

Wi-Fi Gatelink Trial
Frankfurt and Munich, Germany
White Paper

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1. Abstract

This white paper is the result of a Gatelink operational trial sponsored by ARINC, Lufthansa, Fraport, and the Munich Airport Authority. The trial was intended to test Gatelink-specific hardware in an airport test environment and collect data specific to operation. This white paper provides an analysis of the traffic applicable to the current 763-3 AEEC Characteristic.

2.0 Introduction

2.1 Trial Purpose

The purpose of the Gatelink trial was to test the network and available Terminal Wireless Lan Unit (TWLU)(s) as currently defined in ARINC Characteristic 763-3. The trial was conducted in a laboratory environment at ARINC and laboratory and ramp environments at Frankfurt and Munich. The laboratory trial performed at ARINC, was conducted in a controlled environment where only Gatelink trial applications were using the network. The laboratory trials at the airports were also conducted in controlled environments. At the same time the ramp trials were conducted in the operational environment with the network shared with other users.

The following is the list of test-related requirements tested for the ground WLAN network based on the ARINC 763-3 Characteristic:

- IP Address shall be dynamically assigned by the airport router to the TWLU
- The addressing shall be private-space addressing
- Airport network shall support 802.11g
- Network shall facilitate 802.1x authentication to airline host (or similar test box) via proxy
- Airport shall not require further authentication of the device beyond the 802.1x authentication
- Network will provide session persistence as a device passes to different access points.

2.2 Description of trial

The trial focused on the core components of implementing Gatelink service at an airport with TWLU(s) connecting in the same manner. The trial commenced in April and concluded in June 2006. It included three weeks of laboratory testing and two weeks of ramp testing in Frankfurt, followed by three weeks of laboratory and ramp testing in Munich. ARINC configured and pre-staged the system in Annapolis, Maryland, USA, prior to the Frankfurt delivery. The tests that were performed during the trial are described in Appendix A, "Tests and Description." Results are documented in Appendix B, "Tests and Results."

2.3 Trial Participants

The following organizations provided significant resources and were integral in the trials conducted at Frankfurt and Munich airports:

2.3.1 Airports

Both airport authorities, Fraport and Munich International Airport Authority, provided resources and space for the trial. In both airports, the airport authority provided dedicated resources to be available for much of the trial period.

2.3.2 Lufthansa

Lufthansa coordinated the airports involvement in the trial. In addition to personnel to support the trials, they provided a van that represented an aircraft for the Frankfurt ramp trials.

2.3.3 Cisco

Cisco provided networking equipment and support for the trial period.

2.3.4 TWLU Vendors

Four Avionic vendors participated in the trial. They provided the equipment as well as engineering resources to configure them for the trial. Participating vendors included:

- Avionica – with the SecureLINK TWLU
- Honeywell – with their current generation prototype TWLU for the Boeing 787 project
- Miltope – with TWLU Model 1TLP3
- Rockwell Collins – with their current prototype TWLU, Laptop connected to a built-in AP, for the Airbus 380 project

The TWLU(s) that participated were prototypes of the ARINC 763-3 implementation except for the Miltop TWLU. The table below compares the TWLU vendors and their capabilities:

Vendor	763-3 Compliant	Authentication	Switching/Routing
Miltope	Yes	802.1x EAP-TLS/WPA	<i>Ethernet Interface: yes IP Routing: yes Switch: 1 port switch Antenna: 2.4 GHz</i>
SecureLINK by Avoinica	Yes	802.1x EAP-TLS/WPA	<i>Ethernet Interface: yes IP Routing: yes, port forwarding Switch: 5 port switch Antenna: 2.4GHz</i>
Honeywell	Yes	N/A	<i>Ethernet Interface: yes IP Routing: no Switch: 1 port switch Antenna: 2.4GHz</i>
Rockwell WLU-2100	Yes	802.1x EAP-TLS/WPA	<i>TWLU acted as a bridge using a laptop, based on a Cisco 1242 AP and a laptop to simulate TWLU:</i>

2.3.5 Airline Attendance

The following airlines attended the trials:

In Frankfurt:

- Iberia
- SAS
- Virgin Atlantic
- Lufthansa
- UPS

In Munich

- ANA
- JAL
- AviCom
- Cathay Pacific
- Air France

AviCom also visited Munich airport during the trial period.

