THIRTEENTH AIR NAVIGATION CONFERENCE

Montréal, Canada, 9 to 19 October 2018

COMMITTEE A

Agenda Item 2: Enabling the global air navigation system
2.2: Integrated CNS and spectrum strategy

AEROMACS FOR AIR-TO-GROUND COMMUNICATION AND CONNECTIVITY TO SWIM

(Presented by Japan)

EXECUTIVE SUMMARY

This paper presents a demonstration in the air of Aeronautical Mobile Airport Communications Systems (AeroMACS) to extend the coverage from the airport surface to the aircraft near the airport. We also started testing the connection to the SWIM demonstrator through AeroMACS. Some lab exercises were demonstrated to obtain the message from the SWIM network through the AeroMACS.

1. INTRODUCTION

1.1 We are investigating the performance of various radio systems related to the aeronautical systems. 5 GHz band is especially focused on the application for future aeronautical communications. An AeroMACS system is the new aeronautical mobile communication systems to increase the communication throughput using WiMAX technologies [1]. AeroMACS provides high-capacity data transmission and is compatible with internet protocol (IP), reducing both the system introduction and application development costs. In addition, AeroMACS has higher communication link security than current aeronautical communication systems. It can be effectively used to share a large and varied amount of information among air traffic controllers, pilots, airline companies, airport operators, such as SWIM, on both the airport surface and during take-off and landing.

2. DISCUSSION

2.1 We have been studied the availability of the system in Sendai airport [2] and demonstrate the performance of the system in Haneda airport in Japan [3]. However, as AeroMACS is designed for use at speeds of 120 km/h or below. In this paper, we examine the possibility of extension of AeroMACS coverage, with aircrafts moving at speeds above 120 km/h, as are the cases during takeoff and landing. We also conducted flight tests using experimental aircraft in conjunction with a standard-compliant AeroMACS prototype system. To extend the maximum range of coverage without any modification to the RF part of the system, we establish the ground station with high directivity parabola antennas and tracking function. We monitored a received signal strength indicator (RSSI) to investigate 5-GHz air-to-ground propagation. Also, we measured the throughputs to determine what applications can be used over AeroMACS.

2.2 On the other hand, the demand for the service sharing the various information among pilots, air traffic controllers, airline companies, and airport operators is greatly expanding for the improvement of air traffic safety and services. To address this issue, the ICAO has introduced the system-wide information management (SWIM) concept as a means of simplifying information accumulation and exchange through an internationally standardized format [4]. The goal of SWIM is to attain seamless air traffic management (ATM) services worldwide through an efficient integration of current ATM systems. AeroMACS will be a solution to connect between the aircraft and SWIM system. We also introduce a preliminary test for the connectivity in the laboratory.

2.3 The detailed results are described in the Appendices 1 and 2.

3. CONCLUSION

3.1 The Conference is invited to:

a) note the information contained in this paper, and

b) discuss any relevant matters as appropriate.

— — — — — — — —

APPENDIX A

AIR-GROUND TERRESTRIAL CONNECTIVITY TESTS NEAR THE AIRPORT

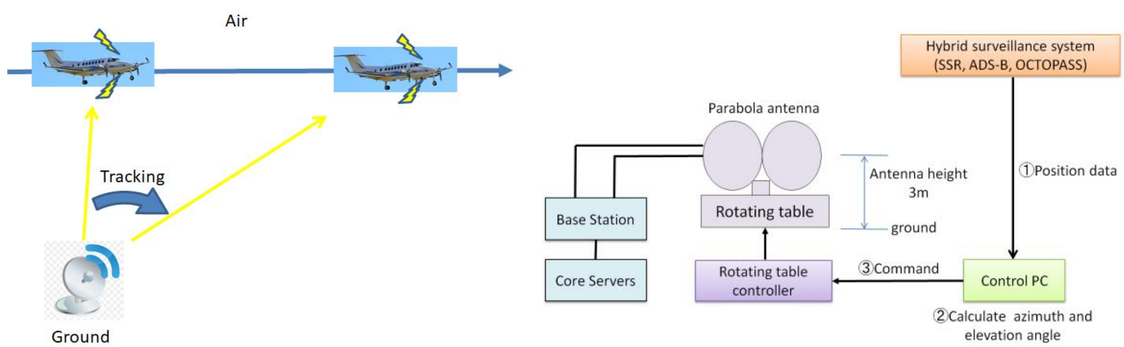
INTRODUCTION

To promote the exploitation of new digital aeronautical communication system, we have been conducting many ground test in Sendai and Haneda Airports [2,3]. As described in the SARPs[1], AeroMACS is based on the WiMAX standard and provides the mobility for relatively slow movement up to 120 km/h. To expand the coverage of the system, we evaluated the performance on the air by several flight tests.

