R-Mode Baltic - A user need driven testbed development for the Baltic Sea

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Outline

- Introduction
- An R-Mode testbed for the Baltic Sea
- Signal-of-opportunity coverage prediction for the Baltic Sea
- R-Mode user requirements
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Introduction: GNSS in the maritime domain today

Safe navigation requires a backup system

- GNSS has become the primary source for maritime positioning and timing
- GNSS data is used in many ship systems e.g. AIS, ECDIS, INS
- GNSS is vulnerable to unintentional and intentional interferences
- IMO: maritime user requires a backup systems for GNSS (MSC 85/26, Annex 20)

ECDIS

www.glasgowmaritimeacademy.com

AIS

www.raymarine.com

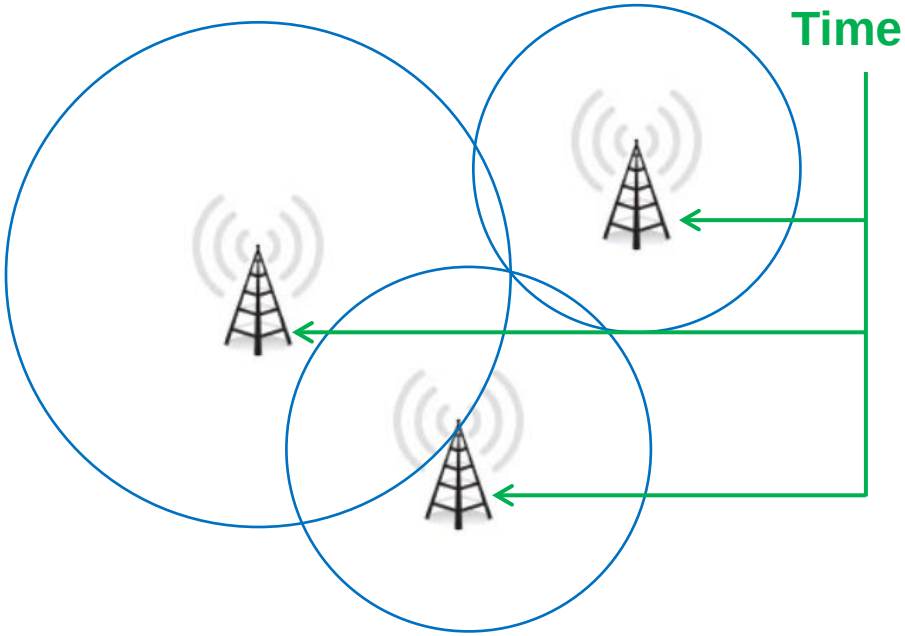
Introduction: R-Mode

A terrestrial maritime backup system for GNSS

- R(anging)-Mode is a positioning system that
  - transmits timely synchronised ranging signals
  - using the communication channel of existing maritime radio infrastructure

- Recent studies show the potential of R-Mode implemented on maritime radio beacons and AIS base stations

- A testbed is needed for
  - Validation and long term studies
  - Development and test of user equipment and applications
  - Development of guidelines and standards

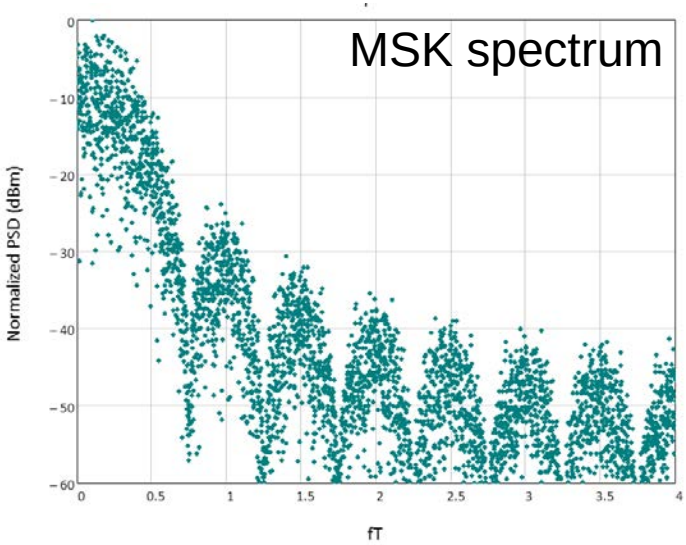


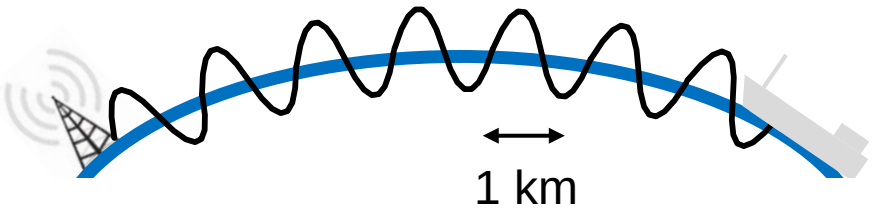
DLR

Signal of opportunity: maritime radio beacon

Maritime standard for navigation in coastal areas

- Transmits a continuous stream of MSK modulated data
- Medium frequency: 283.5 – 325 kHz
- Channel bandwidth: 500 Hz or 1 kHz
- Neighboring stations differ in transmitting frequency

