ABSTRACT
The International Civil Aviation Organization (ICAO) has endorsed a concept for future aeronautical communications, which uses digital data links to supplement voice communications and provide improved air traffic services. A necessary part of this concept is an international infrastructure that manages digital data transfer between aircraft and civil air traffic control facilities. This communications infrastructure is the Aeronautical Telecommunication Network (ATN). It is the intention of certain ICAO member states to provide air traffic services (ATS) that require ATN avionics. As the civil-controlled airspace moves toward requiring new communication capabilities, the military will need to accommodate the ATN if worldwide-unrestricted airspace access is to be maintained. A description of the ATN is provided in this paper. This description includes the ATN solutions for mobility, low-bandwidth, and preference services. Typical applications of the ATN are also described, as well as implementation status. The paper concludes with a review of present military stratagems for the ATN.

THE ATN ENVIRONMENT
Commercial aircraft are expected to be equipped with multiple air/ground data links. This is a consequence of the limited spatial availability of the links and the comparatively higher cost of sending data over some links rather than others. Presently very high frequency (VHF) systems, which include the Aircraft Communications Addressing and Reporting System (ACARS) and its planned replacement, the VHF Digital Link Mode 2 (VDL2), are the cheapest to use. However, these are line-of-site systems and consequently have no coverage over the ocean. Satellite links such as those operated by Inmarsat and Iridium Corporations, and high frequency (HF) links operated by ARINC Corporation, are used to fill this gap. The Federal Aviation Administration (FAA) is planning to replace the present analogue voice radio system with one which can handle both voice and data. This system is known as the VHF Digital Link Mode 3 (VDL3). Finally, a communication link called Gatelink, designed for high-speed data transfer while the aircraft is at the airport gate, is being planned.

To operate within this environment, ATN is designed with four major elements. The first element is the ability to transfer data to an aircraft without sender knowledge of the aircraft location (network mobility). Network mobility is equivalent to a car that has two cellular phones, each phone operated by a different provider and each with different service volumes. A caller wishing to talk to the driver would be automatically routed through the correct service provider without the caller knowing where the car is or which service provider is connected. Notice that within the service volume, it is up to the service provider to locate the car. The second major element is the ability to simultaneously use the multiple air/ground links that are installed in an aircraft. This requires applications to specify cost, link, or speed preferences, which are used by the ATN when forwarding data. Based on these preferences, one link would be chosen to transfer data over others when multiple links are available. The third element is the ability to account for the low bandwidth air/ground data links available today and in the near future. Low bandwidth air/ground links require the use of data compression. The fourth element is the standardization of the services required by ATS applications (i.e., transport, session, presentation, and application functions) and the applications themselves, so that they are the same worldwide.

THE ATN MOBILITY SOLUTION
An essential feature of the ATN design can be gleaned because of the requirements for network mobility and use of multiple data links. There must be a method to advertise to all ground systems the availability of the multiple paths that can reach an aircraft. The obvious method to do this is to promulgate the paths to all ATN ground systems in the world. However, this approach,
termed flooding, is to be avoided. It introduces severe management overhead problems and growth constraints. An intuitive understanding of these problems is easily grasped by asking if the availability of a general aviation aircraft flying in Kansas should be advertised to all ground systems in China. The ATN designers' [1] have introduced the concept of a backbone router system. This concept is designed to restrict the distribution of aircraft path information to avoid the problems of flooding, but still allows every ground system the ability to send data to any aircraft.

Figure 1 is an illustration of a simple backbone implementation. Multiple routers, represented by circles, are a part of the ATN system. The routers in the bold circles are designated backbone routers. Each aircraft has an ATN address assigned to it. Data destined for an aircraft use this address. The address also uniquely determines the home domain of the aircraft. Every home domain has at least one backbone router in it.

