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AMSA's Differential Global Positioning System (DGPS) Network and the Quest for Resilient PNT Services

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ABSTRACT

The Australian Maritime Safety Authority (AMSA) operates a Differential Global Positioning System (DGPS) network, which consists of 16 stations. They are located strategically around Australia's coastline, based on the volume of shipping traffic and degree of risk. Areas covered include major ports and their approaches, the Great Barrier Reef, Torres Strait and Bass Strait. The network aims to improve the accuracy and integrity of the mariner's GPS data. This paper describes how the system meets international maritime performance requirements. The United States is proposing to decommission 62 of their DGPS sites, leaving 22 operational sites available for maritime users. The decision to reduce the number of DGPS sites is based on a number of factors including increased use of the Wide Area Augmentation System (WAAS), the removal of GPS Selective Availability, no mandatory carriage requirement for DGPS receivers, increasing availability of other Global Navigation Satellite Systems (GNSS) and the continued modernisation of GPS. This paper discusses these factors in the Australian context. AMSA's future plans for its DGPS infrastructure are outlined, as are the results of a recent user survey of AMSA's DGPS network. This paper also discusses the importance the International Maritime Organization-led concept of e-Navigation attaches to resilient Positioning, Navigation and Timing (PNT), and the emergence of alternative technologies and innovative solutions (e.g. DGPS in the R mode) in the quest for resilient PNT.

KEYWORDS: *AMSA, DGPS, GNSS, PNT.*

1 INTRODUCTION

This paper discusses the Australian Maritime Safety Authority's (AMSA's) network of Differential Global Positioning System (DGPS) radio beacons, which provides mariners with increased GPS positional accuracy and signal integrity data. While DGPS is intended for the maritime industry, other sectors also enjoy the benefits provided from these signal augmentations.

This paper also outlines the reasons for the United States Coast Guard's (USCG) proposed decommissioning of 62 of their Nationwide Differential GPS (NDGPS) sites. Finally, this paper discusses the International Maritime Organization's concept of e-Navigation and its quest for resilient Positioning, Navigation and Timing (PNT) services for mariners.

2 AUSTRALIAN MARITIME SAFETY AUTHORITY

AMSA is responsible for ship and seafarer safety, provision of marine and aviation search and rescue services, and the protection of the marine environment. AMSA is a self-funded Commonwealth authority that generates its revenue through the application of levies on commercial shipping.

The principal functions of AMSA are to promote maritime safety and protect the marine environment, prevent and combat ship-sourced pollution, provide a national search and rescue service and provide infrastructure to support safe navigation within Australian waters. A part of AMSA's role in supporting safe navigation and providing adequate navigational infrastructure is the provision of the Australian DGPS network.

3 AMSA'S DGPS NETWORK

AMSA's DGPS network provides increased positional accuracy and signal integrity data to vessels navigating off Australia's coastline. 16 broadcast stations are located around the coast of Australia, based on the volume of traffic and degree of navigational risk (Figure 1). DGPS signal coverage includes the Great Barrier Reef, Torres Strait and Bass Strait. Each broadcast station provides signal augmentation coverage out to approximately 150 nautical miles (277 km) from the coast.

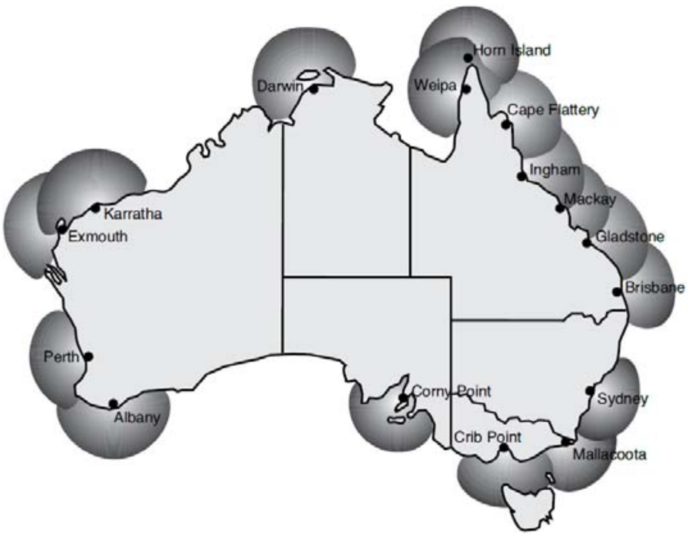

Figure 1: AMSA's DGPS network.

