A Space Based Augmentation System for Australia

Enhancing Australia’s Position Navigation and Timing Capabilities

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Note to the reader

This report was originally prepared in late 2010 as a briefing document for the Space Policy Unit (SPU). It was written in response to the emerging opportunity of adding payload to the NBN communications satellites. The intention was to use this opportunity to build a Space Based Augmentation System (SBAS) to deliver ±1-2m positioning across Australia, particularly in support of the aviation sector.

During 2011 the option of adding payload to the NBN satellites became increasingly unlikely. Nonetheless, Australia still needs an SBAS and, in this context, this report provides a useful summary of the relevant issues and supporting arguments. Only minor modifications have been made to the report in light of the NBN added payload option being lost.

Readers are asked to keep in mind the changed circumstances regarding the NBN satellites as they peruse this report.

The authors
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**Acronyms**

AMSA  Australian Maritime Safety Authority  
APV  Approach Procedure with Vertical Guidance  
ARAS  Australian Regional Augmentation System  
ATC  Australian Transport Council  
AVL  Automatic Vehicle Location  
Baro-VNAV  Barometric Controlled Vertical Navigation  
BITRE  Bureau of Infrastructure, Transport and Regional Economics  
CASA  Civil Aviation Safety Authority  
COMPASS  Chinese GNSS (also referred to as ‘Beidou’)  
CFIT  Controlled Flight Into Terrain  
CORS  Continuously Operating Reference Station  
DGPS  Differential GPS  
EGNOS  European Union SBAS (European Geostationary Navigation Overlay System)  
GAGAN  A regional SBAS planned by the Indian government (GPS-Aided Geo-Augmented Navigation System)  
Galileo  European Union GNSS  
GEO  Geostationary (satellite)  
GLONASS  Russian GNSS (GLObal'naya NAvigatsionnaya Sputnikovaya Sistema)  
GNSS  Global Navigation Satellite System  
GPS  US GNSS (Global Positioning System)  
GRS  Ground Reference Station  
IAP  Intelligent Access Program  
ICAO  International Civil Aviation Organisation  
ITS  Intelligent Transport Systems  
MCS  Master Control Station  
MSAS  Japanese SBAS (Multifunctional Satellite Augmentation System)  
NBN  National Broadband Network  
NPI  National Positioning Infrastructure  
PBN  Performance Based Navigation  
PNT  Position, Navigation and Timing  
RNSS  Regional Navigation Satellite System  
SBAS  Satellite Based Augmentation System  
SES  State Emergency Service  
SIIC  Space Industry Innovation Council  
WAAS  US SBAS (Wide Area Augmentation System)
Executive Summary

Adding hosted payload to the proposed geostationary satellites needed for Australia’s National Broadband Network (NBN) has the potential to realise multi-billion dollar benefits for the nation for a relatively modest investment of USD$30M\textsuperscript{1}. Of particular interest is the addition of an L-band transponder to each satellite to provide the space segment of a Satellite Based Augmentation System (SBAS). SBAS is a perfect candidate for a hosted payload solution as the required hardware is small, light weight and consumes limited power. The in-space capability achieved by an SBAS hosted payload would form the backbone of a new ±1-2 m national positioning service that would allow approach with precision vertical guidance to the general aviation industry operating in Australia and throughout the region, as well as bringing economic, environmental and social benefits to a broad range of non-aviation users.

The potential benefits to aviation alone are considerable. In the first instance, aircraft approaches with vertical guidance (APV), such as those enabled by SBAS, are some eight times safer than those without. Further, during take-off, landing and while in-flight substantial fuel savings result from the improved navigation and trajectory optimisation capabilities SBAS enables. Finally, the adoption of SBAS has the potential to avoid ongoing upgrade/replacement costs of Australia’s aging system of radio navigation aids, which has been forecast to be AUD$106.6M over the next 5 years\textsuperscript{2}.

An SBAS allows the accuracy of stand-alone satellite positioning systems like the Global Positioning System (GPS) to be enhanced from approximately ±10 m to at least ±2 m. More importantly for aviation and other safety-of-life applications, SBAS technology adds a significant level of integrity and quality assurance to the resultant navigation solution, ensuring confidence in its use. Breaches in position quality are detected and communicated to users with very low latency, allowing the implementation of appropriate backup procedures. Users can access SBAS correction signals with commercial grade receivers at no additional expense for supplementary hardware or software, making the service available for a broad range of applications and enabling high accuracy (±1-2 m), high integrity positioning not only across Australia, but across the region. Except in some areas, this capability does not currently exist in Australia.

It is recommended that a feasibility study and cost benefit analysis be undertaken using a simulated SBAS to demonstrate and quantify the value of SBAS to industry sectors other than aviation. The proposed study would take 2 years to complete and would cost an estimated USD$2.5M. The results of the study could be used to justify the investment in a full SBAS capability for Australia. Subject to the outcomes of the feasibility study and cost benefit analysis, it is recommended that the Australian Government subsequently invest the USD$30M needed to add a SBAS payload to the NBN satellites.

\textsuperscript{1} Industry estimate of USD$15M per satellite based on a L1/L5 bent pipe transponder.
\textsuperscript{2} Airservices Australia Corporate Plan 2009-2014.
Cost-Benefit Summary

This section provides a supplement to the Executive Summary. Its objective is to summarise the estimated costs of developing an SBAS for Australia and to highlight, and where possible quantify, the associated benefits. Note that the benefits are those that apply to the aviation industry only. The benefits of SBAS for other sectors have not been included. The feasibility and cost-benefit study proposed in Section 5 will identify and quantify benefits for non-aviation users.

COSTS

- Total SBAS cost\(^1,2\) AUD$190-300m
- Cost of satellite payload on two NBN satellites\(^3\) USD$30m
- Avoided cost\(^4\) AUD$106.6m

BENEFITS FOR AVIATION\(^5\)

- An eight fold increase in aircraft approach to land safety at approximately 250 airfields
- Australia would fully meet its commitment to ICAO Resolution 36-23
- Decreased collision risk through increased surveillance capacity
- Reduced cost of maintaining terrestrial radionavigation aids
- Improved GNSS navigation performance (accuracy, availability and integrity)

Notes:

1. Total SBAS cost has been extracted from the Booz and Co report completed for CASA. The cost range of AUD$190-300m is based on four scenarios for implementing SBAS. The figures include both capital and operating costs for the space, user and ground segments of the system for the period 2008-2025.

