OPEN SYSTEM PROTOCOLS FOR AVIATION DATA LINK APPLICATIONS *

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This paper will discuss the application of "open system" communications protocols in the design and implementation of data link applications for aviation. The term "open system" in this paper refers to a set of communications protocols whose design specification is readily open to the user community, usually via publication by an international standards body. Such open system standards tend to encourage widespread implementation and enhancement of the communications protocols defined in the open standards. Ready availability of well-tested implementations helps to keep the costs of open systems low. Interoperability of equipment is enhanced by the use of open systems, as is the ease of system extensibility. In some cases, system communications infrastructures to support the open system may already be in place (e.g. the Internet).

Data link applications in aviation are increasing at an accelerating rate. Whether for air traffic control, airline operations, or improved pilot situational awareness, data link systems are required for many existing and future functions in aviation. Many aviation data link designs have been proposed and demonstrated over the years. A drawback to most of these designs is their *ad hoc* nature. It is difficult to combine the various aviation data links into a coherent overall system architecture. Since each aviation data link was specialized for a specific task or application, there is little commonality of design, nor is there much opportunity for software/hardware reuse in ground or avionics equipment. Each aviation data link has required its own separate system infrastructure –

leading to considerable overlap, complexity, and expense.

At the same time, the Internet community has seen explosive growth in both the number of Internet users and the types of Internet system applications. Much of this growth may be tied to the "open system" nature of the Internet communications protocols which allows for straightforward implementation of Internet applications. It is difficult to buy a computer today that doesn't have an Internet protocol stack in its system software. Extremely inexpensive Internet implementations are in everything from microwave ovens to laptops. The Internet's dramatic growth is an indicator of the power of "open system" architecture to encourage development of communications applications. This paper will show how the use of suitable open system communications protocols can help to bring increased efficiency and lower-cost equipment to aviation data link systems.

Aviation Communications System Architecture

Figure 1 illustrates the overall architecture of an open system communications architecture for aviation data link. Three typical aviation data link "subnetworks" (Mode S, VHF, and SATCOM) are shown in Figure 1 – although the system architecture would encompass other air-ground data links (e.g. HF) as well. Routers manage the connectivity between data link applications (either ground or airborne) via the air-ground subnetworks.

Note that multiple data link applications may utilize a given air-ground subnetwork. Note, also, that a given data link application might employ multiple air-ground subnetworks (e.g. during different phases of flight).
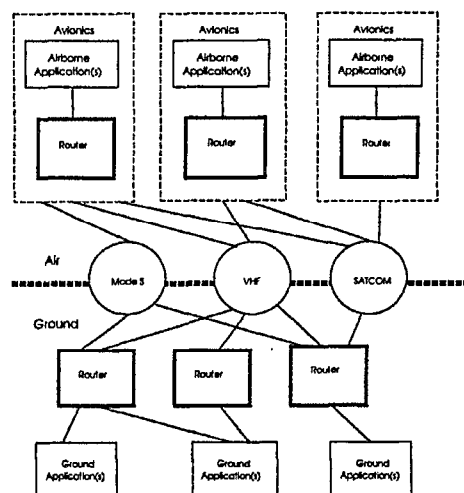

Figure 1. Open System Aviation Communications System Architecture

Figure 2. Open System Subnetwork Architecture

Figure 2 expands the air-ground data link subnetwork "circles" from Figure 1 to illustrate the open system interfaces in the overall aviation data link system architecture. The link-layer design of each aviation subnetwork is unique and specialized. There is little commonality between various aviation subnetworks in terms of communications protocols, supported functionality, etc. To achieve open system connectivity, "Data Link Processors" (DLPs) are placed between the air-ground link-layer transceivers and the rest of the system. The DLPs (the GDLP on the ground and the ADLP in the avionics) translate between the link-specific protocols and requirements of the particular aviation subnetwork and the selected open system communications interface used by the rest of the system. The DLPs allow the routers, ground and air infrastructures, and applications to assume a common open standard for aviation data link communications, regardless of the particular communications path taken in a particular instance of message transmission.
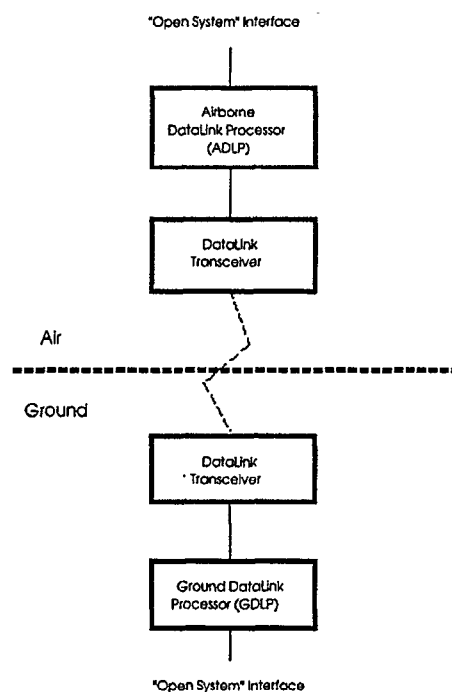
Communications Requirements and Features

The following set of seven criteria for open system communications protocols were used to select among candidate open systems for aviation data link. These criteria encompass some hard requirements and also some highly-desirable features for aviation data link applications. This analysis assumed that flight information (e.g., aviation weather dissemination) was the primary data link function of the system.

