TELESPAZIO
a LEONARDO and THALES company

NAVISP-El1-057
VDES-R Advanced User Technologies for Alternative PNT (VAUTAP)

Final Presentation

Virtual

Q1 2025

VDES-R Advanced User Technologies for Alternative PNT (VAUTAP)

Final Presentation

1. **Welcome!**

2. Project Context and Programme of Work
3. VDES-R Mode Introduction
4. Project Outcomes
   - Consolidation of system and technology requirements for the proof of concepts
   - Down-selection of the most promising techniques
   - System design
   - Development and implementation of the proof of concepts
   - Performance analysis and experimentation, issues and re-testing
5. Conclusions and Lessons Learned
6. Way Ahead and Recommendations

7. **Q & A**

Project Context and Programme of Work

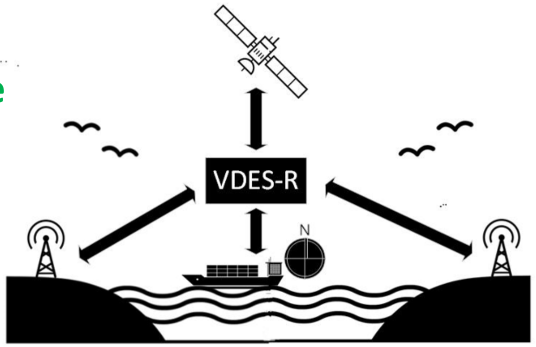
Louise Mercy (Telespazio UK)

VDES-R Advanced User Technologies for Alternative PNT (VAUTAP)
The big picture

Led by Telespazio UK, working with Kongsberg Discovery to..

Investigate and prove novel user segment VDES technologies with the aim of enhancing key performance figures of positioning

…complementing ongoing VDES investigations aiming to **improve A-PNT capabilities for maritime use cases.**



Developing new algorithms, waveforms, software and hardware to…

Evolve VDES R-Mode closer to an operational and viable component of a resilient PNT System-of-Systems

Consolidation of System and Technology REQs for POC
(*3 Months*)
* SoA, UC and scenario review
* Techniques and technologies
* Requirements capture

Preliminary PoC design and down-selection
(*3 Months*)
* Feasibility assessment
* Definition of the PoCs
* Technology shortlisting

Detailed Design
(*4 Months*)
* UE Breadboard & Algorithm
* Test environment definition
* Experimentation Testbed

Implementation of PoC
(*7.5 Months*)
* UE Breadboard & Algorithm
* Test environment definition
* Experimentation Testbed

Performance Analysis & Conclusions
(*9.5 Months*)
* Simulation & field test
* Way forward and lessons learned

Identify relevant **use cases and scenarios** within the maritime context

Design and develop **innovative concepts, techniques and technologies** relevant to user equipment

Assess the alternative PNT solutions based on **VDE-SAT in combination with VDE-TER services**

Investigate **novel user segment VDES technologies**

Investigate and analyse the **impact of key system aspects** such as synchronisation/timing issues of VDES-R

VDES-R Mode Introduction

Martin Bransby (Telespazio UK)

R-Mode, a potted History (1)

Concept and Feasibility

- The concept of a Ranging mode or “R-Mode” was first proposed in 2008, in a paper submitted to IALA by WSV
- A feasibility study of AIS R-mode was successfully completed by the ACCSEAS project in 2014
- ACCSEAS (EU funded) explored different approaches to AIS R-Mode, based around different ranging waveforms
- Conceptually, this places a ranging signal on a communication signal or other signal not specifically used for navigation, but in common use
- WSV identified Marine Beacon DGPS and AIS as candidate technologies for R-Mode
- Since then, technologies have been expanded to include the next-generation successor to AIS, commonly referred to as the *VHF Data Exchange System* (VDES)

ACCSEAS

Image credits: WSV, EU

R-Mode, a potted History (2)

Evolution

- Maritime VHF frequencies freed up by digitalisation, mean more bandwidth for information exchange like VDES
- These frequencies were secured at ITU WRCs 2016 & 2019
- Work continued in the R-Mode Baltic project, which looked at all 3 flavours of R-Mode and has developed new ranging waveforms
- MarRINav (Maritime Resilience and Integrity of Navigation)
  - Looked at combining pseudoranges from GNSS, eLoran signals and R-Mode within a Multi-systems receiver[1]
- Interest from ESA (NAVISP EL1-057 call – Development of Advanced VDES-R User Technologies for Alternative PNT)

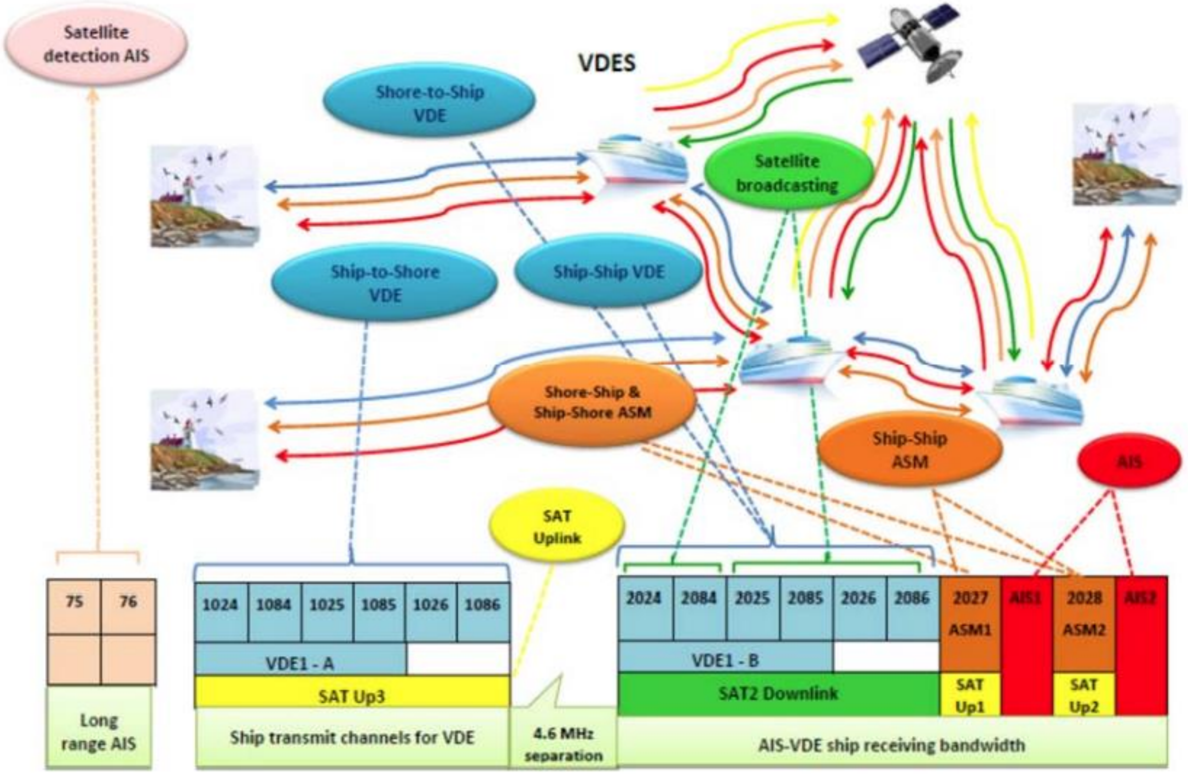


Image credits: IALA, EU, ESA

1. IMO performance standard MSC.401(95)

Project Outcomes

Tim Whitworth (Telespazio UK)
Pekka Peltola (Telespazio UK)
Anders Bjørnevik (Kongsberg Discovery)

Project Aims

Concepts

- Consider different environments with different performance requirements; ocean, coast, and harbour
- Investigate and prove the concepts of novel user segment VDES technologies:
  - Signal Design
  - Meta-signal Processing
  - Multipath and Interference Mitigation
  - Differential Positioning
  - Multi-Epoch Doppler Positioning
  - Antenna Diversity Processing
  - Nav Message Authentication
  - Two-Way Ranging

Testing

- The activity will also assess the alternative PNT solutions based on VDE-SAT in combination with VDE-TER services:
  - Simulations of satellite transmitters to assess performance
  - Simulations of satellite and terrestrial transmitters for a combined solution
  - Real testing of terrestrial transmitters

Consolidation of System and Technology Requirements for the PoC

Signal Design

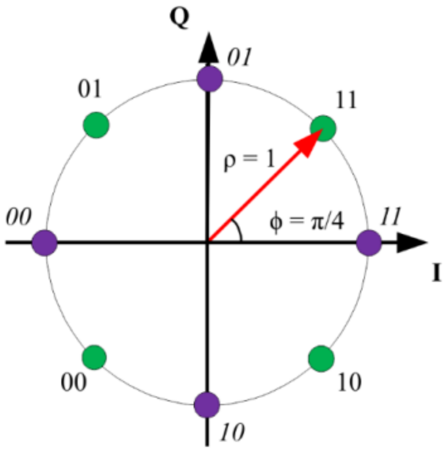
- The new signal design is to improve the code-delay estimate, with the aim of reduction in r.m.s. error of 34% over a PRN, or an equivalent of 3.5dB gain. Available for TER transmitters using the IALA required π/4 QPSK.

- Recommendation - concatenated mixture of alternating symbols and random signals.

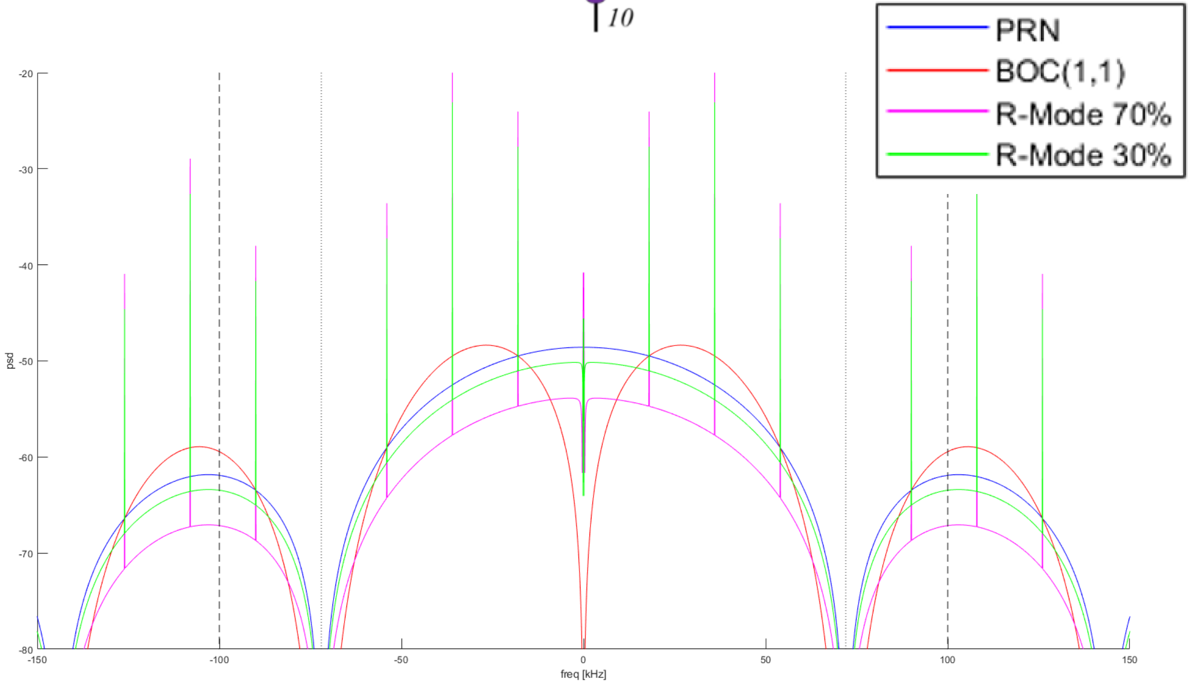
- The highly repetitive segment of the R-Mode signal with both 30% and 70% alternating ratio shows up as spikes in the frequency domain

