Chapter 6
Cloud-Based Simulation

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Abstract In order to accommodate the development and application of simulation systems in network environments, modeling and simulation technology embraced increasingly web-based to cloud-based solutions. This chapter describes the development from the early application of web services, the use of simulation grids, towards modeling and simulation as a service. A current architecture for cloud simulation platforms is presented and key technologies for its implementation are identified. The chapter deals with big data challenges as well as digital twins and provides some applications of cloud-based simulation. It closes with the conclusion that the trend of simulation technology will be cloud-based and intelligent and motivates an intelligent cloud in support of simulation.

6.1 The Development of Modeling and Simulation: From Web to Cloud

Simulation research has been going through several stages in recent decades. While the application of Modeling and Simulation (M&S) technology have become more and more complex, varied resources are involved in the M&S systems (Zeigler et al. 2000). In order to accommodate the development and application of simulation systems in network environment, Web Services (WS) technology was brought in M&S field and Web-based Simulation (WBS) emerged. The basic idea of WBS is to encapsulate M&S resources in the form of web services and expose M&S services on the Web. As the IEEE M&S standard, the High-Level Architecture

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(HLA) has also been updated to provide Web Services support on the basis of original HLA functionality.

Compared to classical simulation systems, WBS facilitates the sharing of M&S resources and improves data accessibility, interoperability and user experience (Fortmann-Roe 2014). However, web service has some drawbacks such as the service statelessness, which makes it difficult to maintain the state of models exposed as services. Grid technology was used in M&S to be complementary to WBS and support the management of M&S services because of its advantages in distribute resource management and collaboration. Simulation grid overcomes some shortcomings existing in traditional distributed modeling and simulation systems.

Cloud Computing has been an extremely popular paradigm in IT industry in the past ten years. By right of the advantages of cloud technologies, Cloud-Based Simulation (CBS) shows superiority over WBS with lower costs and easier ways to develop M&S systems (Wang and Wainer 2015, 2016). Its concept of M&S as Service (MSaaS) attracts an increasing number of M&S practitioners to conduct simulations in the cloud. Later, with some new technologies appear, such as Cyber Physical Systems (CPS), Internet of Thing (IoT), cloud simulation which connect physical objects with cloud environment was proposed and gotten a great development (Zhang et al. 2010).

6.2 Web-Based Simulation

6.2.1 Definition of Web-Based Simulation

Web-based Simulation (WBS) is the integration of Web Services (WS) technologies with modeling and simulation (Wang and Wainer 2016; Yingping and Gregory 2005; Byrne et al. 2010). In WBS, existing models, simulation functions, their simulation environment and other M&S resources are exposed as web services (Byrne et al. 2010). Thus, the M&S resources that are originally accessible on a single computer could be shared through the Internet and experiments could be done using M&S services (Byrne et al. 2010). The user requests with simulation parameters could be sent to the simulator through web servers. The results return to the user after simulator finishes experiments remotely.

The early research on WBS began in 1995. Web-front ends were provided to run simulations as Common Gateway Interface (CGI) scripts/programs. They were developed based on Java-based simulation packages, systems and environments and could run anywhere on the Web (Miller et al. 2000; Miller et al. 2001). One of the early researches about WBS (Paull 1996) presented some issues and concepts on Web-based simulation. Since then, WBS attracted much attention of scientists and industries (Bencomo 2004) and a large amount of projects about M&S WSs were developed. These projects can be divided to two categories, that is, SOAP-based WS (Saurabh 2013) and RESTful WS (Al-Zoubi and Wainer 2013). DEVS (Discrete

Event System Specification) M&S formalism (Bernard et al. 2000) was used to develop many simulators (i.e., DEVS/SOA (Saurabh 2013; Al-Zoubi and Wainer 2013) and RISE (Al-Zoubi and Wainer 2013)) in the form of web services.

6.2.2 *The Advantages and Disadvantage of WBS Compared to Classical Systems*

The main advantages of Web-based simulation compared to classical systems have been researched and classified by many researchers, which are concluded as follows (Guan et al. 2016; Dhananjai et al. 2000; Tsai et al. 2006; Thomas 2001; Whitman et al. 1998; Veith et al. 1999; Chen and Heath 2005; Ashu 2000):

- Ease of use. The M&S services provides standard Web interfaces for users to invoke them.
- Model reuse. The fine granularity and common data access protocols facilitate the reuse of existing simulation models.
- Cross-platform capability. The M&S services could be opened by Web browsers without the limitation of operating system.
- Wide availability. The M&S services are accessible with an Internet connection from anywhere.
- Integration and interoperability. The M&S services could integrate and interoperate with others over the web easily.

