Online Journal of Space Communication

Volume 5
Issue 9 *Global Navigation Satellite System (Winter 2006)*

Article 19

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Galileo in Maritime Applications

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BIOGRAPHY

Mr. Stig Erik Christiansen is GNSS Product Manager for the EGNOS and Galileo activities in the R&D department at Kongsberg Seatex. He holds a M.Sc. degree in Geodesy from the Norwegian University of Science and Technology (NTNU) and is a member of ION and the Nordic Institute of Navigation.

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Dr. Michael Fairbanks is a senior associate in Booz Allen Hamilton's Global Transportation Team and has extensive experience in the radionavigation, aviation and maritime sectors. He has been deeply involved in policy, strategic and business aspects of the European radionavigation programme since its very early days, working on EGNOS, LORAN-C and Galileo. Dr Fairbanks holds Master of Arts (MA) and Doctor of Philosophy (DPhil) degrees from Oxford University. He is a Fellow of the Royal Institute of Navigation (FRIN), a Member of the US Institute of Navigation, and is also a Member of the Institute of Physics and a Chartered Physicist.

Dr. Alan Grant is a Radionavigation Expert for the General Lighthouse Authorities of the UK and Ireland. He received the degrees of B.Sc. and Ph.D. from Staffordshire University and the University of Wales respectively. He is a member of the Royal Institute of Navigation, the US Institute of Navigation, and is a Chartered Physicist.

Dr. Nick Ward is Research Director of the General Lighthouse Authorities of the UK & Ireland, with responsibility for strategy & planning of research & development. His area of specialisation is in radio-navigation and communications, including Automatic Identification Systems (AIS). He is current chairman of the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) Radio-navigation and AIS Committees and UK Observer on the Northwest European Loran System Steering Committee. He is a Chartered Engineer, a Fellow of the Royal Institute of Navigation and a Member of ION.

Mr. Marko Jandrisits received his Diploma degree in Interdisciplinary Management from the University of Applied Sciences in Wiener Neustadt in 2001. Since 2000 he is with via donau, the Austrian waterway management agency, where he has been working on positioning and navigation applications in the inland waterway environment. He is member of the board of the Austrian Institute of Navigation and delegate of Inland Navigation Europe (INE) to the European Maritime Radionavigation Forum.

ABSTRACT

The past decade has seen the continued growth of GPS and its many different applications. The European Union and the European Space Agency has announced the development of the European Global Navigation Satellite System – Galileo. Clearly acceptance of additional satellite systems into markets that successfully use GPS will require identification of those key areas where Galileo is capable of providing added-value, either standalone or more likely as a component of an overall integrated suite of navigation systems. These key areas are often termed the key differentiators for Galileo.

This paper introduces three projects; GALEWAT, MARGAL and GEM. The GALEWAT project is fully funded by the European Space Agency (ESA), while MARGAL is 50% co-funded and GEM fully funded by the European Union (EU) through the Sixth Framework Research and Development Programme which is being administered on behalf of the EU by the Galileo Joint Undertaking (GJU). The overall aim of all three projects is to raise awareness of Galileo. GALEWAT is a project running since 05/2003 with the focus of demonstration the

feasibility of the introduction of EGNOS in the upcoming River Information Services (RIS). The MARGAL project focuses on the maritime use of Galileo, whereas GEM is concerned with the standardisation of Galileo as part of the World Wide Radio-Navigation Service (WWRNS) as well as performance requirements and testing standards for Galileo receivers; both projects are running over a two-year period, commencing from early 2004. This paper aims to provide an introduction to, and an overview of these projects, informing the reader where they may benefit from the introduction of Galileo.

The paper starts by reviewing the perceived benefits of Galileo and demonstrates, through the use of a third party software model, where Galileo will benefit the mariner. The GALEWAT project has analysed the technical feasibility and performance of the introduction of EGNOS in upcoming River Information Services, while the aim of MARGAL is twofold: the demonstration of an end-to-end value added navigation services in the inland waterway domain as well as for port approach and harbour navigation in the maritime domain. For MARGAL, this paper reports on the development of a measurement program to identify where Galileo has the potential to benefit the mariner along with the development of the MARGAL system for harmonised navigation. Finally this paper also details work on the lengthy standardisation procedure that is being undertaken as part of the GEM project.

MARITIME GNSS PERFORMANCE

Previous work carried out for the The General Lighthouse Authorities (GLA) research and development department has produced a software tool called NEMO for modelling the performance of different radionavigation systems, including GPS, with and without augmentation, EGNOS, LORAN C and Galileo. This NEMO software model has been explained in greater depth in a previous publication and the reader is directed to that document for more information [1].