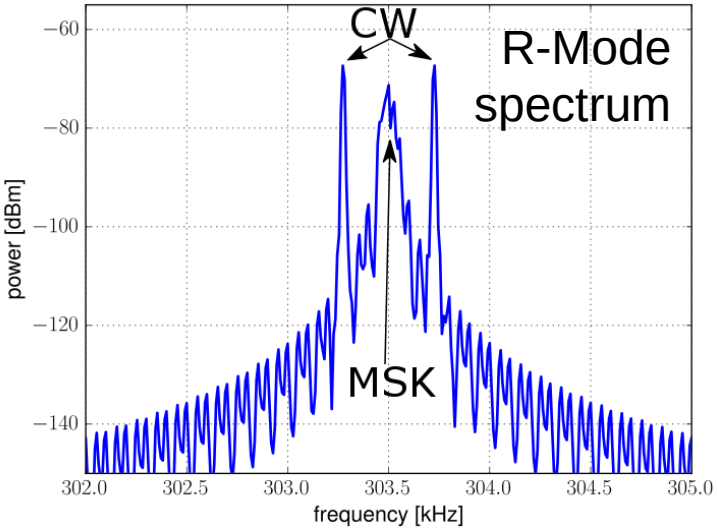


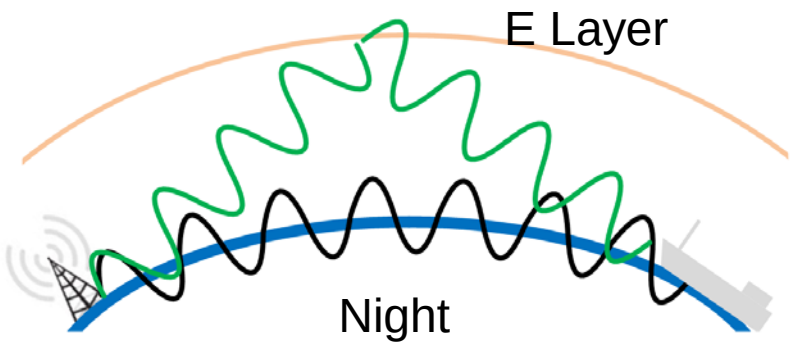


- Wave propagation: ground wave
- Service area: up to 500 km
- Defined in ITU-R M.823-3 and RTCM SC104

Maritime radio beacon as source for R-Mode signals

- Bit length of legacy signal 5, 10 or 20 ms
- Phase measurements are needed for range estimation
- Problem solving ambiguity of complete wavelengths
- Solution: add two 2 continuous wave (CW) signals 225 Hz beside carrier of legacy signal





First results (measured)

- Range : <10 m day ; <50 m night

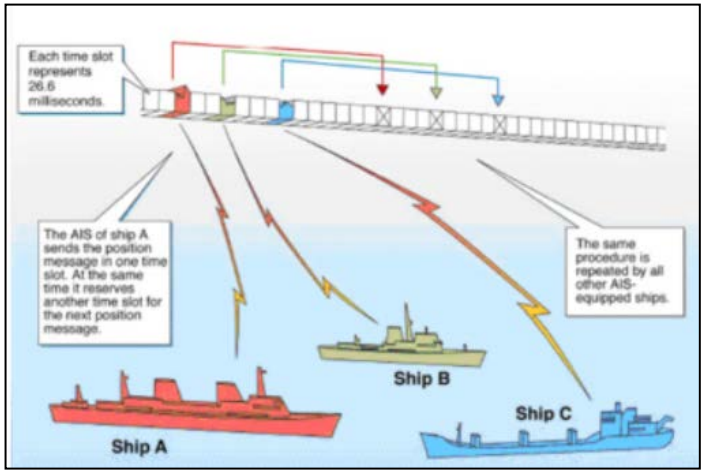
Challenges

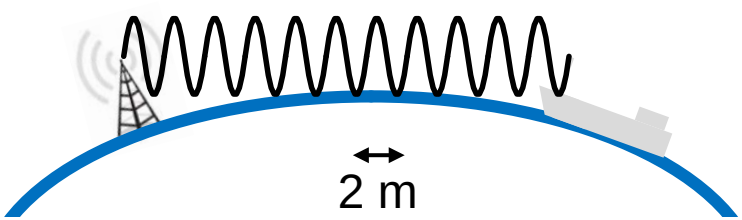
- Mitigate skywave induced fading
- Accurate estimation of beat signal (from both CW) phase

Signal of opportunity: Automatic Identification System (AIS)

Standard for the distribution of safety-relevant data

- Packed based digital communication system between ships and between ship and shore
- VHF frequency: 161.975 MHz, 162.025 MHz
- All AIS user share per channel 2250 slots/min (TDMA)





- Wave propagation along line of sight
- Service area of base station depends on antenna height (up to ~70 km)
- Defined in ITU-R M-1371

