Security Assessment for Prototype First Iteration

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Abstract

SESAR WP15.4.5 is tasked with the implementation of enhancements into the ADS-B ground based surveillance system to address known security and safety limitations of the core ADS-B technology. It is planned that the enhanced ADS-B ground system will be offer a sufficiently robust service so that it augments existing radar services within High Density TMA type airspace.

WP15.4.5b will develop three pre-industrialisation prototypes of the enhanced ADS-B ground system, termed the First, Second or Third Iteration. Each Iteration corresponds to a separate SESAR CONOPS and Prototype First Iteration is aligned with SESAR Time Based Operations CONOPS [1]-[4].

This report assesses the security limitations within an unencrypted broadcast technology such as ADS-B and describes the WP15.4.5 selected enhancements to the ADS-B ground system to address these limitations. The enhanced ADS-B ground system will comprise interconnected remote ADS-B groundstations and a central SDPD system.

WP15.4.5b contains three ADS-B groundstation suppliers; Thales Air Systems, Indra and Selex and one SDPD supplier, EUROCONTROL. Each supplier has implemented different security enhancements into their element of the Prototype First Iteration enhanced ADS-B ground system and these are defined within the Baseline Matrix for Prototype First Iteration and elaborated within this report [5].

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1 Executive summary

SESAR WP15.4.5 is tasked with the implementation of enhancements into the ADS-B ground based surveillance system to address known security and integrity limitations of the core ADS-B technology [1]. It is planned that the enhanced ADS-B ground system will offer a sufficiently robust service so that it can augment existing radar services within High Density TMA type airspace.

WP15.4.5b will develop three pre-industrialisation prototypes of the enhanced ADS-B ground system, termed First Iteration, Second Iteration and Third Iteration. Each Iteration corresponds to a separate SESAR CONOPS and Prototype First Iteration is aligned with SESAR Time Based Operations CONOPS [1]-[4].

This report assesses the security limitations within an unencrypted broadcast technology such as ADS-B and describes the WP15.4.5 selected enhancements to the ADS-B ground system to address these limitations. The enhanced ADS-B ground system will comprise interconnected remote ADS-B groundstations and a central SDPD system.

WP15.4.5b contains three ADS-B groundstation suppliers; Thales Air Systems, Indra and Selex and one SDPD supplier, EUROCONTROL. Each supplier has implemented different security enhancements into their element of the Prototype First Iteration enhanced ADS-B ground system and these are defined within its Baseline Matrix and elaborated within this report [5].

Six areas of security enhancements were selected for incorporation with WP15.4.5b Prototype First Iteration, with different manufacturers implementing different enhancements within their elements of the enhanced ADS-B ground system [5]. Enhancement functional areas for incorporation into Prototype First Iteration comprised:

1. Integration with WAM
2. Angle of Arrival Measurement
3. Position vs Velocity information validation
4. Power measurement & range correlation
5. Time of Arrival vs Distance validation
6. Multi-Sensor target report validation within the SDPD

2 Introduction

2.1 Purpose of the document

This document gives an overview of the enhanced ADS-B ground system specified within SESAR 15.4.5b Prototype First Iteration [1] and a summary of the security weakness and limitations within the basic ADS-B technology. It details the enhancements implemented into Prototype First Iteration to counter the described security issues.

2.2 Intended readership

The audience of this document includes:

- Projects 15.04.05.a and b,
- SJU projects that may require ADS-B Surveillance Systems for their validation activities.
- SESAR ANSP's planning to implement basic ADS-B systems into their ATM system.

2.3 Inputs from other projects

Input documents in the form of system specifications, interface specifications and test specifications for the enhanced ADS-B ground system from 15.4.5a.

2.4 Structure of the document

- Chapter 1: Executive Summary
- Chapter 2: Purpose and scope;
  - enhanced ADS-B ground system overview,
  - enhanced ADS-B groundstation overview
  - enhanced SDPD overview
- Chapter 3: ADS-B security issues
- Chapter 4: ADS-B security enhancements;
  - Integration of ADS-B and WAM,
  - Angle of Arrival,
  - Position vs. Velocity check,
  - Power measurement and range correlation,
  - SDPD Multi-sensor consistency validation
- Chapter 5: References

2.5 Enhanced ADS-B ground system overview

WP15.4.5b is tasked with taking the system, test and interface specifications input from WP15.4.5a and developing enhanced ADS-B ground system prototypes. These were termed Prototype First/Second/Third Iteration and this document is concerned with Prototype First Iteration of the enhanced ADS-B ground system [1].

The enhanced ADS-B ground system comprises the following system elements;

- Enhanced ADS-B groundstation(s) [2]
- Enhanced Surveillance Data Processing and Distribution system [3]
- Modified ASTERIX Category interfaces; comprising ADS-B target reports in CAT 021 and service messages in CAT 023 and System Track data in CAT 062 and service messages in CAT 063 [4]

A schematic representation of the enhanced ADS-B ground system is highlighted within the dashed blue line region in Figure 1 [1]:

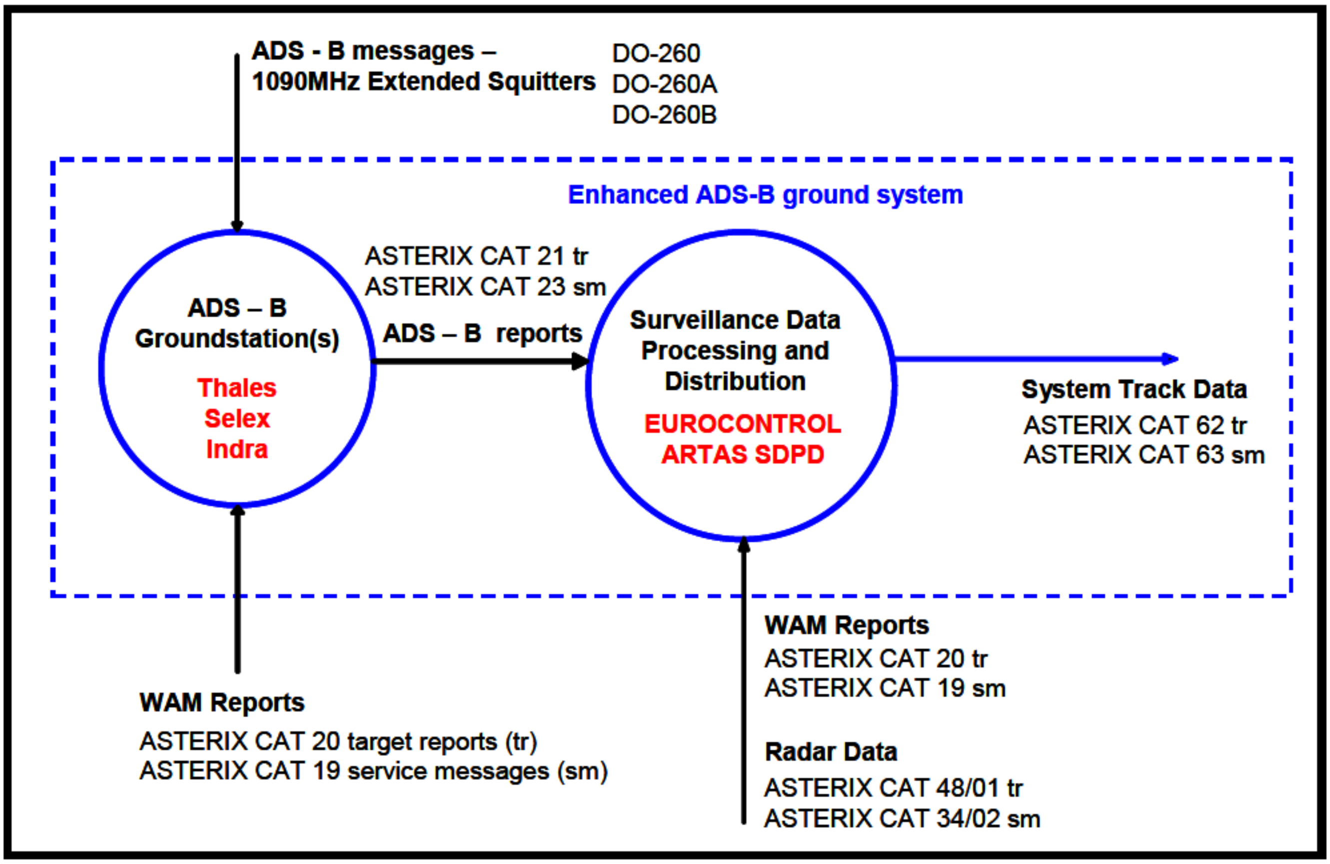

Figure 1. Enhanced ADS-B ground system schematic

2.6 Enhanced ADS-B groundstation overview

The primary functions of the 1090 ADS-B groundstation (GS) are to [2]:

- Receive 1090 MHz RF input on the **Air Interface**
- Extract message payload data from 1090MHz Extended Squitter ADS-B messages
- Timestamp the decoded ADS-B messages using the UTC Time Sync function
- Assemble the ADS-B message data into ASTERIX Category 021 target reports [4]
- Dispatch the ASTERIX CAT 021 ADS-B target reports and ASTERIX CAT 023 service messages to client systems over the **Ground Interface** [4]
- Interacts with the Remote Control and Monitoring system through the **Management Interface**, using SNMP messaging protocols
- Determines the internal status of the groundstation equipment through BITE

A schematic diagram showing the functional block diagram of the 1090 GS is shown in Figure 2.