The first service that was considered was GPS SPS. Previous studies have shown that the accuracy achieved at the 95% level varies over a range of approximately 13m to 23m depending on location [1]. Setting the accuracy threshold at 10m (the minimum maritime requirement for future GNSS) indicates that GPS alone (Figure 1), as it currently stands will not meet any of the maritime requirements for a future GNSS anywhere in the world [2,3,4,5], although the requirements for the WWRNS [3] are met.

Figure 2 shows the results generated for the accuracy performance of the second scenario, which is GPS augmented using IALA DGPS. The current European

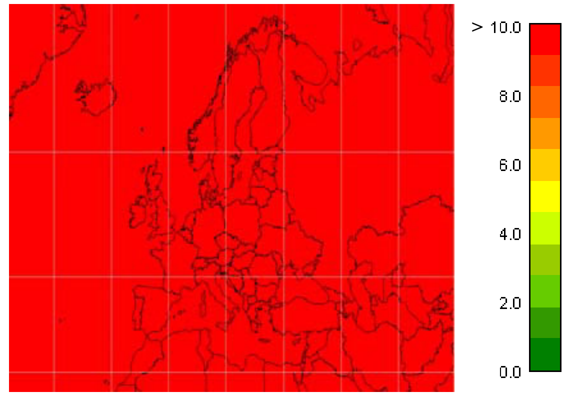

Figure 1*: Accuracy (95%) (m) achieved by current GPS alone*

radiobeacon DGPS system is modelled setting the limit of the range of the beacons to the nominal range for each station as published by IALA. The results show that within the nominal range of the radiobeacons the 10m accuracy threshold is easily met giving good coastal coverage throughout most of Europe (however the system can still be used beyond the nominal range, so performance is better than that indicated in the figure). The horizontal accuracy (95%) achieved within the coverage of the beacons is within the approximate range 0.6m to 2.5m whereas the vertical accuracy achieved under the same coverage area is within the approximate range 0.8 to 2.5m. The best accuracies are only achievable very close to the beacons due to the well-known effects of spatial decorrelation.

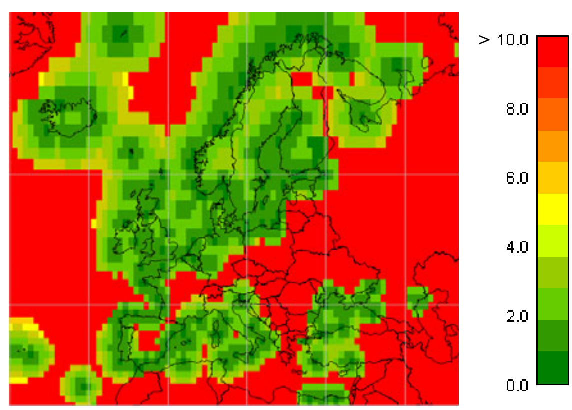

Figure 2*: Accuracy (95%) (m) achieved by GPS augmented by the current IALA radiobeacon DGPS system in the European Maritime Area*

Figure 3 shows the availability and continuity (of both horizontal accuracy and integrity together) performance for GPS augmented by IALA DGPS. The accuracy and integrity benchmarks used to assess availability and continuity are 10m and 25m respectively. The figure indicates that, although availability to the required level is