On the other hand, the disadvantages of Web-based simulation over classical systems are listed as follows:

- Loss in speed. The network communication delay results to loss in speed when users interact with M&S services over the web.
- Web-based simulation application stability. The network environment seriously affects the running and interaction of Web-based simulation applications.
- Graphical user interface limitation. The graphical interface of Web-based simulation applications is constrained by the technology limitation of web service.
- Security vulnerability. M&S applications bear the risk of malicious attacks from other web users.

6.3 Extensible Modeling and Simulation Framework (XMSF)

Extensible Modeling and Simulation Framework (XMSF) is defined as a composable collection of standards, profiles and application instruction for WBS (Brutzman et al. 2002). This work was led by researchers from the Naval

Postgraduate School, Old Dominion University, George Mason University, and SAIC in early 2000 to meet the demand of The Department of Defense (DoD) for web-based simulation. XMSF aims to provide a web-based framework for distributed simulation with great scalability and support the reuse and composition of models. Web-based technologies used in XSMF facilitate the emergence, development and interoperation of M&S systems. Extensible Markup Language (XML)-based languages enables the compatibility of the future M&S requirements and the existing M&S technologies (Blais et al. 2005).

XMSF intended to identify different description methods of M&S resources to guarantee the interoperability of heterogeneous resources. Besides, XMSF must support the reuse and composition of heterogeneous M&S resources, which requires the further researches on ontologies and semantic network (Brutzman et al. 2002).

Many applications of XMSF has been carried out. An XMSF example is the Flexible Asymmetric Simulation Technologies (FAST) program, which integrates the combat simulations, databases, and computational tools for military training and analysis (Blais 2004). XMSF Profiles is studied to define the specification of XMSF. It includes the details of the structure and application of XMSF, protocol standards, composability guidelines and so on.

6.4 HLA Updating Towards Web

High level architecture (HLA), which is a systematic architecture for distributed interactive simulations (DIS), is one of important area of research on simulation technology today (Chi and YU 2015). It was developed in the early '90 s within the U.S. Department of Defense (DoD) to increase interoperability and reusability for simulations. HLA was accepted as an open international standard by IEEE in 2000, called IEEE 1516 (Zhang et al. 2010). The HLA standard has achieved widespread application. More than 200 parts were revised and supplemented to form new HLA Evolved standard in 2010 (Chi and YU 2015).

HLA Evolved is the new version of the HLA (Björn et al. 2008). HLA Evolved provides a lot of improvements for simulation developers and users on the basis of original HLA. The main updates focus on the development, deployment and net centric capacities of HLA federation. Simulation developers and modelers could obtain HLA functionality with Web Services communication frameworks over networks. Distributed federates connect with each other using Web Services to compose HLA federation. A wide range of programming languages are supported to develop HLA federations, such as C, C ++, Java, Fortran, ADA, Perl. Besides, the Web Services support enables HLA to meet the demand of distributed simulation over the web through the new Web Services Description Language application program interface (WSDL API). WSDL is used to describe M&S services as collections of network endpoints, or ports based on XML (Extensible Markup Language).

Run-Time Infrastructure (RTI) is the software developed according to HLA standard. To adapt to the new version of HLA, new RTI software adds Web Services Provider RTI Component (WSPRC) to support the Web Services API. WSDL federates can create and join federation using their URL (Björn et al. 2008).

6.5 Simulation Grid

The Internet and Web Technology has realized the connection of computers and Web pages. The Grid technology, however, attempts to realize the comprehensive connection of various distributed resources on the Internet, including computing resources, storage resources, software resources, information resources, knowledge resources and so on. Its goal is to integrate the entire Internet into one huge supercomputer. Combining modern network technology with networked M&S technology (e.g. HLA), simulation grid was proposed as a new infrastructure for networked M&S in early 2000.

Research projects combining simulation and Grid technology has been carried out. For instance, SF-Express solved such issues as resource allocation and dynamic fault-tolerance based on grid technology. CrossGrid studied the realization of RTI in accordance with HLA standard from RTI Layer, Federation Layer and Federate Layer. DS-Grid, NessGrid and Federation X Grid systematically studied the simulation-oriented application grid.

Simulation grid overcomes some shortcomings existing in traditional distributed modeling and simulation systems in dynamic sharing of simulation resources, autonomy and security mechanism. It not only supports the implementation of simulation system engineering, but also extends simulation application pattern and provides a new simulation method in the following two aspects.