TEST SYSTEM

Figure 1 (a) illustrates an overview of the test scenario. It comprises an experimental aircraft and a fixed ground station equipped with parabolic antennas and tracking function. In the high-speed moving scenario flight tests, the aircraft passes over the runway and then flies out the airport.

The fixed ground station uses two antennas, each having a transmit power of 200 mW within the SARPs regulations. However, to extend the maximum coverage while avoiding interference to adjacent systems, high directivity parabolic antennas are installed to the ground station. The gain of each antenna is 26 dBi and the half width of each is about 5 degree for both elevation and azimuth. We can extend the maximum coverage but we have to provide the signal properly to the aircraft according to its position. Figure 1 (b) shows a block diagram of the tracking antennas system. First, the position of the target aircraft is obtained from a hybrid surveillance system. The system can provide the position data obtained by various surveillance sources such as the SSR, the ADS-B stations and the OCTOPASS which is a new optically-connected RF receiver system. Then, the control PC calculates the elevation and azimuth angle from the ground station to the aircraft and send the commands to the rotation controller every second. Finally, the parabola antennas track the target aircraft properly.



(a) Test scenario (b) Architecture of Ground Station

Figure 1. Overview of Experimental Setup

Figure 2 shows the installation of test systems. Four 5-GHz (C-band) antennas are installed on the front-top, front-bottom, back-top, and back-bottom surfaces of the aircraft body as shown in Figure 2 (a). Each antenna is omnidirectional and has a gain of 0 dBi. Each antenna is connected to four antenna connectors in the cabin of the aircraft, with two of them connected to the airborne mobile station. This onboard system enables us to conduct flight tests using various combinations of aircraft antennas.

AeroMACS have a function to change a transmission rate changing adaptively depending on the received signal power through the application of an adaptive modulation and coding (AMC) scheme for primary modulation. As a secondary modulation scheme, AeroMACS uses orthogonal frequency-division multiplexing (OFDM). AeroMACS also employs a multiple input multiple output (MIMO) system based on multiple transmit and receive antennas. For the Mobile Station (MS), the AeroMACS system employs 2 x 1 MIMO (2 Receivers and 1 Transmitter) scheme. It also equipped a space time block code (STBC) as the MIMO mode. In particular, the reliability of communication is improved by applying these techniques. The minimum receiver sensitivity of the airborne station is -93 dBm approximately and the maximum transmission rate of the system is 7.5 Mbps. In the flight tests, a center frequency is tuned to 5,060 with 5 MHz bandwidth according to the experimental radio license in Japan.

