

Development of Satellite Network Simulation Model for the Testing of Network Elements on the Ship

Sung-Hyung Lee¹, Jae-Hyun Kim¹, Kyoung-Deuk Moon², Kwangil Lee², Jun Hee Park²

¹School of Electrical and Computer Engineering, Ajou University, Suwon, Korea

²Electronics and Telecommunications Research Institute, Daejeon, Korea

E-mail: {xaviersr, jkim}@ajou.ac.kr, {kdmooon, leeki, juni}@etri.re.kr

Abstract

The Ship Network Integration Gateway (SNIG) will be the central network element for the ship area network. For the manufacturing of SNIG, we developed the INMARSAT Fleet Broadband (IFB) network simulation model using OPNET 14.5. This simulation model will provide the testing and debugging environments in the case of satellite communication scenario to the developer of SNIG. In this simulation model, the channel model and service features of IFB are included. Also, this simulation model has compatibility with System-in-the-Loop feature of OPNET therefore it can provide satellite communication test environment without any real satellite network usage. We verify the simulation model by comparing with file transmission and delay result given by the INMARSAT.

Introduction

In the past, the network in the ship is organized as point-to-point serial communication or separated network, therefore the inter connection between all devices are not provided. In this result, controlling, monitoring of device in the ship through the network requires additional cable installation, and ship automation in the ship was difficult. Therefore, we are currently developing the Ship Network Integration Gateway (SNIG), which is the central network element in the ship, and designing the backbone network architecture to provide singularized network in the ship.

We can use real network system for the testing and debugging of SNIG, however it requires connection cost to the satellite network and it has limited time for connection due to the limit of satellite communication. Therefore, the development of satellite network simulation model is started to provide testing environment with unlimited time and low cost.

We select the target satellite network system as the INMARSAT Fleet Broadband (IFB) network system because it is popular satellite network system for the voice and data communication in the sea area. In this paper, we present the development of IFB network simulation model and similarity test of the network simulation model.

Features of INMARSAT Fleet Broadband Network

IFB is the satellite network for the communication between land and ships in the sea. For the communication, three INMARSAT-4 satellites are placed in the sky on the equator, with latitude of 98 °W, 25° E and 143°E, and with height of 35,786 km from the surface of earth. Also, land earth stations are placed in Burum and Fucino for users in Europe and Africa area, and in Hawaii for users in Asia-Pacific and America area. The coverage and position of land earth station of IFB network is provided

in Figure 1. This network provides satellite communication with maximum data rate or 432 kbps and end-to-end delay from 800 ms to 1100ms.

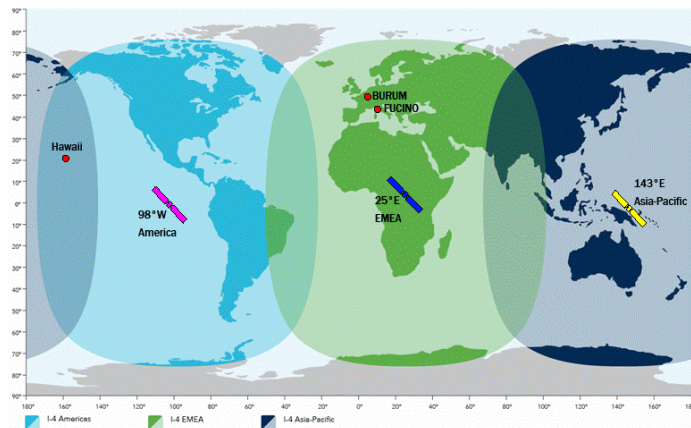


Figure 1: Coverage of IFB Network and Position of Land Earth Station in IFB

Nodes in the INMARSAT Fleet Broadband

In the IFB network, three types of nodes are presented. Their name and description is represented below of this paragraph and their connection diagram is represented in Figure 2.

- Mobile Earth Station(MES): This node is owned by the user. Usually, the antenna gain of this node is limited due to the small antenna in the device. This node accesses the IP network through the satellite and the LES.
- Land Earth Station(LES): This node is owned by the service provider of network system. Usually this node has very large antenna and it provides connectivity to the general IP network system.
- Satellite: this node floated in the about 35,786km from the surface of earth. This node receives the signals from the earth and amplifies it, and sends to another node in the earth.