(1) Simulation models in the form of Grid services

Grid service is a kind of Web service essentially. The simulation model of grid in the form of Grid service has all the advantages of the simulation models in the form of Web service, such as self-inclusion, loose coupling. Furthermore, Grid service addresses some inherent problems of Web service, such as statelessness and non-temporary of instances. A web service can't maintain data and state between invocations, which is adverse to simulation application. Web Service Resource Framework (WSRF) is a Grid resource infrastructure. It provides some functions which support M&S services to realize stateful interaction.

(2) Service-oriented simulation resources integration

Simulation resources include all software and hardware related to modeling and simulation activities, such as computing resources, model resources, storage resources, simulator resources, tool resources. Service-oriented resources integration requires several operations like resources servitization, resources deployment and resources virtualization. The main issues of resource servitization are the content and the form of servitization. The content of servitization means “what is to be a service”. Concerning the current technology, three main forms of servitization are Web Service, GT3 Grid Service and WSRF. Resource deployment means to deploy a developed service into a service container. Resource virtualization is the management of resources after servitization. Services are registered in the management organization, such as information server, resource routing and UDD.

However, from the view of application, the simulation grid also requires improvement in the following directions:

(1) Capability to reusing fine-grained M&S resources.
(2) Capability to fully supporting multi-users.
(3) Collaboration capability of all kinds of simulation resources.
(4) Fault tolerance capability of simulation system.
(5) Security mechanism of application.
(6) Capability to get modeling and simulation services on demand wherever and whenever users are through network.

While grid computing was facing more and more challenges, a new computing technology, cloud computing drawn wide attention because of its outstanding capabilities of resource on-demand sharing and collaboration. Together with the development of cloud computing, by combing the philosophy and methodologies of web-based simulation and grid simulation, a new simulation paradigm, cloud-based simulation, is emerging.

6.6 Cloud-Based Simulation

Cloud-based Simulation (CBS) has attracted a lot of attention in recent years. It integrates WBS and cloud computing technology to manage various simulation resources and build different simulation environments (Erdal 2013).

Cloud computing has shown its increasing importance in many fields. It exposes virtualizing hardware and software as services over a network, which generates the new concepts of infrastructure as a service (IaaS), platform as a service (PaaS), software as a service (SaaS). Inspired by these concepts, a cloud-based simulation technology called “cloud simulation” was proposed (Bo-Hu et al. 2009). Besides, the utilize of web services in CBS has received the name of Modeling and Simulation as a Service (MSaaS). MSaaS is a special form of SaaS, as it hides the details of M&S resources, which are exposed as services to build simulation systems.

Cloud-based simulation generally has such features as: M&S resources are virtualized and stored in a cloud resource pool and users can easily obtain them over the Internet (Tolk and Mittal 2014). The cloud-based scenarios are as follows (Onggo 2014).

(1) Simulation users run simulation applications on cloud infrastructure simulation as a Service).
(2) Simulation modelers build and modify models using simulation development tools on cloud infrastructure (Modelling as a Service).
(3) Simulation modelers configure simulation development tool itself by mixing and matching the components of the tool (similar to PaaS).
(4) Simulation users may operate over storage, execution platform and middleware (similar to the IaaS).

Cloud computing is believed to bring M&S into the Cloud-based Simulation era primarily due to: (1) The performance degradation of simulation applications running in clouds could be ignored with the development of high-performance techniques. (2) CBS owns many advantages such as the centralized software deployment and the sharing of M&S resources on demand. It could solve some difficult problems encountered by M&S community, including expensive cost in hardware but low utilization and the repetitive development of similar simulation application.

But research on CBS is still in the beginning phase. Many researchers consider CBS as a big challenge in the following perspectives (Taylor et al. 2015, 2013; Siegfried et al. 2014; Taylor et al. 2012):

(1) Technical perspective. The requirements of infrastructures, protocols, information exchange formats need to be explored in a cloud.
(2) Governance perspective. The consistent management, cohesive policies, guidance, processes and decision processes should be defined.
(3) Security perspective. The person, organization or service has the authentication required on the cloud platform.
(4) Business perspective. The fair share of the financial burden of setting up and conducting a distributed simulation event, clear rules and value assessment remains to be addressed.
(5) Conceptual perspective. The conceptual alignment of the models to support composability should be uniform in addition to the means required for interoperability of the simulation components to compose and execute services on the cloud.

