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PRELIMINARY STUDY OF SATELLITE SPECTRUM REQUIREMENTS

Review and Update of ESA SDLS and IATA studies

(Presented by Christian Pelmoine)

EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

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Abstract

This report contains a review and critique of a study undertaken by ESA on their Satellite Data Link System (SDLS) from the viewpoint of radio spectrum requirements. In carrying out the review a number of issues have been raised which affect the resulting spectrum calculations. In addition the assumptions were compared with an earlier study undertaken by IATA.

Keywords

SDLS	AMS(R)S	Data link	Vocoder
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FOREWORD

The use of satellite-based communications to support civil aviation requirements has been discussed for over 10 years. The amount of spectrum needed for these satellite systems has been estimated many times based on the anticipated uses ranging from passenger communications to safety-related Air Traffic Management applications. The projected numbers of aircraft equipped were also an important part of the estimates. Civil aviation has presented its case to various International Telecommunications Union (ITU) world radio conferences to defend the need for dedicated spectrum in the aeronautical L-band but the level of effective usage of the band has so far fallen short of the projections.

The European Space Agency (ESA) has proposed a new satellite system – Satellite Data Link System (SDLS) – which is specifically aimed at supporting safety and regularity of flight communications. As part of the feasibility study of the system, a study was commissioned by ESA, which included an estimate of the amount of spectrum required for a range of applications within this category.

This report contains a review of the spectrum calculations in the ESA study and a critique of the results. As a starting point one of the earliest studies on civil aviation spectrum needs – commissioned by the International Aviation Transport Association (IATA) in 1991 – was reviewed and the methods and assumptions compared with the ESA study.

1 OBJECTIVES, SCOPE AND METHODOLOGY

1.1 Objectives

The purpose of this report is to present a review of a study with respect to radio spectrum issues commissioned by the European Space Agency (ESA) entitled "*High Performance Mobile (Communication) System - Potential Applicability to Satellite Data Link System (SDLS)" (ESA Contract n°13019/98/NLUS)* [Ref 1]. During the review areas that needed updating were identified and the comments and corrections to the report, with justification, are contained in this report.

In undertaking this work, a review of the one of the first civil aviation satellite spectrum requirement studies was also undertaken to compare methodology, assumptions and conclusions against the ESA study. This study was undertaken by IATA in 1991 [Ref 2] in support of the need for dedicated aviation satellite spectrum at ITU WARC 1992.

In addition to the above cited documents, other AMSS related documents that have become available since the SDLS study was undertaken were also reviewed e.g. RTCA DO-270 [Ref 6], DO-262 [Ref 7] and RTCA DO-210D [Ref 8]. A list is given in section 5.

1.2 Scope

This report covers the assumptions used in the ESA SDLS study related to determining the spectrum requirements and does NOT comment on the technical design and rationale for the SDLS itself.

1.3 Overview of the Document

This report contains 3 main sections –

- Section 2 gives an overview of the IATA Spectrum Study.
- Section 3 contains a review of the ESA SDLS study regarding spectrum requirements and a comparison with the approach taken by the IATA study.
- Section 4 gives some concluding remarks on the report.

1.4 Methodology

The documents were reviewed to highlight differences between the IATA and ESA studies and also in the light of more recent developments in satellite and data communications in the areas of –

- Approach
- Methodology
- Assumptions
- Traffic Requirements versus applications
- Geographical differences
- Traffic volumes

2 IATA SATELLITE SPECTRUM REQUIREMENTS STUDY

2.1 Background

In the late 1980's satellite technology started to become available to aviation. Satellite communication and navigation systems were being proposed as a major evolutionary step in meeting a common aviation need to achieve a harmonised global infrastructure.

To ensure that aviation had the required spectrum in a dedicated band it was necessary to demonstrate that aviation had detailed and realistic requirements to use the spectrum. The key event at that time was to provide a sound aviation case to the International Telecommunication Union to ensure that aviation had the spectrum it needed to cope with the projected communications traffic levels up to 2020.

The aviation community united to provide the necessary evidence to justify the spectrum requirements. As part of this effort IATA commissioned a study to get an objective determination of the spectrum requirements for the aeronautical mobile safety satellite system over the next century. The study formed the main contribution to the ICAO Communications/Meteorological/Operational meeting in 1990. Therefore the resulting report [Ref 2] fulfilled its purpose and was instrumental in the establishment of the International Civil Aviation Organisation (ICAO) position for the World Administrative Radio Conference (ITU-WARC) in 1992.

However since that time the amount of exclusive spectrum dedicated to Aeronautical Mobile Satellite (Route) System (AMS(R)S)[1] has been progressively reduced to zero due to a large extent to the limited utilisation of the spectrum compared to predictions combined with the pressure from other users for more spectrum in the L-band.

2.2 Approach

At the time of the study in 1991, there was a general belief that mobile satellite communications with aircraft could only be financially viable if all forms of communications could be handled by a single system but with a priority and pre-emption capability for safety and urgency communications. Consequently the spectrum study took into account the 4 main categories of uses –

- Air Traffic Service Communication (ATSC)
- Airline Operational Control (AOC)
- Airline Administrative Communications (AAC) and
- Air Passenger Communications (APC)

[1] AMS(R)S, is the term used by ICAO and ITU for satellite systems supporting two-way communications related to the safety and regularity of flight along national or international civil air routes.

The study was based on a satellite system using the INMARSAT infrastructure primarily using global beams augmented by regional spot beams where there was dense air traffic (e.g. North America or Europe). Various regional satellite systems were being considered at the time.

2.3 Methodology

The study adopted a logical approach by identifying the following criteria –

- the airspace where AMSS[2] was required in the years 2000, 2010 and 2020,
- the functions of the AMSS,
- the class of aviation using AMSS and percentage equipage over time,
- the communications services to be supported in various parts of the world over time,
- the Peak Instantaneous Aircraft Count (PIAC) in the satellite beams including predicted growth for years of 2000, 2010, and 2020,
- The quantity of traffic generated from data and voice,
- Apportioning traffic to either global or spot beams,
- Allowing for evolutionary improvements in the satellite technology over time e.g. lower-rate vocoders, frequency reuse, etc.

