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Interoperability issues for air-ground datalink applications

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SUMMARY

This paper summarises an investigation carried out by Eurocontrol into the issues of interworking between independently developed implementations of the CNS/ATM-1 SARPs. The conclusion of this analysis is that interoperability is not straight-forward, and there are a number of choices that implementors face where a “wrong” decision will be detrimental to the interoperability as perceived by the users (controllers and aircrew).

The paper makes proposals of the steps that ATNP can take to minimise these interoperability problems.

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1. INTRODUCTION

Eurocontrol has been carrying out an engineering analysis of two independently developed implementations (one airborne, on ground-based) of datalink applications as specified in the CNA/ATM-1 SARPs, with a view to predicting any potential problems of interoperability. The conclusion of the analysis was that there were significant interworking problems with these independent implementations. This paper therefore documents for ATNP WG3 the approach used in the analysis, and the lessons learned, in the hope that steps can be taken to minimise the problems of interoperability in the future.

ATNP WG3 is invited to note the finding in this paper and to consider the recommendations described in section 0

2. BACKGROUND

2.1 What Leads to Interoperability Problems?

Interoperability problems arise because of differences in interpretation or application of a specification. These differences can arise from a number of reasons:

- Technical constraints - the hardware/software environment in which the implementation is to function presents some limitations which are difficult to program round, e.g. memory availability, integer size, stack size, number of parameters passed across internal interfaces, finite size of temporary and long term storage. The implementor has to adopt some "pragmatic constraints" to protect his hardware/software environment from being compromised.
- Selection of technical options - the base specification allows a number of valid technical alternative approaches to achieve the same communication purpose, and the implementor selects only those options that are useful in his specific environment.
- HMI constraints - the Human-Machine Interface is limited in the amount of information that can be gathered (input) or displayed (output) and some pragmatic selection is necessary.
- Marketing or service constraints - the marketing or service profile of the product may be so devised that certain capabilities that are allowed in the specification are out of scope of the product characteristics that the vendor or service provider is seeking to achieve.

These factors were observed in the 1980's by the designers and implementors of the ISO OSI standards, and a means of detecting and correcting deviations which could lead to interoperability problems was devised.

2.2 ISO Approach to these problems

The first step that was adopted in the ISO arena to help address conformity and interoperability was the introduction of the "Implementation Conformance Statement" (ICS). The ICS was developed in conjunction with the base specification, and set down in a tabular form the boundaries and constraints included in the base specification. ISO 9646 Part 7 describes the notation used in the ICS to indicate the expected behaviour of an implementation with respect to each entry in the table.

However, the ICS table was only able to restate the requirements that were explicit or implicit in the base specification, but did not address the problems of subsetting for particular applicability. Meanwhile, the implementor groups that were forming in the mid 1980's realised that there were some fundamental problems with the way specifications evolve in standardisation committees, especially international standardisation committees as found in ISO and ICAO. The base specifications emerging from such committees had to include protocol elements to address the needs of all the world regions in which the specification may be applied. This meant that differences of culture, language and working methods had to be addressed. The frequently used solution was to include "options" in the protocol specifications, which could be utilised "where appropriate.

Unfortunately, the high proportion of "optional" elements gave implementors an unintended degree of freedom as to what they would implement, and different choices by different implementors were the basis of many of the early interoperability problems. It was quickly recognised that to achieve open interoperability, there had to be a means by which there could be agreement between vendors on common functional subsets of the base specifications. This evolved into the concept of the "Functional Standard", or "Profile", which were then developed in various regional implementor workshops in North America, Europe and the Asia-Pacific area.

A profile can be specified to meet a particular set of functionality (what we would call an "operational requirement" in the aeronautical arena). The profile incorporates a selection of the appropriate base specification(s), the subsetting rules or constraints on the optionality and pragmatic constraints on unbounded parameters. In this way, all implementors can adopt the same interpretation, option selection and value constraints, which is a key prerequisite to the later interoperability testing, demonstration and commercial deployment of interoperable products.

2.3 Relevance to the Aeronautical Arena

In the aeronautical arena, the ATN CNS/ATM-1 package SARPs were developed on the basis of a plethora of operation requirements that were compiled by expert representatives with operational experience in the voice environment. However, these requirements were not based on any specific datalink-oriented operating concept or operational scenarios. Consequently, the SARPs embody all of the data exchanges that might be required, based on experience of, and extrapolation from, voice exchanges.