- Sequences have been found with good properties for shorter lengths, with a maximum deviation similar to GPS codes of the same length

- Full system will be tested with 4 transmitters and 1 receiver to conduct full PVT testing



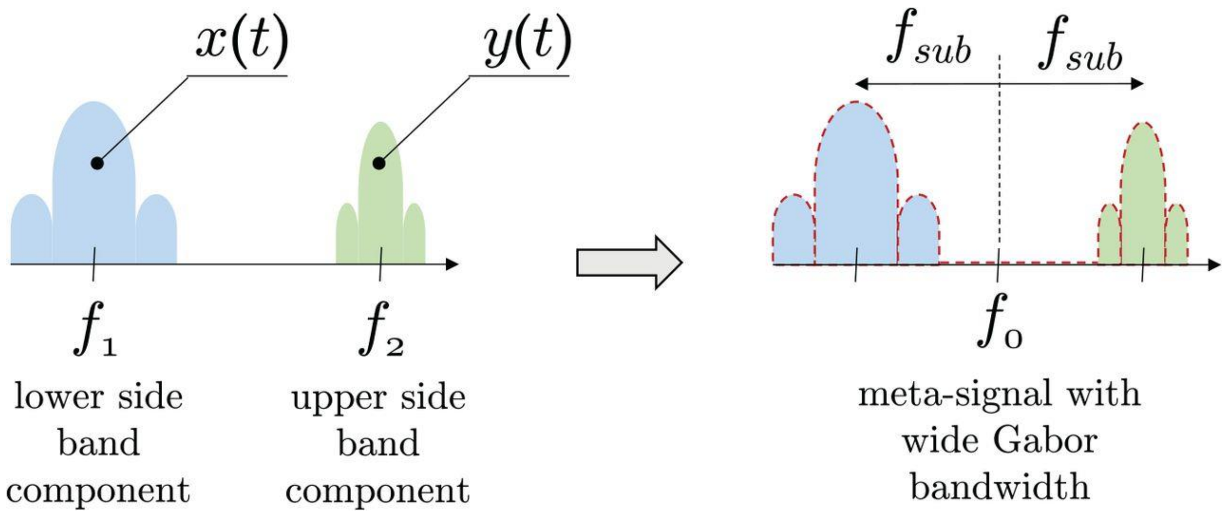
Recommendation ITU-R M.2092-1



Consolidation of System and Technology Requirements for the PoC

Meta-Signal Processing

- The purpose is to improve the code-delay estimate by around a factor of 45, by processing lower and upper bands together.
- The receiver captures both bands together, and digitally separates, down-converts, and down-samples.
- The processing works on these down-sampled streams
- We have shown:
  - expected performance gains
  - simplified processing option at lower sampling rate
  - simulation results in simplified case
  - that it can be combined with our proposed signal design



- The potential performance gains from this method are so high that it is worth considering even if the complexity is high

Consolidation of System and Technology Requirements for the PoC

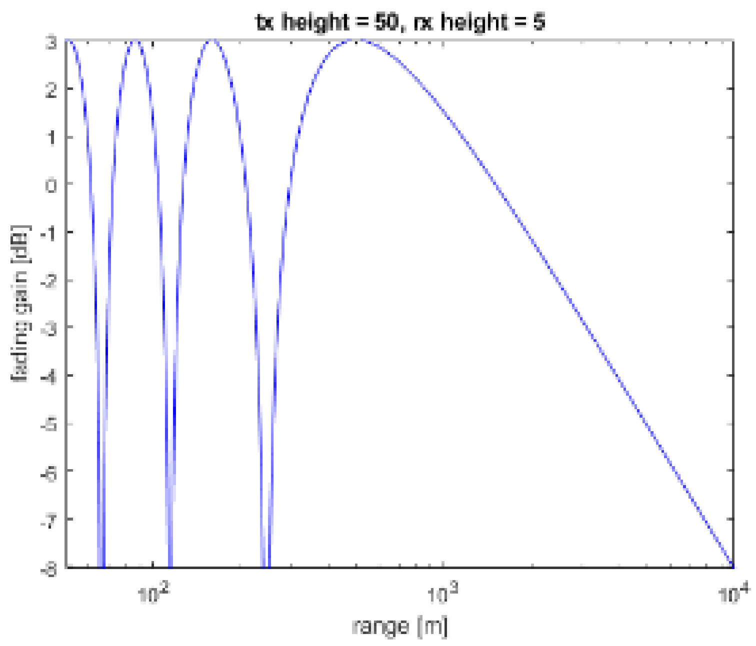
Multipath and Interference Mitigation

- In the sea / ocean environments, the multipath was expected to be a single reflection from the surface of the water.

- There is very little that can be done about this, as the VDES signal BW is small and will look like flat fading.

- In the harbour environment there could be more multipath (and perhaps blocking). Still the low BW will make it harder to do things such as channel estimation.

- There can be many electronics systems on a vessel that can impact the VDES signals, as well as deliberate interference (jamming) signals. There are techniques that can be used to attempt to reduce the impact of these signals

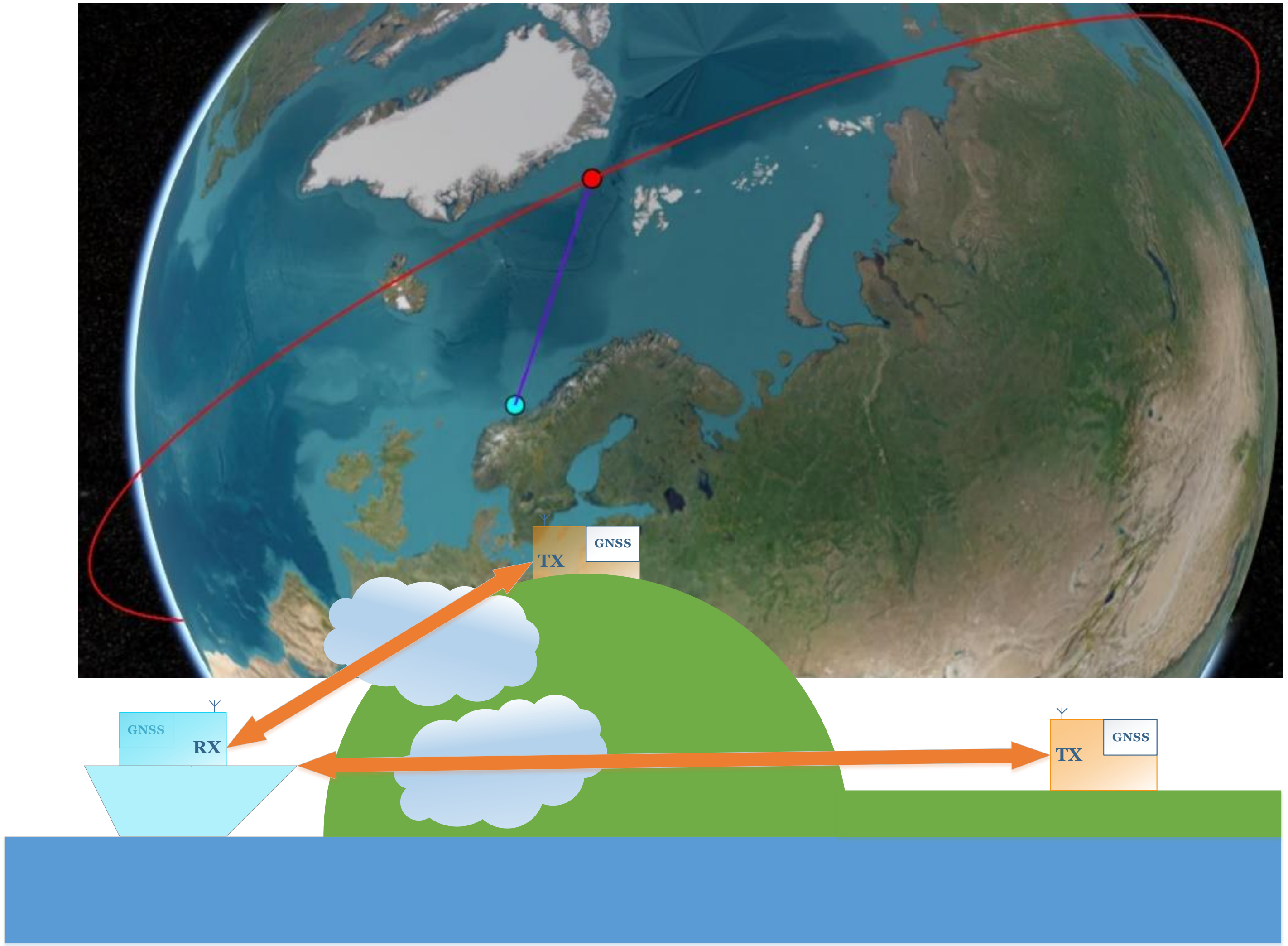


Fading of VHF signal versus range at a near-horizontal angle.

