NTNU
Fakultet for informasjonsteknologi
og elektroteknikk

Navigation and communication systems for autonomous ships

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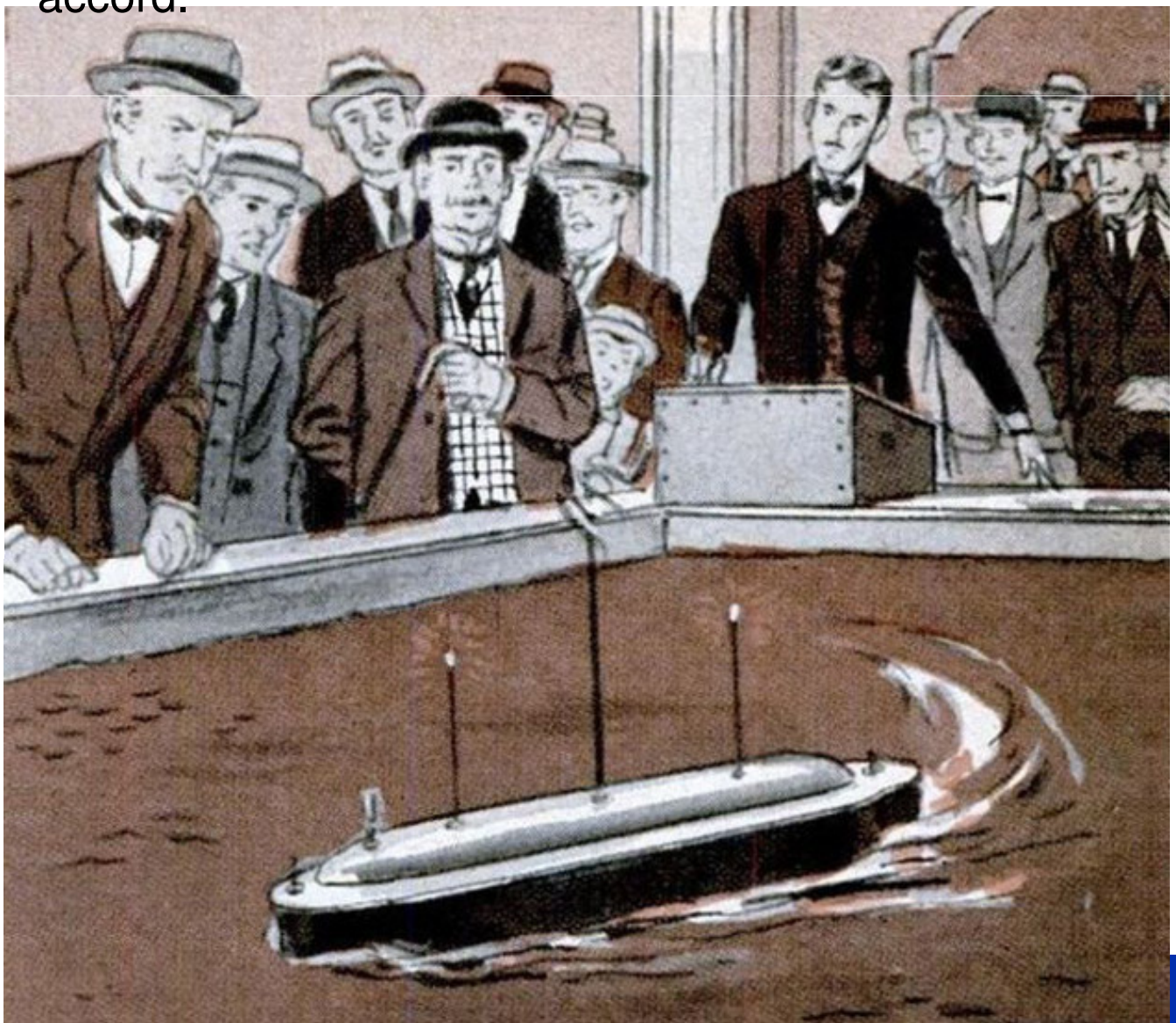
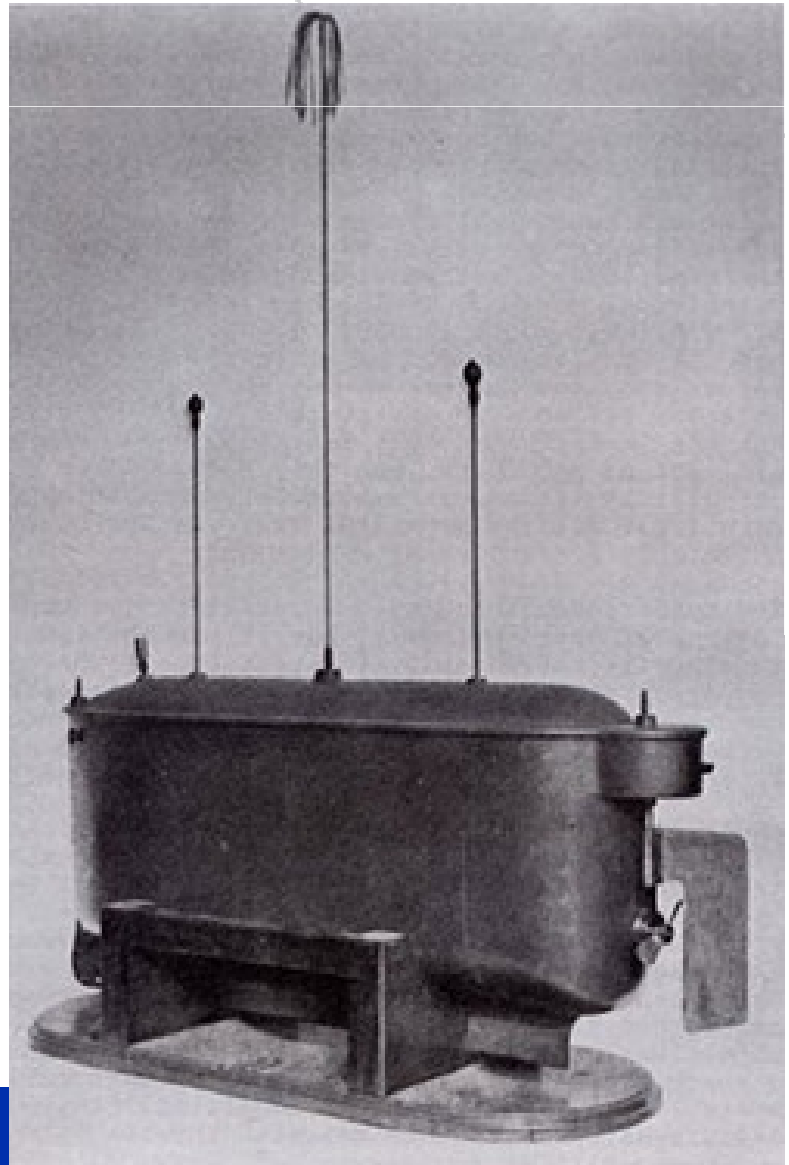
1. Sensors for autonomous ships
2. LIDAR and Radar
3. Land based Radar network
4. Communication systems
5. Massive MIMO
6. Autonomous ferry project