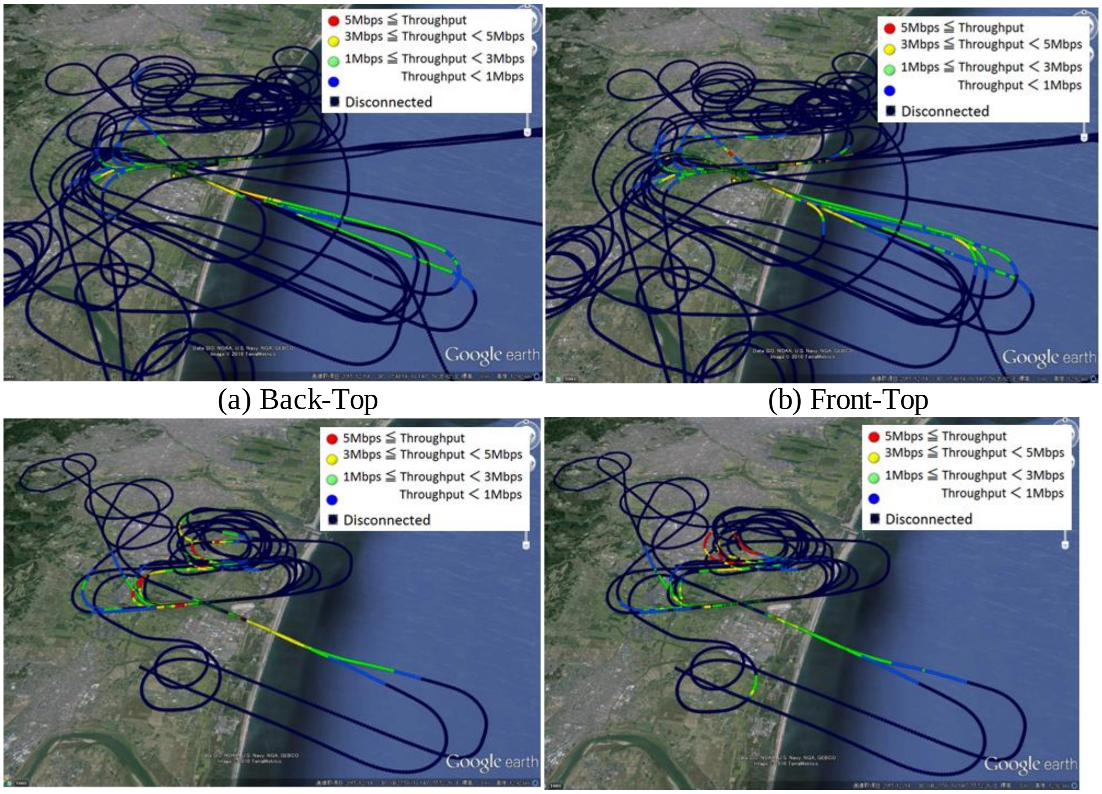
(a) Onboard System (b) Grond Station

Figure 2. Photograph of Experimental System

FLIGHT TESTS

In this study, we focused on downlink transmission, i.e., from the fixed ground station to the airborne station. We conducted many flight test around Sendai airport. The flight path and measured throughput are plotted on the map as shown in Figure 3. It shows all of the flight paths. Each figure indicates different transmitting antenna locations of the mobile station. We obtained RSSI and throughput from an aircraft receding from the fixed ground station at a speed of 200 km/h. As shown the Figures, some directions from the bases station are not applicable because of the shadowing by the environmental structure such as the buildings. 100 degree from the north is better than other conditions. Therefore, we extract a flight path as shown in Figure 4. The color of the points indicates flight altitude. The aircraft departed Sendai airport and flew toward the sea while increasing altitude. At 9 km from the fixed ground station, the aircraft began to turn to the right. Figure 5 shows the relationship between horizontal distance and altitude. The aircraft climbed up until 3 km and maintained the altitude at about 350 m within a range of ±50 m.

We analyzed the RSSI obtained in the flight test to investigate the fundamental properties of 5-GHz air-to-ground propagation. In Figure 6, the vertical axis shows RSSI in dBm while the horizontal axis shows the direct distance between the fixed ground station and the airborne station. Here, the direct distance is defined as the difference between the positions of the fixed ground and airborne stations obtained from the global navigation satellite system (GNSS). The blue and red circles show, respectively, the RSSIs obtained by the antennas installed on the top and bottom of the aircraft body. The yellow line shows the theoretical power calculated using the free-space propagation loss model.



(a) Back-Top (b) Front-Top

(c) Back-Bottom (d) Front-Bottom

Figure 3. Results of connectivity test with changing the airborne transmitting antenna

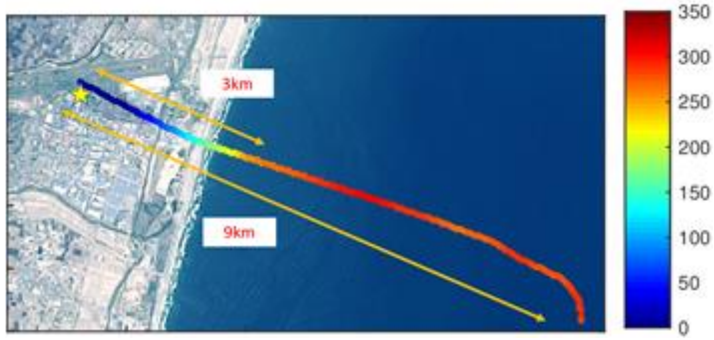


Figure 4. Extracted Flight Path

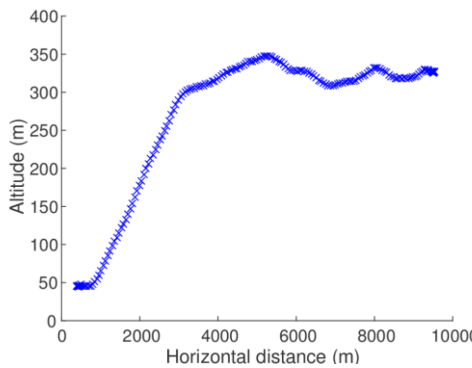


Figure 5. Flight Altitude

Figure 6 shows that the RSSI obtained by the top antenna was larger than that of obtained by the bottom antenna. The difference between top antenna and bottom antenna became much larger when the direct distance was within 3km. The reason is that the top antenna is facing the antenna of the fixed ground station because the heading of the aircraft was slightly upward from the horizon during climbing up phase. On the contrary, the bottom antenna was locating at non-radio-line-of-sight area shadowed by the aircraft body.

The figure also shows that the RSSIs of both the top and bottom antenna fluctuate, instead of decreasing monotonically, as the distance between the aircraft and the fixed ground station. The fluctuation might be caused by the fading by ground (sea surface) reflection. At 9 km from the ground station, the aircraft body goes into a lean because it is beginning to turn right. Consequently, the top antenna is facing the antenna of the ground station, whereas the bottom antenna is shadowed by the aircraft body. These results show that, for 5-GHz air-to-ground communication, it is important to consider the shadowing loss caused by the aircraft body itself because the line-of-sight component of the carrier wave is dominant in this band. One solution to solve the shadowing problem would be to place antennas on both the top and bottom of the aircraft body to increase the antenna diversity and compensate for the reversed correlation between shadowing loss and climbing/descent seen in the top and bottom antennas.

