ACARS to VDL Transition Plan

Prepared By:

Aloke Roy
ARINC Incorporated

For:

AEEC Data Link User Forum
January 28-29, 1998
Orlando, Florida

1. Introduction

The Aircraft Communications Addressing and Reporting System (ACARS) VHF data link has been serving the aeronautical industry well since 1978. Over the last 20 years, a wide variety of Airline Operational Control (AOC) and Air Traffic Service (ATS) voice applications have migrated to data. Majorities of the airlines now depend on the data link everyday for efficient, cost-effective operations. The existing ACARS system, by definition, consists of communications as well as applications components. Both of these components have evolved significantly over the period to cope with additional requirements, but the VHF communications part is still limited to 2400 bps data rate. Also, ACARS communications has some inherent protocol limitations.

The aeronautical community worldwide considers efficient data link to be the key to future air-traffic communications and management. As such, ICAO has developed the VHF Digital Link (VDL) Standards and Recommended Practices (SARPs) to overcome ACARS limitations and to provide a data link capability suitable for future aeronautical needs. The VDL standards are designed to operate under another ICAO specification—Aeronautical Telecommunications Network (ATN). ATN provides higher end-to-end data integrity and allows end systems to seamlessly exchange information across multiple data links and provider subnetworks. ATN is specifically designed to satisfy stringent performance requirements imposed by safety critical air-traffic control applications. ATN is a complex system and the operational implementation of the end-to-end ATN systems may not materialize before year 2005+. Therefore, a need exists to provide an interim solution for airline operational control to overcome ACARS communication limitations and to provide higher VHF capacity required meeting additional system demand by year 2000.

2. Background

In 1997, the Aeronautical Electronic Engineering Committee (AEEC) Datalink Users Forum endorsed an initiative to develop an interim solution to support ACARS applications effectively over VDL Mode-2 and Satellite Data Level 3 bit-oriented communications media.

Since then, SITA presented a high-level proposal at the last ACARS Sub-committee (SC). The SITA proposal recommends VDL coupled with ACARS modifications to improve the efficiency of air/ground data link. At present, ACARS uses stop-and-wait protocol where each transmission is limited to 220 character user data. Also, the analog radios used by ACARS have long receive-transmit turn-around delays and long pre-keys. More RF capacity can be gained by improving these ACARS parameters. As the airlines are required to upgrade the VHF radio to satisfy regulatory requirement of FM immunity and reduced RF channel spacing (to 8.33KHz), VDL can be installed at the same time to improve

VHF air/ground data link capacity. Although the aeronautical industry is committed to ATN, actual implementation of ATN may be deferred till year 2005+ due to unavailability of ground automation systems. Therefore, an interim solution incorporating VDL is highly desirable.

This paper builds on the SITA proposal and provides additional details. It agrees in general with the SITA approach except areas required for backward compatibility and for transition to future ATN implementations.

3. Objective

The key objectives for the proposed solution are:

- To develop an air/ground communication standard to support existing applications while minimizing impact on installed equipment. Any solution that requires substantial changes to the existing applications, ground and airborne infrastructure will not be financially viable for the airlines, data link service providers (DSP) and the avionics manufacturers.
- To maintain backward compatibility with existing character-oriented data links. Aircraft will potentially operate in mixed mode environment for years to come, because the ground infrastructure will be upgraded over a period of time.
- To provide a transition path to full ATN implementation such that both the interim and final avionics configurations can use the same communications infrastructure. Once interim avionics systems are deployed, it will remain operational simultaneously with ATN for a period of time. Separating system configuration by frequency and/or requiring special processing in the ground infrastructure to support both avionics configurations will increase the operating cost of the overall system.
- To provide additional data link capacity to satisfy additional system demand by year 2000. ACARS system demand has been growing at the rate of 12 to 15 percent per year in North America. Up to five frequencies are used in the northeast corridor at present to provide adequate system performance based on current demand. Using current growth rate, air/ground data link demand will double within the next five years. One way to resolve this issue is to add more frequencies when the demand exceeds required capacity. Unfortunately frequency being a scarce resource, availability of another 5 or 6 frequencies is questionable. A technology based solution, such as VDL, is required to improve system capacity using existing frequency allocation.
- To allow local routing of user data instead of centralized distribution network in place today for ACARS. This capability will improve overall system latency and availability while reducing the load on the backbone ground network. This capability will be required for future ATS applications but some airlines and Civil Aviation Authorities (CAA) have already expressed a desire for this capability for their existing applications.
- Gain operational experience with bit-oriented data link before transition to ATN. This will allow the industry to develop operational procedures and new applications effectively for ATN environment.

