Enhancing In-Flight Transoceanic Communications Using Swift-64 Packet Mode Service

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Abstract. Current aeronautical communications can be divided into two segments. The first provides state of the art, packet switched technology to the cabin passengers so that they have access to e-mail and web services. The second provides basic circuit switch communication technology to the cockpit, which does not use bandwidth as efficiently as packet switching nor promotes resource sharing. This paper explores the research efforts currently being conducted by the NASA/Glenn Research Center (GRC) for transoceanic communications. The goal is to bring packet mode services to both the cabin and the cockpit of the aircraft and be able to attain benefits by sharing the data link with cabin services.

First, this paper will outline the goals of the program and detail the benefits and issues related to this research. We will explain our current laboratory setup and show an architecture implemented in the testbed. Finally, we will present a work plan that will show the progression of research over the next year. This plan will describe a complete cycle from conceptual design and laboratory implementation to the final flight testing.

Introduction

The goal of the Weather Information Communications (WINCOMM) Project [1] at GRC, an element of the Weather Accident Prevention (WxAP) Project [2], is to develop advanced communications and information technologies to enable the efficient and timely dissemination of weather information from the ground to the flight deck and turbulence information between relevant aircraft. One of the scenarios currently being studied is the transoceanic operations, as shown in Figure 1, which deals with international flight operations over the oceans where communications are limited to the High Frequency (HF) spectrum and the en-route weather information collection and dissemination are minimal. To improve the timely dissemination of information to the cockpit, our research will focus on using satellite-based communications over regions without ground links, while being able to efficiently and automatically switch to ground links when they are available.

Currently, the mode of communications with the cockpit is via circuit-switching. While circuit switching does provide a dedicated communications path with an allocated bandwidth, it does not make the most efficient use of bandwidth or data links that could be achieved using a packet-mode service. Existing aircraft data links are used for transporting small, low volume messages which do not meet the need for transporting modern data products, such as graphical weather information. Future links are targeting large, high volume, and variable length messages.

The focus of the transoceanic scenario is to investigate the advantages of converting from circuit to packet switched mode using the INMARSAT/Swift-64 [3] service. Packet mode service provides a number of benefits, such as reducing costs by utilizing

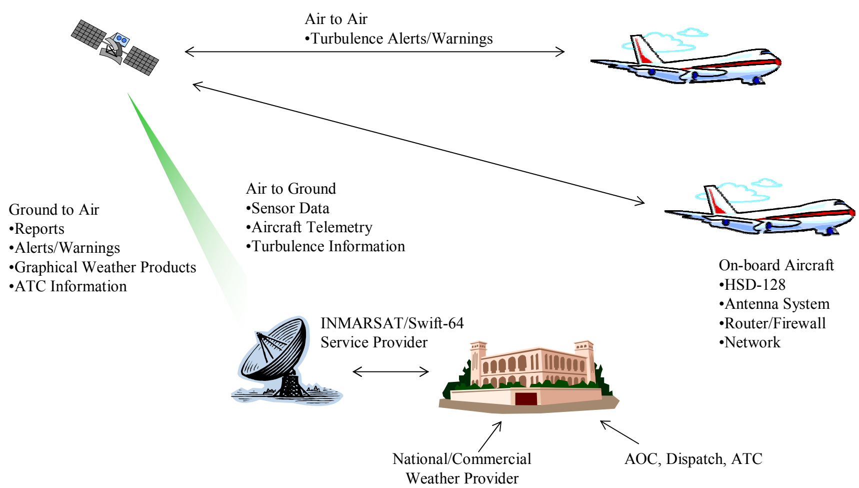

Figure 1: Transoceanic Architecture

commercial services, providing more efficient use of datalinks and bandwidth, and providing integrity and reliability for the data transmissions. On-board the aircraft, the HSD-128 (High Speed Data) Unit will serve as the receiver. Currently, the HSD-128 Unit provides Internet connectivity to the cabin passengers for services such as e-mail, web surfing, and video conferencing. The goal of WINCOMM is to provide both cabin and cockpit services over the HSD-128 unit.

The issues for this research project will focus on the efficient separation of cabin and cockpit communications. The major issues will be quality of service, link availability and security. For instance, if a passenger was downloading a large image, the download process should not preclude the pilot from receiving important weather information about approaching storms or turbulence. The messages that are destined for the cockpit need to have a higher quality of service (or higher priority) that those destined for the cabin. The communications path between the aircraft and ground should always be available for data being transmitted; data should always be able to get to the crew of the aircraft. And, data security is a very important issue. Data must be transmitted quickly, reliably, and securely.

