Aviation Wireless Communications

Chris Wargo
Agenda

■ Today's Aeronautical Telecommunication Network (ATN)

■ Potential of TCP/IP Architecture for Aviation

■ Mobility Management Requirements

■ Summary

■ Discussion
Wireless Application Categories (Voice and Data)

- Air Traffic Management (ATM)
  - Air Traffic Control (ATC)
  - Air Traffic Services (ATS)
  - Communication, Navigation, & Surveillance (CNS)
- Airline Operational Communications (AOC)
  - Flight Operations
  - Maintenance
  - Airport/Ramp Operations
- Airline Administrative Communications (AAC)
- Airline Passenger Communications (APC)
- Entertainment
### Global Customers of the Wireless Aviation Market

<table>
<thead>
<tr>
<th>Type</th>
<th>Size Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Aviation</td>
<td>15,000 Aircraft plus (times # of passengers)</td>
</tr>
<tr>
<td>Business Aviation</td>
<td>25,000 Aircraft plus</td>
</tr>
<tr>
<td>General Aviation</td>
<td>100,000 Aircraft plus</td>
</tr>
<tr>
<td>Cargo Aviation</td>
<td>10,000 Aircraft plus</td>
</tr>
<tr>
<td>Military</td>
<td>50,000 Aircraft plus</td>
</tr>
<tr>
<td>Government</td>
<td>184 Countries of ICAO</td>
</tr>
</tbody>
</table>
Aeronautical Telecommunication (ATN) Network Environment

Management Processor
ATN End System

Data Display Processor
ATN End System

Data Entry Processor
ATN End System

Management Processor
ATN End System

Avionics Subnetwork

ATN ROUTER

VHF Subnetwork

Satellite Subnetwork

Mode S Subnetwork

HF Subnetwork

ATN ROUTER

Airline Ground Subnetwork

ATN End System
Aeronautical Operations Data Base

ATN End System
Aeronautical Operations Control

ATN End System
Weather Data Base

ATN End System
ATC

ATN End System
FIS Data Base

ATN End System
Weather Data Base

CAA Ground Subnetwork

ATN ROUTER

ATN End System
Weather Data Base
Evolution of Aviation Wireless Communications

- SATS
- VDL Mode 4
- NEXCOM VDL Mode 3
- CPDLC II & III
- CPDLC I&IA
- PETAL II & LINK 2000
- VDL Mode 2
- HF Data Link
- GPS
- SATCOM (ATS,AOC,APC)
- EACARS & AVPAC Attempts
- ATN - ISO Definition
- ATN - IPv? Definition
- Passenger Telephone Systems
- FANS Committee
- CNS/ATM - FANS 1&A
- ACARS
- PanAm Satcom Demo

Consists of Applications and communication services that allow ground, air-ground, and avionics sub-networks to inter-operate

ATN Architecture

End System (ES)
Application Entity
Upper Layer Communications Service
Internet Communications Service

Context Management (CM) Application
Controller Pilot Data Link Communication (CPDLC)
Flight Information Service (FIS)
ATS Message Handling Services (ATSMHS)

End System (ES)
Application Entity
Upper Layer Communications Service
Internet Communications Service

Subnetwork
Intermediate System (IS)
Intermediate System (IS)
Subnetwork
Aeronautical Communication Requirements

- Interoperability with existing subnetworks
- High availability
- Mobile Communication
- Message prioritization
- Policy based routing
- Security
- Bit Efficiency
- Support for multiple mobile subnetworks
- Mobile platform forms its own Routing domain
Today’s ATN Status

- ICAO - 91 Nations Agreement 1991
- Published Standards - SARPS Edition 3, end of 2000
- Several Cooperative Attempts - Stalled Out
- FAA Funded Router Development - ATNS, Inc.
- Limited ATN Router Availability
- End System Applications under development
- Wireless Components not yet “Red Label”
- European, Eurocontrol lead early trials ongoing
- FAA CPDLC I - Initial Operation 2002
**ATN Protocol Architecture**