The study pointed out that it was difficult to predict future requirements and assumptions had to be made. Following the report the minimum aviation bandwidth requirements were increased to 29.5 MHz of which approximately one-third were related to safety communications i.e. AMS(R)S.

2.4 Assumptions

The study focused on the worldwide radio frequency bandwidth and spectrum requirements needed for the AMSS to provide **en-route aeronautical communications and surveillance for the years 2000, 2010 and 2020**. The year 2000 was seen as important because it was considered to represent a time, then 9 years in the future, when significant equipage and utilisation of a world-wide aeronautical satellite system would have been achieved and the aeronautical community would have had experience in its use.

However the report also noted that regions with intensive terrestrially based air-ground communications and surveillance infrastructures (e.g. such as the core area of Europe) might not have employed satellite services for ATS extensively by that time. The report felt that in North America and the core area of Europe, the terrestrial communications networks would continue to be used up to 2010 with satellite communications taking more of a role after that date. This was reflected in the spectrum calculations.

In the study some key assumptions were made to determine channel and bandwidth requirements. These were - –

[2] Aeronautical Mobile Satellite Service, AMSS is used as a generic term to mean both AMS(R)S and the non-safety aeronautical services.

- Voice channel bandwidths – there was an assumption that bandwidth would decrease over time with technological advances and as spot beams were utilised. The primary reasons being the elimination of FEC and the anticipated improvement in vocoder rates. Also there was an assumption that voice would gradually be replaced by data link messaging over time. In addition the report also pointed out the problem of estimating channel utilisation for ATC voice communications which would be very 'bursty' due to its use for emergency and non-routine situations. Consequently the estimates produced were conservative,
- ADS packet size and rate – it was noted that ADS messages varied in size and frequency. To obtain a conservative result the smallest ADS message size was chosen i.e. 80 bits/10 bytes. The period of the reports were in the range of 1 per 5 minutes to 1 per minute depending on regional requirements,
- The mapping of information to bandwidth requirements varied with type of beam (global or spot), protocol overhead (the data link layer was used as the reference) and with efficiency of the satellite channel.

2.5 Traffic Requirements versus applications

Communications traffic resulted from the 4 user types ATSC, AOC, AAC and APC for both data messages and voice. The ATS data link applications considered were -

- Assignment/Confirmation of Assigned Attitude
- Automated Airspace Alert
- Clearance Delivery
- Designated Traffic Report
- En-Route Metering Advisory
- In-Flight Plan Filing and Amendment
- Minimum Safe Altitude Warnings
- Transfer of Communication
- Aircraft Estimated Trajectory
- Tactical Manoeuvre Exchange
- Visual Flight Rule (VFR) Flight Plan Activation/Following
- Situation Alerting
- Automatic Dependent Surveillance
- Flight Information Services

No details of the size or frequency of the individual messages were given except for ADS. For each of the years covered by the report a constant value of **10,000 bits per hour per aircraft** were assumed. For ADS the message size was taken as 80 bits and the frequency varied from 1 per minute to 5 per minute depending on the density of traffic in an area.

For AOC communications it is difficult to determine the values assigned to this category as it has been included with AAC traffic for scheduled aircraft. However values range from around 66,000 bits per hour per aircraft (2000) to around 220,000 bits per hour per aircraft (2020).

For voice communications it was assumed that ATS and AOC usage was similar ranging from 0.03 minutes per hour per aircraft (2000) to 0.01 minutes per hour per aircraft (2020) i.e. voice usage reduced over time.

2.6 Geographical differences

The traffic forecast calculations were identified in terms of the coverage of the 3 overlapping global beams i.e. the Atlantic Ocean Region (AOR), the Pacific Ocean Region (POR) and the Indian Ocean Region (IOR) global beams.

The study broke down the requirements in the overlapping areas and produced figures for the European area which lay under the overlapping cover of the AOR and POR satellites.

2.7 Bandwidth and Spectrum Requirements

The major factors that had an influence on the bandwidth and spectrum requirements were -

2.7.1 Peak Instantaneous Aircraft Count

The PIAC was obtained for both scheduled and non-scheduled flights. Scheduled flights information was obtained from scheduled flight listings (OAG) in the peak week of 1989. This figure was then increased in line with projected growth for the years 2000, 2010 and 2020 – the figures used were not given in the report.

For information the PIAC intra- Europe were calculated as –

Year	2000	2010	2020
Scheduled	1800	2200	2500
Non-scheduled	650	790	870
Total	2450	2990	3370

Although the value for 2000 seems to be reasonable, the values for year 2010 and 2020 are probably an under-estimate – see section 3.3.5.

It should be noted that the most significant PIAC occurred in North America where values of nearly 10 times those in Europe were projected.

2.7.2 Aircraft Equipage

An estimate was made of the numbers of aircraft (scheduled and non-scheduled) equipped with high- and low-gain antenna systems for each of the years in the study in the various regions.

2.7.3 Voice and Data Requirements

The basic requirements were identified as mentioned in section 2.5 above. These were seen as conservative (i.e. low) estimates. From these numbers the amount of safety and non-safety communications (both voice and data) was made for each aircraft flight by region for each of the years in the study. Safety communications accounted for approximately one-third of the total data communications traffic.

2.8 Determining the bandwidth and spectrum requirements

A complex set of spreadsheets was developed to combine the information above to calculate the bandwidth requirements in each of the regions for each of the years in question. The detailed working of these spreadsheets was not available.

2.9 Conclusion

Since this study was commissioned the applications of data communications in support of ATS have matured considerably. Comparable studies for other technologies have been undertaken and could now be used to define better the requirements e.g. studies on the capability of VDL Mode 2.

The requirement for voice communication for ATS over the years is not clear. It is likely that voice will remain the main form of communications between the controller and pilot until 2010 and thereafter could reduce due to the increased reliance on data link.

