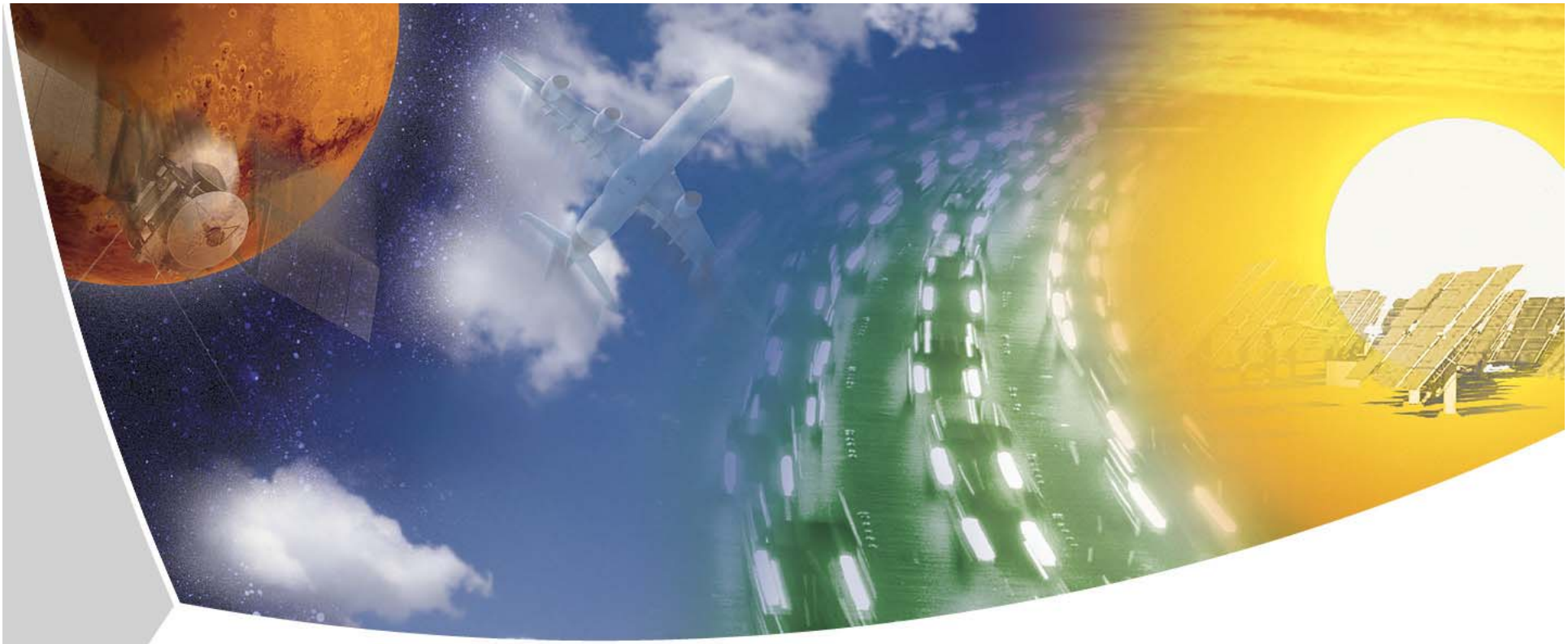

Integrity Concepts for Maritime Ground Based Augmentation Systems

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Topics

- Integrity
- Actual state of maritime DGNSS systems
- Future Concept of a P-DGNSS system
- Experimental GBAS System
- State classification
- Integrity Messaging
- Integrity Monitor (demo)
- Outlook

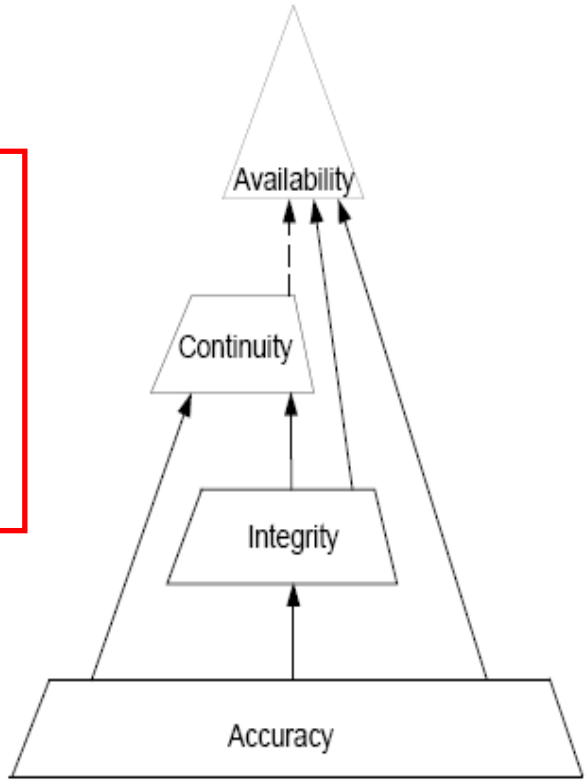
Quality parameters to monitor GNSS system reliability

- **Accuracy:** degree of closeness of a measured or calculated quantity to its true (actual) value → degree of veracity

- **Integrity:** consistency of measured values and generation of user alerts if the system is out of specification
  - Alarm Limit in [m]
  - Time-To-Alarm (TTA) in [s]
  - Integrity risk

- **Continuity:** probability, that user positioning is possible into a specific time slot without breaks

- **Availability:** probability value based on compliance of whole system functionalities during system life-cycle