4. Existing Avionics Data Flow

The existing avionics architecture and decision tree is represented in Figure 1:

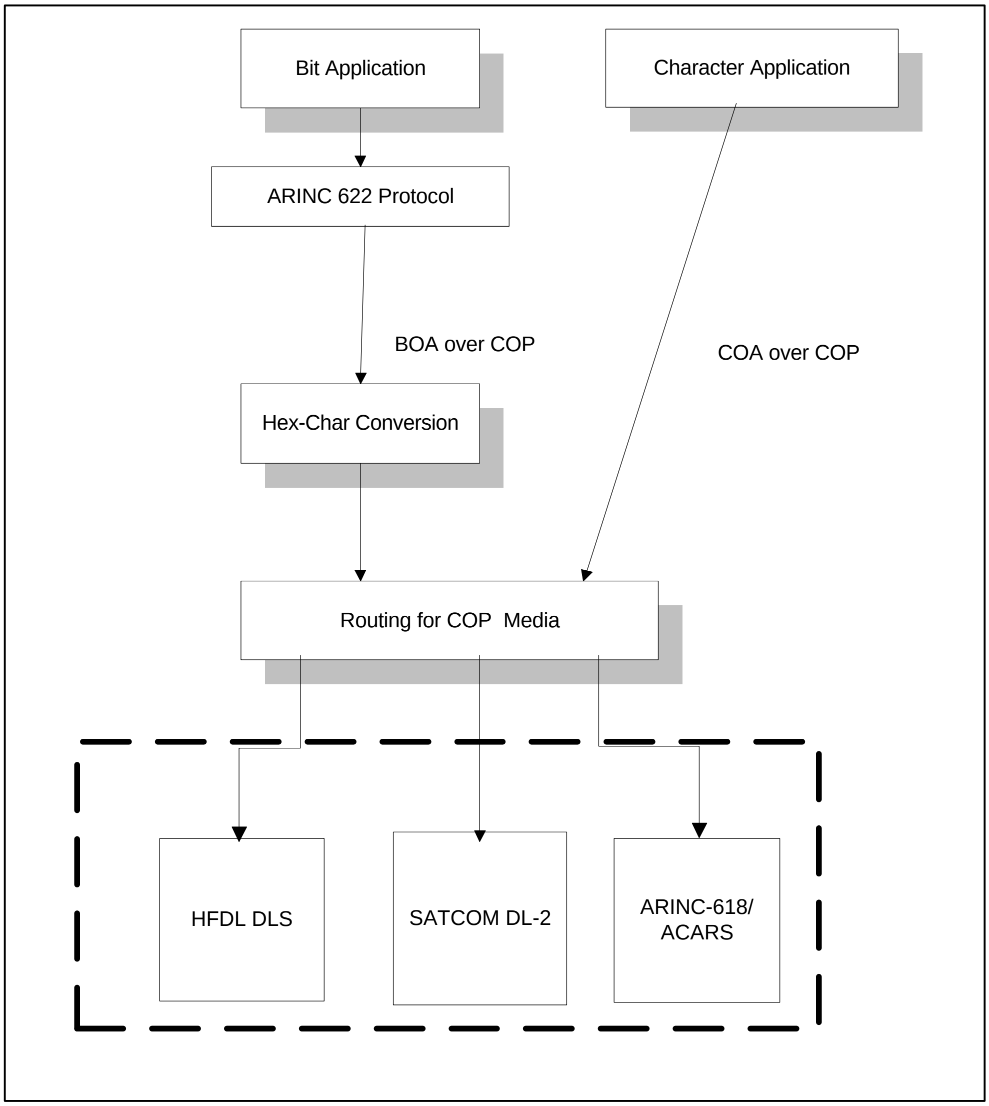

Figure 1: ACARS Avionics Data Flow

There are two types of applications in an aircraft: character-based or bit-based. Any data generated by the bit-based application is first processed by the ARINC 622 functionality that formats data and adds the IMI, CRC check and provides supplemental addressing. Then bit data gets converted to ASCII using bit-to-hex conversion as specified in ARINC 622 and forwarded to COP media routing. Character-based data is forwarded directly to COP media routing. Media routing decides which link is available and will be used for downlink. It should be noted that a given aircraft can only have one link type (COP or BOP) operational at a time for a given media (HF, VHF, SATCOM). On the other hand, a given aircraft can support multiple media with different link type operating simultaneously.

5. Proposed Functionality

As proposed in the SITA paper, the VDL system will satisfy most of the objectives defined above. VDL Mode-2 system provides 31.5 Kbps data rate using the same 25 KHz channel spacing as ACARS, thereby improving the overall system capacity by an order of magnitude. Also, the VDL system uses digital radios that will minimize the ACARS physical limitations. VDL uses a go-back-N connection-oriented protocol with packet size up to 2048 octets and can segment/reassemble larger size user data. Therefore, it will not be necessary to use the ACARS multiblock delivery algorithm over VDL. To minimize changes to existing ground and airborne equipment, the ACARS formatting and basic ACK/NAK protocol should be used as is.