Consolidation of System and Technology Requirements for the PoC

Presenting the Multi-epoch Doppler and Differential positioning concepts

- Multi-epoch Doppler positioning
  - Ocean scenario
  - Single satellite overpass (LEO ~14mins)
  - Multiple measurements of Doppler
  - Dead-reckoning in between measurements
- Differential positioning
  - Harbour scenario
  - Changing environmental conditions
  - Reference station corrections
  - Ionosphere bias (TEC), SAT component
  - Troposphere bias (pressure, temperature, humidity), ducting, TER component
  - Error budget estimation

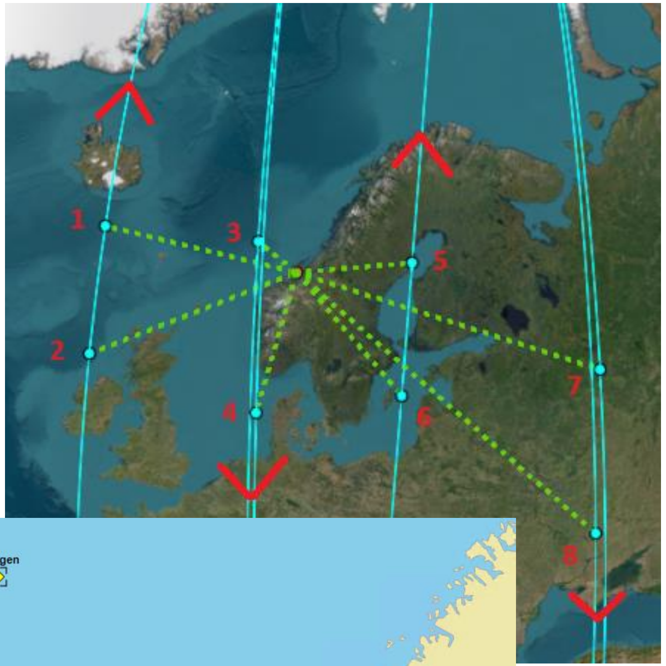


Development and Implementation of the Proof of Concepts

Simulated scenarios

- Technologies (OAP, RMD, PRN) simulated with HW lab runs
- with 1-2 SAT, 1-4 TER
- Shipping lane, pseudoranging and multi-epoch Doppler

	3D	3D	2D	Doppler
OAP	TER1-4/ SAT1	TER1-3/ SAT1	TER1-2/ SAT1	SAT1
OAP	TER1-4/ SAT8	TER1-3/ SAT8	TER1-2/ SAT8	SAT8
OAP	TER1-4/ SAT4	TER1-3/ SAT4	TER1-2/ SAT4	SAT4
OAP	TER1-4/ SAT3	TER1-3/ SAT3	TER1-2/ SAT3	SAT3
OAP	TER1-4/ SAT1+3	TER1-3/ SAT1+3	TER1-2/ SAT1+3	SAT1+3
RMD	TER1-4/ SAT1	TER1-3/ SAT1	TER1-2/ SAT1	SAT1
PRN	TER1-4/ SAT1	TER1-3/ SAT1	TER1-2/ SAT1	SAT1



Down-Selection of the Most Promising Techniques

Trade-off criteria

- There were 6 criteria identified to help downselect the techniques:

  - **Performance**. This will depend on the technique; some techniques are there to improve the positioning performance, whereas some techniques are there to enable other aspects of the system.

  - **Applicability**. How many scenarios the candidate techniques are useful for.

  - **SW gap for the PoC** and **HW gap for the PoC**. The target platform is the KSX receiver, and if the changes to SW and HW are too large it would introduce more risk into the project.

  - **HW gap for a real transmitter** and **HW gap for a real receiver**. If the changes required are too large, then there will be very little uptake from manufacturers/stakeholders in the future.

  - Additionally, we looked at synergy in the techniques.

Criteria	Scoring description
Performance	Depending on the concept, these criteria will be used to judge either direct performance gains, e.g., expected pseudo-range accuracy, or to judge the usefulness of enabling a new method by means of the concept. <u>Accuracy scoring:</u> 1. Almost improvement over a PRN based on the signal BW 2. ~0.75x error 3. ~0.5x error 4. ~0.1x error approx. equal to GPS L1 C/A 5. <0.02x error <u>Usefulness scoring:</u> 1. Doesn't add anything. 2. Adds in new ConOps, but less well than another concept 3. Adds in new ConOps 4. Adds in mandatory requirement from SoW, but less well than another concept 5. Adds in mandatory requirement from SoW
Applicability	1. Useful to 1 user scenario 2. Useful to 2 user scenarios 3. Useful to 3 user scenarios 4. Useful to 4 user scenarios 5. Useful to all user scenarios
SW gap PoC	1. Overhaul of SW for signal processing / PNT 2. Major changes / additions 3. Medium changes / additions 4. Small changes / additions 5. SW already can do almost all of this
HW gap PoC + HW gap transmitter + HW gap receiver	1. Rework with bespoke solutions 2. Major rework, with COTS 3. Medium rework, COTS 4. Minor rework, COTS 5. HW can already do this

Trade Off & Shortlisting

4 – Differential Positioning

7 – Multi-Epoch Doppler Positioning

2 – Meta Signal Processing

1 – Signal Design

Concept:

1 – Signal Design, **2** – Meta Signal Processing
3 – Antenna Diversity, **4** – Differential Positioning
5 – Navigation Message Authentication
6 – Multipath & Interference Mitigation
7 – Multi-Epoch Doppler Positioning
8 – Two Way Ranging

		Concept / (Scores 1 – 5)							
Criteria	Weight	1	2	3	4	5	6	7	8
Performance	2	3	5	3	3	2	1	4	3
Applicability	1	2	2	3	2	3	2	2	2
SW gap PoC	1	5	4	1	3	4	3	3	3
HW gap PoC	1	5	4	1	5	5	5	5	2
HW gap transmitter	2	4	2	5	5	5	5	5	4
HW gap receiver	2	5	4	1	5	5	3	5	4
Total		36	32	23	36	36	25	38	29
Priority		2	4		3			1	

System Design

R-Mode testbed

- VDES R-Mode transmitter
  - Kongsberg VDES BS610
- VDES R-Mode receiver
  - Kongsberg VDES BS620
- Reference clocks
  - Kongsberg 10 MHz, rubidium-based
- External IMU - standard RS-422 interface
  - Kongsberg MGC R3
- Lab tests over air and over wire
  - Ocean Space Lab vessel
- R&S SMBV100A signal generator used for meta-signal tests

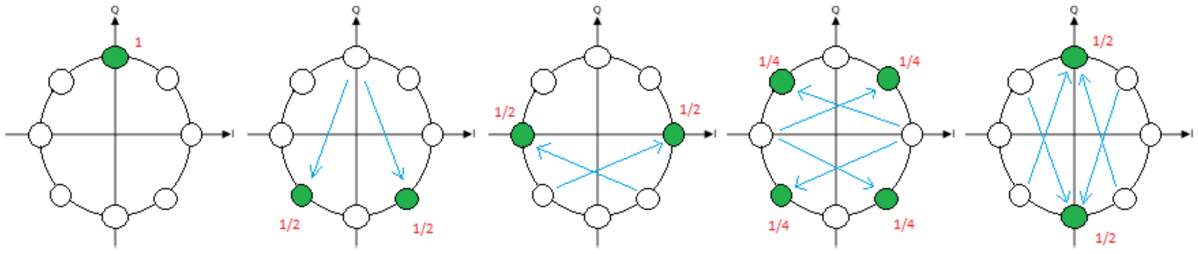
Laboratory test setup in rack

Kongsberg Ocean Space Lab test vessel

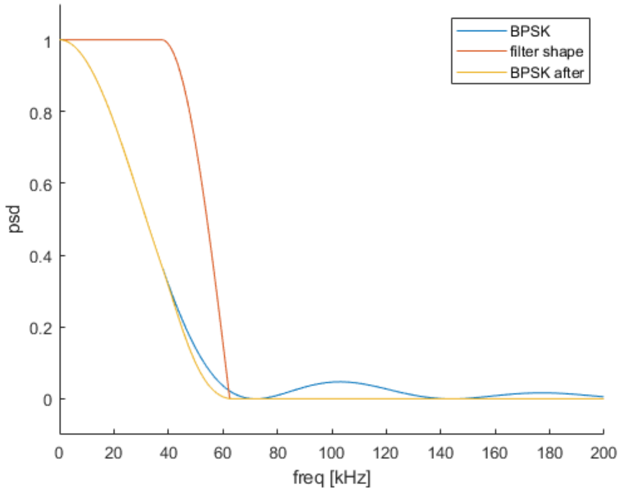
Development and Implementation of the Proof of Concepts

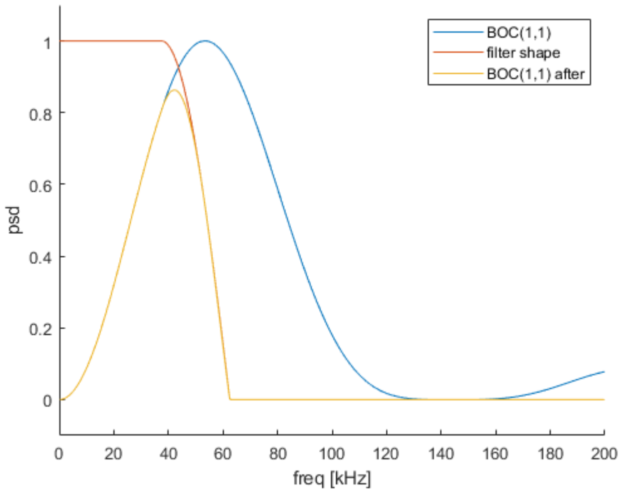
Signal Design

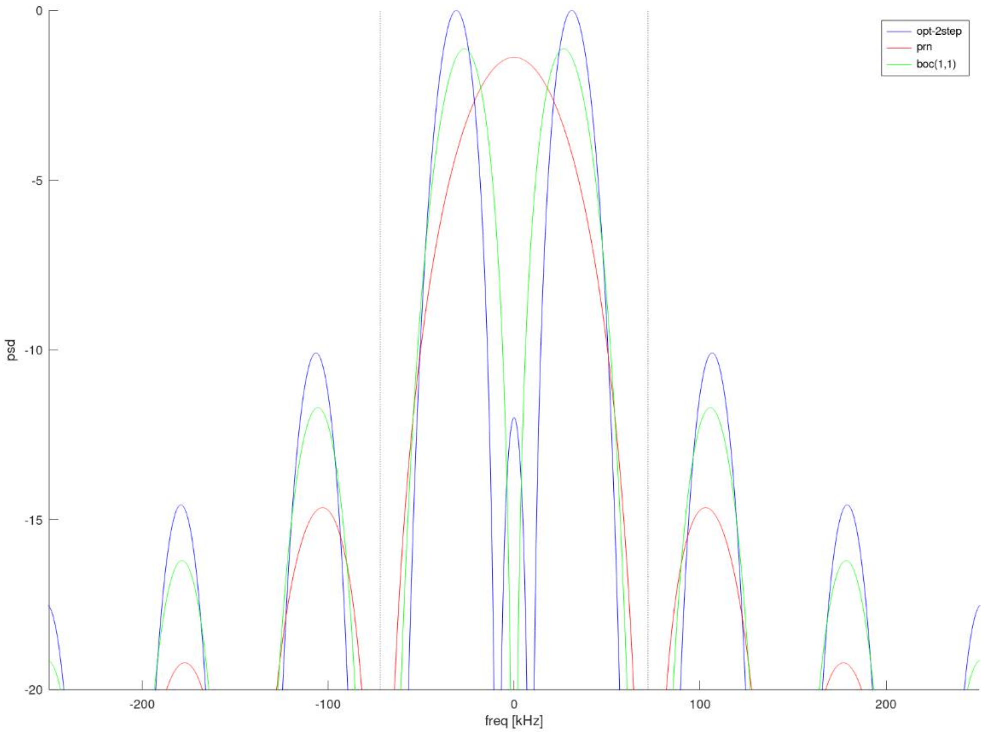
- Proposed new signal, **Offset Alternating Pairs**.
- Every chip is the maximum distance from the previous one.
- Underlying PRN, a balanced sequence found through a search, ensures the (linear) ACF is approximately symmetric
- Possible to have many such sequences with low cross-correlation, very useful for a network of TER transmitters.
- RRC filtering will impact the performance, reducing the improvement from our improved sequences.