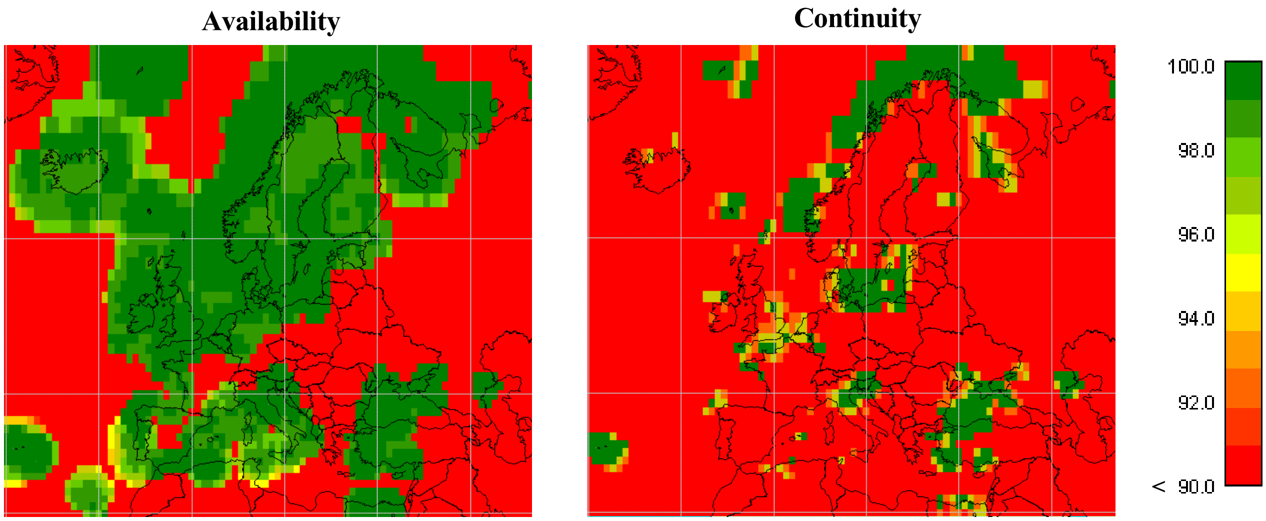

***Figure 3**: Availability (%) and continuity (%) performance of GPS augmented by IALA DGPS for a 10m accuracy and 25m alert limit performance threshold*

achievable throughout the nominal coverage of the beacon system, the continuity performance is very poor.

The principal reasons for the failure of the system to meet the continuity requirement are: 1) the limited number of satellites and geometry of the GPS constellation; and 2) the definition of continuity – this failure is in no way associated with a deficiency of the DGPS infrastructure. The drivers of the poor continuity performance are described in more detail elsewhere [1,6,7] and are currently under review by IALA. Galileo accuracy is considered in Figure 4 where the performance expected from both single and dual frequency modes of operation are shown, indicating that the dual frequency mode of operation meets accuracy requirements everywhere within the European Maritime Area (EMA). For this service the accuracy levels are in the approximate range 2m to 4m. As expected and consistent with the Galileo Mission Requirements Document [8], the single frequency mode does not meet the 10m required accuracy performance.

Galileo availability and continuity were also modelled, as given in Figure 5, showing that dual frequency Galileo meets all availability and continuity requirements throughout the EMA.

The results of the analysis for the 10m service level for standalone Galileo operating on two frequencies can be summarised to show that within the European Maritime Area, the parameters, Accuracy, Availability, Continuity and Integrity should be met for those applications requiring 1-10m accuracy. Standalone Galileo will not be able to meet the requirements for those applications requiring accuracy below 1m – these will need additional augmentation.

However, Galileo local elements are predicted to meet the more stringent accuracy requirements, along with going a great deal further to meet Time-To-Alarm requirements. Table 1 shows the predicted accuracies that will be achievable through the use of Galileo Local Elements in either conventional code corrections or phase corrections and clearly shows that sub meter level accuracy should be normal.

SERVICE	GLOBAL Dual Frequency Code	LOCAL Dual Frequency Differential Code	LOCAL Dual Frequency Differential Carrier
Horizontal Accuracy (95%)	4m	0.5m	0.10m
Vertical Accuracy (95%)	8m	0.75m	0.15m