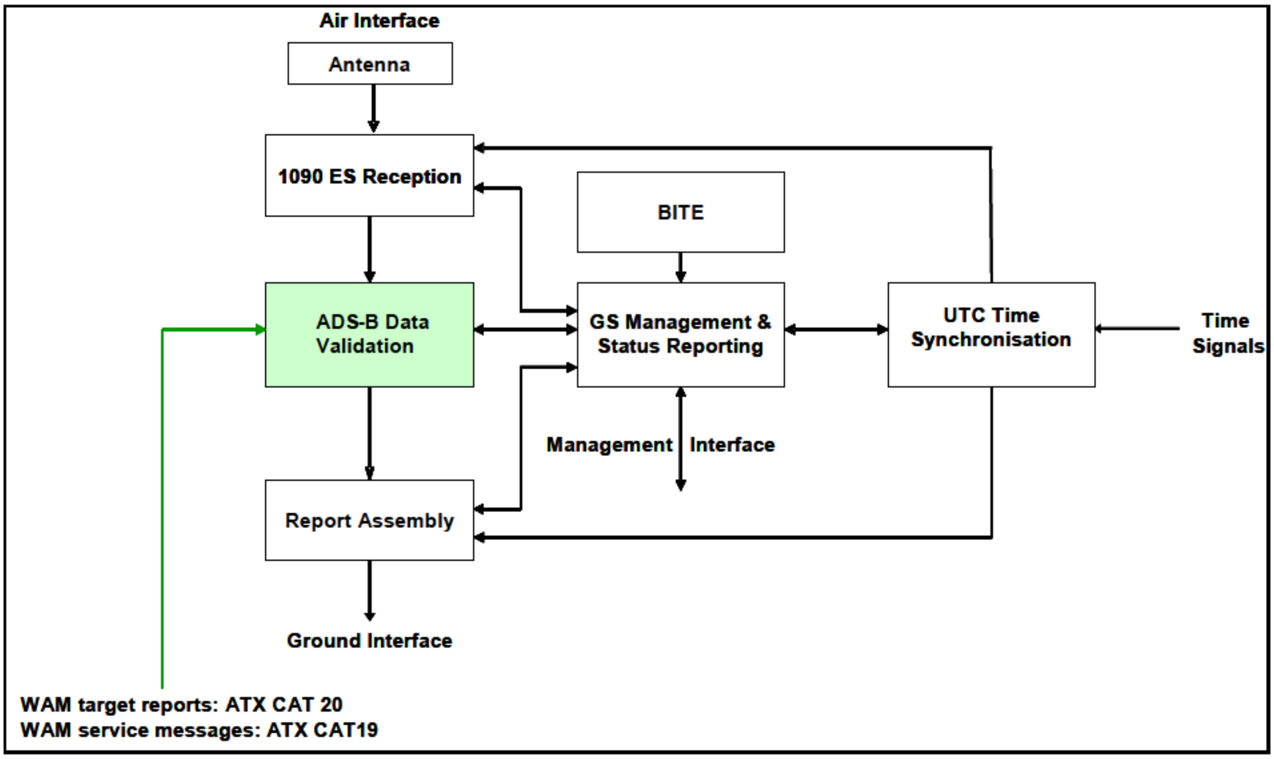

Figure 2: 1090 GS Component Overview[1]

In comparison with the functional blocks foreseen in for the basic ADS-B-RAD groundstation given in ED-129 [6], it is noted that the ADS-B Data Validation functional block (shown in green in Figure 2) has been added and this element performs the new security enhancements implemented into WP15.4.5b Prototype First Iteration groundstation, including integration with WAM target reports and service messages.

[1] The partitioning shown is for the purpose of describing the high level behaviour of the Ground Station and is not intended to convey an implementation requirement or the physical architecture of the equipment

2.7 SDPD system overview

The Surveillance Data Processing & Distribution system (SDPD) receives aircraft data from individual surveillance sensors, including ADS-B 1090 MHz Extended Squitter Ground Station, and serves fused surveillance track updates to client systems such as Controller Working Positions (CWP). Aircraft data updates contains measured or reported 2-D horizontal position, reported altimeter altitude, velocity, status and other information extracted from aircraft onboard systems and received by ground based surveillance sensors [3].

The primary function of the SDPD is to present an accurate and complete air situation picture in ASTERIX Category 062 to its client systems. The CAT 062 picture is composed of input surveillance target report data received in ASTERIX Categories 048/001 (radar), 020 (WAM) and 021 (ADS-B) target messages and fused into a composite air picture [3].

The SDPD uses the input service messages in ASTERIX Categories 034/002 (radar), 019 (WAM) and 023 (ADS-B) to determine the validity of the separate surveillance system supplied target data stream and hence to discard or include each particular surveillance target data stream.

The EUROCONTROL ARTAS product was selected as the SDPD element within the enhanced ADS-B system and is designed around four main functions [3];

- The TRACKER processes the input surveillance information (from the surveillance sensors) and maintains the Track Data Base,
- The SERVER performs the Track Information Service i.e. the management of all requests from Users and the transmission of the relevant sets of track data to these Users. It will also execute the so-called inter-ARTAS cooperation functions.
- The SYSTEM MANAGER performs the functions related to the supervision and management of the ARTAS Unit,
- The RECORDING function will record selected data related to the operational use of ARTAS.

A functional block diagram of the ARTAS SDPD system is shown in Figure 4 [3]:

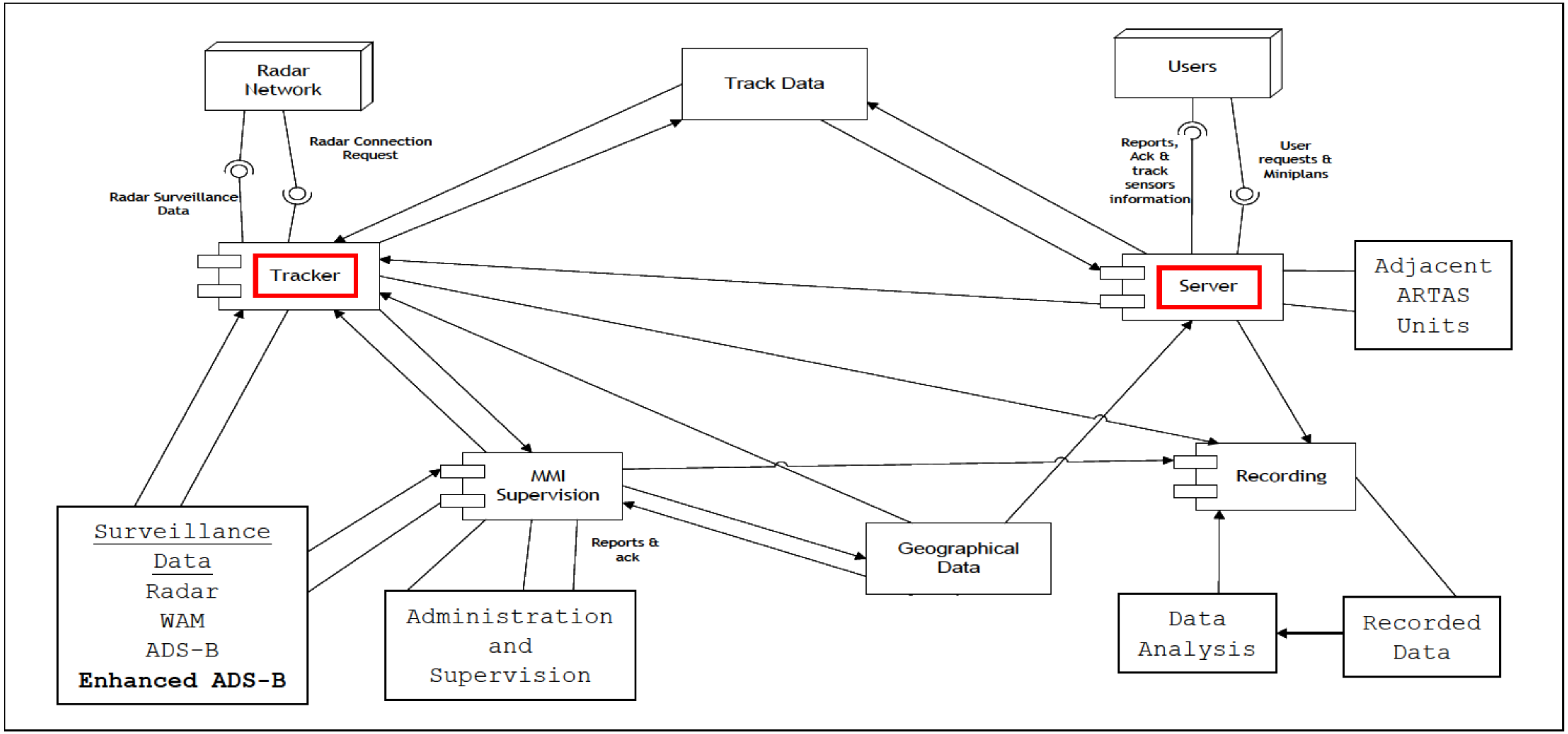

Figure 3. ARTAS functional overview

The enhancements implemented into the ARTAS SDPD product within WP15.4.5b are located within the TRACKER and SERVER functions, highlighted in Fig. 3. The enhancements improve the SDPD’s ability to discriminate false ADS-B targets from real aircraft and to either discounter these from the tracking process or flag them appropriately for display to an ATCO at a Controller Working Position.

2.8 Acronyms and Terminology

Term	Definition
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-B NRA	Enhanced ATS in Non Radar Areas (“ADS-B out” application)
ADS-B RAD	Enhanced ATS in Radar Areas (“ADS-B out” application)
AoA	Angle of Arrival
ARTAS	ATM suRveillance Tracker And Server
ASTERIX	All-purpose Structured EUROCONTROL Surveillance Information Exchange
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
BITE	Built-in Test System
CAT	Data Category
CONOPS	Concept of Operations
CWP	Controller Working Position
DO	RTCA Document
ED	EUROCAE Document
ES	Extended Squitter
EUROCAE	European Organisation for Civil Aviation Equipment
FMS	Flight Management System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GS	Ground Station
ICAO	International Civil Aviation Organization
INTEROP	Interoperability
Mode S	MODE Select

Term	Definition
MOPS	Minimum Operational Performance Standards
MST	Multi-sensor Tracking
NRA	Non Radar Airspace
RF	Radio Frequency
RTCA	Radio Technical Commission for Aeronautics
SDPD	Surveillance Data Processing and Distribution
SESAR	Single European Sky ATM Research (Programme)
SJU	SESAR Joint Undertaking
SSR	Secondary Surveillance Radar
TOA	Time of Arrival
TDOA	Time Difference Of Arrival
TMA	Terminal Manoeuvring Area
WAM	Wide Area Multilateration

3 ADS-B security issues and limitations

3.1 Denial of Service – External ADS-B signals

Automatic Dependant Surveillance – Broadcast or **ADS-B**$_{OUT}$ is a ground based surveillance technology which receives Extended Squitter ADS-B messages transmitted at 1090MHz from suitability capable and enabled transmitter or Mode S transponder devices carried by aircraft and air vehicles. Mode S Extended Squitter ADS-B messages contain the aircraft allocated 24-bit ICAO address, Aircraft Identification, Mode A code, Pressure Altitude coded in 25ft resolution, aircraft velocity and heading and most importantly the aircraft 2-D horizontal position coded in a Lat, Long value.

Several ATC applications are targeted for incorporation within the Prototype First Iteration of the enhanced ADS-B ground system. The principal one is the ADS-B RAD application [7], which involves the augmentation of the current air traffic situation picture created by Primary and Secondary radar surveillance sources within high density airspace by ADS-B surveillance services.

A functional diagram of the ADS-B surveillance system role within the ADS-B RAD logical architecture is shown highlighted within Figure 3 [1], [7]:

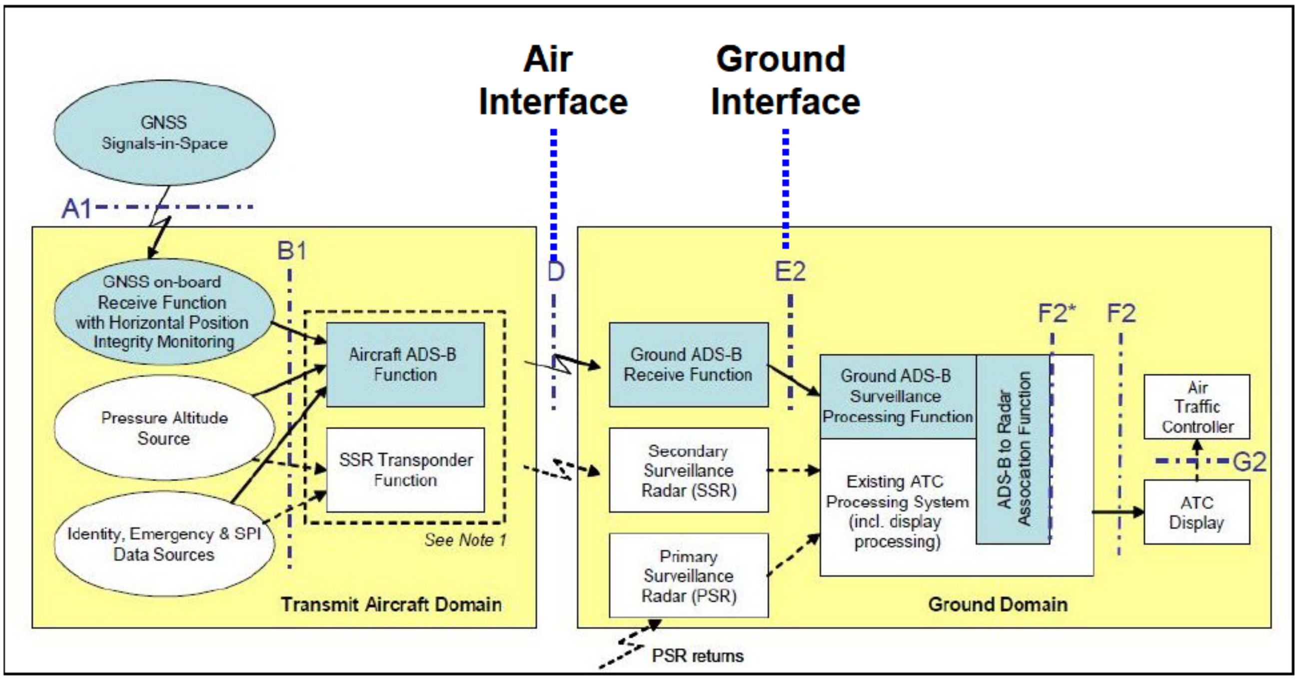

Figure 4. ADS-B surveillance system within the ADS-B RAD architecture

Inspection of the above figure shows that all of the data which is encoded within the ADS-B messages is derived from the aircraft avionics system. The 2D horizontal position contained within the ADS-B message is derived from the on-board GNSS reception function i.e. GPS at present. This dependency on aircraft derived information explains the term 'Dependant' surveillance. Other modern cooperative surveillance technology, such as Wide Area Multilateration and Mode S SSR, measure the aircraft horizontal position and hence these are termed 'Independent' surveillance systems.

The main security issue with ADS-B technology is that the ground system is completely dependant on the integrity of the transmitted information contained within the received and decoded ADS-B messages [8]. The transmission of misleading ADS-B information can be derived from two separate sources:

- The deliberate transmission of false ADS-B messages from an airborne or ground based transmitter which produces ADS-B 1090MHz Extended Squitter messages formatted in accordance with the ADS-B MOPS specified within ICAO Annex 10 and **not** corresponding to real aircraft
- A real aircraft with a mal-functioning transponder/transmitter which broadcasts incorrect and hence false ADS-B messages, possibly in-addition to its correct ADS-B message set.

The impact of the broadcast of false ADS-B messages causes the performance of the ADS-B surveillance technical service to be reduced, as real and false target are now present within the delivered surveillance service.

The presence of the false ADS-B targets has three negative effects on the supplied surveillance service:

1. Increases Air Traffic Controller (ATCO) workload, as the ATCO may have to issue avoidance instructions to real aircraft to avoid a false ADS-B target displayed on the Controller Working Position display. This avoidance action is required as the controller has presently no means to determine if the displayed ADS-B target is a real aircraft or a false target in a non-fusion tracker ATM system. The increased ATCO workload could lead to reductions in airspace capacity in certain ATC sectors and hence a lowering of the ATM system efficiency levels. In an extreme scenario it could result in the ADS-B surveillance service being withdrawn from operational usage, resulting in the implementation of ATC Unit procedural control and hence great loss of airspace load capacity in the affected ATC sectors and resultant aircraft delay and flight cancellation implications.
2. The presence of identified false ADS-B targets would lower the confidence of the ATCO using the service to control real aircraft, again leading to the withdrawal of surveillance service from operational usage with the negative effects described above.
3. The presence of false ADS-B messages from mal-functioning Mode S transponders/transmitters may prevent the successful decoding of the real ADS-B message from the aircraft and hence prevent real aircraft tracks being displayed to the controlling ATCO. The ATCO would be unaware of the lack of real aircraft tracks and may instead be controlling aircraft using false ADS-B information, with the potential for safe separation minima erosion between pairs of real aircraft.

The first two of these issues reduce the efficiency the supplied ADS-B surveillance service operations and may necessitate the withdrawal of its usage. Hence this type of event is termed a ‘denial of service attack’. An alternative term for this injection of false ADS-B targets into the surveillance service is a ‘spoofing attack’, as the surveillance system is spoofed or misled into the true nature of the received false ADS-B messages.

The broadcast ADS-B messages from the aircraft may be used for inappropriate or malicious purposes as they contain aircraft identification information, 3-D position and intention information and ADS-B messages are broadcast without any form of encryption. This security threat is inherent in all types of unencrypted broadcast technology, as it is located at the Air Interface and hence is declared as outside of the scope of the WP15.4.5 enhanced ADS-B ground system.

3.2 Denial of Service – GPS/GNSS jamming

ADS-B is dependant on GPS/GNSS signals for horizontal position information, as shown in Figure 4. Therefore, jamming of input GNSS signals i.e. GPS would prevent the GNSS onboard reception function from producing horizontal position information for broadcast by the ADS-B messaging function.