Maritime Requirements on GNSS based positioning

IMO Requirements for maritime environment

	Ocean/Coastal SAR	Port	Automatic Docking
Position Error H/V (m)	< 10 / NA	< 1 / NA	< 0.1 / -
Alarm Limit (m)	25	2.5	0.25
Time to Alarm (s)	10	10	10
Integrity Risk	1e-5/3h	1e-5/3h	1e-5/3h

Galileo SoL
System Specification

Galileo SoL
< 4 m / < 8 m
12 m / 18 m
< 6
3.5e-7/150s

Challenge

Improvement of Accuracy + **Integrity** by

- new/modified GNSS
- on-board service integration (e.g. PPP)
- sensor fusion (e.g. IMU/GNSS/RADAR/AIS etc.)
- **local and intelligent augmentation systems (GBAS)**

Possible Candidates of GBAS

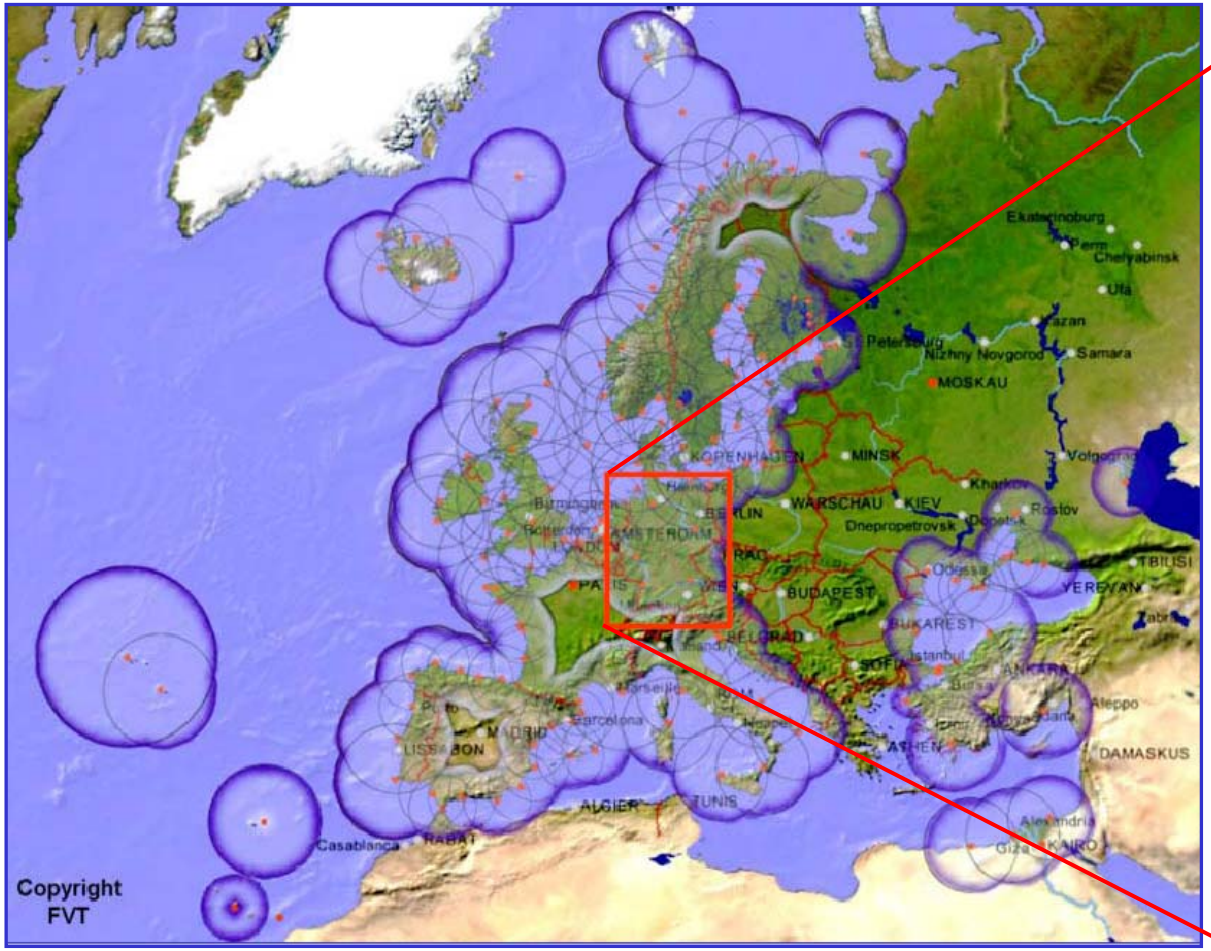
System	Accuracy	Coverage	Integrity/Continuity
IALA DGNSS	1-3 m	local/regional	Yes/High
SBAS	1-3 m	regional/global	Yes/High
AIS [1]	1-3 m	Local	Yes/Moderate
Pseudolites	sub-meter	Local	Yes/Moderate
eLoran	1-3 m	regional	Yes/High
RTK	sub-meter	Local	X/Low

System	Provider cost	User cost	Marine Standard
IALA DGNSS	moderate	Low	Yes
SBAS	very high	Low	No
AIS	low	Low	Yes
Pseudolites	high	moderate	No
eLoran	Low [2]	moderate	No
RTK	moderate	High	No