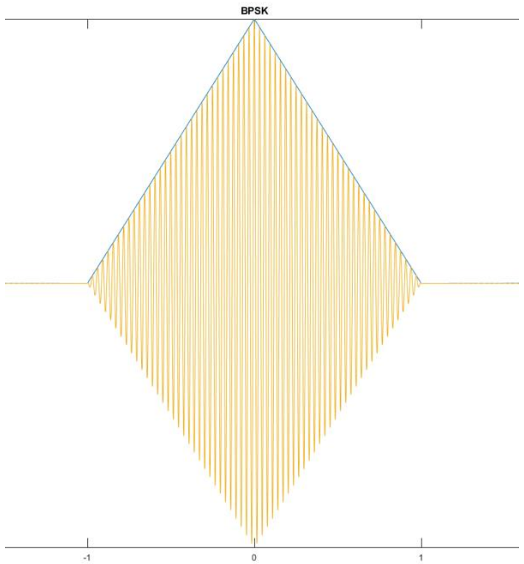
Offset-alternating directional pairs.







Development and Implementation of the Proof of Concepts



Meta-signal processing

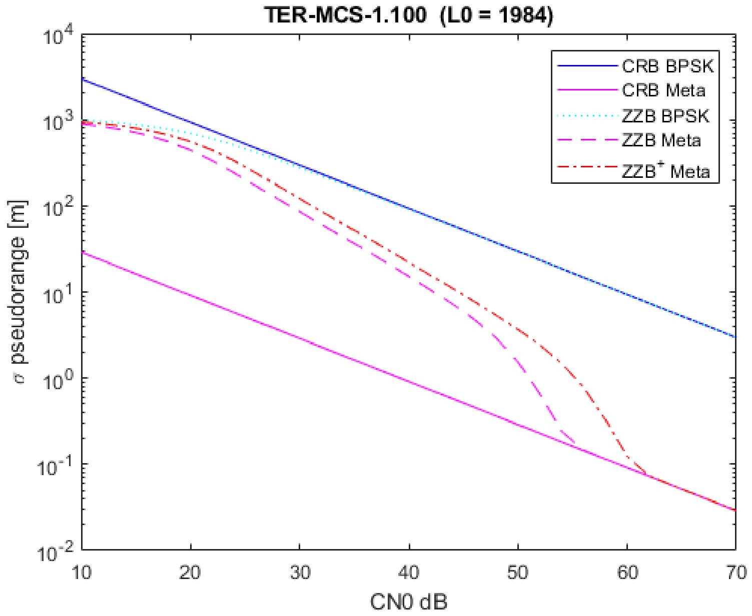
- The combined ACF has many peaks, with an envelope shaped as the ACF of the sideband signals – see for BPSK here.
- The maximum achievable performance is limited to the gradient around the peak, which in this case is around 60 times better than the sideband ACF.
- Much higher probability of selecting the wrong peak – this will only work at very high SNR
- Ordinarily the SW processing requirement would be much higher, requiring sampling rates of many MHz to cover both bands
- However, the KSX receiver operates by sampling the entire VDES band and splitting into different chains, and that can be leveraged here because phase information is retained.
- Take the lower and upper chains independently, and then afterwards find high-rate peak

Expected difference of ACF angles: $\varphi = \mathrm{mod}\left(2\pi f_g * 2\Delta\, , 2\pi\right)$

First estimate: $\Delta_L = \frac{E_L - L_L}{2(E_L + L_L)}, \; \Delta_U = \frac{E_U - L_U}{2(E_U + L_U)}, \; \Delta_C = \frac{\Delta_L + \Delta_U}{2}$

Get $\hat{k}$ that minimizes: $\min_k \left(\left| \Delta_c + \frac{\varphi}{4\pi f_g} + \frac{k}{2 f_g} \right| \right)$

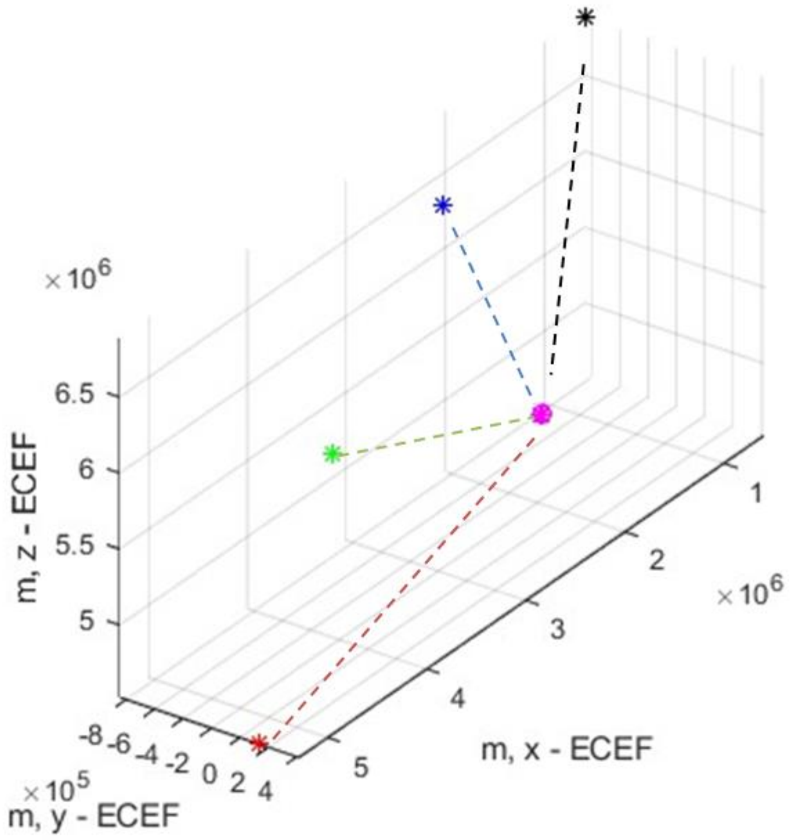
The meta-signal estimate is: $\hat{\Delta} = -\frac{\varphi}{4\pi f_g} - \frac{\hat{k}}{2 f_g}$



Development and Implementation of the Proof of Concepts

Multi-epoch Doppler summary (Ocean scenario)

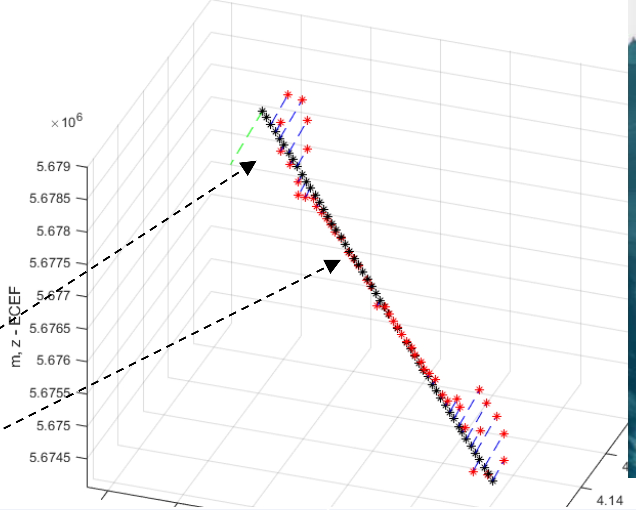
- Multi-epoch Doppler positioning simulations approach
  - First ideal, then introducing noise components
- One sigma receiver PVT error of < 1km achieved with
  - SAT along-/cross –track, P-1/0.1m, V-0.1/0.01m/s
  - SAT T-100ns bias, 0.5ns drift
  - Overpass with >= 4 measurements (best DOP)
  - Receiver T-10us bias
  - Receiver Doppler measurement accuracy T-7Hz
  - Receiver number of measurements available (32 each burst over which to average)
- Conclusion
  - Accuracy may be possible to achieve with current hardware, real testing necessary to validate simulation

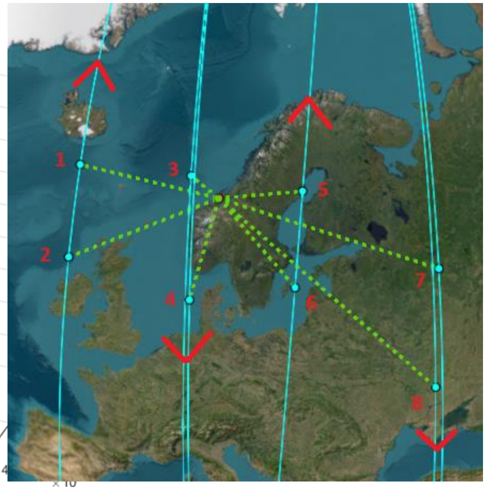


Development and Implementation of the Proof of Concepts

Differential positioning summary (Harbour scenario)

- Positioning approach (pseudo-ranging)
  - SAT and or TER scenario simulation (3-4 TER, 1-2 SAT)
  - Send to HW simulation
  - Derive PVT (assume ideal beacon timing)
  - 4 TER → up component error >1000m due to DOP
  - 4 TER → horizontal error <10m
  - Adding of 1SAT component with 4 TER
  - 1SAT 4TER → up error < 100m
  - 1SAT 4TER → horizontal error < 3m
- Focussed error budget characterisation
  - Iono- bias estimates, NeQuick-G → 100m
  - Tropo- bias estimates, pressure, humidity, temperature (wet/dry) → 10m



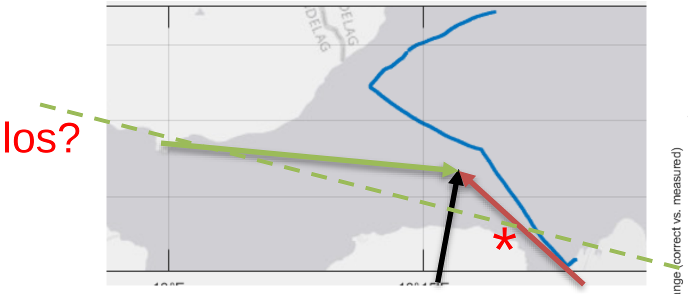


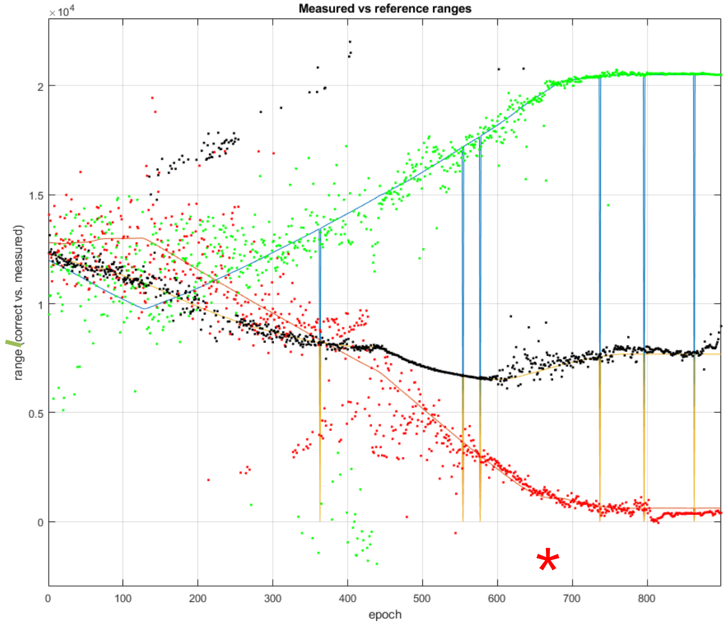
Error Budget	SAT	TER	Priority weight (error 1km)
Beacon timing	Directly affects range estimates → PVT	Directly affects range estimate → PVT	50% (500m)
Beacon pos/vel	Directly affects range estimates → PVT	Is known accurately	25% (250m)
Receiver HW	Measurement accuracy	Measurement accuracy	10% (100m)
Iono-	~100m	-	10% (100m)
Tropo-bias	~10m	~10m	5% (50m)

