METHODS TO PROVIDE SYSTEM-WIDE ADS-B BACK-UP, VALIDATION AND SECURITY

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Abstract

A major part of the business case for Automatic Dependent Surveillance - Broadcast (ADS-B) is attributed to the savings generated by decommissioning or reducing reliance on conventional radar systems. In order to maintain some form of redundancy, a networked, system-wide back-up and validation approach is required. During the transition to end-state surveillance architectures, there will likely be a mixture of various types of surveillance sources including primary surveillance radar, secondary surveillance radar, multilateration, and ADS-B. This paper describes an integrated approach to the surveillance architecture and one means for facilitating the application of multiple surveillance sources.

Surveillance sensor performance is based on the categories defined in ADS-B standards. The relevant parameters are Navigation Accuracy Category (NAC), Navigation Integrity Category (NIC), and Surveillance Integrity Level (SIL). These standards have been adapted to create a generic surveillance performance categorization method. This method would enable air traffic service providers to develop criteria for combining information from multiple surveillance sensors. The categorization also enables a method for defining the associated aircraft separation requirements.

Introduction

ADS-B is a new surveillance system being implemented worldwide by many aviation authorities that offers a great leap forward in aircraft surveillance capabilities. More information is made available through ADS-B than with conventional primary and secondary radars. As ADS-B does not require expensive radar infrastructure, the cost of implementation and maintenance is far lower.

Whether ADS-B will allow substantial decommissioning of conventional radar is the subject of ongoing study and debate. However, most air navigation service providers (ANSPs) see the benefits in the implementation of a relatively low cost flight tracking technology. Countries like Australia, with vast tracts of land and mountainous terrain that is not viable for conventional radar, see the new technology as highly cost beneficial. Countries with a significant investment in conventional radar, such as the United States, see major savings in O&M costs as well as user benefits in upgrading to ADS-B technology.

In the United States, the FAA has successfully used ADS-B in Alaska as part of the Capstone program and is now planning to introduce the system into the Continental United States (CONUS). Other aviation authorities have also embraced the use of wide area multilateration (WAMLAT) coupled with ADS-B, including Taiwan and Austria. A popular notation for ADS-B enhanced by WAMLAT is ADS-X, where the “X” is attributed to extending the capability of ADS-B.

Many standards organizations in international aviation are supporting the development of aircraft avionics and ground systems standards. These include RTCA Special Committee 186, which developed the ADS-B Minimum Aviation System Performance Standards (MASPS) – DO-242A [1], EUROCAE Working Group 51, and the International Civil Aviation Organization (ICAO).

Surveillance Architecture

Currently in the U.S, there are several hundred independent radar systems providing surveillance redundancy in the National Airspace System (NAS). Due to the overlapping coverage, the loss of any single radar can usually be tolerated and surveillance information is still adequate for Air Traffic Management (ATM) purposes. Similarly, A NAS surveillance system based on ADS-B must also position ADS-B ground stations close together to provide overlapping coverage.

The most significant difference between ADS-B and current surveillance is that ADS-B relies

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primarily on the Global Navigation Satellite System (GNSS) as the source of information used to determine aircraft position. Therefore, the viability of the system depends on GNSS performance. Any loss of GNSS information, due to interference or other issues, will result in the loss of the primary source of aircraft position information for ADS-B. Thus, there is still a need for an independent source of surveillance information.

In the context of aircraft surveillance, independence requires that the back-up system is capable of providing surveillance when there is a loss of surveillance from the primary system. There can be no “common mode” failures that affect both the primary and back-up systems. The back-up system must not be dependent on the GNSS.

ADS-B Back-Up Options

Surveillance alternatives generally considered for application as a back-up to ADS-B include:

- Multilateration
- Primary Radar
- Secondary Surveillance Radar (SSR)
- Passive SSR
- Passive Primary Radar

While aviation authorities world-wide discuss the idea of a back up as redundant forms of surveillance, or as interoperable forms of surveillance, there is no existing methodology to combine the different sources of surveillance into an overall surveillance service with a common set of performance metrics.