2. **Update (12 October 2011).** Since preparing the original version of this report (November, 2010), the opportunity for adding hosted payload to the NBN satellites has passed. As an alternative, following material presented at a recent APEC forum, CASA are now considering collaborating with neighbouring countries to extend existing or proposed regional SBAS systems to service the wider region rather than building an indigenous capability. Likely systems include the existing Japanese MSAS system and the planned Indian GAGAN system. Use of third party SBAS infrastructure supplemented by an extended regional ground reference station network reduces the up-front cost of the system to an estimated USD$30m\(^3\). Australia would be liable for only a proportion of this cost due to the collaborative nature of the venture. Operating costs would be in addition to the above but have not been estimated at this stage.

3 Cost estimate supplied by Ian Mallett, Head Aerodromes and CNS/ATM, CASA. (October 2011, personal communication).
3. The space segment cost of USD$30m is the most recent industry estimate. This is the cost of adding the SBAS payload to the NBN satellites.

4. The avoided cost relates to the reduced need to upgrade/replace Australia’s current system of radio navigation aids as Australia transitions to using GNSS for primary navigation and uses the terrestrial radionavigation aid system as a "backup network". Introduction of an SBAS would likely accelerate the transition to GNSS and reduce the density of radionavigation aids required in the backup network.

5. The benefits summarised above have been extracted from CASA’s PBN Implementation Plan.
1. **Preamble**

A relatively modest co-investment of approximately USD$30M to fund additional payload on two proposed geostationary satellites would provide Australia with the space component of a real-time Satellite Based Augmentation System (SBAS). An Australian SBAS would bring substantial economic, environmental and safety benefits to the aviation industry through a new capacity to undertake precision navigation runway approaches with reliable vertical guidance. In broader terms, such a system would provide a national positioning capability bringing benefits and new capacities to a wide variety of users and applications, especially those needing ±1-2 m position accuracy, guaranteed availability and the robustness of service to support safety-of-life applications. Users equipped with satellite navigation receivers would be able to immediately benefit from a new SBAS, since virtually all current and new receivers come with in-built SBAS capabilities. Removing the need for additional or new hardware means the benefits of SBAS would immediately flow at no cost to the ever growing user community.

But SBAS brings other benefits to the users of satellite navigation technologies. At present the use of systems such as the Global Positioning System (GPS) is restricted in environments where obstructions block the reception of satellite signals. In forested areas, steep terrain or when operating between tall buildings, erroneous position information or a loss of positioning capability can result. Such events are undesirable, particularly if critical decisions are being made on the basis of the supplied position information. However, because SBAS satellites are geostationary, they are constantly available and their high elevation angle (generally $\geq 50^\circ$) means their signals will not normally be obstructed by vegetation and buildings. Thus, in addition to improved accuracy and integrity, SBAS enhances positioning capabilities in environments otherwise challenging to conventional satellite navigation systems.

2. **Background and justification**

2.1 **Preamble**

The Australian government is funding the roll-out of a national broadband network (NBN) that will connect 90 percent of Australian homes, schools and workplaces to a new optical fibre network providing broadband speeds of up to 100 megabits per second. The remaining 10 percent of users will be connected to the NBN via next generation wireless and/or satellite technologies delivering speeds of 12 megabits per second or better. The planned satellite component of the NBN will comprise two new, purpose-built, telecommunications satellites located in geostationary (GEO) orbits.

The launching of these two satellites raises the prospect of leveraging this investment to bring additional benefit to the country. The spatial information industry has the capacity to deliver major economic, environmental and social outcomes on the back of the NBN investment through the addition of positioning and/or earth imaging capabilities to the proposed NBN satellite payloads.

In terms of adding a positioning payload, the most immediate and significant benefit can be reaped through the addition of an L-band transponder to each NBN satellite. The L-band transponders can be used to broadcast corrected Global Navigation Satellite System (GNSS) signals and integrity information with an extremely high level of reliability and availability to
a variety of users engaged in a diverse range of applications. In the parlance of positioning, such a system is known as a Satellite Based Augmentation System (SBAS) since it uses satellite communications to enhance standalone GNSS positioning quality and reliability.

SBAS systems already exist in other parts of the world. Examples include the Wide Area Augmentation System (WAAS, USA), the European Geostationary Navigation Overlay System (EGNOS, Europe) and the Multifunctional Satellite Augmentation System (MSAS, Japan). India and Russia will also deploy SBASs in the next few years. These systems are primarily used by the aviation sector. The most pressing demand for an Australian SBAS likewise comes from the general aviation industry. However, as is evident from experience in the USA and Europe, other industries such as safety and emergency services, search and rescue, transport and maritime, stand to benefit from an SBAS capability.

The Civil Aviation Safety Authority (CASA) has done a considerable amount of background research into the requirements to build and operate an Australian SBAS. In this context, Booz and Company produced a report titled “GNSS Augmentation for APV – Technical Options and Cost Benefits” (Booz and Co., 2008). The primary motivation behind the report was Australia’s adoption of a 2007 International Civil Aviation Organisation (ICAO) resolution that requires Approach Procedures with Vertical Guidance (APV) be implemented as either a primary or backup strategy for all runway ends at all aerodromes serving aircraft with a maximum certificated takeoff weight of 5700kg or more. This resolution required complete implementation of APV by 2016. The Booz and Co report considered a number of scenarios for an Australian SBAS as an option for enabling APV. The cost calculations presented in the report included the capital and operational cost (to 2025) for a complete SBAS implementation, including Ground Reference Stations (GRS), two Master Control Stations (MCS) and various options for delivering the space segment, comprising two SBAS-capable geostationary satellites. The estimated costs ranged between AUD$190-$300 m. In addition to numerous other benefits, the report highlighted that such an outlay could save at least the same amount of money by reducing the need to upgrade and maintain the present network of radio navigation beacons.