6.6.1 Modeling and Simulation as a Service (MSaaS)

"Modeling & Simulation as a Service" is the combination of service-based approaches and ideas taken from cloud computing (Siegfried et al. 2014). Over the past years, the concept of MSaaS has been investigated by NATO Modeling and Simulation Group MSG-131. They also collected national perspectives and experiences regarding MSaaS. MSG131 defines M&S as a Service as follows:

"M&S as a Service (MSaaS) is a means of delivering value to customers to enable or support modelling and simulation (M&S) user applications and capabilities as well as to provide associated data on demand without the ownership of specific costs and risks." A service in the MSaaS concept can be a model service or a simulation tool service, such as a aerodynamics model service or a tool for building simulation environment. MSaaS contains the following connotations:

(1) MSaaS as a cloud service model;
(2) MSaaS using cloud service models;
(3) MSaaS as a Service Oriented Architecture;
(4) MSaaS as a business model.

Perspective 1 describes the methods of accessing M&S applications. Perspectives 2 and 3 focus on how to compose M&S applications by the cloud service models. Perspective 4 describes the application mode of MSaaS as an organizational or professional service (Fig. 6.1).

As such, MSaaS features the loosely coupled services and the ability to reuse M&S services. The objectives of MSaaS can be concluded into two kinds, i.e. effectively and efficiently supporting operational requirements (like executing an exercise) and improving development, operation and maintenance of M&S applications. MSaaS is a special form of SaaS but different from SaaS. MSaaS provides developers M&S services on demand. The services are selected and composed according to their functionality and quality of service (QoS) maintained by service providers.

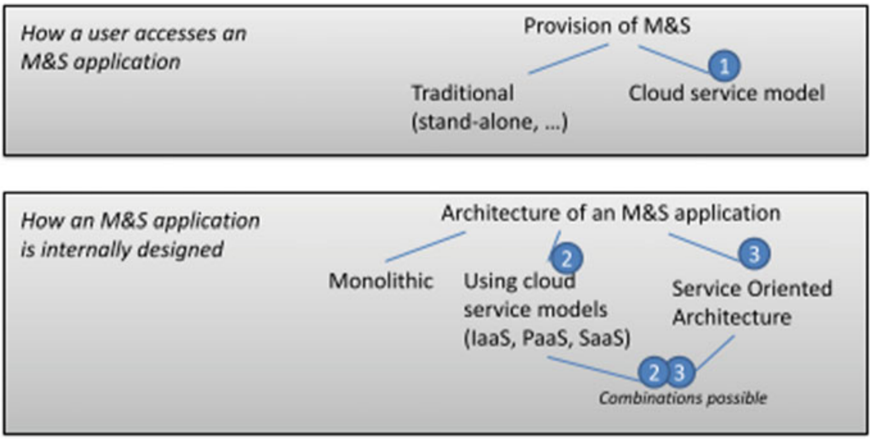

Fig. 6.1 MSaaS perspectives (Siegfried et al. 2014)

6.7 Cloud Simulation

6.7.1 Concept of Cloud Simulation

Based on the research of simulation grid and further integration of virtualization technology, the concept of "cloud simulation" was proposed in 2009 (Bo-Hu et al. 2009). Cloud simulation is a simulation mode to provide simulation services on user's demand from simulation resource cloud pool with network and cloud simulation platform. Its main idea is to encapsulate M&S resources into services and form a cloud service pool, so that they can be easily shared and reused on-demand in a simulation system and support all activities of systems simulation.

A cloud simulation platform can automatically discover the required resources, and dynamically build a simulation system on-demand based on service-oriented composition and scheduling.

Furthermore, a new networked M&S platform "cloud simulation platform" is built to improve the capabilities of existing networked M&S platform. It utilizes network and cloud technologies to compose the M&S services in network on demand, and to provide various simulation services to users.

6.7.2 Architecture of Cloud Simulation Platform

The architecture of Cloud Simulation Platform is illustrated in Fig. 6.2. It consists of 4 layers: resource layer, cloud simulation service layer, application portal and support tools layer, and application Layer.

Resource layer provides network and various M&S resources encapsulated by virtualization technology, including model resources, tools and software resources, computing resources, storage resources, model/data resources, knowledge resources and various types of simulators, scientific instruments and so on.

Cloud simulation service layer provides cloud simulation oriented core services, including multi-user-oriented resource scheduling and management services, pervasive co-simulation services, virtual simulation resources information management services, intelligent resource discovery services, co-simulation scheduling and composition services, simulation resources adaptive and fault-tolerant migration services, collaborative visualization engine services, Simulation resource management services based on web service/grid technology, web-based HLA/RTI distributed interactive simulation services and simulation resource dynamic management and optimization deployment services based virtualization technology and so on.

