Research on Integration Framework and Service Adaptation Technology of Space System Simulation Test-bed

Desheng Liu\textsuperscript{1,\textast}, Qing Chang\textsuperscript{1,b}

\textsuperscript{1}Science and Technology on Complex Electronic System Simulation Laboratory, Space Engineering University, Beijing, China
\textsuperscript{a}email: liudsnudt@126.com, \textsuperscript{b}email: 936500617@qq.com

\textsuperscript{1}Corresponding Author: Desheng Liu \textsuperscript{a}email: liudsnudt@126.com

Abstract. Aiming at the requirements of space system simulation test-bed in heterogeneous integration and co-simulation, the support capability of test-bed integration framework is analysed. A space system simulation test-bed integration framework based on bridging adaptation service is constructed, and adaptation services such as protocol adaptation, information publication, information subscription and service control for service oriented architecture are designed and implemented, which provide integration capability and co-simulation management capability for heterogeneous systems, models and components of space system simulation test-bed.

1. Introduction
Space system is a typical large complex system with wide space-time distribution, deep system integration and high risk of R&D. In the process of manufacturing and testing, its high technology, high risk and high investment must be considered. There are two main ways, the physical-based external field test and simulation-based internal field test, to demonstrate the system design and verify the key technologies of space system\textsuperscript{[1\textendash{}2]}. The internal field test mainly constructs high fidelity test objects, conditions, environment and other elements by means of modeling and simulation, and integrates them to form a test-bed for space systems. By this way, the test and evaluation for the space systems should be implemented based on simulation, which has the advantages of low cost, low risk and good repeatability\textsuperscript{[3]}. This is significant for the demonstration and verification of key technologies, performance test and evaluation. The objects integrated in the test-bed usually have different development time, different mission objectives, and different modeling & simulation methods, which often lead to different abstraction granularity of models, different formats of data, and also problems of cross-platform, cross-protocol, cross-development language environment\textsuperscript{[4]}. Therefore, it is important to design a reasonable test-bed architecture and integration framework to achieve a seamless interface between heterogeneous systems to improve the interoperability and reusability of the test-bed.

In this paper, we propose a new type of test-bed integration framework based on bridge adaptation service, establish a bridge adaptation service mechanism and mapping relationship between different protocols, realize the interface conversion and control between simulation test-bed and other heterogeneous systems, and provide an effective solution to solve the co-simulation test of distributed heterogeneous test systems.
2. Space system simulation test-bed integration capability requirements

Test-bed is essentially a common technology research platform constructed for a series of objects with
common characteristics, which can reduce technical difficulty and investment cost and shorten
development cycle by abstracting key technologies, simulating real conditions and weakening secondary
constraints, etc[5]. Test-bed technology has become an important tool to accelerate the development of
other technologies as a key technology, and thus has received wide attention from countries around the
world, and has been widely used in many fields[6]. According to the application background and test
purposes, test-beds can be broadly divided into three categories: digital test-bed, ground test-bed and
flight test-bed. The digital test-bed is mainly constructed by digital modelling and simulation based on
the opening of information links, digital design, high-performance computing, and lifelike modelling,
etc., which is used to provide a high reliability of theoretical basis before the real test. In addition, digital
test-bed is also widely used in the construction and testing of information network platform. The ground
test-bed relies on ground hardware facilities to build the basic suitable conditions for verifying key
technologies, which is essential to break through key technology bottlenecks and provide reliable
experimental data for technology applications. The flight test-bed is a platform that integrates
technology verification and technology application in the same basic platform with the actual space
environment, and can directly realize technology application after key technology verification. The
space system simulation test-bed is a typical digital test-bed, which should support distributed
simulation test, heterogeneous model/system integration and co-simulation, and plug-and-play
operation.

2.1. Distributed simulation test capability

The space system simulation test belongs to the category of co-simulation, which needs to support
different domain developers located in different locations to work together, therefore, the test-bed
integrated framework must be able to support the whole process of distributed simulation. This is the
first condition that must be satisfied.

2.2. Heterogeneous model/system interconnection capability

In order to enhance the seamless interconnection capability of co-simulation, it is necessary to propose
practical implementation solutions and technologies when designing the integrated framework for co-
simulation, so as to support the cross-platform, cross-protocol, and different development language
environment problems faced in the process of co-simulation, and support the interconnection and
interoperability of heterogeneous models/systems.

