TR 101 130 V1.1.1 (1997-11)

Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); Study of the feasibility for standardizing Self-organizing Time Division Multiple Access (STDMA) system requirements

European Telecommunications Standards Institute

Reference

DTR/ERM-RP05-008 (ago00ics.PDF)

Keywords

Aeronautical, mobile

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

1 Scope

1.1 Background

CE Mandate M/239 [8] was accepted in principle by TA 25 in October 1996 and the Terms of Reference of Special Task Force (STF) 109 [9] were agreed by Board Number 6 (B6(97)08). Under the mandate CEN/CENELEC/ETSI have been asked to draw up a programme of standards to complement Eurocontrol's programme of technical specifications. The present document has been produced by a STF that was set up to deal with one of the items given in an annex to the mandate.

The purpose of the STF was to carry out a study on the feasibility of standardizing Self-organizing Time Division Multiple Access (STDMA) mode 4 and to identify possible requirements for future activity. The overall strategy is to develop a standard in Europe for STDMA to be installed on aircraft, initially on a voluntary basis.

The ETSI standard would be derived from and, wherever possible, maintain compatibility with, the draft Standards and Recommended Practices (SARPs) being developed by the International Civil Aviation Organization (ICAO) for VHF Digital Link (VDL) mode 4 (the ICAO term for STDMA). These ICAO standards will be referred to throughout this document as "VDL mode 4 draft SARPs".

It should be noted that the European Commission is funding the STF work (100 %) because it wishes to speed up the standardization process for STDMA. The Commission is anxious to determine if the standard can be progressed and the predicted timescales for it to become an ETSI European Norm (EN).

The aim of the work was to analyse the available technical specification and produce recommendations for what actions ETSI should take to:

- transfer the technical specification into a standard;
- complete all the required interfaces;
- identify areas needing particular attention;
- define the appropriate time schedule for any future work.

The present document reports the results of the work.

1.2 Organization of the report

The present document is organized as follows:

- Clause 2 lists the references.
- Clause 3 lists definitions, symbols and abbreviations.
- Clause 4 provides a summary of STDMA, describing the system requirements, the main features of the system and the system concept.
- Clause 5 describes the approach that was taken by the STF in the review of STDMA.
- Clause 6 presents the results of the review. It contains the following subclauses:
  - a summary of the perceived need for an STDMA standard;
  - a summary of procedural issues that will have to be addressed to achieve standardization, including the relation to other standards activities and the possible ETSI process that could be used to produce standards material;
  - a summary of the standardization issues that will have to be addressed to improve the presentation of the existing ICAO standard in order to bring it into line with ETSI best practice;

- a summary of the technical issues that will have to be addressed to complete the technical specification of the existing system.

- Clause 7 presents a proposed work plan for STDMA standardization.

- Clause 8 presents the conclusions and recommendations of the study.

More detailed information on the design principles of STDMA, the procedural issues, the standardization issues and the technical issues are presented in annex A, B, C and D respectively.

2 References

References may be made to:

a) specific versions of publications (identified by date of publication, edition number, version number, etc.), in which case, subsequent revisions to the referenced document do not apply; or

b) all versions up to and including the identified version (identified by "up to and including" before the version identity); or

c) all versions subsequent to and including the identified version (identified by "onwards" following the version identity); or

d) publications without mention of a specific version, in which case the latest version applies.

A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

[1] "VDL mode 4 Standards and Recommended Practices - DRAFT", Version 5.4, 21 March 1997 for presentation to Aeronautical Mobile Communication Panel (AMCP), Working Group D, Seventh Meeting, Madrid, Spain, 8 - 17 April 1997.

[2] "VDL mode 4 Manual - DRAFT", Version 1.0, 21 March 1997 for presentation to Aeronautical Mobile Communication Panel (AMCP), Working Group D, Seventh Meeting, Madrid, Spain, 8 - 17 April 1997.

[3] "Changes to VDL mode 4 SARPs in version. 5.4 with respect to version 4.0", Information paper, 21 March 1997 for presentation to Aeronautical Mobile Communication Panel (AMCP), Working Group D, Seventh Meeting, Madrid, Spain, 8 - 17 April 1997.

[4] "A proposal for ATN over VDL mode 4", Information paper, 21 March 1997 for presentation to Aeronautical Mobile Communication Panel (AMCP), Working Group D, Seventh Meeting, Madrid, Spain, 8 - 17 April 1997.

[5] "The choice of modulation scheme for VHF NABS: A comparison of GFSK and D8PSK", paper presented by H Westermark to WG-D of GNSSP 4th meeting, Australia 17 - 28 February 1997.

[6] "Spectrum requirements for a VHF navigation augmentation broadcast system (NABS) for D8PSK and GFSK modulation schemes", paper presented by H Westermark to WG-D of GNSSP 4th meeting, Australia 17 - 28 February 1997.

[7] "Flight trials of GFSK 19.2kbps radios", paper presented by H Westermark to WG-D of GNSSP 5th meeting, Montreal 26 May - 6 June 1997.

[8] Commission mandate M/239: "Mandate to CEN/CENELEC/ETSI for standardization, and a study, in the field of Air Traffic Management Equipment and Systems", 5 September 1996.

[9] "Terms of reference for STF ER on Self organizing time division multiple access system (STDMA) for Aeronautical VHF communications" as agreed by Board 6 (B6(97)08).

[10] "Enhanced TDMA for a VHF Datalink System matching the future European Air Traffic Management System requirements (E-TDMA): Report on System Requirements (WP1)" CEC DGXIII TREATY 8 report, 28 April 1997.

[11] "Maintaining the Time in a Distributed System", Keith Marzullo. 2nd ACM Symposium on Principles of Distributed Computing. Montreal, August 1983 pp 295-305.

[12] "Fault-Tolerance Clock Synchronization", Joseph Halpern, Barbara Simons, Ray Strong. 3rd ACM Symposium on Principles of Distributed Computing Systems. Vancouver, Canada, August 1984, pp 68-74.

[13] "Byzantine Clock Synchronization", Leslie Lamport, P. M. Melliar-Smith, 3rd ACM Symposium on Principles of Distributed Computing Systems. Vancouver, Canada, August 1984, pp 68-74.

[14] "Understanding protocols for Byzantine clock Synchronization", F Schneider. Technical Report 87-859, Dep of Computer Science, Cornell University, August 1987.

[15] "Integrating External and Internal Clock Synchronization", Christof Fetzer, Falviu Christian. 15th International Conference on Distributed Systems, Vancouver, Canada May 1995.

[16] "An optimal Internal Clock Synchronization Algorithm", Christof Fetzer and Flaviu Christian. 10th Annual IEEE Conference on Computer Assurance, Gaitersburg, MD, June, 1995.

[17] "Lower Bounds for Function Based Clock Synchronization", Christof Fetzer and Flaviu Christian. 14th ACM Symposium on Principles of Distributed Computing, Ottowa, CA, August 1995.

[18] "Minutes of Airline Workshop, 18-19 December 1996 in Saltsjöbaden, Stockholm", Information paper, 21 March 1997 presentation to Aeronautical Mobile Communication Panel (AMCP), Working Group D, Seventh Meeting, Madrid, Spain, 8 - 17 April 1997.

[19] ISO 8208 (1995): " Information technology - Data communications - X.25 Packet Layer Protocol for Data Terminal Equipment".

3 Symbols and abbreviations

3.1 Symbols

For the purposes of the present document, the following symbols apply:

dBm	dB relative to 1 mW
kbps	kilo bits per second. (unit of transmission rate)
kHz	kilo Hertz (frequency unit)
nmi	nautical mile. (distance unit equal to 1 832 metres)

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance Broadcast
ADS-C	Automatic Dependent Surveillance Contract
ADSP	Automatic Dependant Surveillance Panel
AOC	Airline Operators Communications
ASAS	Airborne Separation Assurance
ATC	Air Traffic Control
ATM	Air Traffic Management

ATN	Aeronautical Telecommunication Network
AWOP	All Weather Operation Panel
CCI	Co-Channel Interference
CDTI	Cockpit Display of Traffic Information
CFP	Cellular Frequency Planning
CPDLC	Controller pilot data link communication
CNS	Communication, Navigation and Surveillance
D8PSK	Differentially Encoded 8 Phase Shift Keying
DLS	Data Link Service
DME	Distance Measuring Equipment
DoS	Directory of Service
FIS	Flight Information Service
GA	General Aviation
GFSK	Gaussian Filtered Frequency Shift Keying
GNSS	Global Navigation Satellite System
GNSSP	Global Navigation Satellites Systems Panel
GSC	Global Signalling Channel
HF	High Frequency
LLC	Logical Link Control
LME	Link Management Entity
MAC	Media Access Control
MASPS	Minimum Aviation System Performance Standards
MOPS	Minimum Operational Performance Specification
NEAN	North European ADS-B Network
NEAP	North European CNS/ATM Applications Project
RFP	Reuse Frequency Planning
RSSI	Received Signal Strength Indication
SARPs	Standards and Recommended Practices
SICASP	Secondary Surveillance Radar Improvements and Collision Avoidance Systems Panel
SMGCS	Surface Movement Guidance and Control System
SNR	Signal to Noise Ratio
STDMA	Self-organizing Time Division Multiple Access
STF	Special Task Force
T	The baud period or 1/baud rate
TC	Technical Committee
TIS	Traffic Information Service
TDMA	Time Division Multiple Access
UTC	Universal Co-ordinated Time
VDL	VHF Digital Link
VHF	Very High Frequency
VSS	VDL mode 4 Specific Services

4 Summary of STDMA

4.1 Introduction

This subclause sets provides a summary of STDMA, describing the system requirements, the main features of the system and the system concept. This subclause is based on the material provided in references [1], [2], [3] and [10].

4.2 System requirements

STDMA is designed to meet a system requirement that is to provide a data link technology that enables a range of Air Traffic Management (ATM) applications, including:

- **Automatic Dependent Surveillance-Broadcast (ADS-B):** In ADS-B an aircraft broadcasts its position and other related data, such as ground speed and track, to all other mobile and ground based users in the vicinity. ADS-B potentially enables many new user applications including Cockpit Display of Traffic Information (CDTI), station keeping (i.e. one aircraft following another at a certain distance), augmented Air Traffic Control (ATC) surveillance and airborne separation maintenance. ADS-B is the primary application of STDMA. Note that there is another type of ADS system, known as ADS-contract (ADS-C), in which position reports are set up and transmitted using two-way point-to-point communication links.

- **Differential Global Navigation Satellite System (GNSS) augmentation:** When using GNSS data for navigation or surveillance, a GNSS augmentation system may be used to ensure the quality of the position data. An uplink broadcast data link is one way to provide GNSS augmentation signals, which provide information on the quality of the GNSS signals and correction data to overcome errors and inaccuracies in the signals from the satellites.

- **Surface Movement Guidance and Control System (SMGCS):** SMGCSs provide surveillance of ground traffic at airports. The traffic may include ground vehicles and taxiing or parked aircraft. The application requires the exchange of surveillance and other types of data between all users in the vicinity of the airport. SMGCS is essentially a ground-based application of ADS-B.

- **Controller pilot data link communication (CPDLC):** CPDLC provides pilot-controller digital communications for future applications. CPDLC requires a two way data link system for its operation. Such a data link could also support other point to point applications such as Airline Operators Communications (AOC) providing information exchange between aircraft and airlines. CPDLC is an application of the Aeronautical Telecommunications Network (ATN). The VDL mode 4 draft SARPs define functions that could support ATN-compliant point-to-point communication and hence, if these functions are incorporated into the ETSI standard, STDMA could become a mobile subnetwork of the ATN which allows it to support CPDLC and other ATN applications.

- **Uplink broadcast information:** STDMA can be used to provided uplinked information on, for example, meteorological data, Flight Information Services (FIS), Traffic Information Services (TIS) and other broadcast information. Broadcast applications are provided outside of the framework of the ATN.

Wherever possible, these applications should be supported in a variety of airspace conditions such as busy continental regions and low density oceanic airspace.

The exact system requirements for a data link system are difficult to define for a variety of reasons including:

- Many of the application requirements are not well defined and the subject of ongoing debate.

- The mix of data link technologies required to provide a "system solution" to the application requirements, taking account of such factors as:

    - safety and certification requirements (which may lead to the requirement to distribute different applications over a number of physically independent data links);

    - cost (which may lead to the requirement to reduce the number of data link technologies for which aircraft must be equipped),

is not determined and could probably only be finalized once the application requirements are finalized.

Hence, system requirements can currently only be specified against example operational scenarios. For the purposes of discussing the requirements for STDMA, it will be assumed that STDMA will support an "ADS-B rich" scenario in which repetitive broadcast of position information is the dominant data link load. The DGXIII TREATY 8 report [10] derives an example scenario, which also includes applications which give rise to a small point-to-point data load. Typical message transfer requirements based on the DGXIII TREATY 8 report [10] for an en-route scenario are contained in table 1.

Table 1: Typical message transfer requirements for an en-route traffic scenario

Message length	Quality of Service	Priority	Message Frequency (messages per hour)	Message type
Short	Low	Routine	456	Point-to-point
	Medium	Routine	912	Point-to-point
	High	Critical Routine	5 472 3 648	Point-to-point Point-to-point
	Very high	Critical	194 940	Broadcast
Medium	Low	Routine	3 648	Point-to-point
	High	Critical Routine	456 456	Point-to-point Point-to-point
	Very high	Critical	10 620	Broadcast
Long	Low	Routine	2 280	Point-to-point
	High	Routine	2 736	Point-to-point
Very long	High	Routine	456	Point-to-point

In table 1, the terms have the following meanings:

- Message length:
    - short: less than 20 octets;
    - medium: between 20 and 200 octets;
    - long: between 200 and 3 000 octets;
    - very long: over 3 000 octets.
- Quality of service:
    - low: message delivery time greater than 20s;
    - medium: message delivery time between 10 and 20s;
    - high: message delivery time between 5 and 10s;
    - very high: message delivery time less than 5s.
- Priority:
    - Critical: relates to emergencies and flight safety;
    - Routine: other essential messages.

The data in the table assumes that there are 570 aircraft in an area defined by a circle of radius 160 nautical miles (typical of traffic densities predicted for core European airspace in 2005).

There is great potential for different system requirements than those set out above. In particular:

- the communications load requirements will fall substantially over oceanic and non-core continental airspace because the traffic density is lower;
- it would be possible to envisage a scenario that has a low ADS-B requirement but which provides a high level of point-to-point communications.

If possible, the data link solution should be flexible enough to meet these extremes.

4.3 Candidate data link technologies

There are a number of data link technologies that could individually, or in combination, meet some or all of the requirements outlined in subclause 4.2. These include:

- VDL mode 2, which provides a ground/air Very High Frequency (VHF) link using CSMA protocols. It has been standardized by ICAO, is targeted at applications for AOC and is not expected to be suitable for safety critical communications. VDL mode 2 provides ATN data communications only.
- VDL mode 3, which has been developed as a possible extension of the VDL to provide Time Division Multiple Access (TDMA) channel access for ground/air ATN data and voice communication.
- VDL mode 4 (the ICAO term for STDMA), which has been developed to provide support to ADS-B and to also support data communications. VDL mode 4 provides ATN and non-ATN data communications.
- Mode S squitter. This L-band system was originally developed to support Airborne Collision Avoidance System (ACAS) applications but is also has the potential to support ADS-B applications.

STDMA is the subject of the present document. However, standardization of STDMA needs to be justified against a background of technologies that might provide alternative routes for meeting the system requirements set out in subclause 4.2.

4.4 Key features of STDMA

STDMA is a mode for Communication, Navigation and Surveillance (CNS) systems using either a Differentially Encoded 8 Phase Shift Keying (D8PSK) or a Gaussian Filtered Frequency Shift Keying (GFSK) modulation scheme on standard 25 kHz VHF radio channels and a Self-organizing Time Division Multiple Access (STDMA) scheme . The STDMA technology was invented in Sweden.

This data link has been designed to support repetitive short air-to-air position report broadcasts (ADS-B) as well as to support long and non-repetitive transmissions and ATN services. STDMA has the potential to cover a wide variety of data exchanges applications (ADS-B, Differential GNSS, ATN, CPDLC, FIS-broadcast, AOC, CDTI, etc.).