A DGPS transmitter is located with a reference station and integrity monitor, whose location is known precisely. The station compares its known position with the position it derives using pseudo ranges calculated from GPS satellite signals and corrected for atmospheric errors. Corrections to the pseudo ranges are determined and transmitted as 'differential' corrections to vessels fitted with DGPS receivers. DGPS also provides integrity monitoring of the constellation by analysing GPS signals for data that falls outside of specification and notifies users to disregard that satellite's information.

For the maritime environment, typical results achieved by DGPS are a horizontal accuracy of better than 10 metres and a 10 second time to alarm for a failure in the system and its presentation on the bridge of a ship. These accuracies and alarm limits meet the International

Maritime Organization (IMO) requirements for ocean, coastal, port approach and inland waterways transit (IMO, 2001).

4 UNITED STATES COAST GUARD'S NDGPS SERVICE

The United States Coast Guard (USCG) has operated a National DGPS (NDGPS) service since 1999 (Figure 2). This nationwide network has allowed GPS corrections to be broadcast from 84 sites around the continental United States, Alaska, Hawaii and Puerto Rico (USCG, 2016). The USCG NDGPS service provides increased positional accuracy and GPS integrity monitoring to allow for the navigation of vessels undertaking the Harbour and Harbour Approach (HHA) phase of their voyage (IMO, 2001). The USCG assessed that there had been a decline in the use of the NDGPS service, necessitating a review to identify end users and service aims.