The availability of the GNSS function is however declared as outside of the scope of the enhanced ADS-B system, as it is an avionics issue rather than one located with the ADS-B functionality and hence is not addressed by WP15.4.5.

3.3 Denial of Service – Communication Network level

A security issue present within the use of ADS-B surveillance data, in common with all other types of surveillance system, is that the information may be intercepted between the remote ADS-B surveillance sensor and either central elements of the enhanced ADS-B ground system or client systems of the groundstation such as a display or Surveillance Data Processing system on the ground communication network and used for inappropriate or malicious purposes. However, this security threat should be countered on the communication network level and is declared as outside of the scope of the enhanced ADS-B ground system.

4 ADS-B security enhancements

4.1 Introduction

Six areas of security enhancements have been incorporated into the different elements of the Prototype First Iteration of the enhanced ADS-B ground system. Table 1 provides a summary of the incorporated enhancements and which manufacturer which has implemented them into their respective ground system element [5]:

Item No.	Enhancement	Thales ADS-B GS	Selex ADS-B GS	Indra ADS-B GS	EUROCNTRL SDPD
1	**Integration of ADS-B and WAM**	Y	Y	N	Y
2	**Angle of arrival measurement**	N	N	Y	Y
3	**Position versus velocity check**	Y	N	N	Y
4	**Power measurement and range correlation**	N	N	Y	Y
5	**Time of Arrival versus Distance Validation**	N	Y	N	Y
6	**SDPD Multi-sensor data fusion consistency checks**				Y

Table 1. Enhancement incorporation within Prototype First Iteration system elements

As shown in the above table, all of the planned enhancements are incorporated within at least one of the manufacturer produced elements of the first iteration of the enhanced ADS-B ground system.

4.2 Integration of ADS-B and WAM

The prime ATC application which the enhanced ADS-B ground system is required to be compliant with is ADS-B RAD [7], which is defined as the supplementation of radar coverage in high density operational environments with ADS-B coverage. These high density operating environment, such as major airport Terminal Manoeuvring Area (TMA) airspace feature a mixture of aircraft carrying ADS-B enabled Mode S transponders or transmitters and aircraft carrying legacy SSR or Mode S transponder.

Therefore, to ensure full detection of all transponder types ANSP's have tended to deploy combined WAM and ADS-B systems, with the WAM element providing the detection capability against legacy transponder equipped aircraft, such as General Aviation and state aircraft.

The availability of WAM surveillance data derived from a independent cooperative surveillance source provides very robust mitigation against false ADS-B targets broadcast in a denial of service type attack, as the WAM system measures the aircraft transponder 2-D position rather than being dependant on the reported position. Therefore, successful correlation of the WAM derived position against the ADS-B horizontal position enables the exclusion of ADS-B reports which are larger than a configurable set of distance parameters from the WAM reported aircraft position.

This scenario is shown in Figure 5 for a real ADS-B target with matching WAM position report compared to a false target. Correlation of the targets from the different surveillance sources is via the 24-bit ICAO address and/or the Aircraft Identification from the aircraft transponder in-question.