AIS base stations as source for R-Mode signals

Possible implementation

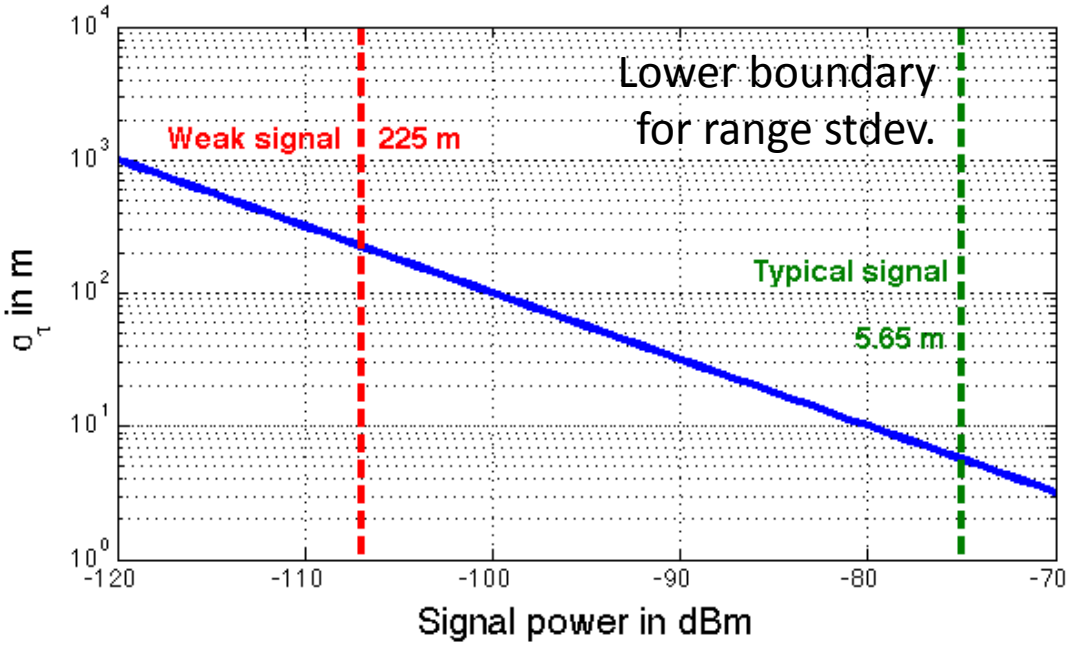
- Range estimation using bit edge of AIS message transmitted from base station
- Data rate 9.6 kbps (bit length 0.1 ms)
- New messages beside AIS base station report (1 per 10 s) are needed

using 5 AIS slots = 1280 bit

$$\sigma_{AISbitedge} = \frac{0.12}{\sqrt{L_0}\, 10^{\frac{s}{20}}}\ nsec$$

Challenges

- Design AIS message with sufficient length and low autocorrelation
- Minimized additional channel load



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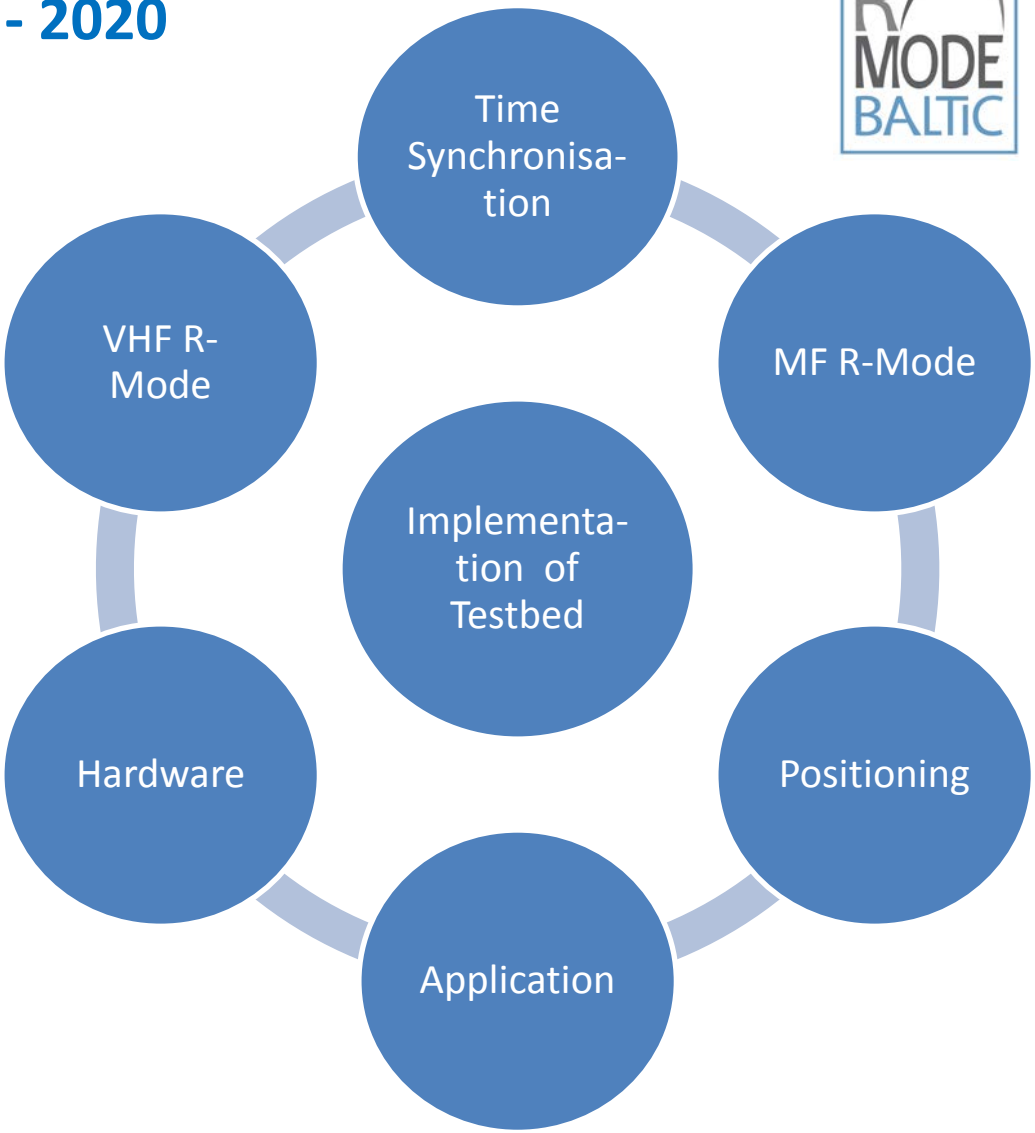
Project R-Mode Baltic 2017 - 2020

Aims

- Build a R-Mode testbed in the Baltic Sea until 2020 that utilises maritime radio beacons and AIS base stations
- Show R-Mode is able to meet maritime user requirements for a backup system.

