

A Design of Data Interaction Interface Based on DDS for UAV-Borne SAR Distributed Simulation

Feixi TANG*, Haowei YANG*, Huibo LI*, Zhixuan FENG*, Peng GONG*

* National Key Laboratory of Mechatronic Engineering and Control, School of Mechatronic Engineering, Beijing Institute of Technology, Beijing, China

tangfeixi@outlook.com, yhw@bit.edu.cn, 2569826229@qq.com, 1308374461@qq.com, penggong@bit.edu.cn

Abstract—UAV-borne synthetic aperture radar (SAR) has played an important role in the field of military reconnaissance, due to its advantages such as strong survivability, high resolution and high flexibility. Distributed interactive simulation technology to evaluate the combat effectiveness of the UAV-borne SAR has become a hot research issue. In this paper, a distributed data interaction interface, namely SARDDS, based on data distribution service (DDS) has been proposed to satisfy the requirements of high real time and high throughput of data interaction in the distributed simulation architecture of UAV-borne SAR. The data interaction interface follows the development specification of QualNet simulator and adopts publish-subscribe communication mode to realize the data interaction between various modules of the distributed simulation system. Experimental results verify the high real time and high throughput of the designed interface, which is of great significance to the distributed simulation for the UAV-borne SAR combat effectiveness evaluation.

Keywords—UAV-borne SAR; distributed simulation; QualNet; DDS; data interaction interface

I. INTRODUCTION

SAR is a kind of remote sensing system with the active detection mode. Compared with the general optical sensors, SAR has the unique advantage of being able to work all day and all weathers regardless of the effects of climate and light [1]-[3]. With the improvement of image technology, SAR has been widely applied in many detection areas due to its high resolution [4]. The combination of UAV and SAR payload which is named UAV-borne SAR plays an increasingly important role in military reconnaissance field because of its advantages of high performance and high mobility [5].

Nowadays, many researches on UAV-borne SAR equipment have been conducted. The evaluation of combat effectiveness is one of the focuses in those researches. In order to realize the comprehensive evaluation of the combat effectiveness of the UAV-borne SAR equipment, it is not only essential to focus on the test and verification of the single function and performance index of the UAV-borne SAR, but also to consider the complex operational environment and the intended operational missions in operational system. Therefore, a complete UAV-borne SAR combat effectiveness evaluation system needs a distributed simulation platform to provide a series of works such as scenario configuration,

situation deduction, SAR simulation, simulation data analysis and evaluation rather than a single network simulation tool [6].

Distributed interactive simulation technology has been developed for many years, which aims to propose a general communication architecture that allows the integration and interconnection of large-scale simulators. The research work of distributed interactive simulation originated from Simulator Networking (SIMNET) plan, but it is only applicable to the interconnection between isomorphic simulators [7]. By standardizing information exchange between heterogeneous simulation nodes through standard communication interfaces, Distributed Interactive Simulation (DIS) solves the interaction problem of heterogeneous simulation nodes [8]. The subsequent Aggregate Level Simulation Protocol (ALSP) is developed on the basis of DIS to meet the requirements of strategic level simulation [9]. In order to better solve the problems of integration, interoperability and reusability of modeling and simulation, a new modeling and simulation standard called High Level Architecture (HLA) is proposed. However, in the large-scale distributed simulation system and high real-time simulation system, the real-time performance of HLA architecture is poor [10].

A DDS specification based on publish-subscribe architecture for distributed real-time systems was proposed in 2004. DDS is designed to be data-centric, and provides rich Quality of Service (Qos) policies, which can ensure real-time, efficient and flexible distribution of data, and can satisfy the requirements of various distributed real-time communication applications [11]. At present, DDS is widely used in distributed simulation system. Paper [12] designs a distributed air-defence engagement simulation model based on DDS. In paper [13], an air combat simulation system based on DDS is designed. However, the research of DDS in the distributed simulation system for UAV-borne SAR is still insufficient.