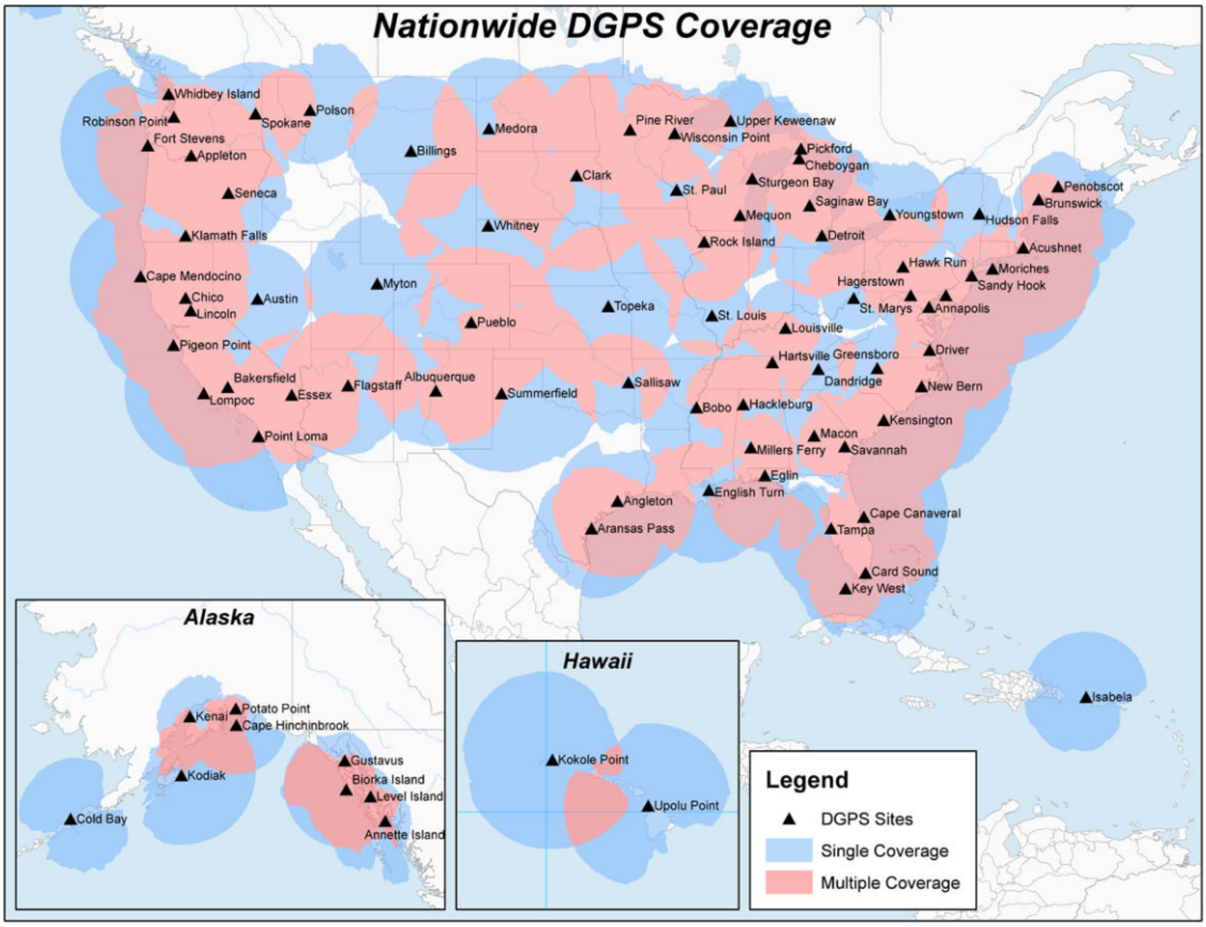

Figure 2: Current NDGPS coverage (USCG, 2016).

4.1 The declining Use of NDGPS

In 2013, the U.S. Department of Homeland Security and the USCG requested public comment on the discontinuation of the NDGPS service. A separate evaluation of the U.S. Government use of and need for NDGPS was also being undertaken. The public request for comment received limited feedback with the majority of responses coming from the maritime sector, primarily marine pilots.

Marine pilots indicated their use of the service for precision ship-handling. Based on this feedback, it was assessed that there were insufficient users to justify the broadcast of corrections inland. As well as the limited response, the Department of Homeland Security and Coast Guard identified a variety of other factors that have contributed to the declining use of the NDGPS service (van Dyke, 2013).

4.2 Lack of USCG Requirements

The USCG amended its internal policy to allow aids to navigation (AtoN) to have their location determined with a GPS unit fitted with and using Receiver Autonomous Integrity Monitoring (RAIM), instead of ordinary GPS receivers augmented by NDGPS signals. RAIM is a method of monitoring the integrity of GPS, which is able to detect failures of individual satellites. RAIM software is incorporated into commercial GPS receivers and compares the time and position data from six or more satellites to determine incorrect information and exclude such data from the positional solution (CASA, 2006).

AMSA, as the provider of AtoN for levy-paying commercial shipping in Australian waters, has not adopted a similar policy to use RAIM as the primary method to measure the location of navigational buoys. The current cost of RAIM receivers makes the adoption of this technology prohibitively expensive.

4.3 Increased Use of WAAS

The introduction of the Federal Aviation Administration's (FAA's) Wide Area Augmentation System (WAAS) has led to a decline in users of NDGPS. WAAS is a Space Based Augmentation System (SBAS) that was developed as an aid to navigation for commercial aircraft operating within the United States' national airspace (FAA, 2016).

WAAS works by receiving and analysing signals from the GPS constellation at numerous land-based reference stations. These reference stations are precisely surveyed and errors in position and time obtained from the satellites can be measured. The information is forwarded to the WAAS master station that generates augmentation messages and provides this data to the geostationary WAAS satellites via an uplink. Finally, the corrections are broadcast from the WAAS satellites on a similar frequency used for the GPS L1 signal (Department of Transportation and FAA, 2008). This process is illustrated in Figure 3.

While WAAS was primarily designed and implemented for the aviation industry, it is now used by other sectors including surveying, construction and major utility companies. WAAS is assessed to be the most widely used GPS augmentation system in non-aviation sectors within the U.S. Indeed, it is now difficult to find new GPS devices that are not WAAS enabled (Gakstatter, 2015).

The Australian / New Zealand region is the only region that does not currently have an SBAS such as WAAS. The Japan Aerospace Exploration Agency has begun launching satellites as part of its Quasi-Zenith Satellite System (QZSS). The final constellation will comprise seven satellites (by 2023) that will be compatible with GPS signals (Office of National Space Policy, 2016). As the constellation continues to grow, the intended orbit design may allow for countries such as Australia to potentially benefit from the use of this new SBAS (Figure 4).