The physical configuration of the aircraft for VDL Mode-2 operation is shown in Figure 2.

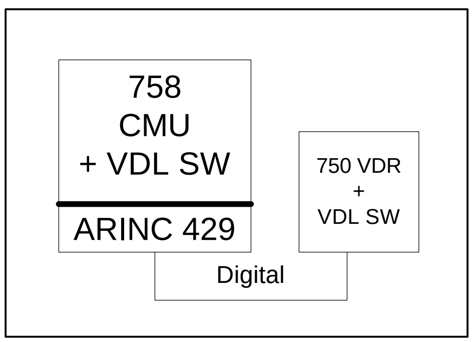

Figure 2: Aircraft Hardware Configuration for VDL

Therefore, both the VHF radio and the ACARS Management Unit (MU) in the aircraft has to be replaced and digital wiring must be installed between the VDL Communications Management Unit (CMU) and the radio. It should be noted that a significant number of airlines are already replacing the radio either to meet regulatory requirements or as part of their natural replacement cycle. A CMU will also be required for the ATN implementation. Therefore, upgrading the MU to CMU for VDL allows the airborne configuration to be ready for ATN software when it becomes available.

In addition to the VDL software shown in Figure 2, special convergence and routing software will be required in the avionics to effectively exchange ACARS information over VDL. This is due to the fact that ACARS inherently is a connectionless system, whereas VDL requires a connection to be established with the peer processes before any data transfer. Therefore, when an application process generates data, a function has to determine the destination address, verify connection availability, and then send the data. Otherwise, this function must hold the user data and request for connection establishment before data can be sent. This scenario is also true for connection-oriented SATCOM Data Level 3 and HFDL RLS links. This functionality is known as Sub Network Dependant Convergence Function (SNDCF) and is already defined by the ISO standards committees.