2.3. Plug-and-play model operation support capability

According to different simulation test requirements, the system may not use the same type model, which
requires that the system should support a more flexible model joining and exiting mechanism, that is,
plug-and-play capability, so that users can quickly configure the simulation test environment to meet the
conditions. At the same time, in order to reduce the coupling between the modeling tools and the
operation support system, the technical work involving data interface conversion, modeling language
interpretation and program framework construction in the domain modeling process is handed over to
the integration framework and the "adapter" technology of model integration, so that “plug-and-play”
can be realized in the integration framework.

3. Design of the integration framework for space system test-bed

Based on the theory of distributed co-simulation, the frameworks of space system simulation test-bed,
including basic framework and operation framework, are built based on the structure and modeling
method of HLA/RTI and other advanced ideas such as SOA service, cloud computing. The system adopts
a flexible and open distributed simulation architecture, where each simulation system has independent
simulation functions to support independent simulation tests. What is more, it can also run jointly with
other systems to form a comprehensive simulation test environment with broader support and more
complete functions to support joint simulation tests in multiple fields. The basic framework of the test bed is shown in Fig. 1.

In the service-centered integration framework, the realization process of information service is decomposed into the business process under SOA architecture, and the various operations involved in the realization process are encapsulated into the corresponding service interfaces. This would separate data and business, process and realization, user and data. This flexible operation mechanism realizes the model and This flexible mechanism can realize efficient management of models and data in system test simulation. By establishing the bridge adaptation service mechanism, followings are realized: the mapping relationship between different protocols, the interface conversion between the test-bed and other systems, the execution of commands for simulation management and control, the transmission and coordination between events and information to the physical system, the conversion of information formats, the function of two-way agent. By this way, The framework realizes protocol conversion of data from different architectures and different data communication protocol interfaces, as well as time synchronization control of different clock frequency systems. This is shown in Fig. 2.

The core of the bridge adaptation service is protocol adaptation. Considering the generality and scalability of the protocol, the schema specification is used to describe the protocol, and the protocols involved in adaptation are divided into primary and secondary roles. The protocol type of the primary protocol must be "publication" or "bi-directional", while the type of the secondary protocol can only be "application" or "bi-directional". In addition, the primary and secondary protocols cannot be the same protocol. If so, the bridge adaptation service might only be used as data forwarding.
The main task of protocol adaptation is to match the “element” in the primary protocol with that in the secondary protocol, which can have different names, but must be uniquely located in the respective protocols’ node. The main elements of the protocol include annotation, type, number and relation. At runtime, the element name of the converted file is used as the element name in the secondary protocol. It is not necessary to match all the elements in the primary protocol and secondary protocol.

4. Design of bridging adaptation service for space system simulation test-bed

Bridging adaptation service provides bridging protocols and interfaces for information interaction between the real-world system and the simulation test-bed, obtaining information such as program plans and commands of the real-world system or data. In order to achieve this purpose, the designed bridge adaptation service consists of functional modules such as protocol management, protocol adaptation management, information subscription service, information publish service and service control.

4.1. Protocol Management

The protocol management module is used to add or remove data format files described by Schema specification to the system, and to browse the existing protocols in the system. The protocol types include publication, subscription, and bidirectional. “Publication” means that the data format described by the protocol is produced by systems or modules to push out; “subscription” means that the data format described by the protocol is produced by other systems or modules and need to convert when using it; "bidirectional" means that the data format described by the protocol can be produced or used by other systems or modules. The workflow of adding protocols is shown in Fig. 3.

In this process, the verification of the protocol file is mainly a formal verification, that is, it is to analyze whether the description of the protocol conforms to the Schema specification.

4.2. Protocol Adaptation Management

Protocol adaptation management is used to adapt and manage the two protocols that need to be adapted or may need to be adapted during daily maintenance. The workflow of protocol adaptation management is shown in Fig. 4.
4.3. Information dissemination service
The information distribution service is used to receive the declaration of information distribution service issued by the information publisher when the system is running, including the data format that can be provided to the system, as well as the information on the time and rate of data provision, which is dynamically stored in the bridge adaptation service module in order to match the needs of information subscribers. The workflow of the information distribution service is shown in Fig. 5.

In this process, the information publisher can only publish the data format that already exists in the bridge adaptation service subsystem, otherwise the bridge adaptation service subsystem will ignore the service statement and feedback.