2.2 Global Navigation Satellite Systems

The term Global Navigation Satellite System (GNSS) refers to the various satellite constellations that broadcast signals from space that can be used to determine geographical 3D position (latitude, longitude, altitude), navigation parameters (e.g. heading, range, speed) and accurate time information. Existing GNSS constellations include the Global Positioning System (GPS, USA) and the GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (GLONASS, Russian Federation). New systems in the planning and implementation stage include bèidōu dāohāng xìtōng or Beidou (COMPASS, China) and Galileo (European Union).

Due primarily to the success of GPS, satellite navigation capabilities have become a vital part of everyday life. For example the precision timing capabilities of GNSS support services such as mobile telephony and international financial transactions while GNSS navigation capabilities support applications in transport, agriculture, logistics, surveying and geodesy, amongst others. In effect, GPS has become a global public utility providing Position Navigation and Timing (PNT) capabilities to the world. The world-wide market for GPS mapping equipment alone is roughly USD$500M and has been predicted to grow to USD$1B by 2013. The economic value of GNSS in business and commerce defies estimation and continues to grow.
2.3 Infrastructure for position, navigation and timing

In a recent report, the Australian Space Industry Innovation Council (SIIC) identified GNSS based PNT capabilities as a strategic priority for space industry development in Australia. The report highlighted two main components of critical infrastructure which are required to augment GNSS usage in Australia and thereby enhance its versatility, value and availability. The two recommended elements were a National Positioning Infrastructure (NPI) and a Space Based Augmentation System.

2.3.1 National Positioning Infrastructure

The NPI concept is based on a relatively dense (50-100 km spacing) network of Continuously Operating Reference Stations (CORS). The GNSS data acquired at the reference stations is sent via high speed internet to one or more Network Control Centres where a series of complex computations are performed and a measurement correction message is created. The correction signal is then transmitted to suitably equipped GNSS users via the internet to achieve real-time positioning accuracies of approximately ±2 cm. The NPI focus is on delivering highly accurate, real-time positioning. Guaranteed levels of availability, robustness of service and solution integrity become secondary considerations when accuracy is the key driver. To achieve consistently high accuracy, the NPI must be based on the measurement of the GNSS carrier signals. This requirement adds significant technical complexity, reduces the robustness of the solution, imposes a significant cost burden on user equipment ($10k+) and demands a very high density of ground stations. Indeed it has been estimated that approximately 2400 stations would be needed to provide a NPI to cover the Australian land mass.

2.3.2 Space Based Augmentation System

The Ground Segment of an SBAS consists of a relatively sparse Ground Reference Station network (approximately 20-30 would be required across Australia) and at least two Master Control Stations (MCS). Via dedicated communications links, the MCS acquires and combines the data from the reference stations and uses it to compute and model signal errors and to verify the integrity of the real-time position solution. Communications with users is based on two or more geostationary (GEO) satellites (the Space Segment) to which the computed signal corrections and integrity message are uploaded and then re-broadcast. The GEO satellites and the dedicated ground communications infrastructure are the distinguishing features of an SBAS, providing the guaranteed levels of availability and system redundancy needed for safety-of-life applications. In contrast to the NPI, the main focus of an SBAS is not positioning accuracy, but rather the availability and reliability of the augmented GNSS signals. The primary requirement is to satisfy the demands of safety-of-life and other mission critical applications. It is for this reason that a satellite communications infrastructure is employed. SBAS systems do not use the GNSS carrier signals, but rather the binary codes to achieve accuracies in the range of ±1-2 m. SBAS capable user receivers are relatively cheap, costing around $300 per unit.

2.3.3 Relationship between NPI, SBAS and existing positioning services

Currently Australia has neither an SBAS nor an NPI. There are parts of the country where free-to-air ±1-2 m DGPS services are available, though generally coverage is limited and
additional hardware is needed to receive the correction signal. Likewise, commercial providers such as Omnistar and Starfire offer national positioning services to customers that have purchased purpose-built receiving technology and pay the relevant subscription fees. However neither the free nor the commercial service providers are able to offer the robustness, reliability and availability of service that is required by civil aviation\(^4\) and other safety-of-life applications. Similarly, none of these services allow users to take advantage of the in-built SBAS capabilities available in most commercial GPS receivers, nor do they offer the advantage to users of enhanced satellite coverage made possible through GPS-like signals transmitted by the GEO satellites.

From an NPI perspective, there are only limited parts of Australia where real-time, ±2 cm accurate positioning is available. The Victorian Government offers a state-wide service, driven largely by the needs of precision agriculture and other machine guidance applications. However, the roll-out of such a network on a national basis brings a number of practical and technical challenges that inevitably mean that a true ±2 cm NPI is likely some years away.

While targeting a different user sector, an SBAS provides an intermediate step toward realising the NPI. The accuracy offered by the SBAS approach is not generally sufficient for applications such as precision agriculture, machine guidance, mining, construction and surveying, however it will enable applications and stimulate advances in many other application domains such as those discussed below. The truly ubiquitous nature of an SBAS and the fact that it can be accessed through existing, low-cost receiver technology, coupled with the high reliability of the service will further promote and encourage adoption, bringing accelerated benefits to many users.

Finally it should be noted, that an NPI will never replace an SBAS nor will the converse occur. Ultimately, as the SIIC has reported, both elements are needed to fully meet the PNT needs of the nation. However, the opportunity to advance SBAS deployment through a hosted payload on the NBN satellites brings the potential for accelerated benefits to many users. Those ultimately seeking NPI capabilities will be able to take advantage of SBAS as an interim step toward their final objective, while those content with a ±1-2 m capability will be able to secure that level of accuracy at an early stage, at no extra added cost from a user equipment perspective, while benefiting from the inherent robustness and integrity of a true SBAS approach.