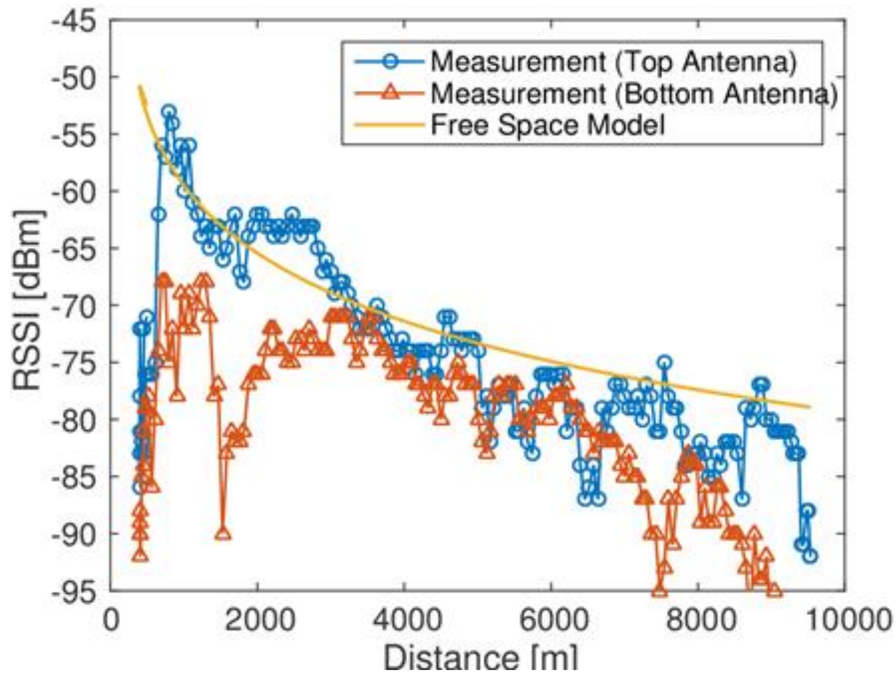


Figure 6. RSSI and the Direct Distance

We then assessed the possibility of using AeroMACS with an aircraft moving at high speeds such as those involved in taking off and landing. Figure 7 shows relationship between throughput and RSSI. The left vertical axis shows throughput and the right vertical axis shows combined RSSI. The RSSI in the Figure 6 shows combined-RSSI, which is the RSSI after combined by both top and bottom antennas, because the throughput is calculated after signal combining and demodulation. From figure 7, we observed a positive correlation between RSSI and throughput, because the throughput was high when RSSI was large and the throughput was low when RSSI was small. Here, we can see that the RSSI and throughput were quite low around the direct distance within 500m. In this region, the aircraft was moving near the fixed ground station at very high speed. Therefore, the updating rate of the tracking antennas was relatively low to track the aircraft. The improvement of the tracking performance based on aircraft position prediction algorithm is a future work.

Finally, Figure 8 shows a relationship between the throughput and the moving speed of the aircraft. As we can see, the throughput was not correlated to the moving speed of the aircraft. We demonstrated that throughput of 3-4 Mbps, which is enough to use real-time video applications, can be achieved when the direct distance was 8000m. Also, the throughput of 6.5 Mbps, which is around the maximum throughput of the system, can be achieved when the direct distance was 3000m, even at the moving speed of 200km/h[5].