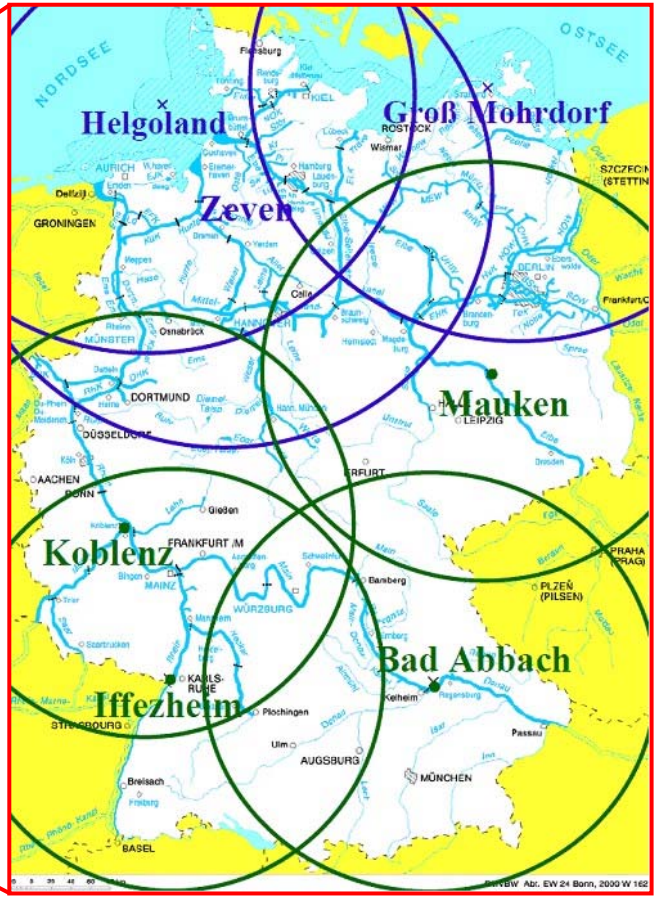
- No maritime standards for RTK and Pseudolites
- Additional Requirements on Aboard Equipment

- Development Demand
  - Integrity Monitoring Concept (e.g. IALA FFIM or by Protection Level)
  - Robust Communication with Higher Data Capacity (RTCM 3)
  - Integrity Messaging Inside RTCM 3

Maritime Reference Networks → IALA DGPS beacon system



Coverage Europe



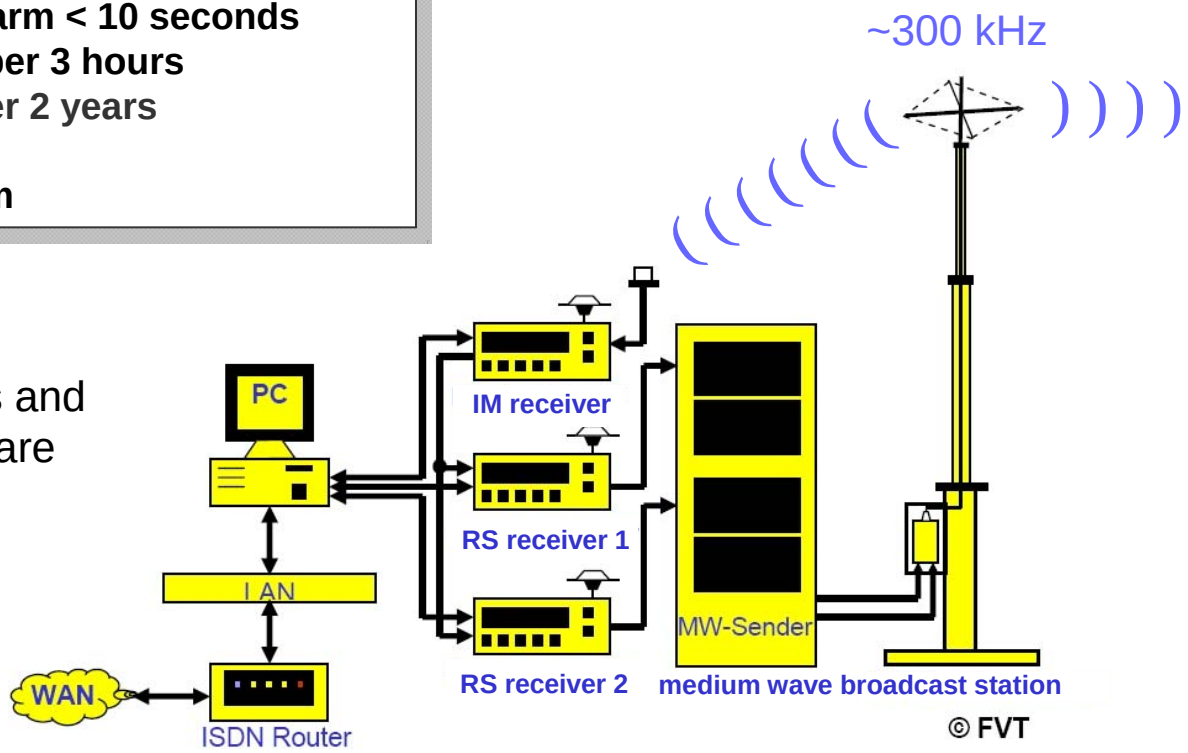
Coverage Germany

IALA certified C-DGPS standard

C-DGPS – Code based Differential GPS → code based pseudoranges are used for differential positioning

Accuracy:	**< 10m off-shore (< 5m inland)**
Integrity:	**Time to alarm < 10 seconds**
Continuity:	**> 99,85% per 3 hours**
Availability:	**> 99,5% per 2 years**
Range of coverage:	**200-300 km**

- Reference station receivers and medium wave transmitters are redundantly equipped



