DEVELOPMENTS IN RADIO NAVIGATION SYSTEMS

by

Michael Hoppe[1], Rainer Strenge[1]

ABSTRACT

Position, Navigation, and Timing (PNT) is part of the critical infrastructure necessary for the safety and efficiency of vessel movements, especially in congested areas such as the North Sea. GNSS (especially GPS) has become the primary PNT source for maritime and inland waterways navigation. The GNSS position is used both for vessel navigation and as the position source for AIS.

Furthermore the IMO e-Navigation concept supports the development of resilient positioning, navigation and timing (PNT) information. Further it is acknowledged that a number of technically dissimilar systems are required to ensure resilient PNT. The combined use of PVT relevant sensors (e.g. GNSS Receiver, DGNSS corrections, Multi-Radionavigation Receiver) and on-board systems (e.g. Radar, Gyro, etc.) establishes the needed redundancy to enable the monitoring of data and system integrity and to improve the performance of provided PNT data. This enables the protection of the on-board process of PNT data generation (cybersecurity) against intrusions by malicious actors.

Unfortunately, GNSS is vulnerable to jamming and interference, intentional or not, which can lead to the loss of positioning information or, even worse, to incorrect positioning information. One potential source of resilient PNT services is the use of Ranging Mode (R-Mode) using signals independent of GNSS. The concept of R-Mode, or ranging mode, was first introduced to the IALA ENAV Committee many years ago. It is a novel way of using existing maritime radio systems (MF radio beacon as well as AIS) to provide GNSS independent PNT. R-Mode could support resilient PNT by providing terrestrial positioning in coastal waters. First developments of this system concept were conducted in a feasibility study as well as a practical field demonstration within a transnational EU project named ACCSEAS (Accessibility for Shipping, Efficiency, Advantages and Sustainability) which ended in February 2015. A follow up project (R-Mode Baltic) has just started (10/2017) to provide a large transnational testbed for dynamic tests and to further develop the R-Mode technology.

The paper presents a brief description of the present developments in the field of radio navigation systems to be used in maritime and inland waterways. These systems comprise usable GNSS constellations, terrestrial radio navigation systems (like R-Mode) as well as the integrating aspect to provide resilient PNT for safety related applications.

1. INTRODUCTION

A reliable knowledge of a ship's position and movement in relation to other traffic participants and obstacles is a fundamental requirement for navigation and to avoid collisions and groundings. This holds true for maritime navigation as well as for shipping on inland waterways. Position, Navigation, and Timing (PNT) is part of the critical infrastructure necessary for the safety and efficiency of vessel movements, especially in congested areas such as traffic separation areas, harbour entrances or busy inland waterways.

GNSS (especially GPS) has become the primary PNT source for maritime and inland waterways navigation. The GNSS position is used both for vessel navigation and as the position source for AIS. Thus the dependency on an electronic position (as provided typically from a single GPS sensor) has increased over the last years (see **Figure 1**).

[1] German Federal Waterways and Shipping Administration, Traffic Technologies Centre, Michael.Hoppe@wsv.bund.de

Furthermore the IMO e-Navigation concept supports the development of resilient positioning, navigation and timing (PNT) information for maritime vessels. Further it is acknowledged that a number of technically dissimilar systems are required to ensure resilient PNT. The combined use of PVT relevant sensors (e.g. GNSS Receiver, DGNSS corrections, Multi-Radionavigation Receiver) and on-board systems (e.g. Radar, Gyro, etc.) establishes the needed redundancy to enable the monitoring of data and system integrity and to improve the performance of provided PNT data. This enables the protection of the maritime on-board process of PNT data generation (cybersecurity) against intrusions by malicious actors.

On inland waterways we could observe new developments towards the use of driver assistance systems, like automatic track control or bridge warning systems. Such systems are also using GNSS and DGNSS to provide the required positioning accuracy and will ask for the same level of resilience, integrity and reliability as in the maritime field.