### 3. Benefits and end users

#### 3.1 Overview

The increased position and navigation performance of GNSS achieved through SBAS, and in particular the resultant integrity and availability enhancements, will bring benefits to a range of applications, particularly those with a safety-of-life or a mission critical focus. The availability of those benefits, at no additional cost to users, will be accelerated by the fact that most GNSS user equipment is already SBAS capable. This inbuilt SBAS capacity results

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\(^4\) Required availability of the positioning service for APV is only 99% but is combined with very high integrity (reliability) and time to alert requirements. Starfire offers 99.999% availability but no information is provided regarding integrity/time to alert capability. The availability for the Omnistar service could not be readily ascertained.
from the fact that most receivers are sold into the US and European markets where SBAS is available through WAAS and EGNOS respectively.

In the following paragraphs, SBAS benefits to some key market sectors are identified and discussed.

3.2 Aviation

3.2.1 Background

The 36th Assembly of ICAO (18-28 September 2007) resolved that Approach Procedure with Vertical Guidance should be implemented as either a primary or backup strategy for precision approaches at all runway ends of all aerodromes serving aircraft having a maximum certificated takeoff weight of 5700kg or more. In Australia, endorsement of the ICAO resolution brings with it the requirement for complete implementation of APV by 2016.

APV is a major safety initiative. ICAO recognises Barometric Vertical Navigation (Baro-VNAV) and SBAS as two acceptable (and often complementary) means of implementing APV. Australia supported ICAO Resolution 36-23 as it addresses some major shortfalls in the terrestrial radionavigation aid infrastructure that supports current aviation operations.

The terrestrial radionavigation aid network provides aircraft with approach to land guidance in adverse weather. Of the 300 aerodromes in Australia that have radionavigation aids, only about 10% have an aid that provides APV. The remainder of instrument approaches are flown without vertical guidance. Such approaches are recognised internationally as being up to eight times less safe than those with APV. Lack of vertical guidance during instrument approach to land operations is a major contributing factor to aviation accidents involving Controlled Flight Into Terrain (CFIT). Such accidents almost always result in 100% fatalities. Recent incidents in Australia, or involving Australians, include the crash at Lockhart River, Queensland in May 2005, resulting in the death of all 15 passengers and a similar incident at Kokoda, PNG in August 2009 which also resulted in the death of all 13 on board.

The Bureau of Infrastructure, Transport and Regional Economics (BITRE) Aviation Statistics Document 158 Australian Domestic Airline Activity 2008-2009 lists the top competitive air routes (city pairs) in the country. Of the top 50 routes, 21 (42%) are flown into aerodromes not serviced by APV. These include the Gold Coast, Mackay, Rockhampton, Maroochydore, Broome, Kalgoorlie, Albury, Ballina, Coffs Harbour, Dubbo, Mildura and Wagga Wagga. Aircraft servicing these routes carried 9.3 million passengers in the 08/09 financial year.

3.2.2 Australia’s Response to ICAO Resolution 36-23

In consideration of ICAO Resolution 36-23, in early 2007, CASA in conjunction with the Department of Infrastructure, Transport, Regional Development and Local Government, and Airservices Australia commissioned Booz and Co to undertake a cost benefit study of APV technology options for Australia. Options considered included aircraft-based, ground-based, and space-based GNSS augmentation systems.

The report concluded that the only way Australia could comply with its responsibilities under ICAO Resolution 36-23 was to implement a dual APV system using both Baro-VNAV and SBAS. The Baro-VNAV system will service the requirements of the major airline carriers,
whose aircraft comprise 15% of the commercial fleet and who carry 97% of Australia’s fare carrying passenger. This is because these aircraft are already equipped with the Baro-VNAV technology. The remaining 85% of the fleet, which carry 3% of the fare paying passengers\textsuperscript{5} cannot be retrofitted with Baro-VNAV technology at a reasonable cost and will therefore be dependent upon an SBAS solution to allow APV. The cost of the Baro-VNAV component has been estimated at AUD\$31.3M and this cost will be borne by the aviation industry. The cost of the SBAS component falls in the range of AUD\$190M - $240M (comprising capital, operating and maintenance costs through to 2025) depending largely on the option selected for the space segment. This cost will not be borne by the aviation industry and must be funded from other sources.

3.2.3 National Aviation Policy White Paper

Since the passing of ICAO Resolution 36-23, Australia has incorporated the implementation of APV into government policy through the National Aviation Policy White Paper, which states that “One of the first tasks for CASA will be to oversee the future implementation of Approach with Vertical Guidance in Australia utilising Baro-VNAV aircraft-based augmentations systems as well as future Satellite-Based Augmentation Systems.”

The White Paper also notes that “A key infrastructure element to further the use of Performance Based Navigation (PBN) and APV is likely to be the availability of an augmentation system, such as SBAS, to improve the performance of a single GNSS constellation...”. The report goes on to note that comprehensive coverage of all passenger transport operations is likely to require the use of SBAS, and that SBAS would be potentially usable by all transport modes and by many other industries. The White Paper notes the potential adoption of SBAS in the 2014-2019 timeframe.

3.2.4 Broader Benefits

The US Federal Aviation Administration (FAA) is working toward the delivery of the NextGen National Airspace System (http://www.faa.gov/nextgen/). NextGen—which is fundamentally a vastly modernised and improved national air traffic control system – will move away from traditional ground based radar navigation aids and be built on new navigation technologies such as the US WAAS (SBAS) system. The NextGen Implementation Plan 2011 (FAA, 2011) thoroughly documents the benefits of adoption:

- **Improved safety** – Substantial safety enhancements will be achieved in all phases of flight including taxiing, take-off, in-flight and landing.
- **Reduced environmental impacts** – Reduced aircraft noise (particularly during landing), reduced CO\textsubscript{2} and other greenhouse gas emissions and reduced fuel usage. Current FAA estimates indicate that by 2018, CO\textsubscript{2} emissions will be reduced by 14M\textsuperscript{6} tons and fuel usage will decrease by 1.4B\textsuperscript{7} gallons.
- **Increased system capacity** – Significant increases in air traffic volumes are predicted over the next decade. Current air traffic control systems and procedures cannot accommodate

\textsuperscript{5} Whilst only carrying 3% of passengers these light, twin engine aircraft are typically servicing remote and regional areas and the loss of such aircraft in accidents such as Lockhart River and Kokoda generally leads to multiple fatalities, a costly search and rescue effort and a time consuming and expensive investigation into the cause of the incident.