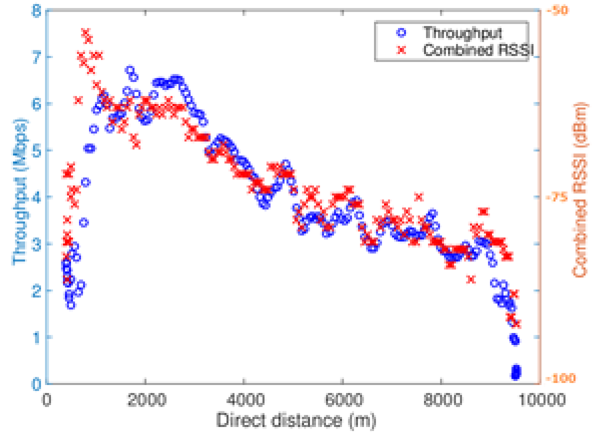


Figure 7. Throughput and Combined-RSSI

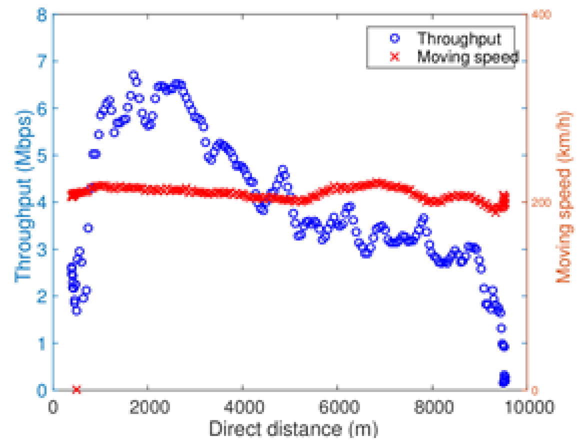


Figure 8. Throughput and Moving Speed

CONCLUSIONS

In this paper, we examined the possibility of using AeroMACS for an aircraft moving faster than 120 km/h, as would occur during takeoff and landing. We conducted flight experiments using the modified system from a SARPs-compliant AeroMACS prototype. The results of this flight experiments suggested that a configuration in which antennas are placed vertically on top of and at the bottom of the aircraft body is an effective MIMO configuration of the onboard antennas. We also found that high capacity data transmission via AeroMACS is possible even for an aircraft moving at 200 km/h.

— — — — — — — —

APPENDIX B

CONNECTIVITY TEST TO SWIM DEMONSTRATOR THROUGH AEROMACS

INTRODUCTION

The expected increase in aviation demands, economic pressure and attention to the environmental impact are relying ever more on accurate and timely information. Such information must be organized and provided by solutions that support system wide interoperability and secured seamless information access and exchange. The System Wide Information Management (SWIM) will complement human-to-human with machine-to-machine communication and shifts the ATM information architecture paradigm from point-to-point data exchanges to system-wide interoperability. Conceptual figure of the SWIM network connected by the AeroMACS is shown in Figure 1. Many mobile stations on the airport surface are connected by the AeroMACS and obtain various aeronautical information provided by the SWIM Network according to the authorization of each user.

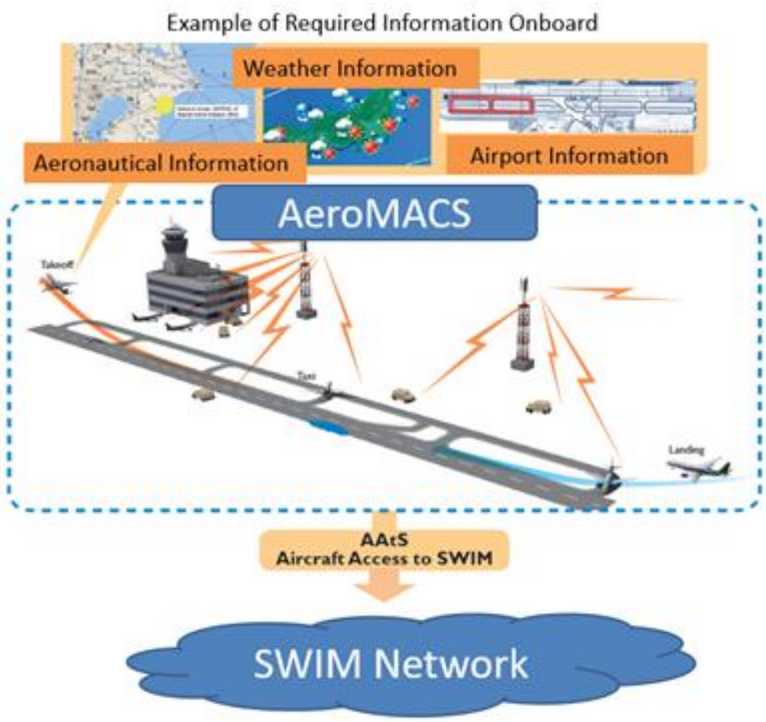


Figure 1. Aircraft Access to SWIM via AeroMACS

The Flight and Flow Information for a Collaborative Environment (FF-ICE) is a SWIM concept-oriented operation [4]. Its concept has been developed by ICAO to illustrate information for flow management, flight planning, and trajectory management associated with Air Traffic Management (ATM) operational components. It will be used by the ATM community as the basis for which ICAO SARPs will be developed in order to ensure that the FF-ICE concept can be implemented globally.

FF-ICE implementation has been divided into two phases proposed by the ATM Requirements and Performance Panel (ATMRPP). The first phase is FF-ICE Planning (FF-ICE/1) that is focused on achieving the interoperability of ground-to-ground information exchanges by using standard information exchange models in the pre-departure phase of flight. The second phase is FF-ICE Execution (FF-ICE/2) that will support Trajectory Based Operation (TBO) through ground-to-ground and air-to-ground (A/G) SWIM exchanges in the post-departure phase of flight. These information exchanges will enable a common operational picture between aviation stakeholders in order to support collaborative ATM and TBO. Therefore, ATM Service Providers (ASPs), Airspace Users (AUs), and other aviation stakeholders will need to determine the operational processes, procedures, and automation changes required for FF-ICE implementation.