For example, the FAA has revealed ambitious plans to commence with a national ADS-B program (www.faa.gov). At the present time, the FAA is interested in back up surveillance and will consider performance-based approaches that are not technology specific. However, there exists no methodology to combine these surveillance sources, be they primary or back up, nor is there a method to categorize the quality of data from different sources.

ADS-B Data Classification

The RTCA MASPS [1] and MOPS (Minimum Operational Performance Standard, DO-260A) [2] define the standards for ADS-B implementation. Aircraft navigation performance, as indicated in the transmitted ADS-B information, is specified in terms of NAC, NIC and SIL, defined as follows:

- Navigation Accuracy Category (NAC) is used to announce the 95% accuracy limits for the position data being broadcast.
- Navigation Integrity Category (NIC) specifies an integrity containment radius integrity for the reported position.
- Surveillance Integrity Level (SIL) is the probability that the integrity containment radius used in the NIC parameter will be exceeded.

NAC is reported so that the surveillance application may determine whether the reported position has an acceptable level of accuracy for the intended application. NIC and SIL are reported so the surveillance application may determine whether the reported position has an acceptable level of integrity for the intended application.

SSR and ADS-B have different methodologies for tracking aircraft; however, as noted above, performance metrics for ADS-B have been established such that the accuracy and integrity of an ADS-B system can be readily determined. Back-up surveillance methodologies may require similar accuracy and integrity standards, but since the methodologies differ in their underlying technology, creating equivalent metrics for monitoring back-up systems may be difficult. Thus, there is a need to provide a system and method for monitoring and measuring metrics of a back-up methodology and presenting such metrics in the same or similar terms as ADS-B metrics.

Surveillance vs. Navigation Performance Metrics

The present ADS-B performance metrics are based on aircraft computed values for quality as determined by the aircraft’s on-board navigation information, hence the use of “N” for navigation integrity and accuracy metrics. A surveillance based approach would not use the on-board aircraft navigation information and would be separate and independent from that data. To distinguish the different sources, it may be useful to consider different nomenclature such as "S" for surveillance-derived metrics, as indicated in Table 1. The proposed parameters are:

- Surveillance Integrity Category (SIC);
- Surveillance Accuracy Category for Position (SAC_P)
- Surveillance Accuracy Category for Velocity (SAC_V)
- Surveillance Integrity Level (SIL)
- Baro Altitude Quality (BAQ).

Table 1. Performance Metrics Summary

Performance Metric	**Aircraft-Based (ADS-B)**	**Non Aircraft-Based (Multilateration or SSR)**
Horizontal & Vertical Containment Bounds	Navigation Integrity Category (NIC)	Surveillance Integrity Category (SIC)
95% Horizontal & Vertical Accuracy Bounds	Navigation Accuracy Category for Position (NAC_P)	Surveillance Accuracy Category for Position (SAC_P)
95% Horizontal & Vertical Velocity Error	Navigation Accuracy Category for Velocity (NAC_V)	Surveillance Accuracy Category for Velocity (SAC_V)
Probability Exceedence Integrity Containment Radius	Surveillance Integrity Level (SIL)	Surveillance Integrity Level (SIL)
Encoding Baro Quality (Future)	Baro Altitude Quality (BAQ)	Baro Altitude Quality (BAQ)

The specific NAC categories defined for ADS-B are listed in Table 2 [1, 2]. It is expected that the same categories would be applied to surveillance performance.

Table 2. ADS-B NAC Classification [1]

NAC_P	**95% Horizontal Accuracy**	**95% Vertical Accuracy**
0	≥ 18.52 km	NA
1	< 18.52 km	NA
2	< 7.408 km	NA
3	< 3.704 km	NA
4	< 1852 m	NA
5	< 926 m	NA
6	< 555.6 m	NA
7	< 185.2 m	NA
8	< 92.6 m	NA
9	< 30 m	< 45 m
10	< 10 m	< 15 m
11	< 3 m	< 4 m

An example of where this is already the case is with the ADS-B safety requirements for ATC surveillance. The draft RTCA/EUROCAE document on the use of ADS-B in Non-Radar Airspace [3], defines the minimum requirements to support surveillance in en route and terminal area operations. Table 3 summarizes the performance requirements to support 5 NM aircraft separation in en route airspace and 3 NM separation in terminal area airspace. ADS-B requirements are based on achieving at least the equivalent of current radar performance (shown in the second column). Conservative margins were built into the minimum NAC categories defined for each application by requiring better accuracy than is achieved by radar. The results are accuracy requirements of 558m for en route and 186m for terminal.

