R-Mode Baltic – Baseline and Priorities

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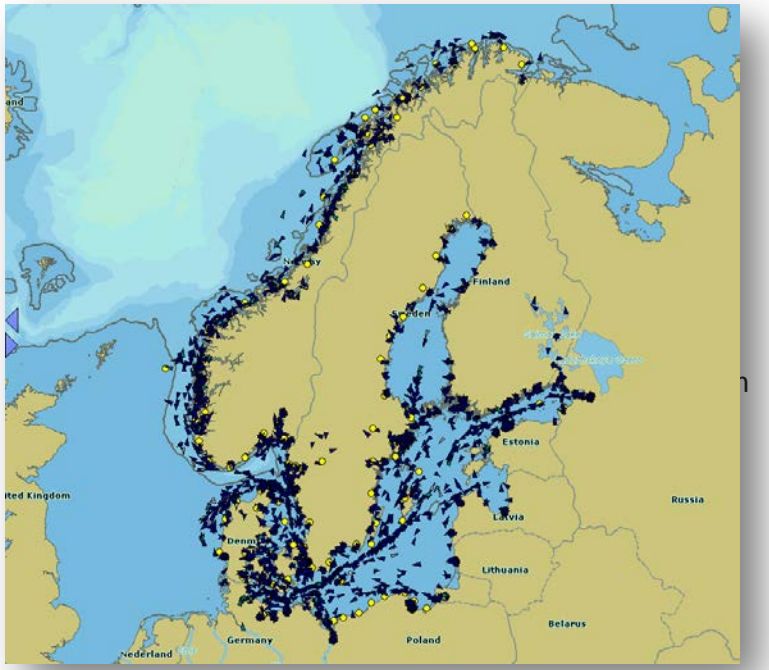
Maritime domain - dominated by GNSS

Safe navigation requires a backup system

- GNSS (GPS, GLONASS, Beidou/Compass, Galileo, QZSS) has become the primary source for maritime positioning and time transfer
- GNSS data is used in many navigation and communication systems (AIS, ECDIS, INS)
- GNSS signals are vulnerable to unintentional and intentional interferences
- IMO, IALA: maritime user requires a backup system independent of GNSS



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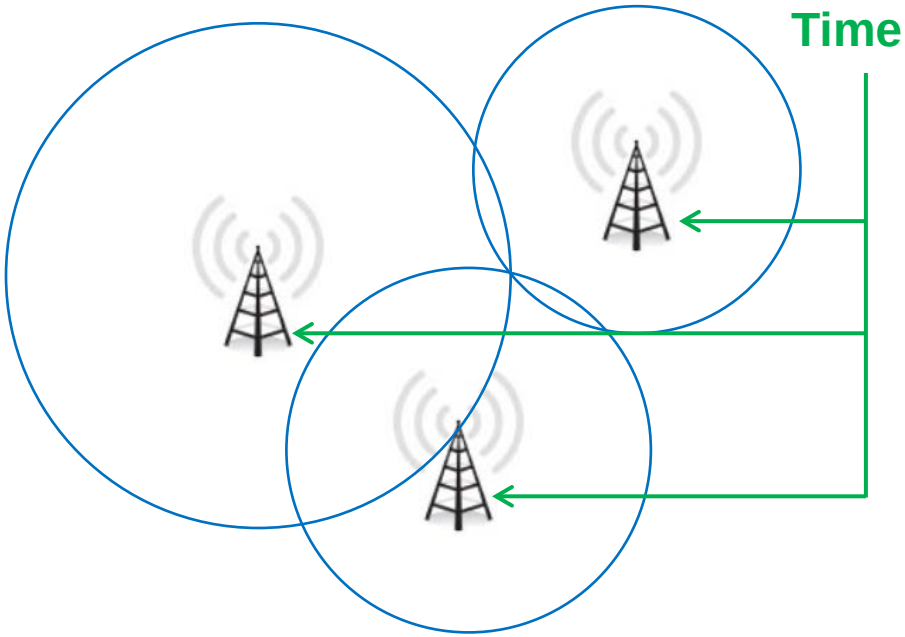
Introduction: R-Mode