This means that there is an extensive set of data exchanges that are standardised, more than would be required in any particular operational scenario. Reasons for NOT using some of the data exchanges include:

- exchange is not relevant in a particular region (e.g. ADS position reports in areas of multiple RADAR coverage)
- underlying data communications services can not meet the required communications performance (e.g. for urgent and distress communications)
- data link service requires a level of automation (ground or airborne) that is not available
- Operational services are now being defined that only use a small subset of the available message exchanges.

All these reasons point to the aeronautical community now being in a very similar position to those ISO implementors of the 1980’s. The published base specifications (SARPs) contain far more functionality than is required for the first batch of operational services that are going to be deployed. In order therefore to minimise the development costs (exclude the need for redundant software) and maximise the interoperability prospects (ensure all implementors are making the same interpretations and using the same or compatible subsets), profiling is necessary.

3. THE CONCEPT OF "OPERATIONAL SERVICES"

The CNS/ATM-1 SARPs describe an extensive set of functionality designed to meet all of the operational requirements that had been identified by the ADS Panel up to 1995. In Eurocontrol, there is an international working group of operational experts who have been evaluating how datalink applications would be used in Europe. This group has defined a set of "Operational Services", based on the data exchanges allowed by the SARPs, that meet European operational requirements. These are published in the "Operational Requirements Document" (ORD).

The ORD services use only a subset of the functionality described in the SARPs, to fulfil the necessary data exchanges required for specific operational scenarios. The table below lists some of the services identified by this group, and the status of that service in the current version of the ORD.

Service	ORD status	Based on:
Automatic Dependent Surveillance (ADS)	Automated Downlink of Airborne Parameters (ADAP) group of services - not yet finalised, except for CAP (see below)	ADS
ATC Communications Management (ACM)	1.0, stable	CPDLC
Clearances and Information Communication (CIC)	1.0, stable	CPDLC
Controller Access Parameters (CAP)	1.0, stable	ADS
Datalink Initiation Capability (DLIC)	Not yet finalised, source ICAO MATS-DLA.	CM
Datalink Operational Terminal Information (D-OTIS)	1.0, stable	FIS
Datalink Runway Visual Range (D-RVR)	1.0, stable	FIS
Datalink SIGMET	Not yet finalised	FIS
Departure Clearance (DCL)	1.0, stable	CPDLC
Downstream Clearance (DSC)	1.0, stable	CPDLC
Dynamic Route Availability Service (DYNAV)	Not yet finalised	CPDLC
Flight Plan Consistency (FLIPCY)	Not yet finalised	ADS
Pilot Preferences Downlink (PPD)	Not yet finalised	CPDLC

As can be seen from the table, there are more operational services than there are datalink applications. It therefore follows that each service only utilises a subset of the functionality provided by the datalink application SARPs on which it is based.

4. MEANS OF COMPARING IMPLEMENTATIONS

In performing the interoperability assessment, a structured approach was adopted, based on the following levels:

Level	Description	Examples
Service Level	Services as described in the ORD	CIC, ACM, DLIC etc. descriptions
Functional Level	How the services map onto (utilise) the functionality provided in the Air-ground ATN SARPs	Protocol Implementation Conformance Statements for the above
Communications Level	How the communications mechanisms described in the ATN SARPs are implemented	Usage rules, dialogue management, encoding rules

The method used in the comparison covered the following series of steps:

Step 1 - Selection of Services

There are a variety of services offered in each implementation, and in the ORD.

The basis of service selection for this analysis was that a service must be:

- described in the ORD
- implemented in the ground system AND in the airborne system
- implemented in a way which is intended to be compatible with the ATN SARPs

Only services which meet ALL these criteria were analysed.

Step 2 - Comparison with the ORD

For each service that was selected, and for each implementation, a comparison was made between the service as implemented and the service as defined in the ORD, to determine the "completeness" of the implementation.

Step 3 - Direct comparison between implementations

Having obtained a direct comparison of each of the implementations with the ORD, they can be compared with each other.

Step 4 - Analysis

Following the comparison, which highlighted the difference between the service that affect interoperability, each of the differences can be analysed to determine the consequences of the difference.

4.1 Service Level

The service level analysis considered services as described in the ODIAC ORD. It was based on a comparison of PETAL-II and EOLIA specifications with the ORD. It was not found to be possible to apply a formal approach at this level, owing to the abstract nature of the services and the different specification approaches.

A comparison of SARPs mapping and user requirements was produced.