It should be noted that ICAO drew heavily on the IATA study to produce its report on spectrum requirements at the ICAO COM/MET/OPS Divisional Meeting in 1990. Due to renewed concern that aviation spectrum is being eroded and new initiatives must be undertaken to defend the need for exclusive use of AMS(R)S IATA updated the report in 1998.

The ICAO report was revised in parts by IATA and the results presented to ICAO AMCP WG-A in July 1998. The main data requirements were not reviewed but other parameters such as PIAC, voice communications, channel utilisation, aircraft equipage and frequency re-use were re-considered. Taking all the factors into account the revised study concluded that overall a global spectrum requirements were almost unchanged at 10.9 MHz for safety and regularity of flight communications.

If the study was commissioned today due to clearer ideas on the potential use of data link to support ATS it is likely that there would be a different result and hence the ESA SDLS study does offer a more up-to-date review of the potential for satellite communications.

3 OVERVIEW OF THE ESA SDLS STUDY

3.1 Introduction

The study reports contains the assessment of implementing a satellite-based communication system “specifically oriented towards the provision of safety related civil ATM services, operable in all categories of airspace and with the view of serving all aircraft”. In terms of spectrum these types of communication are described as related to the safety and regularity of flight typically classified as ATSC and AOC messages. The SDLS therefore supports an **Aeronautical Mobile Satellite (R) Services AMS(R)S** for safety-related communications only.

The study was performed by Alcatel under an ESA contract and was carried out in 5 main workpackages.

- **WP2000** - Service requirements,
- **WP3000 –** Frequency band sizing,
- **WP4000 –** System Requirements,
- **WP5000 -** System Definition,
- **WP6000** – High-Level Segment Specification.

The bandwidth and spectrum issues were mainly related to WPs 2000, 3000 and 5000 and these were the main WPs reviewed in compiling this report. Other WPs dealt with technical requirements and design issues.

The SDLS objective is to use already existing and planned future geostationary satellites in order to provide regional spot beam coverage over major continents and global beam coverage elsewhere. The SDLS aim is to be deployable worldwide, based on an internationally recognised technical standard i.e. ICAO SARPS. However the design was essentially driven by perceived ATS and AOC service requirements and applications in the European environment. These service requirements were basically:

- ATS services over Europe (including ADS applications), in line with the overall improvement of CNS/ATM concept,
- AOC services based on data exchanges,
- ATS and AOC services based on voice communications,
- compatibility with ATN standards.
- specific means to support automatic position reporting (APR)

The SDLS study conclusions resulted in the continuation of the SDLS project by ESA into a practical trial phase to test its feasibility in a limited deployment. This trial is underway at the time of the report.

The remainder of the section discusses specific issues, which have an effect on the bandwidth and spectrum requirements.

3.2 Approach

The approach adopted in the SDLS study to identify spectrum requirements starts by identifying ATS and AOC data link, their message sizes and periodicity in different geographical areas broken down into FIRs and phases of flight. The target aircraft population and numbers of aircraft in the year were identified. From this the bandwidth requirements were calculated and then mapped to the spectrum requirements for both FDMA (such as the current AMSS defined in ICAO SARPS) and a new CDMA system (based on the ESA Mobile Satellite Business Network (MSBN)).

Voice communications requirements were also included in the study and some assumptions for this form of communication were made in terms of vocoder rate, call set-up times and other performance requirements. From this the amount of bandwidth to support voice was determined.

By adding these two requirements together the total spectrum required for Europe was calculated. **The spectrum calculations were undertaken for the year 2020.**

3.3 Review of Assumptions

3.3.1 ATM Operational Concept

In WP 2000 the basic ATM operational concept which SDLS is designed to support in 2020 is described. This is done in very general terms based on the high level objectives of the ICAO CNS/ATM system. The requirements can be inferred from the documents but are not explicitly stated.

The concept is based on use of data link communications using Controller-Pilot Data link Communications (CPDLC), Digital Flight Information Service (DFIS) and other support messages.

SDLS assumes that the current provisions for Automatic Dependent Surveillance – Contract (ADS-C) are inadequate and inefficient using the ATN. Consequently the SDLS has a specific protocol to handle these messages where the ground end-system is located in the Ground Earth Station (GES) and acts as a server to the ATCC.

Voice communications are also supported by SDLS although this is area were assumptions are unclear.

3.3.2 Frequency Band

As the SDLS system is expected to use existing or planned satellite systems it is planned to operate in the Aeronautical Mobile satellite Service (AMSS) L-band at frequencies of :

- - 1545-1555 MHz for the downlink (from satellite to AES),
- - 1646.5-1656.5 MHz for the uplink (from AES to satellite).

3.3.3 Communication Users

The main difference between the IATA study and the SDLS study is the classes of traffic the two systems support. SDLS is dedicated to ATS and AOC communications whereas the IATA study considered all classes of users (ATS, AOC, AAC and APC).

> *{cf. The IATA study included all forms of aeronautical communications ATSC, AOC, AAC and APC. Consequently the spectrum requirements were greater.}*

3.3.4 Aircraft population

It is claimed that only commercial aircraft are considered in the study. This may not take into account all airspace users (e.g. General Aviation or State (e.g. military) aircraft) however spectrum calculations are based on PIAC – see 3.3.5 below – and therefore the proportion of these aircraft will not have a great effect on the result. However this may not be the case in North America where the population is dominated by non-commercial aircraft.

Whilst the study recognises that the number of aircraft actually fitted is the main determinate in calculating spectrum, the study only assumes that all aircraft will be equipped with satellite systems. This is an optimistic assumption but it could be argued that this gives the worst case result.

> *{cf. In the IATA study all airspace users were considered and applied an equipage percentage rate over time was applied}.*

3.3.5 Peak Instantaneous Aircraft Count

The Peak Instantaneous Aircraft Count (PIAC) has a major impact on the spectrum requirements. The SDLS study identified PIACs for Europe (this covers at least the ECAC states) of –

- 3150 aircraft in 2010,
- 4410 aircraft in 2020.