**ISO**
- Application
  - Application Service Element (ASE)
  - Dialog Service (DS)
  - Association Control Service Element (ACSE)
  - Connection Oriented Presentation Protocol (COPP)
  - Connection Oriented Session Protocol (COSP)
  - Transport Layer (TP4)
  - Network Layer (CLNP)

**Air-Ground**
- Application
  - ASE
  - DS
  - ACSE
  - Fast Byte COPP and COSP
  - Transport Layer (TP4)
  - Network Layer (CLNP)

**Sub Networks**
- Air-Ground Subnetwork
- Ground-Ground Subnetwork

---

Fast Byte approach selected to obtain bit efficiency over the Air-Ground Link
With the Fast Byte enhancements, the two architectures appear similar in structure
## TCP and TP4 Features Comparison

Both support Connection-oriented and Connectionless Transport services

<table>
<thead>
<tr>
<th>Function</th>
<th>TCP Protocol</th>
<th>TP4 Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data transfer</td>
<td>Streams</td>
<td>Blocks</td>
</tr>
<tr>
<td>Flow control</td>
<td>Octets</td>
<td>Segments</td>
</tr>
<tr>
<td>Error detection</td>
<td>Checksum</td>
<td>Checksum</td>
</tr>
<tr>
<td>Error correction</td>
<td>Retransmission</td>
<td>Retransmission</td>
</tr>
<tr>
<td>Addressing</td>
<td>16 bit ports</td>
<td>Variable TSAP address</td>
</tr>
<tr>
<td>Interrupt service</td>
<td>Urgent data</td>
<td>Expedited data</td>
</tr>
<tr>
<td>Security</td>
<td>Supported</td>
<td>Variable in TP</td>
</tr>
<tr>
<td>Precedence</td>
<td>Supported</td>
<td>16 bits in TP</td>
</tr>
<tr>
<td>Connection termination</td>
<td>Graceful</td>
<td>Non graceful</td>
</tr>
</tbody>
</table>

Source: [Aeronautical Related Applications Using ATN and TCP/IP Research Report](https://example.com), prepared by CNS for the NASA Glenn Research Center, November 23, 1999
Both support Connectionless Network services

<table>
<thead>
<tr>
<th>Function</th>
<th>CLNP</th>
<th>IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version ID</td>
<td>1 octet</td>
<td>4 bits</td>
</tr>
<tr>
<td>Header length</td>
<td>1 octet, represented in octets</td>
<td>4 bits, represented in 32 bit words</td>
</tr>
<tr>
<td>Quality of service</td>
<td>QoS maintenance option</td>
<td>Type of Service (Class)</td>
</tr>
<tr>
<td>Segment/fragment length</td>
<td>16 bits, in octets</td>
<td>16 bits, in octets</td>
</tr>
<tr>
<td>Total length</td>
<td>16 bits, in octets</td>
<td>16 bits, in octets</td>
</tr>
<tr>
<td>Data unit ID</td>
<td>16 bits</td>
<td>16 bits</td>
</tr>
<tr>
<td>Flags</td>
<td>Don’t segment, more segments</td>
<td>Don’t fragment, more fragments</td>
</tr>
<tr>
<td>Segment/fragment offset</td>
<td>16 bits, represented in octets</td>
<td>13 bits, represented in units of 8 octets</td>
</tr>
<tr>
<td>Lifetime, time to live</td>
<td>1 octet, represented in 500 millisecond units</td>
<td>1 octet, represented in 1-second units</td>
</tr>
<tr>
<td>Higher layer protocol</td>
<td>Not present</td>
<td>Protocol identifier</td>
</tr>
<tr>
<td>Lifetime control</td>
<td>500 millisecond units</td>
<td>1-second units</td>
</tr>
<tr>
<td>Addressing</td>
<td>Variable length</td>
<td>32-bit fixed (128 bits)</td>
</tr>
</tbody>
</table>

