7． 空地統合 SWIM に関する研究開発

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1. INTRODUCTION

With the rapid increase in local and global air traffic, the system-wide operational information exchange and life-cycle management technologies are required to improve the capacity, safety and efficiency of global Air Traffic Management (ATM). The System Wide Information Management (SWIM) concept is to change the conventional ATM information architecture from point-to-point data exchanges to system-wide interoperability, and to achieve life-cycle management of data, information, and service [1]. The main objective of SWIM is to achieve interoperability and harmonization of global ATM operations through seamless information sharing among the multiple stakeholders.

Moreover, the Flight and Flow Information for a Collaborative Environment (FF-ICE) which is a SWIM concept-oriented operation has been developed by International Civil Aviation Organization (ICAO) to illustrate information for flow management, flight planning, and trajectory management associated with ATM operational components [2].

The current collaboration environment focuses on the ground-based ATM service providers and Flight Operations Centers (FOC) with little opportunity for flight deck involvement in the collaboration process. The processes used to collaborate with airspace users, especially those without dispatch operations, are not sufficient to enable the full range of benefits defined in the Global Air Navigation Plan (GANP) [3].

To achieve a safe, secure, efficient and environmentally sustainable ATM operation, not only the ground-to-ground (G/G) ATM systems but also the aircraft and its automation should be fully connected to share different and extensive information through collaborative exchanges. Therefore, the air-to-ground (A/G) SWIM concept has been proposed to enable a richer set of information to be exchanged with the aircraft and its automation to improve operational awareness and collaborative decision making (CDM) using A/G data connectivity and aircraft on-board systems [1].

However, the current A/G communication methods used for command-and-control information, such as A/G voice, Controller-Pilot Data Link Communications (CPDLC), and Automatic Dependence Surveillance - Contract (ADS-C) data link, are not adapted to be used in support of the collaborative exchanges between the information provider and the aircraft [1]. The use of A/G voice to convey non-time critical information by the controller is a secondary responsibility, while the use of traditional data link mechanisms such as Future Air Navigation System (FANS) or LINK2000+ is limited by the message set and associated avionics. As a consequence of the observed limitations, flight crews may currently not have access to a common or shared information platform to fulfil their requirements in flight or on the ground. The information unavailability, whether on demand or in near real-time, prevents flight crews from making informed decisions and hampers their ability to react to Air Traffic Flow Management (ATFM) initiatives. Therefore, the needs for CDM may not be fully supported due to the current lack of information available to the flight crew.

To provide timely, relevant, accurate, authorized, and quality-assured information for high-assurance operation, the architecture and the collaborative information exchange technology of an A/G SWIM integration system are proposed in this paper. Moreover, the development of practical validation system for ground taxiing experiments conducted by Electronic Navigation Research Institute (ENRI) is