The aircraft were then divided into phase of flight as follows –

Phase of Flight	Percentage of Aircraft (At peak hour in 2020)
Airport	8.5%
Terminal Area	14.6%
Continental High density	41.5%

Oceanic High density	25.6%
Oceanic/ Continental Low density	9.8%

As the study assumes all ‘commercial aircraft’ are equipped this approximates to IFR aircraft. These figures seem to be low compared today’s IFR traffic which is around 28,000 movements per day (at least before 11th September 2001). Assuming 15 operational hours per day, ignoring morning and afternoon peaks and assuming a flight duration is 80 minutes, a conservative estimate of the current PIAC is around 2400.

Using the STATFOR model growth rates (prior to 11 September) for the total ECAC area, the annual growth in number of IFR flights used by the model is as follows: 7.5 % during the period 2000-2004, 5.3% during 2005-2009, 5.1% during 2010-2014, and 4.5% from 2015 onwards. Using these figures – which could be considered rather high – gives the PIACs of –

- 4400 aircraft in 2010
- 7100 aircraft in 2020

Recent considerations regarding traffic growth have suggested that the current slow down will last around 2 years with no growth in 2001, minimum growth in 2002 (0.5%) and returning to the previous growth slowly by 2005. Taking these factors into account a revised calculation gives the following -

- 3700 aircraft in 2010
- 5900 aircraft in 2020

Whatever the actual growth rate, the PIACs figures used in the spectrum calculation should be increased by between 17% to 40%. In the revised spectrum calculation in section 3.6 a figure of 33% increase compared to the original figure has been used.

{cf. IATA study of 2990 in 2010 and 3370 in 2020}

In summary the various PIACs for Europe from all sources are as follows –

Source	Year	PIAC
IATA	2010	2990
SDLS	2010	3150
This study	2010	3700
IATA	2020	3370
SDLS	2020	4410
This study	2020	5900

However if SDLS is to be a truly worldwide system then PIACs encountered in other parts of the world also need to be considered. Values of nearly 10 times the European values were projected in the IATA study and it could be expected these should apply to the SDLS study but this was not explored in the study.

3.3.6 Service Area

SDLS is applicable for worldwide use but it is 'essentially driven by service requirements and applications suited for European needs and environment' consequently the majority of the study has been targeted at meeting perceived European needs.

All of the ECAC area was included in the study and viewed as part of the coverage area. The area was then categorised as –

- airport and TMA in Europe,
- en-route continental in Europe (high-density en-route and low-density en-route),
- en-route from/ to Europe (oceanic airspace)

These were further subdivided into different complexities.

> *{cf. the IATA study covered each area of the world by consideration of communication requirements in each global beam with assumptions for regional beams in dense airspace).*

3.3.7 ATS Data Link Applications

The SDLS system has been designed to be able to support the bulk of civil aviation traffic in all parts of the coverage area from 2005 to 2020. The study took into account the 'classical' data link services as being discussed in the ODIAC meetings at that time e.g. CPDLC, ADAP and included a new APR specific service dedicated to the transfer of positional and related information from the aircraft to the ground. The data link services were –

- Departure Clearance (DCL)
- ATC Communication Management (ACM)
- Clearance and Information Communication (CIC),
- Down Stream Clearance (DSC).

Since the SDLS report was written more mature concepts are emerging regarding data link services to support operational concept beyond 2015. Additional data link services to those identified above have now been listed. The current complete list is given below [Ref 11], only some of which were mentioned explicitly in the study however some exchanges were considered under the general heading of CPDLC.

- ATC Communications Management Service (ACM)
- Departure Clearance Service (DCL)
- ATC Clearances and Information Service (ACL)
- Controller Access Parameters Service (CAP)
- Downstream Clearances Service (DSC)
- Pilot Preferences Downlink Service (PPD)
- Flight Plan Consistency Service (FLIPCY)
- Dynamic Route Availability Service (DYNAV)
- Data Link Operational Terminal Information Service (D-OTIS)
- Data Link Runway Visual Range (D-RVR)
- Data Link Logon (DLL)
- Common Trajectory Co-ordination (COTRAC)
- Data Link SIGMET Service (D-SIGMET)
- System Access Parameters Service (SAP)

{cf. The IATA study was produced before the more formal definition of ATS data link applications or services had been produced. Hence only general data link applications were considered.}

These are discussed further in section 3.4.1 below.

3.3.8 AOC Data Link Applications

The SLDS identifies the following AOC applications -

- Flight Management Computer Initiation
- ETA Estimation
- Out-Off-On-In Message
- Flight Plan
- Maintenance data

These are discussed further in section 3.4.3 below

3.4 Traffic volumes

3.4.1 ATS Data Link Applications

The spectrum calculations were based on a set of data link applications, which are summarised in the table below. For each application a comment is made on the reasonableness of the message frequency and size. Comparison is also made with values included in [Ref 10] (EUROCONTROL ST15 Study).

The SDLS study also considered the additional exchanges that support the basic messages e.g. acknowledgements, etc. This demonstrates a thorough approach to determining traffic requirements and is to be commended.

For the applications mentioned, the requirements appear broadly reasonable and are typical of an operational concept under consideration for data exchanges to support operational concepts such as described in the EUROCONTROL COOPATS document [Ref 12]. The COOPATS concept includes the following elements:

1. The communications between aircrew and controllers (Voice and CPDLC);
2. The provision of airborne data to increase controller situational awareness and improve support tools (ADAP);
3. The provision of ground based data, to improve and automate flight information for aircrew, and to allow dissemination of essential meteorological or other flight information to any potential user (D-FIS);
4. The provision of traffic and other information to aircrew, to increase traffic situational awareness and enable delegation of separation assurance (COSEP) and autonomous flight operations (AUTOPS).

In the timeframe of 2020, the COOPATS Level 2 elements should be in place. The SDLS study covers most of the data exchanges under 1,2 and 3 above but did not consider COSEP and AUTOPS. It is likely that air-air communications will be a key requirement to support these services however this is not supported by SDLS consequently this was not considered in revising the study.