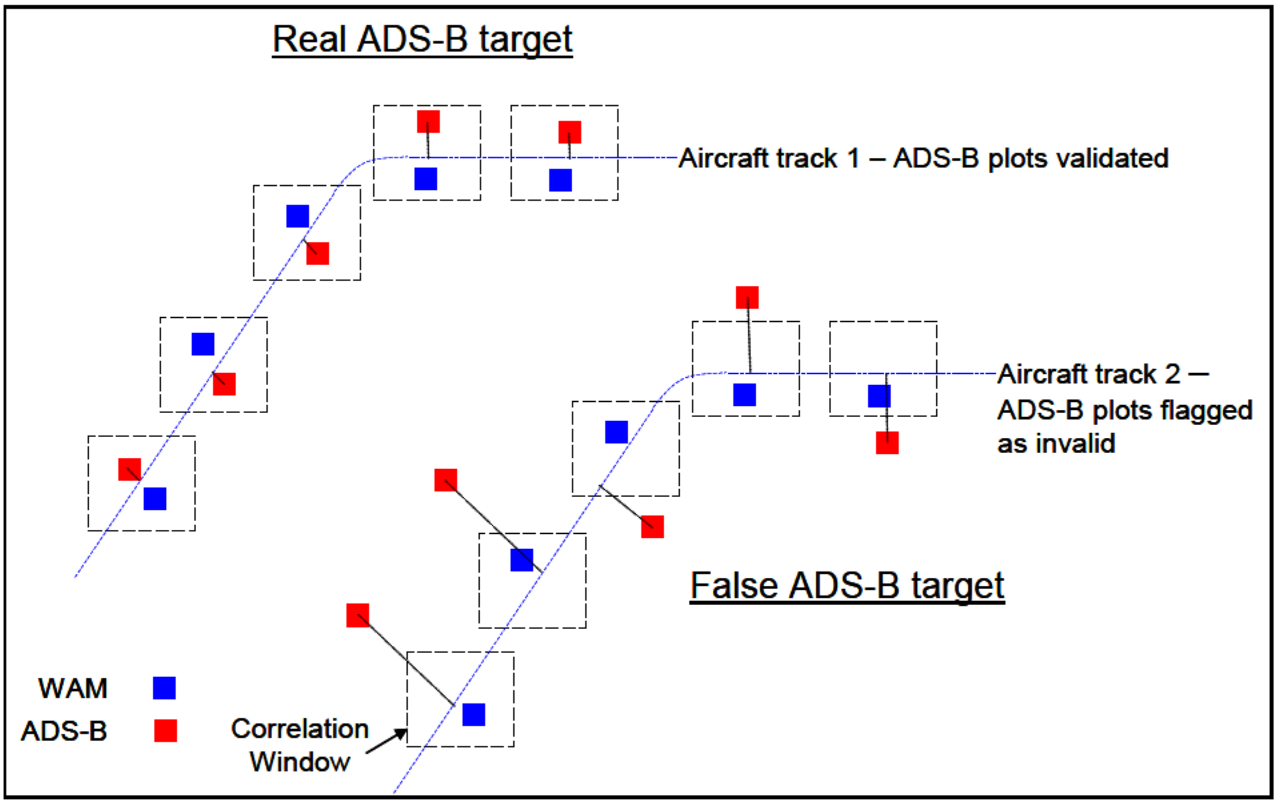

Figure 5. Example of real ADS-B target validation and false ADS-B target flagging

The correlation of the WAM and ADS-B position reports is undertaken within the enhanced ADS-B groundstation [1]. The offset of the ADS-B position from the WAM position can either be a fixed distance or widely varying, or the ADS-B position can be greatly removed from the WAM position information.

The result of the correlation process sets a validity flag on the ADS-B target report, on a plot-by-plot basis and the result is reported to the ARTAS SDPD system for the purpose of determining whether the ADS-B plot shall be input into the Multi-Sensor Tracking (MST) SDPD Tracker process. The MST produces a fused sensor target plot using radar, WAM and ADS-B surveillance sensors as input sources [3].

The only proviso with the use of WAM data to set a validity flag on the ADS-B target report is that the coverage volumes afforded by the WAM system may only be a subset of the total ADS-B system surveillance volume. Therefore, WAM position and identification validation may only be possible within a partial coverage volume of the ADS-B system. Hence, the need for other false plot mitigation techniques within the enhanced ASD-B ground system.

4.3 Angle of Arrival

False ADS-B plot broadcast from either an airborne or ground-based transmitter could feature a direction of arrival to the enhanced ADS-B groundstation which was in variance with the direction of arrival calculated from the reported position information contained within the ADS-B message. This scenario is shown schematically in Figure 6:

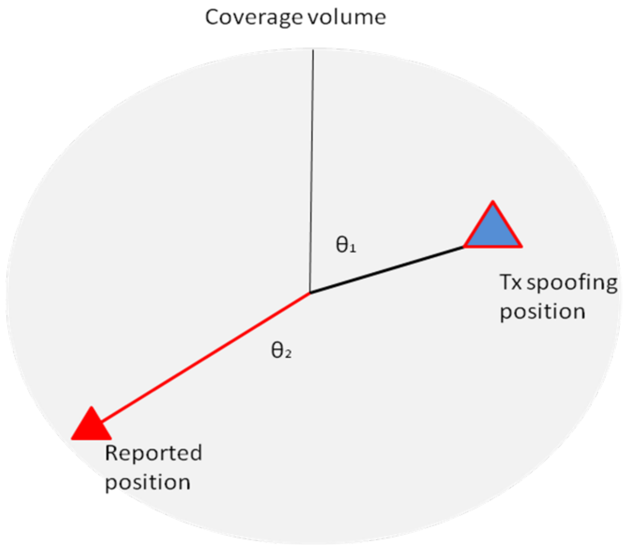

Figure 6. Angle of Arrival validation mitigation

Determination of the real angle of arrival (Θ_1), within a user definable tolerance and comparison with reported direction (Θ_2) would enable the false ADS-B plot to be flagged as invalid after a user defined number of consecutive results and hence discounted for use within the SDPD MST [5].

It should be noted that the AoA determination method is a validation technique and hence is not foreseen for other uses. Therefore, the measured angular accuracy will be considerably less accurate than a radar source for example.

4.4 Position vs. Velocity check

Inspection of the evolution of time-stamped ADS-B positions within a single aircraft track can be used by the enhanced ADS-B groundstation to derive a velocity value for the individual aircraft [1], [5].

This is shown schematically in Figure 7, with the velocity value calculated between pairs of time evolved position reports:

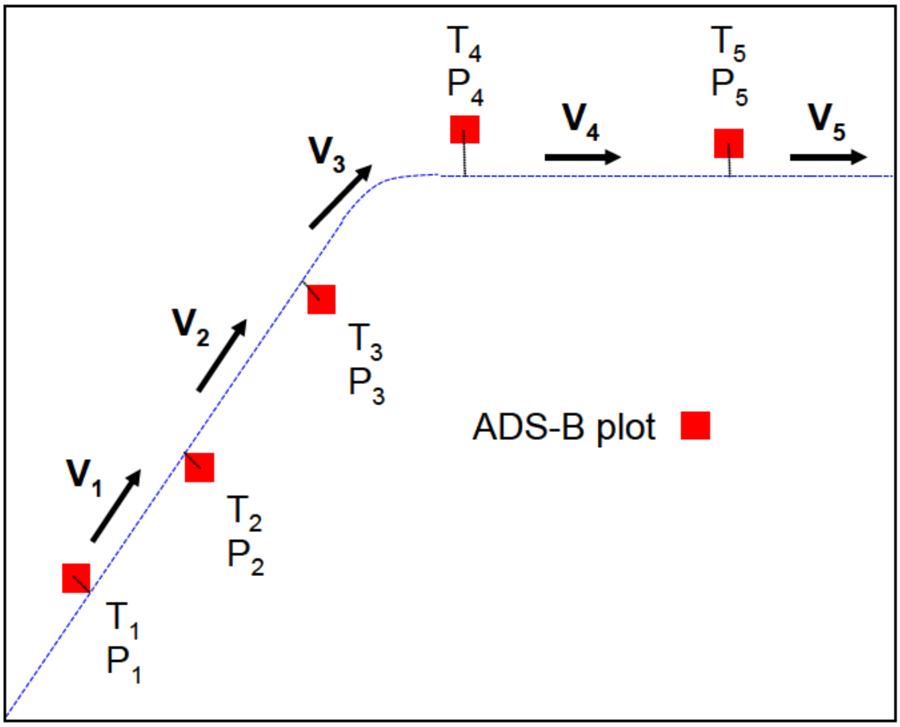

Figure 7. Velocity and Head vector determination from ADS-B time-stamped positions

Aircraft derived velocity information is reported within the ADS-B message payload and hence comparison between the calculated and reported values can be used to validate the reported values and tag plots with velocity values wider than a user definable threshold as false.