Thus, this paper describes a UAV-borne SAR distributed simulation architecture based on QualNet simulator. QualNet is responsible for UAV communication network simulation. At the same time, a data interaction interface, namely SARDDS, based on DDS for the UAV-borne SAR distributed simulation architecture is designed. Experimental results show that the interface can satisfy the bandwidth requirements for real-time SAR image data transmission, and can ensure the real-time data interaction between simulation modules.

The remainder of the paper is organized as follows. Section II introduces a UAV-borne SAR distributed

simulation architecture. Section III describes the designed data interaction interface based on DDS in detail. Besides, relevant experiments are performed to verify the high real time and high throughput of the designed interface in Section IV. Finally, Section V draws the conclusions.

II. ANALYSIS OF DISTRIBUTED SIMULATION ARCHITECTURE FOR UAV-BORNE SAR

A. Overall architecture

The distributed simulation architecture of UAV-borne SAR considered in this paper is shown in Figure 1. The UAV communication network simulation module is implemented based on the QualNet network simulation engine, and the other four modules are implemented based on the Qt application development framework. The functions of each module are described as follows:

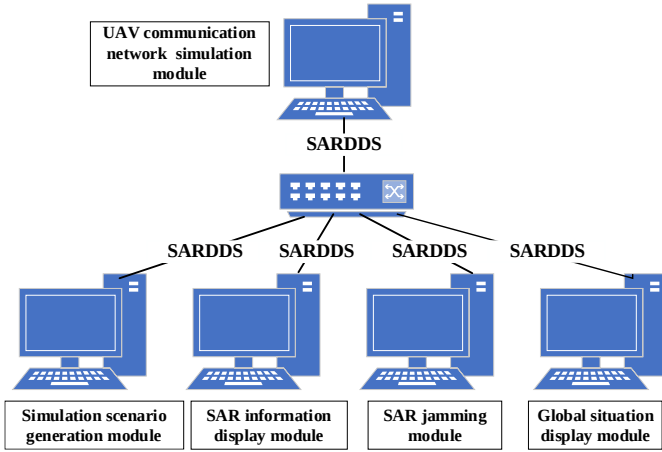


Figure 1. Architecture of UAV-borne SAR distributed simulation system

UAV communication network simulation module: This module applies QualNet to simulate the UAV-borne SAR model, UAV network model and configure the initial simulation scenario, which is the core component of the UAV-borne SAR distributed simulation system.

Simulation scenario generation module: This module mainly completes the creation of simulation scenario, generates scenario scripts, and sends them to other simulation modules before the simulation starts.

SAR information display module: This module is mainly responsible for simulating the ground monitoring station to monitor the real-time status of the UAV-borne SAR, including the parameters of the SAR and the status information of the UAV itself. At the same time, it can display the telemetry image data of UAV-borne SAR in real time.

SAR jamming module: This module is mainly responsible for simulating the dynamic loading of jamming attacks on UAV-borne SAR. In the process of distributed simulation test of UAV-borne SAR, this module can simulate the energy type jamming on the imaging function of UAV-borne SAR by the way of command control.

Global situation display module: The module is implemented based on 3D GIS engine, mainly including real terrain model, node model, motion trajectory model, etc. Its

main functions include: real-time display and plotting of UAV situation in the simulation process, real-time display of UAV-borne SAR detection area, generation of SAR original image and display of SAR jamming attack dynamic loading effect. At the same time, it also has space measurement functions such as point coordinates, flight altitude, flight attitude and flight speed.

Data interaction interface module: This module is mainly responsible for the data interaction between modules in the distributed simulation test system of UAV-borne SAR. Through this interface, the global situation display module can receive scenario data and model status data sent by the UAV communication network simulation module and make real-time response. The SAR jamming module relies on the interface to transmit commands to the communication simulation network and then conduct jamming on the UAV-borne SAR nodes. SAR information display module receives SAR parameters, UAV status information and SAR image data sent by UAV communication network simulation module.

B. System workflow

The main workflow of the UAV-borne SAR distributed simulation system is shown in Figure 2.

Before simulation starts, we need to configure simulation scenarios according to simulation requirements, generate and send scenario script to the QualNet simulation engine. After the QualNet simulation engine receives the scenario script, it starts running the simulation scenario.