3.0 Trial

As previously noted, trials were conducted in three places; at ARINC and two airports in Germany - Frankfurt Airport and Munich Airport.

For all the trial sites the following tests were consistently performed:

- Associations to the Access Points- TWLUs were tested to determine if they could recognize the Service Set Identifier (SSID) and associate to the access point. They were further tested to determine if they could make an appropriate Dynamic Host Configuration Protocol (DHCP) request.
- 802.1x EAP-TLS Authentication- Tested how the TWLU made the 802.1x authentication request. Specifically done using certificates built by Avionica and associating to a server managed by ARINC and built by Avionica.
- Host Connectivity- Tested that the application client on the “aircraft” is able to communicate to the application host on the ground. Also verified that session persists through TLS encryption.

3.1 ARINC Laboratory

ARINC personnel were responsible for building the gatelink network infrastructure at their U.S. Headquarters. It was staged and tested prior to implementation in Frankfurt, Germany. The system shipped consisted of all the gatelink network components. This equipment was integrated into Fraports Airport Network prior to beginning testing. ARINC tested both the Avionica SecureLINK box and Honeywell box. However, due to hardware problems identified during testing, the Honeywell unit was returned to the vendor.

3.1.1 Network Architecture for ARINC

Figure 3.1 shows the network setup for the ARINC laboratory. It shows the equipment and connectivity as well as the addressing structure used.