\textsuperscript{6} 14M tons = 14M tonne

\textsuperscript{7} 1.4B gallons = 5.3B litres
these increases. NextGen will easily accommodate the predicted growth in air traffic volumes while at the same time reducing delays for both in-bound and out-bound passengers.

While many of these benefits require more than an SBAS to be fully realised – they depend on an updated air traffic control system – SBAS technology is essential to safer, more efficient air travel with a smaller environmental impact.

3.3 Marine

The Australian Maritime Safety Authority (AMSA) is responsible for the management of the Commonwealth marine aids to navigation network, which includes a Differential Global Positioning System (DGPS) Service, primarily serving as a navigation aid for commercial shipping. The AMSA DGPS Service comprises a network of radio beacons that improve the accuracy and integrity of GPS around selected areas of the Australian coast. These areas include the Great Barrier Reef and Torres Strait, Bass Strait, the south-eastern ports and selected port regions such as Perth, Brisbane, Darwin, Sydney (including Newcastle and Port Kembla) and Karratha. AMSA's DGPS network was completed in 2002 and consists of 16 stations that broadcast GPS corrections by radio to give a coverage of approximately 150 nautical miles out to sea from each station. AMSA's DGPS service also monitors the integrity of the GPS signals and notifies users to disregard any signals found to be outside specification.

An Australian SBAS could potentially supersede AMSA’s DGPS service by offering superior service and higher levels of availability, coverage, reliability and integrity in addition to eliminating the need for users to purchase and use a separate DGPS receiving beacon. However, even if there are good reasons for the AMSA system to continue operation into the future, an SBAS would offer the benefit of added redundancy and coverage in maritime areas not currently serviced by the AMSA system.

3.4 Road

The benefits that SBAS brings to the aviation and maritime sectors also apply in land transport. For example, SBAS emerges as an enabler of concepts such as Intelligent Transport Systems (ITS) and Automatic Vehicle Location (AVL). The Australian Transport Council (ATC) has endorsed a program through Austroads whereby heavy vehicle compliance is monitored via the tracking and reporting of vehicle location. The idea is to provide a third generation of access to the road network, by complementing General Access (first generation) and Restricted Access (second generation) with Intelligent Access. The Intelligent Access Program (IAP) is being progressed via a staged implementation. Currently IAP is a voluntary system that monitors freight vehicles remotely using satellite-based telematic services to ensure they are complying with their agreed conditions of operation, that is, that they operate how, where and when they should. Given the possible safety-of-life and legal compliance implications of the IAP and similar systems, the accuracy and, more importantly, the integrity levels offered by SBAS become very relevant and attractive.

3.5 Other

One of the significant benefits of SBAS is that many commercial grade GNSS receivers – even low cost/low end units – come with an inbuilt SBAS capability, without the need for
additional hardware. Such units are in widespread use both commercially and privately. However, the inherent SBAS capability of these receivers cannot be taken advantage of in Australia (in contrast to Europe and the USA) because of the absence of SBAS coverage. By providing an Australian SBAS, a large number of GNSS users would instantaneously – and at no additional cost – receive the benefits of improved accuracy (from ±10 m to ±2 m or better) as well as the enhanced reliability and availability achievable as compared to other DGPS options. Admittedly, many such users do not need the added benefits that SBAS brings, but nonetheless, a significant proportion of existing users would reap measurable benefits.

One sector where such benefits can be predicted is the emergency services sector. Many emergency services vehicles currently carry GPS receivers. In the wake of the Black Saturday bushfires in Victoria and the recent recommendations of the Bushfires Royal Commission, it is likely that such technology will soon become mandatory on all fire fighting appliances. If, in this process, SBAS capable receivers are installed and Australia builds its own SBAS, the benefits of improved accuracy and availability as well as enhanced coverage in forested and steep terrain from the simultaneous use of high elevation, geostationary satellites, can be secured at no additional cost. Similar arguments can be conveyed for other emergency service agencies such as police, ambulance and State Emergency Services (SES). The APV capabilities and enhanced positional accuracy enabled through an Australian SBAS would also be available to emergency services aircraft, yielding more efficient and effective operation as well as considerable safety gains.

Benefits of an Australian SBAS would also flow to those users whose primary concern is to improve the reliability (rather than the positional accuracy) of their PNT application. The extra levels of integrity offered by an SBAS would be of particular interest where there are safety-of-life or other mission critical issues involved. Such applications might include systems carried by personnel in law enforcement and emergency services, in specialised applications such a "man-down" systems used by remote workers and by compliance officers gathering evidence of potentially illegal activities. One example is the case of compliance officers investigating illegal tree clearing under the Queensland Vegetation Management Act.

It is important to note that users who might benefit from an Australian SBAS are spread across many sectors and are not necessarily easily assembled or categorised, making it difficult to identify and quantify the resultant economic benefits.
4. Payload specifications

Adding a hosted SBAS payload to the NBN satellites would require both an onboard uplink and a L1/L5 downlink capability. The following table details the likely technical specifications for the proposed SBAS payload.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink bandwidth (Ku/C band)</td>
<td>20 MHz each</td>
</tr>
<tr>
<td>Downlink bandwidth (L1 &amp; L5)</td>
<td>20 MHz each</td>
</tr>
<tr>
<td>EIRP</td>
<td>31.5-33.5 dBW</td>
</tr>
<tr>
<td>Coverage</td>
<td>Global</td>
</tr>
<tr>
<td>Mass</td>
<td>38 kg</td>
</tr>
<tr>
<td>DC consumption</td>
<td>220 W</td>
</tr>
<tr>
<td>L1 &amp; L5 antenna dimensions</td>
<td>620 mm * 850 mm</td>
</tr>
</tbody>
</table>

5. Implementation strategy

While the costs and benefits of an Australian SBAS in support of the aviation industry have been thoroughly investigated and reported in the previously cited Booz and Co report, the applications of SBAS in sectors beyond aviation are less well documented and demonstrated. To justify the cost of building an Australian SBAS, a feasibility study and associated cost-benefit analysis for SBAS usage beyond aviation is recommended. Indeed, such an approach has been adopted in countries such as Russia, Brazil and Argentina and more broadly across Eastern Europe. The feasibility study would provide a low-cost, low-risk approach to assessing the broader (non-aviation) applications of SBAS through the provision of a SBAS trial signal. The trial signal would replicate an SBAS signal and enable users to incorporate SBAS signals into their operational use of GNSS. The generation and broadcast of an SBAS correction signal would be carried out over a 2 year period at an approximate cost of USD$2.5M. Technical details for the study, presented under the title “Australian Regional Augmentation System” (ARAS) are contained in Appendix A.