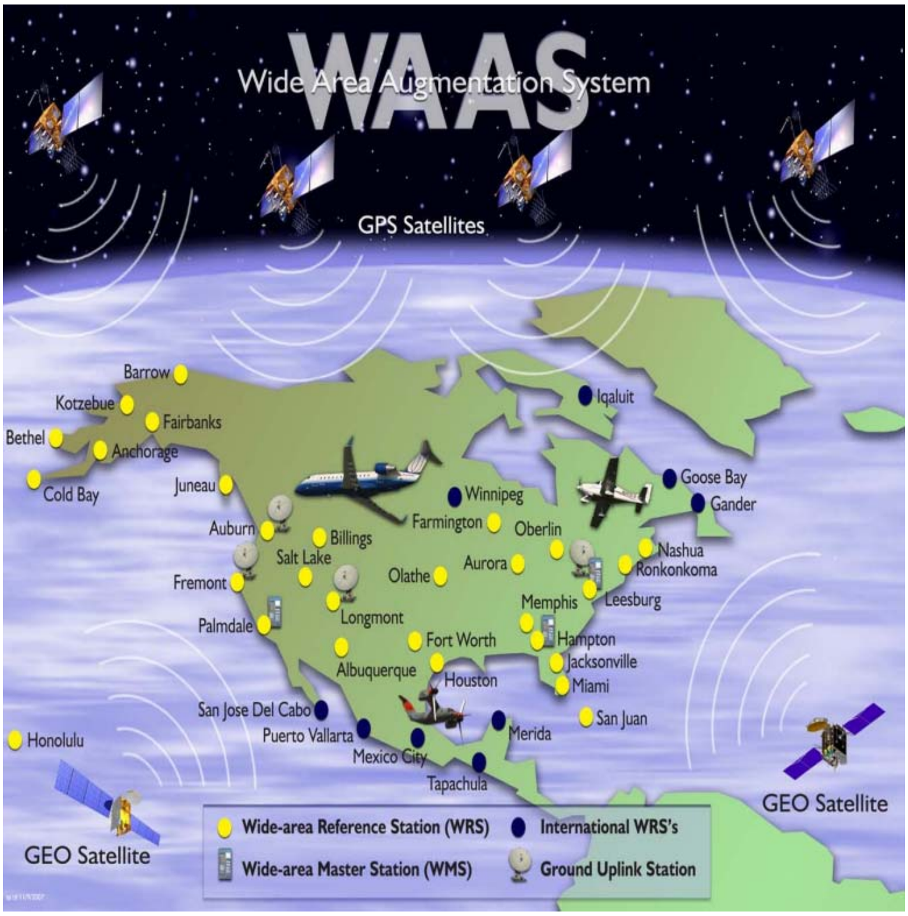

Figure 3: WAAS architecture and operational environment (Department of Transportation and FAA, 2008).

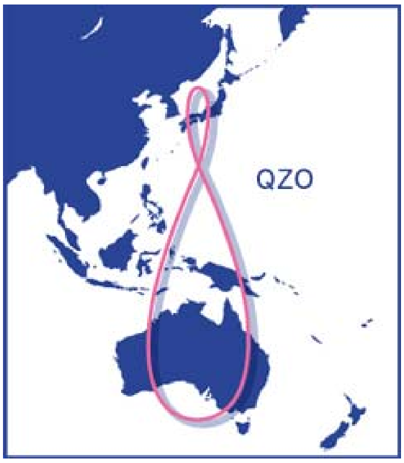

Figure 4: QZSS orbit (Office of National Space Policy, 2016).

4.4 Carriage Requirements and Availability of Receivers

The United States has no legislation that makes the carriage of DGPS receivers mandatory for vessels operating in their waters. There is also no IMO requirement that stipulates the mandatory carriage of a DGPS receiver on board ships. Similarly, Australia has no legislation that makes the carriage of DGPS receivers compulsory on board ships operating within Australian waters. AMSA conducted a DGPS survey in 2014, with results indicating that over 70% of vessels who submitted responses carried two or more DGPS receivers.

4.5 Discontinuation of GPS SA

In May 2000, then U.S. President Bill Clinton announced that the United States would stop the intentional degradation, known as Selective Availability (SA), of civilian GPS signals. The decision to discontinue SA was part of the United States' intent to eliminate a source of global uncertainty of GPS's potential performance (Clinton, 2000). The discontinuation of SA increased the unaugmented positional accuracy from about 100 m to better than 20 m. Multiple sectors and industries derived new benefits from this increase in positional and timing accuracy (Department of Commerce, 2000). As of 2008, the GPS performance standard now states an unaided GPS standard positioning service accuracy of better than 13 m (Department of Defense, 2008).

The NDGPS was designed to correct the intentionally degraded GPS signal to provide better accuracy and integrity data to civilian users. At the time of removal of SA, the United States retained the right to degrade GPS, if required by the National Command Authorities. New satellites that are being procured and launched to replace the existing constellation have had the capability to invoke SA removed. This change will affect the future GPS Block III satellites and is part of the United States' commitment to users that this global activity can be counted on to support peaceful civil activities (The White House, 2007).