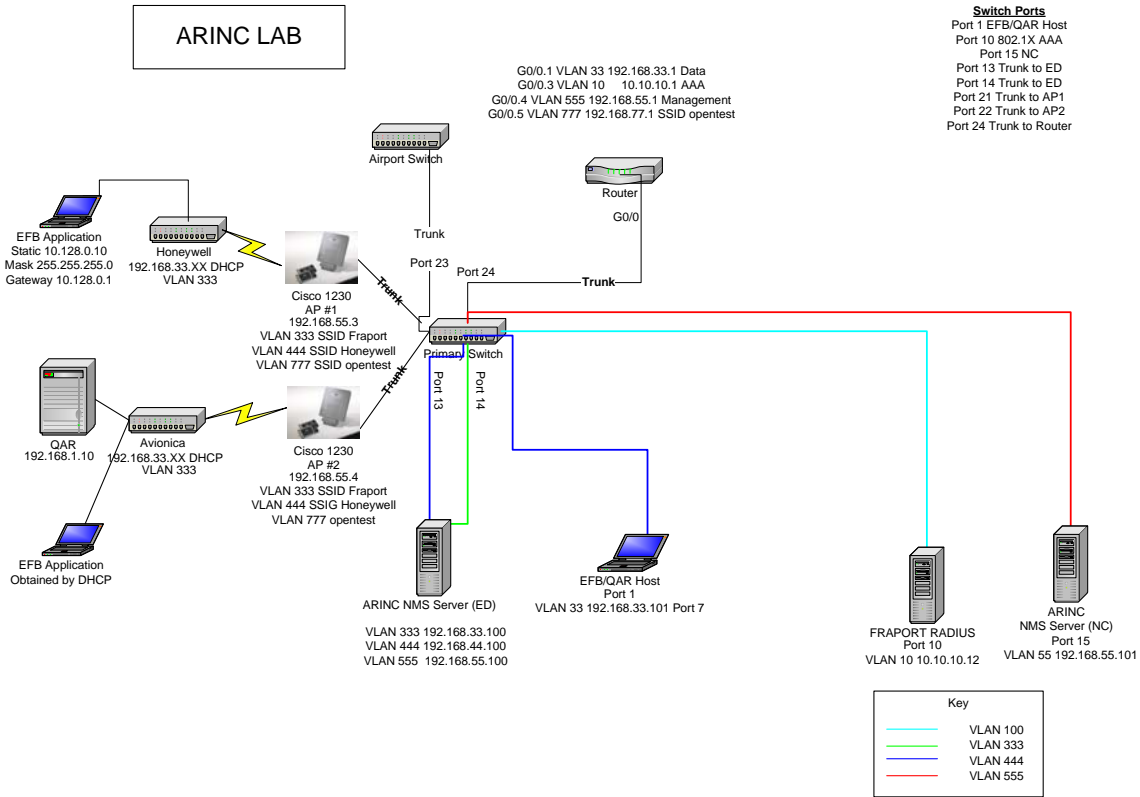


FIGURE 3.1 ARINC Network Architecture

3.1.2 Equipment List for ARINC

Following is a list of the equipment used at ARINC for laboratory setup and testing.

- Cisco 3560 switch
- Cisco 2850 router
- TWLU (Secure link) – provided by Avionica
- TWLU – Honeywell
- Cisco AP 1231 and 1030
- Cisco Wan lan manager
- ACS Server – laptop
- EFB – (3)
- EFB – Server
- NMS Server (ED and NC)

3.1.3 Laboratory Testing

Laboratory testing was conducted at ARINC in a controlled environment. A test document was generated and followed to conduct the tests. The tests are described in Appendix A and the test results are itemized in Appendix B.

3.2 Frankfurt Trial

The Frankfurt trial was conducted for approximately two weeks on an isolated laboratory network. In this environment, the Gatelink equipment was installed and tested without interfering with the normal WLAN operations at the airport. The laboratory test allowed the TWLU vendors and ARINC the opportunity to test and adapt configurations and settings on the equipment before the ramp test. During the laboratory test, ARINC and Fraport, along with the TWLU vendors, defined the first standard configurations between the TWLUs and the airport network components.

Once the laboratory tests were successfully concluded, the network was extended to a limited part of the airport to conduct ramp testing to demonstrate TWLU capabilities in an operational environment. The test network was connected to the Fraport network. This was a dedicated network. The configurations, as set in the laboratory, remained constant during the ramp test.

The ramp test was conducted at the airport for approximately three weeks. Fraport installed three access points at remote stands. The three access points provided coverage of approximately ten gates. Lufthansa sponsored a van with the needed power adaptors, to simulate an aircraft. Tests were conducted with the van in motion, to replicate a taxiing aircraft, as well as with the van stationary. The goal of this simulation was to demonstrate TWLU capabilities to re-authenticate while roaming from one access point to another.

The ramp test was performed with a subset of the TWLUs used in the laboratory testing at Frankfurt - Miltope and Avionica. Honeywell's TWLU did not support the authentication requirements necessary to participate in the ramp testing. Rockwell Collins elected not to participate in the ramp test.

3.2.1 Frankfurt Network Architecture

Figure 3.2 shows the network setup for the Frankfurt laboratory and ramp. It shows the equipment and connectivity as well as the addressing structure used.