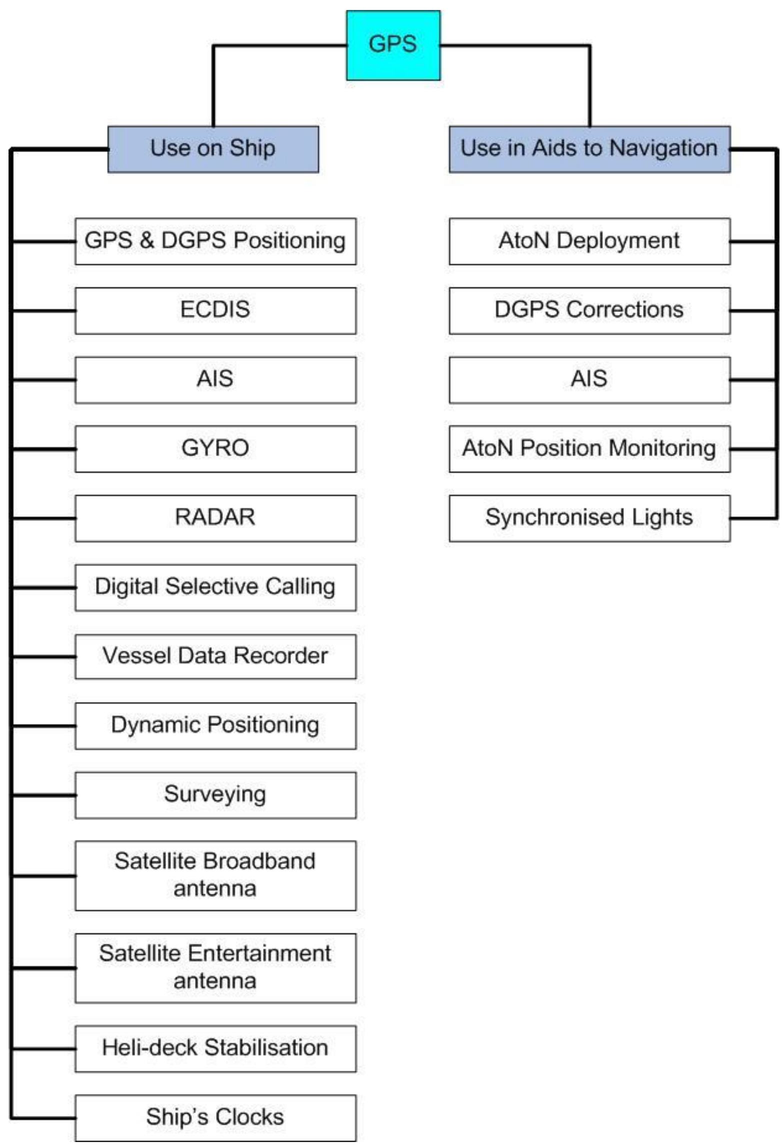

Figure 1 Dependency of an electronic position onboard a vessel

2. Systems and services used for maritime navigation

Nowadays the provision of electronic positioning is typically based on the US Global Positioning System (GPS). This system allows the usage of 32 global satellites which enable the use of the civil L1 frequency. After the deactivation of the selective availability in year 2000, GPS can be used with a positioning accuracy of roughly 10 m (DoD 2008). Also Russia is operating a satellite positioning system called GLONASS. Further systems are still under construction (European Galileo and the Chinese System Beidou) and will become operational within the next few years. Thus a lot of civil navigation signals will be available in near future to further improve the availability of GNSS positioning signals. Due to the fact that the existing and emerging GNSS could not fulfil all demands with respect to accuracy, continuity and especially integrity, coastal administrations are operating so called differential GNSS (DGNSS) to improve position accuracy and system integrity along their coastal waters. The use of GNSS independent terrestrial radio navigation systems is also discussed in the maritime field, due to the vulnerability of GNSS against intended (jamming and spoofing) or unintended (e.g. solar activities) interference. Here a system concept, called R-Mode, is under development which may become a backup in coastal waters to provide resilient PNT on board maritime vessels. The R-mode system concept will be further discussed in chapter 2.3.

2.1 Type of services, sensors and sources for positioning

Maritime positioning services could be classified as follows (IMO 2016):

- Radionavigation services provide navigation signals and data, which enable the determination of ships position, velocity and time (PVT data, as typically provided from GNSS).
- Augmentation services provide additional correction and/or integrity data to enable improvement of radionavigation based determination of ships position, velocity and time (e.g. DGNSS).

Furthermore such services could be classified regarding its geographical coverage:

- Global services are characterized by their world-wide coverage. They may have limitations regarding usability for different phases of navigation due to signal disturbances reducing the availability or performance of transmitted signals and/or provided data.
- Regional services (and maybe local services) are only available in dedicated service areas. They may be used to improve the performance of ships' navigational data in terms of accuracy, integrity, continuity and availability even in demanding operations.

Typically PNT data are provided from type approved sensors and data sources. They could be distinguished into the following categories:

- Service dependent sensors rely on any service from outside the ship provided by human effort. They cannot be used on board without at least a satellite-based or terrestrial communication link to the service provider (shown in **Figure 2**, mainly used to provide data of ships position, velocity and time).
- Shipborne sensors and sources:

  Primary sensors use a physical principle, e.g. earth rotation or water characteristics and are independent of any human applied service provision (shown in **Figure 2**, mainly used to provide data of ships attitude and movement);

  Secondary sensors and sources may be used to provide additional data for the verification of PNT data, e.g. water depth at known position from an ENC, line of position, or directions and distances provided by on-board RADAR.

The above described sensors are considered to be usable world-wide and free of any rebilling user charge.

In addition to sensors, services and sources listed in A.1 and A.2 further PNT-relevant data may be used for shipborne PNT data provision to increase redundancy or to evaluate plausibility and consistency of data input (ship sensed position e.g. by position reference systems). Such data may be provided via AIS or VHF Data Exchange System (VDES), see **Figure 2**.