4.6 GPS Modernisation

The removal of SA was the first step in the GPS modernisation program. Future steps include the upgrade of the space and control segments and the introduction of new signals for both civilian and military use. The GPS constellation will be modernised with the launch of new satellites from 2017 onwards. These new satellites will deliver four new civilian signals to improve accuracy and signal strength, meet safety-of-life requirements for aviation and improve signal reception in cities and other areas considered to be a challenging reception environment. The availability of these signals across the entire GPS constellation is expected to occur by the late 2020s (National Coordination Office for Space-Based Positioning, Navigation and Timing, 2016).

4.7 Positive Train Control

Positive Train Control (PTC) is an integrated system for the command and control of communications with, and information on, train movements. The system is designed to increase safety, security and efficiency and is being implemented across the U.S. with the passing of the Rail Safety Improvement Act. The system aims to prevent train collisions and prevent derailments through the use of physical rail sensors and a complex UHF radio network to determine a train's position and speed. To implement PTC the Department of Transportation determined that NDGPS was not a requirement for the system (FRA, 2016).

Australia is developing a similar system, i.e. the Advanced Train Management System (ATMS). The aim of ATMS is to increase freight capacity, train safety and reliability across the national rail network. The system will use GPS for location determination rather than a dedicated UHF radio network. The benefits in the use of GPS are that it reduces the initial and ongoing costs of sustaining trackside infrastructure. It is currently unknown if DGPS, when within range, will be used to augment the location determination of the system (Department of Infrastructure and Regional Development, 2015).

4.8 Proposed DGPS Site Decommissioning

Comments called for in the U.S. Federal Register, the daily journal of the United States Government, advised that the Coast Guard proposed to shut down 62 DGPS sites, leaving only 22 sites still operational within the network. Comments on the proposed NDGPS decommissioning closed in November 2015. The Department of Homeland Security and the Coast Guard are now assessing the responses to their proposal. The intended date of decommissioning of sites is 15 January 2016. The remaining sites represent the assessed regions that are critical for the provision of augmentations and will service predominantly coastal waterways where marine pilots operate, commercial shipping is the heaviest, and the need for a more precise position is the greatest (USCG, 2015).

Australia's DGPS network was, and still is, operated for the primary benefit of levy-paying commercial ships. The difference between the current United States' network and Australia's is that a large proportion of the U.S. service is devoted to the provision of coverage to inland areas. With the NDGPS review and potential decommissioning, the sites that are proposed to remain in the United States are similar to Australia's, as they provide improved accuracy and integrity monitoring in critical areas of the nation's coastline (Figure 5).