After simulation starts, SAR jamming module can be used to conduct imaging jamming attacks on the SAR payload of the target UAV node. QualNet simulation engine sends global situation data and SAR application data to the corresponding module. In the meanwhile, QualNet simulation engine calculates the SAR imaging area according to the parameters and position information of the SAR payload carried by the task UAV node in the simulation network, and sends the SAR imaging area to the global situation module. Global situation module is implemented based on the 3D GIS engine, which can obtain the corresponding image data according to the SAR imaging area and sends it back to the task UAV node. After receiving the SAR image data, the task UAV node sends it to the base station node through the relay UAV node, and the base station node sends the SAR image data to the SAR information display module for display.

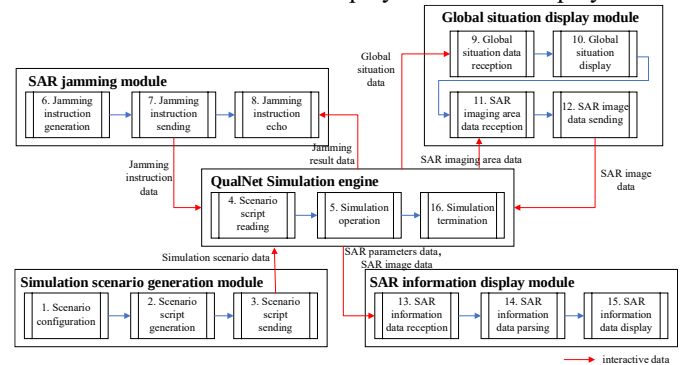


Figure 2. Workflow of UAV-borne SAR distributed simulation system

III. SARDDS INTERFACE DESIGN

A. SARDDS interface overall architecture

The architecture of the SARDDS interface developed based on DDS is shown in Figure 3, which is mainly composed of three modules:

QualNet simulation engine data interface : This interface follows the development specification of QualNet simulator, including publishers and subscribers of almost all topics, and is responsible for data interaction between QualNet simulation software and external simulation interaction modules.

External simulation interaction module data interface: This interface is encapsulated in the visual C++ project of each external simulation interaction model, including publishers and subscribers created by each module according to its own data receiving and sending requirements.

DDS global data space : The data centric publish/subscribe model of DDS establishes a virtual shared global data space for all distributed simulation modules. The publisher of each module sends the data to the global data space, and the subscriber obtains the corresponding data from the global data space according to their own requirements.

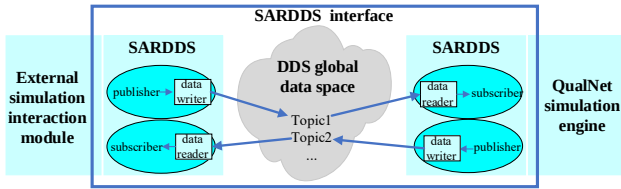


Figure 3. SARDDS interface architecture

B. Design of core data structure of SARDDS interface

According to the requirements of UAV-borne SAR distributed simulation test, the system mainly includes four functions: simulation scenario generation, real-time SAR parameters and SAR image display, jamming attack loading, and global situation display. In order to realize the above functions, the transmission of model parameters, situation information, SAR imaging area, jamming data, simulation scenario data, SAR parameters, SAR image information is mainly carried out in each module. The data interaction relationship between each module is shown in Figure 4.

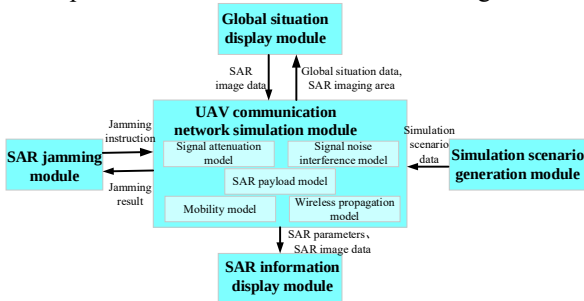


Figure 4. Data interaction relationship of each module

Based on the data interaction relationship between each module, the data structure definition file is designed. Two core data structures are shown in Table 1 and Table 2. Table 1 is the structure of "SarParameter", which describes the parameters of SAR. Table 2 is the structure of "SarImage", which describes the SAR image payload.