Figure 1 illustrates the services and applications that could be provided by STDMA (based on functions included in VDL mode 4 draft SARPs [1]):

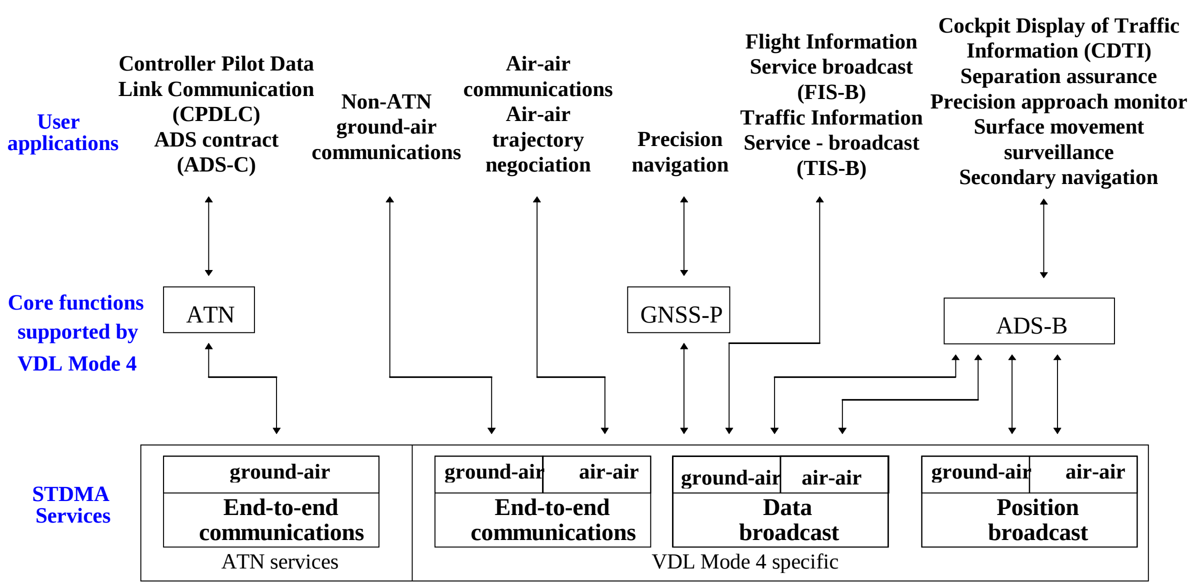

Figure 1: STDMA communications services and example applications

The main concepts of STDMA are:

- A TDMA media access system using a large number of short time-slots.
- Distributed time synchronization: Universal Co-ordinated Time (UTC) time (provided by GNSS receivers or other means) is used to synchronize to the time-slots.
- Managed access to the time-slots: each user maintains information on the planned usage of all timeslots. This information is initially gathered by listening to the channels before attempting to access the data link, and thereafter it is constantly updated. The information is used to decide the time-slots in which a station will transmit data. The intention to use one or more slots for data transmissions is announced using slot reservation protocols. Decisions to transmit data may be made by a mobile user operating autonomously or under the direction of a ground station.
- Adaptive slot selection mechanism: for some types of applications, each user applies an algorithm to avoid long-term slot collisions (i.e. the same slot selected for transmissions by several users). This enables applications such as ADS-B to operate without the presence of a ground infrastructure.
- Position reports broadcast: each user regularly transmits its identity and position (position may be provided by a GNSS receiver or other means) in a synchronization burst. This information is required for communications management, e.g. to provide connectivity information for air-to-air communications.

4.5 STDMA system concept

Each STDMA user may tune to any of the 25 kHz frequency channels from 108 to 136,975 MHz for receiving data, and from 112 to 136,975 MHz for transmitting or receiving data. The band from 108 to 112 MHz is reserved for ground transmissions only. The band from 112 to 136,975 MHz may be used for ground or airborne transmissions.

It is envisaged that two 25 kHz channels, to be known as Global Signalling Channels (GSC), will be assigned *a priori* to STDMA. These channels will be used by ground stations for system management, by transmitting Directory of Service (DoS) messages. DoS messages announce the availability of services on different channels. The channels may also be used to support some uplink broadcasts applications and ADS-B reporting by some aircraft. The use of two channels (as opposed to one) is proposed to allow continued operation in the case of unintentional jamming or blocking of one of the channels. One GSC channel has been proposed as 136,95 MHz, but the other is not defined.

The following airborne architectures of STDMA have been proposed:

- *Commercial air transport:* Aircraft has capability to receive on three channels and transmit on one. Two of the channels are assigned to the GSCs and the third to data communications.
- *General aviation aircraft:* Aircraft has capability to receive on two channels and transmit on one. The two channels are assigned to the GSCs and the aircraft does not have a data capacity.

These architectures define minimum levels of functionality for different users with different requirements. A higher level of functionality may be present on an aircraft and, for example, figure 2 shows a possible architecture that supports reception on four channels and transmission on two.

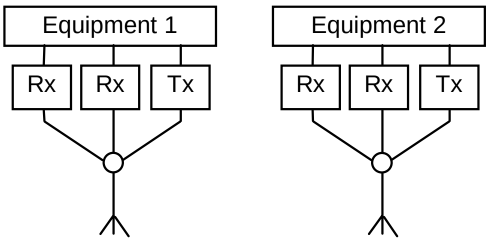

Figure 2: Possible airborne architecture for commercial aircraft

Additional channels may be employed specifically for a particular application, or group of applications. A number of options are possible as illustrated in table 2. These options may be applied individually, or in combination, recognizing the limited number of receivers available on aircraft.

Table 2: Possible options for use of additional channels

Description
Local channel(s) for ADS-B reporting
Channel for wide area en-route end-to-end communications
Channel for local terminal end-to-end communications
Channel for local uplink broadcast applications, including TIS-B, GNSS augmentation and FIS-B
Channel for SMGCS

Physical layer characteristics are assumed to be:

- GSCs are expected to use a GFSK 19,2 kbps modulation scheme.
- Data channels will use a GFSK 19,2 kbps or differentially encoded 8 phase shift keying (D8PSK) 31,5 kbps modulation scheme.

Each user equipment will need to comprise at least (minimum hardware configuration) one transmitter which may tune alternatively to the used frequencies (GSCs and dedicated channels) and two receivers which monitor each GSC full-time.

5 Approach to the review of STDMA

This clause describes the approach that was taken by the STF in the review of STDMA.

An STF of three experts was set up to carry out the required work. The study team comprised expertise in STDMA, air traffic management issues, communication systems and previous experience of the relevant ETSI processes.

The study took place between 12 August 1997 and 29 September 1997. The following phased approach was used:

- In phase 1, the available STDMA documentation was reviewed and a list of issues generated for further study.
- In phase 2, further work was carried out on each issue. This phase included consideration of a possible ETSI standardization process and the generation of a recommended work plan.
- In phase 3, the results of the work were collated and summarized in a draft technical report.

The list of documents analysed are references [1], [2], [3], [4], [5], [6].

Note that the purpose of the study was not to provide solutions for issues raised in the analysis. Rather it was intended to identify the key issues and to produce a study report that could be used to decide whether to proceed with STDMA standardization and, if so, to define the scope of work necessary to complete the standard.

A draft TR was presented for consideration at the Technical Committee (TC) ERM meeting on 6th to 10th October 1997. Comments from that meeting were then incorporated to produce a final TR.

6 Results of the review of STDMA

6.1 Introduction

This clause presents the results of the review of STDMA. It contains the following subclauses:

- a summary of the perceived need for an STDMA standard;
- a summary of procedural issues that will have to be addressed to achieve standardization, including the relation to other standards activities and the possible ETSI process that could be used to produce standards material;
- a summary of the standardization issues that will have to be addressed to improve the presentation of the existing ICAO standard in order to bring it into line with ETSI best practice;

- a summary of the technical issues that will have to be addressed to complete the specification of the existing system.

6.2 The need for STDMA

6.2.1 Market need

Some airlines have expressed a need for the applications supported by STDMA (see "Minutes of Airline Workshop" [18]), establishing a market need for the system. In addition, the system has the potential to offer a low cost data link supporting a range of applications that is affordable by General Aviation users.

6.2.2 Technical need

Annex A summarizes the results of an analysis of the design principles of STDMA. The following characteristics of STDMA have been identified during the review by inspection of the draft VDL mode 4 SARPS [1]:

- both broadcast and point-to-point functions;
- a concept of operation which uses Reuse Frequency Planning (RFP) in which users share access to common channels, a concept which seems particularly suited to ADS-B and other broadcast functions;
- support for Cellular Frequency Planning (CFP), which may be more appropriate for point-to-point functions;
- distributed synchronization, which allows the VDL to work without ground infrastructure;
- ability to also support centralized synchronization and access control;
- short time-slots well suited for repetitive broadcast applications (longer messages can be sent by using a block of slots);
- a flexible channel access scheme that offers enhanced efficiency compared with random access schemes through the use of reservation protocols;
- world-wide signalling channels combining traffic control and data exchanges for various applications;
- spectral efficiency in which two alternative modulations schemes, D8PSK and GFSK, are supported.

The analysis has shown that STDMA appears well suited for repetitive short messages broadcast (position reports) as this function is an inherent core part of the data link.

A decision to standardize STDMA must be taken against a background of other data link technologies that could provide a better solution to the requirements of future applications. As was described in subclause 4.1, there are a wide range of future communications, navigation and surveillance ATM applications, which can provide benefits to users in oceanic, core continental and low density continental airspace. Realization of these applications will require the development of enabling communications technology or combinations of technology.

The detailed requirements for these applications are unknown and subject to change. However, it is likely that the requirements for the enabling data link technology will be diverse and may include:

- operating with and without ground infrastructure;
- providing ground/air and air/air communication;
- providing point/point and broadcast communication functions;
- supporting safety critical communication;
- using a robust handover mechanism between coverage cells, particularly for safety critical applications;
- maximizing spectrum efficiency.

The capability of VDL modes 2, 3 and 4 and mode S squitter to support the applications listed in subclause 4.2 is a subject of debate. STDMA has certain features that are not provided by any other proposed VHF data link in ICAO. These unique functions include:

- operation with no ground infrastructure;
- air-to-air communications, both with and without the presence of ground stations;
- broadcast communications, both from ground and airborne users.

Note also that this review has not attempted a detailed comparison of how well VDL modes 2, 3 and 4 support end-to-end applications such as AOC, FIS etc. Hence, although STDMA as defined in Draft VDL mode 4 SARPs claims [2] the potential to offer an improved throughput compared with mode 2 because of the use of reservation protocols, there are as yet no model results to support this claim. Similarly, the reviewers have not found any side by side comparisons of mode 3 and mode 4 performance.

The reviewers have recommended that any future STDMA standard should be developed in two stages (see subclause 6.3). The first stage would develop the part of the system that would support ADS-B and would enable a side by side comparison with the mode S squitter technology. End-to-end communication would be added in the second stage and it is recommended that a comparison between the VHF modes is made during this stage and, if possible, the mode 4 protocols optimized using experience gained from modes 2 and 3. If possible, opportunities to provide interoperability and transition paths between the different VDL modes should be identified and exploited.

6.2.3 Current progress towards standardization

The most recent ICAO activity relevant to VDL standardization was the AMCP Working Group D (WGD) seventh meeting in Madrid from 8 - 17 April 1997. The key results of the meeting were:

- Mode 3 VDL standardization: A key service supported by mode 3 is voice communication. Difficulties have been encountered in proving the operation of the vocoder, which is required to provide voice services. The difficulties relate to achieving acceptable discrimination and clarity of voice communication against the high levels of background noise encountered in the cockpit. It was accepted at the meeting that the problems with the vocoder would probably delay the completion of the validation process for mode 3 by at least two years. Note that the development of the data functions of mode 3 have been influenced greatly by the need to provide integrated voice and data. Without the vocoder, it is still possible to standardize VDL mode 3 as an ATN data communications system with higher performance than VDL mode2.

- VDL mode 4 (ICAO term for STDMA): The latest version of the SARPs were presented [3]. Discussions were held to decide if mode 4 could enter a validation phase. Objections to the operation of mode 4 were raised on the grounds that the algorithms for frequency sharing were not proven. It should be noted that overall acceptance of mode 4 is hampered by its possible use for ADS-B. Some states, particularly the USA, are committed to using mode S for ADS-B and are unconvinced by the need to consider alternative systems.

There is therefore considerable uncertainty as to the way forward for data link standardization within ICAO and this is hampering progress with the development of VDL mode 4:

- From a technical viewpoint, it may be better to proceed with standardization in order to provide a stable and validated reference system which can then be considered against evolving operational requirements. Since future requirements will be quite hard to determine in detail for any system considered for standardization, a key feature should therefore be flexibility and growth potential.

- On the other hand, an alternative approach is to wait until there is a stable operational requirement before proceeding with standardization activity. This approach would cause significant delay to the progress of VDL mode 4 and greatly reduce its chances of gaining world-wide acceptance. According to current ICAO plans, VDL mode 4 is unlikely to be standardized before 2000.

6.2.4 Ongoing trials projects

There are many tests and evaluation projects involving STDMA (note that the equipment used in these trials is based on an early STDMA specification which pre-dates the VDL mode 4 draft SARPs upon which the proposed ETSI standard would be based). Some are finished and some have not yet started, but some of the most relevant ones that are presently ongoing are described below:

- **NEAN** ***(sponsored by EC DG VII)*** The largest European STDMA activity is known as the North European ADS-B Network (NEAN). Under NEAN, an ADS-B capability is being created through a network of ground stations and mobile STDMA equipment that is compliant with the emerging VDL mode 4 draft SARPs and which is being installed in commercial aircraft and airport vehicles. The network spans Germany, Denmark and Sweden, and once position reports are received by a ground station they are then distributed throughout the network to air traffic control and other users. There will be 15 ground stations in the NEAN project and 16 aircraft equipped including four 747s, two DC9s, two F28s and a helicopter involved in North Sea operations. Around 30 ground-vehicles will also be equipped. NEAN is a collaborative venture between the German, Danish and Swedish Civil Aviation Administrations and the following aircraft operators: Lufthansa, SAS, OLT, Maersk Helicopters and Golden Air. The UK CAA is leading the certification and validation parts of the project. The NEAN ground network was completed in May 1997 and airborne installations will be completed by the second half of 1997.

- **NEAP (*sponsored by EC DGVII)*** The North European CNS/ATM Applications Project (NEAP) is a sister project to the NEAN, with the same participants. Using the infrastructure implemented in the NEAN, the NEAP will develop and demonstrate end-to-end (airborne and ground based) applications using the VDL mode 4/STDMA data link. The applications to be investigated in NEAP include: enhanced ATC surveillance (both while airborne and on the ground); uplinked support information for pilots, e.g. TIS data; uplinked differential GNSS corrections and integrity data.

- **FARAWAY (*sponsored by EC DG XIII)*** The objective of FARAWAY is to investigate the enhanced operational performance of ground surveillance and aircraft navigation made possible through fusion of radar and ADS-B data. The Faraway project is co-ordinated by Alenia Spa, Italy and involves ATM service providers and airlines in Germany, Italy and Sweden. Initially three Alitalia MD-82 will be equipped with STDMA and cockpit display equipment and one ground station will be installed at Ciampino airport, Rome. The FARAWAY trials will run from October 1997 to March 1998.

- **MAGNET B (*sponsored by EC DG XIII*)** The objectives of Magnet B are to develop GNSS1 user segments, to assess their capability to meet the most demanding aviation requirements and to evaluate the benefits that users can achieve from the integration of GNSS1 with a two-way data link. The Magnet B project is co-ordinated by Dassault Electronique, France and includes participants from Germany, UK, Norway, the Netherlands and Sweden. When practical trials start, it is expected that STDMA will be installed in an NLR aircraft in Holland and a base station also located there.

- **PETAL II** ***(sponsored by EUROCONTROL)*** PETAL-II is a Eurocontrol project to investigate use of air-ground data link to perform real-time CPDLCs. Petal II is using the two-way data link capability of STDMA to provide this application. STDMA ground stations were installed at the Maastricht Centre and at the Eurocontrol Experimental Centre during March/April 1997.