This paper will describe the goals and design approaches for the transoceanic scenario. The research will investigate a number of different potential architectures for the on-board networking and enhancements to the ground network. The WINCOMM project will setup a laboratory environment to test these architectures. Data for the testing will initially focus on informational and graphical weather data and will eventually encompass warning/cockpit alerts and, hopefully, air traffic control messages. In mid-2005, the laboratory setting will be flight tested aboard the Langley Research Center (LaRC) Boeing-757. In addition, the researchers will investigate the new INMARSAT-4 satellites that will be launched in the 2004/2005 timeframe and determine the differences in the Swift-64 service from the INMARSAT-3 satellite system.

As a result of this research, data communications from ground-to-air and air-to-air can be greatly improved and higher-quality data products, such as graphical weather products, can be quickly and more efficiently transmitted to the cockpit.

Program Goals/Requirements

Given that the focus of the WINCOMM project is on aviation safety and weather related research, the program goals for the transoceanic scenario focus on providing the pilots of transport aircraft with the best weather information in the timeliest manner. The main products will be turbulence detection and graphical weather products. The project will expand to include cockpit warnings/alerts and, hopefully, air traffic control (ATC). The goals, as listed below, serve as the high-level requirements [4]:

- On-board sensed turbulence information to ground users and between aircraft (air-ground, air-ground-air).
- Broadcast graphical weather products to the pilot (ground-air).
- Transmit cockpit warnings/alerts to the aircraft (ground-air).
- Transmit Aircraft Traffic Control (ATC) information to the aircraft (ground-air).

Each of these tasks can be further divided into the following subtasks that will be the focus of the transoceanic research project:

- Dissemination of data from own ship turbulence to other aircraft and ground users.
- Receive, process and deliver valid turbulence warnings to the cockpit from other equipped aircraft.
- Receive and display Flight Information Service Broadcast (FIS-B) ground-air weather products.
- Receive, process, and display cockpit warnings and alerts from the ground stations on-board the aircraft.
- Receive and process ATC information from the ground stations to the aircraft.
- Verify that ATC information can be transferred reliably and securely using encryption and reliable protocols.

Benefits of the Research

There are a number of benefits that will directly result from this research effort. Since IP-based protocols[1] [5] are already delivering content to the passenger cabin, the aviation community has already realized some of the advantages of putting data over a packet switched network. These same benefits can be extended to cockpit communications and summarized as follows:

- ***Reduce Costs*** – One of the most provoking reasons to switch to a packet switched solution (i.e., IP-based protocols) is reduced costs. These reductions can be realized in two ways. The first is to use commercial services rather than services tailored specifically to the aviation community. Since the commercial systems have a large user base and competition, they should be able to provide more flexible and efficient pricing plans. The second method of reducing costs is by taking advantage of the large body of research by the Internet research community. While IP-based protocols have been studied extensively, the research community is still finding way to improve the protocols. By capitalizing on this research, the aviation community will have a standards-based protocol rather than having to maintain the infrastructure of a custom protocol.
- ***Efficient Bandwidth Usage*** – Currently, when data is being transmitted to the aircraft, circuit

[1] IP-based protocols refer to the IP protocol suite which includes the TCP/IP and UDP protocols.

switching reserves a link and allocates the entire bandwidth. However, the bandwidth is not constantly used since communications is sporadic. In a packet switching mode, data are contained in individual packets that are sent over the network which provides an opportunity for multiple users to efficiently share the same datalink. Since each packet is uniquely addressed, IP-based protocols simplify using the same data link for multiple users. Sharing the datalink makes more efficient use of the bandwidth.

- ***Data Integrity and Reliability*** – IP-based protocols have two built-in mechanisms that would be very important to the aviation community. First, IP-based protocols use checksums[2] to ensure that the data is validated for tampering or corruption, prior to arriving at the destination. Research studies [6] have shown that a 16-bit checksum might not be adequate for critical data (e.g., ATC). So, for critically important data, a more elaborate checksum might be considered. In addition, IP-based protocols provide both reliable and unreliable communications. The source can invoke reliability to ensure that the data has reached its destination and, if it hasn't, it can be retransmitted. For example, reliability would be more important in ATC or Alerts/Warning than in weather data.
- ***Security*** – In the terrestrial Internet, there has been a significant amount of research on the issue of security. Both IPSec [7] extensions to the standard IP-based protocols and Virtual Private Networks (VPN) [8] are being implemented to provide secure communications. The aviation community has the opportunity to leverage these technologies to provide secure communications between the ground and cockpit. One significant advantage is that encryption can be implemented on the packet level, so communications with the cockpit can be encrypted while communications to the cabin is not. This provides the aviation community with the flexibility that it needs for secure but efficient communications.