Application portal and support tools layer provides browser and desktop portals/ tools for users to logon in "CSP" and carry out simulation activities. These portals/ tools include project management tool, simulation database/model base/knowledge base management tool, multidisciplinary virtual prototype problem solving

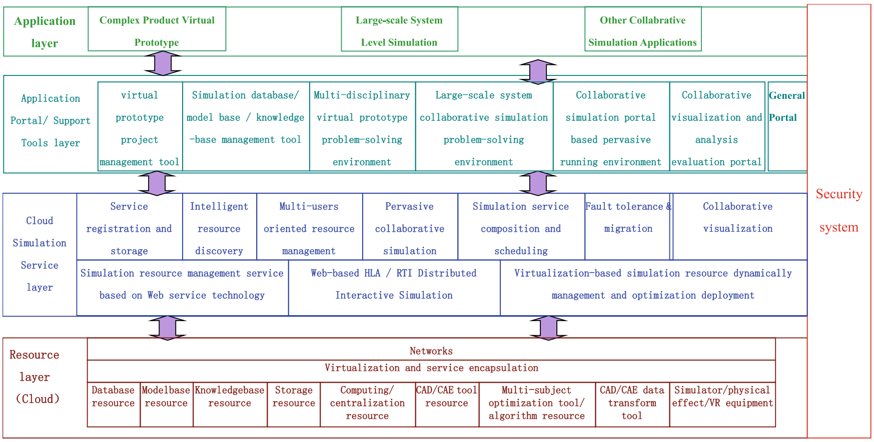

Fig. 6.2 Architecture of cloud simulation platform (Bo-Hu et al. 2009)

environment, large-scale system level collaborative simulation problem solving environment, pervasive collaborative simulation portal, collaborative visualization and analysis evaluation portal and general portal.

Application Layer includes multidisciplinary virtual prototype collaborative simulation applications, large-scale system level collaborative simulation applications and other Collaborative Simulation Applications.

6.8 Key Technologies for Cloud-Based Simulation

There are many enabling technologies for cloud-based simulation. Some of them are introduced as follows.

6.8.1 Virtualization and Service Encapsulation of Model and Simulation Resources

Virtualization layer, based on the simulation resources layer, maps physical simulation resources into a set of virtual machine (VM) templates. According to domain-specific simulation requirements, various simulation resources can be re-organized and encapsulated into VM templates with particular functions. During the run-time simulation, distributed and heterogeneous resources are transparent to users (Ren et al. 2012).

A virtualization management middleware is needed to expose functional interfaces to manage the simulation VMs. The interfaces include the encapsulation interface to package simulation resources into VMs, the register interface to register VMs in the simulation VM templates pool, the discovery interface to match suitable simulation VM templates according to simulation requirements, the monitor interface to monitor running status of both virtual and physical simulation resources, the dispatch interface and instantiate interface to instantiate and deploy a simulation VM (Ren et al. 2012).

6.8.2 Simulation Environment, Management and Interactive Simulation Technology

First, problem-solving environment technology (PSE) is an important part of application portal/support tool layer, which supplies a top-level tool integration environment. Technically, PSE provides a Top Level Modeling Language which adopts meta-model technology, presents the structure and behavior of simulation system, and describes experiment instruction of virtual prototype design and system-level simulation. Secondly, complex product project management technology is also important for cloud simulation. Existing project management tools can hardly meet the project management requirements for complex products. Project management technology mainly includes the planning, organizing, controlling and communication techniques during the whole project life-cycle, which covers project decision, design, implementation and evaluation. Project management model supplies the same view for persons joining in project management and gives an effect of orientation and improvement to their management practice. Thirdly, simulation management technology based on Web Service/Grid Technology mainly provides simulation resources management services for resources deployment/register, batch schedule, monitor and directory. "Cloud Simulation Platform" can be compatible with kinds of resource management middleware to provide management services for M&S resources. Fourthly, the simulation on the "cloud simulation platform" differs from other networked computing tasks. It mainly reflects on multiple iterative calls for services in the simulation application and the strict requirements of consistency of time and space for a wide range of services participated in simulation running. The main idea of Web-based HLA/RTI Distributed Interactive Simulation Technology is to solve collaboration problems among services in simulation application by HLA/RTI technology, and to solve the dynamic scheduling and management of simulation services on LAN and WAN by grid computing and Web Service technology (Bo-Hu et al. 2009).