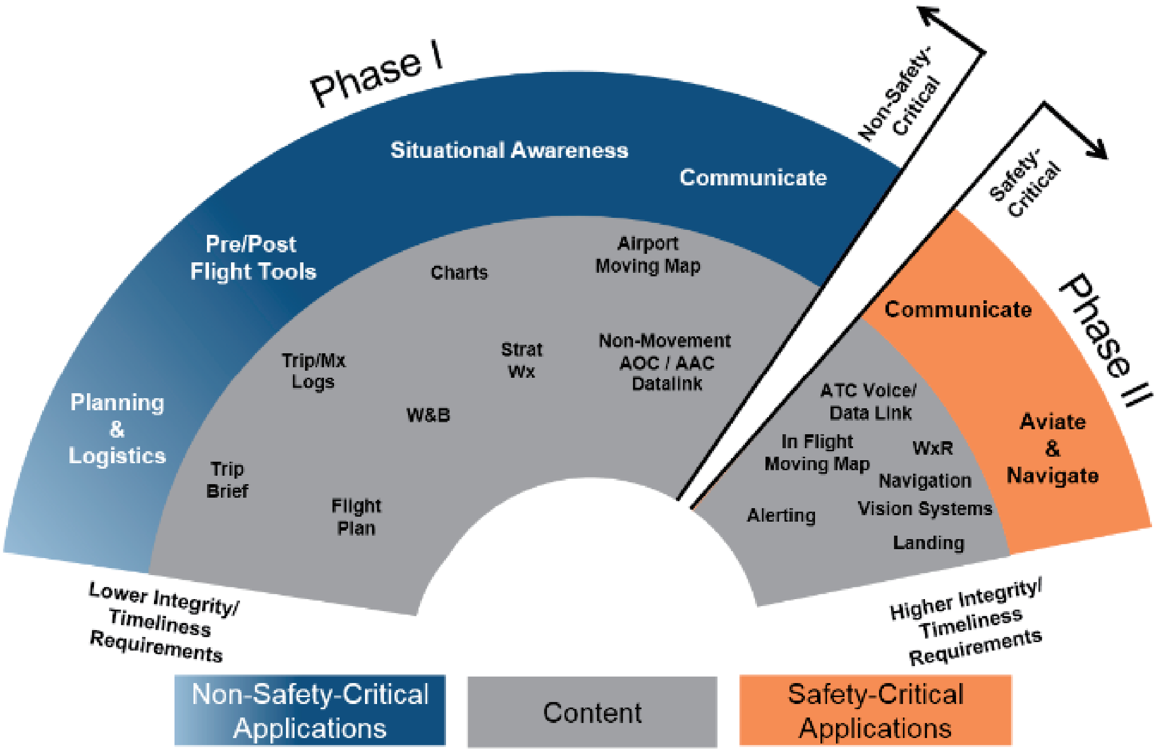

Figure 1: Phases of A/G SWIM

reported. Finally, the analysis of Quality of Service (QoS) and problems for constructing the collaborative operating environment to include interactions of A/G stakeholders, systems, and services through the A/G SWIM integration are discussed.

The paper is structured as follows. In the next section, the A/G SWIM Concept is introduced. In section 3, the proposed system architecture and the collaborative information exchange technology are presented. In section 4, the development and analysis of practical validation system for ground taxiing experiments in Sendai airport are presented. The paper is concluded in section 5.

2. A/G SWIM Concept

2.1 Overview

The availability of low-cost data link capabilities significantly improves the uptake of the aircraft and its automation to become a SWIM participant and obtain information supporting air traffic management and advisory information exchange. A/G SWIM will enable enhanced information exchanges, such as for advisory and trajectory information, between Airspace Users (AUs) and ATM Service Providers (ASPs). As a result of access to shared information, both AUs and ASPs can make improved decisions. Information available on A/G SWIM is applicable to all flight operation phases, including pre-departure, departure, airborne, arrival, and post-arrival phases.

The A/G SWIM Concept envisions two separate phases, as shown in Figure 1. Phase 1 focuses on non-safety-critical information, while phase 2 will extend the concept to include safety-critical information [1]. The current document is focused on Phase 1 of the A/G SWIM Concept, which is not intended to be utilized for safety-critical information or command-and-control functions, but rather to increase situational awareness. The use of A/G SWIM will support FF-ICE by providing a mechanism for the flight crew to exchange flight and flow information and become an integral part of the CDM and 4 Dimension Trajectory (4DT) management processes.

	SWIM Connection \ Avionics Connection	Avionics Connection Level: A. No Connection to Avionics	B. Connection from Avionics Only	C. Connection to/from Avionics
SWIM Connection Level	1. No Connection to A/G SWIM	1A. No Connection to A/G SWIM, No Connection to Avionics	1B. No Connection to A/G SWIM, Connection from Avionics Only	1C. No Connection to A/G SWIM, Connection to/from Avionics
	2. Connection to A/G SWIM Uplink Only	2A. Connection to A/G SWIM Uplink Only, No Connection to Avionics	2B. Connection to A/G SWIM Uplink Only, Connection from Avionics Only	2C. Connection to A/G SWIM Uplink Only, Connection to/from Avionics
	3. Connection to/from A/G SWIM Uplink/Downlink	3A. Connection to/from A/G SWIM Uplink/Downlink, No Connection to Avionics	3B. Connection to/from A/G SWIM Uplink/Downlink, Connection from Avionics Only	3C. Connection to/from A/G SWIM Uplink/Downlink, Connection to/from Avionics