1. Adherence to a well-known and specified open system. Clearly, the closer the candidate system conforms to a standard, the more benefits of having an open system (e.g. low cost, availability of implementations, etc.) will be obtained.

2. Efficient transmission of both long and short messages. Some envisioned data link messages will be quite short (only a few bytes) in length. Others might be very long. (A "worst-case" example might be the national NEXRAD mosaic at

2-km resolution, requiring about 6 megabytes uncompressed – around 300 kilobytes with lossless runlength compression applied.) The aviation communications system should efficiently handle messages over this range of lengths. The communications protocol overhead should not overwhelm the actual data.

3. Support broadcast/multicast modes. A number of envisioned data link applications will seek to transfer a common database of information to many aircraft simultaneously. Hence, provision of an efficient broadcast or multicast mode is highly desirable in the aviation data link communications system.

4. Support reliable addressed messaging modes. This is the complement to (3) above. Some data link applications are assumed to require reliable messaging (i.e. providing an end-to-end acknowledgement of successful message reception at the destination). Individual data link transfer of messages addressed to a specific end system (aircraft or ground receiver) may be required.

5. Support message priority handling. Data link messages will range from "routine" to "critical" in nature. The communications system should provide a priority system that will allow those messages deemed "critical" to avoid getting delayed by "routine" messages.

6. Provide mobile routing functions. Clearly, a communications system intended for aviation must deal with the fact that aircraft move about. The connectivity of a given aircraft (via a given subnetwork) will change with time and application. The communications system should deal seamlessly and transparently with the changes in subnetwork connectivity resulting from aircraft motion.

7. Provide for link-independent routing. The connectivity of aircraft via various subnetwork data links will change over time. The mobile routing functions from (6) above should deal with changes in subnetwork connectivity (in addition to connectivity changes within a given subnetwork). It is desirable to have a means for performing "policy routing" – i.e. to direct certain messages (or message classes) to specific subnetworks as a function of system policy.

Candidate Open System Protocols

There are only two candidate open system communications protocols currently existing that can meet the seven criteria for aviation data link application indicated above. The first is called the "Aeronautical Telecommunications Network" (ATN). The second is the Internet. This section will give a brief overview of each communications protocol, with emphasis on the advantages and disadvantages of each protocol with respect to the seven aviation data link selection criteria.

The ATN is an aviation-specific communications protocol set developed and standardized by the "International Civil Aviation Organization" (ICAO) for aviation data link applications. The ATN is built from a highly-tailored and somewhat modified set of the "Open Systems Interconnection" (OSI) communications protocols as standardized by the "International Standards Organization" (ISO). The design of the ATN is a complex layering of many ISO protocol standards, and it entails a quite-high link overhead. Sixteen distinct levels of communications priority are provided in the ATN protocol (although individual ATN subnetworks may reduce this to as few as two levels). Mobile routing with support for link independence and policy routing is provided by the ATN design. The addressing range of the ATN is huge – ATN addresses are longer than 20 bytes unless an address compression algorithm is applied.

The subnetwork interface (see Figure 2) protocol specified for the ATN is ISO 8208. ISO 8208 is an end-to-end, connection-oriented protocol. The ATN provides no direct way to support broadcast or multicast applications, since these are not available as part of ISO 8208 functionality. Various subnetworks within the ATN design provide link-specific broadcast/multicast mechanisms that extend or bypass ISO 8208, but these are not true open system applications in the design of the ATN.

The Internet's open system communications standards are published and maintained by the "Internet Engineering Task Force" (IETF). The subnetwork interface (see Figure 2) protocol of the Internet is the "Internet Protocol" (IP). Two alternate communications protocols are provided to operate above IP. The "User Datagram Protocol" (UDP) provides for broadcast/multicast

applications. (Note: UDP messages are limited to just under 64 kilobytes of total data length. This limitation is probably not significant to aviation data link applications.) The "Transmission Control Protocol" (TCP) provides for reliable end-to-end communications functions. The term "Internet protocols" here will refer to the complete set of IP, UDP, and TCP.

