RAIM for Ship and Rig Management

Maritime Applications

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We are navigation!

Presentation Overview

- Motivation & Objectives
  - Present eNavigation
- Receiver Autonomous Integrity Monitoring (RAIM)
  - Horizontal Protection Levels (HPL)
  - RAIM Availability
- Simulation Performances
  - HPL Values for the Harbor in Hamburg
  - RAIM Availability Over the Globe
- Threats & Alternative Systems

Motivation & Objectives

- **What benefits does** **R**eceiver **A**utonomous **I**ntegrity **M**onitoring (**RAIM**) **offer to marine navigation?**

- Can **multi-constellation dual frequency GNSS RAIM** meet **Arctic challenges** and provide integrity for the safety, reliable and cost-effective oil transport and exploitation

- Can **classical RAIM** extended to operate with dual frequency and dual constellation GNSS **achieve 99.8%** of IMO future GNSS availability requirements A 22/Res. 915
  - **Availability of RAIM** is the percentage of time that provides usable navigation service within a specified coverage area

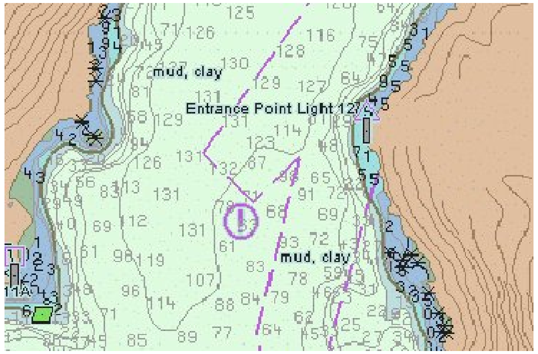
Present eNavigation

Mix of AtoN (**A**ids to **N**avigation)

- **Augmentation** through **IALA** [1] **DGPS**
- **e-Navigation** elements
  - AIS [2,3](**A**utomatic **I**dentification **S**ystem)
  - ECDIS (**E**lectronic **C**hart **D**isplay and **I**nformation **S**ystem)
  - GNSS/DGNSS (**G**lobal **N**avigation **S**atellite **S**ystems/ **D**ifferential GNSS)
  - Radars (**X**-Band or **S**-Band)
  - eLORAN (**e**nhanced **LO**ng **RA**nge **N**avigation)
  - other radio navigation means

e-Navigation is the collection, integration and display of maritime information onboard and ashore by electronic means to enhance berth-to-berth navigation and related services, safety and security at sea and protection of the marine environment

IALA e-navigation definition



RAIM[3] is a vital technology and an easy way to provide a GNSS integrity monitoring solution

[1] **I**nternational **A**ssociation of marine aids to navigation and **L**ighthouse **A**uthorities

[2] http://www.marinetraffic.com

[3] possible integration of position integrity enhanced by RAIM (**R**eceiver **A**utonomous **I**ntegrity **M**onitoring)

RAIM

Receiver **A**utonomous **I**ntegrity **M**onitoring (**RAIM**) is a technique that uses an **overdetermined** solution to perform a consistency check on the satellite measurements

- The **output** of the algorithm is the **H**orizontal **P**rotection **L**evel (**HPL**), which is the radius of circle, centered at the true user position that is assured to contain the indicated horizontal position with the given probability of false alarm ($\mathbf{P_{FA}}$) and missed detection ($\mathbf{P_{MD}}$)

ISTAR (**I**ntegrity **S**imulation **T**ool for **A**dvanced **R**AIM) allows to estimate Horizontal Protection Levels based on the various GNSS constellations and multiple frequencies

- **Ref.: MultiRAIM** Project, founded by the Bundesministerium für Wirtschaft und Technologie (BMWi), administered by the Agency of Aeronautics of the DLR in Bonn (FKZ 50NA1004)

Summary of Major Steps

RAIM Availability

1. Determine the **number of satellites** (Note: affects the $Treshold$ **TH**)
2. Calculate **Observation Matrix** (**G**)
3. Variance of the **User Range Error** (diagonal weight matrix **W**)
4. Calculate **HPL** for the given geometry
5. Determine the availability of the algorithm (**HPL < HAL**[1])
6. Proceed to the next sample point in time, and repeat **steps (1) – (5)**

[1] **H**orizontal **A**lert **L**imit (**HAL**)