Figure 2: Technical Framework of A/G SWIM

2.2 Technical Framework

To ensure the various operational scenarios relative to the differing configurations, the technical framework is organized based on the level of A/G SWIM connectivity available to the airborne platform as well as the level of connectivity between the flight deck application and the avionics on the airborne platform.

Figure 2 is a construct to show various levels of A/G SWIM connectivity and avionics interface [1]. There are three SWIM connection levels defined as below:

1. No Connection to A/G SWIM
2. Connection to A/G SWIM Uplink Only (airborne platform can receive A/G SWIM information)
3. Connection to/from A/G SWIM Uplink/Downlink (airborne platform can receive/send A/G SWIM information)

Three avionics connection levels defined in Figure 2 are as follows:

A. No Connection to Avionics
B. Connection from Avionics Only
C. Connection to/from Avionics

The table represents progressively more sophisticated connectivity/equipage down and to the right. It is not intended that this is the only equipage set in which these operations can be completed, as any less complicated activities can always be accomplished by a more complex system.

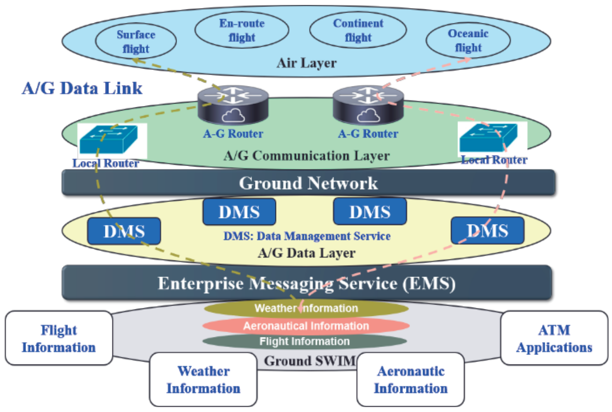

Figure 3: System Architecture

Interoperability is critical to wide-spread adoption of A/G SWIM. Applications and the infrastructure on A/G SWIM should be able to operate across Flight Information Regions (FIRs), through the region, and as practicable, globally, without major modification. This will reduce the AU requirements to equip and train, especially for AUs that operate globally.

3. A/G SWIM Integration

3.1 System Architecture

The A/G SWIM is an integrated combination of air and ground systems, where an aircraft communicates by wireless with other aircrafts, satellites and ground systems, and ground systems communicate by wired networks with different information exchange approaches. There are two major communication network infrastructures required to support A/G SWIM integration (Figure 3). One is the G/G communication network to enable ASPs and flight operators to exchange information. The other is the A/G communication network to provide data link functions for information exchange with aircrafts.

It is expected that open, Internet Protocol (IP) will provide the connectivity for both networks. Many open standards for communications exist and the use of proprietary networks should be transparent. On-board Wi-Fi systems, non-safety satellite communications accessed using passenger networks, Global System for Mobile, etc., would all allow IP-based access to information nodes.