A terrestrial maritime backup system to GNSS

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

- Signals of OPportunity (SoOP) for R-Mode are
  - MF maritime radio beacons
  - VHF (AIS/VDES) base stations



DLR

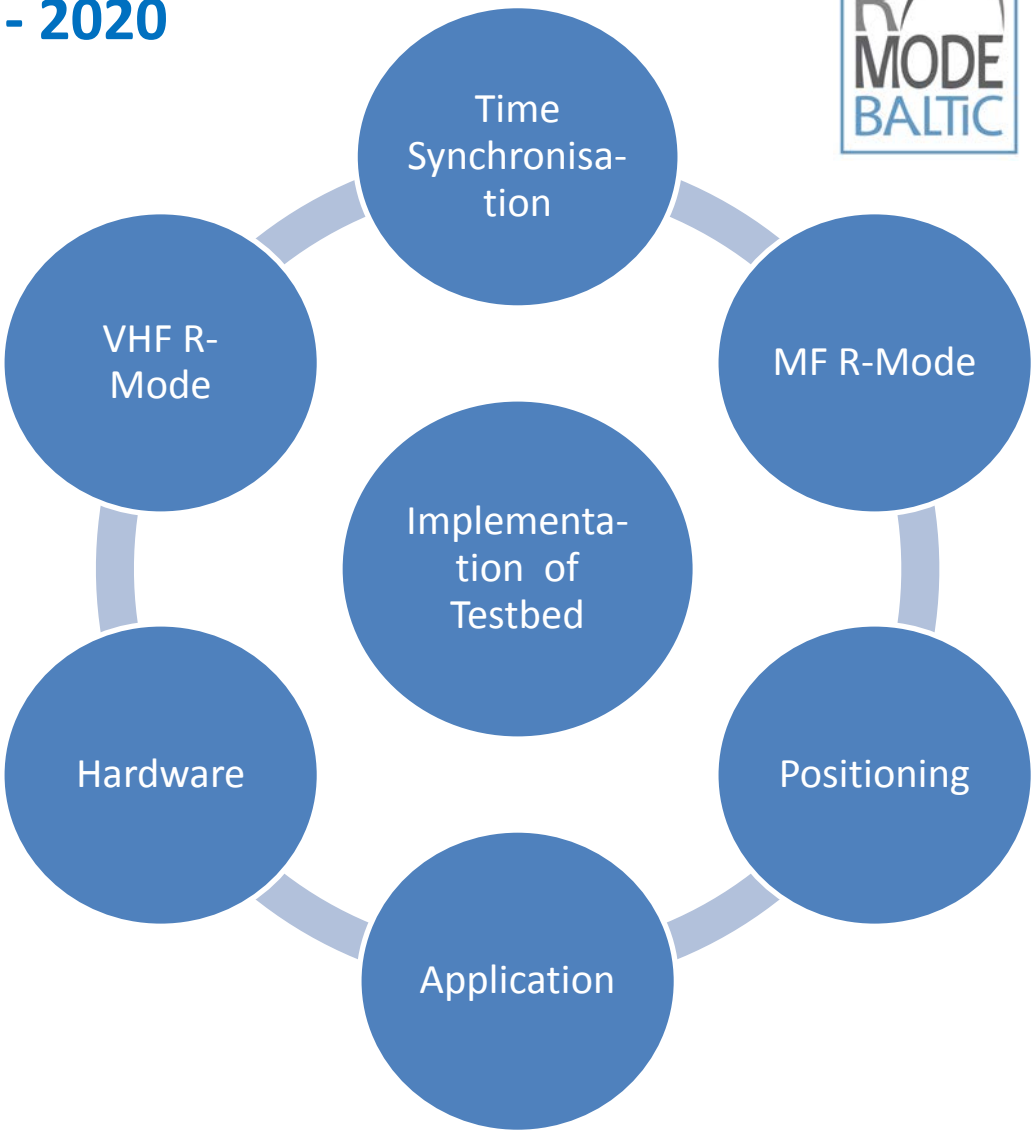
Project R-Mode Baltic 2017 - 2020

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.