Issues Related to Transoceanic Communications

During the research effort, an investigation into a number of issues will be conducted that impact putting both cockpit and cabin data on one link. These issues will be related to not only how efficiently the data will share the same link, but also how they be handled separately once they are on-board. The main goal is that cockpit data must be handled with more importance so that storm information or ATC communication can reach the pilots with assurance and certainty. The following are some of the issues that will be studied under this task:

Quality of Service (QoS) – Once data has been received on-board the aircraft, the cockpit data holds a higher priority than data that are headed for the cabin. If a passenger is downloading a large, multiple megabyte image file, the download should not interfere with data for the pilot (e.g., weather data or ATC traffic). The following will be some of the issues that will be investigated:

- How can data be classified between typical cabin data and weather or ATC data?
- Are there any changes needed to the hardware (e.g., routers) or software (e.g., operating system) to improve QoS handling? How effective or

[2] TCP has checksums enabled by default but, in UDP, checksums must be enabled by the programmer (i.e., they are not used by default).

difficult will it be to make these changes to the system?

Link Availability – In this scenario, the aircraft can be flying anywhere in the world and, during the entire flight, communications must be maintained with the aircraft. Therefore, the following issues concerning link availability will be addressed:

- While INMARSAT/Swift-64 coverage is extensive but not complete, does it provide enough coverage to maintain communications with the majority of flight patterns?
- Can ground networks be relied upon for cheaper content delivery when the aircraft is over land or when INMARSAT/Swift-64 coverage is not available?

Security – Security has been one of the most important issues in the terrestrial Internet. Research has focused on how workstations can be protected from not only illegal attacks, such as port sniffing and buffer overruns, but also from packet spoofing. It is not only important to protect our systems from attack, but also from someone sending rouge data to an aircraft, such as flying at a different altitude or corrupt ATC information. Issues being addressed during this phase of this research will be the following:

- What are the lessons that can be learned from the terrestrial Internet on security and how can they be applied to this scenario?
- How can encryption be used successfully on important content (e.g., ATC messages) to get the traffic from the source to the destination without interception?

Commercial Services

One of the benefits of this research is to reduce costs by utilizing commercial services. This section will highlight those commercial providers and the services they provide.

- ***INMARSAT*** – INMARSAT operates a worldwide network of ground stations and a constellation of satellites to provide seamless communications to any point in the world. Currently, they are operating the INMARSAT-3 collection of four geostationary satellites which provides service to the whole Earth with the exception of the poles. There is a fifth INMARSAT-3 satellite and four previous generation INMARSAT-2 satellites for backup. This research effort will make use of the Swift-64 service which is a high-performing in-flight communications service offered to airlines, business, and government aircraft operators. There are two types of services offered: Mobile ISDN and Internet Protocol-based Mobile Packet Data Service (MPDS). Our efforts will focus on the MPDS mode of operations.
- ***SITA [9]*** - SITA is a partner of INMARSAT and a prime member of the INMARSAT partnership "Connect" program. SITA will be the service provider for the Swift-64 service along with their extensive ground network.
- ***EMS Technologies [10]*** – EMS Technologies develops and markets the HSD-128 – High Speed Data – transceiver, shown in Figure 2 that will be on-board the aircraft and serve as the main interface to the INMARSAT/Swift-64 service.

Figure 2: Viper Roll-On/Roll-Off Communications Pallet (left)
and HSD-128 Receiver (right)

Testbed Environment

The function of the testbed environment is to test software and hardware in a laboratory setting that mimics the operational environment before flight testing. In addition, the testbed should help minimize the time needed for the actual flight testing. It will be used to test and verify the architectures, parameter modifications, and any software developed or changed during this research effort. It will also be able to communicate over the INMARSAT/Swift-64 Service and, therefore, the performance will be representative of what is expected during actual flight testing. Figure 3 shows an architecture in the testbed environment; the dotted lines represent future enhancements to the testbed.

The testbed can be divided into two segments from the perspective of the INMARSAT satellite; the right segment represents the ground station and the left segment represents the equipment and networks on-board the aircraft.

On the right of the figure, the communications path is from a ground station (represented by a PC) through a public or private Internet. This could represent either the Internet or the private SITA internet. The data is then transmitted to the satellite and sent to the appropriate receiver which, in this case, is the testbed.

The left side of the figure represents the network architecture that would be on-board the aircraft. The flow of data will come over the satellite and be received on-board the aircraft via the antenna – in the testbed, the antenna is roof mounted. The data will be received from the antenna by the High Speed Data (HSD-128) Unit which will output the data in packetized form. The HSD-128 is a data transceiver for the INMARSAT/Swift-64 Service. It is capable of accepting two ISDN channels or a single Ethernet connection. Each channel has a data rate of 64 kb/s or the channels can be bonded together for a combined data rate of 128 kb/s. Using ISDN, both channels can be bonded together for data or they can be used independently for either data or voice service. With the Ethernet interface, the channels must be bonded together for a combined data rate of 128 kb/s [11].