4.4. Information subscription service
Information subscription service is used to receive information subscription requests from information subscribers when the system is running, including the data format of the data source, the format of the received data, and the start time and rate of the received data, or directly specify the adopted adaptation protocol and the start time and rate of the received data. The above information is compiled and dynamically stored in the bridge adaptation service subsystem to match the information distribution service. The workflow of the information subscription service is shown in Fig. 6.
In this process, the information subscriber can only subscribe to the data format already existing in the bridge adaptation service subsystem, otherwise the bridge adaptation service subsystem will ignore the service request and feedback; information subscribers can also directly request the bridge adaptation service subsystem that has been established in the adaptation protocol; data reception rate, mode and start time and other information is not related to the data format.

4.5. Service control

Service control is used to establish the connection between information publishers and information subscribers, and to realize the conversion of data formats between published and subscribed information the system operation. Therefore, service control can be generally divided into two steps, one is to create an information bridge adaptation channel between information publishers and subscribers, specifying information publishers, adaptation protocols, information subscribers, adaptation methods between information publishing rate and information receiving rate, etc.; the second is to complete information bridge adaptation, i.e., to receive published information according to the parameters specified in the information channel, to complete data format conversion according to the adaptation protocols, and finally to convert the data format according to the information publishers and subscribers. Finally, the converted information is released to the corresponding subscribers according to the information reception rate. Therefore, the service control consists of two functional modules: bridge adaptation channel construction and bridge adaptation.

4.5.1. Bridge Adaptation Channel Construction.

The bridge adaptation channel between information publisher and information subscriber is dynamically created, which is represented by the data queue and its processing method. The workflow of the bridge adaptation channel construction is shown in Fig. 7.
In this process, the bridge adaptation channel construction is mainly based on the information subscription service entry, and the bridge adaptation channel construction activity is started only when there is a new or unfinished channel construction information subscription service entry; the matching between the information distribution service entry and the information subscription service entry is completed, which can be matched according to both the explicit adaptation protocol of the information subscription service entry and the explicit data source protocol of the information subscription service entry.

4.5.2. Bridging Adaptation.

The information received from the information publisher is stacked into the corresponding bridge adaptation channel and completed data format conversion, filled into the data file instantiated by the sub-protocol in the adaptation protocol, and then the data file is sent to the subscriber according to the information reception method and rate specified in the channel. The workflow of bridge adaptation is shown in Fig. 8.

In this process, after receiving the information released by the publisher, it is necessary to match which channel is used to complete the bridge adaptation task according to the information publisher ID and the protocol ID in the release information, and the matching rule is that if the information publisher ID is consistent with the clear information publisher ID of the channel, the two are matched, and if the channel does not specify the information publisher ID, the two are also matched; the protocol ID in the release information and the channel's explicit master protocol in the adaptation protocol must be a headwind for the two to match. The data queue keeps all the instance texts that are not sent to the message subscriber, and the instance texts are moved out of the data queue once they are sent to the message subscriber.
5. Conclusion
An integration framework of space system simulation test bed based on the bridge adaptation service is proposed, which can effectively shield the heterogeneity from protocol systems, group format, routing algorithm, topology, etc., and achieve the purpose of interconnection and interoperability. This is significant to realize the cooperative simulation test between distributed heterogeneous systems.

Acknowledgments
We gratefully acknowledge the valuable cooperation of Dr. Wei Xiong and Dr. Ping Jian (Science and Technology on Complex Electronic System Simulation Laboratory, Space Engineering University at Beijing) in the preparation of the Application note.

References
[1] Cao Yu-hua, Qian Zhao-yong, Chen Xiao-wei, Wang Zhi-peng. (2021) General Design on the Simulation Test-bed for Equipment System Evaluation. Fire Control & Command Control, 46(05): 168-173+179.
[2] Hu XF, Yang JY, Zhang Y. (2018) Exploration and Practice to the Theory and Method of Evaluating Weapon System of Systems. Astronautical System Engineering Technology, 2(01): 1-11.
[3] Yang JY,Hu XF. (2016) New Quality Combat Capability Assessment Based on System Simulation Test-bed. Military Operations Research and Systems Engineering, 30(03): 5-9.
[4] Zhang Ying, Shi Bin, Gao Yang, Ma Yiyuan. (2021) Research on Multi-model Subscale Test-bed Simulation Technology. In: 2021 National Academic Conference on Simulation Technology. Beijing. pp. 111-115.
[5] Wang Hang, Chen Yong, Song Xumin, Ding Guozhen. (2014) Research on Information-exchange Technology for Space Simulative Test-bed Based on DDS. Modern Electronics Technique, 37(20): 7-10.
[6] Wang Yang, Zeng Rongfei, Li Zhenyu, Xie Gaogang. (2017) A Survey on Key Technologies of Network Innovation Test-beds. Journal of Computer Research and Development, 54(01): 20-33.