Horizontal Protection Level (HPL)

$$HPL1 = max\{Slope_i, i = 1 \ldots N_{sat}\} \cdot \sqrt{pbias_B}$$

Ref.[1]

where $max\{Slope_i, i = 1 \ldots N_{sat}\}$ is a **linear relationship between position error** and **the test statistics** for the largest satellite range error. $pbias_B$ is the non-centrality parameter of the **non-central chi-square density function**.

$$HPL2 = max\{Slope_i, i = 1 \ldots N_{sat}\} \cdot \sqrt{TH} + K_H \cdot \sqrt{(G^T W G)^{-1}_{1,1} + (G^T W G)^{-1}_{2,2}}$$

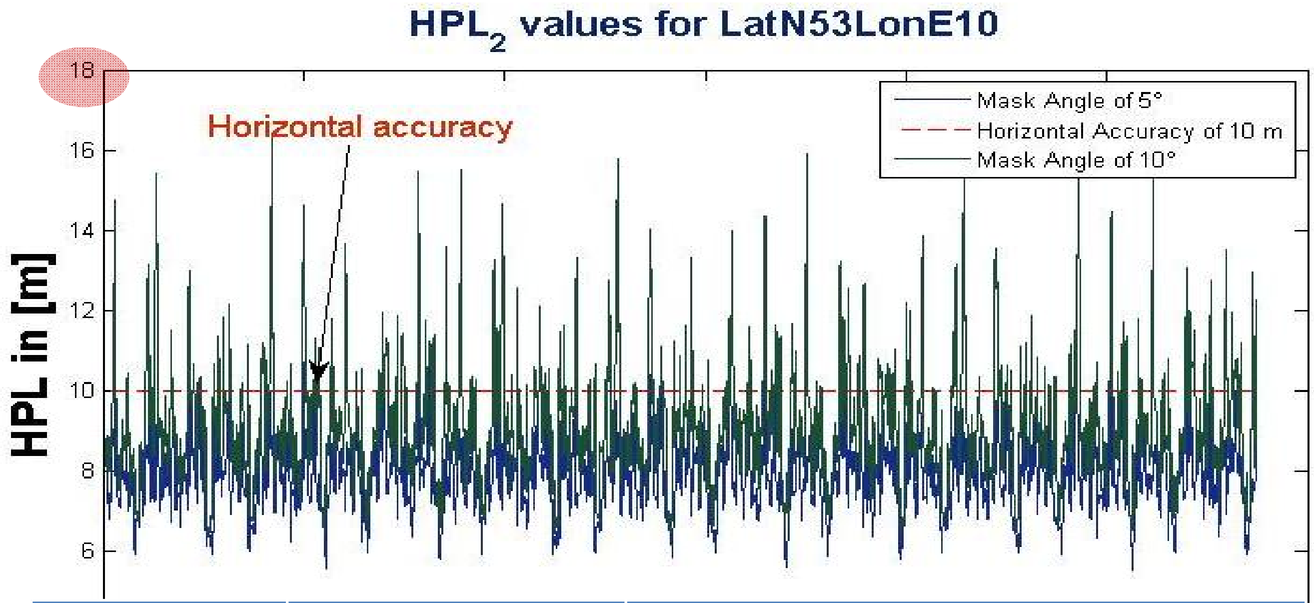
Ref.[2]
Ref.[3]

where TH is the **threshold** for the sum of the squared measurement residuals (chi-square distribution with Degrees of Freedom of [Nsat-5] /2 is applied). The second term is a measure of confidence of the horizontal accuracy. K factor is based on the worst case assumptions (Gaussian) error function.

- **Ref.[1]:** Kaplan, p. 353
- **Ref.[2]:** J.E.Angus, RAIM with Multiple Faults.
- **Ref.[3]:** T.Walter, P.Enge, „Weighted RAIM for Precision Approach“, Palm Springs, CA, September 1995, pp. 1995-2004