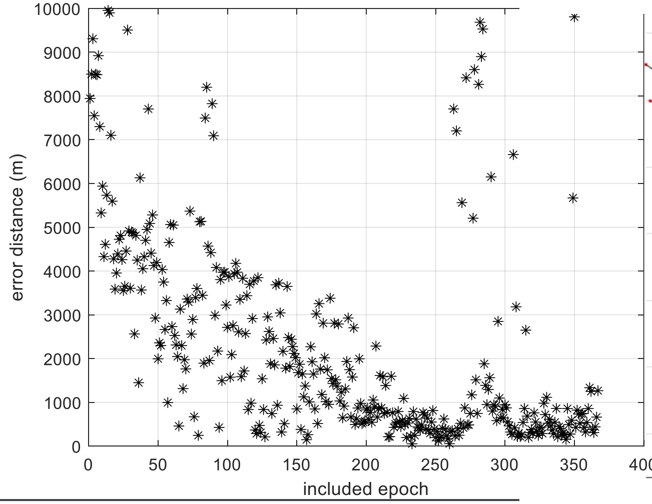
Development and Implementation of the Proof of Concepts

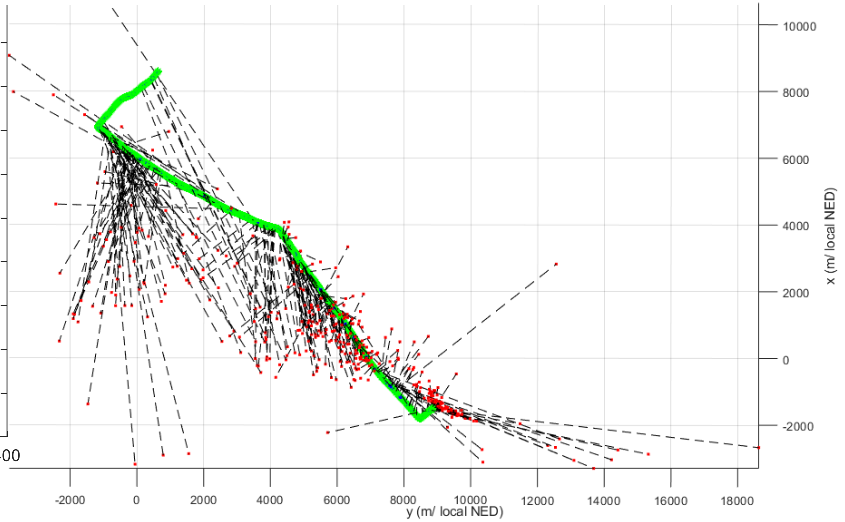
Differential positioning summary (Harbour scenario)

- Positioning approach (pseudo-ranging)
  - TER real testing with z fixed (x, y, t)
  - Beacon timings assumed ideal (calibrated using known ranges)
  - Mirroring before * (as if mirrored peak selected in stead)
  - Grakallen ok, on top of a hill ~558m (black)
  - Piren and Statsbygd issues before 5km from harbour (red, green)
  - Focus now on why hilltop better → ducting? Wind/ temperature above hills so much different
  - Sea level ranging inconsistencies, mirrored from troposphere/ sea/ hills
  - Interference between opposite beacons
- When understood, reapplication of reference





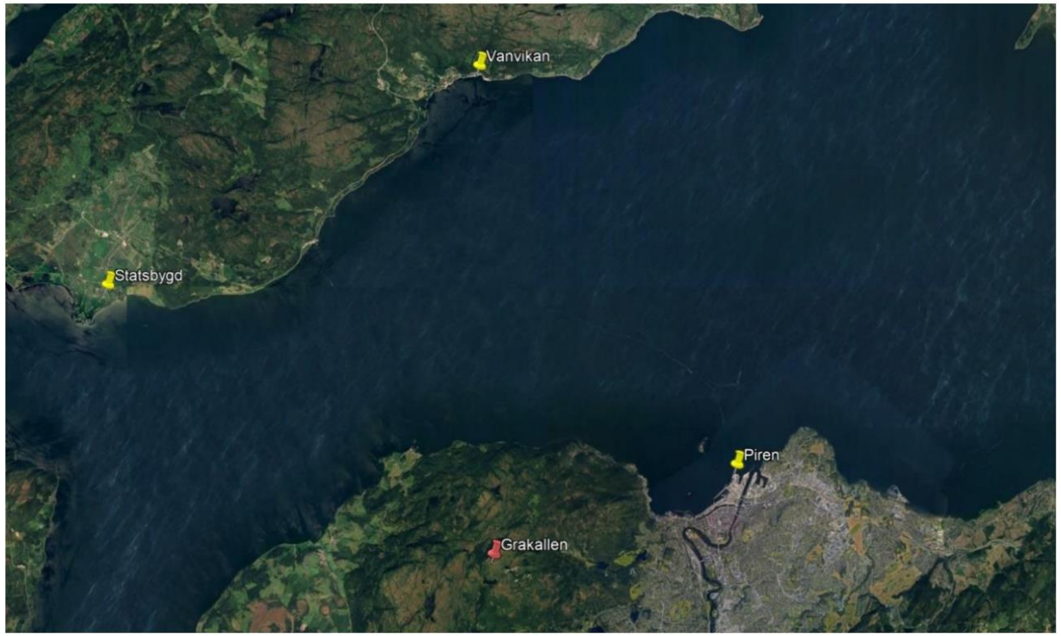




Final Tests and Analysis

Setup shore sites

- Sites at Stadsbygd, Piren, Vanvikan, Gråkallen (mountain)
- License from the Norwegian Communications Authority to use the VDES frequencies
- Transmitting R-Mode sequence every 2nd second (150th slot) in separate TDMA slots



Test area in Trondheim fjord


Vanvikan test site

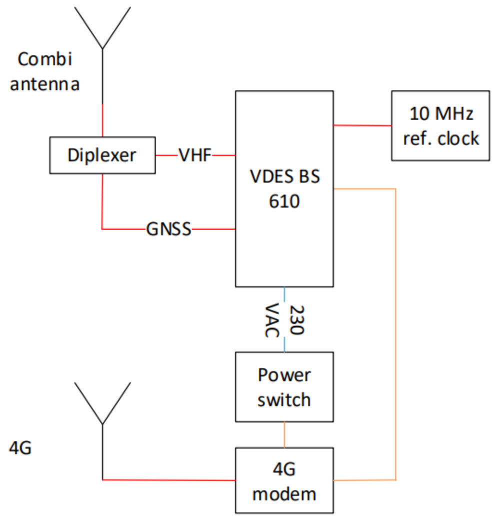

Piren test site


Stadsbygd test site

First Tests and Analysis

Setup shore sites

- Combined VHF+GNSS antenna
- Gråkallen used for VDE-TER comms testing simultaneously
- Scheduling for these tests used 1 % duty cycle for each of the terrestrial link IDs
  - Link ID 17: Slot 0, 100, 200, …
  - Link ID 11: Slot 10, 110, 210, …
  - Link ID 19: Slot 20, 120, 220, …
- Test setup remotely controllable



VHF data exchange-terrestrial link identification parameters

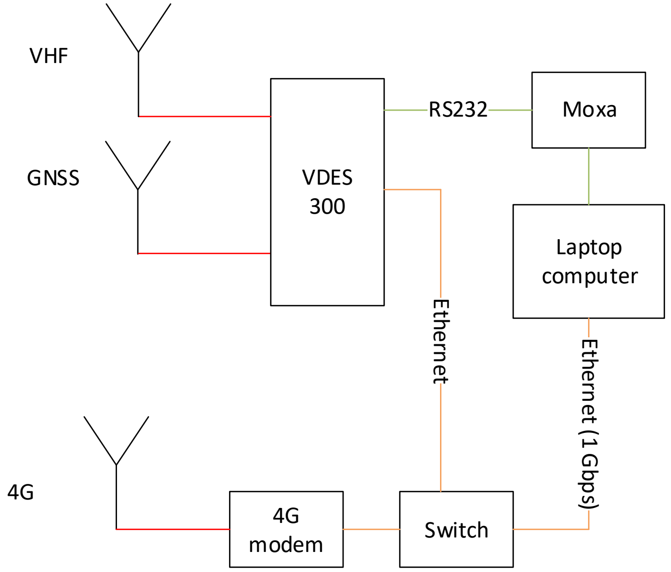
PL format #	TER-MCS-1.25		TER-MCS-3.25		TER-MCS-5.25	TER-MCS-1.50	TER-MCS-3.50	TER-MCS-5.50	TER-MCS-1.100		TER-MCS-3.100		TER-MCS-5.100
Link ID	11	35 [4]	12 [1]	36 [4]	13 [1]	14 [1]	15 [1]	16 [1]	17	37 [4]	18 [1]	38 [4]	19
Channel BW (kHz)	25					50			100				
Roll off filtering [2]	0.3												
Signal BW (kHz)	25.0					49.9			99.8				
Symbol rate (ksps)	19.2					38.4			76.8				
Modulation	π/4-QPSK		8-PSK		16-QAM	π/4-QPSK	8-PSK	16-QAM	π/4-QPSK		8-PSK		16-QAM
PAPR (example) (dB)	3.82		4.4		6.7	3.82	4.4	6.7	3.82		4.4		6.7
Output average power (W)	12.5		11		6.5	12.5	11	6.5	12.5		11		6.5
Burst size (slots)	1												
Guard time (ms)	0.83												
Burst duration (ms)	25.8												
Symbols/burst (symbols)	496					992			1984				
Ramp-up/down (symbols)	8/8					16/16			32/32				
Ramp-up/down (ms)	0.41/0.41												
Syncword size (symbols)	27												
Syncword modulation	π/4-QPSK (00/11 only)												
Link ID size (symbols)	16 (32,6 block code)												
Link ID modulation	π/4-QPSK												
Net symbols/burst (symbols)	437					917			1877				
Channel bits	874		1311		1748	1834	2751	3668	3754		5631		7508
Padding + FEC tail [3] (bits)	0+10	N/A	3+12	N/A	8+12	30+12	51+12	72+12	0+10	N/A	243+12	N/A	8+12
FEC decoder input symbols (symbols)	432		432		432	896			1872		1792		1872
FEC decoder input bits	864		1296		1728	1792	2688	3584	3744		5376		7488
FEC output bits	432		972		1296	896	2016	2688	1872		4032		5616
FEC output bytes	54		121		162	112	252	336	234		504		702
FEC rate	1/2		3/4		3/4	1/2	3/4	3/4	1/2		3/4		3/4
E_s/N_0 on AWGN (dB)	1.0		7.9		10.2	1.0	7.9	10.2	1.0		7.9		10.2
$C/(N_0+I_0)$ threshold (dB/Hz)	43.8		50.7		53.0	46.8	53.7	56.0	49.9		56.8		59.1