In today's ACARS environment, all downlink messages are implicitly addressed. ACARS Central Processor System (CPS) uses the agency code and the message label embedded in a downlink to determine the final end-user address. This capability is not adequate for the VDL system. VDL uses an explicit address to send information to the peer DTE connected to the VDL air/ground subnetwork. Unfortunately, the end-user may not be coresident with the peer DTE and another level of addressing will be required to get the data to the true hosts. When VDL operates within the ATN environment, this capability will be satisfied by the CLSP NSAP address. Although the implicit ACARS addressing can be used if embedded with the VDL user data, this option will require centralized routing in the ground network. Another limitation of this approach is that the VDL subnetwork connection has to be extended all the way to CPS. A custom solution can also be developed in the ground infrastructure to accommodate the user data routing. The best alternative is to use the CLNP address structure as defined in the ATN SARPs. This will allow the ground systems to efficiently route data between destination aircraft and host systems; allow the use of COTS products on ground for routing and relaying of user data; and permit local routing. Use of CLNP basic Protocol Data Unit (PDU) formats, data header assembly and header stripping capabilities provide the minimum required functionality for the interim VDL configuration. By appropriate selection of the CLNP header and addressing parameters, interim system PDUs can be distinguished from full ATN system PDUs. This in turn will permit coexistence of interim solution with full ATN implementation and use same RF/system resources.

In summary, the use of standard ISO 8473-3 SNDCF and basic ISO 8473-1 protocol (e.g., PDU formats, header assembly) combined with full VDL functionality, satisfies most of the objectives established above in Section 3. Specific PDU formats, PICs, options, and addressing schemes are provided in the following Sections 6 through 8.

6. PDU Formats

The recommended CLNP PDU format is shown in Figure 3:

Network Layer PID = 0x81			
Length Indicator = 0x33			
Version/PID Extension = 0x01			
PDU Lifetime = 0xFF			
SP = 0 No Seg.	MS = 0 Full Blk	E/R = 0 No Err Rpt	Type = 0x1C Data PDU
Segment Length = 0x33 + Data Length			
Checksum = 0x00 (Ignore)			
Dest. Address Length Indicator = 0x14			
Destination Address (see Section 7)			
Source Address Length Indicator = 0x14			
Source Address (see Section 7)			
Application Data: ACARS Characters in ARINC 620 A/G format - SOH to ETX			

Figure 3: Recommended CLNP PDU Format

It should be noted that all fields except the “segment length” are predefined. Thus, the header can be easily preconfigured and appended to each ACARS message without much software computation and complexity. None of the CLNP protocol options are supported in this configuration (see CLNP PICS in Figure 4). Also, only Data PDU is the valid PDU type. Any other PDU (error, echo request and echo response) received is ignored and discarded by the airborne system. Segmentation is not permitted for these PDUs at the CLNP layer. Thus, the airborne subsystem will not reassemble user data at the CLNP layer. Also, the header checksum is ignored assuming error detection and recovery at the VDL layer. This simplifies the CLNP part of the protocol implementation to only header assembly and strip-out using fixed header values. As the format of the PDU complies with the standard ISO 8473 specification, it can be properly received and processed by any intermediate COTS component. As a result, the overall implementation cost of the airborne and ground units is minimized while ensuring coexistence with full ATN systems.

In addition to the CLNP PDU formats, a special designator will be required for the SNDCF during ISO 8208 call establishment procedure. This designator is required for mixed mode (ATN and interim solution) operation to differentiate between ATN mobile SNDCF and the interim implementation. Use of the designator will identify the PDU as interim solution and indicate standard SNDCF with scaled down CLNP to the recipient. It is recommended that “0xa1” is used as this designator and inserted as the first octet in the ISO 8208 ”call request packet” of the user data field. If “0xa1” is accepted, then it must be reserved specifically for this implementation.

Air/ground data link frame samples are shown below:

User Data Frame:

AVLC Frame Header	VDL Packet Header	CLNP PDU as shown in Figure 3	AVLC Frame Trailer

VDL (or other ISO 8208 air/ground subnet) Call Request Frame:

AVLC Frame Header	VDL Packet Header	“0x1a” denoting Interim Solution	AVLC Frame Trailer

7. Addressing

It is recommended that standard ATN NSAP address structure be used for the interim solution to allow interoperability with COTS products, local routing of user data and simultaneous operation of ATN and interim systems using the same infrastructure. Sample airborne and ground system addresses are shown below. Definition of the fields are provided in the ISO 8473 specification.