Constraint

- No disturbance of legacy service and equipment

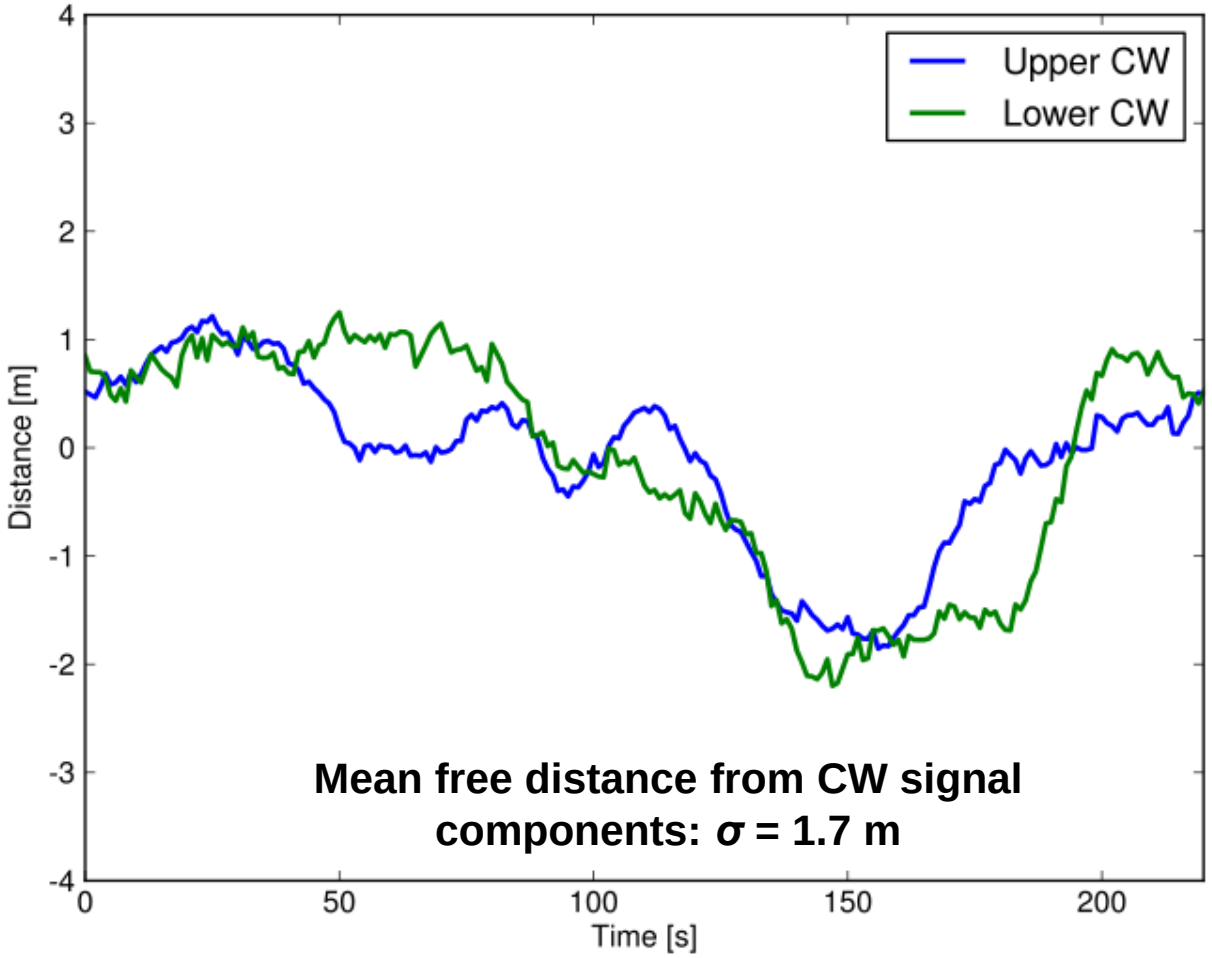


R-Mode implementation on MF maritime radio beacons

Signal, message and algorithm design

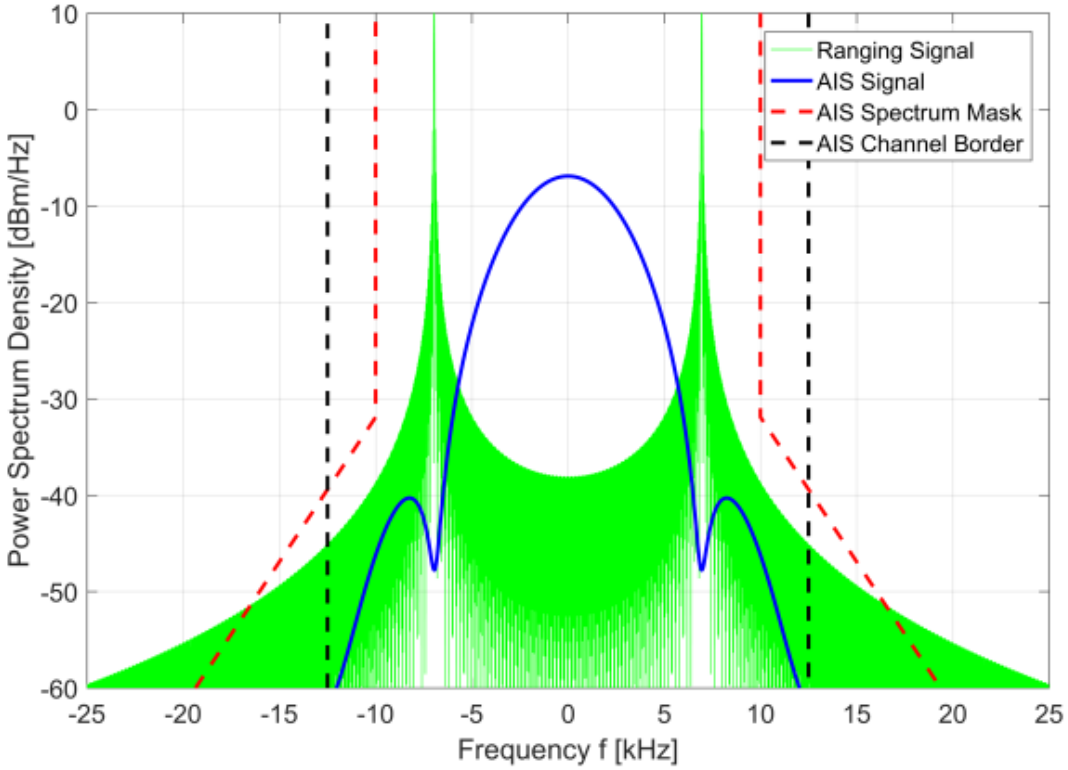
Project approach

- Improved Maximum Likelihood estimator
- Optimised binary message
- Channel modelling to improve skywave mitigation
- Test measurements



R-Mode implementation on AIS base stations

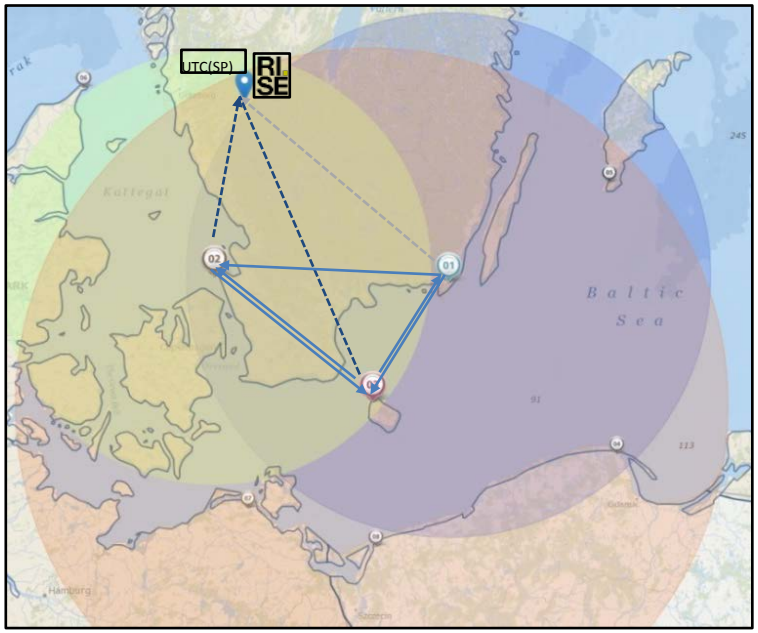
Signal, message and algorithm design



Project approach

- Design of bit pattern for multiple slot binary message (#26) which uses a minimal number of slots
- Prove benefit of additional CW
- Concept for implementation of R-Mode using VDES
- Test measurements

Time synchronisation and positioning



Generated with https://mapmaker.nationalgeographic.org/

Time synchronisation of R-Mode transmitters

- Study on the capability of R-Mode self-synchronisation
- Propose a concept with available technology

R-Mode positioning

- Assessment of accuracy and its dependence on different error sources
- Combined usage of R-Mode AIS and radio beacon ranging

R-Mode hardware and application development

AIS Base Station transmitter

- Adaptation of existing hardware on time synchronisation requirements and optimal R-Mode VHF signal design

R-Mode receiver

- Based on existing GNSS receiver technology
- Digital processing of signals
- Simultaneously support VHF and MF signals

Applications

- **PNT data processing unit** and **Portable Pilot Unit (PPU)** which provides R-Mode based positioning in case of reduced GNSS performance

R-Mode testbed implementation

- Selection of testbed area based on
  - User requirement for a backup system
  - Detailed coverage prediction, which considers significant disturbances of signal propagation and station geometry
- Up to 6 radio beacons and 4 AIS base stations will be equipped with R-Mode enabled signal generators
- Monitor stations will be used to monitor the proper work of the R-Mode transmitter sites
- Perform static and dynamic measurements for validation

The testbed will be available from 2021.