***Table 1** Indicative accuracy levels for locally assisted Galileo services, from [8]*

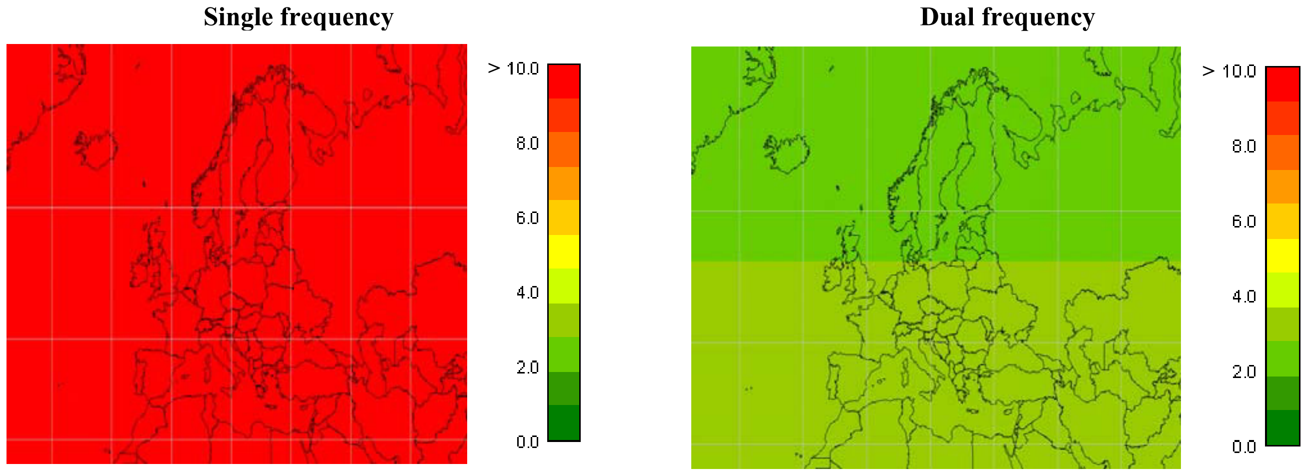

Figure 4: *Accuracy (95%) (m) expected from Galileo as predicted from the NEMO modeling tool.*

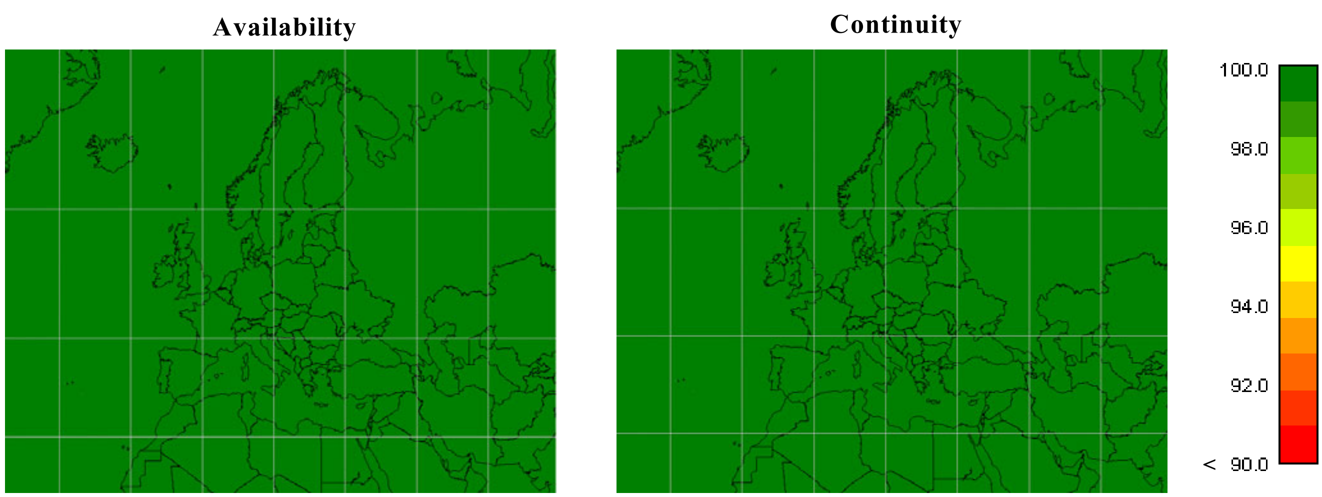

Figure 5: *Availability and continuity (%) of dual frequency Galileo at a threshold of 10m accuracy and 25m horizontal alert limit.*

GALEWAT

River Information Services (RIS) are, per definition, based on a concept for harmonized information services to support traffic- and transport management on inland waterways, including the necessary interfaces to other transport modes. This model has been developed within several European research projects in the 3rd and 4th Framework programme for research and development of the European Union. [9].

The technical basis for RIS is provided by a fast short-distance radio data communication between ships as well as between ships and shore, for the autonomous exchange of ship-related information like name, position, dimension, and other transport-related data (figure 6). Based on this data exchange, the visualisation of traffic information on an electronic nautical chart, the so-called Tactical Traffic Image (TTI), is enabled. The TTI supports the navigator in his nautical manoeuvres, as well as the authorities, which are responsible for supervising the traffic. The communication layer for RIS on the Austrian part of the Danube is based on an Automatic Identification System (AIS) infrastructure.