Airborne system (CMU) address:

AFI 0x47	IDI 0x0027	VER 0x41	ADM 0x55414c = UAL	RDF 0x00	ARS = 24-bit a/c addr.	LOC 0x0000	SYS "000000" decimal	SEL = 0xa1 denoting ACARS over CLNP

NOTE:
1. All fields are fixed for a given aircraft
2. The “SEL” field is used to indicate that the network service user is ACARS application, i.e., ACARS is running directly above the CLNP.

Ground system address:

AFI 0x47	IDI 0x0027	VER 0x01	ADM 0x584141 = XAA	RDF 0x00	ARS = 24-bit grnd. addr.	LOC 0x0000	SYS "000000" decimal	SEL = 0xa1 denoting ACARS over CLNP

NOTE:
1. All fields are fixed for a given ground end-system
2. Address represents a ground end-system within ARINC domain that supports ACARS character-based ground interfaces to user hosts.
3. The “SEL” field indicates this to be for interim solution with ACARS applications riding over CLNP.

8. CLNP PICS

The applicable CLNP protocol options are indicated in the following table:

Protocol Function	***End System***	
	Sending	Receiving
PDU Composition	M	N/A
PDU Decomposition	N/A	M
Header Format Analysis	N/A	O
PDU Lifetime Control	O	O
Route PDU	--	--
Forward PDU	--	--
Segmentation	--	--
Reassembly	N/A	--
Discard PDU	N/A	M
Error Reporting	--	--
Header Error Detection	--	--
Security	--	--
Complete Source Routing	--	--
Complete Route Recording	--	--
Echo Request	--	N/A
Echo Response	N/A	--
Partial Source Routing	--	--
Partial Route Recording	--	--
Priority	--	--
QoS Maintenance	--	--
Congestion Notification	N/A	--
Padding	--	--
Key: M: Mandatory, must be supported by the interim solution --: Not implemented by the interim solution O: Implementation option N/A: Not applicable		

NOTE: It might be beneficial to implement error reporting for network trouble-shooting.

9. Changes to ACARS

It is likely that VDL ground infrastructure will be implemented in phases across various parts of the world. Therefore, VDL coverage might not be available for an aircraft throughout its end-to-end flight path. As such, aircraft needs to be bilingual (ACARS COP and VDL) and be able to switch dynamically from ACARS to VDL or vice versa based on coverage availability. Also, there needs to be some capability to announce VDL service and/or detect aircraft capability and change the aircraft mode of operation. AEEC has considered both these options and is in the process of defining two specific applications as defined below:

- An ACARS Squitter message: Squitter messages are used by ACARS ground stations (GS) to announce VDL service. These messages are transmitted periodically by GSs located around the VDL service volume. The suqitter contains the VDL service provider and VDL GS identity and the VDL operating frequency. On receipt of this message, the avionics switches frequency and VHF mode, then logs onto the VDL network.
- Query aircraft capability: The service provider queries the aircraft on initial contact (or after a predefined event) to learn about aircraft configuration. If the aircraft is capable of operating in VDL mode, the service provider CPS transfers the aircraft to VDL network.

The second approach is more complex, but the transition is completely managed by the service provider. On the other hand, squitter message is simple to implement but can consume a considerable portion of limited RF resources. The actual implementation will depend on specific RF and ground environment.

Once the aircraft is logged on to the VDL network, connectivity is established between the airborne CMU and the VDL DTE on ground. If the ground DTE is not co-hosted within the existing ACARS CPS, full routing path may not be established end-to-end after VDL connectivity. To send character-based data to existing ground hosts, a “Media Advisory” message will be required to update the end-to-end routing path through VDL and the character-based ground network. This will also allow unsolicited uplink messages to be routed appropriately through the VDL network.