The feasibility study would utilise existing ground reference stations, such as those operated by Geoscience Australia, the public internet for the collection of the reference station data and a mock MCS using off-the-shelf software such as magicSBAS. Transmission of signal corrections and integrity data to users would be via an Inmarsat GEO satellite located over the Pacific Ocean. While not adequate for operational purposes, in terms of coverage, availability and robustness, and certainly not meeting the stringent accuracy, availability and integrity levels required for aviation or other safety-of-life applications, the trial signal would appear to users to be a genuine SBAS solution. The advantages, applications and limitations of the service to non-aviation users could thereby be thoroughly explored and evaluated, allowing a cost benefit analysis for the broad application of SBAS to be carried out.

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8 Technical specifications provided by Thales Australia (personal communication).
9 It should be noted that such a trial would also be of benefit to aviation users as it would enable trial procedure design, pilot training, development of operational rules and regulations and also the development of signal correction algorithms tailored to Australian ionosphere conditions.
An important outcome of the feasibility and cost benefit studies would be a proposal for funding the construction and on-going operation of the ground reference stations and network control centres required for full implementation of an SBAS. The Booz and Co report estimated that these additional components would cost in the order of AUD$160-210M dependent upon the SBAS solution selected.

6. Budget

As indicated above, the cost of the SBAS payload has been estimated at approximately USD$30M. The cost of the feasibility study is estimated at USD$2.5M. The GRS and MCS components of the SBAS system add to the overall cost, being estimated at a further AUD$160-210M.

7. Recommendations

(i) Undertake the proposed feasibility and cost benefit study to identify and quantify the benefits to non-aviation users of an Australian SBAS (estimated cost USD$2.5M).

(ii) Based on the findings of the feasibility study, invest in a hosted SBAS payload for the NBN (estimated cost USD$30M).

8. Conclusion

As Australia anticipates an AUD$43B investment in a National Broadband Network, the prospect of leveraging that investment to bring added PNT capabilities looms large. The space segment of an Australian SBAS could be carried as additional payload on the planned NBN satellites at a modest additional cost of $USD30M.

An SBAS is essential if Australia is to meet her commitment to implement Approach Procedures with Vertical Guidance under ICAO Resolution 36-23. Otherwise up to 85% of Australia’s aircraft fleet will be left without an APV capability. The environmental, economic and safety implications resulting from full APV implementation are persuasive. These however cannot be fully realised without an Australian SBAS.

The prospect for broader benefits from SBAS add further weight to the argument. Beyond aviation, applications in the maritime and road transport sectors will lead to improved efficiencies, productivity and economic gains. But applications where safety-of-life is paramount such as in support of emergency services, along with other mission critical applications emerge as those that will gain the most from an SBAS for Australia.
9. Consultation

In addition to the input from the authors, the following individuals and organisations have been consulted during the preparation of this report.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ian Mallett</td>
<td>Civil Aviation Safety Authority</td>
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<tr>
<td>Andrew Dempster</td>
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<td>Jill Edwards</td>
<td>Australasian Fire and Emergency Services Authorities Council</td>
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<tr>
<td>Jack Scott</td>
<td>Thales</td>
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<tr>
<td>Juan Ramón and Martin Piedelobo</td>
<td>GMV</td>
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<td>Rob Lorimer</td>
<td>Position One Consulting</td>
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<tr>
<td>Peter Woodgate</td>
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</tr>
<tr>
<td>Michael Green and Michelle Clement</td>
<td>Space Policy Unit</td>
</tr>
<tr>
<td>Various</td>
<td>Australian Spatial Consortium</td>
</tr>
</tbody>
</table>

10. References


ENOSS Cost Benefit Analysis in Aviation


Satellite Based Augmentation Systems (SBAS) Combined Performance, International Committee on GNSS (ICG-4), Working Group A, St Petersburg, Russia, 15 September 2009, Frederic Bastide and Ken Alexander


Annex 10 to the Convention on International Civil Aviation, Volume I

High Precision Market Overview, Galileo Application Days, 3-5 March 2010, Brussels, European GNSS Supervisory Authority, Carmen Aguilera
Appendix A – Australian Regional Augmentation System Proposal
OUTLINE PROPOSAL

ARAS

Australian Region Augmentation System
CONTENTS

1. Motivation
2. Architecture
3. Uplink Sites Possibilities
4. Technical Specifications
5. WBS
6. Industrial Organization
7. Service Level Agreement and Warranty
8. Assumptions of the Proposal
9. CFIs
10. Time frame
11. Financial Proposal
MOTIVATION

The objective is to deploy a fast, inexpensive and scalable Open Service SBAS for the region of Australia.

SBAS messages would be generated by the GMV’s product *magicSBAS* and broadcast through Inmarsat 4F1 GEO at 143.5ºE (APAC).

The SBAS Open Service would augment GPS (also GLONASS if desired) providing MOPS compliant signal-in-space with ionospheric, clock and orbit corrections and illustrative integrity.

For getting raw data, Australian and IGS real-time sensor stations will be processed (the deployment of some additional stations is also feasible but considered not to be needed at the moment).

Once the SBAS test signal will be in place, flight trials and other demonstrations can take place to prove the benefits of SBAS systems.