These trials programmes have provided early demonstration of the use of STDMA for ADS-B applications. There is the potential for integrating VDL mode 4 draft SARPs or ETSI standard compliant equipment with these trials in 1998 in order to provide an extensive test bed for the validation of the VDL mode 4 draft SARPs or ETSI standard. The early establishment of an ETSI standard is therefore desirable to provide a stable reference specification for development of this equipment.

6.2.5 Summary

In deciding whether to standardize STDMA, the main evidence to be taken account of is therefore:

- a requirement for STDMA has been expressed by some airlines;

- the ability of STDMA to offer a flexible communication system and, in particular, its ability to provide communication functions that are not currently supported by other VDL modes:
  - operation does not require ground infrastructure;
  - air-to-air communications, both with and without the presence of ground stations;
  - broadcast communications, both from ground and airborne users.
- its ability to offer a solution for ADS-B applications;
- progress of the STDMA standard within the ICAO forum is slow and there is no prospect of achieving an early standard.

ETSI can provide a rapid route for standardization through its flexible standards development process:

- making possible the establishment of a regional standard;
- providing a benchmark for Commission funded trials activity;
- promoting the development of the operational uses of STDMA.

ETSI can therefore provide a path to promote a system being developed by European industry.

In developing a possible standard, account should be taken of the development of other standards, notably:

- Mode S squitter as an alternative ADS-B enabling technology;
- VDL modes 2 and 3, taking opportunities, wherever possible, to unify the point-to-point functions of the three modes.

6.3 Procedural issues

The production of an ETSI standard must take account of and, wherever possible, co-ordinate with other standards activities related to STDMA. The necessary activities identified in the study include:

- co-ordination with standards being developed by ICAO AMCP, possibly through exchange of change requests;
- taking account of emerging standards for ADS-B being produced by Radio Technical Commission for Aeronautics (RTCA);
- co-ordination (and potential resource sharing) with VDL mode 4 Minimum Operational Performance Specifications (MOPS) being developed by European Organization for Civil Aviation Electronics (EUROCAE) WG-51;
- information sharing with the Airline Electronic Engineering Committee (AEEC) in order to encourage AEEC to develop common interface standards;
- co-ordination with groups developing STDMA-derived standards in other application areas, notably land and maritime.

As a result of the analysis of the VDL mode 4 standards material upon which an ETSI standard would be based, it has been concluded by the STF that it will take approximately one year to produce an ETSI standard with the same boundaries as the current ICAO standard, followed by a further 6 months to produce an approval and protocol conformance specification. Since there is an urgent need to produce a standard to support trials activity carried out in 1998, a phased approach is recommend in which:

- An initial TS (TS1) is produced which will define a system targeted at ADS-B applications and is the most natural extension of the STDMA system. It is estimated that such a TS could be produced after 6 months work.
- A second TS (TS2) is produced which will define an enhancement to support point-to-point communication. This could be completed after a further 6 months work.

- A third TS (TS3) is produced to contain the approval and protocol conformance specification. An initial version of this would be produced after the first 6 months in order to support the trials use of the system defined by TS1. There would be a later extension produced after the completion of TS2 to define the full approval and protocol conformance specification for an operational system based on the combined TS1 and TS2. Note that it might be preferable to separate TS3 into two TS's, corresponding to conformance specifications for TS1 and TS2 respectively.

- Once TS1 and TS2 are complete, it is proposed that they are submitted for formal approval to produce an EN.

- It is proposed that the required work is carried out by two sub groups:

  - The first one will work on the physical layer;

  - The second one will work on the Logical Link Control (LLC) and network layer, which, in ICAO SARPs terminology includes the link layer (Media Access Control (MAC) sublayer, VDL mode 4 Specific Services (VSS) sublayer, Data Link Service (DLS) sublayer, Link Management Entity (LME) sublayer) and the subnetwork layer.

It will be necessary to set up a liaison activity between the two groups to define the interfaces between the two layers and to liaise with other standards activities. This interface will probably evolve with the technical work within the two subgroups.

More detail on the procedural issues relevant to the standardization of STDMA is contained in annex B.

6.4 Standardization issues

6.4.1 Introduction

The standardization of STDMA will have to follow the usual methodology:

- define precisely the needs and the requirements that this standard will have to satisfy;

- choose the technical solutions that will permit to offer solutions to the previously identified needs and requirements;

- write a standard which clearly and unambiguously reflects the solutions adopted in the standard.

The issues raised by the review process are discussed in this subclause. More detail on STDMA standardization issues is contained in annex C.

6.4.2 The need for a clear system concept

6.4.2.1 The need for clear interfaces

It is necessary to summarize the various functions that STDMA will have to support. Considering that STDMA is intended to support a lot of different interfaces, it may be necessary to organize the offered functions in relation to their main characteristics e.g. connection or connection-less oriented. The defined interfaces will have to be complete with not only the parameters of the requirement but also with the indications returned in case of failure or impossibility to satisfy the service.

6.4.2.2 Clear boundaries for the system

Clear boundaries of the system will have to be defined. These boundaries concern the channel management and the way the functions are supported. One may distinguish between three main approaches to this problem:

- To define a very simple communication system operating on a frequency. This frequency may vary in a given frequency bandwidth.

- To define in addition to the previous communication system tools which may make it possible to manage various channels and to organize various functions sharing a same resource.

- To build a fully integrated telecommunication system capable of taking into account the various services requirement, their need of bandwidth and possible competition between these requirements.

This problem has technical implications. The solution chosen will impact greatly on the architecture of the standard. Because the detailed requirements for services are not yet fully defined (see subclause 6.2.2), it is felt that the third of these approaches is unlikely to be practical. Instead it is recommended that a flexible standard is produced through a combination of the first and second approaches.

6.4.2.3 Clear mode of operation in the given spectrum

The availability of the targeted spectrum has to be clearly identified as well as the possible constraints. One may be in various scenarios ranging from the exclusive use of the bandwidth to the coexistence or inter operation with other systems. As a priority, the standardization work should consider this issue and provide a resolution to it.

6.4.3 The reliability issue

Concerning a telecommunication standard in the aeronautical field, STDMA will have to address the reliability issue. In the DGXIII Treaty 8 report [10], the functions described have an associated reliability requirements. These requirements will have consequences on the design of the STDMA standard.

The reliability issue may be addressed throughout all the whole STDMA standard. For instance the reservation scheme which is a corner stone of the STDMA draft standard will have to address with this concern.

Moreover the reliability issue imposes that a conformance testing specification will be worked out to ensure a proper operation of the system.

6.4.4 Structure and presentation of the standard

The standard will be written in accordance with the chosen architecture and in accordance with ETSI best practice.

6.5 Technical issues

This subclause describes the technical issues that will require investigation during the standardization process. There are four kinds of technical issues:

- provision of procedures which are not yet specified in the draft standard;
- the optimization of the parameters which are used in the standards;
- the possible enhancement of the system;
- the validation of performance with respect to requirements.

The level of effort required to resolve these issues varies between topics. Some will require substantial effort.

More detail on the technical issues relevant to the standardization of STDMA is contained in annex D.

6.5.1 The missing procedures

6.5.1.1 Secondary timing and positioning protocol

The timing and positioning recovery procedure when local UTC source fails is mentioned in the draft but is not specified. A clone of the GNSS procedure based on position broadcast of remote aircraft and tracking of their burst synchronization may suffice. The main difficulties are in the definition of hardware and software timing requirements for this purpose and in providing tests to demonstrate compliance.

6.5.1.2 Channel management

The set of channel management procedures is very important. If the committee plans to include them in the draft standard then there will be the need to specify numerous protocols for dynamic channel assignment and for dealing with possible erroneous behaviours of the system in case of protocol failure.

6.5.1.3 High priority reservation pre-emption protocol

This procedure is mentioned in the ICAO standard but not yet specified. Algorithms exist in case of a centralized protocol where a central agent rules the medium access. In a distributed protocol such as that used for STDMA, the problem might be less easy since the pre-emption poses problems in the case of contention between different priorities.

6.5.2 The optimization parameters

Optimization of parameters in the ICAO standard should not require too much resource, provided the committee has the technical expertise to achieve it, or can rely on technical database and simulation tools. A number of STDMA simulation and modelling studies are currently in progress as part of the ICAO process and it is hoped that this expertise can be drawn upon to carry out the work.

6.5.3 The system enhancements

6.5.3.1 Superframe parameters

Some clarification is required of the superframe parameters. This is not expected to require significant resource to solve.

6.5.3.2 Warming up procedures

The system recovery after a long channel failure or when an aircraft first enters STDMA coverage may be considered too slow, although this may not prove to be operationally significant. A study must be carried out to investigate this issue and possibly to propose an enhancement to the standard.

6.5.3.3 Slot reuse and Co-Channel Interference (CCI) conditions

The CCI condition for slot reuse may be incomplete since it considers only one transmitter per slot, while several transmitters are possible. In this case the CCI conditions may need to be adapted and the resulting broadcast condition may be more complicated. CCI conditions based on Received Signal Strength Indication (RSSI) power measurement instead of position estimate may prove to be an interesting alternative to the currently proposed scheme. It may be possible that CCI conditions and broadcast conditions could be simplified and merged to a single condition based on RSSI with negligible performance degradation. The issue of slot re-use therefore needs substantial study and validation through modelling. Once again, existing simulation work could be used to assist this work.

6.5.3.4 Distributed clock software synchronization

A timing mechanism that does not rely on an external source might be investigated to increase the integrity of the system. Software synchronization mechanisms provide interesting results but require *a priori* a communication whose reliability is independent of clock synchronization, see references [11], [12], [13]. Investigations to find possible less demanding protocols are recommended.

6.5.3.5 Reaction to long jamming periods

Procedures to deal with jamming and other persistent noise events need to be investigated.

6.5.4 Viability check and performance study

6.5.4.1 Modulation choice

STDMA is sufficiently flexible to support two modulation types. The choice of modulation type may need further study. However for ADS-B and Differential GNSS (NABS) applications, it is expected that GFSK will prove to offer the best system performance (see reference [5]). A study needs to be carried out to investigate the relative advantages and disadvantages of the possible modulation types and to make recommendations for the best scheme as a function of service provided.

6.5.4.2 The slot reuse and broadcast reliability

The periodic broadcast is the most demanding function in STDMA. The access protocol needs to guarantee, with sufficient reliability, the performance of the network in the case of heavy traffic, or any other critical conditions against which STDMA needs to be tailored. For example the E-TDMA study (see reference [10]) outlines a worst case en-route situation of 570 aircraft in a radius of 160 nmi, each aircraft broadcasting its position every six seconds. In this very case it is necessary to check that the broadcast transmissions are received with enough range and enough reliability. A modelling and simulation effort is required and an example is given in annex D. Reuse factor, average reception area and reliability estimates are the parameters which should be derived as a result of this study and the result should be used to further develop the system concept including consideration of number of channels required, use of GSCs etc.

6.5.4.3 Remote and hidden node management

One should check under which conditions an aircraft could be visible for a second station and not for a third one. One case is the ground effect on ground stations. The committee should investigate the way to cope with this problem which may affect ground control.

7 Proposed work plan for STDMA standardization

7.1 Introduction

This subclause presents a proposed work plan for STDMA standardization.

7.2 Key issues and recommended approach

The European Commission has indicated that it is desirable to produce an EN for STDMA. This is desirable because it adds force of European Law to the standard and will have most influence on the ICAO process. However, the procedure for achieving an EN will result in delay which may not enable the full impact on the ICAO process to be realized. As described in subclause 6.3, the STF recommend that the development work is divided into three TSs. The first two of these TSs would then be submitted to the full voting procedure to produce an EN. This approach results in the early availability of TC approved standards which can then be converted to EN status in the fullness of time.

7.3 Organization of the work

The recommendation derived from this study is to carry out the development work using the following procedure:

- build a set of functions and associated requirements that STDMA will offer;
- develop a clear system concept and architecture for the system;
- break the committee in charge of the standardization into two subgroups: The Transmission Techniques Group and Protocol Design Group.

The Transmission Techniques Group should study the following points:

- determining an appropriate choice of modulation;

- specification of parameters concerning power limits, switching times, etc.;
- ensuring the interoperability with VDL mode 2 and other media such as ACARS VHF, voice VHF, navigation aids etc.;
- defining antenna requirements to ensure a nearly isotropic radiation;
- defining requirements and suitable techniques for timing synchronization.

The Protocol Design Group should study the following points:

- functions to be offered by STDMA and related interfaces;
- system concept definition, channel management and function management;
- timing synchronization for example, what form of distributed algorithm will be used to synchronize clocks);
- slot reuse algorithms;
- reliability issues in the STDMA functionality.

The two sub-groups will focus on the production of the following deliverables:

- An initial TS (TS1), which will define a system targeted at ADS-B applications and is the most natural extension of the STDMA system. It is estimated that such a TS could be produced after 6 months.
- A second TS (TS2), which will define an enhancement to support point-to-point communication. This could be completed after a further 6 months.
- A third TS (TS3) to contain the approval and protocol conformance specification. An initial version of this would be produced after the first 6 months in order to support the trials use of the system defined by TS1. There would be a later extension produced after the completion of TS2 to define the full approval and protocol conformance specification for an operational system based on the combined TS1 and TS2. Note that it might be preferable to separate TS3 into two TSs, corresponding to conformance specifications for TS1 and TS2 respectively.

In addition, the committee should consider whether a TR deliverable detailing the functions and facilities of the system and the services and applications to be supported should be produced as an aid to explaining the purpose, interfaces and boundaries of the system. The TR should also specify the type approval requirements for the system so as to define the level of conformance testing necessary. Such a document could be produced at the start of the recommended work as a means of providing a reference work for the study.

The committee will need to provide control and co-ordination of the overall activity. This will include:

- defining the terms of reference of each sub-group and ensuring that there is no duplication of effort;
- providing editorial control over the production of the TS document;
- providing liaison support with other standards bodies, notably ICAO, EUROCAE and International Maritime Organization (IMO).

Note that technical constraints may impose that TS1 and TS2 be within the same document (see subclauses B.3.5 and C.2.2).

As was discussed in subclause 6.2, account should be taken of the development of other standards, particularly VDL modes 2 and 3, taking opportunities, wherever possible, to unify the point-to-point functions of the three modes. It is recommended that a review of the current state of standardization of these standards is carried out prior to starting work on TS2 in order to decide on the need for TS2 and the required content of this part of the standard.

7.4 Timescales for the work

It is estimated that it will take 6 months to one year to complete the functional specification work. An additional 8 months will be necessary to perform the radio approval and protocol testing. An initial timing chart is provided in figure 3 showing approximate timescales. It is recommended that a detailed planning activity is carried out at the start of the study. It may be necessary to increase the time taken to carry out the production of TS1, leading to slippage of the delivery date. This will depend both on available resource and on the time taken to complete the first task (production of the TR). If additional time is necessary, it may be possible to reduce the time taken to produce TS2 so as to keep to the overall planned timescales. The detailed planning must also take account of the timing of TC ERM meetings, particularly as a decision to proceed with the production of TS2 will have to be taken by that committee after the completion of TS1.