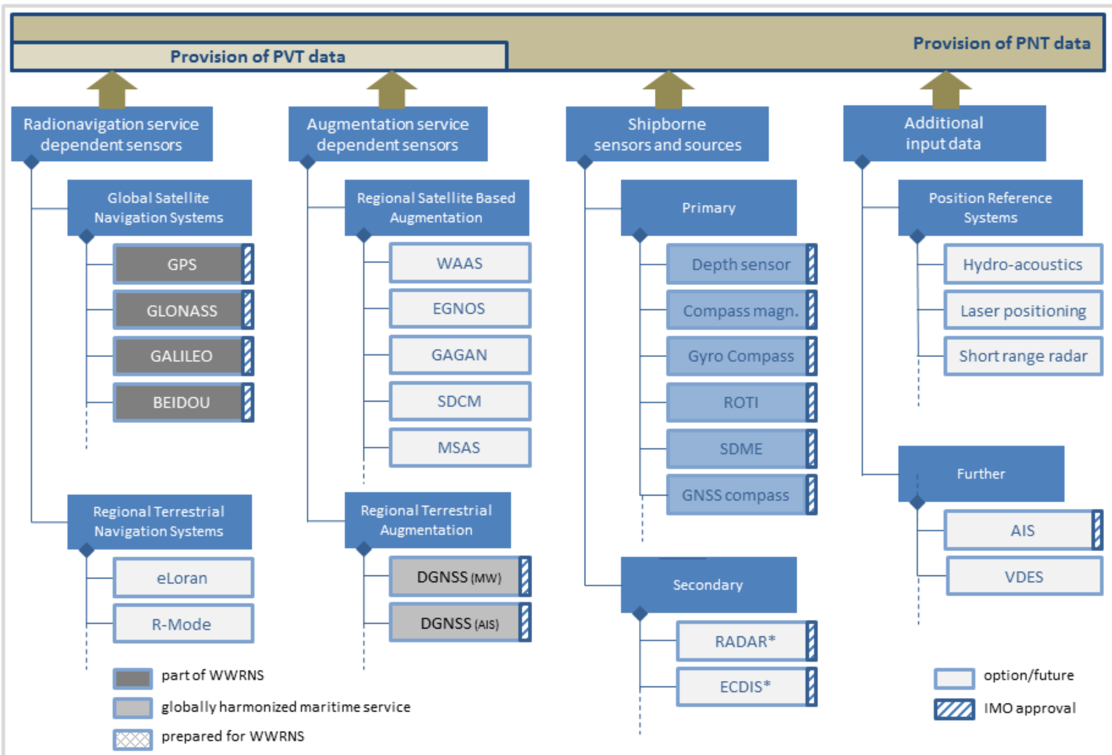

Figure 2: ***Systems, Services and Sensors in the maritime field, (IMO 2017)***

2.2 Requirements for Maritime Navigtaion

The International Maritime Organization (IMO) has defined operational requirements for the service provider of radio navigation (RNAV) services. To be recognized as part of the world wide radio navigation system (WWRNS), maritime RNAV systems have to fulfill the operational requirements of IMO Resolution A.1046(27), (IMO 2011). Within this resolution two different areas were defined with different sets of requirements (See **Table 1**).

Navigation Area	**Absolute horizontal Accuracy**	**Signal Availability**	**Continuity**	**Integrity warning of system malfunction**	**Position Update Rate**
NAVIGATION IN OCEAN WATERS	≤100m (95%)	>99.8%	-	as soon as practicable	2 s
NAVIGATION IN HARBOUR ENTRANCES, HARBOUR APPROACHES AND COASTAL WATERS	≤10 m (95%)	>99.8% (2 Jahre)	≥99.97% (15 Minuten)	< 10 s	2 s

Table 1: Operational requirements for RNAV systems being part of IMO WWRNS (IMO 2011)

In addition IMO has defined minimum maritime requirements for general navigation (IMO 2001).This document provide as well requirements for position accuracy, integrity, availability, continuity and position update rate for various navigation phases including inland waterways. Unfortunately no values are given for other navigational parameters (e.g. heading, COG, SOG, etc.). On the other hand the resilient onboard provision of position, navigation, and time data (**PNT**) is emphasized by the IMO e-navigation strategy, solution S3 "Improved reliability, resilience and integrity of bridge equipment and navigation information" and assigned risk control option RCO5 "Improved reliability and resilience of onboard PNT systems" (IMO 2008).

A comprehensive specification of maritime requirements on PNT data provision and integrity monitoring is a complex task. Many factors should be taken into account: ship types and carriage requirements, diversity of nautical applications and tasks, changing complexity of situation, deviations from nominal conditions up to customized level of support. Therefore it is difficult to determine the true development needs on the maritime PNT system regarding architecture, components, and functions to ensure a demanddriven provision of PNT data and associated integrity information. It should also be noted that during ship's berth-to-berth navigation the requirements on data output of onboard PNT (data processing) unit vary in time and space as a result of changing environmental conditions and nautical tasks. The challenge for the maritime community is to find an efficient way specifying current and evolving requirements on PNT data provision.

An initial step towards resilient PNT has been realized by the maritime community with the development of the Performance Standards for multi-system shipborne radionavigation receiver equipment (MRR). This MRR PS supports the full use of data coming from current and future radionavigation systems and services. Consequently, the combined use of several GNSS and the additional use of Space Based Augmentation Systems (SBAS) as well as optional terrestrial radionavigation systems (e.g. eLoran or RMode) will be supported to increase the performance of positioning and timing.

As a second step the development of Guidelines for onboard PNT (data processing) Unit has been identified as supplementary and necessary. Initial point is the on board use of GNSS receivers (Global Navigation Satellite System) and autarkic systems (e.g. radar, gyro, echosounder with bathymetric data) in combination for a comprehensive provision of required PNT data. Redundancy in available data enables the application of integrity monitoring functions to evaluate the current usability of safety-critical data and components. Aim of the guidelines is the specification of data processing rules towards resilient provision of standardized PNT data and integrity information. For this purpose a modular architecture of onboard PNT system is introduced and scaled to the need on data input as well as the performance of data output.