![Figure 1. Distribution of Mobile Information in the ATN](image)

When an application existing on a host machine (represented by squares in Figure 1) wishes to transfer data to an aircraft, it provides the destination address of the data and delivers the resulting network packet to its nearest router. In the example, assume that H1 has delivered the packet to R8. R8 has no information about the aircraft. Under these conditions, R8 always sends the packet to its nearest backbone router, which is R2. R2 does have information about the aircraft and forwards the packet to R1, which in turn sends the packet to R7 for delivery.

A more informative case is that of host machine H2 wishing to contact the aircraft. As described above, R18 receives the packet and forwards it (through R16) to R5. This backbone element has no information about the aircraft. The ATN rule in this situation is: Forward the packet in the direction of the home domain for this aircraft. In this case, R5 forwards the packet to R4. The same rule applies at R4, and the data is forwarded to the router in the Home Domain, which does have routing information about the aircraft. Subsequently, the data is forwarded to router R2, then through R1 and R7 for eventual delivery to the aircraft.

In the ATN, the protocol which distributes the aircraft path information to the backbone router is the Inter-Domain Routing Protocol (IDRP) [2]. This protocol is also used by the aircraft to inform the ground routers that it is available for network communications.

**PREFERENCE BASED SERVICES**

The ATN mobile routing solution must allow for multiple paths to an aircraft and for these paths to be used simultaneously. Applications may require delivery via specific links or with specific Quality of Service (QOS) to control costs or for safety and performance reasons.

Consider the case in which an aircraft is simultaneously in the service area of both VHF and satellite communication. In Figure 1, the aircraft router, R0, is in contact with the ground via both satellite (through R9) and VHF (through R7). Applying ATN backbone dissemination rules to the satellite path, backbone router R4 has an entry for the aircraft. The entry shows that the aircraft is available...
through R9 over a satellite connection. R3, the home domain backbone router, now has two routes available for the aircraft—one through R3 over VHF, the other through R4 over satellite.

ATN allows a ground application to indicate the specific QOS/priority desired and a list of preferences for data link delivery. For example, the packet should be shipped via VHF and if VHF is not available, satellite. This information is recorded in each packet emitted by an end-system destined for an aircraft. Each ATN router can then examine the information and choose the best path to use when forwarding the packet. For example, if end-system H2 sends a packet to the aircraft, the packet will eventually reach R4, which will send the packet to R9 or R3, depending on the QOS/preference indicated.

ACCOMMODATING LOW BANDWIDTH LINKS

The throughput available for the air/ground links expected to operate with the ATN is much smaller than the typical ground/ground links used today. In the case of VDL2, 32k bits per second are shared among multiple aircraft, using carrier sensed multiple access (CSMA) technology. Because of these low bandwidths, it is required that the ATN perform compression. The ATN standard allows for multiple types of compression to occur within ATN routers. The exact compression or compressions performed on a data unit transferred between air and ground is negotiable and determined when an aircraft enters the jurisdiction of an ATN router. Header compression of the network protocol information is presently required. The ATN uses the open systems interconnection (OSI) connectionless network protocol (CLNP) and typically will reduce the 100 bytes of CLNP header to 6 bytes. A second available technique uses the deflate algorithm, originally developed for use over the Internet. This technique is similar to that used for the gzip and pkzip compression utilities available to Unix and Microsoft users. Deflate compresses the entire data unit transferred, both protocol headers and user data.

ATN APPLICATIONS

As part of the international standardization of ATN, four air/ground applications have been standardized: Context Management (CM); Automatic Dependent Surveillance (ADS); Controller Pilot Data Link Communications (CPDLC); and Digital Flight Information Services (D-FIS). The D-FIS application set allows pilots to request continual updates about flight conditions, for example, weather, airport conditions, etc. The CPDLC application set is meant to replace the present controller/pilot voice interactions with digital messages to the extent possible. CPDLC includes over 200 uplink and 100 downlink messages. The ADS message set is designed to allow position information determined by onboard navigation equipment to be transferred to the ground in order to supplement present radar position reporting. CM messages support a directory service that allows the aircraft to ‘login’ whenever it enters a new ATS authority (e.g., the U.S.) and exchange application and associated network address information with the ground CM application server. CM messages control this process. The resulting directory is used to determine the network addresses of aircraft and the installed applications.