The packetized data that flows from the HSD-128 to the router will be distributed on one of the two subnets, in this architecture. Dividing the network into subnets provides three significant advantages, as follows:

- ***Security***. Using subnets, the router will be able to separate the data into cabin data and cockpit data. By doing so, the two types of data will not be intermixed on

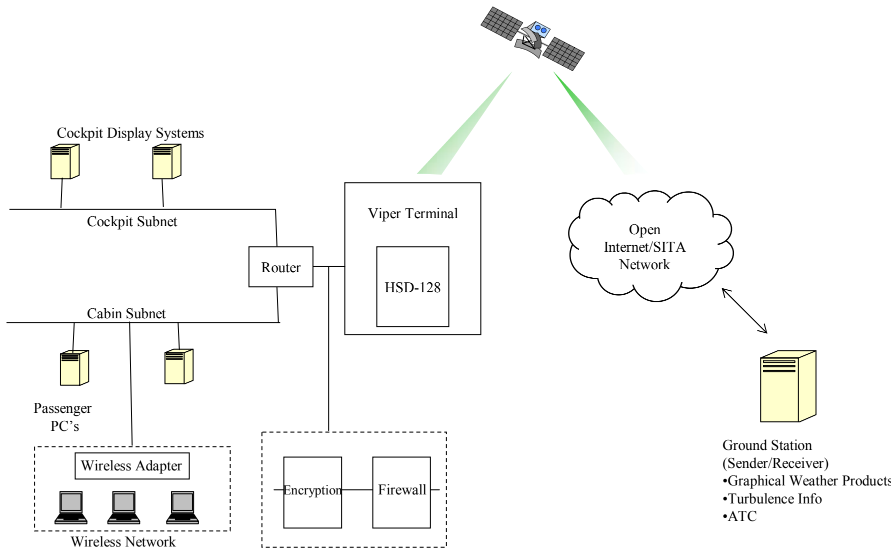

Figure 3: Testbed Environment

the same wire and a rouge user will not be able to access cockpit resources.

- ***Reduction of Data Traffic***. Using two subnets will reduce the amount of data is that will have to transverse each segment. This will help to reduce the number of data collisions and improve the efficiency of the network.
- ***Quality of Service***. Another added benefit of multiple subnets is that they should provide an advantage with the Quality of Service issues. Once the data arrives on-board the aircraft, it can be classified as either cabin or cockpit data and can be immediately prioritized to the appropriate network. This will hopefully serve as a first step to prioritizing the data.

The data will then be placed on the appropriate subnet where it will be received by the network device.

Before flight testing, additional enhancements to the testbed will be as follows: addition of a wireless segment on the subnet so that cabin passengers can bring laptops on board and access the network; addition of a firewall to scan the data for basic security checks; addition of encryptors to encrypt command and control data that is destined for the cockpit; and testing a Virtual Private Network (VPN).

Work Plan/Approach

The research plan for the transoceanic scenario is divided into three phases which consist of investigation and design in Phase I, implementation in Phase II, and flight testing in Phase III. According to schedule, flight testing occurs in mid-2005 which will test the enhancements to the transoceanic scenario in an operational setting. The phases are divided as follows:

Phase I – Investigation and Design

Phase I is comprised of the elements needed to design a new architecture that meets the goals presented earlier. Each of these steps will be investigated and documented in a report produced at the end of the project.

1. Requirements Definition – Requirements will be defined to detail the functions outlined earlier in the section called *Program*

Goals/Requirements. The requirements will touch on such things as the types of information that must be transmitted, Quality of Service (QoS) and standard protocols.
2. Define Potential Architectures - This task will investigate alternative architectures that can satisfy the requirements. Items investigated will include the following: types of networks, operating systems (OSs), data encryption, and Virtual LANs (VLANs).
3. Investigate the architecture of the HSD-128 – This task will analyze the function and architecture of the HSD-128 data unit. Some of the issues that will be investigated include the following: What are the interfaces of the HSD-128? What are the protocols and how is PPPoE implemented? What are the user and maintenance commands for the HSD-128.
4. Investigate the SITA and INMARSAT Networks – As part of the investigation, the SITA and INMARSAT systems will be thoroughly researched so that their functions are well understood and any potential improvement to their systems can be recommended.

Phase II – Implementation

Phase II contains steps that implement elements investigated during Phase I. These elements will be tested in the laboratory setup at GRC and then worked into Phase III during flight testing. This phase is divided as follows:

1. Implement the architectures developed during Phase I - This task will implement and test the networks developed during Phase I. The parameters tested will be ease of setup, number of modifications to the hardware and software, and performance of the network.
2. Implement any Parameter Changes - Any parameters that have been identified during the Phase I design and Phase II testing will be implemented or modified. Included are operating systems (OSs), protocol stacks, HSD-128 or the SITA Network.
3. System Testing - Once all of the modifications are made to the test networks, the system will be tested for end-to-end performance. All communications will be directed through the INMARSAT satellite.