EGNOS OVER AIS

When analyzing the potential use of EGNOS for inland waterways, the question of signal availability is a critical issue. Due to the environment around the shoreline of the rivers/canals, the danger of losing line-of-sight to the EGNOS satellites is quite high. Obstacles could be

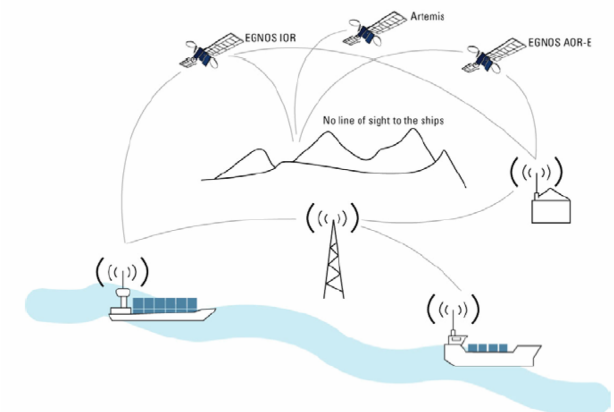

Figure 6*: EGNOS based River Information Services Navigation Principle*

terrain, buildings, bridges, or other technical structures (e.g. in harbour areas). In order to complement the direct line-of-sight reception and considering the capacity of AIS, the GALEWAT project uses EGNOS TRAN [10] transponders that can also receive the EGNOS message encapsulated in RTCM format from an AIS Base Station, which tracks the EGNOS Geostationary satellites.

Parts of the EGNOS message received on shore are then converted into AIS message type #17, which is defined by the AIS standard. This message is retransmitted from the AIS Base Station to all AIS Mobile Units (transponders) within the coverage area in order to increase the availability of EGNOS information. Hence, navigation accuracy and integrity calculated by the AIS Mobile Units are considerably improved.

MEASUREMENT CAMPAIGN

A first GALEWAT measurement campaign was run in Vienna (Austria) in 2004, while the second campaign and public demonstration was carried out within the timeframe from March to June 2005 in Lisbon (Portugal). In Lisbon one ferry was used for carrying the GALEWAT ship equipment. During normal ferry operations the GALEWAT team was able to carry out measurements.

A geodetic reference system solution computed in kinematic mode the trajectory of the ferry. A Ship Performance Monitor recorded data including time stamp, position latitude, and position longitude for each available positioning mode (GPS stand alone, GPS augmented by EGNOS from SIS, GPS augmented by EGNOS over AIS, and GPS augmented by IALA differential corrections. Even a weighted solution (WDGPS), i.e. a weighted mean computed over all modes of positioning was computed. In addition, heading data provided by the heading sensor was also recorded onboard. The analysis of performance during the test campaign was focused on:

- The visualization of the vessel movement (trajectory, heading, course, speed and height graphs).
- The analysis of horizontal accuracy by means of the computation of northing and easting errors for the different positioning systems.

The measurements, which produced the results shown subsequently, were carried out on 6 May 2005. EGNOS information was continuously received from AOR-E (PRN 120).

MEASUREMENT RESULTS

This section presents a subset of the measurement results, obtained for kinematic vessel operations [10]. Figure 7 holds scatter plots showing the position differences from the reference trajectory (i.e., the position error), and Figure 8 shows the position error plotted against time. As expected, GPS in stand-alone mode shows worst performance and also some jumps, which can be seen in both figures. GPS/EGNOS from SIS compared to GPS/EGNOS from AIS show nearly identical behaviour, which also could be expected as they both use the same source of differential pseudo range corrections for position computation.

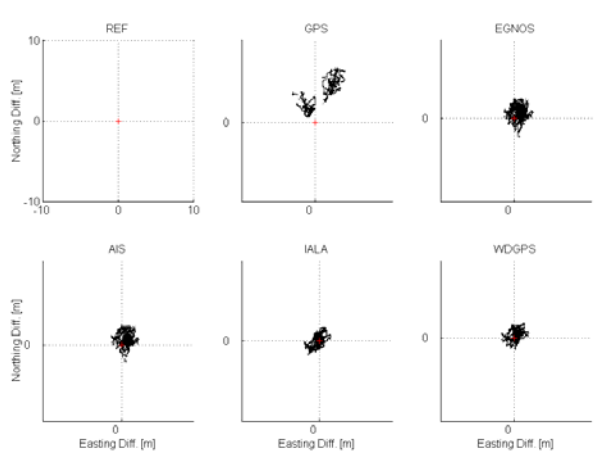

Figure 7*: Scatter plots, position error*

GALEWAT CONCLUSIONS

The results obtained from measurements in Lisbon (Portugal) on 6 May 2005 using EGNOS signals. GPS augmented by EGNOS from SIS has proved to be a good candidate for maritime/inland waterway safety-critical applications with required accuracy below 10 m, high system availability, and protection level below 25 m. EGNOS over AIS has proved to be a good complement for the direct reception of the EGNOS signal in space when the latter is being blocked by obstacles in the environment or its reception is weak (low elevation situations). A future test campaign is foreseen to be carried out in Constanta (Romania) during 2005 and will provide complementary results for other environments (waterway to open sea scenarios).