2.3 R-Mode as a potential maritime Backup to GNSS

The need for resilient positioning, navigation and time (PNT) data has been well documented (Porathe 2013). Systems such as AIS (Automatic Identification System), ECDIS (Electronic Chart Display and Information System), ARPA (Automatic Radar Plotting Aid) and other navigation sensors use GNSS derived PNT data, the reception of which can be denied through natural and man-made interference. In the near future further GNSS will become fully operational (Galileo and BeiDou) which will further increase the number of available satellite signals. However, these all GNSS share similar signal structures, frequency bands and low signal power levels, and therefore have a common vulnerability to signal interference (Volpe 2011). Thus the development of an alternative backup system is recommended.

R-Mode (Ranging Mode) is a proposed terrestrial backup navigation system, independent to GNSS, which uses ranging signals typically transmitted from existing maritime infrastructure, for example, medium frequency (MF) radio beacons and/or AIS base stations, with the potential to be a component of the future VHF Data Exchange System (VDES).

Adding additional R-Mode functionality to existing maritime infrastructure is appealing, as much of the hardware is already in place, removing the need to procure and install expensive transmitters and antenna systems. In addition, the broadcast frequencies are protected and already established for this maritime radionavigation use and marine radiobeacon reference stations are already installed along most major shipping routes. AIS base stations have also been installed in significant numbers around many coastlines, have protected frequencies and already serve the mariner; and therefore are a good candidate for R-Mode transmissions.

The concept of R-Mode has been developed over a number of years and through various funded and national interest projects, each of which is summarized below.

2.3.1 Early Considerations

First ideas of an R-Mode system, which make use of existing maritime radio systems, were given as an input paper to IALA eNavigation committee in 2008 (Oltmann et al 2008). The main idea was to add a synchronized timing signal to existing radio infrastructure used in the maritime domain and has a worldwide distribution. Identified systems in this respect were the MF radio beacon system which provides GNSS corrections in the radio beacon band (at 300 kHz) and the AIS shore systems transmitting in the VHF band). Although the general idea of R-Mode was presented on several conferences no detailed investigation could be performed. A first detailed investigation on potential methods and an analysis of achieved R-mode performance of could be performed in the European ACCSEAS project.

2.3.2 The ACCSEAS-Project

The European collaborative project ACCSEAS developed the idea of R-Mode by supporting a feasibility study which considered the suitability of adding ranging information to marine radiobeacon DGNSS and AIS base stations.

The ACCSEAS feasibility study was split into the following parts:

- Parts 1 and 2 examined the R-Mode potential of the MF DGNSS signal (Johnson et al 2014); the recommended approach was to add CW signals to the broadcast and to develop the pseudorange from the carrier phase.
- Part 3 and 4 examined the R-Mode potential of the AIS signal (Johnson et al 2014); the recommended approach was to estimate the pseudorange from timing bit transitions and requires no modification to the signal structure.
- Part 5 examined the combination of MF transmission together with AIS and the combination with eLoran which at that provided time operated from 5 stations around the North Sea area (Johnson et al 2014).

The performance assessments for each of the three signal types outlined above were considered in the feasibility study, and the lower bounds of the expected positioning accuracy were calculated, based on conservative assessments.

As the position is calculated through trilateration from terrestrial transmitters, the resulting performance is a function of the received signal power, the observation time of the receiver (nominally assumed to be 5 seconds), and the geometry of the known transmitter locations. For each signal considered, sources of error were considered where possible, however errors such as unknown offsets in the synchronization of transmitters (this is relevant to all three signals) and propagation delays that would increase the observed range estimates (this is known to impact both MF and eLoran signals since they propagate as ground waves) were omitted.

The ACCSESS ACCSEAS project concluded in 2015, and the project information remains available on the project website [www.accseas.eu] with the project deliverable reports available on the IALA website, within the e-Navigation test bed area.

2.3.3 R-Mode via MW-DGNSS

The ACCSEAS feasibility study considered a number of possible methods of adding a ranging signal to the existing marine beacon system. The different options considered are outlined in the ACCSEAS feasibility study (Johnson et al 2014), from which the approach of adding two CW signals in the MSK spectrum was selected as the optimum solution at this time. The selected approach was to maintain the existing MSK signal for legacy users, but to add two continuous wave transmissions to the band, one above and one below the central frequency. The time of arrival (TOA) of the R-Mode signal will be determined by using phase estimation methodology. Due to a wave length of roughly one km there is a need to solve the ambiguity within the nominal range of a radio beacon (typically < 300 km). The addition of a separated CW signal allows for the ambiguity solution (using the beat frequency between the added CW's).The legacy MSK signal may be used to provide other information to the receiver. Further the data stream used for DGNSS transmissions may be another alternative to resolve the ambiguity. The ACCSEAS report suggests the two CW signals are positioned ±250Hz with respect to the center frequency, however this has been amended to ±225Hz to prevent overlap of CW signals between neighboring (in terms of frequency) stations. The ACCSEAS feasibility study provides an estimation of the expected accuracies of marine radiobeacon R-Mode for day and night time conditions, taking into account the radiobeacon sites located in the North Sea region (**Figure 3**). The theoretical performance by day is promising with the expected accuracies in the order of 20-30m deemed possible. At night the expected accuracy drops to 90+m as the effect of skywave interference is observed.