Although there may be the need for air-ground co-ordination via data link during the delegation of separation tasks, no details of what these may be are included in the COOPATS document. Therefore it was not possible to add additional air/ground exchanges for COSEP or AUTOPS. Without a detailed operational concept of 2020 it is difficult to say whether the exchanges are fully representative but they are believed to be.

With the above discussion in mind the data exchanges identified in the table below (based on the SDLS study) were reviewed for their acceptability. The terminology used in the SDLS study does not fully match the current EUROCONTROL descriptions for data link services. Exchanges entitled CPDLC are defined in the SDLS study but as these include DSC, DCL and ACM some of which are also defined, there is a degree of double counting. Therefore traffic associated with DCL, ACM and CIC has been removed. It is also assumed that ADAP supports CAP, SAP and PPD.

Application	Phase of Flight	No. of Transactions per Flight	Number of Messages per Flight (forward/ return)	Mean Message Size (in bytes)	Longest Message Size (in bytes)	Comments	Estimated effect on spectrum
DLIC	TMA/ Airport	2	8 (4/ 4)	70	126	There is an assumption that DLIC needs to be initiated when transferring between ATSUs.	Reduction of approx. 10kHz on the downlink and negligible on the uplink (FDMA)
DLIC	Continental	3	12 (6/ 6)	70	100	In Europe it is likely that the DLIC ground forwarding function will be used. This would reduce the numbers of transactions to 1.	
DCL	Airport	1	6 (3/ 3)	50	250	This application is covered by CPDLC which is included below. Therefore delete this traffic.	Minimal effect
ACM	Continental	6	42 (18/ 24)	25	120	This application is covered by CPDLC which is included below. Therefore delete this traffic.	Reduction of approx. 8kHz on the downlink and negligible on the uplink (FDMA)
CIC	Continental	16	64 (32/ 32)	25	30	This application is covered by CPDLC which is included below. Therefore delete this traffic.	Reduction of approx. 15kHz on the downlink and negligible on the uplink (FDMA)
CPDLC	Continental	100	400 (200/ 200)	25	120	These exchanges are now considered to include CIC, ACM, DCL and DSC	No effect
CDPLC	Oceanic	100	400 (200/ 200)	25	120	For a 300-minute flight used in the study this is a	Reduction to 20 transactions per flight has a negligible effect

						rate of over one message per 3 minutes which is very high. ST15 uses a value of around 20 for the equivalent period.	on the uplink and a reduction of approx. 10kHz on the downlink (FDMA)
DFIS	TMA	1	5 (3/ 2)	1000	3000	There is an inconsistency in the report regarding DFIS and ATIS. The report claims that ATIS is the only example of DFIS and it then describes the ATIS application.	Removal of the DFIS message has minimal affect therefore no change.
DFIS	Continental	2	10 (6/ 4)	1000	3000	However in this table both ATIS and DFIS are defined. Although the size of the DFIS message is large and it is very infrequent.	
ATIS	TMA	2	10 (6/ 4)	80	240	The ATIS message sizes seem acceptable and no change is proposed in the values used in the calculation.	
ATIS	Continental	1	5 (3/ 2)	80	240		
ADAP	Continental	500	500 (0/ 500)	20	20	It is assumed that this supports CAP and PPD SAP. Acceptable.	
FLIPCY	Continental	2	8 (4/ 4)	270	530	Acceptable.	No change
DYNAV	Continental	1	3 (1/ 2)	190	530	Acceptable.	No change
PUSH-TAXI	Airport	1	8 (4/ 4)	50	140	Acceptable.	No change

The overall affect from the comments in the above table are a reduction in spectrum requirements (for an FDMA based system) of approximately 43kHz in the downlink and negligible on the uplink. This small reduction will have little affect on the spectrum requirements for a CDMA based system as the granularity of the channels (1MHz) is so large.

3.4.2 Surveillance Requirements

SDLS has been designed with specific Automatic Position Reporting (APR) protocols to efficiently handle frequent short messages such as ADS-type, ADAP or position reporting messages. In the spectrum calculations is has been assumed that all aircraft use the APR specific service except in the Airport or TMA phase of flight.

The periodicity of APR messages is defined a:

- 60 seconds for continental high density en-route airspace (basic scenario),
- 30 seconds for continental high density en-route airspace (enhanced scenario),
- 300 seconds for oceanic en-route airspace.

{cf. This is similar to the IATA study which also considered only en-route requirements}

The APR requirements identified in the SDLS report are summarised in the table below with comments on their acceptability.

Phase of Flight	No. of Transactions per Flight	Number of Messages per Flight (forward/ return)	Mean Message Size (in bytes)	Longest Message Size (in bytes)	Comments
Continental	360	360 (10/ 350)	25	50	This is the so-called 'basic' scenario with a reporting rate of 60 s. This value is low for high-density airspace.
Continental	720	720 (10/710)	25	50	This is the so-called 'enhanced' scenario with a reporting rate of 30 s. This value is still low for high-density airspace.
Oceanic	360	360 (10/ 350)	25	50	This rate of 5 minutes is acceptable.

The sensitivity analysis carried out in the SDLS study on the amount of traffic generated in high density en route airspace between the basic (60 seconds APR rate) and enhanced APR (30 second APR rate) scenarios showed only a minimal increase in spectrum requirements – (around 70kHz for FDMA).

To provide a surveillance service commensurate with an en-route radar in continental airspace a reporting rate of 10s would be more realistic. If this higher rate was adopted for all aircraft in continental high-density airspace (approximately 41% of total PIAC) the additional spectrum needed to support APR is estimated to be approximately 230 kHz on the downlink for FDMA and may cause an additional 1 MHz CDMA channel to be needed. It should be pointed out that this is a worst case situation.

3.4.3 AOC Services Based on Data Communications

For AOC some very simple assumptions were made regarding data link requirements in same areas as the ATS data link services namely Airport/TMA, Continental en-route and Oceanic.