Assuming end-to-end route has been established as defined above, the application data flow within the avionics is shown in Figure 5:

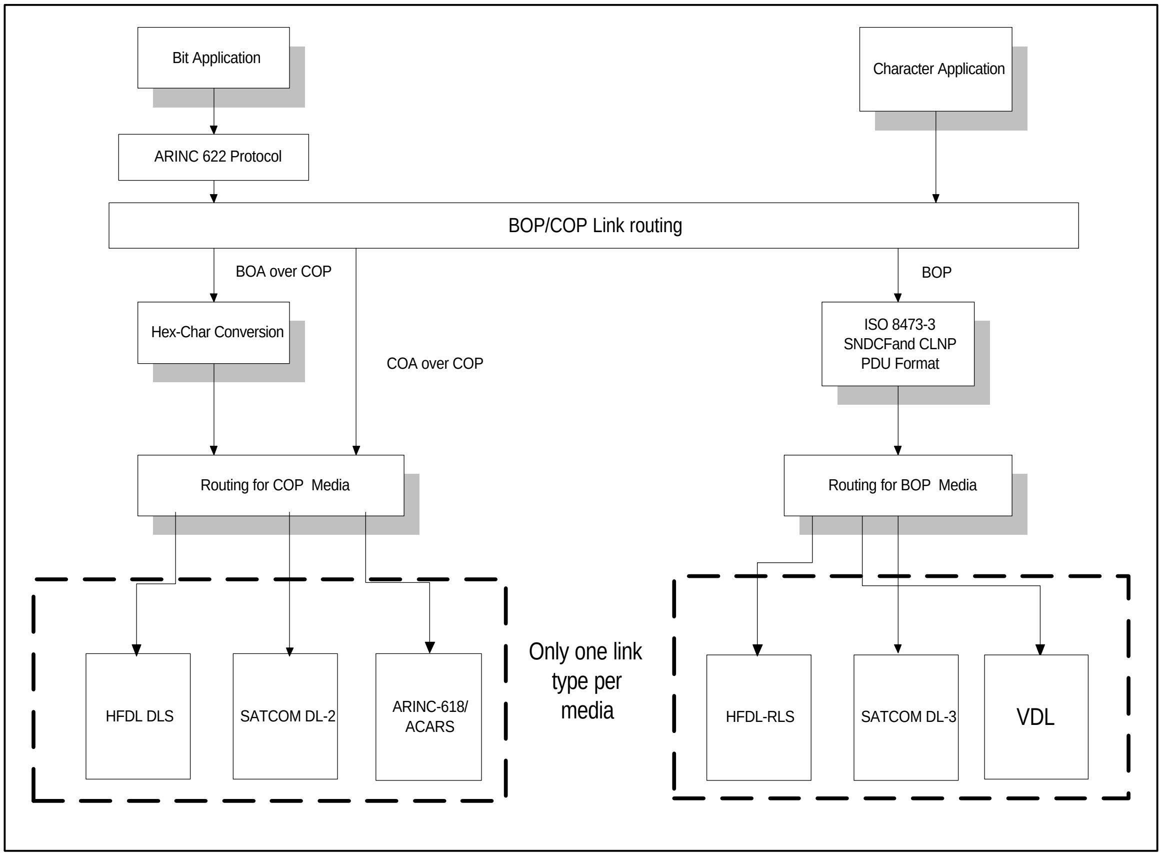

Figure 5: VDL Avionics Data Flow

Once character- or bit-based data is generated by respective applications, it is passed to the air/ground link determination process. Bit-based ATS data goes through ARINC 622 processing as shown in Figure 5 before it is passed on to COP/BOP link routing. If a bit-oriented link is available (i.e., VDL, SATCOM DL-3 or HFDL RLS packet connectivity has been established), link routing picks the applicable BOP link and forwards data to the ISO 8473 routing and SNDCF function. It should be noted that bit-to-hex conversion is not required for any data destined for a bit-oriented link. The ISO-8473 and SNDCF function formats the PDU header as discussed in Section 6 and forwards data to BOP media routing which in turn downlinks the PDU via the appropriate medium.

Any ACARS user data coming out of the Character application or the ARINC 622 protocol processes should be already formatted in ARINC 620 air/ground format, and should be enveloped within the “SOH” and “ETX” ACARS delimiters. ACARS protocol ACKs should still be used between these application processes and CPS to ensure ACARS data delivery and to minimize changes to the existing implementations.