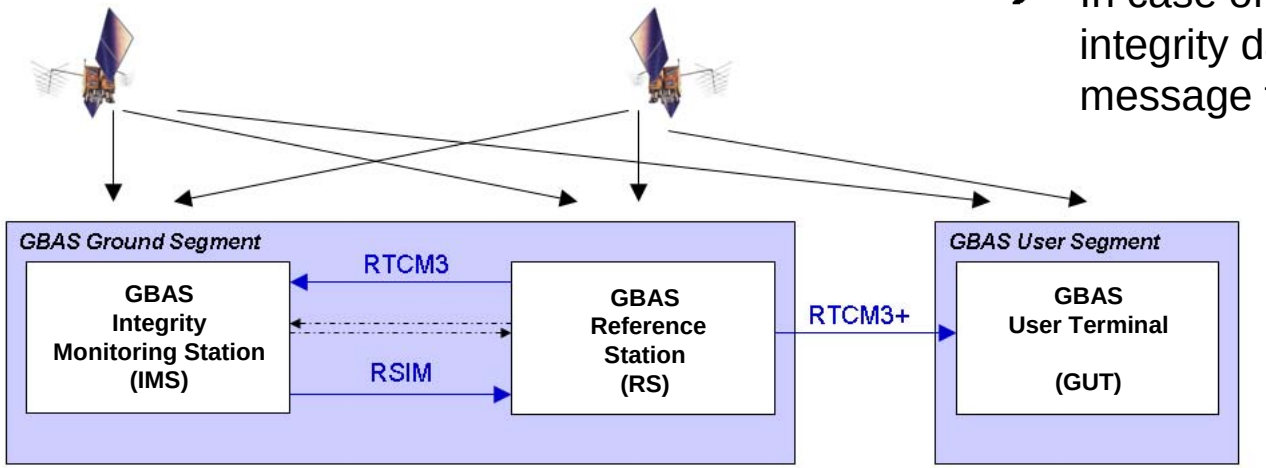
IM – Integrity Monitoring receiver
RS – Reference station receiver

Future concept → P-DGNSS evolution

P-DGPS – Carrier Phase Based Differential GNSS → carrier phases are used for differential positioning

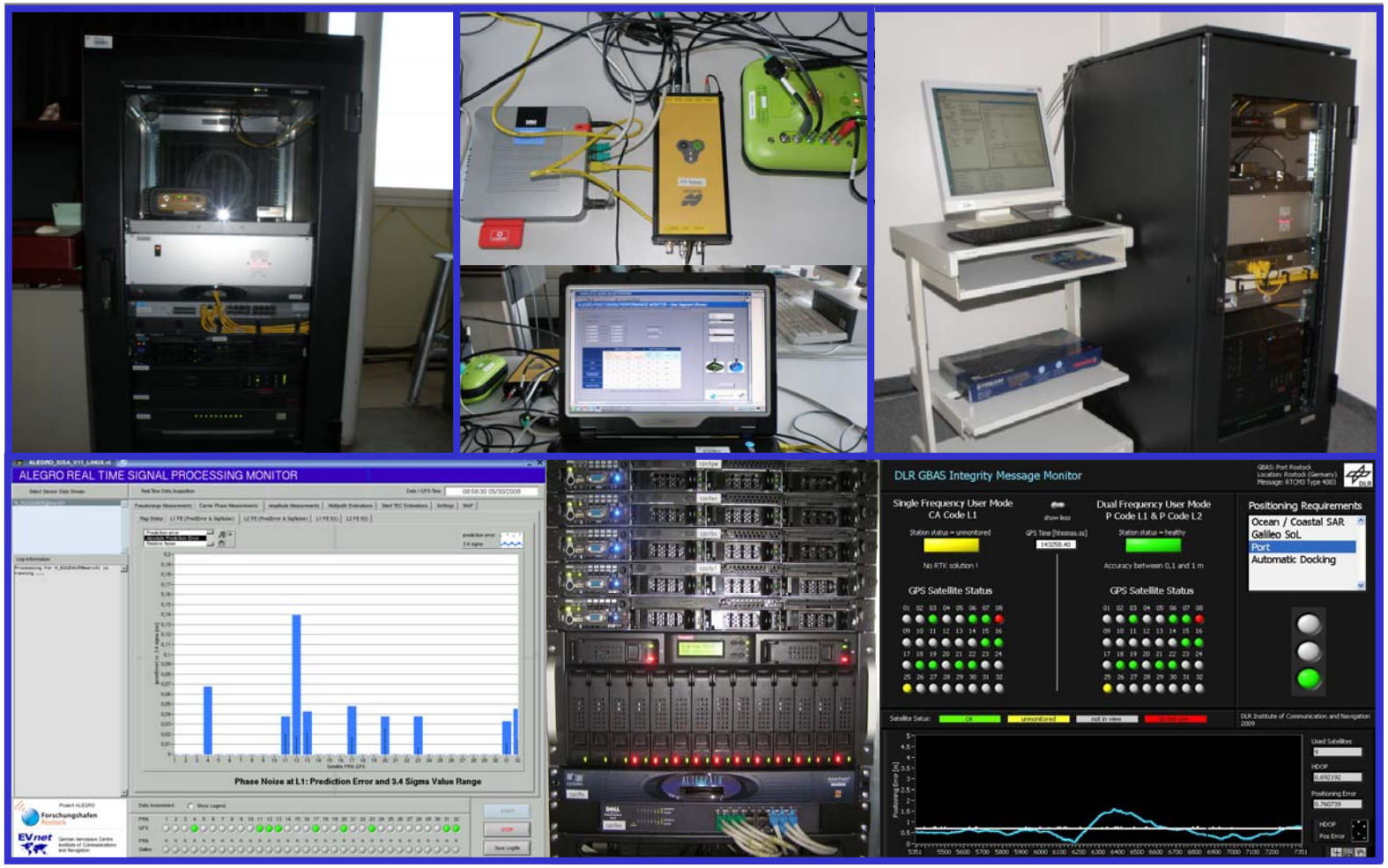
Accuracy:	**< 1m port (< 0,1m docking)**
Integrity:	**Time to alarm < 10 seconds**
Continuity:	**> 99,85% per 3 hours**
Availability:	**> 99,5% per 2 years**
Range of coverage:	**~ 40 km**