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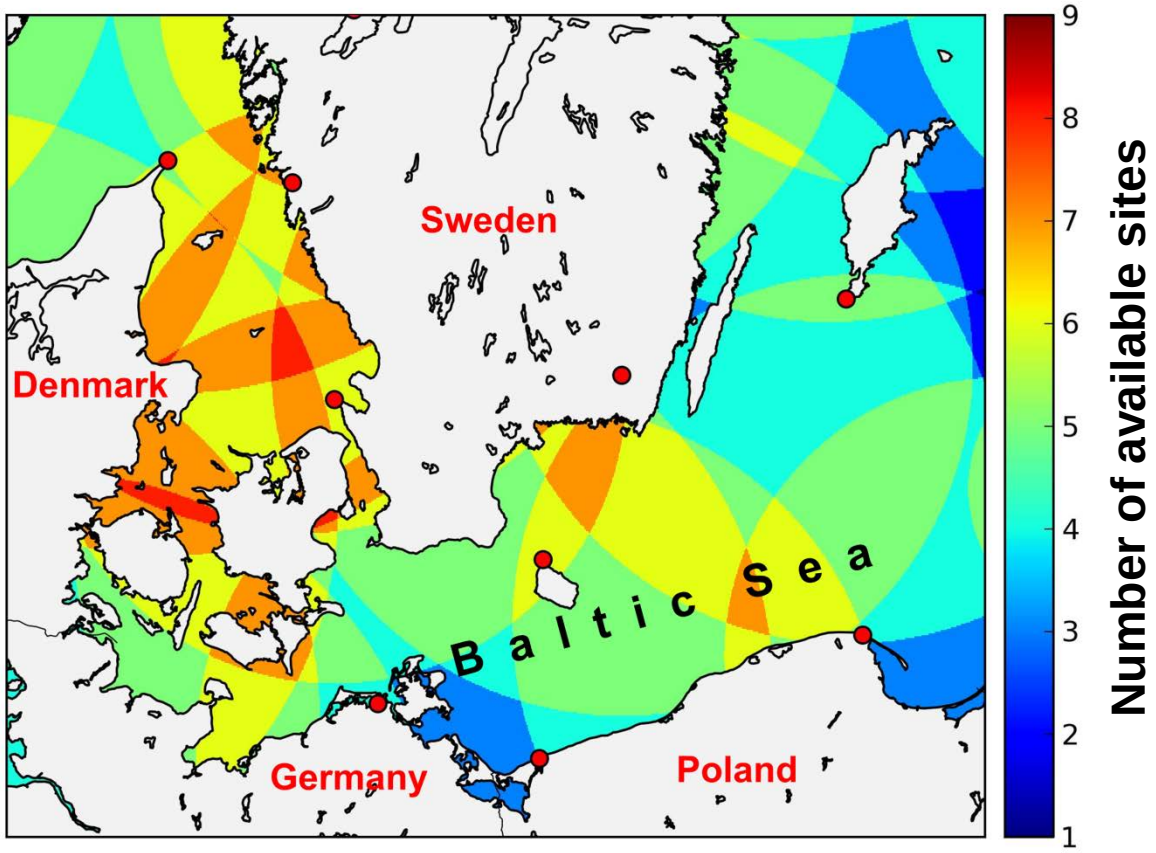
Coverage of the Baltic Sea with MF radio beacon signals

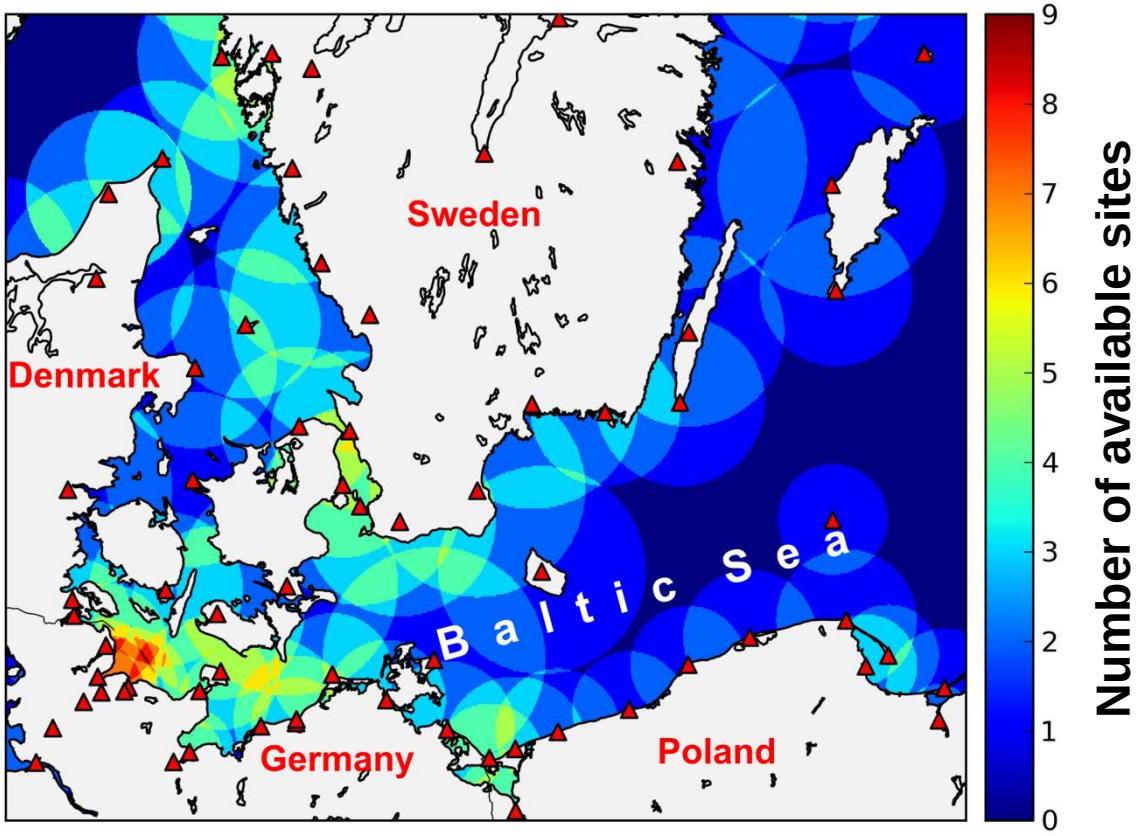
Based on given nominal range



Sufficient (>3) number of beacons for positioning in wide areas of the Southern Baltic Sea