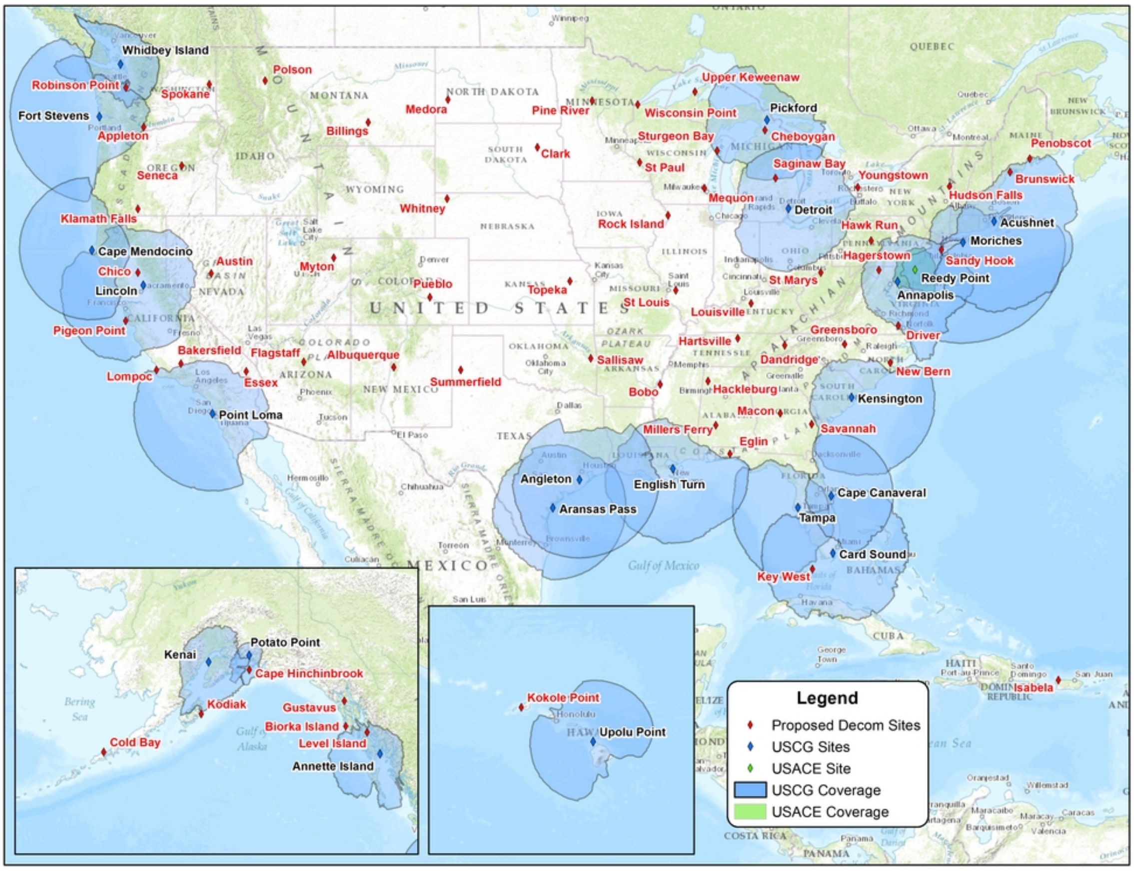

Figure 5: NDGPS Network – Post site decommissioning (USCG, 2015).

4.9 DGPS Site Status

The U.S. Federal Register completed the comment period in November 2015. Over 160 comments were received from various sectors including federal and state government departments, marine and land surveyors, marine pilots and commercial business operators. Most comments highlighted the importance of NDGPS for real-time augmentations as well as

the contribution that the sites make to the U.S. CORS network. No formal announcement has been made about the future of the NDGPS network. However, in January 2016 the USCG commenced decommissioning NDGPS sites, with notices issued through the DGPS advisory section of their Navigation Centre webpage. As of the end of January 2016, 15 sites have been decommissioned with users provided less than two weeks' notice (Figure 6).