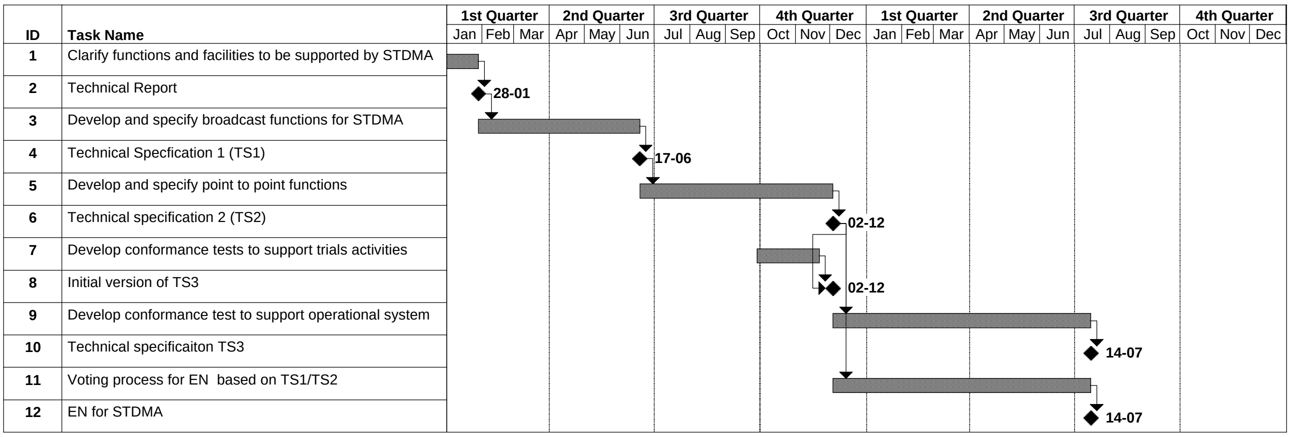

Figure 3: Initial study timescales (assuming start date 01/01/98)

7.5 Estimated resource requirements

According to the previous organization of the work and taking into account annex B, C and D for further refinement, one can estimate that a committee must be set up to cover a period of 20 months (in accordance with the timescales set out in figure 3). According to the initial timescales, this work can be divided between around 12 months for the functional specifications and around 8 months for the conformance testing issue. The exact number of meetings necessary is difficult to assess, but it could be assumed that the committees would have to meet at least every 2 months. Since it is probably unlikely that sufficient resources can be found within ETSI to enable the work to be carried out wholly by a committee, it is recommended that an STF is used to:

- carry out the bulk of the required work and provide specialist expertise in air traffic management and STDMA (estimated effort required is 14 man months, dependent on the level of expertise available within the committee);
- support the conception of the whole system including modelling and simulation of various possible approaches, dimensioning, ensuring reliability and performances of the system (estimated effort required is 6 man months);
- to carry out most of the work on the radio approval and conformance testing specification (estimated effort required is 10 man months).

Overall, therefore, it is recommended that over an elapsed period of 20 months, the effort required to carry out the work is estimated to be 30 months of contracted STF effort.

8 Conclusions and recommendations

In accordance with CE Mandate M/239, a Special Task Force has carried out a study on the feasibility of standardizing self organized time division multiple access (STDMA) system requirements. The available specification material for STDMA has been analysed to see what actions ETSI should take to:

- transfer the technical specification into a standard;

- complete all the required interfaces;
- identify areas needing particular attention;
- define the appropriate time schedule for any future work.

The following conclusions have been reached as a result of carrying out this review:

- STDMA appears to provide a flexible data link that has the potential to act as an enabling technology for a wide range of future Air Traffic Management applications. In particular, the system has been optimized to support ADS-B applications.
- There is a market requirement for the system.
- Although there are rival candidate systems for ADS-B, notably a system based on mode S squitter transmissions, there is, as yet, no international consensus on the eventual choice of data link for ADS-B and it is not certain when such a consensus could be reached.
- STDMA has a number of unique functions that differentiate it from other VDL standards, notably:
    - operation with no ground infrastructure;
    - air-to-air communications, both with and without the presence of ground stations;
    - broadcast communications, both from ground and airborne users.
- Current trials activity urgently require the establishment of a standard in order to promote further understanding of the operational uses of STDMA.
- The current progress towards standardization of STDMA (known as VDL mode 4) within the ICAO forum is slow and there is no prospect of achieving an early standard.
- The current ICAO standards provide a reasonable starting point for ETSI standards but the review has identified a number of presentational and technical issues that must be resolved before a standard can be produced. These issues include the need to:
    - define clear interfaces, system boundaries and the mode of operation for the system;
    - change the presentation of the standard to conform with ETSI best practice;
    - define procedures that are currently absent from the standard including timing, channel management and pre-emption protocols;
    - optimize certain parameters;
    - consider possible system enhancements including alternative slot re-use algorithms based on RSSI and resistance to jamming and other interference sources.
    - carry out system viability checks including modelling of broadcast delivery reliability and remote and hidden node management.

The STF makes the following recommendations:

- A standardization activity for STDMA should be started within ETSI based on the existing ICAO standard. The aims of the standardization activity should be to:
    - respond to market need;
    - support the development of the STDMA system, particularly the functions provided by system, namely broadcast functions, air to air functions and operation without ground infrastructure, that are currently not supported by any other VDL modes and which enable STDMA to support a wide range of applications and to provide a data link in core continental, oceanic and low density continental airspace;
    - provide a stable standard for trials assessment of ADS-B applications;

- provide extensions to the standard that are capable of supporting point-to-point communication.

- The deliverables for such an activity should consist of:

  - An initial TS (TS1), which will define a system targeted at ADS-B applications and is the most natural extension of the STDMA system. It is estimated that such a TS could be produced after 6 months.

  - A second TS (TS2), which will define an enhancement to support point-to-point communication. This could be completed after a further 6 months.

  - A third TS (TS3), which will contain the approval and protocol conformance specification. An initial version of this would be produced after the first 6 months in order to support the trials use of the system defined by TS1. There would be a later extension produced after the completion of TS2 to define the full approval and protocol conformance specification for an operational system based on the combined TS1 and TS2. Note that it might be preferable to separate TS3 into two TS's, corresponding to conformance specifications for TS1 and TS2 respectively.

  - An EN based on TS1 and TS2. The voting process for this EN will start once both TS1 and TS2 are complete.

  - In addition, consideration should be given to the production of a TR deliverable detailing the functions and facilities of the system and the services and applications to be supported. This would be useful as an aid to explaining the purpose, interfaces and boundaries of the system. The TR should also specify the type approval requirements for the system so as to define the level of conformance testing necessary. Such a document could be produced at the start of the recommended work as a means of providing a reference work for the study.

- The committee in charge of the standardization should be divided into two subgroups : The Transmission Techniques Group and Protocol Design Group.

- Overall, therefore, it is recommended that over an elapsed period of 20 months, the effort required to carry out the work is estimated to be 30 months of contracted STF effort.

- Development of STDMA should take account of activities in other standards bodies. In particular, account should be taken of:

  - VDL mode 2 standards and the emerging VDL mode 3 standards within ICAO. Some functions provided by STDMA are also provided by VDL mode 2 and mode 3 and any further development of these functions within STDMA should be fully justified in terms of operational advantage and user benefit. It is recommended that a review of the current state of standardization of these standards is carried out prior to starting work on TS2 in order to decide on the need for TS2 and the required content of this part of the standard;

  - emerging standards for ADS-B being produced by RTCA and also alternative ADS-B system solutions such as mode S squitter;

  - the need for co-ordination (and potential resource sharing) with VDL mode 4 MOPS being developed by EUROCAE WG-51;

  - the potential benefits of information sharing with AEEC in order to encourage AEEC to develop common interface standards;

  - the need for co-ordination with groups developing STDMA-derived standards in other application areas, notably land and maritime.

Annex A: Design principles of STDMA

A.1 Functions and traffic requirement addressed by STDMA

Typical operational scenarios to be supported by STDMA mix broadcast applications (and, in particular, ADS-B applications) with point-to-point applications (CPDLC etc.).

ADS-B applications are expected to be the main traffic contributor to STDMA. ADS-B requires that aircraft position parameters are periodically broadcast to other aircraft (air-air) and to ground stations (air-ground). The ADS-B operational environment places special requirements on the design of a multiple access technique to be employed.

- Firstly, aircraft ADS-B transmitters are highly mobile such that the environment around any given surveillance receiver is rapidly changing.
- Secondly, it is necessary that for air-air ADS-B applications, the system should be able to operate autonomously without a central controller in many environments, including oceanic and low density continental airspace.
- Finally, ADS-B must appear seamless to an ADS-B surveillance receiver; i.e. an airborne sensor must always be able to hear all nearby aircraft reports regardless of their location with respect to any "cell" or "sector" boundaries.

Point-to-point functions are also important requirements in order to support ATN protocols and these could be supported by STDMA if the point-to-point functions defined within the ICAO VDL mode 4 draft SARPs are incorporated into the ETSI standard. However, its performance will need to be compared with that offered by other VDL standards such as modes 2 and 3.

Note that in order to achieve optimum use of the data link, it may be necessary to partition the different applications on to different channels and to use different parameters (e.g. guard time, modulation scheme, slot length etc.) for each channel. Obviously, this increases the system complexity and is probably not desirable if it can be avoided.

Because ADS-B requirements dominate the expected operational scenario, it is expected that STDMA will be optimized with respect to this service. Also, because STDMA could support point-to-point communication (particularly if such support is on a separate channel), it is expected that it will provide a potential solution for end-to-end applications.

A.2 STDMA system concepts and frequency allocation

A.2.1 Introduction

The system concept should take account of the frequency shortage in Europe and elsewhere. A concept based on distinct coverage cells relies on different frequency cells for data link activity and will probably have to use spectrum currently used for voice communication. There will therefore be difficult transition issues to solve. A possible solution in which a frequency for data link is assigned to each air traffic sector is probably not practical in the early days since there will be insufficient spectrum (it is possible that the migration of voice to 8,33 kHz channels may free up some spectrum in the longer term and if not limited to upper airspace only). A better approach may be to define a large region served by the same frequency and which operates near to capacity in the early days, and to reduce the size of that region as the data link load increases and as more spectrum becomes available. Alternatively, use of a system that allows re-use of the same channel may be a better, more efficient approach. This subclause explores these issues in more detail.

A.2.2 System concept

CFP is a VHF coverage concept which is organized into distinct coverage cells, such that there is no overlapping coverage between cells using the same frequency. RFP is a VHF coverage concept which allows the same frequency to be used on adjacent cells, taking advantage of capture effect on packet reception.

The proposed STDMA concept uses RFP and does not require specific CFP. Note, however, that STDMA does not preclude the use of CFP in its channel management architecture.

CFP has the advantage over RFP that it allows a very simple and centralized channel access management around every base station. RFP needs more sophisticated distributed channel access which takes into account interference from remote stations and hidden nodes. However the RFP concept presents numerous advantages over CFP as listed below:

- CFP consumes greater frequency resource since strict cell mapping would require at least four distinct frequency sets (experience with GSM suggests that at lest six distinct frequency sets would be required). In theory RFP would need only one set of frequencies. Furthermore frequency planning on empty areas (i.e. without ground stations) would be difficult to manage.

- In general CFP is difficult to manage in a dynamic configuration. For example as air traffic load increases it will be difficult to add new frequencies in each cell or to reduce the size of cells. Adding extra frequencies in RFP is trivial. Note that, in RFP, a higher load on the same frequency may simply lead to smaller link range which may be tolerable if the available range does not drop below critical values.

- RFP does not need a channel hand-over protocol between cells. In CFP, handover is a potentially weak part of the system since channel misallocation could disrupt the communication link. STDMA can use the same channel on two adjacent cells, thus neighbouring ground stations will be able to monitor the air traffic beyond their own cell boundary.

The system concept can have an important impact on the data link protocols. For example:

- Aircraft moving from one ground station to another in an RFP concept, require co-ordination of coverage in overlapping regions to ensure that there is no channel contention. Such co-ordination could be provided by a ground network (with resultant networking design, implementation and running costs) or (preferably) could be provided by link management protocols defined as part of the data link standard.

- Aircraft moving from one cell to another in a concept using distinct coverage cells also require co-ordination. For point-to-point communication, this involves maintaining peer-to-peer links and is achieved by ATN protocols. The situation is more difficult if ADS-B applications are being supported, since all aircraft in the overlapping region needs to receive transmissions from all other aircraft in the region, some of which will be operating on different channels. In this case, the data link protocols need to support parallel operation on more than one channel.

Therefore ADS-B applications suggest the use of global channels, since otherwise, a non-trivial co-ordination mechanism will be needed to maintain a full surveillance picture for all users in the transition region from one frequency to another. In this case, RFP management, which is supported by STDMA, is expected to be a key for such an application. ADS-B ground-air applications could be implemented using a CFP concept with the transition from one frequency to another controlled by the ground system. However, since ADS-B could be used to provide the ground based surveillance service, the control mechanism would have to be of the highest integrity and could result in costly ground networking solutions.

Furthermore, local constraints may impose CFP for VDL. In this case, the STDMA concept does not preclude the use of any particular channel management technique, with or without CFP in its channel architecture. STDMA will provide the elements needed for the implementation of the preferred management scheme.

A.2.3 Frequency allocation

The bands currently allocated to the aeronautical service by ITU and potentially available for data link are:

- VHF with 50 and 25 kHz channelization (currently used for navigation and VHF communications).

- L-band with 1 and 8 MHz channelization (currently used for navigation and secondary surveillance radar).

Both of these bands have advantages and disadvantages for use by an ADS-B system:

- Power requirements: Propagation path loss is proportional to the transmit frequency. This generally allows systems operating in a lower frequency band to use less transmit power than a comparable system at a higher frequency. Since the transmitters are airborne-based for this service the advantage of lower power could be an important consideration, particularly for the General Aviation (GA) market.

- Spectrum availability: The VHF band is constrained due to current use world-wide. Given the current constraints, a system operating in this band must operate within the channelizations of 50 or 25 kHz to "fit in" amongst current assignments. Currently VHF communications channels are in great demand. Therefore, initially finding and co-ordinating the international use of one or more of these channels solely for ADS-B may be difficult. However, depending on the actual installed implementation of navigational aids, there may exist the possibility to intermix ADS-B channels in that portion of the VHF band. In addition to the old 112,0-136,0 kHz band assigned by ITU for aeronautical functions there are also new 25 kHz channels assigned to aviation by ITU in the 136,0-137,0 kHz band of which four of them have been designated by ICAO for data link functions. Within L-band it may also be possible to co-ordinate a global channel due to the nature of the current ICAO band plan for Distance Measuring Equipment (DME) channel pairing, where one channel of the DME pair overlaps the SSR portion of the band. Since that DME channel pair cannot be used because of interference with secondary surveillance radars, then one channel of the pair is for the most part unused and could provide a clear channel.

STDMA operates in the VHF band and therefore offers the potential for a low power and hence low cost data link. However, problems of VHF channel congestion will have to be solved to allow a suitable allocation to be made for its use.

A.3 STDMA modulation scheme and physical layer

STDMA is based on high speed (10 to 30 kbps) channels in order to satisfy the load needed by the traffic requirement. Among its optional scheme there is a modulation scheme GFSK at 19,2 kbps, which is resistant to noise (Signal to Noise Ratio (SNR) of 7 dB) which is needed for high link reliability. Furthermore it allows a good frequency reuse and is particularly well adapted for RFP. In particular ADS-B applications would need the use of a global channel with the following requirements:

- use of a modulation scheme that can tolerate CCI from other users on the same channel (this points towards lower data rate);

- a relatively large guard time to enable a user to receive transmissions from distant users (resulting in a reduced channel capacity).

Point to point communications in ATN protocols would require:

- use of a modulation scheme that maximizes data rate (this may points towards schemes that have relatively poor CCI performance, which limits frequency reuse but ATN protocols could be implemented in CFP);

- a guard range targeted at the expected coverage range for each cell (probably results in a smaller guard time than used for a concept that uses a global channel and therefore is a more optimum use of the channel leading to higher capacity).

STDMA proposes an alternative modulation scheme which is D8PSK at 31,5 kbps.

A.4 STDMA Access protocols

General access protocols for VDL need to be derived:

- VDL mode 2 uses random access on a shared channel for ground-air communication.

- VDL mode 3 uses ground controlled TDMA for ground-air communication.

- STDMA offers a slot reservation process which is particularly suited to meet the requirements for periodic broadcast of short packet as specified in ADS-B. The channel access of STDMA is distributed which is important to support RFP and does not need a centralized management (while not precluding it). It allows the system to work without ground control (opening up the possibility of air-air point-to-point communication).

STDMA therefore offers a flexible channel access scheme that offers enhanced efficiency through the use of reservation protocols and distributed access.

A.5 STDMA interoperability with other standards

STDMA, as defined in VDL mode 4 draft SARPs, will mandatorily be backward compatible with ICAO VDL mode 2.

Annex B: Procedural issues

B.1 Introduction

This clause describes a number of procedural issues relevant to standardization of STDMA:

- the relationship to other standards;
- the selection of a standardization route.

B.2 Relationship to and co-ordination with other standards

This clause describes the various standardization activities relevant to STDMA.

B.2.1 ICAO - International Civil Aviation Organization

Global standards for aviation are published as annexes to the Chicago Convention. In annex 10 SARPs for Aeronautical Telecommunications are published, where VDL is one part.