The AOC applications supported were described as –

- Flight Management Computer Initiation
- ETA Estimation
- Out-Off-On-In Message
- Flight Plan
- Maintenance data

In the SDLS study the quantity of AOC data exchanged is estimated at 18 000 bytes per aircraft and per flight. Today ACARS message exchange is estimated at around 5000 bytes per aircraft per hour or 8000 bytes per aircraft per flight. Based on the growth of ACARS traffic today, doubling the traffic by 2020 in the ESA study is considered an underestimate.

In summary the AOC data requirements used in the ESA study are summarised in the simple table below -

Phase of flight	Number of Messages per Flight (fwd)	Number of Messages per Flight (ret)	Mean Message Size (bytes) (fwd)	Mean Message Size (bytes) (ret)	Total bytes exchanged
Airport / TMA	5	9	500	20	2680
Continental	0.5	7.5	5000	300	4750
Oceanic	0.5	7.5	5000	300	4750
				Total	12180

Note :the total traffic in the table taken from the SDLS study does not equal 18,000 bytes but it is assumed that some other applications not listed are supported.

Analysis of typical ACARS air-to-ground and ground-to-air traffic shows that about 50%-60% of the communications takes place on the ground (33% at the gate plus an additional 18% away from the gate on the surface of the airfield) and the balance 50% in the air. The majority of the data link traffic is in the 'to the aircraft' direction; 58% at the gate and 65% at other ground locations. The values used in the ESA study do not reflect this split however it is probably immaterial for the spectrum calculations.

The growth in ACARS traffic is high and this growth is expected to continue and is the justification for the introduction of VDL Mode 2. Typically today, data is exchanged as characters rather than as binary messages hence many messages for human interpretation are in the form of text. There is a trend to provide more user friendly data to the aircrew and it is likely that graphical information will be used to replace or augment current messages. This could increase the typical size of an AOC message.

> *{cf. The IATA study used a value of around 200,000 bits per aircraft per hour or 25,000 bytes per hour per aircraft. For a European flight of 80 minutes this would generate around 33,000 bytes per flight – nearly twice the value used in the ESA study}*

Considering todays AOC traffic and the rate of traffic growth being experienced by communication service providers, a value of around 33,000 bytes per flight as used in the IATA study is a better estimate.

The estimated increase in spectrum requirements to meet this increased traffic assuming the traffic is primarily downlink (say 70%) will be approximately 120kHz (FDMA) on the airport and in TMA – minor effect on the uplink. For en-route the increase is estimated at approximately 50 kHz. It is not considered necessary to change the oceanic estimates.

3.5 Voice Communications

The requirements for voice communications as supported by SDLS are not clearly described. It is assumed that they are used for emergency or non-routine voice communications and that most communications will take place by data link. The table below summarises the figures used in the SDLS report:

User	Phase of Flight	Number of Transactions per Flight	Duration of Communication (in seconds)	Maximum Delay to Establish Com. (in seconds)
ATS	Airport	2	20	5
ATS	TMA	2	20	5
ATS	Cont. high density	6	20	5
ATS	Cont. Low density	3	30	30
ATS	Oceanic	5	30	30
AOC	TMA	2	30	30
AOC	Continental	2	30	30
AOC	Oceanic	2	60	30

Given that the operational scenario timeframe (2020) is one in which voice is used only rarely then the above values are a reasonable estimate of numbers and duration of transactions. However call establish times need to be very short to support emergency and non-routine communications therefore adequate satellite resources need to be available to handle this situation. The ability to achieve these set-up times or even shorter ones needs to be reconsidered. The loss of party line is another consideration but its importance in the timeframe of 2020 is unclear. However greater acceptance would be achieved if emulation of the features of current VHF RT was possible.

> *{cf. The low utilisation of voice for ATC was one of the problems highlighted in the IATA study. It was difficult to model the call set-up times using a Erlang model as estimating channel utilisation for ATC voice communications is very bursty for emergency and non-routine communications.}*

3.6 Mapping Voice and Data Requirements to Spectrum

From the amount of voice and data traffic generated as shown above, the bandwidth requirements were calculated for both FDMA (such as the current AMSS defined in ICAO SARPS) and a new CDMA system (based on the ESA Mobile Satellite Business Network (MSBN)). The mapping was based on a theoretical assumption of channel utilisation and guard times.

For the FDMA calculations, the existing AMSS channels P, R, T and C were assumed plus an additional channel specifically to support APR. This is designated the S-Channel which is a Reservation TDMA channel, used in the return direction only and this channel is dedicated to safety periodical messages (APR and ADAP). This took into account the mean sizes of messages which were mapped onto the appropriate channel type. The size of channel bandwidths used was 10 kHz for data and 5 kHz for voice applications.

For the CDMA calculation two basic channels were defined – asynchronous and synchronous. The asynchronous channel is used for carrying short messages such as APR. The synchronous carries longer messages. Due to the CDMA technique including codes used, filtering characteristics, and guard bands the channels have a bandwidth of 1 MHz.

A summary of the spectrum requirements for the basic and enhanced scenarios is given in the tables below. It should be pointed out that there is little difference in the results between FDMA (i.e. AMSS) and CDMA for high traffic loads such as over Europe. Where there is light traffic then the 1 MHz granularity of CDMA channels leads to larger allocations than required in, say, oceanic areas.

	Basic scenario	
	FDMA	
	Forward link	Return link
ATS (Regional beam)	0.62 MHz	1.67 MHz
ATS (Global beam)	0.64 MHz	1.71 MHz

AOC (Regional beam)	0.37 MHz	0.57 MHz
AOC (Global beam)	0.39 MHz	0.60 MHz
	CDMA	
	Forward link	Return link
ATS (Regional beam)	1 MHz	1 MHz
ATS (Global beam)	1 MHz	1 MHz
AOC (Regional beam)	1 MHz	1 MHz
AOC (Global beam)	1 MHz	1 MHz

The above figures were recalculated using an APR rate of 30 second which resulted in the following table. The main difference is the increase in return traffic of around 70kHz for FDMA. For CDMA this requires an extra 1MHz channel.