The current proposal can be tailored to involve local organizations.
ARAS ARCHITECTURE

- NTRIP real time stations (already deployed and available)
- Optional dedicated reference stations
- Commercial internet communication lines
- **magicSBAS** Real Time Processing (state-of-the-art algorithms)
- **magicSBAS** Monitoring tools (**eclayr** and **magicGEMINI** included)
- Reused up-link center
- GEO SBAS broadcast & Internet broadcast
- Possibility of flight procedures validation

Some of the available NTRIP stations
UPLINK SITES POSSIBILITIES

- Possible Uplink Sites:
  - Auckland (New Zealand)
  - Batam (Indonesia)
  - Paumalu (Hawaii)
  - Perth (Australia)
  - Subic Bay (Philippines)

- Summarizing technically the different Uplink sites possibilities:
  - **Auckland** and **Subic Bay** presents the best features to host the ARAS uplink station
  - Perth requires some significant CaPex investment to upgrade the site (HPA and L-Band antenna)
  - Batam C-band antenna is smaller than minimum required size and it might be re-pointed to the Garuda satellite in case of emergency
  - Paumalu is well equipped for hosting ARAS uplink station (it already hosts a WAAS GUST); however, a 1.8m L-band antenna would need to be procured and hosting services are more expensive than in other sites
TECH SPECS (I)

- Input data
  - NTRIP L1C/L2 GPS and GLONASS (optional) 1Hz data
  - RINEX

- Output format
  - SBAS Open-Service message
    - RTCA SBAS (MT27), with MT0 to notify “test mode”, TTA ~ 10 seconds
  - RTCM DGPS
  - SISNET (Signal In Space through Internet)
  - Reports/figures on performances - provided by different tools

- Output channels
  - GEO SBAS Broadcast
  - Internet Broadcast

- Operation modes
  - Real time
  - Post-processing fast replay (optional)
TECH SPECS (II)

- Configuration capabilities
  - GPS, GPS+GLONASS
  - Service area
  - Reference stations

- GEO SBAS Broadcast
  - Satellite Inmarsat 4F1, PRN 130
  - EIRP @ L1: 28.1 dBW (EoC). L1 Bandwidth: 4.0 MHz. CCC not assured.
  - SBAS Signal used for data-only services (not GEO Ranging) as in Inmarsat 4F3 GEO satellite used by FAA

- Internet Broadcast
  - SISNET Format
  - Compatible with Rx (Septentrio/GMV’s I10) and processing SW (ESA UAS)

- Performance
  - Depending on the network of reference stations.
  - Target: Open Service LPV 200 available 99% of time in Australian continent.
  - See next slide with example.
Example of APV-I availability with real data (real performance)
WORK BREAKDOWN STRUCTURE

Organizations

GMV
INM: Inmarsat
CUS: Customer (TBC)

2000-GMV
System Engineering

2100-GMV
System Architecture and Performance

2200-GMV
Processing Engineering

2300-INM
GEO Broadcast Engineering

3000-GMV
Procurement, Integration Validation and Installation

3100-GMV
Processing Facilities & Analyses Tools Procurement, Integration and Validation

3200-INM
GEO Broadcast Facilities Procurement, Integration and Validation

3300-GMV
System Integration, Validation and Installation

3400-CUS
Station Networks Access Agreements

4000-INM
Operation & Maintenance

4100-INM
Processing Facilities Hosting, Operation and Maintenance

4200-INM
GEO Broadcast Facilities Operation and Maintenance

4300-GMV
Support and Maintenance to Operation, Reconfiguration and SW upgrades

5000-CUS
Exploitation

5100-CUS
Exploitation Plan and Execution

5200-GMV
Support to Exploitation

5300-GMV
Support to Roadmap for Safety of Life Service
INDUSTRIAL ORGANIZATION

- Tailoring of the industrial organization
  - Proposed an organization involving the customer at a given extent for Exploitation activities and to optimize governance of the programme (e.g., agreements with NTRIP regional networks).
  - Possible to involve local organizations on demand.
  - Possible to readjust the role of the customer on demand.

- Organizations and roles
  - **GMV**: System engineering, processing facility provider, performance analysis tools provider, performance consultancy, support to processing facilities operation, roadmap consultancy.
  - **INMARSAT**: GEO payload provider, GEO uplink facilities provider, GEO payload operations, GEO uplink facilities operations and maintenance, processing facility hosting and operation (including communication lines to internet).
  - **Customer**: agreements with regional organization to access the NTRIP data during the project lifetime, definition and execution of the exploitation plan.
SERVICE LEVEL AGREEMENT & WARRANTY

- **Service Level Agreement (SLA)**
  - Baseline proposal
    - Use of existing Inmarsat Navigation Transponder Test Equipment (NTTE) for ARAS signal generation and reception at GEO Uplink Site.
    - Maximum reuse of existing RFS systems and no spare parts for NTTE and RFS procured.
    - GEO uplink operations and 1st level maintenance during local working hours only. No 2nd level maintenance provided for NTTE and RFS.
    - No monitoring of NTTE/RFS or SIS
    - Service restoration time provided on a best-effort basis.
    - ARAS CPF to be installed at the selected GEO uplink sites.
  - High Quality SLA possible with additional procurement of spare equipment and 24/7 O&M.

- **Warranty**
  - Warranty of procured equipment during the whole project life.
  - GEO satellite and navigation payload not covered by warranty: solution depending on the availability of GEOs covering the region.
ASSUMPTIONS OF THE PROPOSAL

Inmarsat standard Terms & Conditions (T&Cs) for GEO transponder lease and GEO uplink site apply (also to GMV due its role as Prime). In particular:

- The overall liability for the Contractor will be limited;
- The Contractor will be indemnified for any third party claims (e.g. for non-availability due to satellite failure);
- The Contractor will have the right to reposition the satellite (without penalty);
- In case of loss or damage to the satellite and/or damage to the hosting site(s) and/or equipment at such hosting site(s) which introduces long-term or permanent non-availability of the service then both parties shall have rights to terminate the agreement.
- The Contractor will have the right to pre-empt the service at any time.
- In any case, upon long-term or permanent non-availability of the service, a pro-rata reimbursement of the paid charges will be applied.