6.9 Resource Discovery, Composition and Scheduling Technology

Semantics-based simulation model resource discovery technology is a key technology of cloud-simulation oriented services layer. The traditional keyword-comparison discovery method only performs matching based on syntax. Implementation of semantic-based model resource discovery by introducing semantic ontology in cloud simulation platform improves the accuracy, efficiency and intelligence of the resource discovery mechanism.

In simulation cloud, simulation tasks are always complicated which are composed dynamically by distributed simulation models. Traditional service composition technology can hardly be used to realize the description and execution of complex interactive operation because they commonly describe, schedule and implement service composition based on workflow. In most cases, more than one simulation tasks exist at the same time. Different tasks could use the same resource at the same time. Hence scheduling process is an essential step in this situation. Networked Simulation Resource Scheduling Problem has following Features: (1) Resource selection takes the goal of completing simulation tasks with the most proper resources; (2) Most of the cloud simulation applications involve collaboration among multiple computers; (3) Node computing performance and inter-node network communication speed and delay must be taken into consideration (Laili 2012; Ren et al. 2012).

In the cloud simulation environment, models and the related tools are encapsulated into simulation services. User requirements submitted the simulator can be divided into single-service requirement and multi-service requirement. For the single-service requirement, the platform picks up the most appropriate service to perform the task from a large number of cloud services, which is called cloud service optimization. In terms of the multi-service requirement, the platform decomposes the task to many subtasks and searches the services to support the subtask. Then platform picks up the most appropriate group of services to perform the task, which is called cloud service composition. When more than one multi-service requirement exists, scheduling process of services to fulfill multiple requirements is essential. The number and types of resource services in practical cloud simulation are numerous. How to correctly incorporate multiple services together to accomplish a multi-disciplinary simulation task and how to tackle multiple tasks requirements are two important concerns not only for users, but also for the cloud center itself. Feng et al. (2018) investigated the problem of service composition and scheduling for cloud simulation and proposed a new service network-based method. In this method, the number of composition steps was uncertain before to be executed. The execution of service composition and scheduling was based on a service network-based model. In this model, nodes represented tasks or services while the weight of edges was the performance of services. Through the built model, different composition paths can be obtained for a certain requirement and a near-optimal solution can be established with optimization algorithms.

6.10 Big Data for M&S

Cloud-based simulation will produce large amount of data, such as the simulation service information, simulation results and so on. As the volume of data is increasing exponentially, big data technology is used to process data that are huge in terms of volume, velocity, variety and veracity. Therefore, these data are stored in the cloud and all the analysis is done in the cloud by big data technology (Dasoriya 2018).

Big data challenges to modeling and simulation in many aspects including basic theory of simulation, modeling method, simulation method and tools (Feng et al. 2018). At the meantime, big data also provides opportunities to M&S. For example, based on big data and machine learning, a new type of model of the system can be established, which is called data model. Although it is a “black box” model, it can be optimized by continuously learning from the real system. This kind of method might be available for the simulation of complex systems that are difficult to be modeled with traditional methods. Based on the analyses of big data, simulation process, such as simulation resource assignment, simulation service matching and scheduling, can be more intelligent. Big data can also be used to enable quantitative evaluation of model credibility and assessment of simulation system risks.

6.11 Digital Twin

Digital Twin is the virtual representation of a physical object and can interact with the physical object. Digital twin was descripted by NASA (Dasoriya 2018) as an integrated multi-physics, multi-scale simulation of physical objects to reflect the behavior of the corresponding physical objects. It can be used in design and optimization, remote monitoring and control, cloud planning and scheduling, fault prediction and tracking, etc. Digital twin is defined by what you want to analyze, simulate, predict related to the physical product. It involves engineering data, operation data and dynamic behaviors of the models (Rosen et al. 2015).

A Digital Twin is actually a Cyber-Physical Dynamic Model that is generally stored and managed in a cloud. It connects the model to the real physical system and evolves the real-time data along the full life cycle of the system. Based on digital twins we can realize online simulation to provide more precise analyses and prediction to get better decision support.

Digital Twin is considered as a great improvement in the field of M&S (Rosen et al. 2015; Weyer et al. 2016). Its realization is significant for the development of manufacturing industry. It will simplify the simulation of the manufacturing processes and provide operation support along the life cycle (Boschert and Rosen 2016).