Source: Aeronautical Related Applications Using ATN and TCP/IP Research Report, prepared by CNS for the NASA Glenn Research Center, November 23, 1999
## IP and CLNP Features Comparison

<table>
<thead>
<tr>
<th>Function</th>
<th>CLNP</th>
<th>IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Options</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Security</td>
<td>• Security</td>
<td></td>
</tr>
<tr>
<td>• Priority</td>
<td>• Precedence bits in TOS (Class)</td>
<td></td>
</tr>
<tr>
<td>• Complete source routing</td>
<td>• Strict source route</td>
<td></td>
</tr>
<tr>
<td>• Partial source routing</td>
<td>• Loose source route</td>
<td></td>
</tr>
<tr>
<td>• Record route</td>
<td>• Record route</td>
<td></td>
</tr>
<tr>
<td>• Padding</td>
<td>• Padding</td>
<td></td>
</tr>
<tr>
<td>• Not present</td>
<td>• Timestamp</td>
<td></td>
</tr>
<tr>
<td>• Reason for discard (Error PDU only)</td>
<td>• Uses ICMP messages</td>
<td></td>
</tr>
</tbody>
</table>

Source: [Aeronautical Related Applications Using ATN and TCP/IP Research Report](https://www.nasa.gov), prepared by CNS for the NASA Glenn Research Center, November 23, 1999
Could TCP/IP protocol meet Aeronautical requirements?

**Benefits:**
- Lower Infrastructure cost
- Potential for new services:
  » VoIP
  » Multicast
  » Security
  » Integration with Public Infrastructure

**Challenges:**
- Modifying Political agreement/ Industry Standards
- Addressing Technical Issues for:
  - Mobility Management
  - Policy based routing capability
Subnetworks

Air-Ground (A/G):
- Aeronautical Mobile Satellite
- VHF Data Link
- Mode S
- HF Data link
- Passenger Telephony

Ground-Ground:
- X.25 PSDNs
- Frame Relay
- LANs
- Leased Lines
- NADIN
## Overview of VDL Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Data</th>
<th>Voice</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDL Mode 1</td>
<td>Yes</td>
<td>No</td>
<td>• Data rate of 1200 bps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Channel shared among all using aircraft</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Channel access based Carrier Sense Multiple Access (CSMA)</td>
</tr>
<tr>
<td>VDL Mode 2</td>
<td>Yes</td>
<td>No</td>
<td>• Uses the same frequency band as Mode1, but uses better data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>encoding modem</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Differentially encoded 8-phase shift keying (D8PSK) with channel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>data rate of 31.5 kbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Channel access based Carrier Sense Multiple Access (CSMA)</td>
</tr>
<tr>
<td>VDL Mode 3</td>
<td>Yes</td>
<td>Yes</td>
<td>• Provide 4 logically independent channels in a 25kHz frequency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>assignment.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Each channel can be allocated to voice or data. Uses differentially</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>encoded 8-phase shift keying (D8PSK) at 31.5 kbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Standard media access control based on 4 slots structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Extended range uses 3 slot structure</td>
</tr>
<tr>
<td>VDL Mode 4</td>
<td>Yes</td>
<td>No</td>
<td>• Uses Self-organizing Time division multiplexing (STDMA)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Uses TDMA based short time slots</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Uses a reservation protocol to gain link access</td>
</tr>
</tbody>
</table>
Subnetworks Requirements

- Byte and code independence
- Address individual systems
- Provide error detection
  - Undetected error better than $1 \times 10^8$
- Packet mode technology
- Connectionless and Connection mode
- Prioritization of data
  - Important for safety related data
- QoS Management
  - Throughput and Transit delay guarantees
- Mobile subnetworks
  - Ability to report aircraft joining the subnetwork
  - Ability identify aircraft leaving a subnetwork
Mobility and Roaming

- Mobility between subnetworks while staying in contact
  - Supported by the data link layer