Phase III – Flight Testing

All of the changes that have been designed and implement during the Phase I and Phase II activities will be operationally tested during Phase III.

1. Flight Testing – The enhanced version of the HSD-128 and antenna system will be installed on a NASA-owned aircraft for flight testing. The flight testing will verify the requirements developed during Phase I and whether the enhancements made during Phase II are viable in flight testing mode.
2. Investigate New INMARSAT Satellites – INMARSAT will be launching new satellites in the 2004/2005 timeframe with advanced capabilities. Part of this effort will be to evaluate the satellites and the new capabilities provided by the satellites. The research includes the differences between the Swift-64 service of the INMARSAT-3 and INMARSAT-4 satellites.

Conclusion

This paper proposes a method for improving communications during transoceanic flights. The improvements come in two phases. First, the current communications links are becoming outdated and would benefit significantly from newer technologies. By changing from circuit switched technology to packet switched technology and standards-based protocols, the aviation community could reduce costs and infrastructure while gaining integrity, reliability and security. While benefits can be realized, issues must first be resolved and thus provides the impetus for this research effort. Issues range from ensuring that important data gets to the correct destination in a timely manner, that the data link is always available and security. To test these issues, we are in the process of constructing a testbed environment that will mimic the on-board setup. The testbed should provide a realistic communications environment by communicating directly with the INMARSAT satellite using the Swift-64 service. Our results will be verified during flight testing in mid-2005.

Secondly, the types of products going to the cockpit can also be greatly improved. Our research will focus on providing graphical weather products to the cockpit along with on-board sensed turbulence information that can be sent to the ground or to other aircraft in the area. These products will provide more detailed and real-time information to the pilots that help them avoid adverse weather conditions. Eventually, the research will encompass cockpit warning, alerts and ATC information. These requests represent ground-to-air transmissions.

While the cabin passengers have been enjoying state-of-the-art communications, the cockpit communications have been lagging in technology. This research effort is directly focused on improving cockpit communications while getting the added benefits of sharing the same data link.

Acknowledgements

I would like to thank Tom Tanger and Jim Griner for their ideas and thoughts behind this research effort and help with aeronautical communications.

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Introduction

- WINCOMM
  - Develop advanced communications technologies
  - Timely and efficient dissemination of weather information
- Transoceanic Scenario
  - Focus on international flights over the ocean
  - Communications are limited to HF spectrum
  - Minimal enroute weather information collection and dissemination
  - Flight testing by mid-2005
- ***Overall Goal:*** *Employ satellite-based communications to provide weather information to the cockpit using packet mode delivery service and efficiently share the same link with cabin data.*