Services were selected for in-depth analysis based on the observation that any EOLIA aircraft must be able to respond to all the PETAL II services that can be initiated from the ground in an ATN environment. This gave the following selection:

Service	Based on (Data Comms Service)
Datalink Initiation Capability (DLIC)	CM
ATC Communications Management (ACM)	CPDLC
Clearances and Information Communication (CIC)	CPDLC
Controller Access Parameters (CAP)	ADS

4.2 Functional Level

The functional level considered the selection of application elements and message sets from those possible in the SARPs, to meet the requirements of each service (above). The usage rules in chapter 7 of each SARPs were taken into consideration. A formalised approach was adopted based on well-established conformance and interoperability standards. A Protocol Implementation Conformance Statement (PICS) proforma was produced for each of the following services:-

- Datalink Initiation Capability (DLIC) -> CM
- Clearances and Information Communication (CIC) -> CPDLC
- ATC Communications Management (ACM) -> CPDLC
- Controller Access Parameters (CAP) -> ADS

An example PICS proforma is given below:

The VCI message contains the instruction to change data and voice communications channels. It shall be composed of the following CPDLC message elements:

Table "n" Voice Change Instruction (VCI) Message

Item	Item Description	Status	
		SEND	**REC**
uM#117	CONTACT unit name frequency	O C2 C2	M M M
uM#120	MONITOR unit name frequency	O C2 C2	M M M
N2	CONTACT ME AGAIN ON frequency	O M	M M
N2	MONITOR ME AGAIN ON frequency	O M	M M
uM#118	AT position CONTACT unit name frequency	O C1 C1 C1	M M M M
uM#119	AT time CONTACT unit name frequency	O C1 C1 C1	M M M M

Item	Item Description	Status	
		SEND	REC
uM#121	AT position MONITOR unit name frequency	O C1 C1 C1	M M M M
uM#122	AT time MONITOR unit name frequency	O C1 C1 C1	M M M M
unit name	Facility Designation (4 - 8 characters) Facility Name (3 - 18 characters) Facility Function	M O M	M O M
Facility Function	(0) centre (1) approach (2) tower (3) final (4) ground Control (5) clearance Delivery (6) departure (7) control (8) radio	C2 C2 C2 C2 C2 C2 C2 C2 C2	M M M M M M M M M
frequency	HF (Range 2,850 - 28,000 kHz, in 1 kHz increments) VHF (Range 118.000 - 136.990 MHz, in 0.005 MHz (5kHz) increments) UHF (Range 225.000 - 399.975 MHz, in 0.025 MHz (25kHz) increments) Sat Channel (12 digit telephone number)	C2 C2 C2 C2	M M M M
Position	Fix Name Navaid airport (1 - 4 characters) Latitude Longitude Place Bearing Distance	C2 C2 C2 C2 C2	M M M M M
Fix name	Fix (1 - 5 characters) Latitude Longitude	M O	M O
Navaid	Navaid Name (1 - 4 characters) Latitude Longitude	M O	M O
Latitude Longitude	latitude longitude	O O	O O
Latitude	Latitude Type Latitude Direction (North or South)	M M	M M
Latitude Type	Latitude Degrees (Range 0-90, resolution 0.001 degrees) Latitude Degrees Minutes Latitude Degrees Minutes Seconds	C2 C2 C2	M M M
Latitude Degrees Minutes	Latitude Whole Degrees (0 - 89) Minutes (0 - 59.99, resolution 0.01)	M M	M M
Latitude Degrees Minutes Seconds	Latitude Whole Degrees (0 - 89) Whole Minutes (0 - 59) Seconds (0 - 59)	M M M	M M M

Item	Item Description	Status	
		SEND	REC
Place Bearing Distance	Published Identifier Degrees Distance	M M M	M M M
Published Identifier	Fix Name Navaid	C2 C2	M M
Degrees	Magnetic (Range 1-360, resolution 1 degree) True (Range 1-360, resolution 1 degree)	C2 C2	M M
Distance	Nautical Miles (Range 0 - 999.9, resolution 0.1NM) Kilometres (Range 0-8000, resolution 0.25Km.)	C2 C2	M M
Time	Hours (Range 0 - 23, resolution 1 hour) Minutes (Range 0 - 59, resolution 1 minute)	M M	M M

Notes - "N2" signifies use of the free text message number …
C1 - Mandatory if the item to which this sub-item belongs is present
C2 - one and only one of the items in this group must be present

Comparison of the PICS filled out for each implementation then revealed the areas where there are interoperability issues.

4.3 Communications Level

The communications level is concerned with “bits-on-wire” compatibility based on the detailed versions of ATN protocols specified. The assessment at this level involved baseline comparison and convergence strategy for PDU selection, encoding and mapping onto underlying communications stacks. It also addressed the need for ongoing configuration control (as the implementations migrate from “early” versions of the SARPs through to the 9705 version).