Coverage of the Baltic Sea with VHF AIS signals

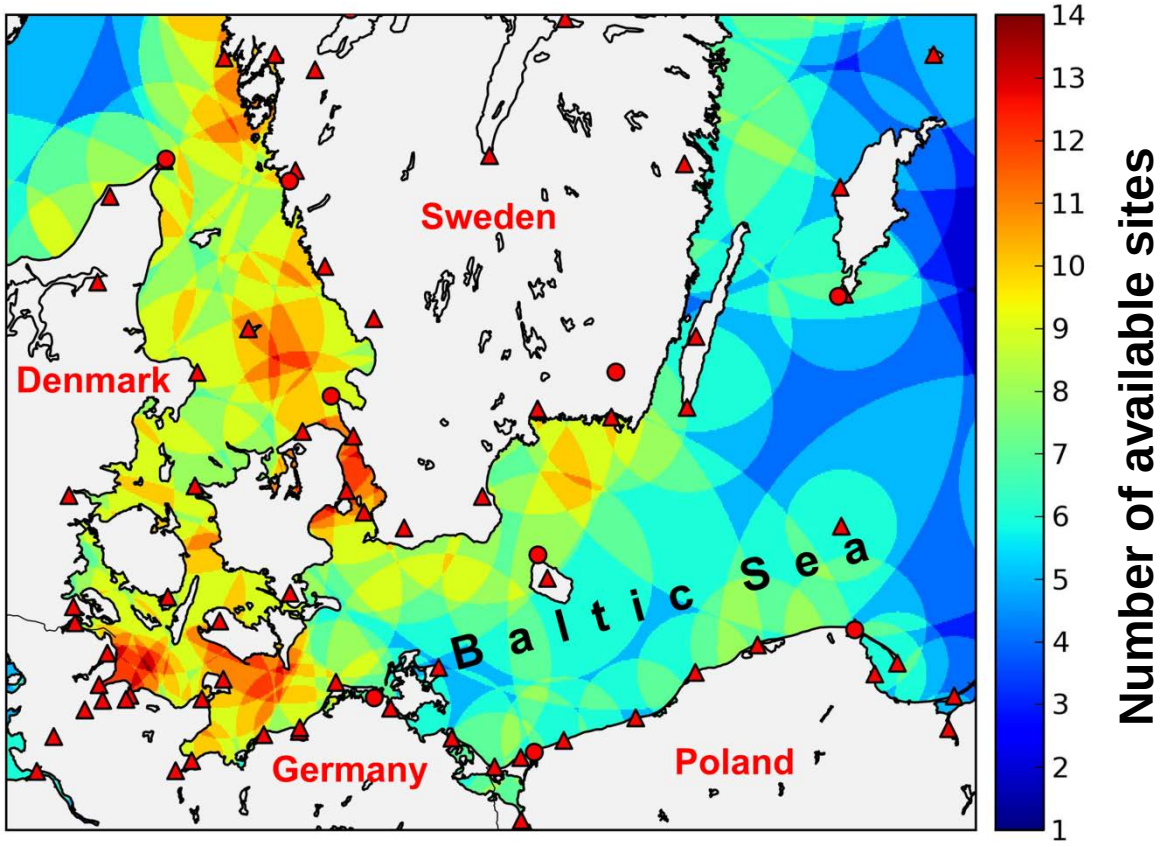
Based on geometrical range (vessel: 10 m antenna height)



Insufficient (<4) number of stations for positioning in wide areas of the Southern Baltic Sea

Coverage of the Baltic Sea with VHF and MF signals

Considers not disturbances of signal propagation



Sufficient number of available signals (>3) for positioning in the Southern Baltic Sea – R-Mode based positioning requires both signals-of-opportunity

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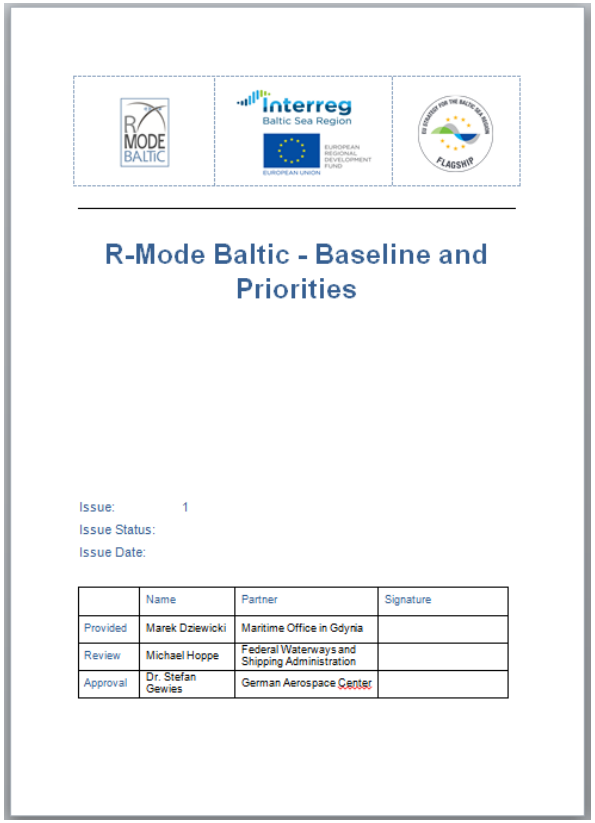
Maritime user requirements on a backup system?