Waveform parameters from ITU-R M.2092-1

First Tests and Analysis

Setup vessel

- Ocean Space Lab test vessel
- Kongsberg VDES 300 mobile station
- Data logged to laptop computer
- Retrieved and controlled remotely from 4G

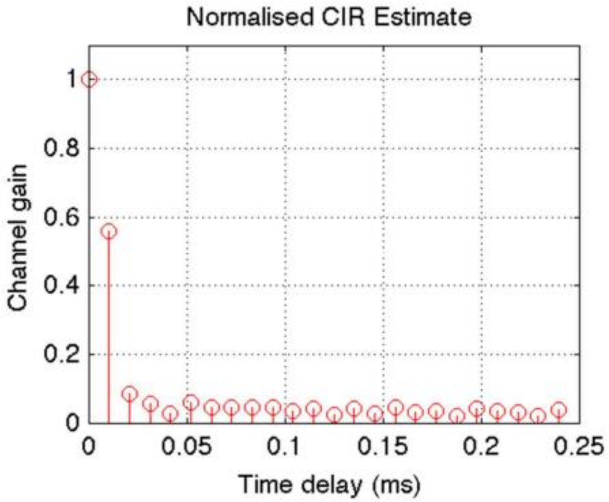


Kongsberg VDES 300 mobile station

First Tests and Analysis

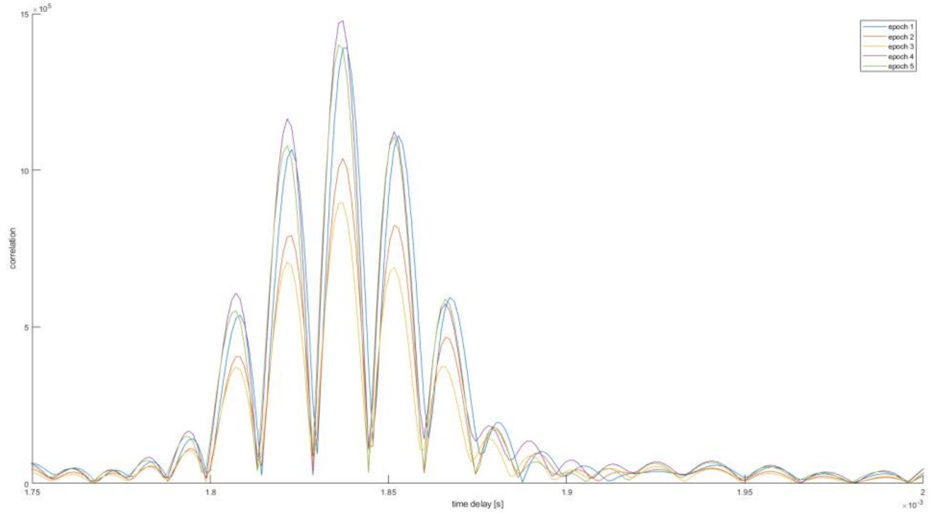
Multipath Issues

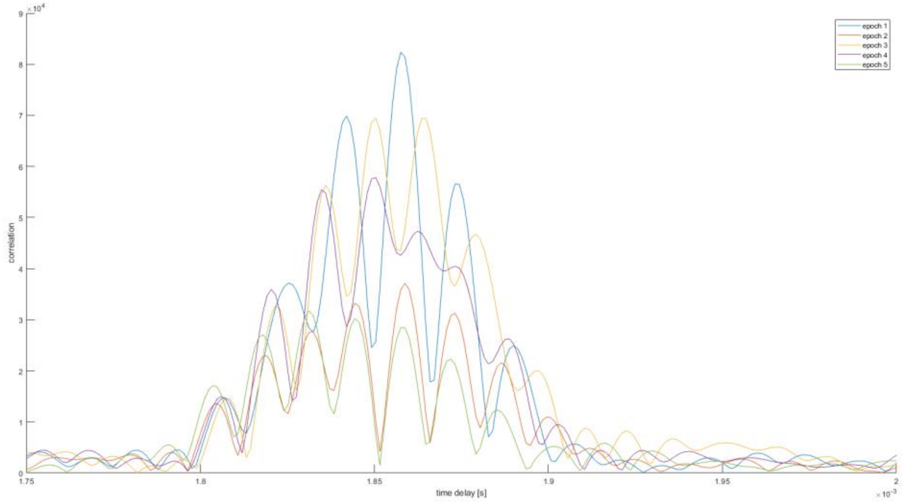
- Surprised to see some very unusual ACF shapes in the initial tests.
- The expected ACF has:
  - Consistent shape epoch-to-epoch
  - Only a few peaks, with the values going to zero in between
- We did several checks to make sure the other stations were not transmitting at the same time, were not sending repeats, were not sending the wrong signal, etc
- The result looks a lot like multipath, which was unexpected, so the test plan was shifted to identify and try to understand the issue
- There was a channel sounding campaign led by Jan Safar carried out for the GLAs in 2014, testing several areas in the UK, and finding some multipath
- The author suggested that it may be tropospheric reflection



From VDES Channel Sounding Campaign

https://www.itu.int/pub/R-REP-M.2317

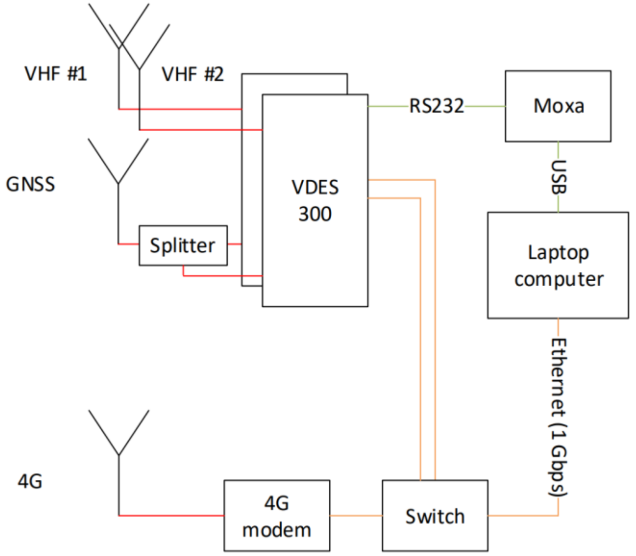


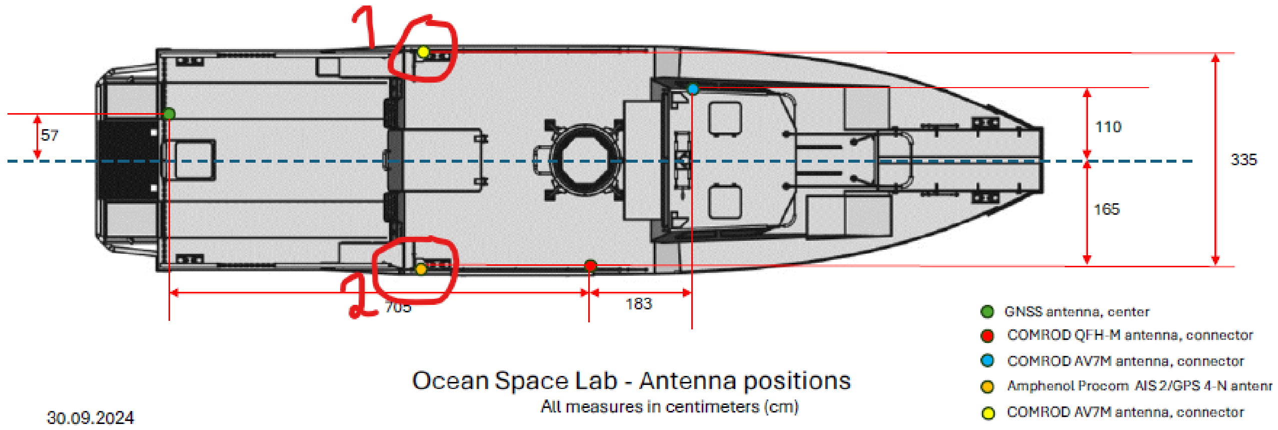


Final Tests and Analysis

Setup vessel

- Changed to dual-antenna test setup on Ocean Space Lab to analyze multipath effects
- Two VDES 300 receivers with separate VHF antennas
- Shared GNSS antenna