Nikola Tesla demonstrated radio controlled boat i 1898

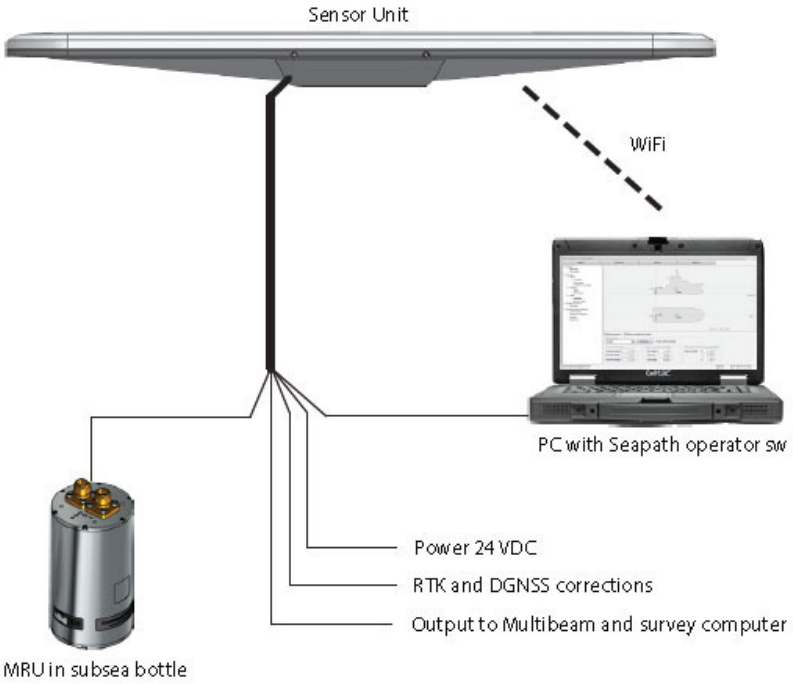
Century Magazine 1900: - “Tesla believed that one day we may be able to endow a machine with its "own mind," where it can act on environmental stimuli of its own accord. “