Table 2 shows the numerical accuracy and availability results. Note that the availability of each system was 100% for these trials, i.e., each system has provided a position solution every second throughout the measurement period.

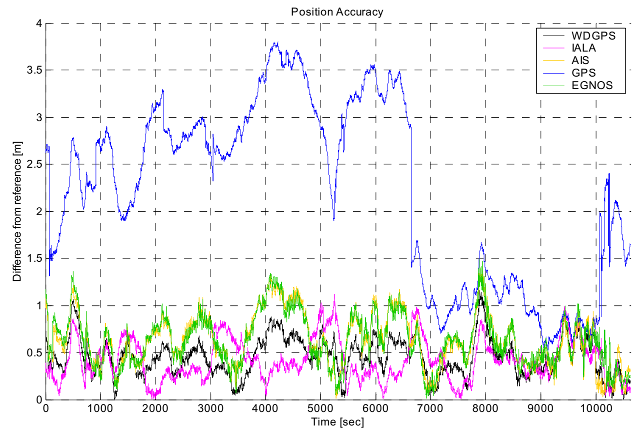

Figure 8*: Time series, position error*

Position Accuracy	GPS	GPS/EGNOS from SIS	GPS/EGNOS over AIS	GPS/IALA
Position bias (m)	2.05	0.47	0.47	0.11
Position std. dev. (m)	1.27	0.51	0.50	0.46
Position accuracy (95%)	5.12	1.64	1.62	1.15
Number of Epochs	10629	10629	10629	10629
Availability of position fix (%)	100	100	100	100

Table 2*: GALEWAT results, position accuracy and availability*

MARGAL

MARGAL (MARitime GALileo) is a project that has been launched in the frame of the Galileo-related activities of the Sixth Framework Programme (FP6) for R&D of the EC (European Commission) managed by the GJU (Galileo Joint Undertaking).

MARGAL is focusing on future requirements for maritime navigation, which have already been expressed formally from IMO (International Maritime Organisation) and other authorities. This includes future requirements for important performance parameters like accuracy, integrity, continuity and availability as well as functionality related to security and safety at sea.

Specifically, MARGAL addresses challenges related to:

- Port and harbor approach; navigation, monitoring and docking
- Inland waterways monitoring
- Precise navigation and calamity abatement

Part of the MARGAL project is the development of the MARGAL prototype system. This system will take advantage of the improved accuracy and integrity that EGNOS and Galileo will provide to enhance vessel safety, in all areas of navigation.

It is proposed that ultimately the MARGAL system will continuously provide vessels with precise position and integrity information based on the Galileo/EGNOS and GPS systems. Static and dynamic information from each vessel will be broadcast to other nearby vessels and shore/inland stations. A suitable mechanism for the transfer of data from vessel to vessel and from vessel to shore is through the Automatic Identification System (AIS). AIS Class A is already being used world-wide, is mandatory for all SOLAS vessels, and non-SOLAS vessels are also fitting AIS at an increasing speed. With the introduction of AIS on inland waterways it will be possible to create a seamless service for shore, coastal, inland and ports/harbour operations.

MARGAL will provide integrity monitoring along with suitable communications and information exchange between vessels and shore based installations such as VTS/VTMIS. The integrity monitoring concept works in a similar manner to the IALA radiobeacons and uses RTCM Messages over AIS to broadcast this information to the mariner.

One of the more significant benefits of this approach is the potential to harmonise the use in ports and to increase efficiency. For example, when a vessel approaches a port,