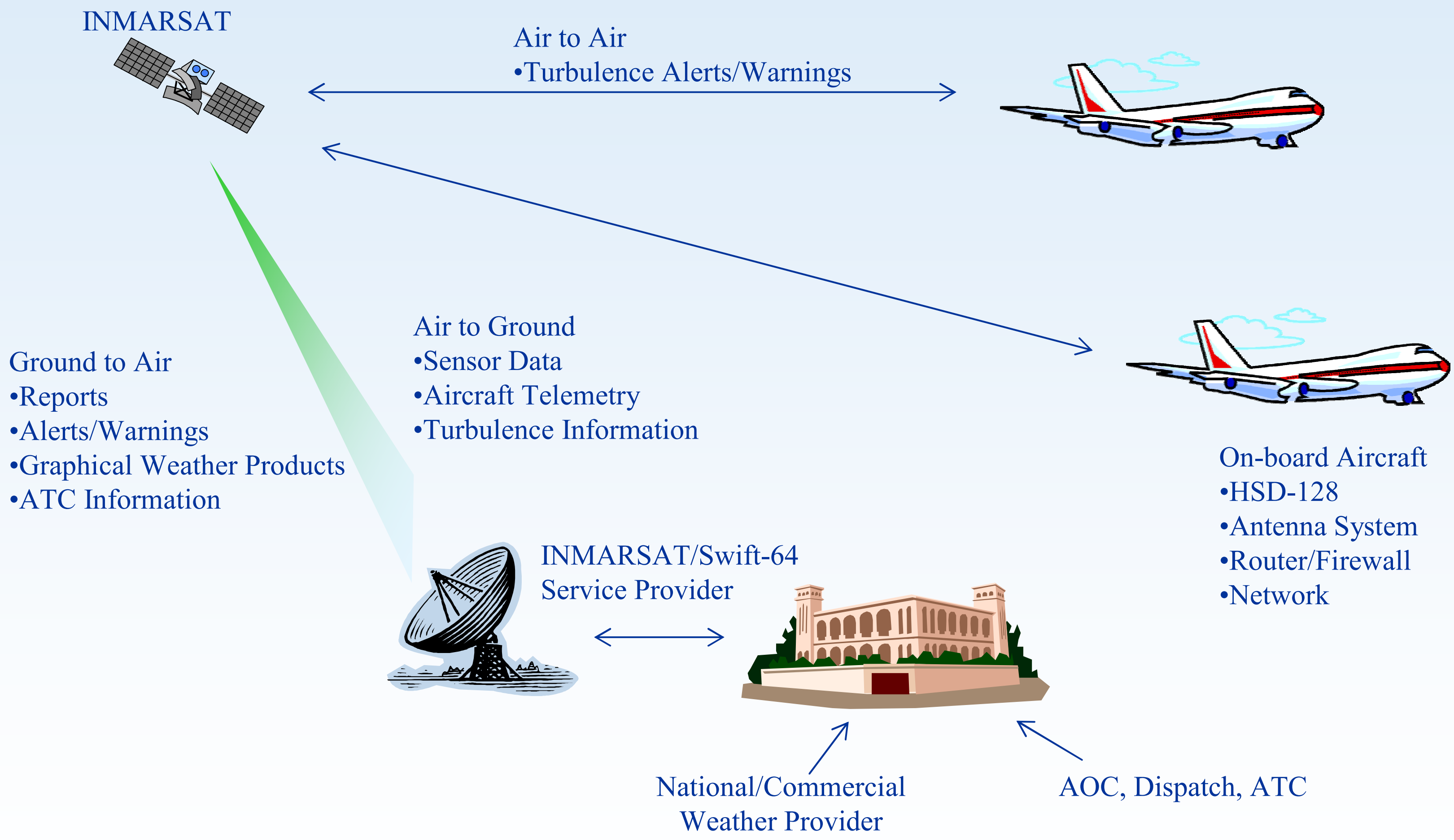
Updating the Communications Architecture

- What are the current capabilities -
  - Communications via circuit-switching
    - Dedicated communications path and allocated bandwidth
  - Existing data links transport small, low volume messages.
- Future Capabilities
  - Convert existing systems to use satellite communications and packet-mode service.
    - Use commercially available services and standard protocols.
  - Efficiently and effectively separate cabin and cockpit data from shared link.
  - Provide advanced data products.

Data Products

- Turbulence Data
  - Disseminate to other aircraft or ground.
  - Receive and display warnings to the cockpit from other aircraft.
- Graphical Weather Products
  - Receive, process and display weather products.
- Cockpit Warnings and Alerts
  - Receive, process and display warning and alerts.
- Air Traffic Control (ATC) Data.
  - Receive and process ATC information from ground stations.
  - Verify that ATC information can be transferred reliably and securely.