Further consideration and work is required to understand the impact of skywave effects and whether they can be suitably mitigated for MF R-Mode solutions. This question and others will need to be addressed in due course and will form part of the further work.

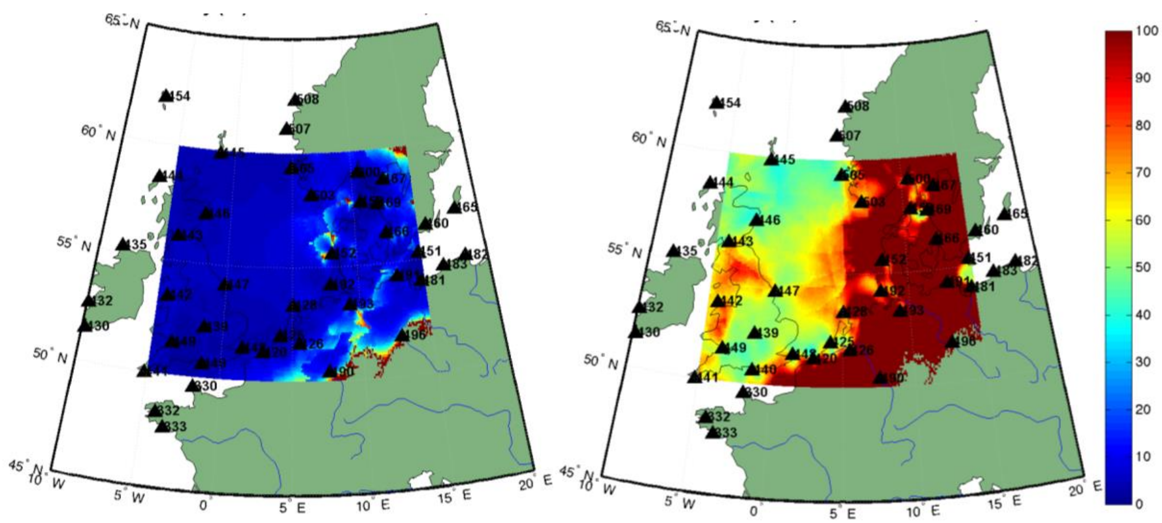

Figure 3: MF DGNSS R-Mode day (left) and night (right) predicted positioning accuracy (m) using a 0-100m scale (Johnson et al 2014).

2.3.4 R-Mode via Automatic Identification System (AIS)

AIS broadcasts are in the Very High Frequency (VHF) maritime mobile band (156.025 - 162.025 MHz) and currently transmit information both ship-to-shore and shore-to-ship (the base station broadcasts) using Gaussian minimum shift keying (GMSK) in a time division multiple access (TDMA) mode. Within part 3 of the ACCSEAS feasibility study (Johnson et al 2014) the following potential ideas and methods to implement VHF R-Mode were identified.

1. Existing AIS: this solution involves ranging off of the existing base station AIS messages, using Message 8s to increase the signal energy and duty cycle.
2. CW Aiding: this solution consists of adding continuous wave (CW) signals in other VHF channels and ranging off of the carrier phase of beat signals generated from pairs of such CW signals.
3. Spread Spectrum: this solution considers using more of the VHF bandwidth by transmitting direct sequence spread spectrum signals, akin to GNSS pseudolites.

For the Existing AIS case, the analysis shows that the TOA performance is a function of the number of bits in the processed message(s) and the signal energy and that the performance ranges from 225m for a marginal signal level to 5m for a typical signal level. The raw TOA performance of CW Aiding using the CW carrier is a function of signal strength, averaging time, and frequency and can achieve sub-meter accuracy. However, since the cycle ambiguity must be resolved, the overall performance depends upon how many, and what frequency, CW signals are added. For example, 10m ranging accuracy is possible using 3 CW signals. Finally, while a complete analysis of the Spread Spectrum solution is beyond the level of this report, we argue that performance at a level of approximately 12 meters appears achievable over a limited coverage area.

The recommended solution is the first, existing AIS including Message 8s. With this solution 10m performance appears achievable using the existing system with no modifications other than adding some additional transmissions. The CW solution is not preferred as it requires additional VHF channels plus adds the complexity of resolving cycle ambiguity. Spread spectrum, while interesting, is also not preferred as its coverage area is likely to be more limited than the other solutions.

The ranging performance is impacted by a variety of factors that are explored in this report: time stability and synchronization, signal power loss with distance, noise levels, and geometry. In the position analysis it is assumed that the time stability (on the order of 1 ns) and synchronization (to within 50-100ns) to a common reference such as UTC is achievable. Algorithms to predict power as a function of distance for the line-of-sight transmission of VHF signals are known. Noise in the VHF band has been previously studied. The geometry of the position solution, as measured by the Horizontal Dilution of Precision (HDOP), is a major factor in overall positioning performance, but HDOP values in the North Sea Area are quite good (generally less than 2).

The predicted bound on R-Mode positioning using TOA accuracy bounds is good (10-30 m) in most of the investigated area (North Sea Area, see **Figure 4**). Accuracy at the 10m level could be achieved in critical areas (port entrance) e.g. by adding additional transmitters to improve station geometry.