- Standard format for provision of P-DGNSS augmentation data is RTCM3
- RTCM3+ indicates augmentation data which passed the integrity monitoring successfully
- In case of additional GBAS integrity data a new or special message type has to be specified



Current development state of P-DGNSS GBAS by DLR

- GBAS station at Research Port Rostock is in operational state



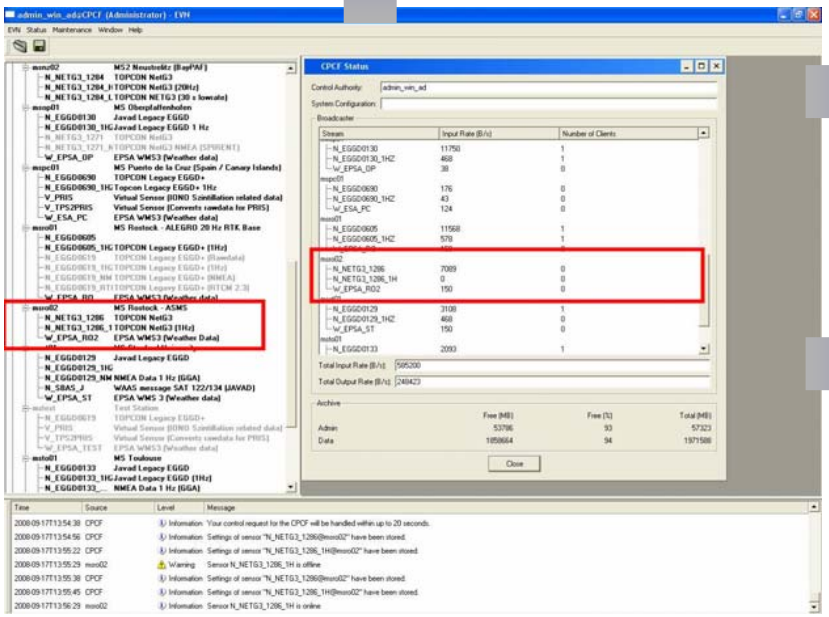
IMS = Integrity Monitoring Station RS = Reference Station GUT = GBAS User Terminal

Experimental GBAS – HW Built Up

User Segment

Javad TRIUMPH1

- RTK for GPS, Glonass, (GALILEO)
- GPS L1, L2, L5; GLONASS L1, L2; GIOVE, GALILEO L1, E5
- 20 Hz raw data und position data



Remote control by Central Processing and Controlling Facility (CPCF) via EVnet

RS and IMS are physical constructed, implemented as EVnet Station

Reference Station

TOPCON NetG3

- RTK for GPS & Glonass
- GPS L1, L2, L5; GLONASS L1, L2; prepared GALILEO
- 50 Hz raw data und position data

TOPCON CR-G3

- Multi frequency antenna
- Choke ring (multipath mitigation)