	Extended scenario	
	FDMA	
	Forward link	Return link
ATS (Regional beam)	0.62 MHz	1.74 MHz
ATS (Global beam)	0.64 MHz	1.78 MHz
AOC (Regional beam)	0.37 MHz	0.57 MHz
AOC (Global beam)	0.39 MHz	0.60 MHz
	CDMA	
	Forward link	Return link
ATS (Regional beam)	1 MHz	2 MHz
ATS (Global beam)	1 MHz	2 MHz
AOC (Regional beam)	1 MHz	1 MHz
AOC (Global beam)	1 MHz	1 MHz

Taking into account the recalculations discussed in the earlier parts of section 3 covering -

- Increased PIAC
- Revised ATS and AOC application requirements
- An APR rate of 10 seconds

The table shown above summarises the increase in spectrum requirements for FDMA and CDMA. It is considered that the numbers of channel needed in the case of CDMA remains unchanged as there is sufficient unused margin to absorb the increased data requirements.

	Updated Spectrum	
	FDMA	
	Forward link	Return link
ATS (Regional beam)	0.80 MHz	2.53 MHz
ATS (Global beam)	0.85MHz	2.37 MHz
AOC (Regional beam)	0.50 MHz	0.93 MHz
AOC (Global beam)	0.51 MHz	0.60 MHz
Total	2.66 MHz	6.43 MHz
	CDMA	
	Forward link	Return link
ATS (Regional beam)	1 MHz	3 MHz
ATS (Global beam)	1 MHz	3 MHz
AOC (Regional beam)	1 MHz	1 MHz
AOC (Global beam)	1 MHz	1 MHz
Total	4 MHz	8MHz

3.7 Performance Requirements

As pointed out in the SDLS study performance levels are as important as the overall quantity of data exchanged. To achieve the performance requirements targets identified in the SDLS study certain parameters of the satellite channel were chosen to ensure adequate performance. These parameters spread codes, guard bands, utilisation, etc all have an affect on the spectrum requirements. For example, in estimating the spectrum the utilisation of the channel has to be taken into account to achieve the required performance; the lower the utilisation to achieve a performance figure the more channels and hence spectrum required.

Based on the assumed requirements taken from the ATN QoS table defining such parameters as integrity, availability, reliability, end-to-end delay the following The basic SDLS services were defined as -

- SDLS 1 : point-to-point ATN-compliant data services (packet mode),
  - SDLS 1H services between aircraft and ATCCs with high QoS,
  - SDLS 1L : services between aircraft and ALOCs with low QoS,
- SDLS 2 : point-to-point bi-directional voice services (circuit mode),
  - SDLS 2H : services between aircraft and ATCCs with high QoS,
  - SDLS 2L : services between aircraft and ALOCs with low QoS,
- SDLS 3 : point-to-point specific data services (packet mode),
- SDLS 4 : data broadcast services (packet mode) from ATCCs to aircraft.

Based on link budget and channel performance values for the basic SDLS modes were calculated as follows -

Services	Link type	Availability, Continuity, Reliability (%)	Integrity	Transit Delay (in seconds)
SDLS 1H	Fw-Rt	99,96%	10^{-7}	8
SDLS 1L	Fw-Rt	99,795%	10^{-6}	30
SDLS 2H	Fw-Rt	99,96%	10^{-7}	NA
SDLS 2L	Fw-Rt	99,795%	10^{-6}	NA
SDLS 3	Fw-Rt	99,96%	10^{-6}	8
SDLS 4	Fw	TBD	TBC	TBD

The acceptability of these values depends to a large degree on the operational requirements. The transit delay times equate to levels E, F, G and H of the ATN performance level table. This is probably acceptable for the ATS data link applications considered assuming that the concept is not based on tactical control.

The figures for availability, continuity, reliability have been assigned the same values for each service which is unusual.

3.8 Frequency Reuse

Frequency re-use could allow the bandwidth required to be supported by fewer channels. It was also pointed out in the SDLS report that frequency re-use could mitigate the effect of underestimating requirements due to a higher PIAC than projected.

The SDLS report states that either by orthogonal polarisation or by angular beam separation or a combination of both were possible techniques. Orthogonal separation could double the bandwidth whereas with angular separation, the bandwidth could be re-used for as many beams as the permissible interference level allows depending on the antenna directivity and beam pattern.

However further analysis shows that orthogonal polarisation is not possible with the isotropic antennas which will be employed in the SDLS AESs. This is because the achievable polarisation discrimination (axial ratio) of this type of antenna does not offer any polarisation re-use.

This leaves angular separation using spot beams as the only viable method of frequency re-use. Under these conditions, as the SDLS report pointed out, CDMA based systems are far more flexible under conditions of overlapping coverage than FDMA ones. The actual reuse factor will therefore depend on the particular satellite system used.

{cf. The IATA study assumed frequency reuse (in 2020) of 1.4 for global beams and 2 for regional beams}

4 CONCLUSIONS

4.1 General

This report has concentrated on reviewing the bandwidth and spectrum requirements identified in the SDLS study reports and highlighted those areas where adjustments should be made to reflect better the needs of aviation in the light of current experience. The report does not comment on the technical aspects or concepts behind the SDLS design.

Any bandwidth or spectrum calculation should be based on a credible operational scenario otherwise the results will not be taken seriously. However, this is not a precise science and assumptions must be made especially when trying to predict 10 or 15 years in the future. But any assumption must be credible if the conclusions are to be believed. A great deal of consideration has been given to the sizing and design of the SDLS from the basic requirements to the design of the satellite channels. Most of the assumptions are plausible but a projection 20 years in the future are always likely to be inaccurate.

The IATA study, to which the SDLS study was compared, provides a good example of the problems of prediction. Firstly the spectrum requirements were derived in good faith based on expected equipage rates which seemed plausible at the time based on a considerable amount of market survey work. Secondly, the spectrum requirements for all communications traffic types was included (i.e. ATSC, AOC, AAC and APC) with priority and pre-emption rules defined enabling high priority communications to get the service they require. The objective of obtaining the predicted dedicated aviation spectrum at WARC-92 was achieved. However over the years since then, due to lack of use of this spectrum, it has gradually been eroded.