The SARPs material is prepared by ICAO panels of experts. Several different panels can be identified which have an interest in the area of STDMA:

1) **AMCP - Aeronautical Mobile Communications Panel:** This panel has already published standards for satellite communication and is currently working on High Frequency (HF) and VHF Digital Link (VDL) standards. Draft VDL mode 4 SARPs have been developed by the AMCP. The documentation consists of:

   - draft SARPs version 5.4 [1] and [3];
   - draft Manual version 1.0 [2].

   There was reasonable expectation of published standards for VDL mode 4 in 2000 on the assumption that a suitable panel meeting is held in 1999). However, ICAO has just announced that the next panel meeting (AMCP/5) will be held in Spring 1998. This is likely to result in further delay for VDL mode 4 since acceptance would now have to wait until the next panel meeting (AMCP/6) which is now more likely to be held later than 1999 (probably 2000).

2) **ADSP - Automatic Dependant Surveillance Panel:** This sets requirements for ADS applications and the deliberations of this panel will therefore impact on the potential surveillance uses of STDMA.

3) **GNSSP - Global Navigation Satellites Systems Panel:** This sets requirements for GNSS technology and applications and the deliberations of this panel will therefore impact on the potential navigation uses of STDMA, particularly with respect to the use of STDMA for differential correction uplinks. GNSSP is expected to choose a specific data link in the near future for GNSS augmentation signals - STDMA is a candidate for such a data link.

4) **AWOP - All Weather Operation Panel:** This sets requirements for applications to support poor weather conditions (i.e. poor visibility on approach and taxiing) and the deliberations of this panel will therefore impact on the approach and ground movement uses of STDMA.

5) **SICASP - SSR Improvements and Collision Avoidance Systems Panel:** This sets requirements for surveillance systems and applications and the deliberations of this panel will therefore impact on the potential surveillance uses of STDMA, in particular the use of ADS-B for Airborne Separation Assurance (ASAS). The next panel meeting, SICASP-7, will be held in 2000. Sub-group 2 looks at ACAS and ASAS.

It is important that standards activities undertaken by ETSI are co-ordinated wherever possible with those carried out by ICAO to ensure that standards for mode 4 do not diverge. However, because the ETSI process is more efficient, ETSI can provide support to the ICAO process by providing an early standard which can later become adopted as ICAO SARPs.

B.2.2 RTCA - Radio Technical Commission for Aeronautics

RTCA is an organization formed by the US industry. Special Committees are formed to carry out particular tasks, e.g.:

- SC172 - VHF Digital Link (VDL);
- SC186 - Automatic Dependence Surveillance Broadcast (ADS-B).

RTCA is publishing Minimum Aviation System Performance Standards (MASPS) and MOPS for ADS-B. ETSI needs to take account of these emerging standards for ADS-B in optimizing the standards for STDMA.

B.2.3 EUROCAE - European Organization for Civil Aviation Electronics

EUROCAE is the European equivalent to the RTCA in the US. To some extent these two bodies co-operate and share their results. Working Groups are formed with special tasks:

- WG41 is working on advanced SMGCS.
- WG47 is working on MOPS for mode 1 and mode 2 VHF data links.
- WG51 is working on ADS-B. EUROCAE MOPS based on VDL mode 4 draft SARPs which will only deal with those parts of the standard necessary to support ADS-B applications, although it has not yet been determined how to (or even whether it will be possible to) make a suitable partition of ICAO SARPs to reflect this. The issue of partition also needs to be addressed for the ETSI work (see subclause C.2.2). Note that MOPS depend on SARPs but could be available earlier (therefore MOPS will really be draft only until SARPs is published).
- WG 53 is working on the definition at a system level of the future data link applications. Decisions made in this group could influence the targeted availability of STDMA.

A key issue is to align the development of ETSI standards for mode 4 with the MOPS development process, so a to prevent duplication of work. It is expected that draft MOPS will be available in mid-1998 and hence this would fit reasonably well with the development of the first ETSI TS proposed in subclause B.3.5.

B.2.4 AEEC Airline Electronic Engineering Committee

The AEEC is an airline organization which is defining standards for how equipment physically should be designed. Purpose is to ensure common interface standards at the lowest level (form, fit and function). AEEC is organized and driven by ARINC, who are a leading airline operators communications service provider. It is important to inform AEEC of ETSI standards activities in STDMA and to encourage them to provide suitable AEEC standards.

B.3 Selection of standardization route

B.3.1 ETSI documents and procedures

ETSI can produce three different kinds of standardization documents:

- Technical Specification (TS);
- ETSI Standard (ES);
- European Standard (Telecommunications series) (EN).

These documents correspond to three different procedures for the elaboration of the document:

- The technical specification reflects the work of a technical committee and its agreement on the obtained work. The document is formally approved after work in sub technical committee by the technical committee.
- The ETSI specification is obtained from a technical specification if this ES is voted by ETSI members. ETSI has a formal voting procedure which takes 16 weeks. This vote is only between ETSI members.
- A TS or an ES can become an EN. The document has to follow the public enquiry procedure. After this period of examination the document receives comments explained by countries represented at ETSI. These comments are then treated during a resolution meeting which provides a formal document which is then proposed to the vote. After the result of the vote the document is either accepted or rejected.

It is understood that the EC wants an EN and this is desirable because it adds force of European Law to standard and will have most influence on ICAO process. However, the procedure for achieving an EN will result in delay which may not enable full impact on ICAO. The members of STF 109 believe that the type of document (TS, ES, EN) which is to be started by ETSI around STDMA is a committee choice. However, a set of recommended deliverables are presented in subclause B.3.5.

B.3.2 Proposed approach to the work

In the following we try to divide the remaining work to do to obtain an STDMA specification and to give recommendations about the amount of effort that is required to obtain this specification.

As usual in a radio telecommunication system we can divide the standardization activity in two sub groups which can work quite independently:

- The first one will work on the physical layer;
- The second one will work on the LLC and network layer, which, in ICAO SARPs terminology includes the link layer (MAC sublayer, VSS sublayer, DLS sublayer, LME sublayer) and the subnetwork layer.

It will be necessary to set up a liaison activity between the two groups to define the interfaces between the two layers and to liaise with other standards activities. This interface will probably evolve with the technical work within the two subgroups.

The STDMA specification will require, as described in the standardization issues in subclause B.3.5 an attached specification concerning the radio type approval and conformance testing. STF 109 advise that it is possible to carry out this work after the STDMA functional specifications are complete and the results could be gathered into a separate document (probably a TR or EG). However the work for the technical specification needs to take into account the need to be able to test the radio protocols. This criteria will be very important in defining the technical specification.

B.3.3 Physical layer work

The work for the physical layer seems to be the simpler. Mainly we find the following remaining points to study:

- determining an appropriate choice of modulation;

- specification of parameters concerning power limits, switching times, etc.;
- ensuring the interoperability with VDL mode 2;
- defining antenna requirements to ensure a nearly isotropic radiation;
- defining requirements and suitable techniques for timing synchronization.

The following effort is foreseen for the tasks involved in this work:

- For the modulation choice, the missing figures and the check of the interoperability with VDL mode 2, one can foresee that these issues can be solved with two or three sub-group meetings if convenient inputs are given before the meeting.
- The definition of antennas to ensure a nearly isotropic radiation can probably be solved in one sub-group meeting.
- The timing synchronization is the most difficult part of the physical layer. It can be estimated that this work will require between two to four meetings depending on the complexity of the choices . Moreover it is possible that if a synchronization algorithm based on packets exchange is used then this will mix deeply the physical layer and the network layer.

These tasks could be carried out independently of each other.

B.3.4 LLC and network layer approach

The work for the network layer is more important and will depend on the technical choices that will be done during the committee work. The following points need to be covered:

- functions to be offered by STDMA and related interfaces;
- system concept definition, channel management and service management;
- timing synchronization for example, what form of distributed algorithm will be used to synchronize clocks);
- slot reuse algorithms;
- reliability issues in the STDMA functionality.

The following effort is foreseen for the tasks involved in this work:

- We can foresee that the discussion about the functions to be offered by the STDMA standard may be solved in two meeting with proposals before the first meeting. The proposal will be discussed during the first meeting. Another meeting may be necessary if there is a lack of expertise in the aeronautical fields. With the selected functions to be offered by STDMA we have to attach precise requirements. These requirements will deal with bandwidth, access delays, reliability . It could be useful if at the end of this work the committee will be able to define a model for the traffic that STDMA will have to support. This model will be used to set up objective comparisons.
- The clear definition of the functions to be offered with their attached requirements will be the basis of the definition of the system concept. The channel management and quality of service management is deeply linked with the definition of the system concept. This work may call for modelling, simulations, objective comparisons between various approaches. There may need to be a formal proof to ensure proper operation of the system. One can evaluate that this work will require between two to six meetings. It is likely that the time required to carry out this work, which will probably require simulation and modelling, could be reduced with the help of an STF.
- The timing synchronization is an independent work that can be done independently of the previous two main tasks. Depending on the solution that will be chosen we can evaluate the amount of work between one to four meetings.
- The slot reuse is also an independent task. This work will require simulation and analytical models. This a very technical task where the help of a STF could be useful. The duration of this work can be evaluate between two to four meetings.

- Reliability issues can be considered as a general task that is to be considered in all the procedures that will be defined.

We can notice that in the physical layer the schedule is less tied than in the network layer. We have interaction between the work in the physical group and the work in the network group especially one the following points: timing synchronization, slot reuse and modulation choice. According to this division of the work one can see that the critical path is within the protocol work and mainly on the system concept definition and the corresponding procedures to offer the functions.

B.3.5 Phased approach to standard production and proposed timescales for the work

Actually it is possible that a further division in the standardization work can be introduced. This split comes from a division between the functions offered by STDMA. These parts will be:

- a system targeted at ADS-B applications;
- enhancement of the system to support point-to-point communication and compatibility with modes 2 and 3.

The verification that such a split is possible should be an early sub-group task. Deliverables associated with each part are discussed below.

An initial TS (TS1) will define a system targeted at ADS-B applications and is the most natural extension of the STDMA system. The TS would provide a stable baseline for equipment to be produced in mid-1998 to support trials activity.

The offered functions will be as follows:

- Autonomous scenario, consisting of:
  - autonomous aircraft scenario (i.e. no ground station);
  - periodic broadcast protocol;
  - incremental broadcast protocol;
  - combined incremental/periodic broadcast protocol;
  - random access protocol;
  - autonomous net entry;
- Ground station functions, consisting of:
  - directed request protocol;
  - procedures for ground directed control.

A next TS (TS2) will define an enhancement to support point-to-point communication. Although derivation of the necessary functions could be based around the current draft ICAO SARPs [1, 2], the timescales for production of this TS (say late 1998) would allow a detailed study of the usage of a separate data communication channel and the compatibility with modes 2 and 3 to be examined in detail. Possible modifications to optimize the mode 4 standard for data communications could be proposed at this stage.

The proposed functions of TS2 would be:

- End-to-end VSS protocols, consisting of:
  - remaining VSS protocols to provide end-to-end VSS functions;
  - unicasted protocol;
  - information transfer protocol;

- DLS protocols, consisting of:
  - build the DLS protocols on top of the VSS protocols in order to provide ISO 8208 [19] compatible data link functions;
  - DLS protocols will be restricted to ground/air communication only;
  - connect to ATN using the existing mode 2 model functions wherever possible;
- Subnetwork layer functionality, consisting of:
  - ATN connection;
- Air-air end-to-end communication;
- Multi-cell support.

It is proposed that TS1 and TS2 are then submitted as an EN, for agreement some time in 1999.

It is also possible that these two documents can not be separated. In that case a single document containing the whole system could produced for late 1998. This document could be submitted as EN, for agreement some time in 1999.

The standard concerning the functional specifications will have to be followed by another specification for radio type approval and protocol conformance specification. These conformance specifications can be gathered in an ETSI document TS3. The radio type approval and the protocol conformance testing can be worked out independently. This work is extremely technical and does not generally generate long debate. One can estimate this testing work between six to eighteen months depending on the complexity of the network protocols and the offered support to do this work. Companies can support this work but the past shows that this work is completed more rapidly by a dedicated STF. It can be foreseen that this conformance document will be available in late 1999 and could submitted as EN for agreement in 2000. It can be noticed that the conformance testing of corresponding to TS1 can be started at the end of TS1 allowing to have earlier TS1 with a conformance specification. If the alternative of two TSs (TS1 and TS2) is adopted, one may envision to have two TS for the conformance testing related respectively to TS1 and TS2.

In addition, the committee should consider whether a TR deliverable detailing the functions and facilities of the system and the services and applications to be supported should be produced as an aid to explaining the purpose, interfaces and boundaries of the system. The TR should also specify the type approval requirements for the system so as to define the level of conformance testing necessary. Such a document could be produced at the start of the recommended work as a means of providing a reference work for the study.

Account should be taken of the development of other standards, particularly VDL modes 2 and 3, taking opportunities, wherever possible, to unify the point-to-point functions of the three modes. It is recommended that a review of the current state of standardization of these systems is carried out prior to starting work on TS2 in order to decide on the need for TS2 and the required content of this part of the standard.

Annex C: Standardization issues

C.1 Introduction

The standardization of STDMA should follow the rules that are common to the standardization of telecommunication systems:

- First, one has to define the need and requirements that this standard will satisfy (for example, to avoid the lack of capacity and services on the present systems). This exercise is important and not so easy because the communication system based on the standard will probably have a long lifetime. Therefore the need and requirement shall take into account not only currently existing applications but also to forecast possible air traffic increases and the coming of new applications.

- Second, one has to determine and define how these needs and requirements will be satisfied. Two areas must be investigated:

  - The first one concerns the physical layer: how data will be coded, modulated and received.

  - The second one concerns the network architecture: how the mobile stations will organize their access to the medium and how the services will be supported.

Sharing a communication medium organized in multiple access is a problem which has received intensive attention for more than 20 years and there are numerous classes of solutions which are well studied. The scheme proposed for the standard is well documented in references [1] and [2] and belongs to the family of slotted reservation access. Since the radio spectrum resource is scarce, it is important to identify immediately the allocated frequencies and bandwidth and under which conditions they will be used.

Last but not least, the protocols adopted in the standard need to be written in a way that removes all kinds of ambiguities while keeping them in easily understandable clauses. This standard also needs to be produced by a convenient standardization body. For STDMA this can be an issue since the standard is both within the telecommunication area and the aeronautical area.

These issues are examined in more detail in this subclause.

C.2 ETSI requirements for a clear standard

C.2.1 The need for clear interfaces

STDMA is intended to support different services and applications. We find mainly: Automatic Dependent Surveillance Broadcast (ADS-B), Differential GNSS, SMGCS, ATN. The standardization work will have to define clear interfaces between these services and applications and the STDMA communication system.

First one has to collect the various services that STDMA may be foreseen to support. To the previously mentioned services one may add expected services to be supported in the future. For example, systems based on SDTMA are already being developed to support maritime and land mobile applications and hence it is possible that STDMA might also need to support these applications. Precise requirements are to be defined encompassing size of packets, generation process, requested access delay, reliability requirement, distribution mode etc.

Second, these requirements are to be translated in well defined interfaces. Preferably one shall try to group the supported functions in order to rationalize the interfaces. For example, one might make use of the well established telecommunication characteristics:

- connected versus connection-less function;

- multipoint versus point-to-point function;

- periodic or asynchronous data transfers;

to simplify the various interfaces.

C.2.2 Clear boundaries for the system

Apart from the crucial necessity to clearly define interfaces, one also needs to define exactly the system that we are aiming to standardize. This system may range from a simple VHF link operating on given frequencies within a given frequency band to a more complex system able to handle various frequencies. We may envision a system where the telecommunication system will precisely handle the coexistence of many services using a same resource. Actually we can distinguish roughly three main architectures:

- Architecture 1: The first way is to define a very simple communication system capable of supporting various functions. This communication system will operate at a given frequency. This frequency may be within a given frequency window.
- Architecture 2: The second way is to define in addition to the above mentioned simple telecommunication system additional tools which make it possible to manage various frequencies and to organize various functions sharing a same resource. In other words, management tools should be defined which can be used in an upper layer to integrate various functions.
- Architecture 3: The third way is to build a full system which will support various applications. This way will make it possible to fully organize various functions sharing a same resource. For instance this approach will manage possible competition between functions and will be likely to guarantee quality of services to the various supported applications. This approach is distinct from the second one in the sense that integration of the various functions will be organized within the communication system itself; primitives and schemes which will handle this system will likely be integrated in the low layers : LLC, MAC layers and even may be in the physical layer.