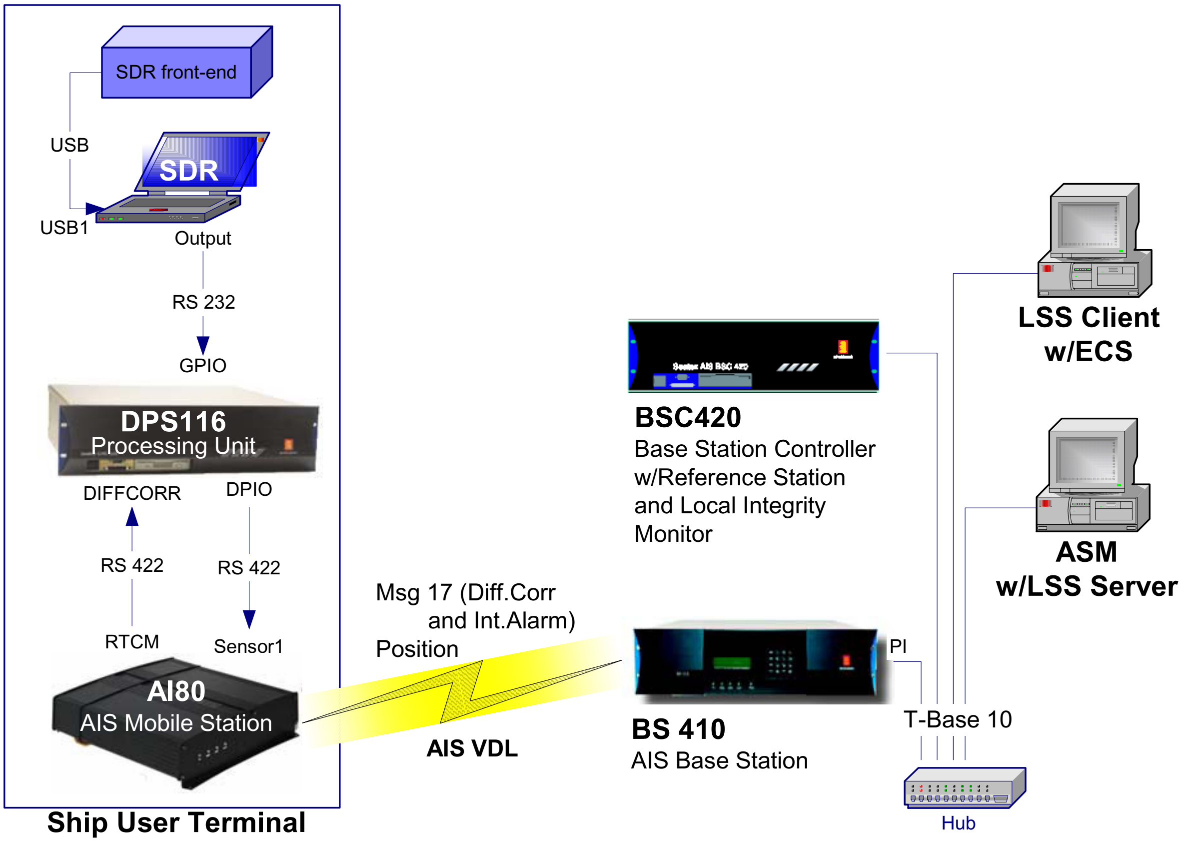

Figure 9 : MARGAL Demonstration Equipment

an approach area may be defined so that the vessel may be detected, and the port vessel traffic management system acknowledges their approach. A similar detection area can be set inside the port itself so that an approaching vessel could be kept informed whether its berth is available, and if not, what action they can take to ensure they arrive shortly after it has cleared, reduce speed, change berth etc.

This proactive management should save time (and therefore yield direct cost benefits) in vessel turnaround and also allow the port authority to make earlier decisions regarding piloting or towing. In today's ports, security is of utmost importance and this system could also raise awareness of unannounced arrivals.

MARGAL DEMONSTRATIONS

In order to illustrate the perceived benefits of Galileo and EGNOS, two independent, but harmonised public demonstrations have been organised.

In particular the use of differential corrections and integrity alerts are demonstrated in order to provide more accurate and reliable positioning services, as well as providing a harmonized, seamless service from high seas to inland waterways. The demonstration equipment is shown in Figure 9.

The first demonstration will take place on the 6th of September 2005 and will focus on calamity abatement services in an AIS based River Information Services environment. The demonstration will show the benefits of the introduction of EGNOS, as a reliable and accurate navigation service for the value chain of a calamity abatement service in Budapest (Hungary). This demonstration will involve several vessels as well as actors along the value chain like Supreme Shipping Authority, Calamity Abatement Centre etc.

The second demonstration will take place in the port of Harwich (UK) on the 27th of September 2005. This demonstration will show the harmonised approach by utilising the same infrastructure as the Inland Waterways demonstration, however with the aim of identifying Galileo key performance differentiators - those areas where the mariner will benefit from the use of the Galileo. The demonstration will highlight the improved economic benefits to both vessel users and ports operators, whilst demonstrating enhanced accuracy and integrity for Port Navigation.

GEM

GEM, is the project funded under the Galileo Activity E workstream, running from January 2004 to December 2005 to undertake some of the support actions needed for Galileo. The project, which is funded by the Galileo Joint Undertaking (GJU addresses a wide range of issues and is broken down into a number of discrete, independent work packages that are running autonomously. The General Lighthouse Authorities are leading a work package concerned with maritime standardisation, supported by Kongsberg Seatex on RTCM differential Galileo standards and IEC testing standards for Galileo receivers.