Multilateration Surveillance

Wide Area Multilateration (WAMLAT) is widely viewed as a potential back-up/validation to ADS-B. A detailed description of multilateration surveillance can be found in Reference 5. A more detailed analysis of the performance of WAMLAT as a back-up for ADS-B is described in Reference 6.

Table 3. Summary of Radar and ADS-B Performance Requirements [3]

	Radar Performance	ADS-B			
		Accuracy		Integrity	
Phase of Flight	Accuracy (95%)	Accuracy (95%)	NAC_P	NIC	SIL
En Route (5 NM separation)	911 m	558 m	≥ 6	≥ 4 (2 NM)	≥ 2 $(<10^{-5})$
Terminal (3 NM separation)	304 m	186 m	≥ 7	≥ 5 (1 NM)	≥ 2 $(<10^{-5})$

In addition to back-up surveillance, other possible roles for WAMLAT are:

- Verification of navigation accuracy, comparing ADS-B data with multilateration data to verify data accuracy and integrity. Techniques are available to compare annunciated position with an independently determined position allowing an assessment to be made regarding the difference between the two results. Position differences of significance would trigger an alert. From the various data sources employed, correlated aircraft identification is available, which has an associated confidence based on the number of independent data sources and the level of agreement between the sources. From tracking systems, aircraft flight performance is determined and correlated with the announced identification for consistency. Aircraft identification and flight tracking *a priori* information, including schedule and normal operations, can also be used to assist in building the confidence of an aircraft's correct identity.
- Spoofing detection: WAMLAT systems can be used to identify valid aircraft position reports and the source of spoof transmissions. The threat of ADS-B spoofing is of concern to many organizations and altering existing and planned ADS-B infrastructure to prevent such spoofing would require extensive investment in revising existing infrastructure and also changing out ADS-B equipment in existing aircraft. Such a radical overhaul of the ADS-B system is not cost-effective or practical. WAMLAT can provide Air Traffic Service Providers the capability for detecting ADS-B spoofing with a surveillance source that is independent of ADS-B. In May 2006, ADS-B potential vulnerabilities to spoofing were highlighted in a letter from the Australian Civil Aviation Authority's former Chairman to the Australian Government's Minister for Transport and Regional Services [4].
- Providing surveillance without additional aircraft equipage. ADS-B requires the installation of new aircraft avionics and the avionics transition will take a significant period of time and will likely never achieve 100% equipage due to the large number of general aviation aircraft. WAMLAT can provide full surveillance for all transponder equipped aircraft, including aircraft with ADS-B and current transponders (Mode A, Mode C, and Mode S).

Surveillance Data Classification

To support the various functions associated with multiple surveillance sources, a method is needed to classify the performance of each surveillance sensor. The method proposed is to apply the same categorization of performance, used with ADS-B, to other surveillance sensors. Figure 1 is an example of WAMLAT accuracy performance. The example is from the Ohio Valley where there are four Rannoch multilateration systems implemented at Louisville International Airport, Ohio State University, Cincinnati Lunken Municipal Airport, and Indianapolis International x