The choice between these various approaches will clearly be a committee choice. Among the points which can lead to a choice we may find:

- status of existing services and applications to be supported by STDMA;
- stability or possible evolution of these services and applications;
- reliability required by these services and applications;
- technical consideration about resource requirements of the various supported services;
- level of competition for the resource of the various service.

One may give simple hints to help this choice. If the service to be supported may change a lot that is in favour of architecture 1 or 2. Conversely if the requirements of the services are very stringent this suggests the use of architecture 3 since one will have a better control of the whole system. However a refined technical analysis will indicate if a precise control of the system is possible above the LLC layer.

C.2.3 Clear mode of operation in the given spectrum

Concerning a radio telecommunication system, one has to define the available spectrum to support this application and the acceptable out of band radiated power.

Another very important aspect is the way the spectrum will be used. Will STDMA be used in an exclusive way? Will STDMA suffer from low power interferers? Will STDMA have to coexist or inter operate with another transmission system? This needs to be carefully studied during the standardization process.

C.2.4 The reliability issue

The reliability issue is not usually a major point for a telecommunication system based on a shared medium. However, because of the particular integrity requirements in the aeronautical field, the reliability issue is certainly to be carefully studied. This issue will have to be addressed throughout all the standard. However, the following precise examples are given for illustration:

The first example concerns the reservation scheme. First of all we can notice that the correct operation of STDMA requires that the reservations of slot are correctly and consistently registered. We then need this procedure to be tested to ensure that all the STDMA equipment produced by different manufacturers respect minimum rules. These rules will ensure that the system shows the required reliability.

The reliability issue means also that the system needs to be able to cope with faults. Let us try to illustrate this problem by different situations. In a first situation, we will have to react to possible intrusion or jamming in the system. In this case we will have to define special operational rules. For instance, after a long jamming on a channel, we will have to restart completely the access to this channel. Moreover, the way the nodes will access it will follow special rule to avoid collisions. In a second situation, we may be in a situation where one station fails and transmits for a long period. This transmission does not correspond to real packet transmission but to a faulty operation of the system. In this case the standard should mandate a procedure to stop this faulty behaviour (a similar procedure can be found in the current aeronautical VHF voice communications system).

The third situation concerns the problem of the timing synchronization. Reference [2] proposes the use of more than one source of time. Let us suppose that we have a primary and a secondary source of timing. Let us also assume (see annex D) that the primary source of time provides an absolutely synchronized timing as the secondary time source provides a relatively synchronized time source. Then the following situation may occur if the primary timing fails but non uniformly in the network. We have then nodes receiving both the primary and secondary timing sources and other nodes which will receive only the secondary timing source. There is an issue since the secondary source does meet the requirement of an absolutely synchronized timing. Therefore if the nodes do not uniformly use the secondary timing source the requirement of a relative synchronization is not met. Therefore we will need special procedure to cope with this case.

The reliability issue is of course linked to the ability to ensure the correct operation of the system. This is the area of the conformance testing. It will be necessary to produce conformance testing specification attached to the functional specifications. One can notice possible standardization difficulties. For instance, there is an issue on how the final system would be tested. One may want to test the whole set (device plus antennas plus aircraft) since the proper protocol operations needs a correct position estimate and an isotropic antenna coverage (in order to fit CCI conditions on slot pre-emption). Therefore there would be a need to specify an anisotropy radiation tolerance window.

C.2.5 Structure and presentation of the standard

The standard needs to be written in accordance with the chosen architecture. The selected interfaces need to be carefully described. The organization of the document needs to reflect the architecture choices of the system in order to ease the comprehension and to reduce the risk of misunderstanding. Moreover for the simplicity of the presentation basic primitives need to be identified. This will reduce the size of the standard by reducing inappropriate repetitions. The standard will use also the ETSI presentation.

C.3 Illustration of previous points on the current ICAO standard

C.3.1 Clear interfaces

We can not identify in the current draft ICAO standard clear and well defined interfaces. For instance although most of the necessary parameters of the functions are defined, the operation of the functions in case of failure is not described. For example, there is insufficient detail of the response if a function can not be provided or the response does not come in time. In addition the functions parameters are numerous and as are the number of functions described. One may think that a simplification could be useful.

C.3.2 The system boundary

Apparently the system defined by the current draft ICAO standard [1], [3] only specifies a simple communication system. This is not in conformance with reference [2] (appendix B), where notions of channel management are introduced. Moreover the functions described in the current ICAO standard [1], [3] (SARPs) are the basis of a multi application telecommunication system. But it is not described how these different functions can coexist. For instance will they use the same channel or different channels? How will the quality of service be insured?

C.3.3 Reliability procedures

We do not find in the current draft any procedures related to the reliability issue. For instance, if a node suffers from a clock failure, this failure may damage the framing structure and may spoil other node transmission. The STDMA standard needs to take such situations into account by defining appropriate procedures to cover the most obvious case of failures leading to performance degradations.

We also note that there is no conformance test associated to the draft standard.

C.3.4 Structure and presentation of the standard

The presentation of the current draft standard does not satisfy the requirement of ETSI presentation. In an ETSI standard one first describe the conditions under which the procedure is invoked. Then the procedure itself is described. Moreover to ease the understanding the notation takes into account the layer in which the procedure operates.

The same procedures are described many times.

The following illustration gives an example procedure in which the reservation is registered in the reservation table.

Reservation information recording:

This procedure is executed to record the reservation information of a received STMPDU in the local STM-entity's reservation information base upon receipt of a STMPDU.

Procedure:

The STMPDU is received from a neighbouring STM-entity, which is identified by the source address parameter of STC–UNITDATA indication primitive delivering the received STMPDU. The destination STM-entity of the STMPDU is identified by the destination address parameter of the STC-UNITDATA indication primitive delivering the received STMPDU. The number of the slot where the STMPDU has been received is identified by the slot number parameter of the STC-UNITDATA indication primitive delivering the STMPDU.

If the destination address parameter of the STC-UNITDATA indication primitive delivering the received STMPDU is a unicast address, then a new reservation entry is recorded in the local reservation information base for a holding time tRE, where:

- Rsource is set to the source address parameter of the STC-UNITDATA indication primitive; and
- Rdest is set to the destination address parameter of the STC-UNITDATA indication primitive; and
- Rslot is set to the slot number parameter of the STC-UNITDATA indication primitive delivering the received STMPDU plus the reservation offset value of the received STMPDU reservation offset field modulo M1.

While recording this new reservation entry, an earlier reservation entry with the same Nsource and same Nslot, if it exists, is considered outdated and is replaced.

If the destination address of the STC-UNITDATA indication primitive delivering the received STMPDU is not a unicast address, then a new reservation entry is recorded in the local reservation information base for a holding time tRE, where:

- Rsource is set to the source address parameter of the STC-UNITDATA indication primitive; and
- Rdest is set to broadcast reserved destination address value; and

- Rslot is set to the slot number of the STC-UNITDATA indication primitive delivering the received STMPDU plus the reservation offset value of the received STMPDU reservation offset field modulo M1.

While recording this new reservation entry, an earlier reservation entry with the same Nsource and same Nslot, if it exists, is considered outdated and is replaced.

Annex D:
Technical issues

D.1 Introduction

The aim of this clause is to identify the potential technical issues that should be addressed in order to:

- specify the missing procedures in the current ICAO draft;
- fix the parameters in the standard in order to optimize the system;
- demonstrate that the system meets the system service requirement;
- check that the system is technically viable and to evaluate its performance.

D.2 Missing specifications

D.2.1 Secondary timing and positioning protocols specification

It is said in the ICAO draft standard that a node can retrieve a slot synchronization and its position from the reception of packets from the other nodes. These procedures are not described in the draft standard.

Five techniques have been identified [2] to synchronize timing:

- nominally, independent users are synchronized by their local GNSS equipment, providing UTC time;
- synchronization from ground stations transmitting synchronization broadcast bursts;
- use of low-cost atomic clocks;
- synchronization from users transmitting synchronization broadcast bursts;
- a fallback synchronization mode called "floating network" in which each user synchronizes from the others.

Techniques 1 and 3 are related to primary timing, Technique 2 and 4 are secondary timing procedure.

Some of these techniques can also be used to derive secondary position estimates. Note that position information is required to support the slot-sharing algorithms in STDMA, although these algorithms probably only require crude position estimates, perhaps to 1 nmi accuracy. Secondary position estimation may however be important in backing up the position estimates for ADS-B applications, and, for this reason, higher accuracy may be required. Notice that technique 3 does not provide a position estimate. Technique 2 will provide position estimate but in this case there should be more than 3 ground stations in range. Technique 5 is related to distributed clock synchronization which will be discussed in system enhancement subclause (see subclause D.4.2.4).

Below we discuss secondary timing and positioning. We basically focus on technique 4 since technique 2 is just a subset of technique 4 restricted to ground stations.

If there are three or more remote stations in range (aircraft or ground stations), the unsynchronized station can make a secondary time estimate by using those remote stations as timing and positioning beacons. Indeed the remote stations periodically broadcast their respective positions. Upon reception the unsynchronized station can compute the deltas of the propagation delays from accurate measurement of the burst starting time at its own antenna. The delta estimates together with the position indication of the remote station will provide an estimate of the secondary timing and position.

In case there would be only two remote stations in range, the equation with the deltas contains an extra unknown parameter. To get rid of this unknown the unsynchronized station could use an RSSI estimate of the distance with the remote stations which will translate the measure of burst signal power at local antenna into metric distance to remote transmitter.

In order to avoid "tertiary" timing being derived from a secondary timed station, with a resultant further reduction in accuracy, it should be necessary that stations indicate in their position bursts the nature of its timing (secondary or primary).

A study therefore needs to be carried out to address the timing and positioning recovery procedure when the local UTC source fails. A clone of the GNSS procedure based on position broadcast of remote aircraft and tracking of their burst synchronization may suffice. The main difficulty is in the definition of hardware and software timing requirements for this purpose and in providing tests to demonstrate compliance.

D.2.2 Channel management

The channel management is an important issue of the STDMA standard. Actually the offered bandwidth on a given channel is not sufficient to cover all the requirements that may be addressed to STDMA. Therefore it is necessary for the different functions to be able to share different frequencies. This issue is of course linked to the clear definition of the STDMA system concept.

Mainly we can distinguish between two approaches to this problem.

The first approach, which we call 'distributed approach', will be based on the main principle according to which the nodes will use an additional frequency when the load on the already occupied bandwidth has reached a given threshold. This approach requires that primitives providing the load status of the system be defined.

This approach has the following advantages:

- it is simple, the channel management is not directly tied with the access scheme;
- there is no need for a master station.

This approach has the following drawbacks:

- the distributed selection of the additional channel may cause the problem of coherency and fault tolerance;
- the primitive which will indicate if a new frequency is necessary may be complicated since the quality of service requirements are different for the various applications. For instance the ADS-B requirements are more stringent than a simple packet exchange.

The second approach, which we call 'centralized approach', is based on the main principle according to a master node will control the use of the different channels. This node will have the knowledge of all the resources required by the other nodes and can therefore manage the various frequencies to satisfy the requests.

This approach has the following advantage:

- the master station having the knowledge of the whole system can use the frequencies very effectively;
- the management related to the quality of service can be more effective;
- there is no fault tolerance problem except the failure of the master station;
- it is easier to handle the coexistence with a ground control mode in that case.

This approach has the following drawbacks:

- it is rather complicated approach, the channel management will be mixed with the access scheme;
- how can we choose the master station? This station can be a ground station but in that case all the node of the network must be within range. If more than one master station is needed, these stations must react coherently;
- cannot work over sea or areas without ground infrastructure.

Both of these approaches have to manage the problem of jamming on a given bandwidth. This problem can be difficult if the jamming is only local and not well spread on the network.

The set of channel management procedures is very important. If the committee plans to include them in the draft standard then there will be the need to be study to specify numerous protocols for dynamic channel assignment and for dealing with possible erroneous behaviours of the system in case of protocol failure.

D.2.3 High priority pre-emption procedure

A procedure that allows a station holding a high priority burst to steal the reservation slot of lower priority belonging to another user is claimed but not yet described. Algorithms exist in case of a centralized protocol where a central agent rules the medium access. In a distributed protocol such as that used for STDMA, the problem might be less easy since the pre-emption poses problems in the case of contention between different priorities. This issue should be studied during the standardization work.

D.3 System optimization

D.3.1 Physical layer

The following issues need to be resolved:

- power limits for in band emission due to modulation and switching (in dBm versus distance to carrier frequency);
- power limits for out of band emissions;
- ramp-up and ramp-down timing tolerances (upper bound to be quantified, lower bound would come from in-band and out-of band power limits requirement);
- receiver power threshold spacing (-87 dBm, -90 dBm, -92 dBm);
- limits of frequency change during emission.

D.3.2 Link layer

The following issues need to be resolved:

- maximum clock shift rate with respect to UTC;
- retransmission parameters;
- random access parameters.

D.3.3 Summary

Optimization of parameters in the draft ICAO standard should not require too much resource, provided the committee has the technical expertise to achieve it, or can rely on technical database and simulation tools. A number of STDMA simulation and modelling studies are currently in progress as part of the ICAO process and it is hoped that this expertise can be drawn upon to carry out the work.

D.4 System enhancements

D.4.1 Physical layer

No significant issues were found during the review.

D.4.2 Link layer

D.4.2.1 Superframe parameters

Parameter M1 could be fixed in order to set superframe duration to exactly one minute. Doing so will relieve the ambiguity about absolute numbering of slot and the fact that each beginning of M1/60 slots coincide with the start of an UTC second. In this case it will suffice to specify that that the start of any UTC second shall coincide with a beginning of slot as it is the case in the current STDMA draft.

Some clarification is therefore required of the superframe parameters. This is not expected to require significant resource to solve.

D.4.2.2 Warming up procedure

A system starting from scratch must wait for a superframe duration before getting any access right. This duration could be considered as being too long. Furthermore the process may not be efficient in case of many stations simultaneously starting from scratch. This could be case when the channel has been disabled after a long jamming period. A real improvement of the system should be to find a faster warm up procedure in order to increase safety. A possible way might be to specify a reservation map exchange procedure, or to reserve some slots in the channel for new aircraft to enter the system. However, it should be noted that most aircraft will enter the system during its start up procedure on the ground, and hence the warming up time may not be significant.

A study needs to be carried out to investigate this issue and possibly to propose an enhancement to the standard.

D.4.2.3 Slot reuse

Slot reuse is when a new station can successfully transmit a burst on an already reserved slot without damaging the transmission of the previous user. The draft standard allows slot reuse but the new station needs to compute both its own signal decays and signal decay of the other user in order to compare them at the antenna of the intended receiver of the other user. Then it needs to check that its own transmission will not prevent the correct reception from the other user on its intended receiver: i.e. to let the latter to receive the signal from the other user C times greater than the signal of the new station. C is determined by the CCI conditions. When the user is transmitting in broadcast mode the condition is equivalent to guaranteeing a circle of correct reception around the transmitter. Therefore the worst case receiver will on the circle on the segment between the new station and the other user.

D.4.2.3.1 Superframe multiple slot reuse

The draft standard specifies only the case when there is only one alternative user on the same slot. But since the protocol allows slot reuse and requires to track multiple reservations of the same slot, the CCI condition should also take into consideration the sum of all the simultaneous signals arriving on the receiver antenna, and not only make the comparison with only one targeted user. Notice that the case of broadcast may not reduce to simple distance ratios comparison.

D.4.2.3.2 RSSI based slot reuse versus position based slot reuse

The draft standard requires that stations use aircraft position broadcast and assumes isotropic antenna coverage and free space propagation in order to compute signal decays. Therefore the CCI condition deals with distance ratios. An alternative procedure should be to use RSSI instead of position and free space propagation assumption. The station would maintain a RSSI table whose entry will be every neighbour stations and whose data would be the RSSI power measurement of the burst received from this neighbour.

The RSSI measurement is a good indication of distance to a remote transmitter, and if the reverse light path principle applies, then it is a good estimate of the power at which the remote user would receive a signal from the host station. If there would be a way to exchange such RSSI information, then the CCI condition will only consist to add and compare the RSSI estimate on targeted receivers. For broadcast it would suffice to compare the RSSI of the burst in the current reserved slot with a simple threshold.