First step

- Baseline and priorities report



Scope of *Baseline and Priorities* report

- Answer for **R-Mode system justification** – why, what for, how?

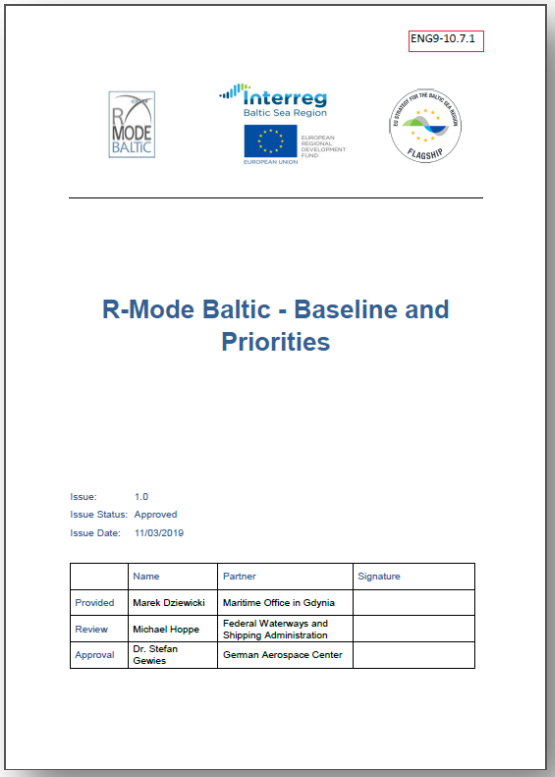
- perform an **analysis and evaluation** of the **current international legal documents** treating about maritime radionavigation systems in the light of e-Navigation strategy looking for backup to GNSS (IMO, IALA, ITU, IEC, RTCM, EMRF) ….

- **review** of Terrestrial Radionavigation Systems (**TRS**) and their **ranging methods, historical and contemporary** (GSM, UMTS, LTE networks)

- **Impact from other Projects:** ACCSEAS, Germany, Netherlands, UK, Canada, China, Korea

Scope of *Baseline and Priorities* report

- to **define service and user requirements** focusing on ability to exploit **existing infrastructure and standards** of MF and VHF services also taking into account VDES
- **Sources of possible errors** (positioning, timing, ambiguity algorithms, propagation, spoofing, jamming)
- **Combined signal** MF (MSK+2CW radio beacon) , VHF (AIS, VDES) reception
- **to develop preliminary specification** for the new R-Mode positioning system necessary when GNSS is corrupted or unavailable.



ENG9-10.7.1

R-Mode Baltic - Baseline and Priorities

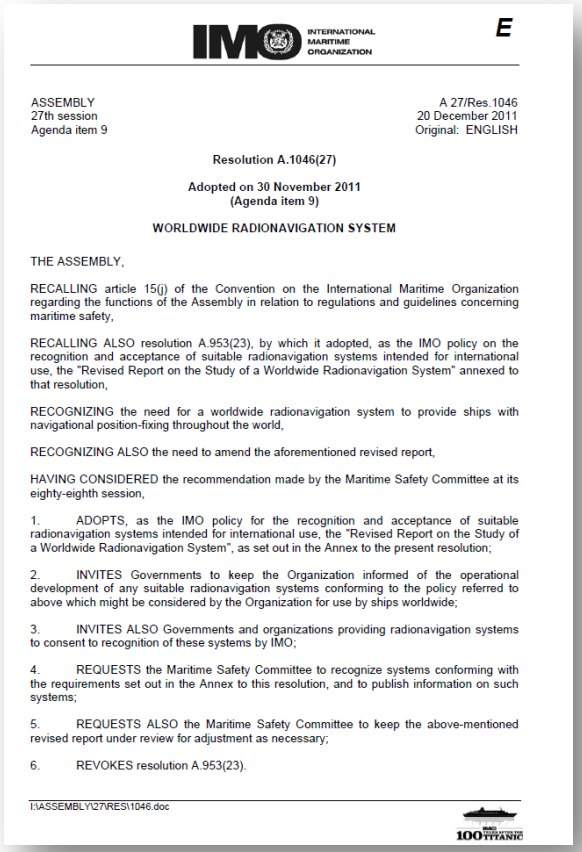
Issue: 1.0
Issue Status: Approved
Issue Date: 11/03/2019

	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?