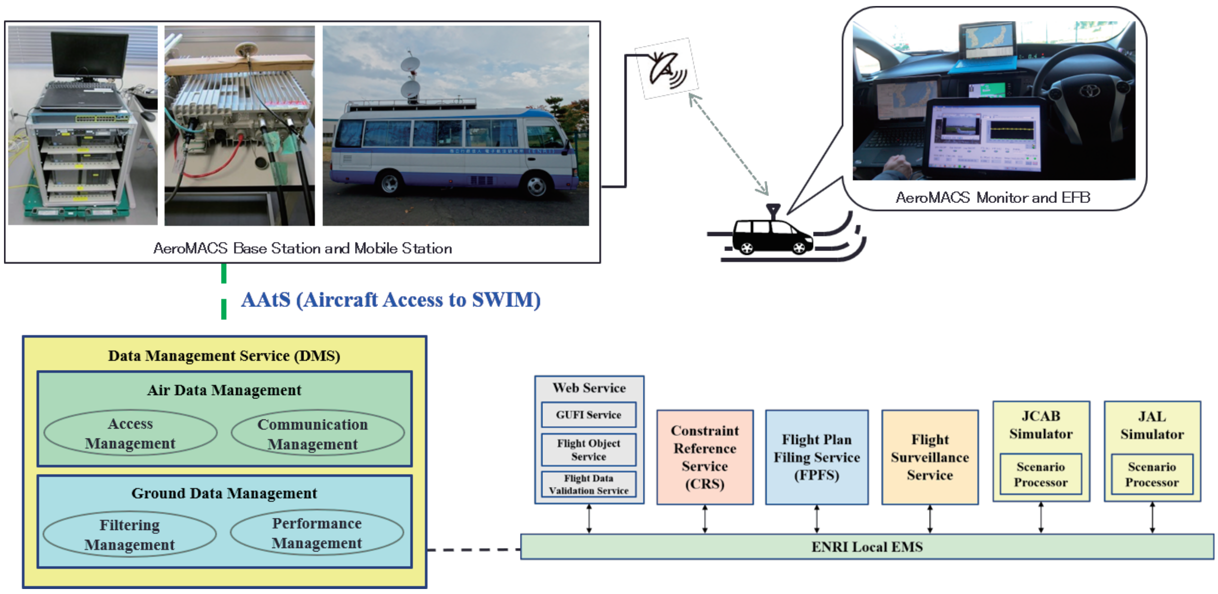

Figure 4: Validation System for A/G SWIM Integration

According to different communication environments and capabilities, several data-link technologies have been developed and applied for A/G communications. However, most of them are applied for special on-board devices without interoperability. As the in-flight Wi-Fi service has been available for most airlines, the concept of Data Link as a Service (DLaS) is proposed to provide adaptive Aircraft Access to SWIM (AAtS) approaches for non-safety-critical and safety-critical information exchanges according to different communication environments and capabilities [4].

To connect A/G communication network infrastructures for interoperable information exchange, the A/G Data Layer with functionalities to allow the delivery of services to an aircraft is required. The Data Management Service (DMS) is an access point for achieving AAtS developed to store, manage, filter, and deliver ground data and air data to related users. The functionalities of a DMS can be implemented external to or internal to ground SWIM. Each DMS has a high degree of autonomy to control itself and coordinate with others. As shown in Figure 4, the access and communication management for air data and the filtering and performance management for ground data are main functions of a DMS to enable consumption of services and information sharing not only between A/G communication networks but also within A/G Data Layer [5].

3.2. Collaborative Information Exchange

In the loosely coupled SWIM environment, to achieve collaborative information exchange by a number of entities, a common messaging infrastructure is required. The Enterprise Messaging Service (EMS) is a logical layer that can be implied in different levels. It can provide security, routing, metadata, subscription and policy functions to assure that a message is transported from its source to its destination by using the appropriate message format and communication protocol [6].

From the view of applications, the requirements for types of data, volume of data and real-time scales of data during the different operation phases are different and changing dynamically. Due to different conditions and specific operational requirements, three communication approaches are developed to achieve collaborative information exchange between G/G and A/G applications.

- Publish/Subscribe (Pub/Sub) approach for dynamic and real-time information;

- Request/Reply approach for static and non-real-time information;
- Push/Pull approach for emergency information.