Sensors for autonomous ships

- **Navigation sensors**
  - GNSS
  - GNSS Compass
  - INS (MRU)
- **Anti-collision sensors**
  - Radar
  - Camera (visible plus IR)
  - Lidar
- **Instrumentation**
  - motors, batteries
  - monitoring

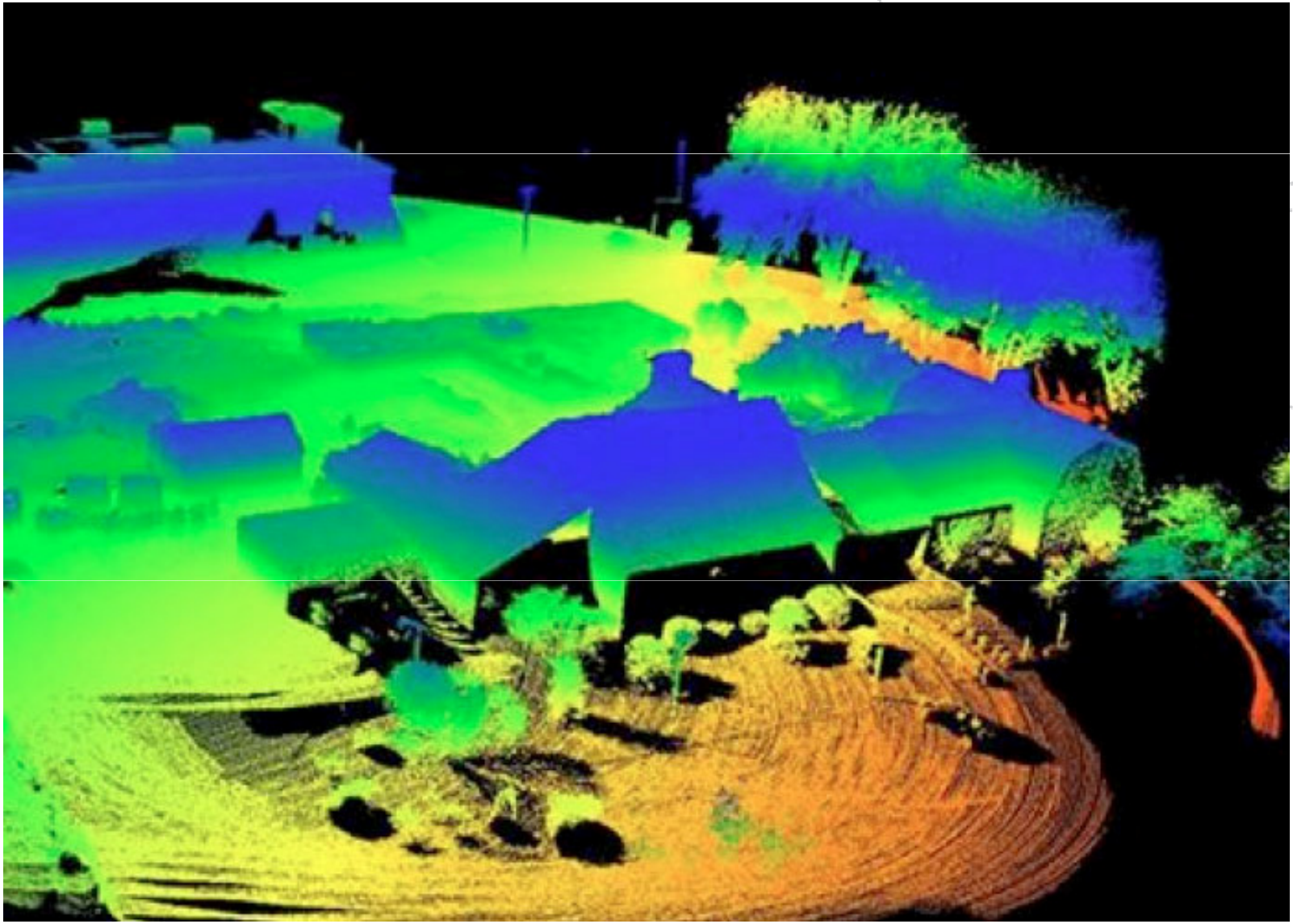


Kongsberg Seapath

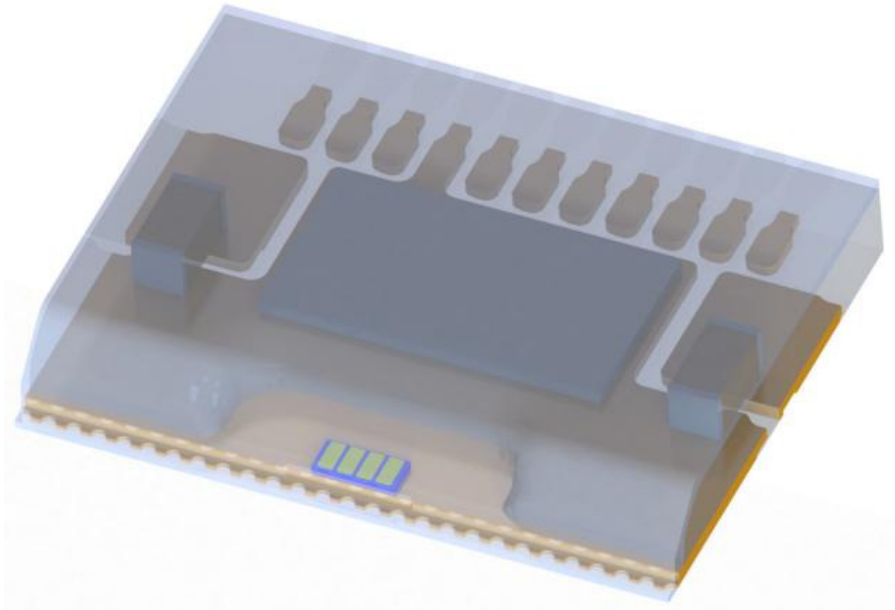
Lidar (Velodyne VLP-16)

- High update rata
- 16 parallel beams in the vertival plane +/- 15 deg
- Range 100 meter