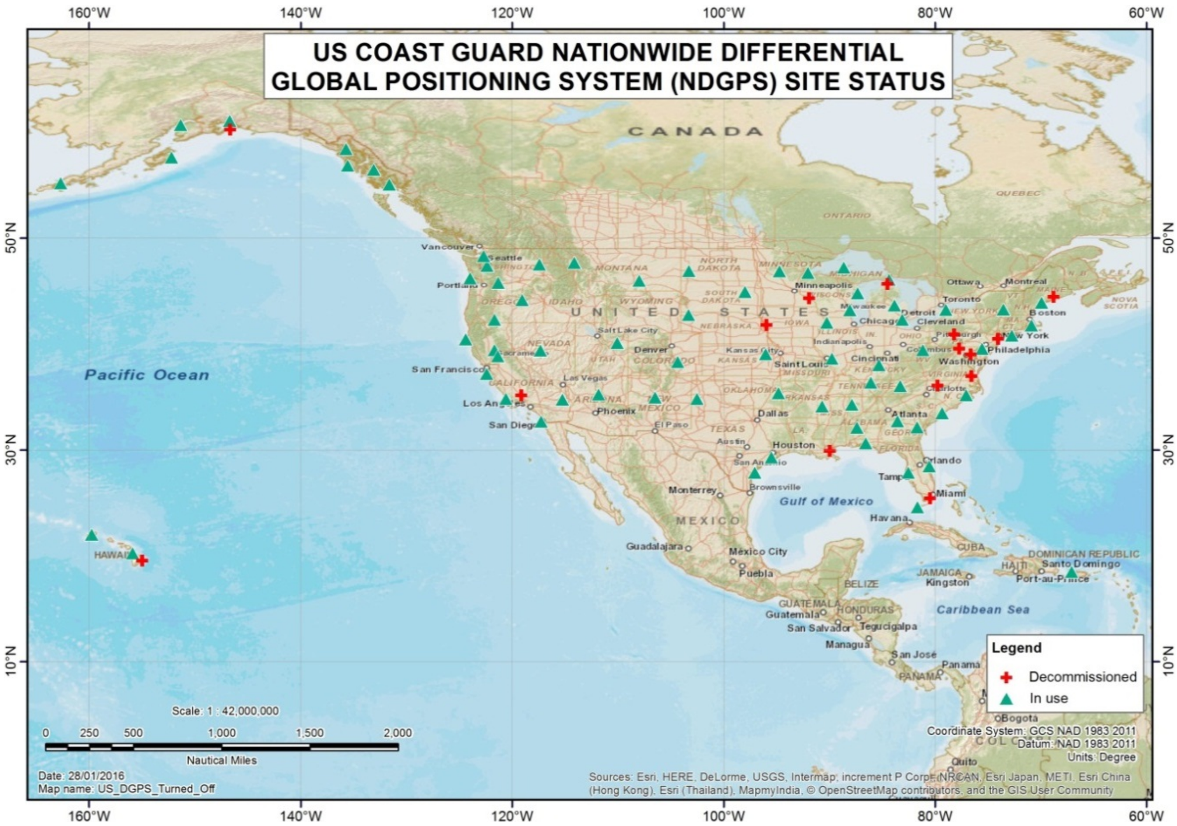

Figure 6: NDGPS Network – January 2016.

5 USER REVIEW OF AMSA'S DGPS NETWORK

In 2014, AMSA conducted a user survey to gauge the uptake and usefulness of its DGPS service. A total of 134 responses were received with distribution of surveys undertaken via peak bodies and AMSA's marine surveyors conducting Port State Control inspections. Respondents identified the primary use of DGPS for general navigation, pilotage in ports and complex waterways and monitoring of anchorage positions. Other identified uses of the DGPS service included commercial fishing, hydrographic and geotechnical surveying, maritime enforcement, research and work involving aids to navigation.

The majority of vessels surveyed, over 70%, carried two or more DGPS receivers. Maritime users also identified a wide variety of navigational aids that DGPS fed into including radar, electronic charting systems, a vessel's Automatic Identification System (AIS) and communications systems. 98.5% of respondents said that they found AMSA's DGPS service to be useful. As maritime organisations continue with the development of e-Navigation, one of its five prioritised solutions is improved reliability, resilience and integrity of bridge equipment and navigation information. To achieve this e-Navigation solution, other independent (yet complementary) forms of PNT will need to be developed (IMO, 2014).

6 E-NAVIGATION

The International Maritime Organization (IMO) is a specialised agency of the United Nations that is responsible for the safety of shipping and the prevention of pollution of the marine environment. AMSA represents Australia at IMO for the development of standards for ship safety, safety of navigation, search and rescue, maritime communications and the prevention of marine pollution.

E-Navigation is an IMO-led concept that was initiated in the mid-2000s and is driven by user needs, based on the harmonisation of navigation systems and supporting services. E-Navigation is defined as "*the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment*" (IMO, 2007).

Two core objectives of e-Navigation are to facilitate the safe and secure navigation of vessels having regard to hydrographic, meteorological and navigational information and risks and demonstrate defined levels of accuracy, integrity and continuity appropriate to a safety-critical system (such as an electronic charting system). To complete these objectives and to achieve the e-Navigation solution, nations must consider the need for resilient PNT infrastructure whose components operate independently, yet are complementary to each other (IMO, 2008).

7 RESILIENT POSITIONING, NAVIGATION AND TIMING

In the maritime sphere, resilient PNT has to meet IMO requirements for accuracy, integrity, availability and continuity. The provision of resilient PNT for maritime users is vital, due to heavy reliance on GNSS. Use includes being a key input to Electronic Chart Display and Information Systems (ECDIS), in positioning of aids to navigation, input into Global Maritime Distress and Safety Systems (GMDSS), obtaining a ship's position for transmission through Automatic Identification System (AIS) and for the coordination of Vessel Traffic Services (VTS). Due to the altitude of GNSS satellites and the weak received signal strength of GNSS, the signals can be easily blocked or interfered with.

Jamming devices can be used to intentionally block or disrupt signals by transmitting their own signal on GNSS frequencies. They cause excess noise that prevents a unit from receiving useful PNT data. Spoofing is where false PNT data is transmitted and where it is indistinguishable from authentic GNSS signals, allowing continuation of activity without users suspecting there is a position error. This was proven in 2013 when a research team from the University of Texas at Austin spoofed the navigation system of a superyacht. The team were able to alter the course of the yacht by several degrees without any alarms being triggered. The ability to spoof a vessel's navigation system without warning could have potentially serious consequences for the safety of navigation (The University of Texas at Austin, 2013).