ATN IMPLEMENTATION

The ATN is an international civil aviation effort; as such, the standards for the ATN are being determined by ICAO. Presently, all-necessary documentation has been completed and approved by the ICAO. The ATN Standards and Recommended Practices (SARPs) will be published in August 1998 with an applicability date of November 1998. Once this occurs, as ICAO is a United Nations treaty organization, ICAO states must adhere to the SARPs when implementing ATN.

Within the U.S., interim data link implementations are being scheduled. This is because it is felt that a complete ATN installation, which supports all applications, would not be available soon enough due to the significant changes required in FAA ground infrastructure, FAA controller workstations, and avionics. The first step toward full ATN capabilities will be an ICAO SARPs compliant communications infrastructure. Succeeding steps will build up the supported message set and available air/ground data links. The first step, which includes limited CPDLC and CM application capability, is to be installed at a key site for operational evaluation in 2001. This system will use a single data link (VDL2) and will employ four classes of CPDLC ATN messages. These are:

- Transfer of Communication (TOC) - Provides pilot with voice frequency of next sector;
- Initial Contact (IC) - Informs controller that aircraft has data link capability;
- Altimeter Setting Message (ASM) - Provides altimeter assignment to the aircraft;
- Pre-defined Message (PDM) - Provide text message transfer between controller and pilot.

Subsequent phases will support multiple data links and increase the number of messages used. It is intended that the full CPDLC message set, applicable to en route
airspace, will be implemented by 2004 and support for additional air/ground data links will be added by 2007.

Eleven U.S. air carriers in cooperation with the FAA have formed a consortium, ATN Systems Inc. (ATNSI), to address institutional issues involved with developing and fielding ATN software which requires peer elements in both the public and private sector. The consortium will license ATN software to interested manufacturers to (1) reduce development costs, (2) guarantee interoperable installations, and (3) reduce implementation time. ATNSI has contracted for delivery of software by 1999 with the expectation that certification and operational evaluation will be completed by the early part of 2001. The products of ATNSI are expected to be the basis for the initial ATN airborne implementations.

The European Civil Aviation Conference member states have committed to a program to increase the capacity of the present air traffic management system and to optimize the interface between ATS and airports using extensive automation and enhanced data communications. The program is denoted the European Air Traffic Control Harmonization and Integration Programme, or EATCHIP. ATN is listed as one component within this program. The European ATN project includes standardization activities, ATN trials, prototypes, and validation programs. The European prototyping, testing, and validation efforts of ATN are expected to conclude by 2005. It is thus expected that ATN European implementation will occur in the 2005+ time frame [3]. However, the U.K. is planning on having operational ATN capability in place over the North Atlantic by 2001.

**MILITARY ISSUES**

There are a number of Federal, Department of Defense, and Air Force documents that require military aircraft to comply in peacetime with civil aviation requirements in civil-controlled airspace. In addition the U.S., as a member of ICAO, accepts ICAO standards as binding. The U.S. Air Force’s Electronic Systems Center (ESC) global air traffic operations/mobility command and control (GATO/MC³) program office carried out a study which assessed the requirements, primarily for large transports, for operation in the new communication environment [4-6]. The need to conduct operations worldwide, in peacetime and in times of crisis, means that military aircraft must operate in civil-controlled airspace and comply with future ICAO requirements. In order to comply, an ATN compatible avionics system with integrated data links may be required.

To achieve worldwide air/ground link capability certain military aircraft will be required to equip their aircraft with dual beyond-line-of-sight (BLOS) data links, and line-of-site (LOS) data links. The links must comply with ICAO requirements for aeronautical mobile service. Currently, only the Inmarsat satellite system has been approved for use as a BLOS ATS data link. ICAO has been developing the SARPs for an HF data link (HFDL) which will allow it to be used as an ATS data link. The military, along with several airlines, are encouraging this use of HFDL due to the large installation cost of the Inmarsat system and since many military aircraft, particularly the cargo carriers, are already equipped with HF antennas for voice operation. The management of the data links, including choice of media, will require the addition of a communications management function (CMF) that contains an ATN router, and will require supporting applications.