The Internet protocols are quite simple and bit-efficient as compared to the ATN protocols. The current Internet protocol addressing range is somewhat limited – IPv4 addresses occupy 4 bytes (compared to over 20 bytes for ATN addresses). A new version of the Internet protocols (IPv6) is coming into service which, among other changes, extends the addressing range – IPv6 addresses will occupy 16 bytes. (Note: ICAO has developed an addressing scheme for all aircraft worldwide – it requires only 3 bytes.)

While the current Internet protocols (IPv4) provide a place-holder to specify a sort of message priority (termed "type of service" (TOS)), the existing router implementations and infrastructure do not currently support this feature globally. The Internet designers have determined that it is a better utilization of network resources to optimize the system overall rather than to try to provide "special handling" for certain messages. It should be noted that IPv6 will provide for an effective message priority mechanism.

The mobile routing protocols of the current Internet treat all system routers and message paths equally – there is no concept of specialized subnetwork routing. (Internet routing is typically concerned only with the final destination address of the message, not its source.) It is a relatively straightforward addition to the Internet routing algorithms to provide for "policy routing" (see Communications feature (7) above). The "policy module" would need to be added only to those Internet implementations (the aviation DLPs from Figure 2) that require support for subnetwork-dependent routes (if this is deemed necessary for the aviation data link). It should be noted that the new version of the Internet protocols (IPv6) will provide a means to perform policy-routing.

Selecting an Open System Protocol

Based on the discussion of the ATN versus the Internet protocols, the Internet protocols seem the better choice for an open system aviation data link, particularly for non-flight critical functions. The Internet protocols are entirely open system and general, while the ATN uses tailored and modified versions of the ISO protocols specific to aviation. The infrastructure of the Internet is ubiquitous worldwide, while the ATN infrastructure would have to be built up and supported entirely by the aviation community. (Note: much useful aviation information is already available on the Internet today.) The Internet protocols allow for simple, inexpensive implementations that are readily available on a wide variety of existing platforms, while ATN implementations would have to be developed and maintained specially for aviation customers. The Internet protocols are more efficient in terms of bandwidth usage than the ATN, and the Internet has proven its extensibility and robust nature in the face of heavy usage.

Technically, it appears that the drawbacks of the current version of the Internet protocols (minimal policy-routing support, lack of direct priority support, limitation of UDP message length) are not "show-stoppers" for many aviation data link applications – in particular, those involved with the dissemination of weather and other "flight information". There are known ways to add most of these communications capabilities to the aviation-specific implementations of the Internet protocols (and they would not impact the operation of the rest of the standard Internet infrastructure). On the other hand, the ATN's lack of an open system broadcast/multicast mode could prove more difficult to overcome for aviation data link.

Path to Open System Implementation

In order to actually implement an open system communications system for aviation like that illustrated in Figure 1, the specific subnetwork DLPs of Figure 2 must be designed. This work is ongoing for the ATN – DLP specifications for Mode S, VHF radio, and SATCOM exist and are being validated. Development of DLP designs for the Internet protocols has begun with the VHF Data Link Mode 2 (VDL-2) subnetwork. (VDL-2 is a higher-capacity replacement for the current "Airline

Communications and Reporting System" (ACARS).
VDL-2 operates at 31.5 kilobits/second, as opposed
to 2.4 kilobits/second for ACARS. VDL-2 supports
binary messages, while ACARS is a character-
oriented system.) The VDL-2/IP design seeks
transparent interoperability with the ATN and other
users of the VDL-2 data link (transitional ACARS
operation, "Flight Information Service via
Broadcast" (FIS-B), etc.). The remainder of this
section will give a brief overview of the proposed
VDL-2/IP DLP design.

Figure 3 illustrates the typical architecture of a
VDL-2/IP installation (either avionics or ground
station). The "VHF Data Radio" (VDR) performs
the transmission and reception of VDL data. (The
VDR might also support VHF voice and ACARS
communications.) The VDR connects to a software
block termed the "VHF Management Entity"
(VME). The VME's software functions would be
hosted in a processor that might also support other
data link subnetworks such as SATCOM. The VME
contains an incarnation of a "Link Management
Entity" (LME) for each VDL-2 air-ground data link
connection currently being maintained. The LMEs
handle such functions as tuning the VDR and
performing link handoffs as the aircraft move
between the coverage areas of individual VDL-2
ground stations.

