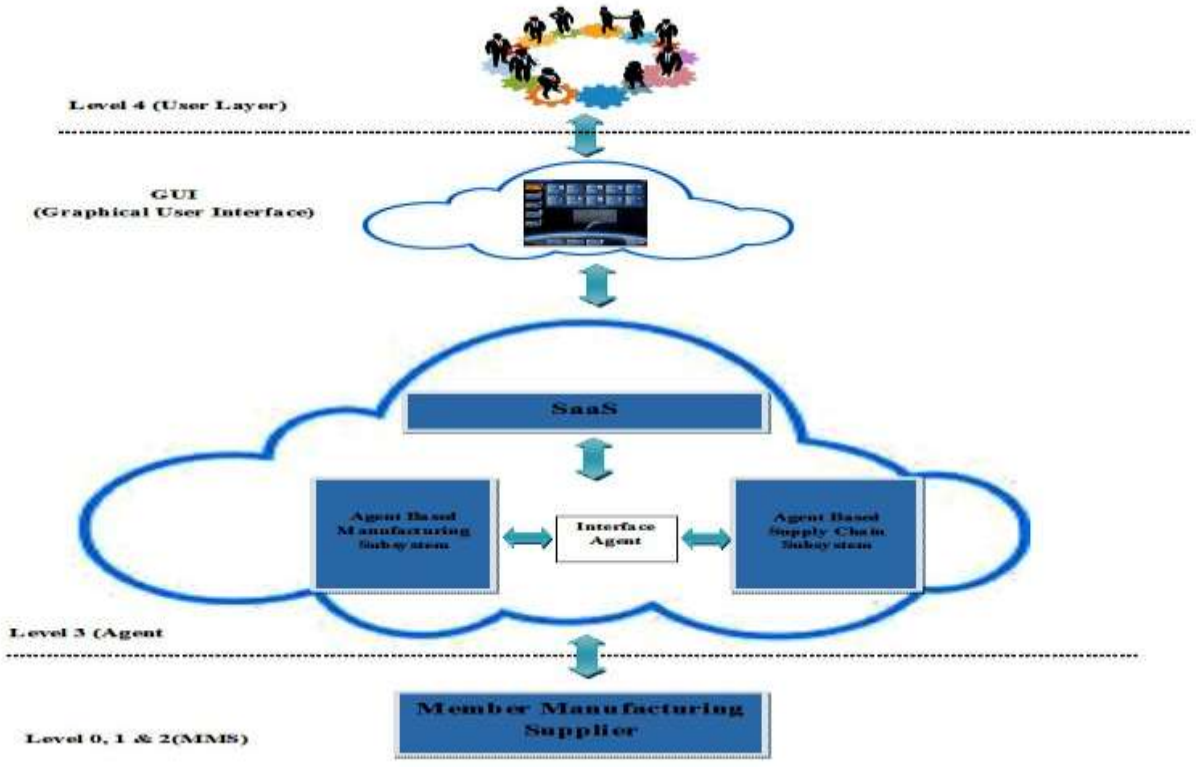

Figure 5: CIMS Layered Architecture

5.1 Member Manufacturing Supplier Layer (Level 0, 1, 2)

Member Manufacturing Supplier (MMS) layer comprises of proprietary hardware interfaces on level 0. These proprietary hardware interfaces communicate with other layers by unified protocol. The unified protocol provides linking with service-oriented cloud i.e. on level 1 and 2. Level 1 is responsible for conversion of proprietary protocols to a unified protocol. Note: An extended description and specification of level 1 is beyond the scope of this paper. Level 2 which is service-oriented cloud is responsible for virtualisation of hardware components.

Hardware functionalities are used as a service by using service-oriented cloud. This means that shop-floor hardware components are accessible from OEM cloud by using service-oriented concept. This helps in virtualisation of hardware components.

5.2 Agent Layer (Level 3)

The agent layer is smart and self organising for controlling OEM production operations. The aim of having agent layer is to manage, configure, reconfigure and structure the enterprise to cope up with agile customer demands and market trends. Level 3 comprises of two integrated subsystems i.e. multi-agent based manufacturing subsystem and multi-agent based supply chain subsystem. Interface agent between the two subsystems acts as a bridge for passing, receiving and replying messages from other agents. Interface agent is a kind of two-way application that acts as a bridge for communication with back-end multi-agents. Software as a Service (SaaS), which is also on the same layer, provides an interface for communicating with users by using service-oriented cloud graphical user interface (GUI)

5.3 User Layer (Level 4)

At the top level of the architecture is the user layer. Users access the OEM private cloud by graphical user interface (GUI), and use manufacturing resources. It provides easy access to users for vast variety of functionalities of integrated enterprise.

6. Conclusion

This paper has discussed the integrated OEM architecture for new product development by using cloud based multi-agents. The dynamic nature of architecture makes it a flexible reconfigurable solution for catering new and customized requirement for products. Focal point of this architecture is multi-agent based cloud integrated framework which provides a central platform for collaboration. The OEM cloud platform is well suited for dynamic changes taking place is global manufacturing and in new product demand. Proposed multi-agent based new product development process enables agents to interact with each other for cost and delivery calculation, quote for new product, optimal resource allocation, distribution and finally availability of product to customer through retailer. The architecture is still under development. Many aspects of architecture dynamics were not considered nor tested due to limitation of test data. Future work is to extend the architecture further for resource allocation in a recursive, dynamic and integrated way to cope up with the customized product requirement, changes in economics and operational conditions over time in global manufacturing.

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