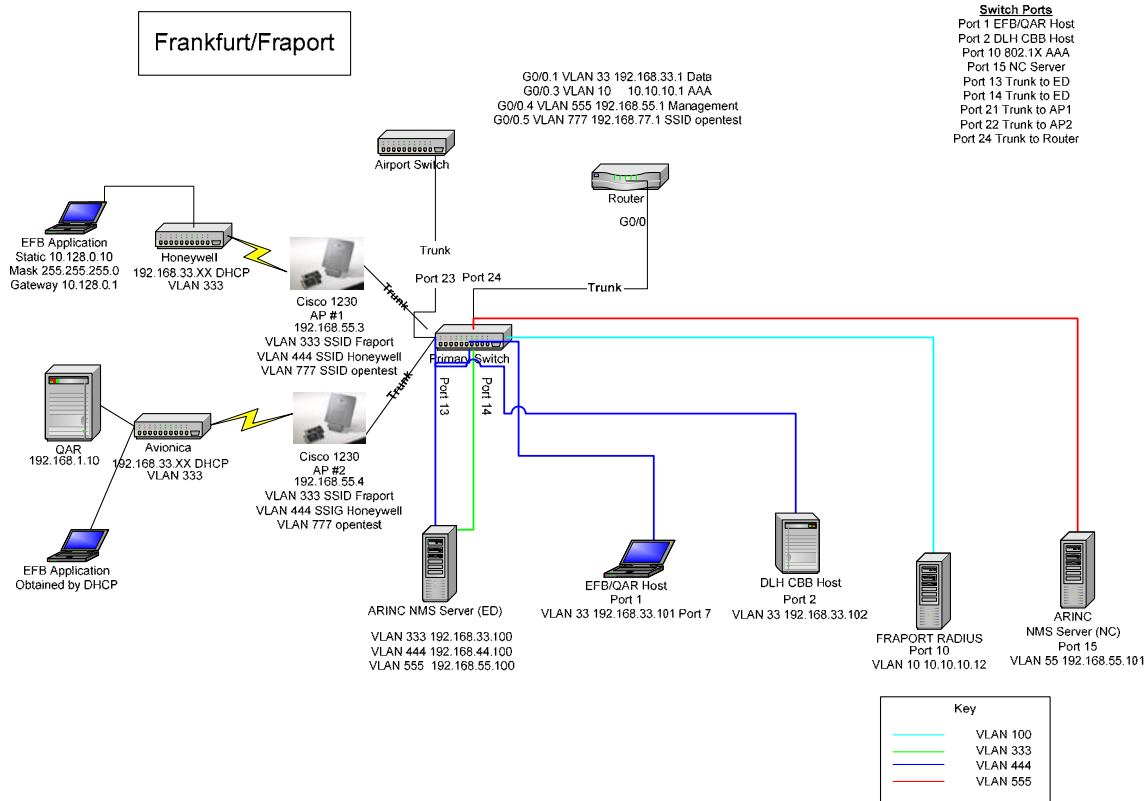


FIGURE 3.2 Frankfurt Network Architecture

3.2.2 Equipment List for Frankfurt

Following is a list of the equipment used during Frankfurt laboratory and ramp setup and testing.

- Equipment provided by Fraport
 - Access points: Cisco 1230
 - IOS version: 12.37 JA3 (lab) and 12.2.15xr2 (Ramp)
 - Authentication server: Cisco RADIUS server
 - Core switches: Cisco 3550
- Equipment provided by ARINC:
 - Cisco switch 2950 (IOS version: 12.2)
 - Cisco router 2800 series (IOS version 12.4)
 - Network Management Servers ED and NC
 - IBM X40
 - Linux OS
 - EFB/QAR Host:
 - Windows 2000 Workstation
- Equipment provided by Vendors
 - Avionica – SecureLINK for the trial
 - Honeywell – Provided their current generation prototype for the Boeing 787 project, which did not have 802.11 EAP/TLS Authentication built into the box
 - Miltope – TWLU Model 1TLP3

- Rockwell Collins – Current generation prototype for the Airbus 380 project. Laptop connected to a built in AP.

The access points had direct IP connectivity to the primary switch, NMS server and EFB/QAR host.

3.2.3 Testing

Laboratory and ramp testing was conducted at Frankfurt both in a controlled environment and an operational environment. However, at the ramp test, not all the TWLUs participated, as stated above. The tests conducted are described in Appendix A. Test results are itemized in Appendix B.

3.3 Munich Trial

After the conclusion of laboratory and ramp testing in Frankfurt, ARINC decommissioned the system and recommissioned it at the Munich International Airport. ARINC's goal was to maintain TWLU configurations identical to those tested at Frankfurt, and make changes to the wireless network as needed to insure TWLU connectivity. This was done to simulate an aircraft flying into both airports and using the Gatelink system without change to their TWLU.

As at Frankfurt, initial testing in Munich took place in a laboratory environment. In Munich Airport, unlike Frankfurt, the network used MPLS technology between the data center (where the core system was installed) and the ramp. The Munich Wi-Fi system also differed by using Cisco Airespace access points, which operate through a WLAN manager. The end result is a different network configuration on the ground, but ultimately replicated the operating environment seen in Frankfurt.

During the ramp test, EFB data was transferred to the Miltop and Avionica TWLUs which were driven between two access points installed at the cargo terminal.