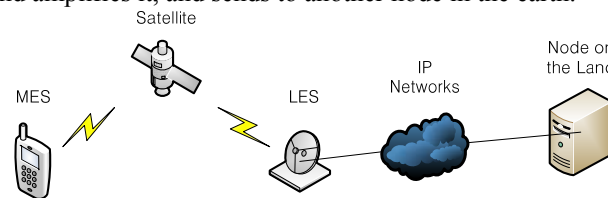


Figure 2: Connection between Three Nodes in IFB

The INMARSAT Fleet Broadband Network Simulation Model

We develop the IFB network simulation model using OPNET 14.5 for the testing of SNIG, as shown in Figure 3. This simulation model can provide the similar environment as the real IFB network because it contains the features of IFB as shown in Table 1. The simulation model also can be used in testing and debugging of SNIG because the simulation model provides possibility of System-in-the-Loop features in OPNET 14.5.

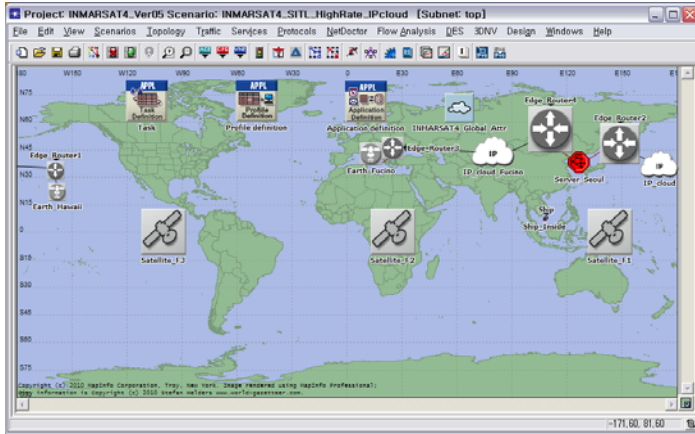


Figure 3: The INMARSAT Fleet Broadband Network Simulation Model using OPNET 14.5

Table 1: Features of the IFB Simulation Model

Target network system	INMARSAT Fleet Broadband
Frequency band	1626.5 ~ 1660.5 MHz (Downlink, LES → MES) 1525.0 ~ 1559.0 MHz (Uplink, MES → LES)
EIRP [1-2]	67 dBW (satellite) 80 dBW (LES) 15.1 ~ 22.0 dBW (MES)
G/T [1-2]	11 dB/K (satellite) 20 dB/K (LES) -15.5 dB/K (MES)
Data rate	284, 432 kbps
Channel access control protocol	Reservation TDMA
Applied channel models [4-5]	Path loss, Atmosphere absorption, Ionospheric effect, Rain fade, Multipath effect by sea wave reflection

Short Description about Reservation TDMA[3]

The reservation TDMA is the channel access method for sharing medium networks. In this protocol, bandwidth is divided into three channels: uplink control channel(UCC), downlink channel(DC), uplink data channel(UDC). UCC and DC are divided into time slots. UDC is divided into frames and the frame is divided into slots. The slot duration of each channel may not same.

Figure 4 shows the packet transmission example of reservation TDMA. The LES transmits its control message or downlink data through the DC without any coordination, because DC is not the

shared medium. However, the UDC is the shared medium, therefore the MES and the LES perform the reservation procedures to use the channel without collision.

When a MES wants to use a slot of UDC, then it transmits its request message (e.g. “User1 Req” and “User2 Req” in Figure 4) through UCC to LES. When a collision occurs in UCC, two MESs do backoff and retransmit their request message. When a LES receives the request message, the LES allocates a slot for the MES and send a response message(e.g. “User1 Use 1” and “User2 Use 2” in Figure 4) to LES through DC, to inform the LES of reservation result.