Accounting for operational and technical interactions between different ATM systems, the International Interoperability Harmonization and Validation (IIH&V) project has been conducted by Federal Aviation Administration (FAA) to validate the ICAO provision changes for potential implementation. In order to promote the SWIM construction and the FF-ICE implementation in the Asia-Pacific region, Japan Civil Aviation Bureau (JCAB) joined this project from January, 2017. As a technical supporter of JCAB, Electronic Navigation Research Institute (ENRI) developed a test system for validation and participated lab exercises of validation in collaboration with FAA, NAV CANADA, NEC, NTT Data, ANA and JAL. The goal of the Validation 1 is to evaluate the viability of the implementation of FF-ICE/1 in the 2020 timeframe. That includes Flight Plan Submission, Monitoring, and Distribution which targets the pre-departure coordination of flight plans between ASPs in a mixed-mode environment. Validation 2 and 3 expanded trajectory negotiations to the post-departure portion concerning with the A/G SWIM integration by applying Electronic Flight Bag (EFB) with single or bi-directional data link communications. This information paper describes the development and analysis of lab exercises related to the SWIM implementation through the AeroMACS.

TEST SYSTEM FOR LAB EXERCISE

In Lab exercise, the mixed-mode environment that includes participation by both FF-ICE/1 capable and FF-ICE/1 non-capable ASPs is established to evaluate the operational and technical aspects of the global implementation of FF-ICE/1. A block diagram of lab exercise system is shown in Figure 2.