Care must be exercised when using FMS reported velocity information, as faulty/incorrect reported values could lead to the removal of valid ADS-B target reports from the MST SDPD tracking process. This issue could be addressed through a mitigation track weighting function within the SDPD Tracker process.

4.5 Power Measurement and Range correlation

RF signals decrease in signal power level as they travel in distance. Therefore, the received power level of a real signal will ratio compared to the transmitted distance of the signal, in a $1/R^2$ relationship as it is a one way path loss. The situation is more complicated with ADS-B, as two sets of ADS-B transponders output RF signals at different power levels. The ADS-B transponder classes are divided into 2 bands; A1-A3 which are intended for commercial aircraft carriage and broadcast signals at 125W and A0 transmitters which are focused on General Aviation and broadcast at 70W [9].

If a received ADS-B signal with a measured signal level which does not approximate to the expected signal level from the aircraft range derived from the ADS-B reported 3D position, within a user definable tolerance, then this report could be tagged as of low confidence. Care must be taken in this approach, as it assumes a perfect propagation path between the aircraft transponder/transmitter and groundstation antenna.

The impact of analogous propagation and localised signal loss through precipitation need to be carefully considered when assigning a weighing factor to this mitigation mechanism, as it could result in valid ADS-B plots being prevented from use within SDPD Tracker process.

4.6 Time of Arrival in ADS-B transmitter position localisation

In a network of interconnected ADS-B groundstations a single ADS-B message broadcast from an aircraft is received at different times at different receivers, with the time of arrival being directly dependant on the distance from the groundstation to the aircraft.

If the Time of Arrival of the ADS-B message is accurately recorded at all of the ADS-B groundstations then this information could be collated, either within the groundstation or in a central server function and used to localise the position of ADS-B message transmitter through calculation [1].

When the same 1090 Extended Squitter message is received by multiple remote sensors, the ToA/Distance Validation Function receives multiple position reports for the same target, differing in their time of arrival dependant on the distance of the target from the corresponding sensor. Thus, the sensor nearest to the target will provide a position report at an earlier point in time than the other sensors and so on. In this way, the following validity conditions apply for each incoming 1090ES position message:

- Time of Reception of position message in the nearest sensor is less than the Time of reception of the same position message in the second nearest sensor.
- Target Distance from nearest sensor is less than Target Distance from second nearest sensor.

ADS-B messages which did not feature the correct Time of Arrival to reported position relationship would be flagged as ‘inconsistent TOA/distance’ and hence may not be used within the SDPD MST process.

4.7 SDPD Multi-Sensor Consistency Validation and ASTERIX interface modifications

The final mitigation against false ADS-B plots being injected into the enhanced ADS-B ground system is that all ADS-B plots flagged as NOT_VALIDATED and NOT_VALID can be processed in three ways within the SDPD Tracker function, either:

a) Discounted from the MST track creation process

b) Flagged for appropriate display to the ATCO on a Controller Working Position, using ASTERIX 062.

c) Have appropriate weighing attached to the different mitigation mechanisms, dependant on how reliant they are on external influences and these weighting factors used as factors to influence the plot creation process.

ADS-B plots flagged as VALID will be input into the ARTAS Multi-Sensor Tracker and hence contribute to the track creation and maintenance process in the normal way.

To enable this final security mitigation process to be implemented the validity flags from the implemented mitigation techniques must be incorporated into ASTERIX Category 021 for the ADS-B target reports and CAT 062 for the System Track Data plots. The required security modification requirements are captured in the Interface Specifications for First Iteration [4]

5 References

[1] SJU 15.04.05a ADS-B Surveillance System Spec. for It 1, **D18**, Ed. 00.02.00, March 2011

[2] SJU 15.04.05a ADS-B 1090MHz Ext. Squitter Ground Station Spec – Iteration 1, **D05** Ed 00.02.00, March 2011

[3] SJU 15.04.05a SDPD Specification – Iteration 1, **D06** Ed 00.01.04, March 2011

[4] SJU 15.04.05a Interface Specifications for First Iteration, **D07** Ed 00.01.00, March 2011

[5] SJU 15.04.05b First Iteration – Baseline Report/Matrix, **D02** Ed 00.01.01, July 2011

[6] EUROCAE **ED-129**: Technical Specification for a 1090 MHz Extended Squitter ADS-B Ground Station, June 2010

[7] EUROCAE/RTCA SPIR Document for ADS-B RAD Application, **ED-161**/DO-318, Sept. 2009

[8] SJU 15.04.05a Specification Baseline Document, **D17**, Ed. 00.01.00, Oct 2010

[9] Minimum Operational Performance Standards for 1090MHz Extended Squitter Automatic Dependant Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B), RTCA **DO-260B**, Dec 2009

5.1 Use of copyright / patent material /classified material

No copyright/patent material is included in this specification.

- END OF DOCUMENT -