TABLE 1. SARPARAMETER STRUCTURE

Variable Name	Variable Type	Variable Description
nodeId	unsignedShort	SAR carrier node number
longitude	double	SAR carrier longitude
latitude	double	SAR carrier latitude
altitude	float	SAR carrier altitude
txPower	float	SAR transmission power
gain	float	SAR antenna gain
signalFreq	double	detection signal frequency
incidentAngle	float	incident angle
angleX	float	range direction beam width
angleY	float	azimuth direction beam width
antennaRecvArea	float	effective receiving aera

TABLE 2. SARIMAGE STRUCTURE

Variable Name	Variable Type	Variable Description
srcid	short	source node id
destid	short	destination node id
errorCode	double	BER of image caused by jamming
size	short	payload size
payload	char	video payload information

C. SARDDS interface workflow

The SARDDS interface workflow is shown in Figure 5.

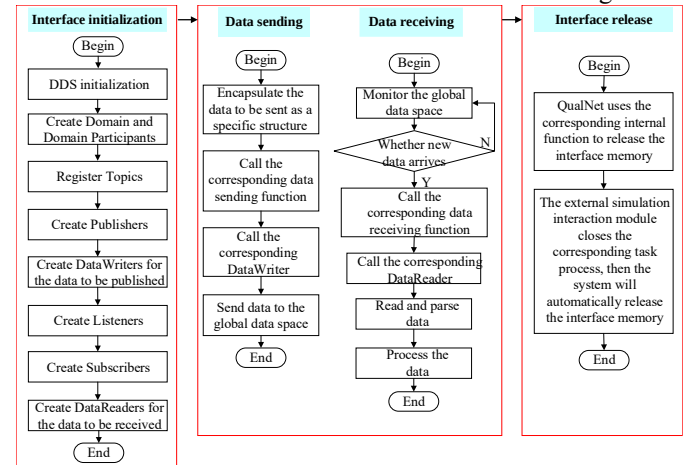


Figure 5. SARDDS interface workflow

Interface initialization : As shown in Figure 5, the initialization of the SARDDS interface is completed in the constructor of the customized MyDDS class, which successively completes the creation of the Domain, Domain Participants, Topics, Publishers, DataWriters, Subscribers, Listeners and DataReaders.

Data sending : As shown in Figure 5, after the simulation starts, each module encapsulates the data to be sent into a specific structure, then calls the corresponding data

sending function, and uses DataWriter to send the data to the global data space.

Data receiving: As shown in Figure 5, after the simulation starts, the SARDDS interface will monitor the global data space. When new data arrives, the corresponding data receiving function will be called, the DataReader will be used to receive the data, and finally the corresponding data processing function will be called to process the data.

Interface release: In the end of simulation operation, the interface memory resources should be released. QualNet uses the corresponding internal function to release the interface memory. The external simulation interaction module closes the corresponding task process, then the system will automatically release the interface memory.

IV. EXPERIMENTS AND RESULTS

A. Experimental environment and scenario

According to the requirements, the experimental test environment is shown in Figure 6. The switch is equipped with a CISCO SG95D-08-CN 8-port gigabit switch, which can adapt to the network speed of the Ethernet port. The data packet exchange rate can reach 11.9Mpps, which can meet the experimental requirements. The specific configuration of the server is described in Table 3.