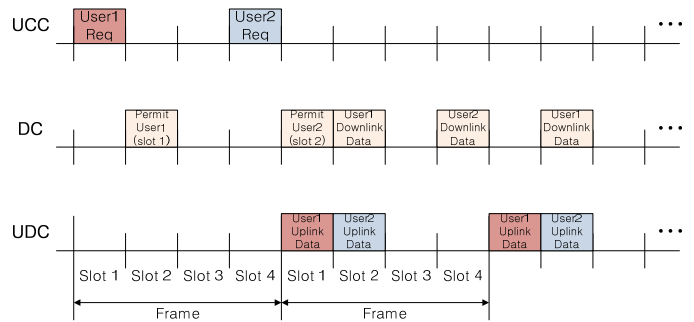


Figure 4: Example Packet Transmission of Reservation TDMA

Implementation of Satellite Node

Although the satellite is complex electronic device, the role of satellite is only the amplify-and-forward: it only receives the signal from the LES or MES, amplifies the signal, and then forwards it. Therefore, in the implementation of satellite node, the receiver and transmitter is used without any medium access and upper layers, as shown in Figure 5. The register process is used to provide information of satellite for the pipeline stage of simulation model.

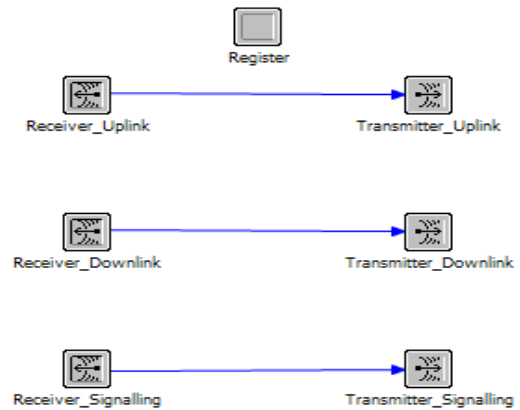


Figure 5: Node Model of Satellite Node

Implementation of Land Earth Station and Mobile Earth Station

We implement the LES by changing the Ethernet-IEEE 802.11 WLAN router in the OPNET 14.5 to provide possibility of System-in-the-Loop, because “Ethernet-to-implemented protocol” router is required to connect “sitl_virtual_gateway_to_real_world” node with our implemented INMARSAT protocol. In the

implementation, the medium access control(MAC) and physical layer of IEEE 802.11 below the “ARP1” is changed to the our MAC process model and transmitter/receiver model, respectively, as shown in Figure 6.

In the process model of our MAC for IFB, initialization process is used to exchange information with ARP process, as shown in Figure 7. The data exchange process is used to perform data and control message exchanges, as shown in Figure 8. We implemented LES and MES respectively, but they have almost same process model. So, in this paper, we basically describe about the process model of LES, and represent additional description if the state has different operation in the MES. The details of data exchange process are represented below:

Sync and Sync_Wait state: This state is used to find the start time of Reservation TDMA frame.

Wait_Ev state: In this state, the machine waits for an incoming event. The event can be either an incoming packet from the higher, two lower layers (control channel, data channel), or the expiration of the clock timer which means that it is time for sending data packet in the queue to other nodes.