IMO documents

- 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**



IMO INTERNATIONAL MARITIME ORGANIZATION

E

ASSEMBLY
27th session
Agenda item 9

A 27/Res.1046
20 December 2011
Original: ENGLISH

Resolution A.1046(27)

Adopted on 30 November 2011
(Agenda item 9)

WORLDWIDE RADIONAVIGATION SYSTEM

THE ASSEMBLY,

RECALLING article 15(j) of the Convention on the International Maritime Organization regarding the functions of the Assembly in relation to regulations and guidelines concerning maritime safety,

RECALLING ALSO resolution A.953(23), by which it adopted, as the IMO policy on the recognition and acceptance of suitable radionavigation systems intended for international use, the "Revised Report on the Study of a Worldwide Radionavigation System" annexed to that resolution,

RECOGNIZING the need for a worldwide radionavigation system to provide ships with navigational position-fixing throughout the world,

RECOGNIZING ALSO the need to amend the aforementioned revised report,

HAVING CONSIDERED the recommendation made by the Maritime Safety Committee at its eighty-eighth session,

1. ADOPTS, as the IMO policy for the recognition and acceptance of suitable radionavigation systems intended for international use, the "Revised Report on the Study of a Worldwide Radionavigation System", as set out in the Annex to the present resolution;

2. INVITES Governments to keep the Organization informed of the operational development of any suitable radionavigation systems conforming to the policy referred to above which might be considered by the Organization for use by ships worldwide;

3. INVITES ALSO Governments and organizations providing radionavigation systems to consent to recognition of these systems by IMO;

4. REQUESTS the Maritime Safety Committee to recognize systems conforming with the requirements set out in the Annex to this resolution, and to publish information on such systems;

5. REQUESTS ALSO the Maritime Safety Committee to keep the above-mentioned revised report under review for adjustment as necessary;

6. REVOKES resolution A.953(23).

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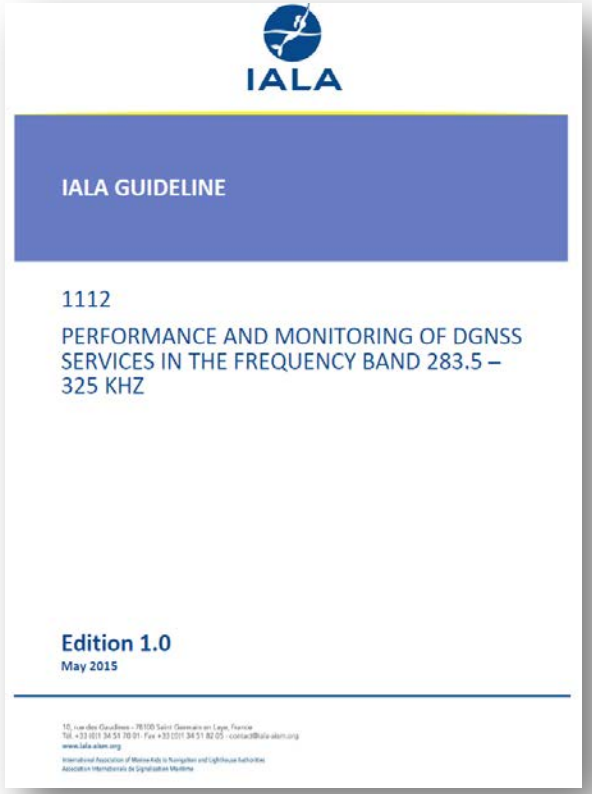
Maritime user requirements on a backup system?