10. Operational Scenarios

The following paragraphs define a typical downlink scenario:

1) Avionics running in ACARS mode receives squitter message announcing VDL service availability.
2) Avionics tunes to advised VDL frequency and establishes VDL Mode-2 subnetwork connection with the peer ground DTE. It uses “0xa1” in the user data field of the “call request” packet to denote interim solution.
3) Avionics sends “Media Advisory” message to update end-to-end routing through the service provider CPS and ground host.
4) Application generates downlink message.
5) If the message is character-based, it is formatted based on ARINC 620 starting with SOH and ending with ETX.
6) If the originator is bit-based ATS application, ARINC 622 formatting, and CRC is applied. Then the message is formatted in ARINC 620 as (5) above. For new bit-applciations, the message can be send directly over CLNP/VDL instead of processing through ARINC 622.
7) If the message is to be sent over VDL (or other BOP Links), NSAP PDU header is added. The destination NSAP for this message would likely be the service provider CPS for message delivery to existing character hosts.
8) The message is downlinked via VDR.
9) On receipt of the downlink, the ground DTE forwards the message to CPS using standard COTS CLNP based routing. At the VDL network exit point, it strips off the CLNP header.
10) CPS receives the full message, generates ACK back to the aircraft, converts messge from air/ground to SMT format and sends to ground host.

The following paragraphs define a typical uplink scenario. It is assumed that the actions defined in steps (1) through (3) of the downlink scenario has been completed prior to sending uplinks:

1) CPS gets input message from ground host using existing mechanism.
2) CPS identifies VDL as optimal path based on routing table entry generated from “Media Advisory” message.
3) CPS forwards message to VDL network.
4) VDL network pre-pends CLNP PDU header with aircraft NSAP and forwards via COTS CLNP network to target ground station.
5) Ground station transmits message over VDL frequency.
6) Aircraft VDL process receives uplink and forwards the PDU to ISO-8473 & SNDCF process.
7) ISO-8473 process strips the CLNP header and sends full message to appropriate application.
8) The application generates ACARS ACK and sends to CPS.

11. Conclusion

The interim air/ground data link proposal outlined in Sections 5 through 10 above satisfies all of the objectives established in Section 3. It maintains backward compatibility with applications and software in place in the avionics, ground networks and the hosts while it provides a transition path to ATN. A significant benefit of this approach is the interoperability with COTS ATN network/routers and the ability to coexist with full ATN implementation. Therefore, this approach reduces the overall industry investment. As the solution requires minimal ISO-8473 functionality, it also minimizes the initial software development cost. If and when the ATN software becomes available, the interim avionics systems can be upgraded to full ATN capability without making any changes to overall system design.

The interim solution proposed in this paper relies on CLNP addressing for end-to-end data delivery through the VDL network. Although this is a very limited subset of ATN, CLNP protocol and NSAP addressing is the heart of ATN. Therefore, substantial experience can be gained on ATN through early implementation of the proposed solution. Use of COTS products in the ground network will prove the viability of ATN with minimal investment.

The only disadvantage of the proposed solution is that it requires the transmission of full CLNP protocol header with every RF transmission. This adds a fair amount of overhead on the RF. On the other hand, VDL Mode-2 will increase the overall RF capacity by more than an order of magnitude from 2400 bps to 31,500 bps. During the initial years of VDL implementation, only a limited number of aircraft will be using this capacity. Therefore, a small RF penalty incurred by this solution can by justified by the simplicity of the solution requiring lower initial capital outlay.

Based on the current schedule published by the FAA, ATN based ground automation systems will not be available till year 2005+. It is likely that the available ACARS frequencies will be fully saturated by that time resulting in considerable air-traffic congestion and performance degradation. The proposed solution provides an efficient mechanism to address that issue while reducing and protecting the initial investment through smooth migration path to ATN.

It is strongly recommended that the proposed solution be accepted and adopted by AEEC for implementation by year 2000.