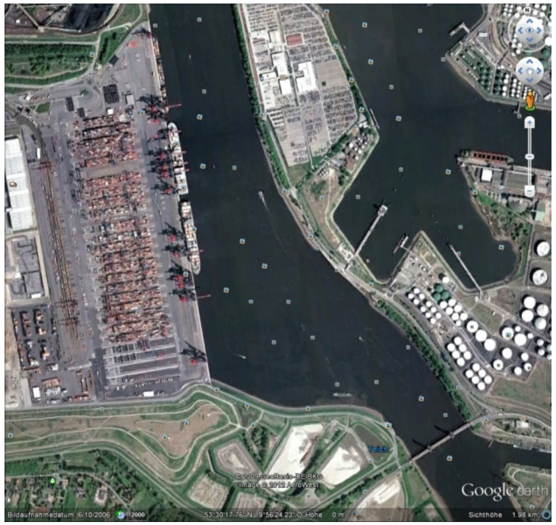
HPL over 10 Sidereal Days

Hamburg harbour



GPS **27** Sat
GAL **27** Sat
Time period: 10 Days,
Time step: 600 s

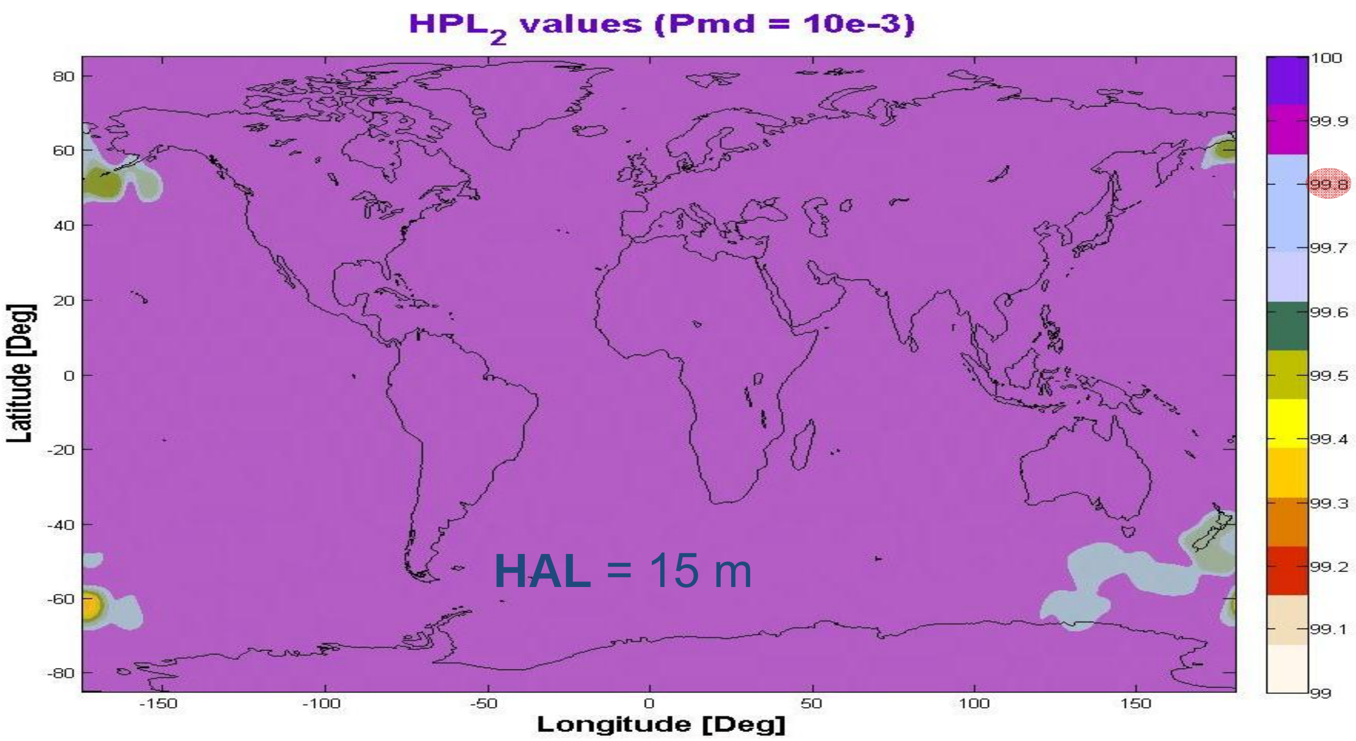
Pmd = 10^{-4}



System Level Parameters	Absolute accuracy	Integriy		
	Horizontal (Meters)	Alert Limit (Meters)	Time to Alarm (s)	Integrity Risk per(3 hours)
Port approach and restricted waters	10	25	10	10^{-5}

IMO GNSS performance requirements for general navigation according to Res. A.915(22) on future GNSS

RAIM Availability (HPL_2)



Grid: 5°x 5°

Time period: 10 Days
Time step: 600 s

GPS **27** Sat
GAL **27** Sat

URA = 1.2 m
SISA = 1.2 m
Pfa = $2.1 \cdot 10^{-5}$
$P_{apriori\_sat}$ = 10^{-4}

Mask angle:10°

Service Level Parameters	Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval (s)
Port approach and restricted waters	99.8	N/A	Global	1