3.3.1 Network Diagram Architecture in Munich

Figure 3.3 shows the network setup for the Munich laboratory and ramp, including the equipment and connectivity as well as the addressing structure used.

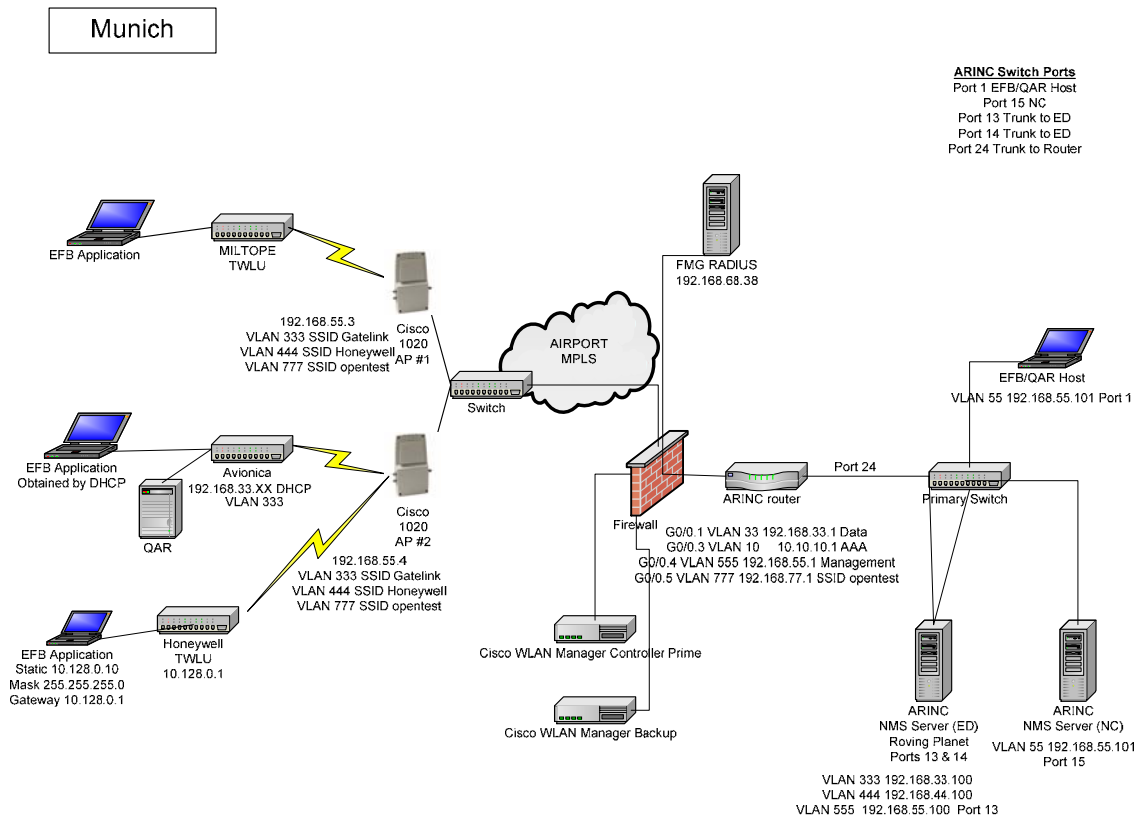


Figure 3.3 Munich Network Architecture

3.3.2 Equipment

Following is a list of the equipment used during Munich laboratory and ramp setup and testing.

- Equipment provided by Munich Airport Authority:
 - Access points: Cisco Airespace 1020
 - Cisco WLAN Controllers, primary and backup
 - Authentication server: Linux based RADIUS server
 - Core switches: Cisco 2950 IOS version
- Equipment provided by ARINC:
 - Cisco switch 38xx (IOS version: 12.2)
 - Cisco router 2800 series (IOS version 12.4)
 - Network Management Servers ED and NC
 - IBM X40
 - Linux OS
 - EFB/QAR Host: Windows 2000 Workstation
- Equipment provided by Vendors
 - Avionica – SecureLINK for the trial
 - Honeywell – Provided their current generation prototype for the Boeing 787 project. Which did not have 802.11 EAP/TLS Authentication built into the box
 - Miltope – TWLU Model 1TLP3

- Rockwell Collins – Current generation prototype for the Airbus 380 project. Laptop connected to a built in AP.