The data with different time scales are divided into different logical layers and the life-cycle management is applied. As a result, if trouble occurs, the trouble will not expand into the whole system. Moreover, the data with low real-time priority will not interfere with the applications in high real-time level. Finally, in order to secure the system expendability, the EMS is configured in autonomous architecture to associate with application systems so that it is easy to add different types of application systems according to their service level requirements.

4. Practical Validation

4.1. Test System

To validate the services and functions of A/G SWIM integration system, the ground taxiing experiments have been deployed in the Sendai airport (Figure 4). The vehicle used the EFB (Electronic Flight Bag) simulator to achieve information exchange with SWIM. The EFB simulator was developed to subscribe related flight information, aeronautical information, and weather information for a certain aircraft; show related information and documents on the map; generate takeoff and landing report according to the onboard and ground information and submit it to the DMS; request NOTAM (Notice to Airman), METAR (Meteorological Aerodrome Report) and TAF (Terminal Aerodrome Forecast) information from the ground SWIM services.

The aeronautical mobile airport communications system (AeroMACS) using WiMAX technologies was applied for A/G communication to achieve effective information exchange between the vehicle and the ground facilities. AeroMACS provides high-capacity data transmission and is compatible with IP network, 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 on both the airport surface and during takeoff and landing [7].

In the practical validation, ENRI Local EMS facilitates data sharing between a variety of services and applications. It is charged to enforce the use of the standardized aeronautical, flight and weather information exchange models (AIXM, FIXM and IWXXM) with the updated versions for SWIM services to ensure the interoperability of the exchanged information.

The network connection between AeroMACS and SWIM system is established on the VPN (Virtual Private Network) over Internet. The communication between EFB and DMS is based on Secure Sockets Layer (SSL). The communication standard for Publish/Subscribe messaging is Advanced Messaging Queuing Protocol (AMQP 1.0).

The evaluation systems of JCAB (Japan Civil Aviation Bureau) and JAL (Japan Airlines) are constructed on the ENRI local EMS. They serve as an ASP system and an AU system respectively to support the scenario-based validation and demonstration. There is a set of services and applications developed that support both FF-ICE based message process and practical validation.

- The Globally Unique Flight Identifier (GUFI) is a key component of flight object management. The GUFI Service in local system provides the functionality of generating and tracking GUFIs.
- The Flight Object Service maintains an up-to-date version of all subscribed flight data. The flight data is organized into flight objects by GUFI and then stored in a database for continuous updates and queries.
- The Data Validation Service provides validation and reporting on FIXM, AIXM and IWXXM messages conformance to schema and set of business rules.