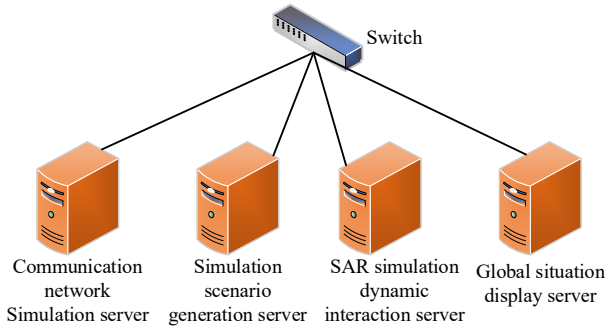


Figure 6. Experimental test environment

TABLE 3. SERVER CONFIGURATION

Server	Running Software	Memory	Processor	Operating System
Communication network simulation server	QualNet network simulation software	4GB	Intel core i5 CPU M520@2.40GHz*4	Ubuntu 12.04 LTS 64bit
Scenario generation server	Scenario generation software	4GB	Intel(R) Core(TM) i3-2310M CPU @ 2.10GHz	Windows 10 Ultimate 64bit
Simulation dynamic interaction server	SAR jamming software, SAR information display software	4GB	Intel(R) Core(TM) i3-2310M CPU @ 2.10GHz	Windows 10 Ultimate 64bit
Global situation display server	Global situation display software	4GB	Intel(R) Core(TM) i3-2310M CPU @ 2.10GHz	Windows 10 Ultimate 64bit

The experimental scenario used for simulation test in the simulation scenario generation module is shown in Figure 7.

No. 1 relay UAV node (Predator UAV), No. 2 task UAV node (Global Hawk UAV) and No. 3 ground monitoring station node are deployed in the same TDMA subnet. No. 4 and No. 5 jammer nodes are deployed in another TDMA subnet.

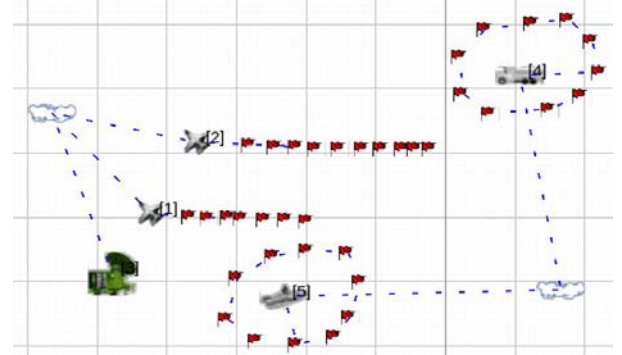


Figure 7. UAV-borne SAR simulation scenario

B. Connectivity test

After configuring the simulation scenario in the simulation scenario generation module, click "Start Simulation" and send the scenario script to the UAV communication network simulation module through SARDDS.

After the simulation starts, SAR image and parameters can be displayed correctly, as shown in Figure 8. It means that the global situation display module can successfully send the image data through SARDDS interface, and then the UAV communication network simulation module receives the image data through SARDDS interface, transmits it to the base station node in the UAV simulation network, and then sends it to the SAR information display module for display through SARDDS interface.

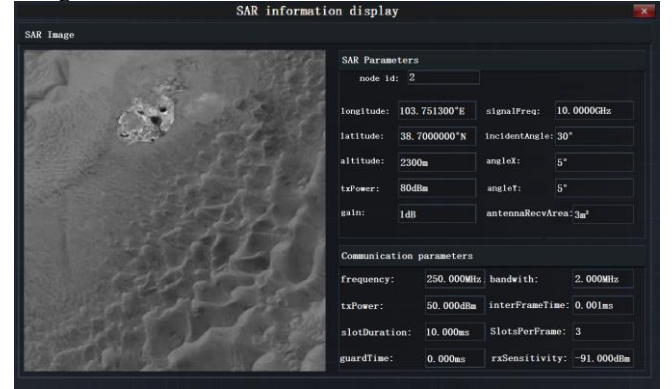


Figure 8. SAR information display interface

When the jammer is turned on and the jamming power is 80dBm, the SAR image display result is shown in Figure 9:

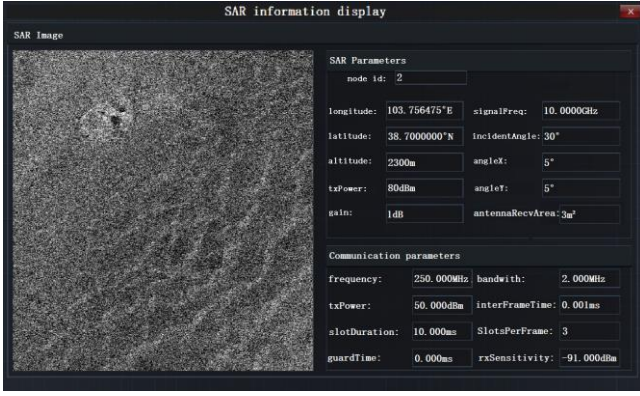


Figure 9. SAR image interfered by jammer

When jammer is turned off, SAR image display results are shown in Figure 10:

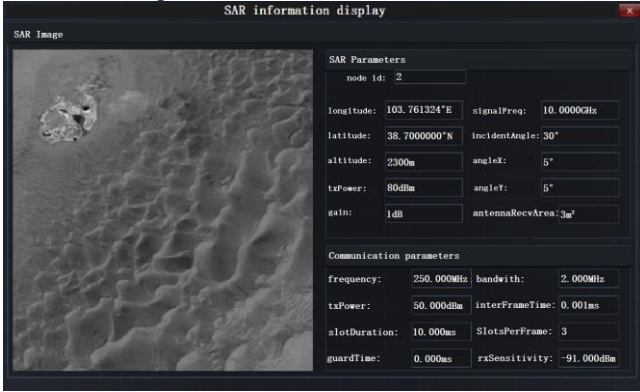


Figure 10. SAR image when jammer is turned off

It can be seen from the results in Figure 9 and Figure 10 that the SAR jamming module can send jamming instructions to the UAV communication network simulation module through the SARDDS interface, and can effectively jam the SAR payload in the simulation

The experimental results show that the SARDDS interface can effectively support the data interaction between various modules of the distributed simulation of UAV-borne SAR.

C. Stress test

In order to determine the upper limit of data traffic transmission supported by the designed SARDDS interface, the following experimental tests were carried out: set the image payload size of each data packet (S_{payload}) to 1KB and increase the rate of sending SAR image data packets from 0 to 24Kpps in 2Kpps steps. The relationship between the packet sending rate of global situation display module and the packet receiving rate of SAR information display module is shown in Figure 11.

It can be seen that when the rate of sending data packets reaches about 16Kpps, there is an obvious turning point in the performance of data transmission. When the sending rate of packets exceeds this turning point, with the increase of the sending rate of packets at the sending end, the receiving rate of packets at the receiving end does not increase, indicating

that the performance bottleneck of data transmission at the SARDDS interface has been reached.

When the data packet transmission rate (R_{packet}) reaches 16Kpps, which is the performance bottleneck of the SARDDS interface, the image payload information transmission rate (R_{image}) is:

$$R_{\text{image}} = R_{\text{packet}} S_{\text{payload}} = 16\text{Kpps} \times 1\text{KB} = 16\text{MB/s} \quad (1)$$

According to statistics, the size of each SAR image (S_{image}) is basically below 500KB. Therefore, it can be calculated that the refresh rate (R_{refresh}) of the displayed SAR image in the SAR information display module is about:

$$R_{\text{refresh}} = R_{\text{image}} / S_{\text{image}} = 16\text{MB/s} / 500\text{KB} = 32\text{fps} \quad (2)$$

As we all know, the minimum frame rate of smooth video viewed by human eyes is 24 frames per second (fps). This SARDDS interface supports the transmission of SAR image data to the SAR information display module for display at a maximum frame rate of 32 fps, which can ensure the smoothness of SAR image display. This shows that the data transmission bandwidth of the designed SARDDS interface is sufficient to meet the transmission of SAR image data.