The VME supports two system interfaces. The
"Aviation VHF Link Control" (AVLC) interface is
a slightly modified version of the industry-standard
HDLC binary serial protocol. (Figure 4 illustrates
the AVLC frame format.) The AVLC interface
supports the transitional mode of ACARS (running
existing ACARS applications over VDL-2) termed
"ACARS Over AVLC" (AOA). The AVLC
interface was also chosen to support the FIS-B
application being developed through the RTCA SC-
195. The ATN's ISO 8208 interface is the other
component hosted in the VME. Note that the ISO
8208 interface and the ATN router function are
shown shaded in Figure 3 – these components of
the VDL-2/IP architecture could simply be omitted
if the particular implementation did not require
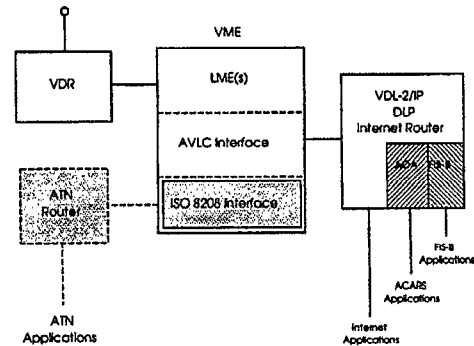support for ATN applications.

**Figure 3. VDL-2/IP Implementation
Architecture**

The VDL-2/IP DLP is basically just a
somewhat modified Internet router/host standard
implementation. (The Internet treats router and
end-system implementations as basically
interchangeable.) The Internet "Point to Point
Protocol" (PPP) that is one of the standard Internet
router/host interfaces is itself also a slightly-
modified HDLC, quite similar to AVLC. The
VDL-2/IP implementation will transform the PPP
standard interface into an AVLC interface. The
standard Internet "Address Resolution Protocol"
(ARP) will be used to map IP addresses to their
corresponding VDL-2 addresses. The separation of
AVLC frames into IP, AOA, FIS-B, and ATN
streams is performed using the technique called
"encapsulation" and illustrated in Figure 4. The
initial byte (or two) of the payload in an AVLC
frame is used to identify the type of data in the
frame. ISO 8208 packets go on to the ATN
processing, ACARS messages to their applications,
etc. while IP packets go on to the standard IP
processing. Standard ISO 9577 protocol encodings
of the "Initial Protocol Identifier" (IPI) byte are
used to specify the type of payload in the AVLC
frame. (Note: the current RTCA SC-195 FIS-B
message header definition in RTCA SC-195 also
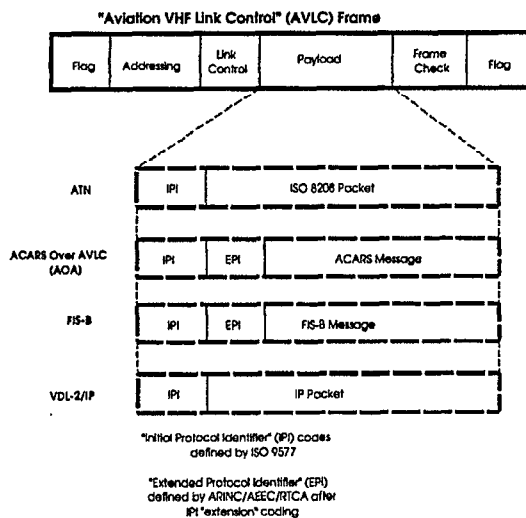utilizes an ISO 9577-compatible IPI/EPI coding.)

"Aviation VHF Link Control" (AVLC) Frame

Flag	Addressing	Link Control	Payload	Frame Check	Flag

| ATN | IPI | ISO 8208 Packet |

| ACARS Over AVLC (AOA) | IPI | EPI | ACARS Message |

| FIS-B | IPI | EPI | FIS-B Message |

| VDL-2/IP | IPI | IP Packet |

"Initial Protocol Identifier" (IPI) codes defined by ISO 9577

"Extended Protocol Identifier" (EPI) defined by ARINC/AEEC/RTCA after IPI "extension" coding

Figure 4. AVLC Frame "Encapsulation"

Summary and Conclusions

This paper has discussed the advantages to the aviation data link community of employing "open system" design in the data link communications system architecture. The two candidate open system protocols, ATN and Internet, have been outlined and compared against a set of criteria for aviation data link applications. It is argued that the Internet protocols should be selected as the communications framework for aviation data link. A design for inter-operating the Internet protocols over the existing VDL-2 subnetwork has been proposed and outlined. It appears to provide all the benefits of the Internet open system approach while simultaneously supporting the ATN (if desired).

Future work in this area clearly involves finishing the development and prototyping of the VDL-2/IP DLP design. Internet DLP designs for other aviation data link subnetworks need to be developed. (An outline of the Mode S subnetwork DLP design has already been done. It appears that a SATCOM or HF subnetwork DLP might prove to be similar to that for VDL-2/IP.) A complete end-to-end demonstration of the system would complete the design. Then, aviation data link could join the rest of the world "online".