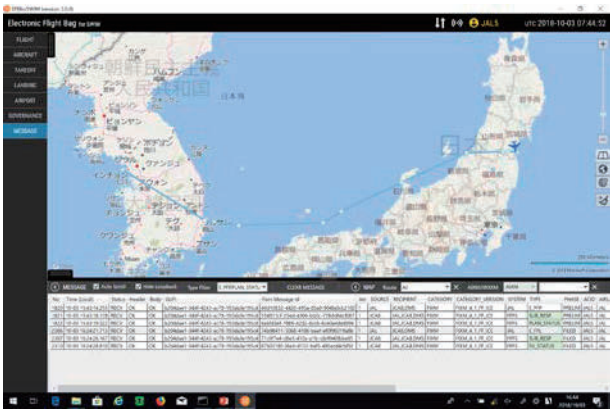

Figure 5: Pub/Sub for Flight Plan Messages

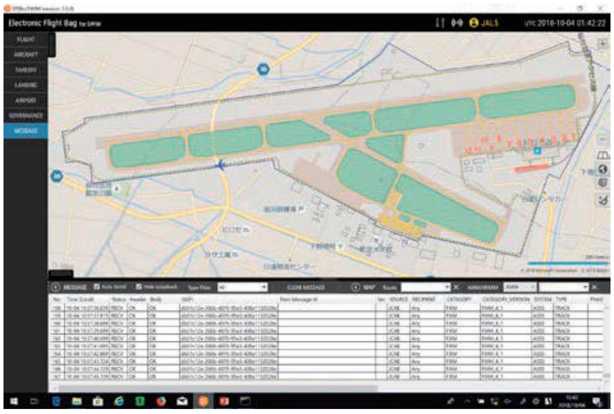

Figure 6: Pub/Sub for Track Messages

- The Constraint Reference Service (CRS) provides aeronautical and weather information in AIXM and IWXXM format to support continuous monitoring for FF-ICE flight plans.
- The Flight Plan Filing Service (FPFS) evaluates the flight plan messages and checks the constraints affecting the route. It provides continuous monitoring functions for filed flight plans according to the updates of constraints.
- The Flight Surveillance Service transforms airport surface and en-route surveillance data to FIXM format and publishes to other SWIM services.
- The Simulator of JCAB processes received FF-ICE Flight Plan messages from AUs. It also supports publishing constraints with AIXM and IWXXM messages and submitting the response that includes the constraints to AUs.
- The Simulators of JAL generates FF-ICE Flight Plan messages and submits Trail Requests and updated Flight Plans according to the constraints provided by ASPs and CRS.

4.2. Validation

To evaluate the information sharing via Pub/Sub among related stakeholders, the FF-ICE/1 flight plan message defined in the ICAO FF-ICE/1 Provisions were exchanged between JAL and JCAB. There are two phases in the FF-ICE/1, Preliminary phase and Filed phase. In each phase, ASPs should reply to the AU regarding the operational acceptability of their flight plans [8]. The Preliminary and Filed Flight Plans for JAL5 from Sendai airport (RJSS) to Inchon International airport (RKSI) were submitted by the JAL that contain additional information including 4DT, aircraft dynamics, weight, etc. According to the evaluation of format and constraint, the FPFS replied CONCUR and ACCEPTABLE for Planning Status and Filing Status to the JAL [9][10]. As a subscriber of the information of JAL5, when the EFB connected to the DMS with JAL5 account, all published messages related to JAL5 were received automatically (Figure 5). Moreover, when the vehicle started to move, the Track messages in FIXM format provided by the Flight Surveillance Service were subscribed by the EFB in real time (Figure 6).

The latest weather information of the airport is required to generate the take-off report of the flight before departure. The EFB is able to send the request to the SWIM service and get the reply of the latest METAR and TAF information from CRS (Figure 7). Other constraints registered on the CRS are also available for Request/Reply access via the EFB.

Each ASP is able to publish constraints, such as aeronautical information, traffic flow management data, and severe weather conditions. For some emergency information and constraints, the ASP is able to send a notification to a certain flight using Push/Pull approach. It not only assists the flight in making decision by identifying the operational environment and ATM constraints, but also enables