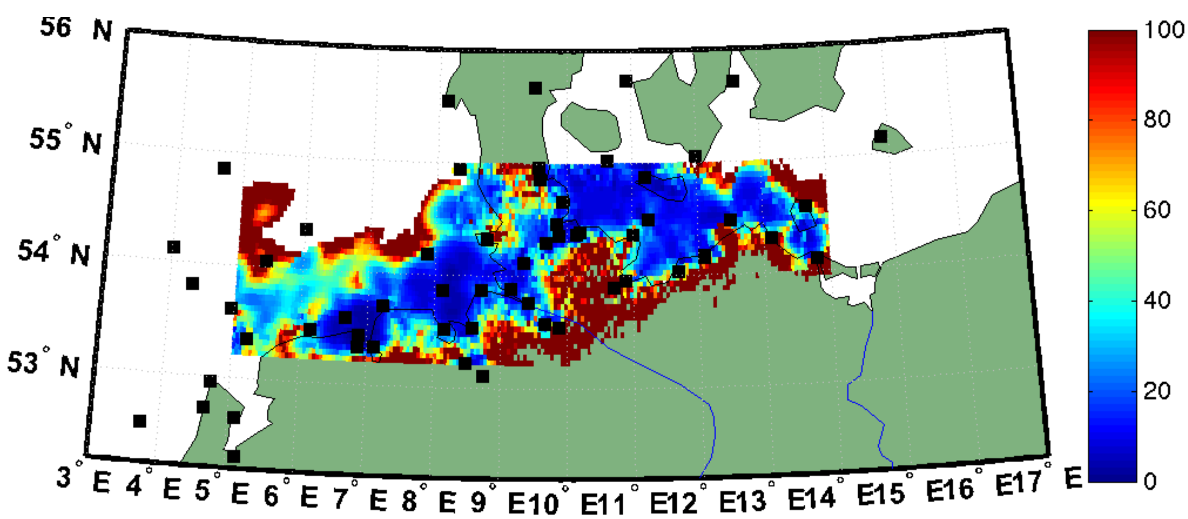

Figure 4: AIS R-Mode predicted positioning accuracy (m) using a 0-100m scale, (Johnson et al 2014)

2.3.5 Combination of various R-Mode-Signals

Furthermore the ACSSEAS study considered the combination of R-Mode signals for a better position solution (Johnson et al 2014). Part 3 of this study describes the architecture of an “all-in-view” receiver that could combine signals from two or more sources (e.g. MF, AIS and eLoran). The potential performance of this all-in-view receiver was computed for the North Sea Area with various combinations of the above mentioned signals to demonstrate potential synergies. As expected, the best performance can be achieved using ALL signals. Performance at night is slightly worse than during the day due to the reduced MF DGNSS performance at night. A single eLoran station can provide a large improvement at night over a large coverage area. Sylt alone for example, can cover the North and Baltic Seas sufficiently as an R-Mode signal to supplement AIS or MF DGNSS R-Mode; it is a very efficient augmentation to AIS R-Mode. Also, even a single strategically positioned eLoran station can provide cost-efficient time transfer for all R-Mode MF and AIS shore stations in such an area; precise timing of transmissions is one of the fundamental pre-requisites for any R-Mode at MF and/or AIS shore stations. In summary, depending upon availability, 1 or 2 eLoran signals can be combined with AIS and MF DGNSS to offer improved performance. In general performance results are strongly position dependent – in many areas one system (signal type) dominates performance. Also, as expected, more signals results in increased performance (or at least no worse). To achieve widespread resilient PNT, the best solution is to use all signals available in a true all-in-view receiver. It is also important to note that the need for a backup PNT is not uniform. The performance of a backup PNT system is most critical in the areas with the highest density of shipping traffic. **Figure 5** shows the predicted R-Mode performance for region II overlaid on top of the ACCSEAS shipping density plot to illustrate this alignment. It is likely that this alignment of R-Mode performance with the high density shipping lanes will be true in other parts of the world as well, since those are the areas with the largest numbers of AIS (and MF DGNSS) stations.