IALA documents

- 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-123 – 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 Guideline 1117 **Overview on VHF Data Exchange System (VDES)**
- IALA R-129 - **GNSS Vulnerability and Mitigation Measures** – minimum user requirements for a backup navigation system proposed



Maritime radio requirements

ITU-R documents and others …

- **Technical characteristics of DGNSS** differential transmissions Recommendation M.823-3
- **AIS Technical Characteristics** - Recommendation M.1371- ver.5
- **ITU-R Recommendation M.2092**, - provides the technical characteristics of a **VHF data exchange system (VDES)**
- **IEC, RTCM, RSIM, NMEA, …**

Impacts from other projects – status of R-Mode

MF	VHF
ACCSEAS	
R-Mode in Germany	
R-Mode in the Netherlands (planned)	
R-Mode in UK	
R-Mode in Canada	
	R-Mode in China (AAPS)
R-Mode Korea	

R-Mode applications

- Navigation operations
- traffic management
- port operations
- casualty analysis
- offshore exploration and exploitation
- fisheries
- search and rescue
- pilotage
- support of e-Naviagtion (resilient navigation)
- military

T. Häntzschel

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 signals					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

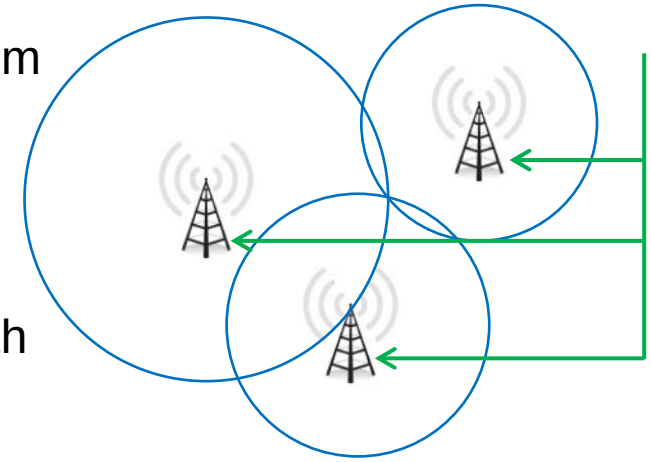
User requirement used in the project R-Mode Baltic

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)				
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
Inland Waterways	10	25	10	10^{-4}	99	99,97	Regional	2

Basic R-Mode system requirements

- work independently from GNSS, based on existing but modified infrastructure,
- have unlimited user-capacity,
- provide a two-dimensional position fix (x,y),
- provide a position referenced to geographical system WGS84,
- provide position ambiguity resolution at high confidence level,
- be based on Coordinated Universal Time (UTC) with an error of less than 10 ns per station,
- be designed to support self-test ability (e.g. clock), remote monitoring and integrity warning-reporting to the user,



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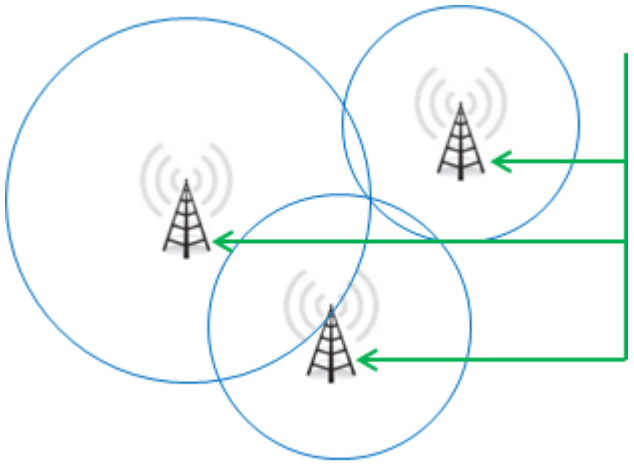
Basic R-Mode system requirements

- not disturb or degrade any legacy services (e.g. additional R-Mode messages should not prevent transmission of legacy service integrity information that the user can always be informed about a system unavailability in the defined time to alarm),
- provide in each minute all necessary information for a cold start of the receiver (e.g. station coordinates, clock error) and
- MF and VHF R-Mode transmitters shall be usable for positioning in a mixed signal mode.