A copy of Inmarsat standard T&Cs can be provided upon request.

Prices in this proposal are exclusive of any Third Party Liability insurance. In addition, the Contractor has assumed that it will not be responsible for insurance (equipment or service) during the operational service.
CFIs

- The proposal assumes the following Customer Furnished Items
  - Agreements with NTRIP regional networks for the access to the NTRIP data during the project life (see Appendix)
    - IGS
    - Geoscience Australia
    - Geonet New Zealand
    - Other

- CFIs can be undertaken by the Contractor
  - The contractor may be in charge of those CFIs tasks in case the customer prefers this approach.
PROPOSED TIMEFRAME

- **T0: Start**
- **System Acceptance (AR): T0 + 4 months**
  - Completion of “WP-2000 System Engineering”
  - Completion of “WP-3000 Procurement and Deployment”
  - Provision of real-time SBAS message through Inmarsat GEO
  - Provision of real-time SBAS message in Internet

- **Two years of Operation**
  - WP-4000 Operation
  - WP-5000 Exploitation
FINANCIAL PROPOSAL

- Provided in the Cover letter (separate document) of this Technical Proposal
magicSBAS SUITE

- SBAS algorithms and analyses tools for real-time SBAS test signal (Open Service) and fast-replay SBAS analyses (real or simulated data)

- **EETES**
  Synthetic GNSS Raw Data Generator

- **Real Data**
  GNSS Real Data
  From Deployed Stations

- **magicSBAS**
  State-of-the-art SBAS
  - also GLONASS -
    (used in Europe, South-America, Russia)

- **eclayr**
  System Level Perform.
  (Unique tool used in Europe to measure EGNOS performances)

- **magicGEMINI**
  User Level Perform.
  (used in Europe, South-America, Russia)

- **Service Volume** to evaluate the possibility of different configurations for the SBAS system (extension to other regions, less stations, etc)

- **Polaris**
  Service Volume Simulator

- **Flight procedures validation** during flight trials → ISAGNSS
FURTHER DETAILS ON magicSBAS SUITE

- **magicSBAS algorithms:**
  
  i. **SBAS state-of-the-art algorithms**, already working in EGNOS and improved for high-demanding ionosphere regions (tested for South-America in ICAO SACCSA project where GMV is priming the SBAS feasibility analyses in the region).

  ii. **Multi-constellation capability** by introducing GLONASS augmentation and integrity thanks to GMV collaboration in SDCM (Russian SBAS) where GMV is providing **magicSBAS** for evaluation of state-of-the-art performances in Russian Federation (with GLONASS).

- **magicSBAS Monitoring tools and others:**
  
  i. **System level performance analyses** with the tool used by ESSP (EGNOS Service Provider) for the evaluation of EGNOS performances: GMV’s **eclayr**.

  ii. **User level performance analyses** with one of the tools used by ESSP/ESA for the evaluation of EGNOS performances: GMV’s **magicGEMINI**.

  iii. **Flight Procedures Operational Validation** for SBAS and GBAS procedures with the tools used by EC/Eurocontrol/AENA: GMV’s **ISAGNSS** (optional).

  iv. **Service Volume simulator** to evaluate the possibility of different configurations for the SBAS system (extension to other regions, less stations, etc) with one of the tools used in EGNOS: GMV’s **polaris** (optional).

  v. **Raw Data Generator** to simulate different Feared Events (e.g., SV failure) to which the SBAS system should be robust against: GMV’s **EETES** (optional).
COVERAGE FOR 4F1 INMARSAT GEO
REAL-TIME GNSS DATA AVAILABLE OVER AUSTRALIA (NTRIP FORMAT)

Stations from Geoscience AUSTRALIA – left – and IGS – right - casters (freely available)

Stations from SYDNET LANDS – left- and CGPS-GEONET_NZ – right- casters (up to 3 and 4 stations freely available respectively; rest upon fee payment)
## magicSBAS IN SHORT

### IN SHORT

| Input Formats       | NTRIP (RTCM through Internet)  
|                    | RINEX                        
|                    | EGNOS format                 |
| Output Formats      | RTCA DO-229D SBAS / ICAO SARPs for SBAS  
|                    | RTMC SC-104 v2.3 DGPS        
|                    | SISNET (Signal In Space through Internet) |
| Operating Modes    | Real-time                    
|                    | Post-processing fast replay  |
| Configuration Capabilities | Constellation: GPS, GPS+GLONASS  
|                        | Service areas                
|                        | Reference stations           
|                        | Many others                  |
| Key Algorithms      | Precise Orbit                
|                    | and Time synchronisation     
|                    | Ionosphere determination      
|                    | SBAS Integrity computation   |
| Website             | http://www.gmv.com/magicsbas/magicsbas.html |
| Real-time performances | http://magicgnss.gmv.com/sbas |
## CURRENT USE

<table>
<thead>
<tr>
<th>Region</th>
<th>Customer</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>European Space Agency - ESA</td>
<td>EGNOS programme for performance evaluation and troubleshooting</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>Russian Space Systems - RSS</td>
<td>Feasibility and performance analysis of a GLONASS-based SBAS in the Russian Federation</td>
</tr>
<tr>
<td>Central, Caribbean and South America</td>
<td>International Civil Aviation Organization - ICAO</td>
<td>Feasibility analysis of a SBAS system in Central, Caribbean and South America</td>
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<tr>
<td>Eastern Europe</td>
<td>European GNSS Supervisory Authority - GSA</td>
<td>Feasibility of EGNOS extension to Eastern Europe</td>
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<tr>
<td>Brazil and Argentina</td>
<td>European Commission - EC</td>
<td>SBAS real-time prototype in Brazil and Argentina for demonstration purposes</td>
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<tr>
<td>Europe</td>
<td>European Space Agency - ESA</td>
<td>EGNOS extension to GLONASS and multi-constellation benefits for SBAS</td>
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<tr>
<td>Spain</td>
<td>Spanish Air traffic control service provider - AENA</td>
<td>EGNOS service area and performance improvement over Spain</td>
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</tbody>
</table>
Thanks!

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