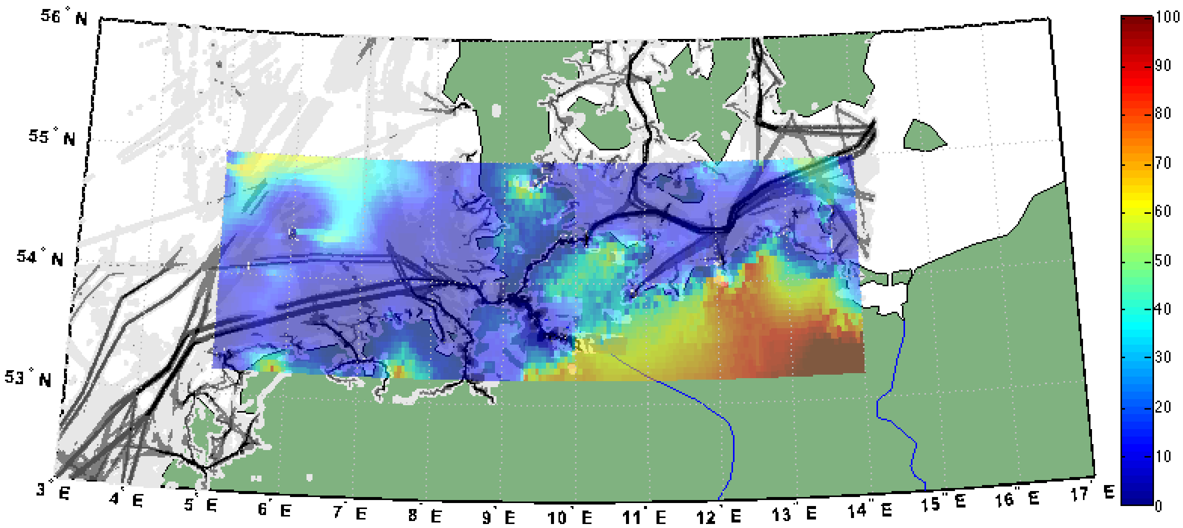

Figure 5: R-Mode performance overlaid on top of shipping density plot. Predicted R-Mode performance shaded using 0-100m accuracy scale. Shipping density shaded so that darker is higher density traffic, (Johnson et al 2014).

3. DEVELOPMENTS ON INLAND WATERWAYS

Considering the growing interest in a more efficient use of inland waterways a lot of new developments have been undertaken within the European RIS (River Information Services) concept with the following aims: economical use of the existing inland waterways improving the safety of the inland waterways increasing the commercial benefit for the skipper reducing the workload of the skipper One major improvement is the development of an Inland ECDIS (Electronic Chart Display and Information System) and the appropriate standard which is compatible to the existing maritime ECDIS. Also the development of a system for vessel tracking and tracing on inland waterways will lead to an important tool to exchange navigational data between ships and between ships and shore stations. One essential requirement for such new telematic applications is the use of an appropriate radio navigation system, like DGNSS. The use of DGNSS will provide a position with high accuracy, availability and integrity which will significantly enhance the safety for RIS applications (Hoppe 2016).

3.1 Present Applications and Requirements

2.3.6 Inland ECDIS

As mentioned before one major improvement is the development and introduction of an Inland ECDIS and the appropriate standard which is compatible to the existing maritime ECDIS. When using such a system in "navigation mode" the inland ECDIS provides information about the precise position of the ship in relation to the fairway edge. This development is based on a task providing Rhine river depths information on an electronic chart (Krajewski et al 2002).

Within the Inland ECDIS standard two modes of applications are described:

- information mode
- navigation mode

In the information mode the electronic chart is displayed without the overlaid radar picture. The skipper can use this mode to collect information about the waterway or for journey preparation. The Inland ECDIS information mode has low demands concerning position accuracy, availability and integrity. Hence a typical GNSS receiver could be used to position the map, e.g. on a typical PC. **Figure 6 (left)** shows an inland ECDIS chart in information mode. It should be mentioned that it is not allowed to use the information mode for navigation purposes. When using the Inland ECDIS in navigation mode the radar picture is overlaid the inland chart. Near the typical information about the waterway the chart will also contain depth information with respect to the current water level, the draught of the ship and the required safety margin. Equipped with all this information the skipper is able to maximise the cargo during a journey. As a result of increasing the draught of the ship the map will show the reduced fairway in parts of the waterway. It is obvious that using the Inland ECDIS in navigation mode will effort a positioning system with high demands concerning accuracy, availability, continuity and integrity. **Figure 6 (right)** illustrates the Inland ECDIS in navigation mode.

Figure 6: Inland ECDIS in information mode (left) and navigation modus (right)

2.3.7 Inland AIS

The Automatic Identification System (AIS) is a ship-borne radio data system, exchanging static, dynamic and voyage related vessel data between equipped vessels and between equipped vessels and shore stations. Ship borne AIS stations broadcast the vessel's identity, position and other data in regular intervals. By receiving these transmissions, ship borne or shore based AIS stations within the radio range can automatically locate, identify and track AIS equipped vessels on an appropriate display like radar or Inland ECDIS (CCNR 2011). In inland navigation the European RIS platform, the Central Commission for Navigation of the River Rhine and the Danube Commission have considered AIS as a suitable technology that can also be used for automatic identification and vessel tracking and tracing in inland waterways. An inland AIS standard is developed to serve the specific requirements of inland navigation while preserving full compatibility with IMO's maritime AIS and already existing standards in inland navigation.

The German Federal Waterways and Shipping Administration (WSV) has installed an AIS network which covers the coast as well as major inland waterways like River Rhine, Moselle, Danube, Main and Main Danube channel. It is planned to expand this coverage within the next years to enable a nationwide AIS shore infrastructure along most inland waterways. Furthermore a mandatory carriage requirement already exists on the River Rhine and Moselle (CCNR 2015). Meanwhile the carriage requirements have been extended to all vessels on German inland waterways since beginning of 2017. The described applications have specific requirements with respect to position accuracy, availability, continuity and integrity which are detailed in the performance standards on vessel tracking and tracing (CCNR 2006) and inland ECDIS (CCNR 2003). **Table 2** provides an overview about these performance requirements.