3.3.3 Testing

The laboratory environment in Munich was used to set up and test the Wi-Fi and local area network, observing how the TWLUs were working with the new network equipment.

It is important to note that the configurations of the router, switch, and NMS servers remained unchanged during testing at both airports.

Test descriptions for test conducted are found in Appendix A and the test results are shown in Appendix B.

4. Results

This section summarizes what was tested at all three locations for the trial and the results received. It also includes any concerns we have noted.

4.1 ARINC Laboratory Test Results

ARINC implemented the Gatelink network at its headquarters in Annapolis. Both Avionica and Honeywell provided TWLUs to be staged and tested prior to being delivered to Germany for the trial. The tests performed are described in Appendix A. ARINC's goal was to stage and test the units and network prior to delivery to the trial. Results show that this was accomplished, for the units that were available during the laboratory testing. Appendix B itemizes the results of the tests.

4.2 Frankfurt Results

Results from the laboratory trial were generally as expected based on published technical data from the vendors. The tests performed are described in Appendix A. ARINC's goal was to incorporate ARINC Gatelink Network Infrastructure with minimal changes to Fraport's network and to allow all TWLU vendors to bring their equipment and test in a "live" test environment. This provided vendors an opportunity to identify and resolve issues and concerns prior to deploying to their customer bases. The results of the tests were promising and can be found in Appendix B.

4.3 Munich Results

Results from the laboratory trial were generally as expected based on published technical data from the vendors. Testing in Munich was conducted in the laboratory and ramp. The TWLUs were shipped to Munich immediately following the ramp trials in Frankfurt. Configurations, as set for the Frankfurt ramp trial, were maintained when the equipment arrived in Munich. The tests performed are described in Appendix A. Similar to Frankfurt, the goal was to incorporate ARINC's Gatelink Network into Munich's Airport Authority Network without many network changes. Munich airport was specifically selected due to differences in the wireless infrastructure implemented versus the Fraport network. The results of the tests were promising for the vendors that participated and can be found in Appendix B.

5 Comments

Based on the completed trial, there are a number of findings to be noted regarding the feasibility of Gatelink for the application types tested. In general, the TWLUs of all vendors were fairly successful in providing a very high bandwidth connection through an 802.11g connection to a host application. There were a few major findings considered significant for an airline's implementation of Gatelink. This section outlines those items and provides some clarification. It should be noted that this list is based on the tested elements of the trial, and does not include other potential implementation concerns such as off-airport connectivity, mixed fleet implementation, or service performance variables based on service provider. Airlines looking for information on these topics should contact their TWLU or Gatelink provider.

5.1 802.1x and WPA-2 may be a requirement for TWLU implementation

The current ARINC 763-3 Characteristic only defines a requirement to utilize 802.1x EAP/TLS for authentication of the TWLU, without accommodation for any security implementation beyond the certificate. However, in discussions with Fraport and Munich Airport, it was discovered that wireless network policy at those airports included the utilization of WPA-2. Follow up with several other airports indicated that this would indeed be a requirement for network utilization of their infrastructure. Given this indication, WPA-2 was added to the testing and is expected to be a requirement at many airport locations for Gatelink.

5.2 Publicized Speeds for Wi-Fi are not throughput rates

The 802.11g wireless link data rate is 54 Mbps. However, as with any communication link, the user data transfer rate is significantly less. The difference between user data transfer rate and the link data rate is due to media access control logic for multi-user media (802.11), link layer protocol overhead (802.3), network layer protocol overhead (IP), transport layer protocol overhead (TCP), encryption overhead for security on the link (WPA.1), and interfering RF signals in the wireless environment.