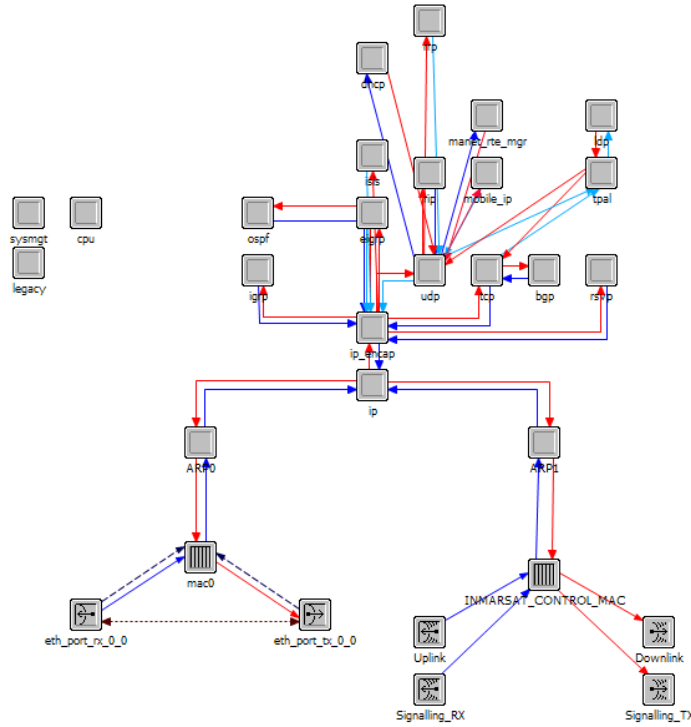


Figure 6: Node Model of LES

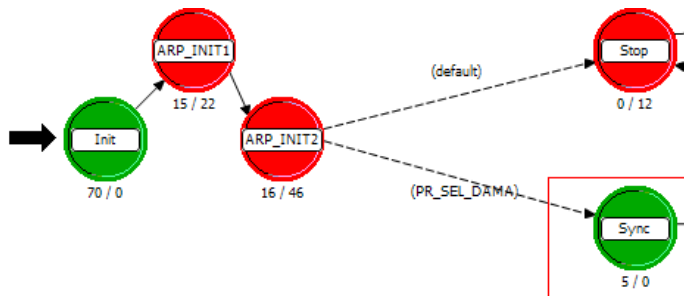


Figure 7: Initialization Process of LES

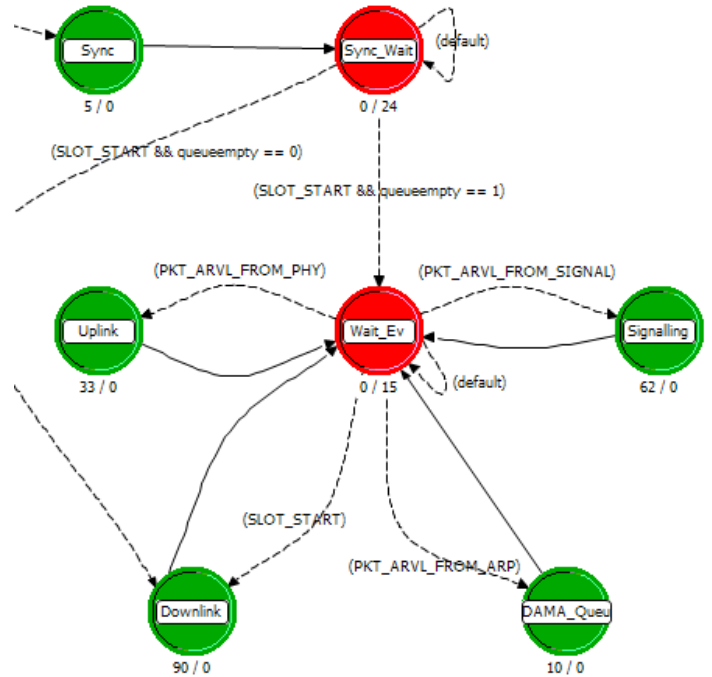


Figure 8: Data Exchange Process of LES

Uplink state: The machine enters this state if the machine receives data packet from other nodes. In this state, the machine decodes the packet and forwards it to upper layer. If the machine is MES, then the name of this state will be “Downlink state” with same operation.

Signaling state: The machine enters this state if the machine receives signaling packet from other nodes. In this state, if the machine is LES, the machine decodes the packet and allocates the time slot which will be used by requested node for the resource. If the machine is MES, then it decodes the control packet from LES and uses the allocated slot in the data transmission.

DAMA_Queueing state: The machine enters this state if the machine receives any packets from upper layer. In this state, the machine inserts the received packet into the sub-queue. Also, if the machine is LES, then it invokes the timer for the self interrupt at the start of time slot in the time division multiplexing. If the machine is MES, then it invokes the timer for the self interrupt at the start of allocated time slot in the reservation TDMA.

Downlink state: The machine enters this state if the machine is invoked by the timer interrupt at the Wait_Ev state. In this state, the machine sends control or data packet to other nodes in the simulation model. If the machine is MES, then the name of this state will be “Uplink state” with same operation.

Implementation of Pipeline Models

For the implementation of coverage, channel model, we change the pipeline model from the default radio model.

Power model: We modify the calculation of received power to apply channel models of satellite network which include the atmosphere absorption, the ionospheric effect, the rain fade, and

the multipath effect by sea wave reflection. These fading effects are affected by the operational frequency band. Therefore, we present global attributes for controlling amount of fading in the simulation model, rather than fix it.

In the frequency band of INMARSAT Fleet Broadband, the atmosphere absorption appears as additional constant fading. Therefore, we present a global attribute F_{atmo} (dB) for the atmosphere absorption, and received signal power in dB at the receiver is subtracted by this value. We use default value as 0.05 dB.