Application	**Position accuracy [m]**	**Integrity**
Inland ECDIS		
Navigation Mode	< 5 (absolute) < 5 (1 σ)	Detection on errors > 3 σ within 30 seconds
Information Mode	-	-
Inland AIS		
- Medium-term ahead	15-100	-
- Short-term ahead	10	-
- Lock/Bridge operation	1	-

Table 2: Performance requirements for Inland AIS and Inland ECDIS

To provide the required position accuracy and integrity for inland AIS and Inland ECDIS in navigation mode the WSV has implemented a DGNSS service along German inland waterways in 2005 (Hoppe et al 2006). This service is based on the maritime radio beacon service according to the recommendation given by IALA (IALA 2015). The IALA DGNSS can provide accuracy in a range of 1-3 m and provide integrity information to the users in less than 10 seconds.

3.2 Future Developments

Beside the established applications (as described above) new driver assistance systems are studied in various research projects to further improve the safety of navigation and to develop the basic technologies for a future autonomous inland ship. One of this research projects is LAESSI (Control and Assistance Systems to Enhance the Safety of Navigation in Inland Waterways). The aim of the project LAESSI is to support the skipper in his tasks of guiding the vessel and thus make inland shipping safer and also more efficient. To reach this aim, LAESSI makes use of latest GNSS navigation technology and data transmission developments. Within the project LAESSI, which is funded by the Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie, BMWi), efficient navigation assistance functionalities for the inland waterway transport will be developed. The application of these novel functionalities aims at the enhancement of safety and efficiency of inland waterway transport by reducing the risk of collisions. The need for this is indicated by a number of recent accidents involving inland vessels. Specifically, the project focuses on the development of the following navigation assistance functionalities: bridge approach warning system, guidance assistance and mooring assistance including the associated Conning Display.

- The bridge approach warning system should provide a timely warning signal to the skipper, whenever the vessel and particularly the wheelhouse or the radar mast cannot safely pass under the bridge. A possible warning has to be issued several hundred meters before the bridge is reached in order to ensure a sufficient reaction time.
- For the mooring assistance the position and attitude of the vessel has to be linked to the surroundings of the vessel. The skipper should get an accurate representation of the actual situation, in particular, the current distances to piers and other vessels and will be supported by this information during the maneuvers.
- The guidance assistance will relax the load on the skipper during the on route navigation of the ship. A highly accurate and integrity tested positioning information serves as a basis for this functionality.
- The Conning Display will present the motion of the ship in a clear form. Especially, the skipper has to be promptly informed about the relevant changes of the motion. For this purpose it is not only necessary to provide a very accurate position and attitude information of the vessel, but it is also important to consider the information from the propulsion systems as well as the influence of the wind and current.

The essential basis for the aforementioned functionalities is the provision of reliable and comprehensive nautical information. This includes the position, attitude and movement of own vessel with the associated integrity information, exact and valid electronic charts (maps) as well as the information regarding the situation in navigational area (construction sites, accidents, water levels) and characteristics of the infrastructure (e.g., dimensions of the bridges and locks).

In the following table accuracy as well as integrity requirements are listed for the different assistance functions. The basic idea of a bridge collision warning is to compare the geodetic height of the vessel with the geodetic height of a bridge. This results in requirements for the height measurement. The algorithm will further be divided in two parts, a long distance part starting about 10 minutes before the bridge passage and a close up part in the last 2 minutes. The first lines in **Table 3** in column bridge collision warning refer to the close up part. As a warning in the close up part requires immediate action of the skipper, higher integrity requirements have to be taken into account there. Also the time to alarm is lower there. Position and heading are used as a basis for prediction the ships movement in the close up part high requirements for position and heading accuracy are necessary of for the mooring assistant. These are based on the requirement that each point on a 185 m convoy shall be known with 30 cm accuracy. The integrity risk is based on the assumption, that 1 non detected error within 3 years of normal operation can be tolerated. The time to alarm requirement takes into account, that on the one hand mooring is a critical operation. On the other hand the vessel is moving at low speed in this situation.

	Bridge collision warning	**Automatic guidance**	**Mooring assistance**	**Conning display**
Position accuracy [cm]	20	30	10	20
Height accuracy [cm]	10	not relevant	not relevant	not relevant
Heading accuracy [°]	0,3	0,17	0,07	0,1
Integrity risk	10 10^{-5} / 2 min 30 10^{-5} / 8 min	0,55 10^{-5} / 3 h	18 10^{-5} / 10 min	18 10^{-5} / 1 h
Time to alarm [s]	4 6	2	6	6

Table 3: Accuracy and integrity requirements of assistance functions (Sandler et al 2016)

Quite similar are the requirements for the conning display. Here the vessel operates in confined waters, but most times not close to walls or other vessels. Thus accuracy requirements are lower. Also the time of using a conning display is longer than a typical mooring situation. For automatic guidance of the vessel no especially high accuracy is required. As a difference to the other assistance functions, the skipper is not part of the control and action loop. His functions are monitoring of the system as well as tactical trajectory planning. Jumps due to errors in the position measurement might have immediate impact on the rudder commands. Thus the function has to be very reliable. Basis for the proposed integrity risk is the assumption, that within one year on 100 vessels only 1 case of not detected integrity problems may occur. Also a very short time to alarm is required. The required level of accuracy (dm – cm) cannot be achieved by currently used code based positioning techniques. Therefore phase based GNSS positioning (RTK) needs to be applied. Furthermore exact and valid electronic charts, as well as information regarding the actual situation in the navigational area (e.g. temporary restrictions at construction sites) are required.

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