802.11g operates in an uncontrolled public band frequency. Therefore the impact of the RF environment on the data transfer rates that can be expected is not deterministic and cannot be predicted with accuracy. There was significant variance observed in data rates on the ramps at Frankfurt and Munich during the test period. At Frankfurt the observed data rates ranged from 10 Mbps to 17.9 Mbps. At Munich the observed data rates were 13.1 Mbps to 16.5 Mbps. As stated in Appendix B, an insufficient number of data points were taken to establish a reliable expected user data transfer rate under various RF environmental conditions other than the realized data throughput rate will be significantly less than the 802.11g link data rate of 54 Mbps. Similar results can be expected for the other 802.11 specifications such, 802.11a, and 802.11b.

5.3 Routing on the aircraft is essential

ARINC Characteristic 763-3 defines avionics form, fit, and function for an aircraft Network Server System architecture that consists of either (1) a Network Server Unit (NSU), a Server Interface Unit (SIU), an aircraft Local Area Network (LAN), a Terminal Wireless LAN Unit (TWLU) and a Cabin

Wireless LAN Unit (CWLU), or, (2) an Integrated Network Server Unit (INSU), an aircraft LAN, a TWLU, and a CWLU.

Significant aircraft functions that support end-to-end data transfer over gatelink and are not formally defined as part of the TWLU include a routing function, a network address translation function, the aircraft LAN, an authentication client, an authentication server, and a DHCP server supporting aircraft terminals. While most of these functions are defined to reside within an ARINC Characteristic 763-3 compliant NSU/INSU, avionics vendor implementations have incorporated one or more functions within their respective TWLU. As vendors have not implemented addition functions uniformly, airlines are cautioned to carefully consider the suite of equipment necessary to support end-to-end delivery over Gatelink.

5.4 802.1x EAP-TLS Implementation Findings

Testing during the trial demonstrated that this authentication standard was usable and many vendors either support or will support in the short term. There may be an issue with the implementation of the standard, however, when the airline plans multiple airport destinations.

As the TWLU must share a certificate with a designated authentication server on the ground, those must match. The certificate for the TWLU, therefore, must be provided by the authenticating agent on the ground. When an airline implements on the networks of multiple service providers, it is likely that the service provider will require their authentication on the TWLU. This would result in a requirement of maintaining multiple certificates on the TWLU, which also brings the requirement of location awareness for the TWLU.

Appendix A – Tests and Description

Test 1 – TWLU Setup

This test is to start the configuration setup for the TWLU in order to connect to the Gatelink network.

Test 2 – Authentication

The TWLU will provide a means to authenticate to the airport WLAN network. The TWLU will detect the network and send an IP address request. This request will be made each subsequent time following device reboot. This shall be through the request of an 802.1x EAP authentication request, and will not require human intervention to complete.

Test 3 – Operation

The TWLU will be configurable from both the operator (user GUI) and the network via administrator function. The TWLU should conform to all ARINC Characteristic 763-3 requirements. The TWLU will be capable of operating in a laboratory environment, and transportable to operations within a van on the ramp.

Test 4 – Application Connectivity to TWLU

Connectivity from the application to the TWLU shall be the Ethernet. It is expected that the ground and air applications will reside on a laptop, but there may be other equipment used in the trial such as EFBs on a Panasonic tough book. In either case, the connection to the TWLU will remain Ethernet.

Test 5 – TWLU Connectivity to WLAN Network

The TWLU shall connect using 802.11x to the airport WLAN network. WEP shall not be used in connecting to the network, and the TWLU and the Access Point will be set to the Airports' SSID for the test.

Test 6 – Connectivity to Host Application

Connectivity from the WLAN network to the host application will be through the ARINC NMS system. All computers/servers that are hosting the applications will be behind the NMS system and will only be accessible through successful authentication. It should also be noted that the Internet connection will also be behind the NMS system and will only be accessible to non-Gatelink devices (not the TWLU) for the purpose of testing congestion issues and troubleshooting.

Test 7 – Security

The network will support EAP-TLS authentication standards, otherwise described as 802.11x. Certificate exchange will be effectively within the airline itself for testing purposes, and TKIP will not be used. The SSID will not be broadcast, but the network will not implement WEP. The ARINC NMS system will proxy the 802.1x authentication request back to the ARINC ACS server and the certificate exchange will be internal to ARINC.