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Additional MF R-Mode requirements

- The system is designed to work within the 500 Hz channels spacing in Europe (USA 1 kHz channel spacing)
- The system is designed to work with up to 200 bps Minimum Shift Keying (MSK)
- Additional CW carriers can be required to be broadcast along with standard MSK signal
- Precise and stable clock – the source for both the carrier phase and the time of bit transmission
- Any additional CW and resulted spectrum change should comply with ITU-R regulations as investigated in the study.

Additional AIS R-Mode requirements

- AIS use the two channels of 161.975 and 162.025 MHz with and bandwidth of 25 kHz. Only these are allowed for signal transmissions. An exception exists when switching to VDES.
- The exchange of safety-relevant information has priority. This limits the possibilities to add additional AIS messages which increase the channel load in a certain region.
- Precise and stable clock – the source for both the carrier phase and the time of bit transmission

R-Mode station coordinates

Coordinate system

- It is recommended to survey and provide coordinates in WGS84.

Coordinate accuracy

- Regular survey of current position depending on the level of accuracy requirement necessary.
- The date of coordinate survey should be made available together with station coordinates in WGS84.

R-Mode station time

- Recommended time base is UTC.
- Different options for the type of station clock and the way of time synchronisation with UTC
- Each administration has to consider which solution fulfils their requirements.
  => A cost-benefit analysis necessary.

- R-Mode Baltic: station synchronisation error should not exceed a 10 ns deviation to UTC

Various levels of R-Mode implementation

Suggested levels of R-Mode usage

Level of R-Mode usage	Method	Use case	Remarks
Low	Ranging with less than 4* R-Mode signals	Integrity for GNSS positioning	(MF, AIS/VDES or combined)
Medium	Positioning (Lat/Long) with 4* or more R-Mode signals	Combined GNSS/R-Mode Positioning	(MF, AIS/VDES or combined)
High	Positioning (Lat/Long) with 4* or more R-Mode signals	GNSS independent positioning	(MF, AIS/VDES or combined)

*) The number of stations could be reduced by one if priory information is available.

Various levels of R-Mode implementation

Suggested modes of operation

Level of R-Mode implementation	Method	Gap-Time during GNSS outage	Use case
Very Low	GNSS time synchronization	No	Bridge outages at user site (e.g. local interference)
Low	Use of protected GNSS-Antenna Use of Galileo PRS	Depends on reason of outage	Bridge outages at user site (e.g. local interference). R-Mode TX site may withstand local jamming spoofing
Medium	GNSS time synchronization with Rb-clock GNSS time synchronization with CS-clock	< 3-6 h < 12-24 h	End manoeuvre in case of full GNSS outage
High	Use of R-Mode specific time synchronization corrected time differences of an asynchronous R-Mode system	24/7	Independent system in case of full GNSS outage

Sources of errors when using terrestrial SoOP

- Positioning domain
  - Positioning error sources
  - Potential methods to mitigate errors in positioning algorithms
  - Other methods to minimize positioning errors
- R-Mode signal generation: MF / AIS
- Potential R-Mode errors sources
  - Ambiguity resolution (MF)
  - Propagation delay (MF)
  - Skywave interference (MF)
  - Ducting effect (AIS/VDES)
  - Interference in the VHF band (AIS/VDES)
  - Jamming and spoofing (MF and AIS/VDES)
- Radiowave propagation: MF / VHF

Conclusions

- International documents of IMO, IALA, ITU-R express the need of a backup system to GNSS in the radio frequency (RF) domain using so-called “Signals of OPportunity” (SoOP)
- Legal documents has to be considered
- Basic R-Mode requirements could be defined based on already existing documents
- Consider available material which support R-Mode development

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