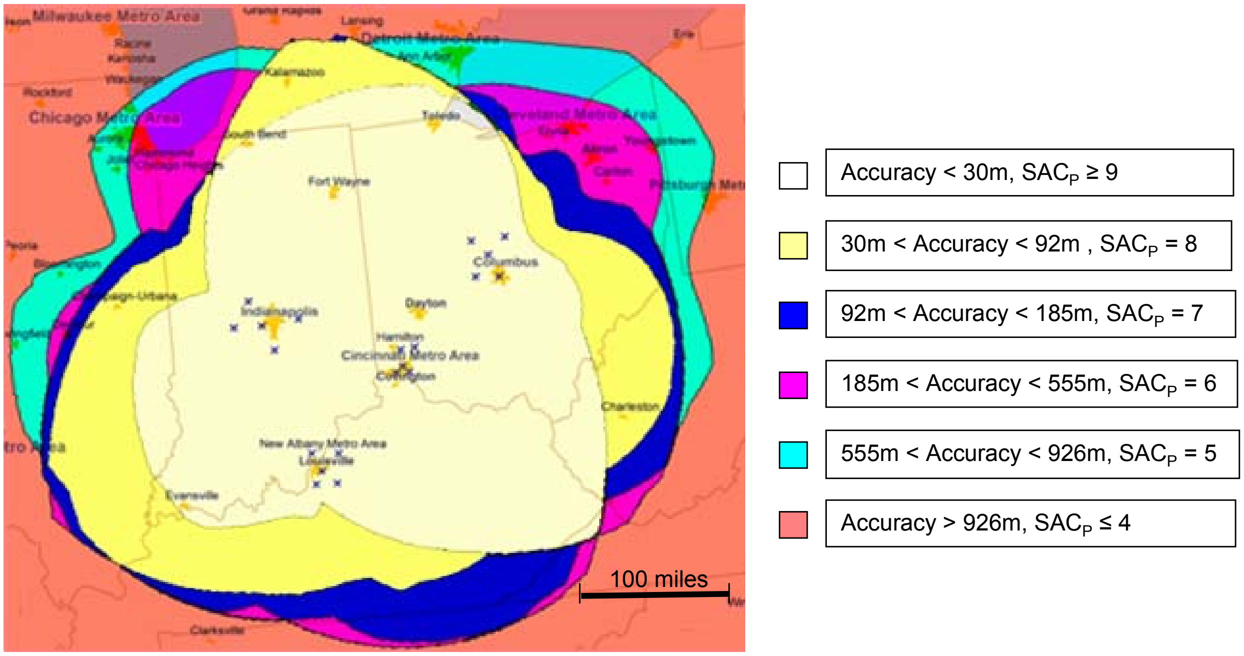

Figure 1. Example of Multilateration Surveillance Sensor Accuracy

Airport. Each system consists of five sensors, one on-airfield and four off-airfield (indicated as an x on the map). When combined together, a wide area regional network of 20 sensors can be considered in this particular example. The accuracy contours in Figure 1 (at 18,000 ft altitude) correlate to the NAC_P and SAC_P accuracy classification defined in Table 2. Figure 2 illustrates an example comparing three different surveillance sources (ADS-B, radar, and WAMLAT) over a range of 180 NM. ADS-B should have relatively constant accuracy, assuming it is based on GNSS. Radar is an angular based system, therefore the errors increase linearly with range.