Test 8 – Application Provisioning

It is expected that the trial will test the following applications:

- Electronic Flight Bag (EFB)
- Flight Operations Quality Assurance (FOQA)
- In-Flight Entertainment (IFE) – files that are the size of IFE data were transferred between the ground EFB management system and the air EFB using FTP.

Each application will be provided by a vendor who will provision the application to operate under the parameters of this trial. The vendor will also supply all equipment needed to operate the application in the trial format. The data provided for the application does not need to be operational data.

Test 9 – Monitoring/Management of Network

For the trial, each airport authority shall have full responsibility for the monitoring of the network for reliability and availability. Each airport authority shall also have full responsibility for the management of the WLAN network. ARINC will be responsible for monitoring and managing the NMS components of the trial. The TWLU vendor will be responsible for troubleshooting any problems with their equipment. The application vendor will monitor and manage their applications for the trial. The system should be presentable (meaning applications would work in a reasonable fashion) by a member of ARINC or the airport authority during normal business hours.

Appendix B - Tests and Results

The following tables outlines all the tests performed at each location. It's noted which TWLU and the pass/failed status of each test. If a test was not run because of the functionality not being available, it is indicated so by NA – Not Available.

TWLU Testing:

Avoinea TWLU Tests

Test Case Number	Test Case Description	Test Case Status	ARINC	Frankfurt	Munich
1	TWLU Setup		P	P	P
2	Authentication		P	P	P
3	Operation		P	P	P
4	Application Connectivity to TWLU		P	P	P
5	TWLU Connectivity to the WLAN Network		P	P	P
6	Connectivity to Host Application		P	P*	P
7	Security		P	P*	P
8	Application Provisioning		P	P*	P
9	Monitoring/Management of the Network		P	P*	P

Note: P* means that the TWLU was failing these tests in the beginning, after some firmware updates the tests passed

Miltope TWLU Tests

Test Case Number	Test Case Description	Test Case Status	ARINC	Frankfurt	Munich
1	TWLU Setup		NA	P	P
2	Authentication		NA	P	P
3	Operation		NA	P	P
4	Application Connectivity to TWLU		NA	P	P
5	TWLU Connectivity to the WLAN Network		NA	P	P
6	Connectivity to Host Application		NA	P	P
7	Security		NA	P	P
8	Application Provisioning		NA	P	P
9	Monitoring/Management of the Network		NA	P	P

Honeywell TWLU Tests

Test Case Number	Test Case Description	Test Case Status	ARINC	Frankfurt	Munich
1	TWLU Setup		P	P	NA
2	Authentication		NA	P	NA
3	Operation		P	P	NA
4	Application Connectivity to TWLU		P	P	NA
5	TWLU Connectivity to the WLAN Network		P	P	NA
6	Connectivity to Host Application		P	P	NA
7	Security		NA	F	NA
8	Application Provisioning		P	P	NA
9	Monitoring/Management of the Network		p	P	NA

Rockwell-Collins TWLU Tests

Test Case Number	Test Case Description	Test Case Status	ARINC	Frankfurt	Munich
1	TWLU Setup		NA	P	NA
2	Authentication		NA	P	NA
3	Operation		NA	P	NA
4	Application Connectivity to TWLU		NA	P	NA
5	TWLU Connectivity to the WLAN Network		NA	P	NA
6	Connectivity to Host Application		NA	P	NA
7	Security		NA	P	NA
8	Application Provisioning		NA	P	NA
9	Monitoring/Management of the Network		NA	P	NA

Data Transfer Rates:

ARINC verified end-to-end connectivity over gatelink by performing file transfers between ground systems connected to the airport LAN and avionics end systems. Data transfers of 10, 47, 860, and 1500 Mbytes were performed and connectivity to QAR, EFB, and an aircraft terminal were verified. Connectivity was verified in laboratory tests and ramp tests at both Frankfurt and Munich airports. A sufficient number of data points for test runs and measurements points was not available to draw conclusions that characterize the throughput performance of avionics or ground system elements. More detailed testing will be necessary to accurately estimate the effective throughput of the wireless link in both congested and non-congested RF environments.