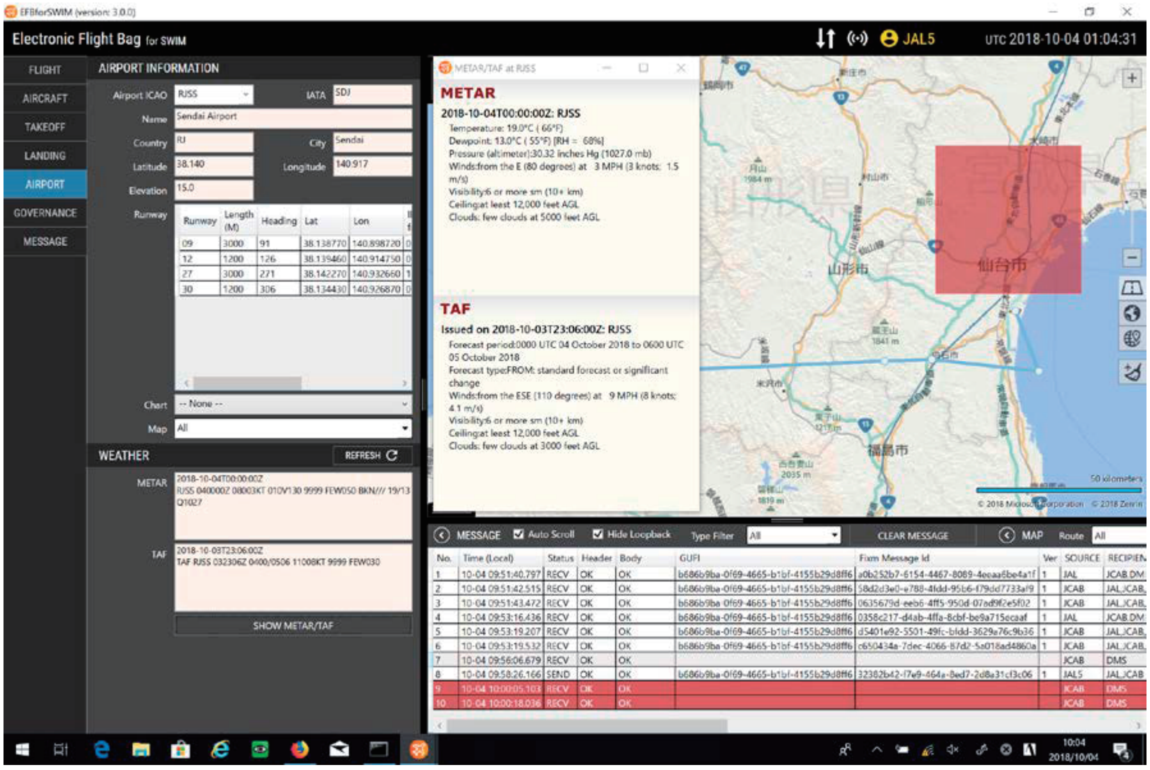

Figure 7: Test of Request/Reply and Push/Pull

the flight to obtain an earlier, more detailed and more accurate assessment of the anticipated traffic demand. As shown in Figure 7, the limited air space information near the Sendai airport was pushed from JCAB to JAL5 in AIXM message and automatically shown on the map of EFB.

4.3. Analysis

The main objective of A/G SWIM integration is to improve the Quality of Service (QoS) for meeting the information requirements of flight crews. Some QoS parameters for G/G SWIM have been analyzed and discussed in some local and international validation experiments. Table 1 shows the QoS comparison between current A/G communications and A/G SWIM integration. As shown in Table 1, the A/G SWIM integration is able to provide not only higher performance but also more flexible and less costly for achieving information exchange and interoperability in global, regional and local levels.

Due to the unstable connection of A/G wireless communication, the package loss might occur in the real applications according to the different network conditions. To solve this problem, the A/G synchronization technology by setting the timestamps in the metadata of message header has been proposed and applied in the test system. The efficiency of the

Table 1. QoS Comparison

QoS	Current Approach	A/G SWIM
Availability	Low with limited information	High with rich information
Capacity	Simple information exchange	Complex information exchange
Throughput	Low with voice centric	High with data centric
Response Time	Difficult to be changed	Able to be improved
Recoverability	Difficult for point-to-pint process	Easy for service cooperation
Security	Difficult and high cost for special systems	Easy and low cost for standard technologies

proposal was proved in the ground taxiing experiments by getting the lost messages after the EFB reconnected to the DMS via synchronization process.

5. CONCLUSIONS

In this paper, the A/G SWIM concept for achieving FF-ICE and Trajectory Based Operation (TBO) is introduced. Then, based on this concept, the architecture and the collaborative information exchange technology of an A/G SWIM integration system are presented. Moreover, the development of a practical validation system for ground taxiing experiments by using AeroMACS as a A/G data link is reported. Finally, the comparison of QoS between current A/G communications and A/G SWIM integration for constructing the collaborative operating environment is analyzed. The results and analysis of practical validation show the efficiency of proposed system architecture and technology. In the future, the flying experiment and the quantitative evaluation of the A/G SWIM integration will be conducted.

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