Monitoring Station

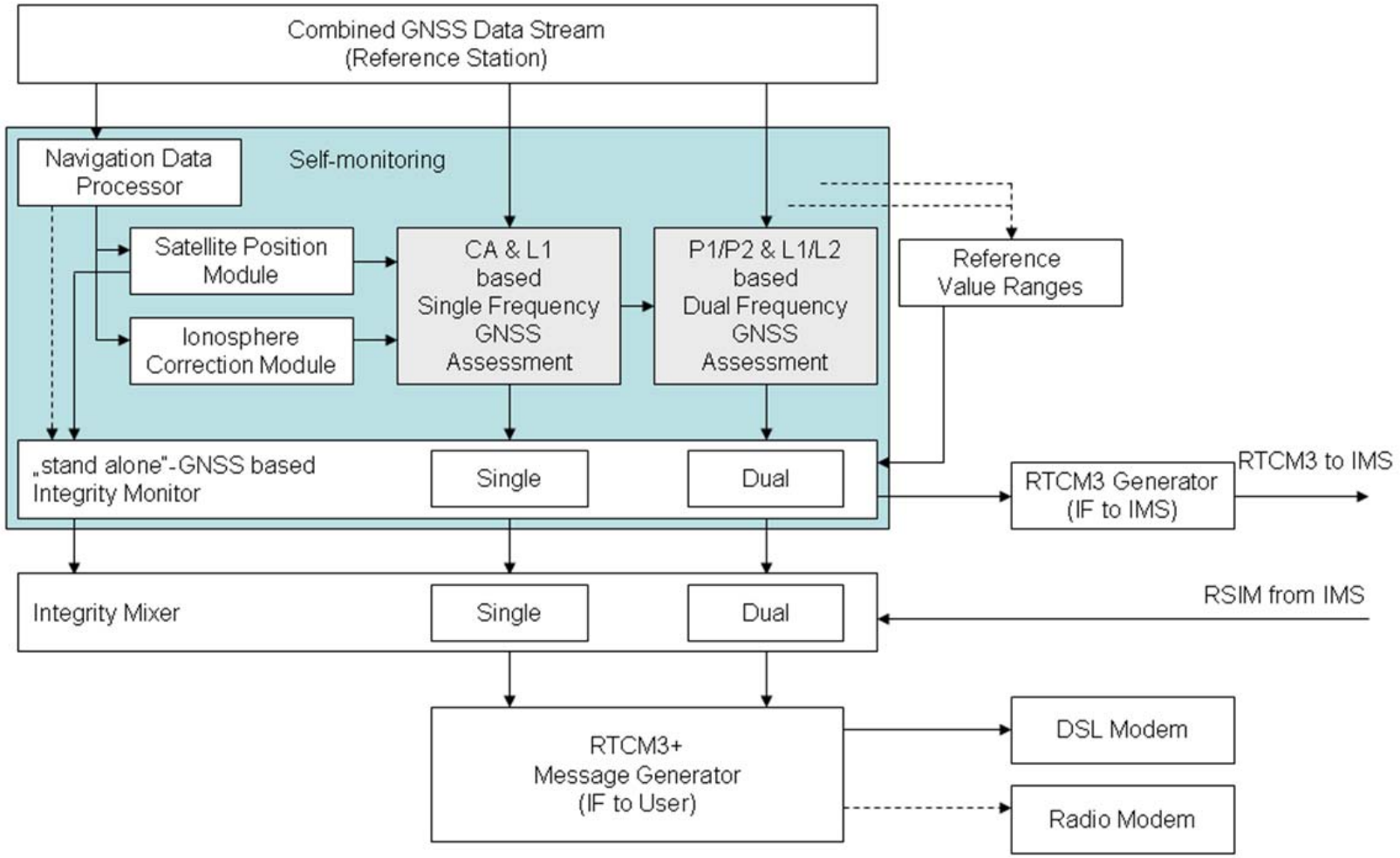
TOPCON NetG3

- RTK for GPS and Glonass
- GPS L1, L2, L5; GLONASS L1, L2; prepared GALILEO
- 20 Hz raw data und position data