Transoceanic Scenario Architecture



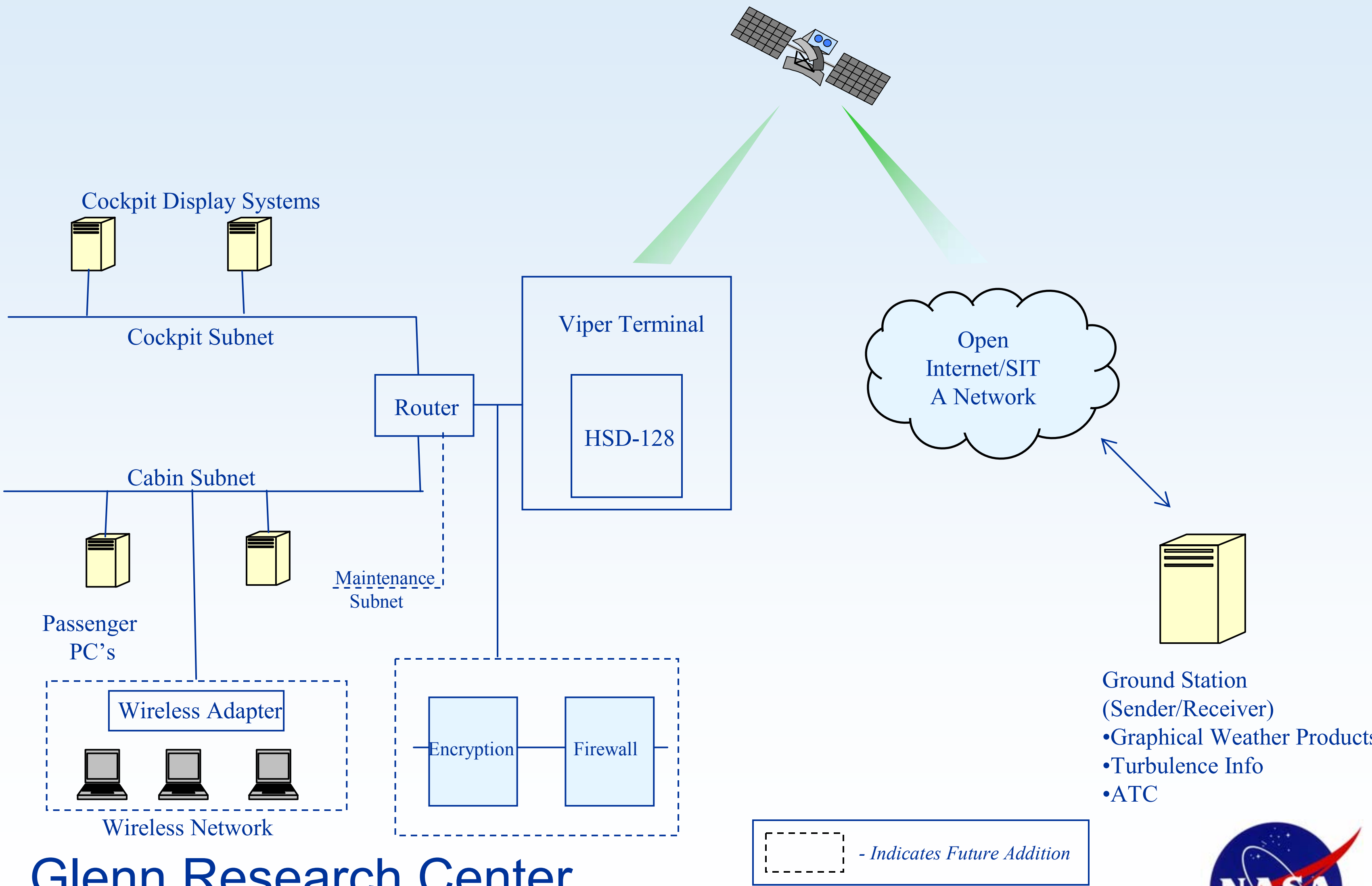
Research Issues

- Quality of Service (QoS)
  - Cockpit data must maintain a higher level of priority than the cabin data
    - Differentiate between cabin data, weather data or ATC data.
    - Determine changes to router OS for QoS and determine how effectively the OS handles QoS.
- Link Availability
  - Must maintain communications with the cockpit at all times.
    - Determine if INMARSAT/Swift-64 coverage is extensive enough to cover the majority of the flight patterns.
    - Determine if ground networks be relied upon for cheaper content delivery.
- Security
  - Protect the shared link from unauthorized users.
    - Apply lessons learned from the terrestrial Internet.
    - Application of security devices (e.g., encryptors, VPN, firewalls) to the on-board network.

Research Benefits

- Reduce Costs
  - IP-based Protocols
    - Take advantage of large body of researchers.
  - Commercial Services (SITA and INMARSAT)
    - Packet Mode Service – Pay by amount of data transferred.
- Efficient Bandwidth Usage
  - Using Packet Mode Services
    - No Allocation of the Data Link.
  - Multiple Users can Share the same Link.
- Data Integrity and Reliability
  - Validate Data via Built-in Checksums
    - 16-bit Checksums may not be sufficient for ATC data.
  - Reliability via Acknowledgement Schemes
- Security
  - Leverage Terrestrial Security Scheme
    - Encryption, VPNs, IPSec, etc.