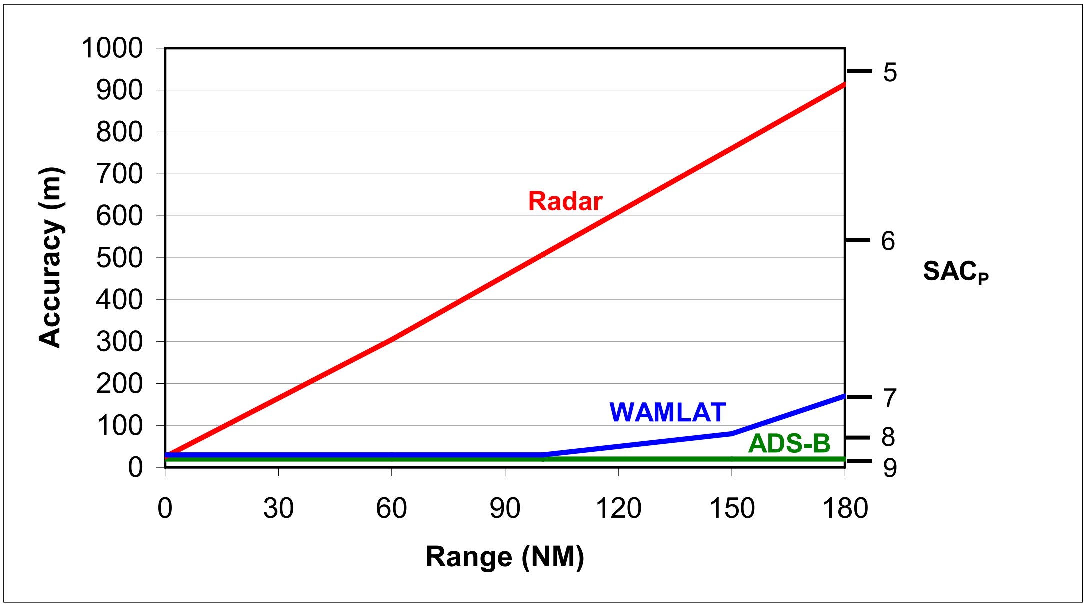

Figure 2. Surveillance Sensor Accuracy and Associated SAC_P

WAMLAT accuracy depends on the location of the ground sensors and geometry associated with the aircraft position relative to the sensors. The key parameter is dilution of precision (DOP). The WAMLAT accuracy in Figure 2 is based on the example from Figure 1. At longer ranges, WAMLAT will generally provide better accuracy than radar.

Table 4 shows the SAC_P categories that would be associated for each of the three surveillance sources at ranges of 60 NM and 180 NM. The reference for the ranges is assumed to be the center of Figure 1, which is the approximate location of Cincinnati. This assumes a single, long range radar, the WAMLAT configuration shown in Figure 2, and ADS-B ground stations providing coverage throughout the region. Similar categorization can be applied for SIC and SIL performance parameters.

Table 4 indicates that WAMLAT should easily meet the performance requirements proposed for ADS-B for en route and terminal area surveillance. For en route (5 NM separation), the minimum SAC_P is 6, and in the example, WAMLAT is supporting a SAC_P of 7. For terminal (3 NM separation), the minimum SAC_P is 7, with WAMLAT supporting a SAC_P of 9.

Table 4. Example SAC_P Categorization

	SAC_P	
Surveillance Source	**60 NM Range**	**180 NM Range**
ADS-B	9	9
Radar	6	5
WAMLAT	9	7

Surveillance in Multi-Sensor Environment

Figure 3 shows an architecture with four sources of surveillance information – primary radar, secondary radar (SSR), ADS-B, and multilateration. The data from the four sensors has to be processed prior to its use in Air Traffic Service (ATS) automation, which is typically done by a sensor fusion function.

The previous example illustrates the utility of instituting surveillance sensor categorization when an ATC service provider has implemented multiple types of sensors. Figure 2 indicates that ADS-B and WAMLAT are almost always going to provide better surveillance accuracy than conventional radar. ADS-B and WAMLAT also support higher update rates than do terminal and en route radars. Therefore, in a region with multi-sensor coverage, the preferred sensor should be selected in the following order: 1) ADS-B; 2) WAMLAT; 3) Radar.

This can also be used as an example of the use of multiple sensors in a region of overlapping coverage. A likely future scenario is that each sensor will provide a unique coverage volume. In that case it may be necessary to rely on all three sensor types to provide the overall coverage required. The result would be a mosaic of coverage with each sensor contributing different areas. For the Ohio Valley example in Figure 1, assuming there are terminal radars located at the major airports, and at least one en route radar, there are still gaps likely in radar coverage at lower altitudes. ADS-B or WAMLAT could be used to fill in the coverage. In this scenario, the sensor categorization shown in Table 4 would be useful in determining how the surveillance information from each sensor could be used by ATM. This performance information would also be used in defining the aircraft separation requirements associated with specific volumes of airspace, depending upon the surveillance source.