For other fading, power received at the receiver in dB is subtracted by randomly generated variables. The input parameters for generating random variables are represented in global attributes. Ionospheric effect F_{iono} (dB) and sea wave reflection F_{sea} (dB) appear as fast fading and Rayleigh distributed, and rain fade F_{rain} (dB) appears with slow fading and exponentially distributed. We use default average fading of Ionospheric effect as 3dB, sea wave reflection as 3dB. Also, we use rainfall rate as 42mm/h, which is the input parameter for generating rain fade(you can get information about detailed generation of each fading in [4] and [5]).

If the transmitter sends a signal with power of P_{send} and path loss is PL , the power received at a LES and a satellite are represented as equation (1) in dB. A MES experiences sea wave reflection therefore the received power of the MES is represented as equation (2) in dB.

$$P_{recv} = P_{send} - PL - F_{atmo} - F_{iono} - F_{rain} \quad (1)$$

$$P_{recv} = P_{send} - PL - F_{atmo} - F_{iono} - F_{rain} - F_{sea} \quad (2)$$

Closure model: To consider the coverage of satellite, we gather the latitude and longitude information of satellite's sender and receiver nodes. If a node is placed outside of satellite's coverage, then closure model blocks the communication between the node and satellite.

Receiver group model: To prevent direct communication between nodes in the earth, we use the receiver group model. In each node in the simulation model, each node has attributes for recognizing their node types (earth, satellite) and their target receiver types (earth node only, satellite only, both). The receiver group model gathers this attributes from each node, and if the target receiver of sender and the node type of receiver are not matched, then the receiver group model blocks the communication between sender and receiver.

Verification of Our Simulation Model

For the verification of our simulation model, we perform the FTP file transmission test. In the FTP file transmission, we send three 500 Kbytes file using several FTP clients as shown in Table 2 and Table 3. We measure total transmission time for the transmission of three files, as represented in the INMARSAT's user guide [6]. For using real FTP clients, we used the System-in-the-Loop module of OPNET 14.5 and three personal computers as shown in Figure 9. The connection diagram is represented in Figure 10. The comparison result is represented in

Table 2 and Table 3, which represent the downlink (Server on the land → LES → MES), and uplink (MES → LES → Server on the land) transmission result, respectively.

We also performed the measurement and comparison of end-to-end delay of the network, as represented in the INMARSAT's another user guide [7]. In this test, we send 400 ping messages from the MES to the LES and measure minimum and maximum delay to compare the result from INMARSAT's. The comparison result is represented in table 4. In this result, the errors of minimum and maximum delay are 3.75% and 0.55%, respectively.

In these results, although we don't know the information about FTP server program and detailed environment such as antenna gain, weather or position in the test result in INMARSAT's user guide, our network simulation model can represent the IFB network system with acceptable errors.