To defend any spectrum there must be a sound basis for the requirements and there has to be acceptance by the entire aviation community where the system will be implemented. In the aviation community this is usually worldwide hence the importance of international organisations such as ICAO and IATA to act as focal points for obtaining aviation consensus on spectrum requirements backed by realistic implementation plans.

4.2 Comparing the IATA and SDLS studies

In reviewing and comparing the SDLS study with the IATA reports the main differences between them are summarised below –

- PIAC: both studies contain PIAC values which are lower than is currently predicted. Neither study took into account any military requirements – if any.
- ATS applications: The IATA study was produced when concepts for use of ATS data link applications were immature and hence the requirements are unclear. The SDLS study was able to use a more mature concept with some idea of how ATS data exchanges might be utilised. However even now the concept of operations for the year 2020 are still not mature and therefore requirements have yet to be proven.
- AOC applications: In both the IATA and SDLS studies the requirements for AOC are unclear and not justified. Based on current AOC traffic, the figures used in both studies are considered an underestimate.
- Equipage rates: The IATA study assumed a gradual increase in equipage rates over time and assumed that in some high density parts of the world e.g. Europe the equipage rate would be slower. In the SDLS study, to determine the maximum spectrum requirement, the assumption was made that all aircraft in the ECAC area would be equipped. Whilst this could be argued as the worst case scenario this may not be the case in the timeframe of 2020. A range of factors including cost of equipment, size of equipment, installation costs and operating costs will drive equipage rates. If a satellite system can be developed that addresses these issues then equipage may be rapid.

4.3 Updating the SDLS study

4.3.1 Operational scenario

A lot of consideration has been put into the SDLS study in trying to quantify the requirements for data communications to support ATM and AOC with emphasis on the perceived European needs.

The ATS applications considered in the SDLS study seem representative of the expected operational scenario in 2020 based on the COOPATS Level 2 elements. These applications which have been applied across the entire ECAC airspace which may not be realistic but yields the worst case scenario.

Little detail was given on the AOC applications and they are considered to be incomplete. A revised calculation of spectrum requirements was undertaken based on traffic volumes rather than specific applications.

4.3.2 Surveillance

The SDLS has a specific protocol for position reporting (APR) so it must be assumed that the reason is to offer a replacement service for an existing surveillance system. The requirements however do not replace the existing surveillance requirements, for example, an en-route radar, where an update rate of 6 to 10s would be expected. Hence the fastest rate considered in the study (30s) does not offer a similar level of service.

Additionally the EUROCONTROL ADS Concept document states 'Where ADS is assumed as a sole-means surveillance system in place of another surveillance system, this is assumed to happen starting from 2015.' It goes on to say that 'ADS-C has not been assumed in high-density airspace because current datalink technologies are not expected to be able to support high-density ADS-C applications. However, this assumption needs review. ADS-C is assumed as a potential fall-back option for small numbers of aircraft in high-density areas.' but that primary radar (PSR) is always used in major TMAs, in addition to whatever other surveillance systems are used. It could be that SDLS is a reason to reconsider that statement.

4.4 Bandwidth and Spectrum Requirements

The elements in determining bandwidth and spectrum requirements that are the most sensitive are the traffic generated by the applications and numbers of aircraft using SDLS. The application that generates the most traffic is APR.

The spectrum calculations were based on for a European environment and the results for other parts of the world might be different e.g. North America would be different as there is a larger PIAC as identified in the IATA study.

Taking all the comments in section 3 into account the revised requirements and higher PIAC the additional spectrum needed is approximately 600kHz in the Forward direction and 1.74MHz in the Return direction. This affects only the FDMA spectrum as the margin in the CDMA case can absorb the increase.

The SDLS study attempted to calculate spectrum requirements in a very thorough manner and adopted a complex approach. Unfortunately there are a number of assumptions in the calculation of spectrum requirements which cast doubt on some of the results.

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6 LIST OF TERMS AND ABBREVIATIONS

ACC	Area Control Centre
ADS	Automatic Dependent Surveillance
AEEC	Airlines Electronic Engineering Committee
AES	Aircraft Earth Station
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
ALOC	Airline Operations Centre
AMCP	Aeronautical Mobile Communication Panel
AMS	Aeronautical Mobile Service
AMS(R)S	Aeronautical Mobile (Route) Service
AOC	Airline Operational Control
AOR	Atlantic Ocean Region
APC	Aircraft Passenger Communications
ATC	Air Traffic control
ATN	Aeronautical Telecommunications Network
ATS	Air Traffic Services
ATSC	Air Traffic Service Communications
ATSU	Air Traffic Service Unit
bps	Bits per second
CDMA	Code Division Multiple Access
CFMU	Central Flow Management Unit
CPDLC	Controller-Pilot Data Link Communications
EATMP	European Air Traffic Management Programme
ECAC	European Civil Aviation Conference
ESA	European Space Agency
ETSI	European Telecommunication Standardisation Institute
EUROCAE	EURopean Organisation for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of the Air Navigation
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FIR	Flight Information Region
FL	Flight Level
FMG	Frequency Management Group
FMS	Flight Management System
GES	Ground Earth Station
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
IOR	Indian Ocean Region
ISO	International Organisation for Standardisation
ITU	International Telecommunication Union
JAA	Joint Aviation Authorities
LSDU	Link Service Data Unit

MOPS	Minimum Operational Performance Standards
MSBN	Mobile Satellite Business Network (ESA)
MTBF	Mean Time Between Failure
OSI	Open System Interconnection
PIAC	Peak Instantaneous Aircraft Count
POR	Pacific Ocean Region
SAR	Search And Rescue
SARPS	Standards and Recommended Practices (ICAO)
SATCOM	Satellite Communication
SDLS	Satellite Data Link System (ESA)
TDMA	Time Division Multiple Access
TMA	Terminal Manoeuvring Area
UIR	Upper Information Region
UTC	Universal Time Coordinated
VDL	VHF Digital Link
VDR	VHF Digital Radio
WG	Working Group