6.12 Applications of Cloud-Based Simulation

The cloud-based simulation can be used in manufacturing as well as design of a product. Two case studies are introduced in the following sections.

6.12.1 Cloud-Based Simulation for Manufacturing

Cloud-based simulation plays important role for manufacturing. Theoretical simulation analysis for manufacturing requirements is needed before the truly processes are executed. Some manufacturing problems, such as manufacturing recourses collaboration, matching and composition of cloud services, cloud scheduling, etc., can be simulated in a cloud platform. Paper (Zhao et al. 2017) proposed a conceptual model of the simulation platform based on service as shown in the Fig. 6.3. Many researches have adopts agent to support the simulation process. For example, an agent-supported meta-level interoperation architecture is proposed to address the interoperation and dynamic composability of disparate simulations (Yilmaz and Paspuleti 2005). Service agent combines the function of service and the intelligence of agent (Liu et al. 2013). In this model, each manufacturing enterprise in the cloud environment acts as an independent agent. The relationship between them can form a service agent network. The simulation platform includes two libraries named data interface and function interface which can realize some management function in the cloud environment. The architecture of the manufacturing simulator is divided into five layers: the data layer, the lower tool layer, the management layer, the upper tool layer, application layer. This five-layer correlation, from data generation to analysis of final results, constitutes a complete manufacturing service platform prototype system. Each simulation requirement for a manufacturing task can be completed in the service platform. Three typical application scenarios are introduced in the following:

(1) Simulation of Manufacturing Resources cooperation

There are many kinds of manufacturing resources in the manufacturing environment. One of the relation between the resource and the service: several manufacturing resources provide a service. When a service gets a task, several manufacturing resources of service can perform the task coordinately. The simulation platform built above can support this application scenario.

(2) Simulation of Service Composition

In the field of manufacturing, according to user requirements or task granularity, user requirements can be divided into single task requirement and multiple tasks

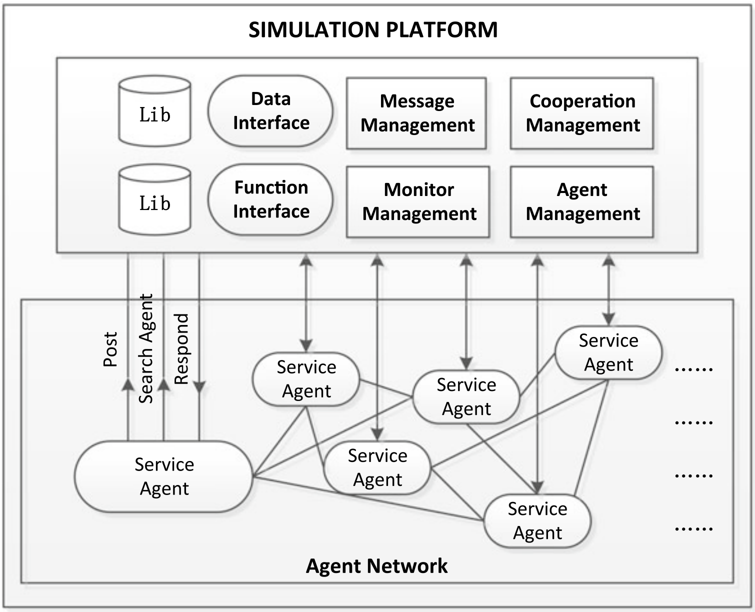

Fig. 6.3 A conceptual model of the simulation platform

requirement. For the single task requirement, the platform picks up the most appropriate service to perform the task from a large number of cloud services. In terms of the multiple task requirement, the platform decomposes the task to many subtasks and searches services to support the subtask. Then platform picks up the most appropriate group of services to perform the task, which is called cloud service composition. The simulation platform can support this kind of scenario, and generates different services in a certain range and constraints. The user can verify their service composition algorithm in simulation platform.

(3) Simulation of Service Collaboration

In the platform, each enterprise user can finish a specific task or subtask independently, and adapt itself to the environment initiatively. In addition, they can communicate, and cooperate, and compete for each other. In the simulation platform, each enterprise is a service agent. Different enterprises in the platform can establish a multi-agent network. Based on the network, the researcher can describe, explain, predict, analyze the behavior, and collaboration model, and rule among the enterprises in the cloud manufacturing complex system.

6.13 Cloud-Based Simulation for Optimized Design

In the design process of a product, the design parameters should be optimized through multi-disciplinary collaborative simulation. Cloud simulation platform eases the building of simulation system to realize the above simulation optimization tasks.