The approach was based on claims of conformance to ICAO documents, together with reported defects that have been resolved by the ICAO ATNP Change Control Board (CCB). A detailed analysis of PICS for the supporting communications layers was not performed, as the technical requirements are believed to be sufficiently unambiguously specified.

5. RESULTS

5.1 Incompatibilities

Both of the implementations which were studied were capable of sending message elements that the other implementation could not process.

Both implementations made restrictive selections of the parameters in message elements that could be input and/or displayed, particularly for parameters where the SARPs allow a number of possibilities, e.g.

- speed,
- position,
- level.

5.2 CPDLC closure

The CPDLC closure is clearly problematic as specified. The "End Service" message is being considered for use when control is transferred between sectors within a single ATC centre, and hence without the datalink being interrupted. The CPDLC-End service is used to close the connection, but there are some unexpected situations with respect to outstanding responses (particularly negative responses) which can arise.

5.3 Ground implementations do not conform to SARPs

Although this was not the original intention, the “shall” clauses in the SARPs have in fact been constructed to set down the requirements on airborne implementations, which are effectively the “client” systems. Ground implementations take the service provider role, and as such, only need to implement those “shall” clauses that correspond to services that the ground system is offering.

A good example is the support of emergency mode in ADS. If the ATSO has an operating concept that any emergency situation is handled using voice communication only, there is no need to implement ADS emergency reporting in the associated ground automation, even though the SARPs say that support of emergency mode is mandatory.

In summary - ATNP WG3 should recognise that Regional Planning Groups, ATSOs, and individual ATC centres will only need to implement a subset of the total functionality provided by the SARPs, which is appropriate to the local operating conditions and requirements. An ATC centre should not be regarded as "non-conformant" for not implementing those services which are inappropriate for the area, or which it believes it can offer more effectively based on voice communication.

5.4 Need for “multi-lingual” airborne implementations

The corollary to the above observation is that airborne implementations have to be able to work in accordance with whatever local conventions and restrictions have been applied by the ATSO for the area of operation. Examples where the airborne system has to take care to include only information types that the local ground system can handle include:

- requesting of LACKs for downlink messages, where the ground can choose between “Required”, “Permitted” or “Prohibited”,
- use of only the permitted SPEED parameters, IAS, True or Ground, knots or km/hr, or mach,
- Longitude/latitude measured in degrees to 0.001 degree, or degrees and minutes to 0.01 minutes, or degrees, minutes and seconds to whole seconds,
- Level (altitude) in feet, meters, flight level or metric flight level.

In conclusion, airborne implementations can not be subsets, unless the aircraft is destined to operate exclusively in a particular geographic area where only a subset of services are available. This is unlikely to be the general case. An airborne implementation must be a FULL implementation. Moreover, the airborne implementation needs some PRIOR KNOWLEDGE of what is acceptable in downlink messages for each ATC centre where it wishes to enter into datalink operation, if communications are to be successful.

5.5 New “Usage Rules” arising from the ADS Panel

It was noted that the ADS panel are documenting new “usage rules” (“Potential ADS Material for PANS-RAC and Annexes”) which, had they been established earlier, would have been incorporated into chapter 7 of the SARPs. The new material includes “shall” statements. This means that an implementor needs to be aware of what is currently being published by the ADS Panel as well as what is in ATN SARPs in order to complete a successful implementation.

As an example, The use of "Service Not Available" (UM 162 in CPDLC) has been proposed by the ADS panel to be used as the response to any downlink message for which the ground can not provide automated handling. (ADSP-JWG/A&B-WP/60 page C-5 para 2.3.1.1) If this is accepted, it needs to be recognised in avionics implementations, so that it does not lead to unnecessary closure of the data link.

Another example relating to multiple message elements in a CPDLC message, now states that "…the response shall contain as many message elements (and in the same order) as there were message elements requiring a "Y" in the initiating message." (Draft Modifications to Annexes and PANS-RAC for ATS Data Link Applications)

6. RECOMMENDATIONS

ATNP WG3 should develop generalised PICS proformas for each of the datalink applications, to allow regional subsetting and implementation conformance statements to be developed in a consistent manner.

The appropriate sub-group should ensure that the issues surrounding the use of the CPDLC "End Service" message, and CPDLC-End service are unambiguously and completely specified.

The significance of additional usage rules from the ADS Panel needs to be recognised and accommodated in the ATN SARPs and/or Guidance Material.