The advantage of RSSI based reuse are as follows:

- it does not rely on position broadcast, since this position broadcast would rely on CCI condition it removes a potential vicious circle in reliability;
- it allows to simplify the problem of testing antenna isotropic coverage (with the difficulty of testing this on the aircraft itself);
- it simplifies the broadcast CCI condition;
- it makes it possible to cope with the problem of possible discrepancy between free space propagation and actual propagation conditions, for example, in case of ground effects.

The drawbacks are as follow:

- The RSSI information table exchange may be costly (but is not needed for broadcast operation).

The issue of slot re-use therefore need substantial study and validation through modelling and should include consideration of an RSSI approach. Once again, existing simulation work could be used to assist this work.

D.4.2.4 Distributed software clock synchronization

A precise timing is a key point of the STDMA protocol. The issue of maintaining a synchronized timing in a distributed system is a classical problem [11]. There are two kind of clock synchronization requirements: the absolute synchronization and the relative synchronization. In absolute synchronization there is an universal time, for instance UTC, that every clock must indicate, within a specified tolerance window. In relative synchronization it is only required that all clocks indicate the same time, whatever be this time, within a specified tolerance window. What is needed in STDMA is relative synchronization but with absolute rate: i.e. the clock rates are aligned with UTC rate within a tolerance window (see reference [15] for the formal definition of these two kinds of synchronization). In fact the relative synchronization needed in STDMA should be weaker, since it suffices that all clocks indicate starts of slot at the same time, regardless of the local number of this slot.

An absolute synchronization requires an absolute time source. This source may be given by a broadcast system for example the GNSS or a set of ground stations having an absolute reference. The satellite system or the ground station system periodically broadcasts the absolute time within the network. Every node accurately updates its local clock provided it can infer its propagation delays. An absolute synchronization can also be achieved by independent local clock, for instance atomic clocks, if their rates are steady enough to keep the synchronization during long periods of time. In this time atomic clocks should have to be re-synchronized before each flight.

A relative synchronization can be achieved with independent clocks even if their precision is not very high. This is a classical problem in the field of distributed computing systems [12]. In that case one needs to implement a synchronization algorithm which will maintain the clocks synchronized. This algorithm will be based on the exchange of synchronization packets which, to simplify all the nodes, periodically broadcast their local time. This exchange of packets is called a round. At the end of each synchronization round each node reads the clocks of all processes and then adjusts its clock value for the next round by applying a convergence function. With such algorithms, it is possible to get a precision in the synchronization which depends of the difference between the propagation delays, the time interval between two successive rounds and maximum clock rate discrepancy. One can find academic works which describe how to cope with the case where clocks fail or if packets are lost [14]. It is also well studied how the function can be chosen in order to provide the better synchronization [16], [17].

The drawback of such algorithms is that they theoretically require that the medium access be independent of the slot synchronization, which is not the case with STDMA which would need slot synchronization to communicate. A possible short-cut could be to allow STDMA to operate in degraded mode when there are clock synchronization problems.

There is also an issue if one has two timing sources and if the secondary timing source is only relatively synchronized. In that case the nodes of the network need to use consistently either the primary timing source or the secondary timing source. Actually it is not obvious that the primary timing source will consistently disappear. We need to know what timing source we use in the network.

Therefore, a timing mechanism that does not rely on an external source might be investigated to increase the integrity of the system. Software synchronization mechanisms provide interesting results but require *a priori* a communication whose reliability is independent of clock synchronization. Investigations to find a possible less demanding protocol are recommended.

D.4.3 Reaction to long jamming periods

This is *a priori* a modulation issue, the modulation scheme needs to be resistant enough to cope with persistent noise. But if a persistent jamming occurs there would be a need to adjust the power threshold used for detecting idle/busy slot status. For example the threshold would rise when the minimum detect level during a long period is too high. Doing so will always allow stations to transmit anyhow, maybe with a smaller efficient range.

If the jamming occurs at a high power level which is to high as to prevent correct reception of packets, then there will be the need to fall back on an alternative channel. In this case a blind channel selection protocol should be specified as part of channel management. Of course this might not be sufficient if the jammer creates white noise with large bandwidth.

D.5 Viability check and performance studies

D.5.1 Choice of the modulation scheme

ARINC characteristic 750 is the proposed 31,5 kbps D8PSK solution for VDL modes 2 and 3. Its advantages are:

- relatively high data rate for a 25kHz channel, making it a good choice for point-to-point data link systems (note that final validation of adjacent channel interference levels has not yet been satisfactorily demonstrated and hence there is some doubt about whether D8PSK data can co-exist adjacent to current voice channels);
- active development in support of mode 2 and mode 3 equipment;
- adoption as the ICAO approved data link.

Its disadvantages are:

- poor CCI performance making it less well suited to single channel broadcast applications where frequency re-use is a fundamental issue;
- poor CCI also means that, even if distinct coverage cells are used, there is an increased distance between cells using the same frequency: this may become problematic in Europe given the shortage of frequencies;
- it is a complex modulation scheme whose realization requires relatively sophisticated processing. This increases the cost of the equipment and may be a barrier to General Aviation users;
- suspected poor linearity and thermal problems;
- not proven to fall within 25kHz channel.

An alternative to ARINC 750 is GFSK modulation at 19,2 kbs [7]. This is being proposed as one scheme supported by mode 4. The advantages of GFSK are:

- relatively good CCI performance (in theory, validation is not yet complete although tests are underway) which makes it more suitable for applications where frequency re-use is an issue (e.g. ADS-B and to a lesser extent point-to-point);
- because of its frequency re-use characteristics, it is claimed to be more spectrum efficient than D8PSK and therefore to achieve a higher data rate over a large geographical area (see references [5] and [6]);
- it can be realized using simple and cheap hardware.

Its disadvantages are:

- lower data rate within a single cell making it less suitable for point-to-point applications if the system uses distinct coverage cells;

- not an approved ICAO scheme.

A conclusion at the recent AMCP WGD meeting in Madrid was that D8PSK would not be a practical modulation scheme for ADS-B because of its poor CCI characteristics (the assumption here is that ADS-B would use global channels) but that it would probably be the best for point-to-point communications using distinct coverage cells. The choice of optimum scheme should therefore address the balance between the basic data rate at the physical layer and the ability of the modulation scheme to support frequency sharing.

STDMA is sufficiently flexible to support two modulation types. The choice of modulation type may need further study. However for ADS-B and DGNSS (NABS) applications, it is expected that GFSK will prove the offer the best system performance. A study needs to be carried out to investigate the relative advantages and disadvantages of the possible modulation types and to make recommendations for the best scheme as a function of service provided.

D.5.2 Impact on performance of CCI conditions

The distinction between broadcast and unicast for slot reuse may not be worthy in terms of performance. A simpler scheme based on power measurement and adaptive would probably provide similar performance (see subclause D.4.2.3).

D.5.3 Broadcast range and reliability

If we refer to E-TDMA study there is a need to guarantee a reliability and a minimal range for correct reception. These requirements would be necessary in order to use STDMA as basis of ADS-B application. The E-TDMA study [10] notices that the reliability should be higher than $1\text{-}10^{-6}$ for a maximum outage duration of 30 s. A minimal interpretation of this requirement could be that at least one position broadcast should be received in any random period of 30 s with probability higher than $1\text{-}10^{-6}$.

The E-TDMA suggests the following worst case *en-route* scenario:

- a density of 570 air planes per 160 nmi radius air cylinder;
- a position broadcast period of 6 s per aircraft.

Using GFSK channel parameter (i.e. 75 slots per second), the position broadcast period corresponds to an average individual load of $\mu = 2{,}22 \times 10^{-3}$ per slot, considering one channel for ADS-B. For two channels this data should be divided by two.

A first remark is that it is impossible to guarantee a minimal successful coverage for a broadcast burst. Indeed there is a gracefully decreasing function p(r) which provides the probability of successful reception of a broadcast burst by a random receiver at distance r. If p(r) <0,9 then it will mean that a minimum of six position broadcasts would be needed during any period of 30 s in order to achieve the $1\text{-}10^{-6}$ reliability target, assuming the broadcasts are independent (i.e. include some randomness). Since the specified number of broadcast per 30 s is five the reliable range should be set at p(r) >0,94.

Function p(r) will decay as function of actual traffic load decreasing the broadcast reliability. From function p(r) one derives the average reception area σ per broadcast.

In the following we present a simple model as an example of study which could be carried out with respect to this topic. Of course this simple model relies on simple assumptions. A more accurate model would need much more involvement.

Simple model

We assume that a receiver receives successfully a burst when the signal of the latter is greater than C times the cumulated signal of the other simultaneous reception.

We assume that at each slot there is a Poisson density of transmitters of λ per unit area. If the area unit is the square nmi the E-TDMA worst case assumption [10] will lead to $\lambda = 1{,}57 \times 10^{-5}$. We neglect the propagation delays. Our aim is to derive an estimate of function p(r). From this quantity we can deduce the average area σ of reservation successful reception:

$$\sigma = 2\pi\int_0^\infty rp(r)dr$$

We investigate two propagation models: the α attenuation model and free space attenuation model with horizon.

D.5.3.1 The α attenuation model

In this model we assume that signal decays in $r^{-\alpha}$ with distance r, with α greater than 2. Let W be the measure of the cumulated signals received by a random receiver on a random slot. Quantity W is a random variable, we define its Laplace-Stieljes transform w(t) as the average value of e^{-tW}. Assuming that the circles around the receiver are independent:

$$w(t) = \exp(2\pi\lambda\int_0^\infty(\exp(-tx^{-\alpha}) - 1)xdx$$

easy calculations yield:

$$w(t) = \exp(-\pi\lambda\Gamma(1-\frac{2}{\alpha})t^{2/\alpha})$$

where $\Gamma(.)$ is Euler's *Gamma* function. This expression can be used to get asymptotic estimates of the function of distribution of W. Let F(x) denotes the probability that W be greater than x, we have:

$$\mathrm{F(x)} \approx \lambda\pi x^{-2/\alpha} - \frac{\lambda^2\pi}{2}\sin(\frac{4\pi}{\alpha})\Gamma(\frac{4}{\alpha})\Gamma^2(1-\frac{2}{\alpha})x^{-4/\alpha}$$

Since $p(r) = 1 - F(1/Cr^{\alpha}) \approx 1 - \lambda\pi C^{2/\alpha}r^2$

we obtain the asymptotic equivalent of p(r) when r tends to 0.

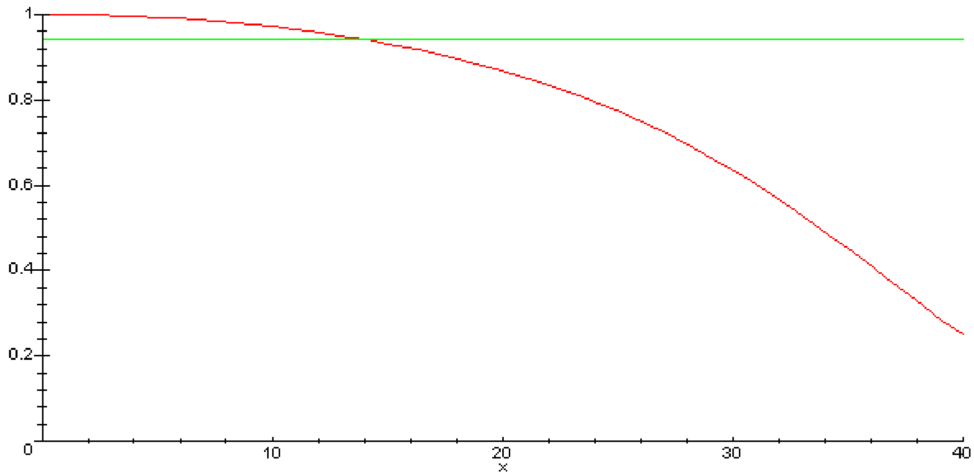

Figure D.1: p(r) as function of r for λ = 1,57 × 10^{-5}, α = 2,7, C = 10, r in nmi

In the figure above we display a plot of function p(r) with the load conditions of E-TDMA scenario. We have also plotted the estimated threshold for the 1-10^{-6} reliability per 30 s target. Notice that it provides a reliable range of 14 nmi.

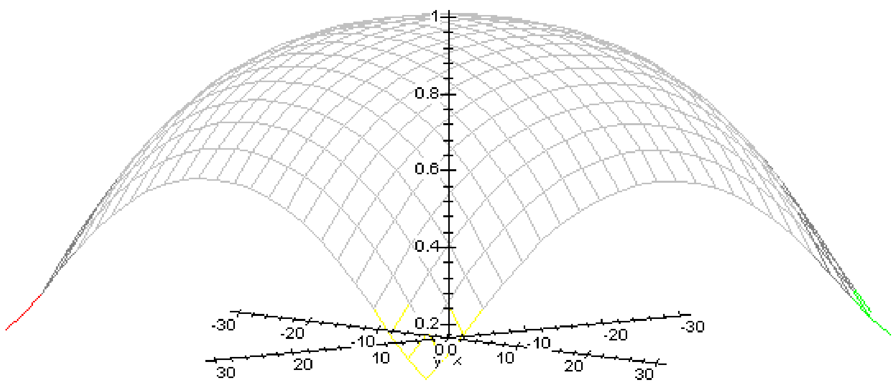

Figure D.2: 3-D version of Figure D.1

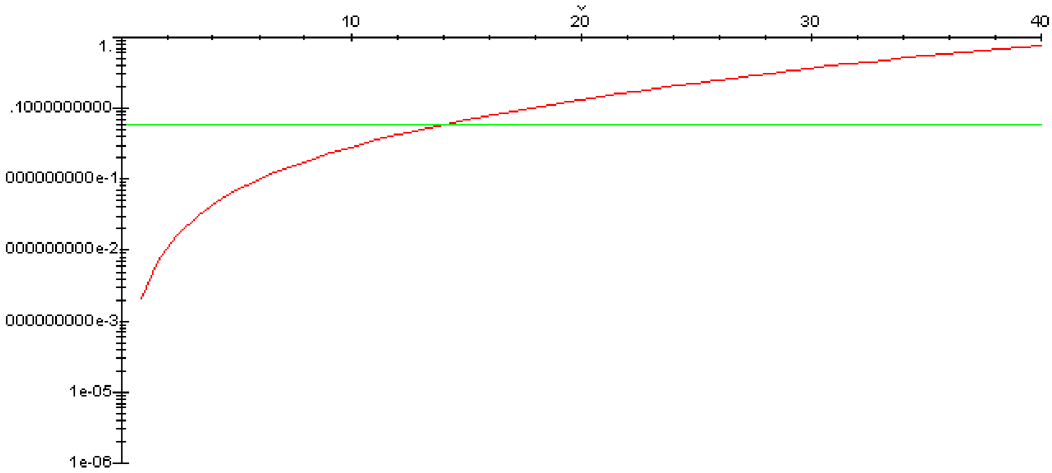

Figure D.3: Reservation failure probability (1-p(r)) with $\lambda = 1{,}57 \times 10^{-5}$, $\alpha = 2{,}7$, C = 10

The average successful area has an exact expression: $\sigma = B\lambda^{-1}$, with $B = \frac{2\sin(2\pi/\alpha)}{\alpha C^{2/\alpha}}$. The quantity $\lambda\sigma$ is constant and can be called the *reuse factor*. Notice that this quantity tends to zero when α tends to 2.