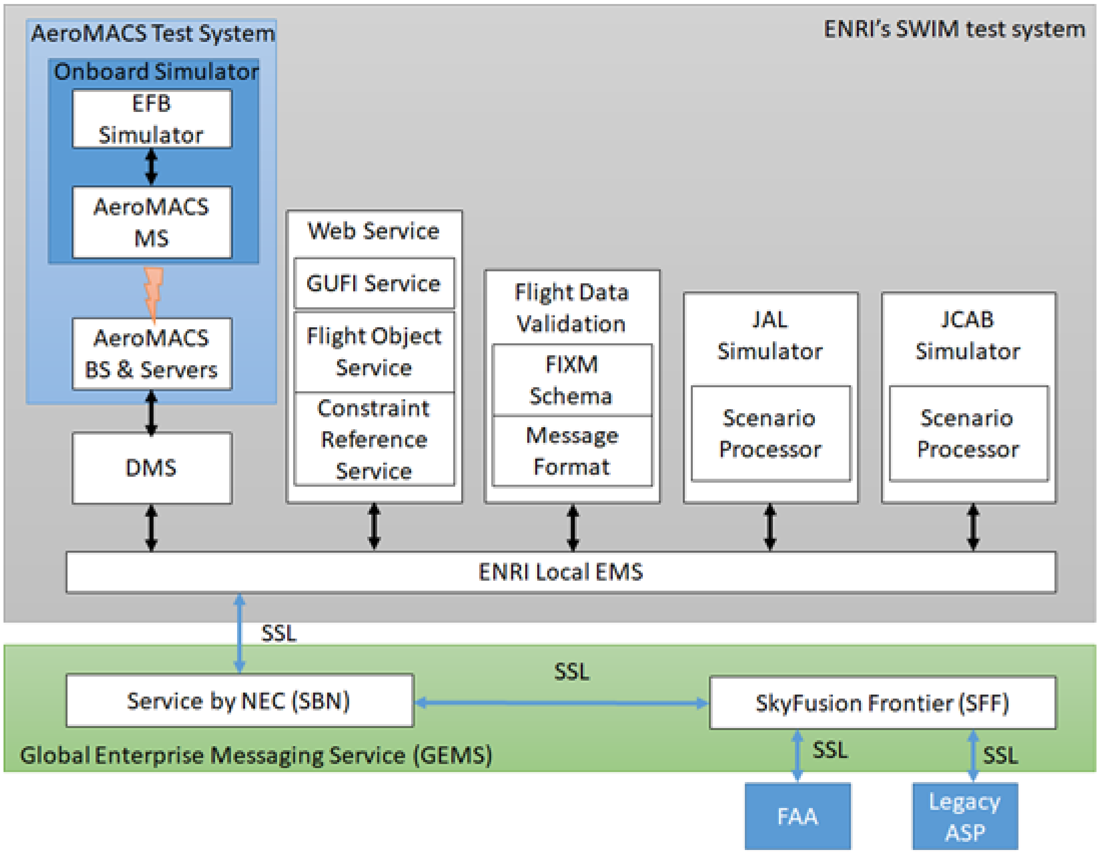


Figure 2. Local System Architecture for SWIM demonstrator through AeroMACS

The FF-ICE/1 capable ASP and AU are referred to as eASP and eAU (enabled ASP and AU). In the Validation 1 Lab exercise, there are two Global Enterprise Messaging Service (GEMS) providers that facilitate data sharing between a variety of partners and applications. As shown in Figure 2, the FAA, NAV CANADA and legacy ASPs connect to SkyFusion Frontier (SFF), which is supported by Harris Corporation. NEC provides the GEMS connections. ENRI's SWIM test system simulates regional eASPs and eAUs (JCAB, ANA, JAL). The GEMS Providers are charged to enforce the use of the standardized aeronautical, flight and weather exchange models (AIXM, FIXM and iWXXM) with the updated versions for each of their SWIM nodes to ensure the interoperability of the exchanged information. The communication between SFF and NEC is based on Secure Sockets Layer (SSL). And the SSL is also used for communication between NEC and local users. The communication standard for Publish/Subscribe messaging is Advanced Messaging Queuing Protocol (AMQP). The Data Management Service (DMS) is an access point for achieving Aircraft Access to SWIM (AAtS) developed to store, manage, filter, and deliver ground data and air data to related users. And to increase efficiency by removing extra process for information exchanges, all SWIM-enabled applications are connected to the ENRI Local EMS that directly connected to the Service By NEC (SBN). The Electronic Flight Bag (EFB) simulator was developed to subscribe related FIXM, AIXM and iWXXM messages for a certain aircraft. It can also generate the messages and submit them to the DMS[6].

The structure of practical prototype is shown in Figure 3. The AeroMACS base station and servers were located in the Radio System Building of ENRI. The SWIM test system and the onboard simulator were placed in the SWIM Evaluation Building. The distance between them is about 80m. The flight information, aeronautical information and weather information are generated by the SWIM test system according to the scenario. Moreover, the real-time Flight Object information is also available and accessible by using AeroMACS system. The live surveillance data was provided by the Secondary Surveillance Radar (SSR) system in ENRI.

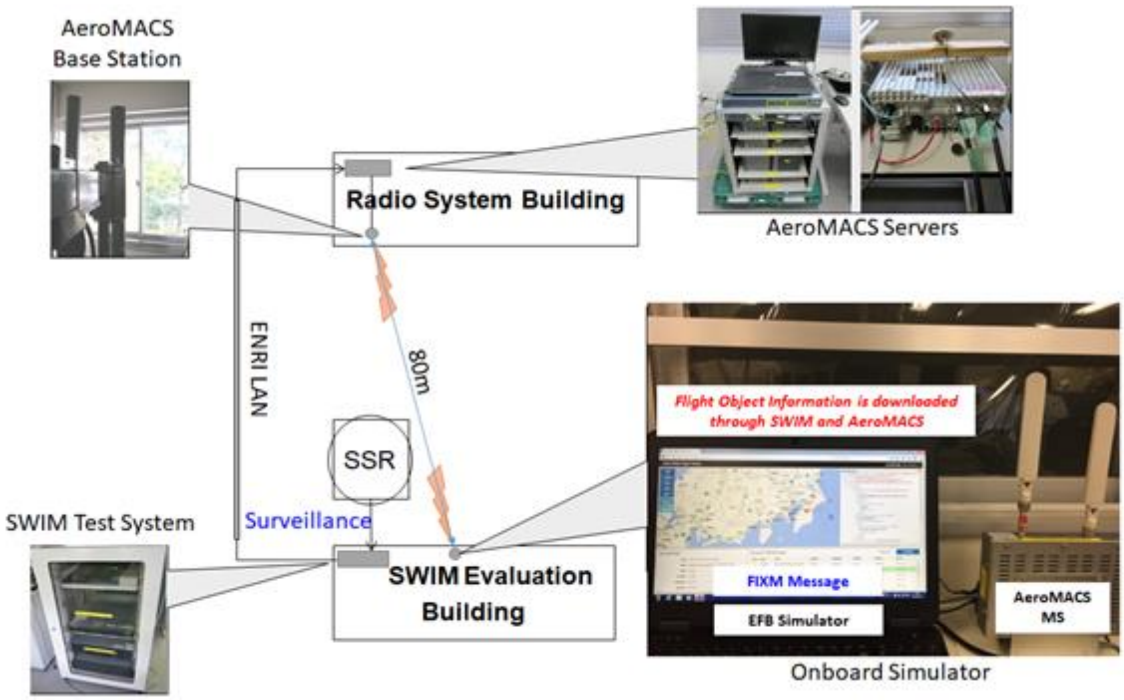


Figure 3. The installation of the prototypes for the lab exercise

For the lab exercise, several scenarios are defined by the origin and destination city pairs and associated constraints. The scenario proposed by JCAB is the flight planning for Japan Airlines (JAL) flight 5, a Boeing 777 aircraft with regularly scheduled service from John F. Kennedy International airport (KJFK) to Narita International Airport (RJAA). The FF-ICE/1 messages, defined in the ICAO FF-ICE/1 Provisions were exchanged between related stakeholders (JAL, JCAB, FAA, NAV CANADA). There are two phases in the FF-ICE/1, Preliminary phase and Filed phase. In each phase, eASPs should reply to the eAU regarding the operational acceptability of their flight plans. The Preliminary and Filed Flight Plans were submitted by the JAL that contain additional information including 4DT, aircraft dynamics, weight, etc. This enables the eASPs to generate a more accurate model of the flight path. Moreover, several constraints were introduced to address variable operational events, such as congested departure waypoint, airspace closure in JCAB FIR and so on.