Examples such as this demonstrate the need to develop resilient PNT services that are independent and dissimilar of existing services, but are able to complement current services. Possible PNT options for the maritime environment include eLoran and DGPS beacons fitted with R mode.

7.1 eLoran

Enhanced Loran (eLoran) is the modern day successor to the old Loran-C navigation system. Loran-C provided PNT services across much of the northern hemisphere with an accuracy of 0.25 nautical miles (460 m). With the development of GPS and the resultant increase in PNT accuracy, The United States' Loran-C was no longer seen as a viable option for transportation or military use and the program was terminated in 2010 (USCG, 2012). China still operates a Loran-C chain, as does Russia with their CHAYKA chain. Both chains are mainly used by the country's military as a redundancy to the United States owned and operated GPS service.

eLoran emits timed radio pulses at 100 kHz from terrestrial base stations. These stations form part of a chain with the master station initiating pulse transmission, followed by successive transmissions from secondary stations. The PNT outputs provided by eLoran are similar to GNSS but benefit from being a completely separate network that requires no data input from satellites to provide information to end users. The low frequency and high power transmissions make eLoran signals difficult to jam or spoof and are complementary to the GNSS low-power, high-frequency signals. Ranges achieved by eLoran depend upon the local terrain near the transmitter and the transmitted power. However, current infrastructure in Western Europe typically achieves 540 nautical miles (1,000 km).

Trinity House (the English General Lighthouse Authority) announced in December 2015 that the transmission of eLoran would discontinue with effect from 31 December. Signals from other Western Europe transmitters in Norway and France will also cease at this time (Trinity House, 2015). As Western Europe ceases transmissions, the U.S. is considering the implementation of eLoran. The National Executive Committee for Space-Based Positioning, Navigation and Timing (PNT ExCom) has recommended the use of eLoran as a near-term alternative to GPS for essential timing data while they consider what capabilities are required for a complete GPS backup. PNT ExCom is responsible for co-ordinating GPS related matters across different federal agencies to ensure the system is able to fulfil national and military requirements (Divis, 2015).

For the maritime user, eLoran seems to be a viable alternative to GNSS for PNT services due to transmission ranges, signal strength, signal frequency and eLoran's ability to operate without input from GNSS constellations. The service may also meet IMO requirements of availability and accuracy for a radionavigation system. However, with mixed messages coming from the UK and the U.S. the future of e-Loran is far from certain.

7.2 DGPS R Mode

Trial transmission of R mode (or Ranging) from existing DGPS infrastructure was conducted as part of the Accessibility for Shipping, Efficiency Advantages and Sustainability (ACCSEAS) project being conducted in the North Sea region. ACCSEAS was able to use the existing DGPS radio beacon infrastructure and were able to transmit both R mode and DGPS signals within a single channel. The R mode receiver measures the pseudo range from the transmitter and decodes signals and messages sent by the transmitter, allowing a ship receiver to determine range from the transmitting beacon – this is quite similar to eLoran.

The benefits of DGPS with R mode are that much of the infrastructure is already in place and would only require modifications to the transmitter. What is required to bring this technology to fruition is the development of commercially available receivers that can receive the pseudo

ranges and decode the signals. For the conduct of the testbed, ACCSEAS developed their own receiver to process R mode data. The usable range for the R mode test was assessed to be to 54 nautical miles (100 km). Analysis at the completion of the testbed indicated a measured range error of better than 10 m (Williams et al., 2015).

8 CONCLUDING REMARKS

The United States Coast Guard's decommissioning of NDGPS sites will reduce the availability of corrections to inland users of the service. The Coast Guard's mission is to protect those at sea and the recent review of the need to maintain their extensive NDGPS network can be seen as a method to ensure that they focus their finite resources on those they primarily aim to serve (USCG, 2014).

AMSA's DGPS network services cover the main shipping arteries and navigationally complex areas of Australia's coastline. For the short to medium term, and in the absence of updated guidance from the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), AMSA has no intention of discontinuing its DGPS service.

Resilient PNT is critical to facilitate the safe and secure navigation of vessels and to demonstrate defined levels of accuracy, integrity and continuity in associated safety critical systems. AMSA's DGPS service is a key component of our commitment to facilitate safe navigation. As e-Navigation continues to evolve, the quest for resilient PNT will be a core component requiring further studies, testing and implementation to achieve the program's outcomes and to provide both the maritime and non-maritime community with alternative PNT services that are independent of, yet complementary to, GNSS.

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