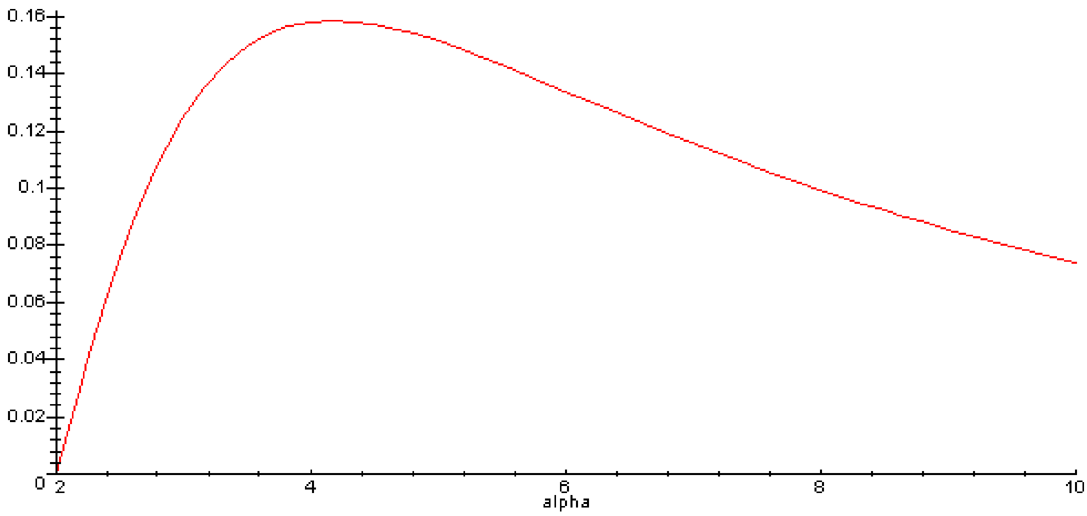

Figure D.4: Reuse factor as function of parameter α

For $\alpha = 2{,}7$ and $\lambda = 1{,}57 \times 10^{-5}$ we find $\sigma = 6\,214$ sq nmi. If the individual load μ is given the average number of aircraft correctly receiving a broadcast would be $\frac{B}{\mu}$, for $\alpha = 2{,}7$ this number would be 44. By pure symmetry argument this number should also be equal to the average number of aircraft detected and correctly received by a random station. Notice that the quantity is far below the worst case 570 aircraft in 160 nmi range of E-TDMA study. In case these figures were confirmed by a more involved studies, it would imply that ADS-B needs several channels in parallel, at least 11. Indeed the number of detected aircraft in presence of n parallel channels would be $n\frac{B}{\mu}$.

The figure below display the average number of detected aircraft as a 2D function of α and individual broadcast period y in seconds.

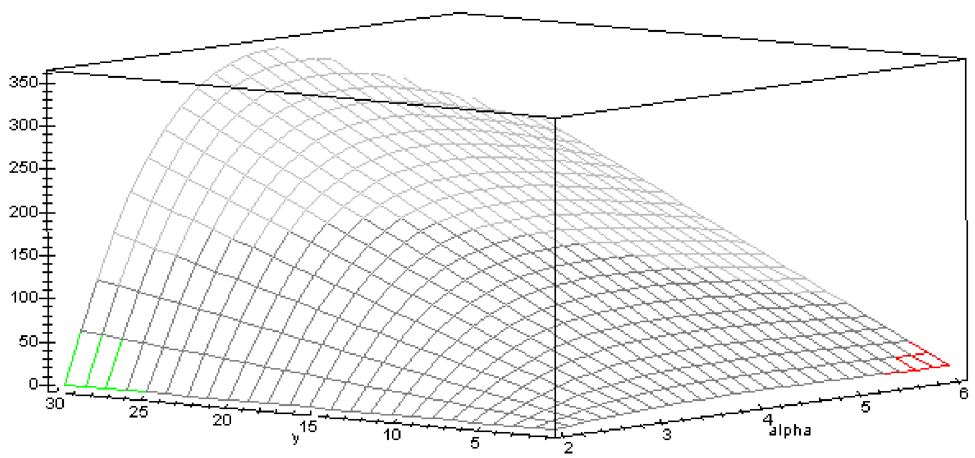

Figure D.5: Average number of detected aircraft versus α and individual broadcast period y (in seconds)

Notice that the longer the broadcast period the larger is the number of detected aircraft, but this to the cost of a lower reliability.

D.5.3.2 The free space propagation with horizon

When α = 2, equivalent to free space propagation, the above integrals diverge. Therefore in free space propagation it is needed to introduce an horizon R due to Earth roundness beyond which two aircraft are not in line in sight and therefore cannot receive signal from each other. Assuming an altitude of 10 km we obtain an horizon of 400 nmi for the aircraft and 200 nmi for the ground stations.

The Laplace-Stieljes now reads:

$$w(t) = \exp(2\pi\lambda\int_0^R (\exp(-tx^{-2}) - 1)x dx$$

which can be rewritten in:

$$w(t) = \exp(-\pi\lambda t \psi(\frac{t}{R^2}))$$

with $\psi(z) = \int_z^{+\infty} (1 - e^{-x}) \frac{dx}{x^2}$.

The interesting case is when the horizon is large. When R is large, to be more precise when the *horizon load* $\lambda\pi R^2$ is large we have the following estimate: $F(x) \approx \frac{\lambda\pi}{x - \lambda\pi\log(\lambda\pi R^2)} + O(\frac{1}{x^2 \log^2(\lambda\pi R^2)})$ which is valid when x increases significantly above the logarithm of the horizon load. Therefore when r tends to zero we have:

$$p(r) \approx 1 - \frac{\lambda\pi C r^2}{1 - \lambda\pi r^2 C \log(\lambda\pi R^2)}.$$

The data for worst case scenario in E-TDMA study provide a horizon load estimate of horizon load estimate at 8.

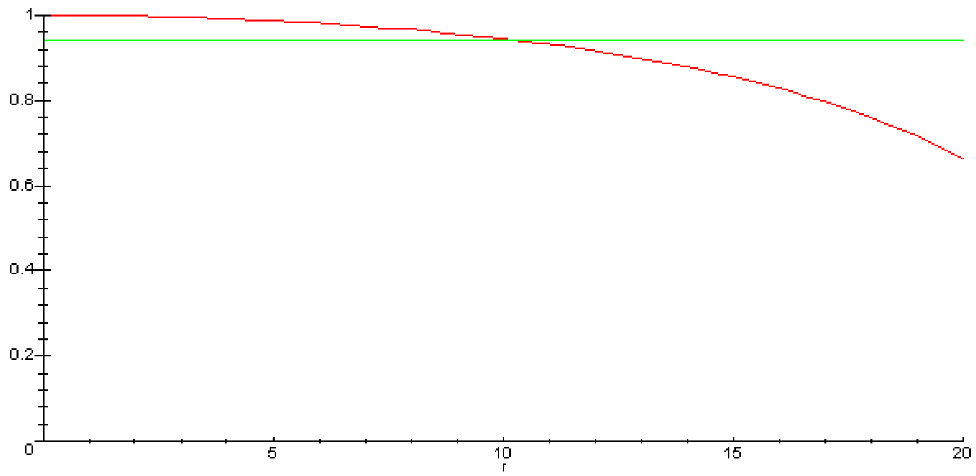

Figure D.6: The function $p(r)$ versus r (in nmi), with horizon load equal to 8, C=10, free space propagation

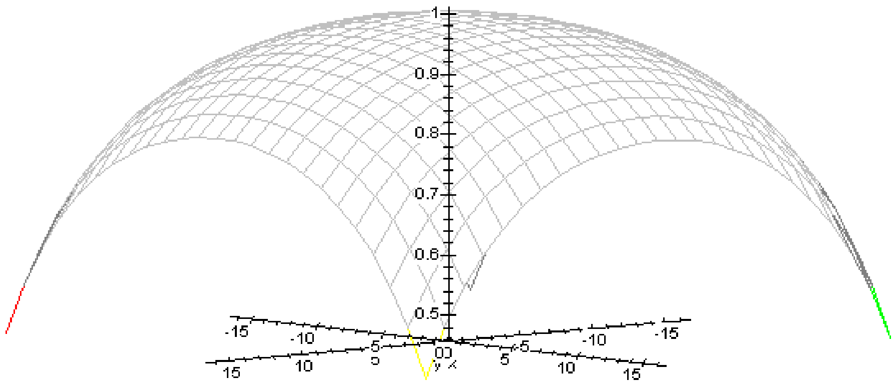

Figure D.7: 3-D version of Figure D.6

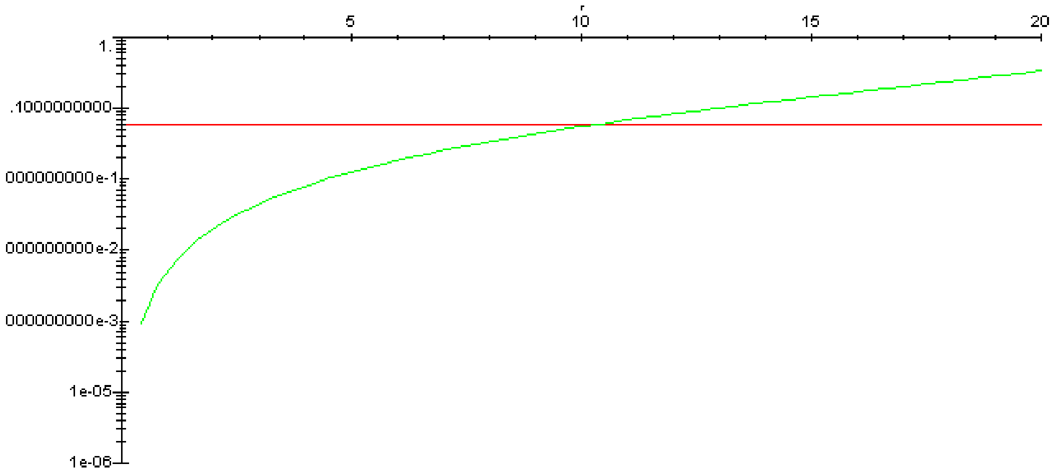

Figure D.8: Reservation failure probability (1-p(r)) versus in nmi, with horizon load equal to 8, C=10, free space propagation

Remark the above estimate provides a reliable range of 10 nmi.

The average successful reception area σ has an asymptotic expression which is:

$$\sigma \approx \frac{1}{\pi C \lambda \log \ (\lambda \pi R^2)} + O(\frac{1}{\log^2 (\lambda \pi R^2)})$$

the utilization factor can be derived as well. Notice that the reuse factor does not converge to a constant but decreases when the horizon load increases.

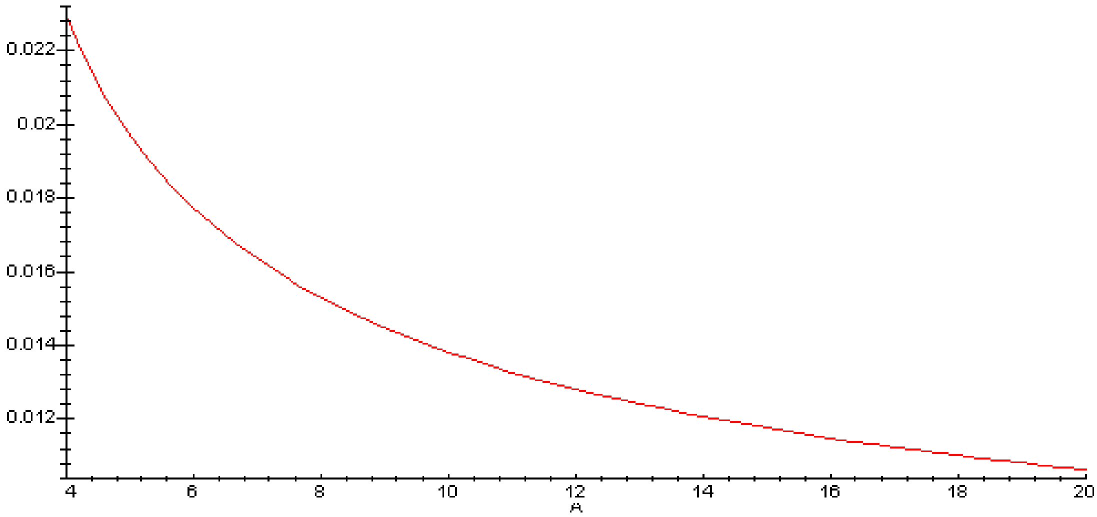

Figure D.9: The reuse factor as a function of horizon load, free space propagation

We notice that the reuse factor with the horizon load of 8 is around 0,015. With the same horizon load, which corresponds to the worst case scenario of E-TDMA we find an average reception area of 977 sq nmi. The average number of detected aircraft would be 7. This number is small and is probably inaccurate and should be taken carefully.

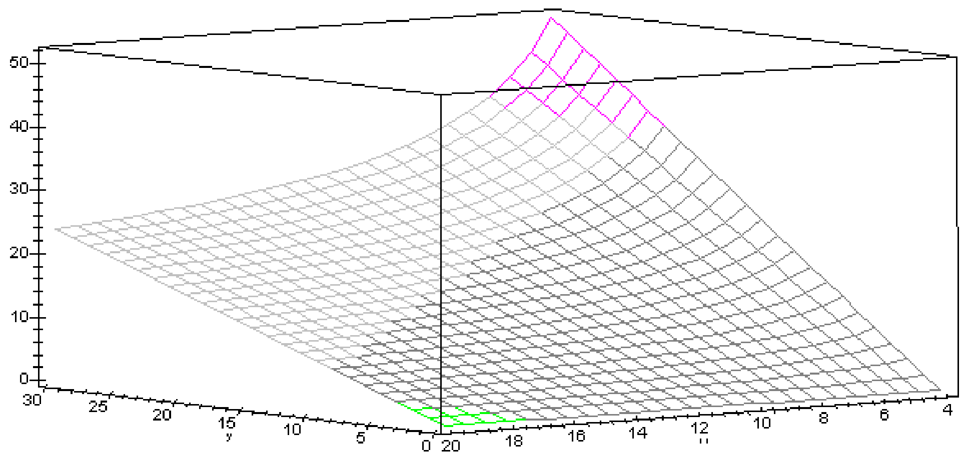

Figure D.10: Average number of detected aircraft versus horizon load H and individual broadcast period y (in seconds)

D.5.3.3 Conclusion of the model

The simple model is independent of the access scheme because the captured effect is the cumulative effect of transmissions from distant aircraft using a single frequency. The results would be the same with any another access scheme. The model needs more detailed development and we must be cautious about the precise result. In particular, there is a need to take account of the distribution of traffic since a significant volume of traffic is low level and hence below the horizon for distant users. However one do sees that there is a dimensioning problem to be investigated in order to determine the number of channels required to support the expected applications. For instance, the model illustrated the kind of analysis which would help the determination of the number of needed parallel channel for ADS-B. As a matter of fact one can notice that n channels in parallel also divides the horizon load by n in the expression of the reuse factor. More refined models will be necessary to dimension and to design the system for proper operation.

D.5.4 The effect and management of remote and hidden terminals

When two stations are at distance greater than 300 km (160 nmi), the propagation delays exceed 1 ms and the bursts are mis-synchronized in such a way that they occupy two consecutive slots on the receiver side. Therefore a protocol malfunction will occur that should be analysed since the load due to remote stations might be not negligible. Maybe D8PSK/GFSK guard times versus received power thresholds could be optimized.

For a system using global channels and providing ADS-B information it is necessary to co-ordinate the access to the channel so as to prevent some users being unable to receive position information on other users. This "hidden terminal" problem arises when two users broadcast in the same slot with the result that other users receive a transmission from only one user, or in the worst extreme, neither user.

In a ground controlled system, it is relatively straightforward to define a co-ordination mechanism to ensure that all users that can be heard by a ground station can also hear each other. However, this does not ensure that mobiles can receive other mobiles that are not within reach of the same ground station and hence there is some risk to the integrity of the ADS-B air-air application. Note that mobiles are better placed to make decisions on channel usage since they receive transmissions from the greatest number of transmitters, many of which are not received by the ground station because of ground shielding (which should be investigated in details).

STDMA uses a self-organizing access scheme that combines access control by mobiles with the option of ground control where practical. The scheme has been demonstrated at low traffic levels but will probably require further refinement to deal with higher traffic levels and to achieve high integrity performance. For example the possible discrepancies between airborne reservation map and ground station reservation map (leading to hidden nodes cases) could be removed if one allows aircraft to forward their own reservation map to the ground station. Alternatively, an aircraft at higher altitude than the hidden transmitters could notify those of the garbling situation and order some to change slots.

The hidden node problem depends also of the required Signal over Noise ratio. The larger is the latter the higher will the collision rates due to hidden nodes. In this perspective D8PSK would perform less than GFSK.

History

Document history		
V1.1.1	November 1997	Publication

ISBN 2-7437-1798-X
Dépôt légal : Novembre 1997