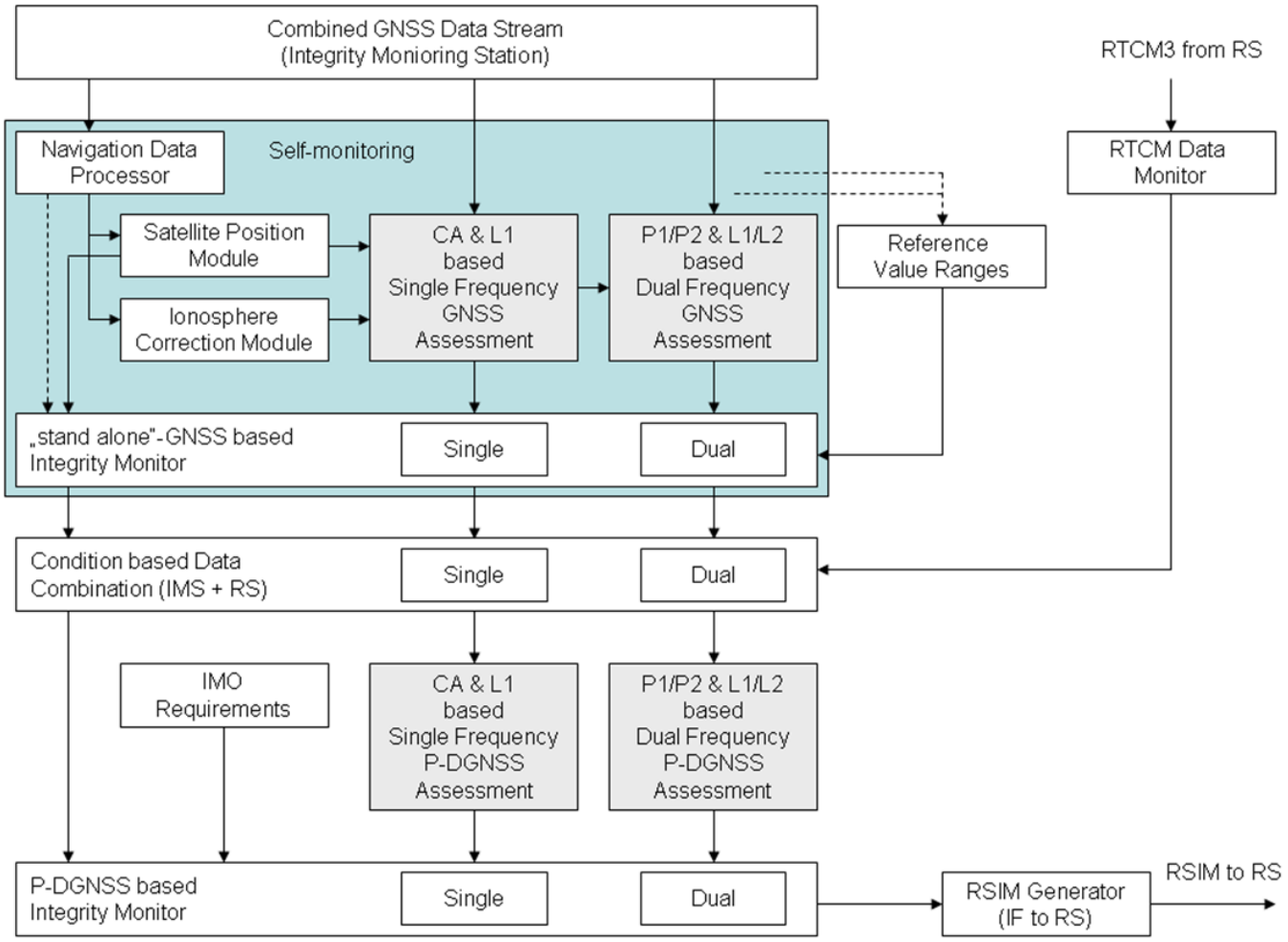
TOPCON G3-A1

- L1/L2 antenna

Architecture of integrity monitoring at RS of GBAS



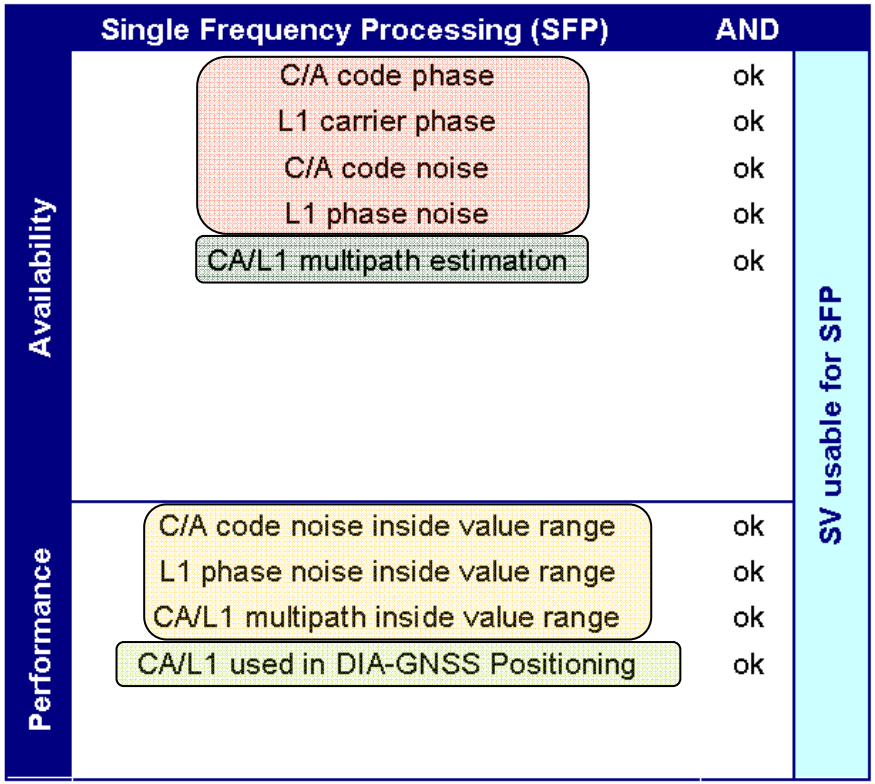
Architecture of integrity monitoring at IMS of GBAS

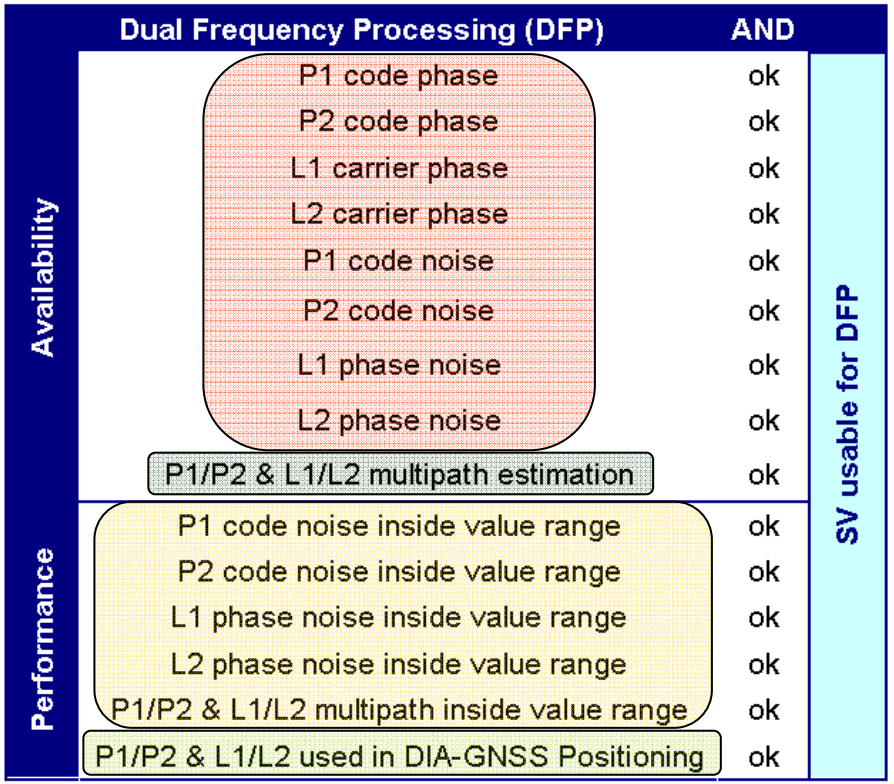


Performance Key Identifiers

Code-Phase and Carrier-Phase Pre-processing

Carrier Smoother for multipath & IPE propagation





Pre-selection by comparison with reference values

Pre-Selection by DIA Positioning

Sum of PKI applied to pre-specify the satellite state by self-monitoring

Concept on state classification

	Single Frequency Mode	Dual Frequency Mode	Satellite state
1	usable	usable	usable
2	do not use	usable	Single do not use
3	usable	do not use	dual do not use
4	do not use	do not use	Do not use
5	(*)	(*)	unmonitored

→ States at GNSS satellite level

(*) If GNSS observations of a specific satellite are missed on IMS side (*) and the assessment is only based on the validation results of the RS side, the satellite is assigned to "unmonitored"

State	Single Frequency Mode	Dual Frequency Mode
1	unhealthy	unhealthy
2	unmonitored	unhealthy
3	healthy	unhealthy
4	unhealthy	unmonitored
5	unmonitored	unmonitored
6	healthy	unmonitored
7	unhealthy	healthy
8	unmonitored	healthy
9	healthy	healthy

→ States at GBAS level

At states 2 – 9 the GBAS is qualified for P-DGNSS → is has to be considered that state 5 (and partly the states 2, 4, 6 and 8) induce the utilization of P-DGNSS techniques without validation by IMS

Derived state classification for GBAS

- Number of usable Satellites (NSAT) greater than 3
- Horizontal Dilution of Precision lower than 7.5
- Horizontal Positioning Error can be estimated (yes/no)
- Horizontal Positioning Error fulfils requirements (e.g. for Port operations HPE < 1 m)

			HPE available / HPE < 1 m			
			0 / 0	0 / 1	1 / 1	1 / 0
Acceptable delay of RS data	NSAT >3 / HDOP < 7.5	0 / 0	unmonitored			
		0 / 1				
		1 / 1	unmonitored		healthy	unhealthy
		1 / 0	unmonitored			
Unacceptable delay of RS data	NSAT >3 / HDOP < 7.5	1 / 0	unhealthy			
		1 / 1				
		0 / 1				
		0 / 0				

Additional Performance Flag	
0	0.1m <= HPE < 1m
1	HPE < 0.1 m

- Additional performance flag to fulfill requirements on automatic docking maneuvers HPE < 0.1 m)

Integrity Messaging

New RTCM3 message applied by DLR and granted by RTCM!