- IMO Resolution A.915 (22) – user requirements for future GNSS
- IMO Resolution A.1046 (27) – service requirements for Worldwide Radio Navigation Systems
- IMO the SAR Convention and reports of NAV-Committee meetings – need for alternative navigation system to increase robustness, reliability and availability
- IMO MSR performance standard and PNT guideline – use of terrestrial services would improve redundancy and introduce new integrity concepts



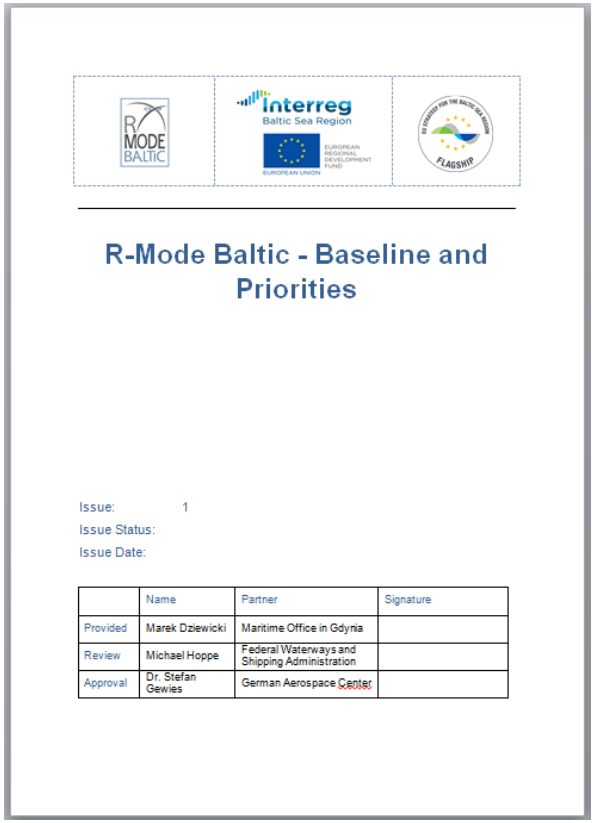
R-Mode Baltic - Baseline and Priorities

Issue: 1
Issue Status:
Issue Date:

	Name	Partner	Signature
Provided	Marek Dziewicki	Maritime Office in Gdynia	
Review	Michael Hoppe	Federal Waterways and Shipping Administration	
Approval	Dr. Stefan Gewies	German Aerospace Center	

Maritime user requirements on a backup system?

- IALA R-115 – DGNSS Services: recommends the use of proper radio frequency bands
- IALA R-150 - future of IALA DGNSS: NMA asked to consider the implementation of new services
- IALA Recommendation A-124 – encourages administrations to provide an AIS shore infrastructure in terms of navigation safety
- IALA R-124 – management and prevention of AIS data channel overload
- IALA World Wide Radio Navigation Plan
- IALA R-129 - GNSS Vulnerability and Mitigation Measures – Minimum user requirements for a backup navigation system proposed



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Minimum user requirement on a backup system

IALA R-129 based on IMO Resolution A.915(22)

Maritime region	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability % per 30 days	Continuity % over 15 minutes	Coverage	Fix interval (seconds)
	Horizontal (meters)	Alert limit (meters)	Time to Alarm (seconds)	Integrity Risk (per 3 hours)				
Ocean	~~1000~~	~~2500~~	Not covered by MF or VHF transmitter sites					60
Coastal	100	250	30	10^{-4}	99	N/A[2]	Regional	15
Port approach and restricted waters	10	25	10	10^{-4}	99	99,97	Regional	2
Port	1	~~2.5~~	Not reachable		99	99,97	Local	1
Inland Waterways	10	25	10	10^{-4}	99	99,97	Regional	2

R-Mode service area

Types of alternative system

Definitions in IALA Recommendation R-129

- A **redundant system** provides the same functionality as the primary system, allowing a seamless transition with no change in procedures.

- A **backup system** ensures continuation of the navigation application, but not necessarily with the full functionality of the primary system and may necessitate some change in procedures by the user.

R-Mode

GNSS independent time synchronisation

- A **contingency system** allows safe completion of a manoeuvre, but may not be adequate for long-term use.

GNSS dependent time synchronisation

User requirement used in the project R-Mode Baltic

The project team will setup a contingency system for GNSS, which in case of unavailability of GNSS should allow positioning for at least **2 hours** with:

	System level parameters				Service level parameters			
Maritime region	Absolute Accuracy	Integrity			Availability % per 30 days	Continuity % over 15 minutes	Coverage	Fix interval (seconds)
	Horizontal (meters)	Alert limit (meters)	Time to Alarm (seconds)	Integrity Risk (per 3 hours)				
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- Safe navigation on Baltic Sea needs a backup system for GNSS for continuous and reliable positioning and timing
- R-Mode is a cost-efficient system to provide ranging, positioning and timing
- Project R-Mode Baltic team will perform fundamental developments and build up a first testbed that utilises maritime radio beacons and AIS base stations
- A first coverage prediction of radio beacons and AIS base stations shows the feasibility of the R-Mode approach for Southern Baltic Sea
- Requirements on a backup system for GNSS proposed in IALA R-129 will be used for the R-Mode system development

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