The simulation system includes 3D view federate design, control federate design, hydraulic federate design and dynamic federate design is submitted into cloud-based simulation platform. There are different kinds of interdisciplinary simulators in the cloud platform, such as visualization services, dynamics system simulators, control system simulators and hydraulic system simulators. There are more than one candidates for each kind of resource.

The problem is to choose one simulation resource from the candidates that registered as services in the cloud. The platform uses service matching and composition algorithms to form a simulation process and assign suitable computing resources for each simulation service. The simulation resources and simulation system built by the cloud platform is shown in Fig. 6.4.

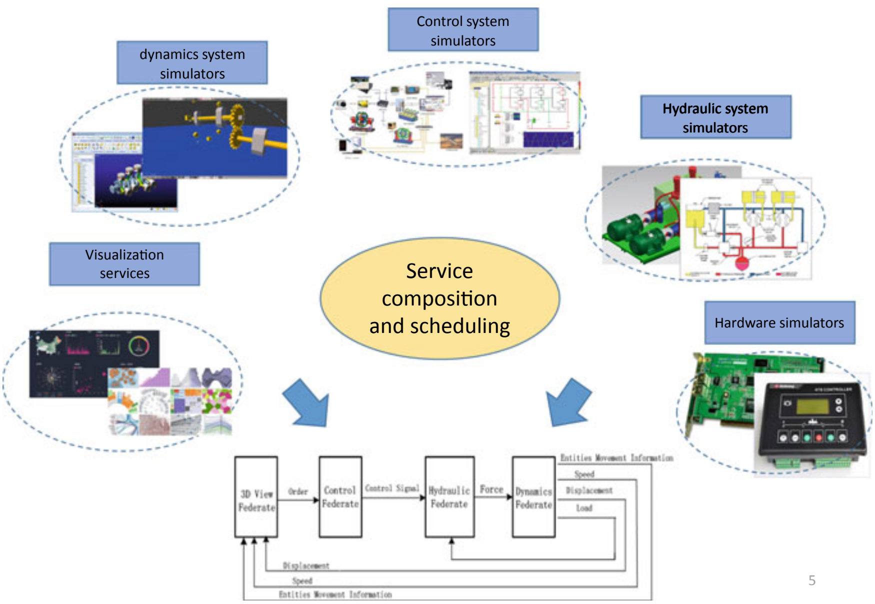

Fig. 6.4 Collaborated simulation for design optimization

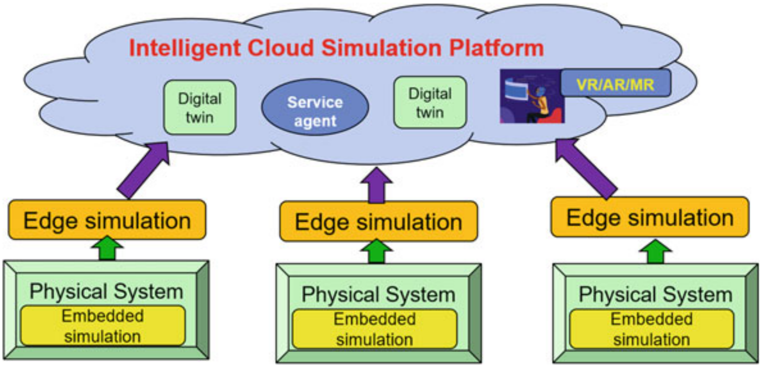

Fig. 6.5 The cloud-based intelligent simulation system

6.14 Conclusion and Future Work

Simulation research has developed from Web-based Simulation to Cloud-based Simulation. MSaaS provides M&S resources and capabilities on demand in the form of Web service. Cloud Simulation has transplanted traditional simulation system to cloud platform so that M&S resources can be easily shared and reused on-demand in a simulation system and support the activities in the full life cycle of systems simulation. Other technologies such as Big Data, Digital Twin and Edge Computing are also important enabling technologies of promoting the development of cloud-based M&S.

The trend of simulation technology will be cloud-based and intelligent. Figure 6.5 give a picture of an envisioned intelligent simulation system, in which an intelligent cloud-based simulation platform will be the core part of the system while the edge simulation will be used to do quick analysis and optimization for high real-time processes. In some cases, the embedded simulation is needed to participate in the operation of the physical system to help the physical system to make a better decision quickly. The physical systems are modeled as digital twins and integrated into intelligent cloud simulation platform through IoT. The intelligent cloud simulation platform finally supports the collaborative simulation of distributed and heterogeneous physical systems.

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