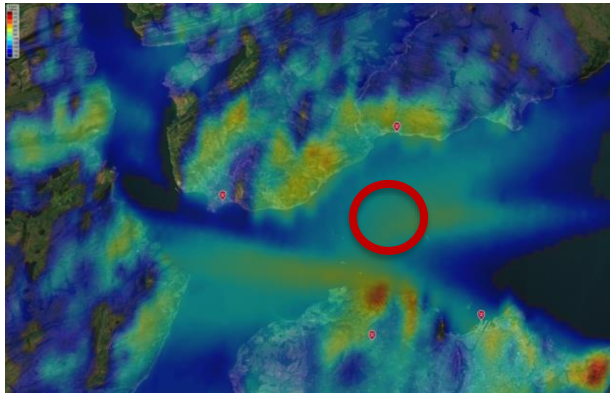




Final Tests and Analysis

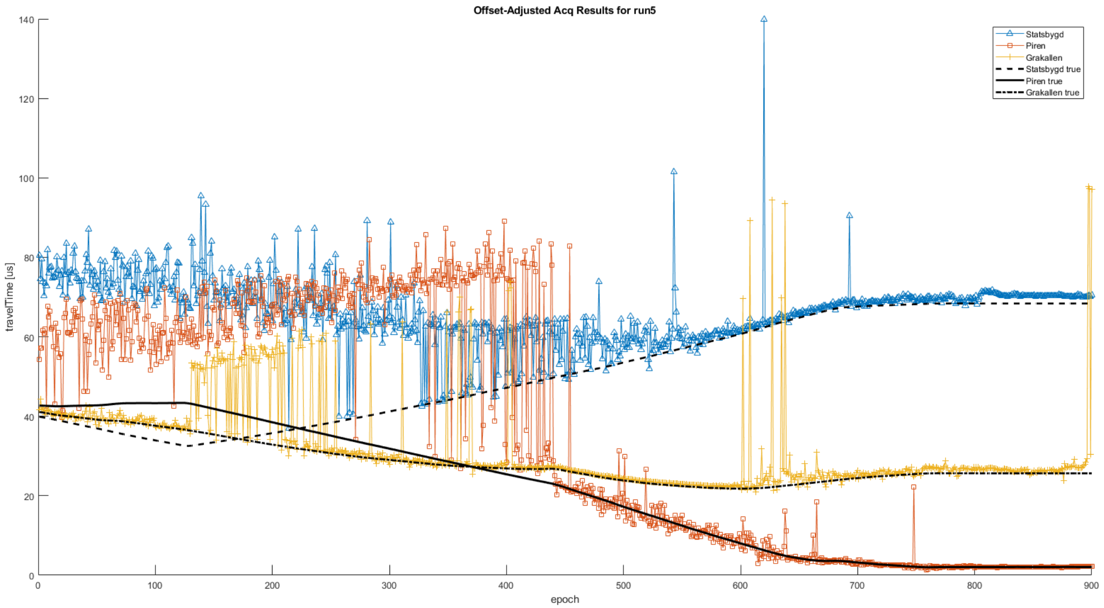
Multipath Issues

- With two receivers, we showed that the angle of arrival was different, confirming multipath
- The setup we had was not enough to show that the reflection was from the troposphere, however the difference in distance could match the lower height of the troposphere at higher northern latitudes
- It was impacting all of the transmitters, but the site higher on a hill was suffering less than the others, and this was the site that had the highest LOS received power.
- Looking at some of the outliers in the plots, it seems clear that the multipath element is always there, and sometimes it overpowers the LOS
- Minimum received signal strength from all sites simulated



Real Test Path.

Simulated minimum received signal strength using Longley–Rice radio propagation model

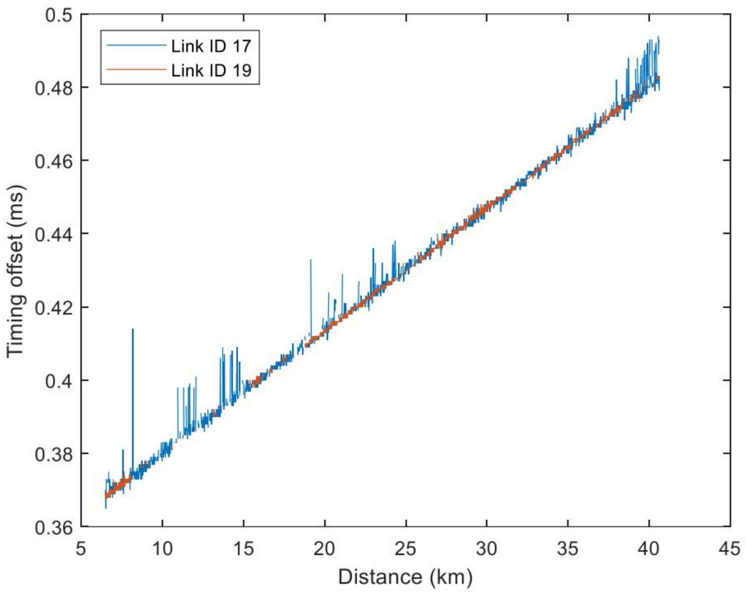


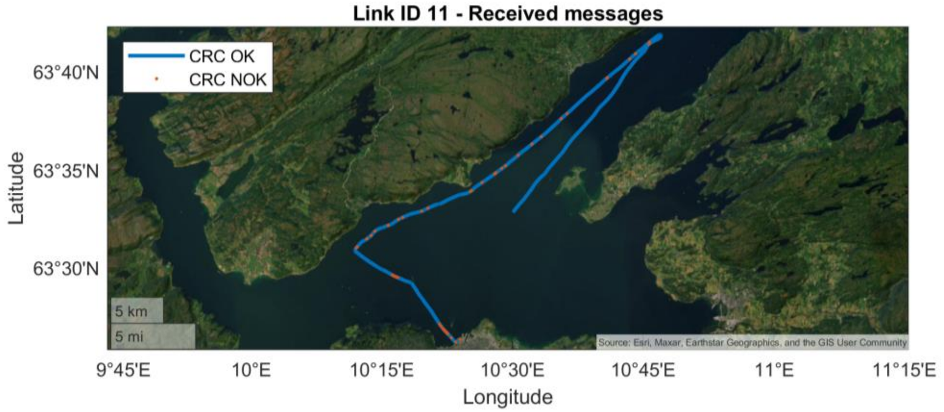
Acquisition of Real Signal.

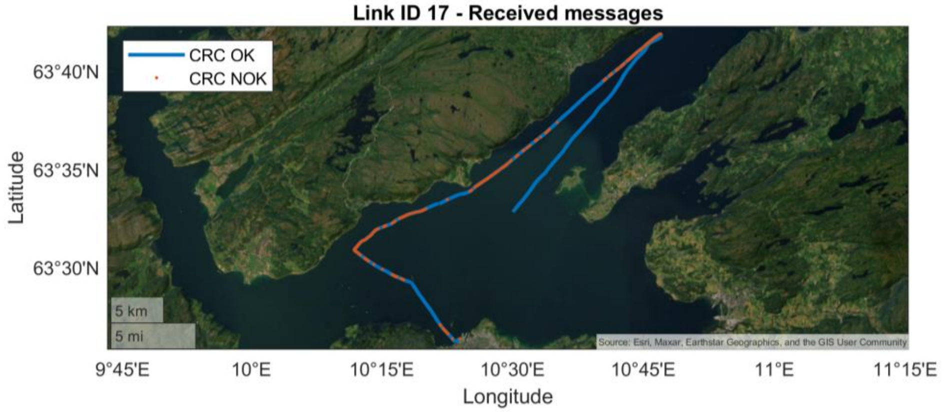
Final Tests and Analysis

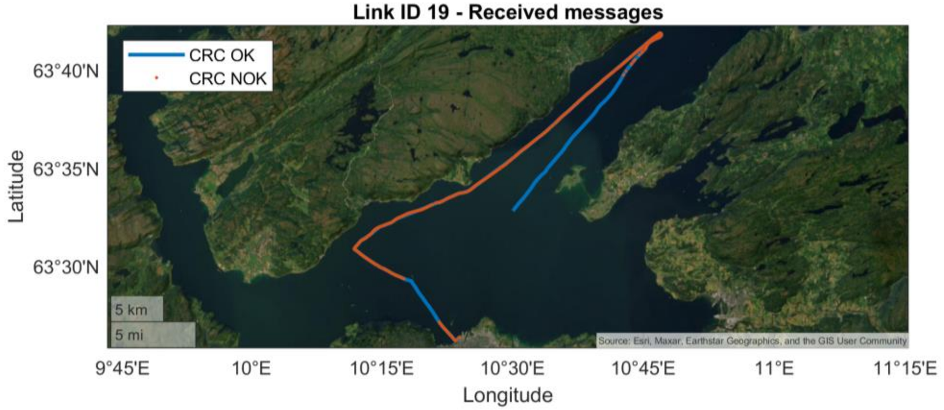
Comms test results

- C/No thresholds can explain some of the packet loss
- Timing estimator from demodulator reports higher timing offset before failing decoding
  - Indicates multipath (longer path)
- Both receivers decoded similar number of packets