Summary and Conclusions

This paper has presented a method for categorizing generic aircraft surveillance performance, including accuracy and integrity. The categorization is the same as is currently defined for ADS-B, which would enable air traffic service providers to develop criteria for combining information from multiple surveillance sensors. The categorization also enables defining the associated aircraft separation requirements. Techniques, such as these, are essential to the continuing evolution of global interoperable surveillance systems and provide a practical framework to expedite the implementation of ADS-B on a large scale.

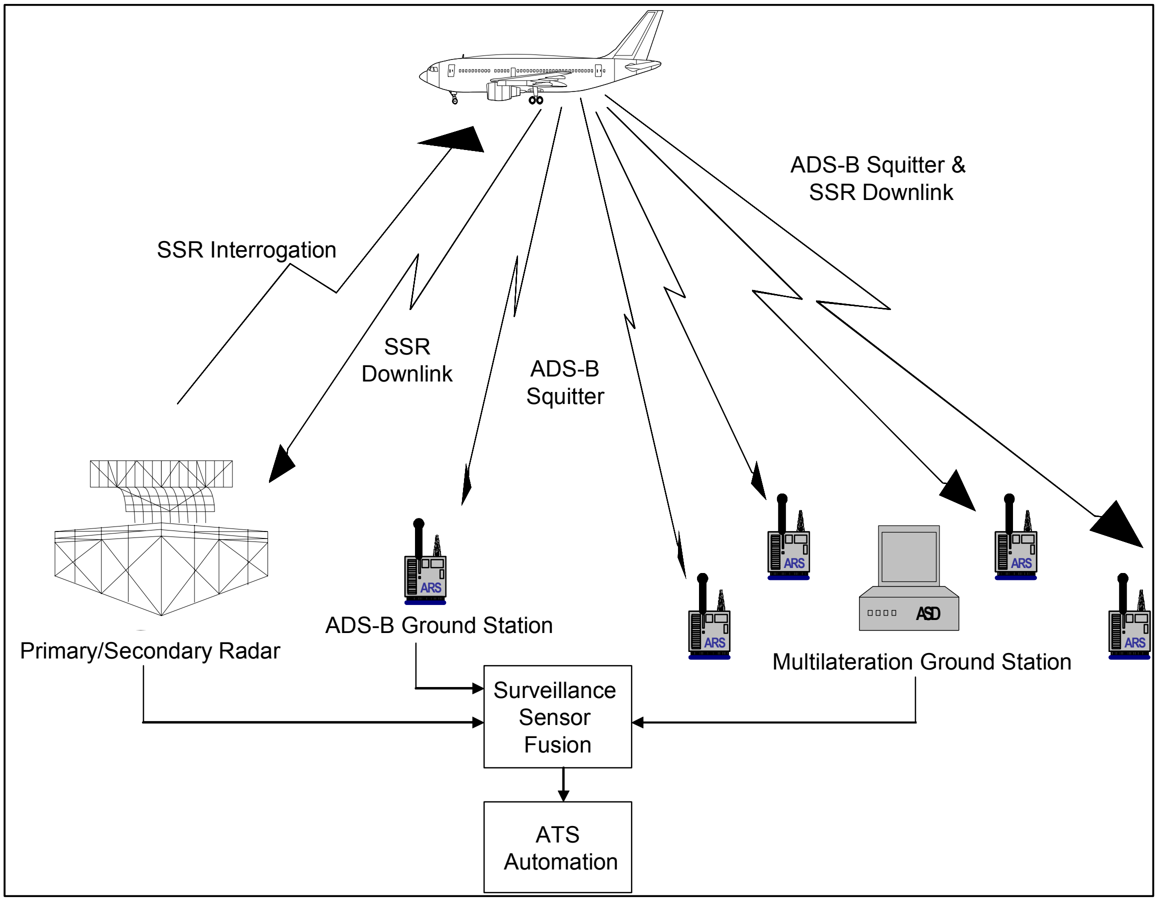

Figure 3. Multi-Sensor Surveillance Architecture

References

[1] *Minimum Aviation Performance Standards for ADS-B*, RTCA DO-242A, June 25, 2002.

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