To continue this scenario, the JAL5 from KJFK to RJAA uses EFB simulator for post-departure negotiation to achieve A/G SWIM integration. Before entering the FUKUOKA FIR, a digital NOTAM was received on the EFB that the primary runway at the RJAA has been closed due to a disabled aircraft. As shown in Figure 4, according to the latest weather information (METAR and TAF) for RJAA received via A/G SWIM and the onboard data of aircraft, the EFB generated a landing report and identified that diverting to Haneda International Airport (RJTT) is necessary due to a runway closure at RJAA. Using Trial Request and Update Request messages while enroute, the JAL5 was able to negotiate the diversion with related stakeholders.

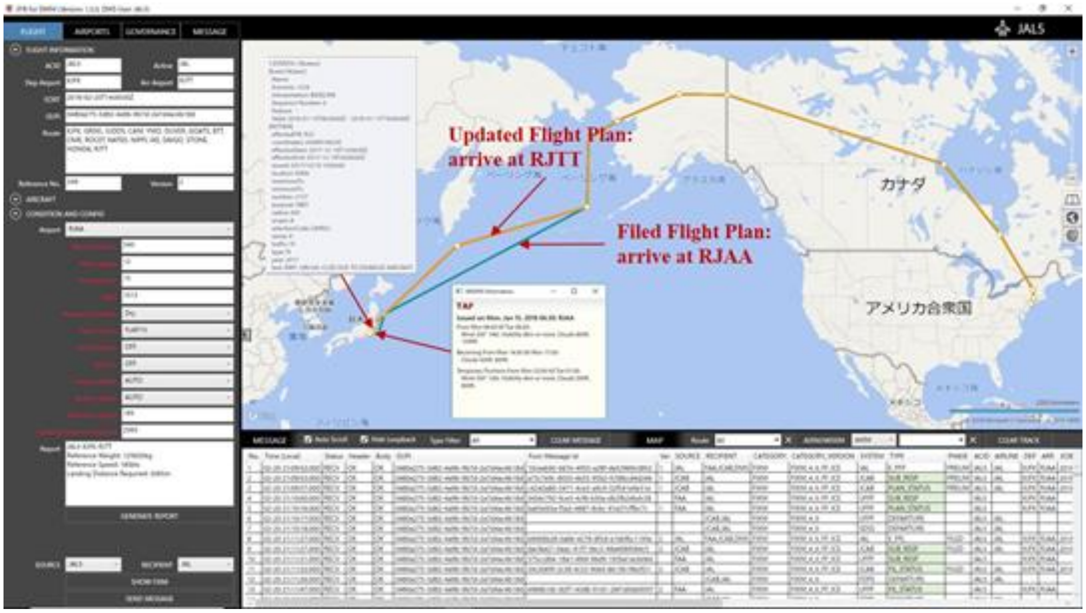


Figure 4. EFB Simulator for Validation 2/3

CONCLUSIONS

In this paper, we examined the availability of AeroMACS for the SWIM demonstration. The system successfully provide the appropriate information to the onboard simulator according to the scenarios. In the future, we will demonstrate the connectivity test using actual aircraft.

REFERENCES

[1] ICAO Annex 10, Aeronautical Communication Systems

[2] Y. Sumiya, N. Kanada, N. Yonemoto, A. Kohmura, S. Futatsumori and E. Isozaki: “ENRI Status and work plan for AeroMACS”, ICAO ACP WG-S1 WP05, March 2012

[3] Shoichi Hanatani, Yasuhiro Ouchi, Hidefumi Kawaguchi, Toshiyuki Inagaki, Kazuyuki Morioka, Naruto Yonemoto and Yasuto Sumiya, “AeroMACS Field Trial at Haneda Airport for Next Generation Mobile IP-data Network”, ICAO CP WG-S Mobility SG, May 2017

[4] Manual on System Wide Information Management (SWIM) Concept, ICAO Doc 10039, ICAO, 2015.

[5] K. Morioka, Junichi Naganawa, Naoki Kanada, Shunichi Futatsumori, Akiko Kohmura, Naruto Yonemoto, Yasuto Sumiya, “5GHz Ground-to-Air Communication Link by AeroMACS in High-speed Movement Scenarios”, The 23rd Asia-Pacific Conference on Communications (APCC2017), Perth, Australia, December 11-13, 2017

[6] ENRI, “Lab Exercises for FF-ICE/1 and A/G SWIM Validation”, ICAO SWIM TF/2 IP, Bangkok, Thailand. 9-12 April 2018

— END —