- ATN must support Roaming between networks
  - Aircraft may move from one mobile subnetwork to another
  - Aircraft may be simultaneously attached to more than one mobile subnetwork
Mobile Routing Issues

- Routes cannot be aggregated
  - Mobile addresses not related to topology
- Route changes every time aircraft changes point of attachment
  - High rate of routing updates
- Routers have to keep a route for each aircraft
  - ATN size limited by router table capacity
Uses Inter Domain Routing Protocol (IDRP) for routing

Implements distributed IDRP directory using Boundary Intermediate Systems (BISs)

Two level directory
  - ATN Island concept consisting of backbone BISs
  - Home BISs concept

Scalability obtained by the two level structure

Resilience is provided by the distributed approach
ATN Island Routing Domain Confederation

- Mobile RD
- Another ATN Island
- Mobile RD
- ATN Backbone RDC
- ATN TRD
- ATN TRD
- ATN ERD
- ATN Island RDC
- ATN TRD
- ATN ERD
- Mobile RD
Mobile Routing Example

- RD1, RD2 and RD3 support air/ground data links and RD4 depends on the other three (3) for A/G communication.

- Using IDRP RD1 and RD2 advertise a route to the aircraft and RD4 can choose one of the route based on Routing policy.
Mobile Routing Example

- As the aircraft travels it may lose contact RD1, RD1 informs others using the route withdraw message.
- RD4 now has one path to the aircraft through RD2 and thus routes all traffic through RD2.
- Further along in the flight, the aircraft may come in contact with RD3. A data link is established and routing information is exchanged. RD3 then advertises a new route to the aircraft.
- RD4 again has two routes to the aircraft and chooses a route based on local routing policy. The aircraft goes through a similar process to select a route.
ATN Mobile Protocol Requirements

- Shall support wide variety of mobile communications networks including aeronautical mobile-satellite service (AMSS), VHF digital link (VDL), HF digital link and SSR Mode S. Shall be possible to communicate with airborne avionics in any part of the world.

- Shall support wide range of Organizational and National polices, including the enforcing of restrictions on what types of traffic can pass over both ground and air/ground data links, and control over which air/ground data link types are used by which applications.

- BISs shall advertise routes to each other, where a route consists of the set of addresses which identifies the destinations reachable over the router, and information about the route's path including the Quality of Service and Security available over the route.

- Shall support policy based routing that enables users to control external access to their communications resources, and to protect themselves from problems elsewhere in the internetwork.

- The ATN, mobile “platforms” on board an aircraft shall form a Routing Domain and must include an ATN Router that is also a BIS.

- Shall support a two level concept of default route providers (ATN Island and Home) for containing high rate of information flow, and also to avoid the problems of routing instability caused by a rapid turnover of routing information.

- Mobile routing shall support the user requirement that the users can specify, on a per application basis, routing control requirements.
NASA System Testbed Configuration

Testbed Protocol Stack

Controller Pilot Data Link Communications (CPDLC)

Context Management (CM)

Application Service Element (ASE)

Dialogue Service
Association Control Service Element

FastByte COPP
FastByte COSP

Transport Switch

COTP TCP
CLNP IP
MAC
Physical

NASA DC-8 Experimental Aircraft

VHF Mode-2

Transceivers
CMU (ATN compliant)
Display ‘MCDU’

NASA Experimental CPDLC Ground System

‘CMU’

LAN

Ground Controller Display

‘MCDU’

Telemetry
Admin
Summary

- Aviation’s use of TCP/IP could yield significant benefits.

- Without a common solution for mobile routing, Aviation’s ISO oriented ATN will remain in place.