The principal objectives of this work package are to draft the standards necessary for Galileo, and possibly EGNOS, to be recognised as part of the World Wide Radio Navigation System (WWRNS) by the International Maritime Organization (IMO), facilitate this recognition process and, also, to develop the standards necessary for Galileo, and possibly EGNOS, to be deployed and utilised by the maritime sector, both in European and globally. This process must consider all elements and relevant Galileo and EGNOS services, including EGNOS alone to cover the period prior to Galileo operations; the Galileo Open Service; the Galileo Safety of Life Service; and Galileo Local Components.

To date, information and action papers have been submitted to the relevant International Maritime Organization (IMO) committees. In particular the Sub-Committee on the Safety of Navigation (NAV) accepted the need to develop Galileo receiver performance standards, in advance of the Galileo service being available, as well paving the way for Galileo to be recognised by IMO as a component of the World-Wide Radio Navigation System (WWRNS). NAV established a Correspondence Group to address these issues and finalise the draft performance standards proposed for the Galileo open service and the Galileo safety of life service. The correspondence group presented their findings at the NAV meeting in June where it was deferred to be discussed at the next meeting, pending authorisation from the Maritime Safety Committee (MSC).

In order to support the locally assisted Galileo services as given in Table 1, GEM partners has actively taken part in the work of the RTCM SC104 committee. Two input papers addressing the need for new GALILEO DGNSS standards have been submitted and is an ongoing area of debate. No major obstacles have been identified with respect to future incorporation of GALILEO in the RTCM SC-104 DGNSS V2 and V3 standards. As a result of discussions during and between SC-104 meetings draft proposals for RTCM SC-104 V2 and V3 Recommended Standards for Differential GALILEO Services have been developed and may possibly be accepted later this year.

In addition, preparations have been made to include testing standards for Galileo receivers as a new work item within the IEC TC80 – WG 4A. A formal decision to start the new work item is expected to take place at the TC80 Plenary meeting in October this year.

ACKNOWLEDGMENTS

The authors would like to thank the European Space Agency (ESA) and the Galileo Joint Undertaking (GJU) for their financial support to the GALEWAT, MARGAL and GEM projects and it is mainly upon the results of these projects this paper is based. However, it should be pointed out that the views and opinions expressed throughout are those of the authors, and as such do not necessarily represent those of ESA and GJU.

Acknowledgements are also made to the partners of the GALEWAT and MARGAL projects, namely Kongsberg Seatex, FDC, Telematica, CRUP, Via Donau, INOV, TeleConsult Austria, VUD, RSOE and NordNav as well as Nottingham Scientific Limited who developed the NEMO software.

REFERENCES

1. European Maritime Radionavigation Forum, "*EMRF Workshop Report*", December 2004.

2. International Maritime Organisation, Resolution A.915 (22), "Revised maritime policy and requirements for a future global navigation satellite system (GNSS)", 22nd January 2002.

3. International Maritime Organisation, Resolution A.953 (23), "World-wide radionavigation system" 26th February 2004.

4. IALA, "Recommendation on the performance and monitoring of DGNSS services in the frequency band 283.5KHz – 325KHz", IALA Recommendation R-121, 2002.

5. US Department of Transportation and United States Coast Guard, "*Broadcast Standard for the USCG DGPS Navigation Service",* COMDTINST M16577.1, 1993.

6. Dr. M. Fairbanks et al, *"Maritime GNSS Performance",* European Navigation Conference, Rotterdam, 16-19th May 2004.

7. Dr. M. Fairbanks et al, "*Maritime benefits of GNSS*", Royal Institute of Navigation NAV/AIS 04, 9-11th November 2004.

8. European Commission and European Space Agency, "*Galileo Mission Requirements Document, Issue 5, Revision 1.1*", March 2003.

9. PIANC Working Group 24: Guidelines and Recommendations for River Information Services (RIS Guidelines 2002) (http://www.pianc-aipcn.org/main/ris.html)

10. S. E. Christiansen, *"AIS as a Regional Augmentation Network for EGNOS"*, The European Navigation Conference GNSS 2003, Graz, 22-25th April 2003.

11. Günther Abwerzger, Paulo Chaves, Bernhard Hofmann-Wellenhof, Marko Jandrisits, Per Erik Kvam, Juan Carlos de Mateo; Galileo and EGNOS for Waterway Transport – The GALEWAT project; GNSS 2005; July 2005.