IMO GNSS performance requirements for general navigation according to Res. A.915(22) on future GNSS

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RAIM Availability

Constellation	Pmd = 10^{-3} 95%	Pmd = 10^{-3} 99.8%	Pmd = 10^{-4} 95%	Pmd = 10^{-4} 99.8%	
GPS 27 GAL 27	100	100	100	100	HPL_1
GPS 24 GAL 24	99.9	100	99.7	100	
GPS 24 GAL 18	96.2	98.1	94.6	96.9	

The percentage of the globe between **70°S** and **70°N** that has 95% and 99.8% RAIM availability

Constellation	Pmd = 10^{-3} 95%	Pmd = 10^{-3} 99.8%	Pmd = 10^{-4} 95%	Pmd = 10^{-4} 99.8%	
GPS 27 GAL 27	100	100	100	100	HPL_2
GPS 24 GAL 24	100	100	99.9	100	
GPS 24 GAL 18	97.9	99.2	97.1	98.8	

INTEGRITY REQUIREMENTS

HAL = 15 m
Pfa = $2.1 \cdot 10^{-5}$

URA = 1.2 m
SISA = 1.2 m

Mask angle: 10°
$P_{apriori\_sat} = 10^{-4}$

Dual Frequency GNSS RAIM

With the 15m Horizontal Alert Limit the simulation results meet the reuquired availability

Threats

- **GNSS-Weakness**
  - Large Distance to Satellites
  - Low GNSS-Signal Power
  - Space Weather
- **Spoofing**
  - Simulation and Transmission of fake GNSS-Signals
  - Manipulate NPT-Solution
- **Denial of Service**
  - Intentional Jamming
  - Unintentional Radio Interference

Alternative Systems

Navigation Parameter	Measurement Principle	Accuracy	Availability
Heading	Mechanical Gyroscope FOG (**F**iber **O**ptic **G**yroscope) THD (**T**ransmitting **H**eading **D**evice) Magnetic (Compass)	0.1 deg < 0.5 deg < 1.0 deg < 5 deg	100 % 100 % <100 % 100 %
Position	GNSS DGNSS LORAN C eLORAN	4.5 – 25 m 0.1 – 25 m < 450 m < 20 m	≈100% (for 2 GNSS) Station dependent Chain dependent
Speed	Doppler Speed Log Electromagnetic Log Satellite Log	< 0.2 kn < 0.5 kn < 0.1 kn	Depth 80 – 400 m 100% ≈ 100%
Depth	Echo Sounder	< 1 m	<300 m

- **Ref.[1]:** Dr. v. Koehler, Integrated Navigation Systems for Commercial Shipping, CCG e.V. Oberpfaffenhofen, 2010

Summary & Conclusions

- **Dual Frequency Dual GNSS constellation RAIM** Algorithms **can achieve 99.8%** of IMO future GNSS availability requirements A 22/Res. 915
  - **Ships** have to carry a **GNSS receiver** (AIS). **RAIM** could be **integrated**
  - Moreover **RAIM** can be supported by **additional INS** or **augmentation system information**
- **Multi-constellation GNSS RAIM** can support in demanding applications such as navigation in Arctic
- The **RAIM** already used in **aviation** is fairly **efficient against** a large number of threats (including **spoofing**)
- Future GNSS systems & increased number of satellites will allow **best selection of the NPT information** in order to provide integrity to the user's position; achieve safety and cost-effective navigation solution