Testbed Architecture



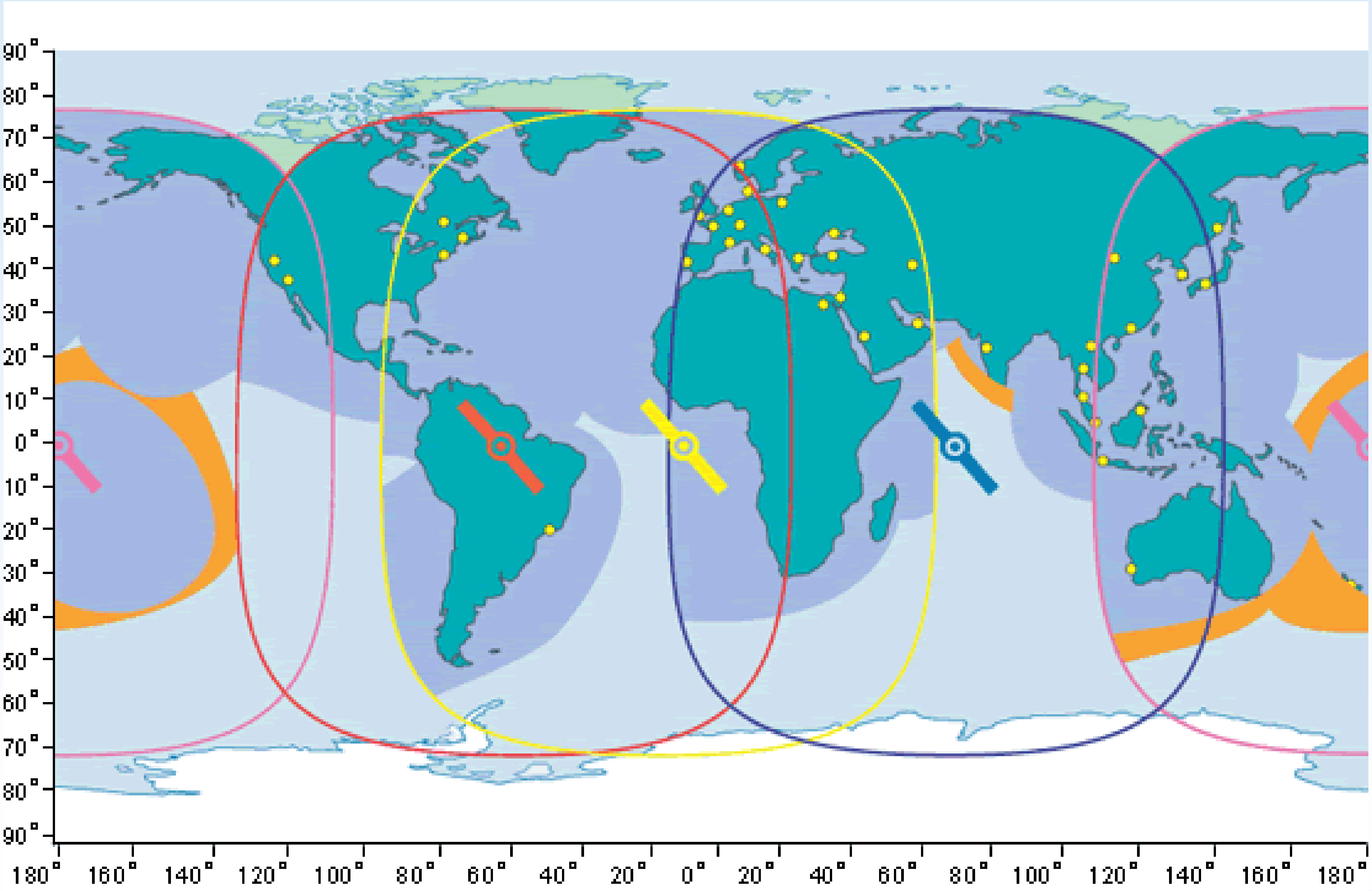
High-Speed-Data SATCOM Transceiver

- HSD-128 – Aeronautical High Speed Data Terminal
  - 2 – 64 kbps dual channel capacity for voice or data
    - Can be bonded together for 128 kbps
  - Interfaces
    - ISDN, 10-Base-T Ethernet and RS-232
  - Operates with any ARINC 741 compliant High-Gain Antenna
- Viper II
  - HSD-128 in a ruggedized, modular platform
  - Ideal for roll-on/roll-off airborne pallet for rapid deployment
  - All interfaces and configuration pins are accessible from rear panel.

Commercial Services

- INMARSAT
  - Worldwide network of ground stations and satellites.
  - Swift-64
    - High-performance in-flight communications service.
  - Two types of services
    - Mobile ISDN
    - Mobile Packet Data Services (MPDS)
- SITA
  - Provides INMARSAT/Swift-64 Service
  - Extensive ground network
  - Partner of INMARSAT
- EMS
  - Develops and markets the HSD-128 transceiver.

INMARSAT Coverage



Approach

- Phase I – Investigation and Design
  - Requirements Definition
  - Design Candidate Architectures
  - Research QoS and Security Issues
  - Setup Testbed
- Phase II – Implementation
  - Implement the Architectures in Testbed
  - Implement Parameter Changes
    - QoS
    - Security
- Phase III – Flight Testing
  - Installed on NASA-owned aircraft
    - 757 stationed at Langley Research Center (LaRC)
  - Investigate New INMARSAT-4 Satellites

Conclusion

- Improve communications during transoceanic flights
  - Using packet mode service
  - Differentiate between cabin and cockpit data
  - Improved weather data products
- Validation and Testing
  - Using actual equipment in testbed
  - Flight Testing in mid-05
- Improved data products
  - Provide graphical weather products
  - Improved Turbulence Information
  - Cockpit Warnings/Alerts
  - Air Traffic Control data

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Relevant Publications

"Enhancing In-Flight Transoceanic Communications Using Swift-64 Packet Mode Service"