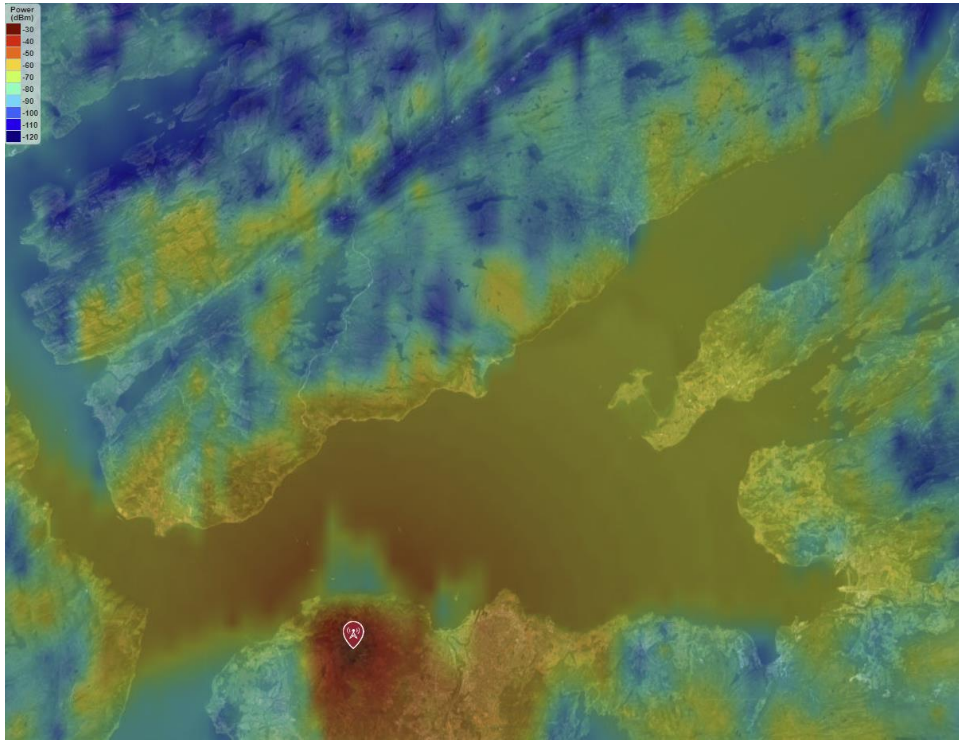


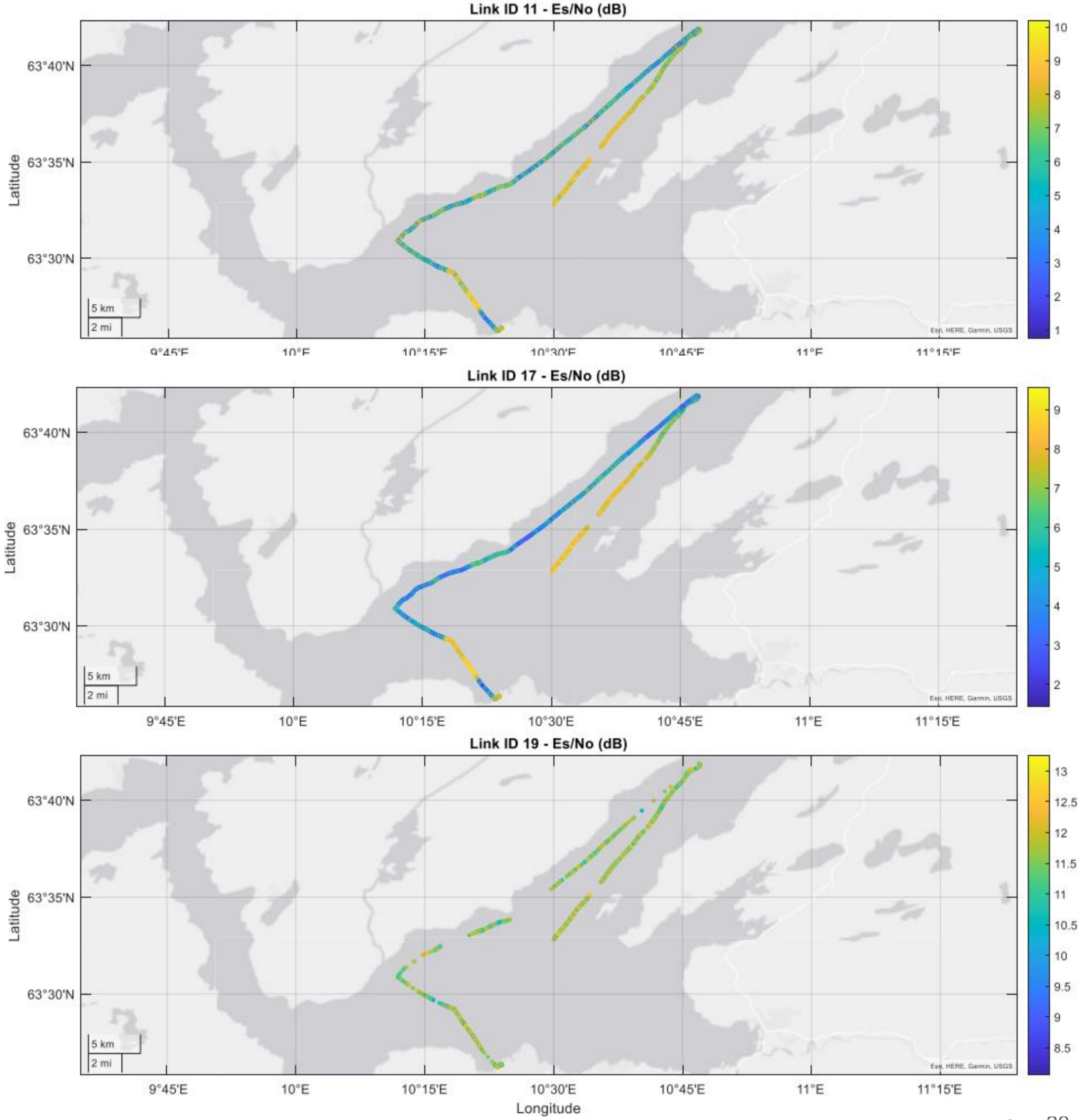
Final Tests and Analysis

Comms test results

- Signal-to-Interference-plus-Noise Ratio (measured as Es/No) as function of position shows areas with lower values close to shore

- Simulations does indicate some degradation close to the site (NLOS)
  - No change in signal strength close to shore (LOS)





Conclusions and Lessons Learned

Tim Whitworth (Telespazio UK)

Conclusions and Lessons Learned

Signal Design

- Simulation and real testing shows that the pseudorange performance is better; however, the multipath issue impacts this greatly.
- The better performance of the new signals comes from the ACF having two larger negative side-peaks, but these side peaks make the impact of multipath even more destructive.
- If future work shows methods to reduce the multipath effect, then the designed signals could help performance, and it is useful that nothing different needs to happen inside the receiver to use these new proposed signals

Meta-Signal Processing

- Simulation and lab testing shows higher performance can be achieved, however it is very sensitive to multipath, and so is not seen as viable.

Antenna Diversity

- This concept was not taken to the design phase due mainly to the fact that it is not seen as being a product that vessel-owners would want, as the increased cost is prohibitive.
- With the difficulty of using pseudorange; however, it might be better to use triangulation with terrestrial transmitters, rather than trilateration.
- This would still depend on whether users would be willing to pay for this additional functionality though

Conclusions and Lessons Learned

Differential Positioning

- Using reference stations to estimate the current environmental conditions helps the vessel to set the ionospheric and tropospheric delay estimates.
- The aim of differential positioning is to enable high-accuracy positioning for the harbour use case.
- However, the current feeling is that the multipath issue will never be 'resolved', only partially mitigated, and that will perhaps never be good enough to reliably get this accuracy without some extreme measures, e.g. 4 TER all around the harbour, very close together, etc.
- In this case, it is unlikely that VDES is the best system to do positioning, and differential will not be that important anyway

Multi-Epoch Doppler Positioning

- Given that the terrestrial transmitters have had such problems with multipath, using LEO and Doppler-based positioning seems attractive.
- The performance was suitable for the ocean use case, and that performance could certainly be improved with a larger constellation
- Although Doppler positioning takes the whole overpass of 12 mins to achieve the 1km accuracy, in the ocean scenario this would be usable.

Multipath and Interference Mitigation

- As a concept, the work here was focussed on expected multipath elements from the sea reflections (which would appear as fading and be impossible to remove).
- The apparent tropospheric reflections were unexpected, and mitigation efforts need serious additional work to understand / overcome.
- This is true not only for ranging, but for general VDES ship-shore communications.

Conclusions and Lessons Learned

Nav Message Authentication

- As a concept this was removed during down-selection early, due to the lack of synergy with other testing.
- It is not clear from the work in this project what the best system is for disseminating Nav message information/authentication.
- However, with the negative impact of multipath on terrestrial transmitters, the potential of LEO as a solution is higher, and so as a concept this is still worth pursuing in future work.

Two-Way Ranging

- The two-way ranging (TWR) concept was not taken forward. Main reason for dropping this concept is that it is technically complex and requires accurate calibration of the receiver and transmitter frontends.
- In light of the multipath problems, the TWR concept could be even more challenging due to the fact that the forward and return delay estimates might not be reciprocal

Way Ahead and Recommendations

Martin Bransby (Telespazio UK)
Anders Bjørnevik (Kongsberg Discovery)

VAUTAP Way Ahead and Recommendations

Main recommendations from VAUTAP

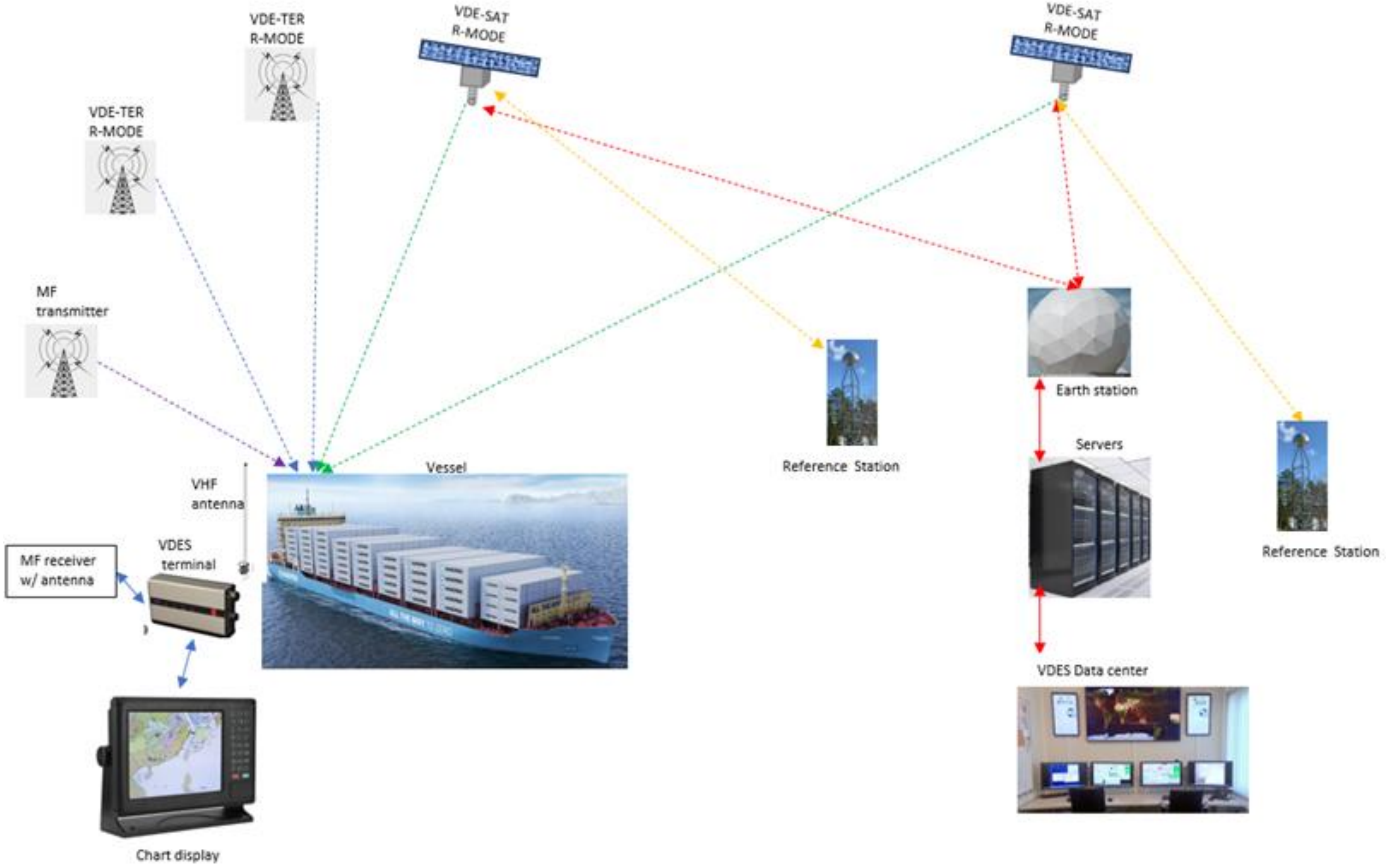
- Multipath:
  - The Multipath problem must be studied further if terrestrial transmitters are to be used for ranging
  - The MP problem should be publicised in the relevant communities such as IALA, IMO and the ITU to engender further debate/work
  - If TER transmitters are designed for ship-shore ranging, they should be designed to have much more power between e.g. ±10-degree elevation
  - Real-world testing campaign should be conducted to understand how significant the MP impact is in other geographical areas

- Other recommendations:
  - A test campaign is conducted to test the links with higher bandwidth signals, and plot received power vs. distance for both LOS and multipath
  - Testing should be tried with several different TER antenna heights
  - Test different links with the VAUTAP signal design
  - Conduct real-world testing on LEO satellite considerations not within the scope of VAUTAP
  - Simulation tools are developed to conduct coverage analysis

Way Ahead and Recommendations

Maritime Alternative Positioning Service (MAPS)

- New ESA NAVISP Element 2 Activity
- Kongsberg Discovery (prime), Space Norway, German Aerospace Centre, Telespazio UK
- Builds upon the foundation of the ESA ICING, VAUTAP and multiple European Union INTERREG R-Mode activities
- Aim to combine VDES and MF R-Mode concepts and create demonstration service
- Investigate multipath fading effect on R-Mode
- Test and demonstrations using existing satellite and terrestrial assets (phase 1)
- Launch dedicated satellites for A-PNT system (phase 2)



Q&A

Tim Whitworth (TPZ-UK)

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