- Adopting IDRP-like mechanisms for mobile IP versus a BGP-like approach is a step in Aviation’s direction.
Wireless Application Categories (Voice and Data)

- Air Traffic Management (ATM)
  - Air Traffic Control (ATC)
  - Air Traffic Services (ATS)
  - Communication, Navigation, & Surveillance (CNS)
- Airline Operational Communications (AOC)
  - Flight Operations
  - Maintenance
  - Airport/Ramp Operations
- Airline Administrative Communications (AAC)
- Airline Passenger Communications (APC)
- Entertainment
# Acronym List

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATN</td>
<td>Aeronautical Telecommunication Network</td>
</tr>
<tr>
<td>ACARS</td>
<td>Aircraft Communications Addressing and Reporting System</td>
</tr>
<tr>
<td>ACSE</td>
<td>Association Control Service Element</td>
</tr>
<tr>
<td>AMSS</td>
<td>Aeronautical Mobile-Satellite Service</td>
</tr>
<tr>
<td>ASE</td>
<td>Application Service Element</td>
</tr>
<tr>
<td>BIS</td>
<td>Boundary Intermediate System</td>
</tr>
<tr>
<td>CF</td>
<td>Control Function</td>
</tr>
<tr>
<td>COPP</td>
<td>Connection Oriented Presentation Protocol</td>
</tr>
<tr>
<td>COSP</td>
<td>Connection Oriented Session Protocol</td>
</tr>
<tr>
<td>CPDLC</td>
<td>Controller-Pilot Data Link Communications</td>
</tr>
<tr>
<td>DS</td>
<td>Dialogue Service</td>
</tr>
<tr>
<td>ERD</td>
<td>End Routing Domain</td>
</tr>
<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
</tr>
<tr>
<td>FANS</td>
<td>Future Air Navigation System</td>
</tr>
<tr>
<td>IDRBP</td>
<td>Inter Domain Routing Protocol</td>
</tr>
<tr>
<td>NADIN</td>
<td>North American Digital Information Network (FAA)</td>
</tr>
<tr>
<td>PETAL</td>
<td>Preliminary European Test of Air/Ground Data Link</td>
</tr>
<tr>
<td>RD</td>
<td>Routing Domain</td>
</tr>
<tr>
<td>RDC</td>
<td>Routing Domain Confederation</td>
</tr>
<tr>
<td>TRD</td>
<td>Transit Routing Domain</td>
</tr>
<tr>
<td>VDL</td>
<td>VHF Digital Link</td>
</tr>
</tbody>
</table>
Industry Initiatives

- ATN
  - Context Management (CM) Application
  - Automatic Dependent Surveillance (ADS)
  - Controller Pilot Data Link Communication (CPDLC)
  - Flight Information Service (FIS)
  - ATS Message Handling Services (ATSMHS)
Air Traffic Management (ATM)

- Predeparture Clearance
- Taxi Clearance
- Context Management
- Controller to Pilot Data Link Communication
- Automatic Dependent Surveillance
- Waypoint Position Reporting
- Emergency Messages
- Future Air Navigation System
- Oceanic Clearance
- Future Free Flight
- Flight Information Services
- Airport Terminal Information Service
- Digital Airport Terminal Information Service
- Flight Information Services Broadcast
- Notice to Airmen
- METAR
- Terminal Weather Information to Pilots
- Local Area Augmentation System
- Wide Area Augmentation System
- Cockpit Voice (ATC)
### AOC, AAC, APC and Entertainment

#### Airline Operational Communications (AOC)
- Data Link Related System Control, Peripherals, and Subsystems (6 Applications/61 Formats)
- Flight Operations (14 Applications/30 Formats)
- Maintenance Operations (6 Applications)
- Airport/Ramp Area Operations
- Cockpit Voice Operations (Company)

#### Airline Administrative Communications (AAC)
- Airlines Gate Connections
- Medical Assistance Requests
- Crew Schedule and Lodging Information
- Miscellaneous Freetext Crew Information
- Future Applications – Passenger Handling

#### Airline Passenger Communications (APC)
- Telephony
- E-Mail
- Internet Services
- Facsimile

#### Entertainment
- Games
- Movies/Videos
- Gambling
- Shopping
- Automated Teller Machines