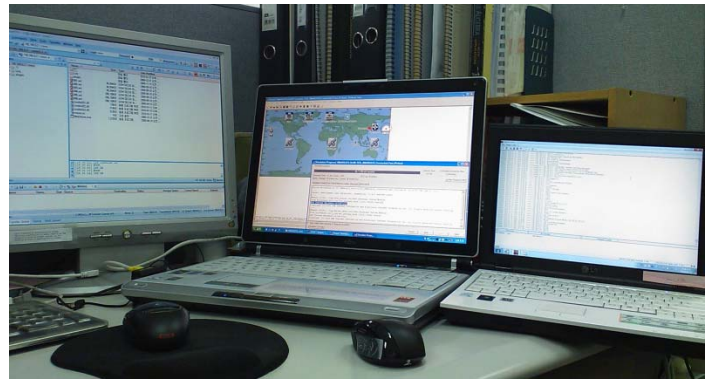


Figure 9: FTP File Transmission using System-in-the-Loop

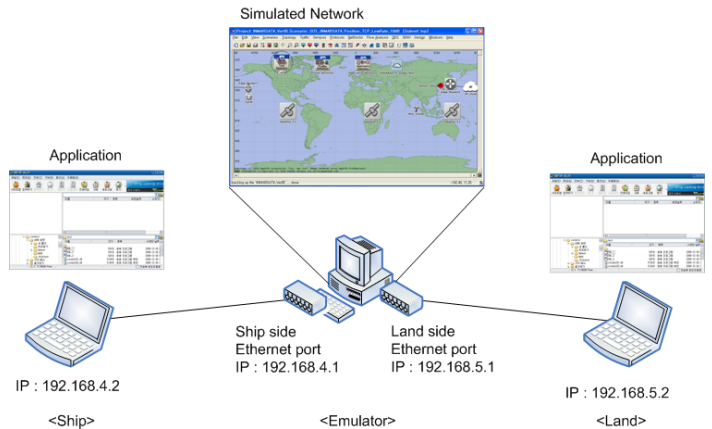


Figure 10: Connection Diagram for FTP File Transmission

Table 2: FTP File Download Test Results

FTP Client	Total Time(sec)	Reference(sec)	Error(%)
DOS FTP	35.94	32.05	12.14%
Cute FTP	46.62	44.12	5.66%
Smart FTP	72.55	73.38	-1.13%
WS FTP	49.07	59.07	-16.93%
Average	51.05	52.16	-2.13%

Table 3: FTP File Upload Test Results

Client	Total Time(sec)	Reference(sec)	Error(%)
DOS FTP	57.27	47	21.85%
Cute FTP	73.58	86.52	-14.96%
Smart FTP	108.97	111.09	-1.91%
WS FTP	55.39	65.16	-14.99%
Average	73.80	77.44	-4.70%

Table 4: End-to-end Delay Measurement Test Results

Source	Minimum(ms)	Maximum(ms)
Reference	800	1100
Our's	770	1106

Possibility Test of Ship Automation through the Satellite Network

For the ship automation through the satellite network, the ship can transmit emergency position indication message and periodic ship status indication message to the server on the land, at least. The description, period, size and expected protocol of two messages are represented below:

■ Emergency position indication message: This message transmitted when the ship is in the status of accident and it contains the position of ship. This information is transmitted periodically with minimum period of 1 minute. Size of message is about 60 bytes. Expected transport protocol is UDP or TCP.

■ Periodic ship status indication message: This message transmitted to notify the position and status of ship periodically. This information is transmitted periodically with minimum period of 1 minute. Size of message is about 716 bytes. Expected transport protocol is UDP or TCP.

Also, the requirements for two messages are represented below:

■ The delivery ratio of emergency position indication messages must be larger than 95% to get emergency message within 5 minutes on the land with probability of 99.999999%

■ The delivery ratio of periodic ship status indication messages must be larger than 80% to get status and position of the ship within 5 minutes on the land with probability of 99.9999%

We measure the packet reception ratio of two messages through the satellite network, using our simulation model. The results are represented in Table 5. In this result, if the ship use antennas with sufficient antenna gain and coding gain, then the all message types are can be transmitted through the satellite network, which means the possibility of ship automation through

the satellite network. However, if the network system uses an antenna with a low antenna gain and a low coding gain, then bit error rate is increased, and it causes decreasing in packet reception ratio. Therefore, a high antenna gain or a high coding gain must be provided to provide emergency position indication and ship status indication service for the ship.

Table 5: packet reception ratio through the satellite network

Protocol	TCP			UDP			
	Antenna gain (Coding gain)	High (7dB)	Low (7dB)	Low (10dB)	High (7dB)	Low (7dB)	Low (10dB)
Emergency Msg.	100.00%	8.17%	100.00%	100.00%	82.17%	99.97%	
Status Msg.	100.00%	19.33%	100.00%	100.00%	27.33%	100.00%	

Conclusion

In this paper, we presented the INMARSAT Fleet Broadband network simulation model using OPNET 14.5. This simulation model contains the channel model and parameters of the IFB system. The simulation model also provides the usage of System-in-the-Loop feature, therefore this simulation model can be used the testing and debugging of network device. We evaluate the similarity of real IFB system and our network simulation model based on the testing result of FTP file transmission and end-to-end delay from INMARSAT's guidebook. Moreover, we can check and confirm the possibility of ship automation with satellite network by our simulation model.

Acknowledgements

This work was supported by the IT R&D program of MKE/IITA, [2008-S038-01, Development of IT based Total Solution for Shipbuilding]

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