Format Specification (Version 1):

RTCM Message 4083 – Submessage 1: GPS C/A & L1 Service

RTCM Message ID	Sub-Message ID	Version ID	ID GBAS	TOW	GBAS Status	HPE Status	
(12 Bit)	(12 Bit)	(8 Bit)	(12 Bit)	(30 Bit)	(2 Bit)	(2 Bit)	

78 bits

RTCM Message 4083 – Submessage 2: GPS C/A & L1 Service

RTCM Message ID	Sub-Message ID	Version ID	ID GBAS	TOW	NSAT	PRN ID	PRN Status	PRN ID	PRN Status	
(12 Bit)	(12 Bit)	(8 Bit)	(12 Bit)	(30 Bit)	(5 Bit)	(6 Bit)	(2 Bit)	(6 Bit)	(2 Bit)	

79 + Nsatx8 bits

RTCM Message 4083 – Submessage 3: GPSP1/P2 & L1/L2 Service

RTCM Message ID	Sub-Message ID	Version ID	ID GBAS	TOW	GBAS Status	HPE Status	
(12 Bit)	(12 Bit)	(8 Bit)	(12 Bit)	(30 Bit)	(2 Bit)	(2 Bit)	

RTCM Message 4083 – Submessage 4: GPSP1/P2 & L1/L2 Service

RTCM Message ID	Sub-Message ID	Version ID	ID GBAS	TOW	NSAT	PRN ID	PRN Status	PRN ID	PRN Status	
(12 Bit)	(12 Bit)	(8 Bit)	(12 Bit)	(30 Bit)	(5 Bit)	(6 Bit)	(2 Bit)	(6 Bit)	(2 Bit)	

tbc

Example:

GPS L1L2/P1P2
with 12 tracked satellites
observables = 312 Byte
message 4083 ~32 Byte
→ 10% increase

Integrity Message Monitor

Graphical Integrity Message Monitor (real-time) created

Monitors the two provided GBAS-Services regarding satellite and service status

Different colours for status of a satellite: usable (green), do not use (red), unmonitored (yellow)

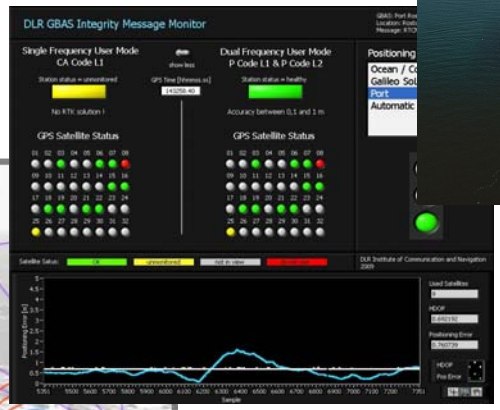
Status colours for provided service: healthy (green), unhealthy (red), unmonitored (yellow)

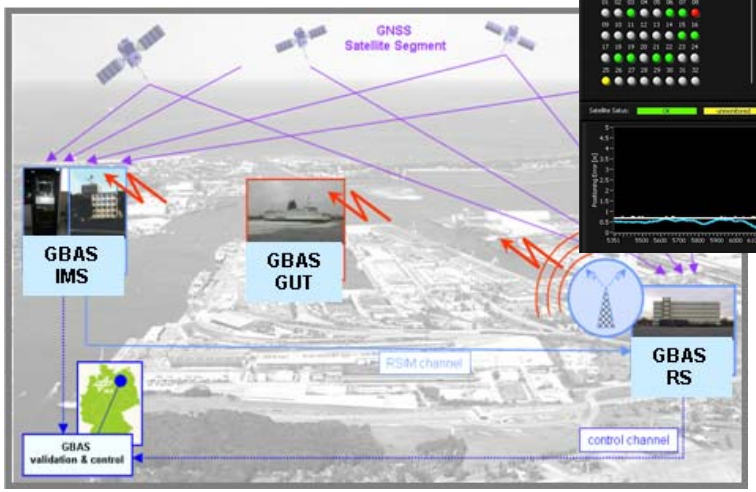
Graphical illustration of achieved position accuracy at IMS

Outlook

- Improvement Phase-based Maritime GBAS
  - Data Analysis for Reference Values (e.g. satellite- or station-specific, update)
    - A-priori P-DGNSS measurement error model
- Extension of Maritime GBAS:
  - Integration of GPS 3, GALILEO and Pseudolites (optional)
  - Calibration of Monitors for GALILEO Sensor Stations (quality parameters)
  - Integrity Risk Determination
- Aboard GNSS/GBAS:
  - Performance Controlled Positioning Techniques (Crossover from GBAS to stand alone GNSS)
  - Consideration of E-navigation Redundancy, Backup and Contingency Requirements Regarding GNSS as Core Element for Vessel Navigation
- GNSS Risk Analysis
  - E-Loran, R-Mode

Thank You For Your Attention





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