Whenever future data link military requirements are discussed, the possibility of the use of existing and planned military data links has been raised. The idea is to save money by using the existing equipment and by providing a ground entry point into the ATN using a translation process. The two data links typically mentioned are UHF SATCOM for BLOS and Link16 (Joint Tactical Information Distribution System [JTIDS] or Tactical Digital Information Link [TADIL] J) for LOS.

This approach, while feasible, presents a number of problems to be overcome. To be approved as an ATS data link, the military data links would have to meet the service and performance requirements in the ICAO SARPs for safety communications. This implies, in part, that UHF SATCOM would have to meet delay recovery time requirements (90 seconds after satellite failure). The demand-assigned multiple access (DAMA) protocols would need to provide ATS data a higher priority. The UHF SATCOM avionics equipment would need to provide an input to the CMF and would have to be modified to implement current CMF protocols. The effect of added ATS traffic on the UHF SATCOM data link may result in poor performance for both military and ATS data when using this approach. ATS applications would also need to be implemented in the avionics. A ground entry point into ATN would need to be implemented in UHF SATCOM ground terminals. In addition to these technical issues, programmatic issues regarding the modification of the system requires Air Force-wide and joint service concurrence and funding.
The use of Link16 has been examined in enough detail to indicate that the ATN networking issues may be problematic, while the link performance is adequate to meet ATS data link throughput requirements. The Link16 terminal employs a MIL-STD-1553B data bus that does not support ATN communications without extensive protocol changes. The Link16 network management software and hardware are inadequate to support ATN network administration and would need to be modified. Allocating Link16 time slots for ATN would be difficult and even inefficient, since TADIL J messages defining positional and navigational data are already sent into the network, and ATN messages would duplicate these messages. Once the technical issues were solved, SARPs would have to be developed in order to use Link16 as an ATS data link. An approach that employs a ground entry into ATN and translation of the TADIL J positional data is conceivable. But, since Link16 is a line-of-sight tactical system, it would require installation of an infrastructure of approximately 300 Link16 terminals for U.S. en route and terminal areas at an estimated cost of $100M. It is also unlikely that other countries would adopt a U.S. DoD-unique infrastructure which has not been standardized by ICAO.

The issues related to the use of current data links and the interoperability requirements with civil avionics has led many in the military to conclude that the most feasible approach is to equip with civil ATS data links. Manufacturers are addressing the use of civil data link systems on military aircraft by developing solutions that port the civilian HFDL hardware and software onto circuit cards for installation into military HF radios. The addition of VDL2 and VDL3 protocols to military radios is being handled in a similar manner for VHF radios. Interfaces to a commercial off-the-shelf CMU are also being developed for military radios and for the military-specific flight management systems. Once ATN is implemented, the expected upgrades to the commercial avionics would also benefit the Air Force, provided they were carrying the appropriate equipment.

The primary military issue for use of ATN is security. Military aircraft will require the ability to inhibit transmission of data using ATS data links and ATN. In addition, the military use of ATN for data transmission may require encryption of the data. Preliminary efforts have begun to test the ability of the current ACARS network to handle encrypted data. It is expected that these efforts will continue as ATN is developed. There are a number of proposals that address the issue of encryption of the aircraft’s tail number. The primary issue is that the tail number can be extracted from the network address and the aircraft’s future position may become compromised.

One proposal employs a ground server to dynamically assign tail numbers from a fixed pool of tail numbers. A second proposal implements an encryption algorithm to the database of aircraft addresses.

The issue of authentication between controller and pilot digital data messages is another important area for consideration by the military. ICAO is currently developing enhancements to the ATN standards to allow for authentication of application information, routing information, and systems management information exchanges. These enhancements to ICAO ATN standards are expected to be completed/approved in 2000. The authentication standards may need to be completed before widespread implementation of ATN occurs by the military.

REFERENCES


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