Questions and Discussion

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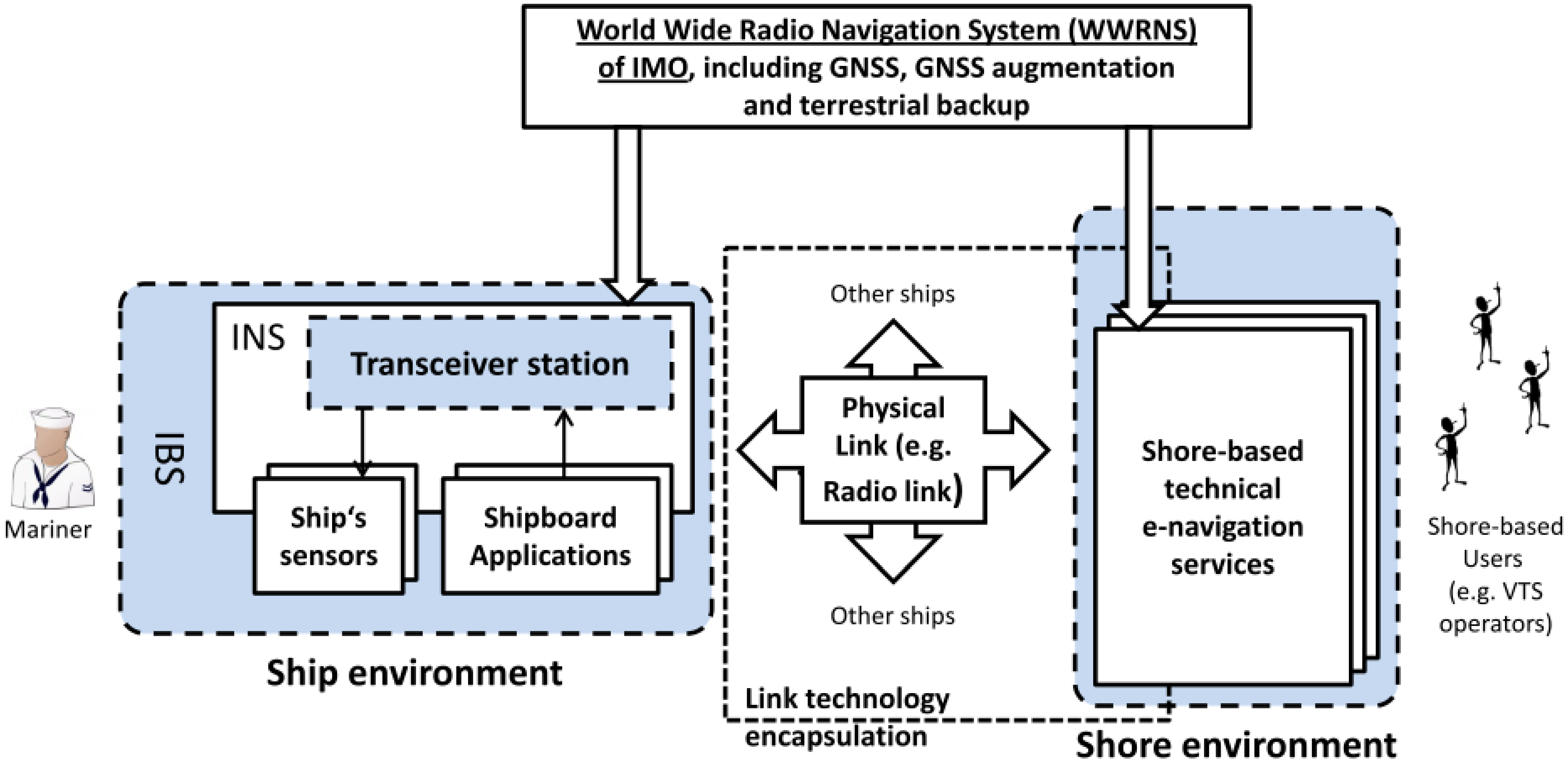
Thank you four your attention!

eNavigation Architecture



- **Ref.:** e-Nav 140, „The e-Navigation Architecture – the initial shore-based architecture perspective", Ed. 1.0, IALA Recommendations, Dec. 2009

RAIM Availability

Constellation	Pmd = 10^{-3}		Pmd = 10^{-4}		
	95%	99.8%	95%	99.8%	HPL_1
GPS 27 GAL 27	100	100	100	100	
GPS 24 GAL 24	100	100	100	100	
GPS 24 GAL 18	99.6	99.9	99.4	99.9	

The percentage of the globe between **70°S** and **70°N** that has 95% and 99.8% RAIM availability

Constellation	Pmd = 10^{-3}		Pmd = 10^{-4}		
	95%	99.8%	95%	99.8%	HPL_2
GPS 27 GAL 27	100	100	100	100	
GPS 24 GAL 24	100	100	100	100	
GPS 24 GAL 18	99.9	99.9	99.9	100	

INTEGRITY REQUIREMENTS

HAL = 25 m
Pfa = $2.1 \cdot 10^{-5}$

URA = 1.2 m
SISA = 1.2 m

Mask angle: 10°
$P_{apriori\_sat} = 10^{-4}$

Dual Frequency Dual GNSS RAIM
with 2 simultaneous failures