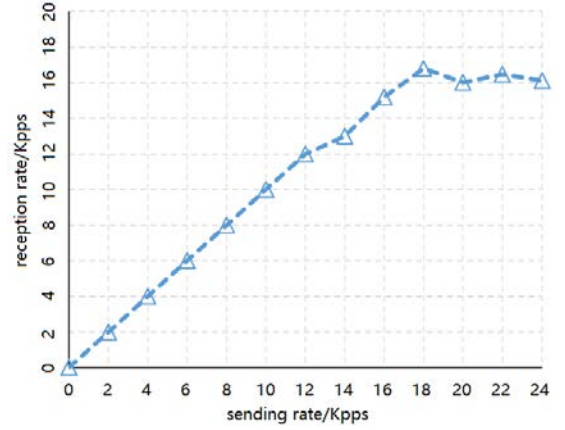


Figure 11. Interface stress test results

D. Delay test

The delay of the SAR DDS interface consists of four parts: the time of receiving the packet, the time of parsing and reconstructing the packet, the time of processing the event, and the time of sending the packet. In order to evaluate the delay of the proposed SARDDS interface, 100 tests were conducted. As shown in Figure 12, the average value is 0.0785ms, which is negligible compared with the transmission delay of data in the virtual simulation network. It can be seen that the interface can ensure the real-time data interaction in simulation test.

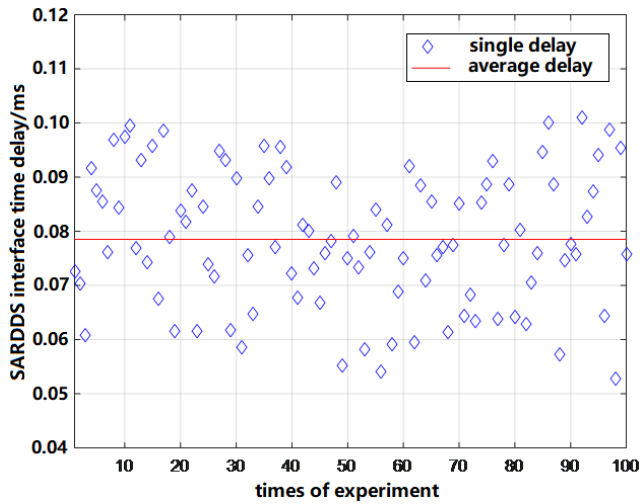


Figure 12. Interface delay test results

V. CONCLUSIONS

In this paper, a distributed data interaction interface, namely SARDDS, based on DDS has been proposed for UAV-borne SAR distributed simulation. The interface adopts publish/subscribe communication mode to realize the data interaction between various modules of the distributed simulation system. Through the tests of the connectivity, pressure and delay of the interface, the experimental results show that the interface can meet the bandwidth requirements for real-time SAR image data transmission, ensure the real-time data interaction between simulation modules, and provide effective data interaction support for the distributed simulation of UAV-borne SAR.

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Feixi Tang received the BS degree in Mechatronic Engineering from Beijing Institute of Technology in 2020, and now he is a MS candidate in School of Mechatronical Engineering, Beijing Institute of Technology. His research interests include wireless network simulation and emulation, information security, wireless communication and so on.



Haowei Yang received the BS degree in Mechatronic Engineering from Beijing Institute of Technology in 2015, and then he received the MS degree in Beijing Institute of Technology in 2018. Now he is a DS candidate in School of Mechatronical Engineering, Beijing Institute of Technology. His research interests include network simulation and emulation, VANET and so on.



Huibo Li received the BS degree in Mechatronic Engineering from Beijing Institute of Technology in 2016, and then she received the MS degree in Beijing Institute of Technology in 2019. Now she is a DS candidate in School of Mechatronical Engineering, Beijing Institute of Technology. Her research interests include wireless network simulation and emulation, resource management in wireless systems and development of secure network protocols for wireless networks.



Zhixuan Feng received the BS degree in Mechatronic Engineering from Beijing Institute of Technology in 2022, and now she is a MS candidate in School of Mechatronical Engineering, Beijing Institute of Technology. Her research interests include wireless network simulation and emulation, wireless communication and so on.



Peng Gong received the BS degree in Mechatronical Engineering from Beijing Institute of Technology, Beijing, China, in 2004, and the MS and Ph.D. degrees from the Inha University, Korea, in 2006 and 2010, respectively. In July 2010, he joined the School of Mechatronical Engineering, Beijing Institute of Technology, China. His research interests include link/system level performance evaluation and radio resource management in wireless systems, information security, and the next generation wireless systems such as 3GPP LTE, UWB, MIMO, Cognitive radio and so on.