- Law power consumption 8 Watt, 830 gram
- 3D-360 degree LIDAR (903 nm) Class 1 Eye-safe
- 5 – 20 Hz rpm (300.000 points/sec)
- +/- 3cm range, 0.1deg Azimuth, 0.4 deg Elevation
- Sea clutter performance is still to be analyzed

Example LIDAR data



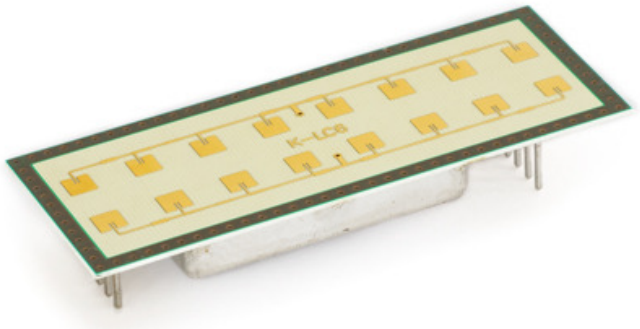
Multi-channel laser for scanning LIDAR



Osram Semiconductor
4-Channel LIDAR

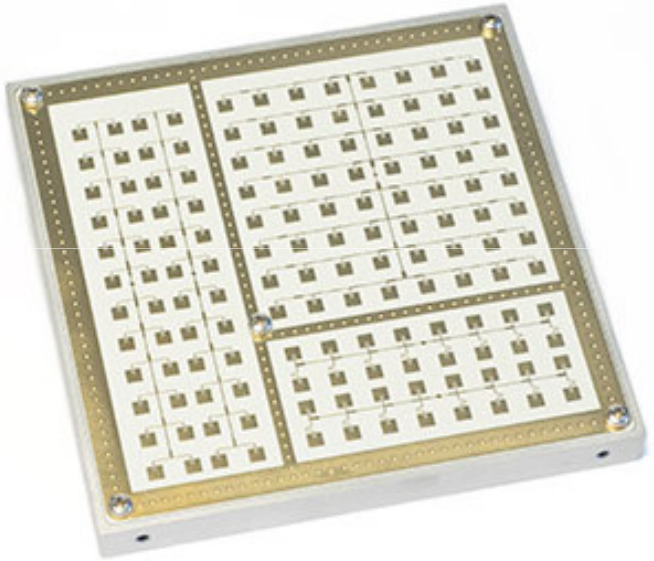
- **MEMS scanning LIDAR**
- **Field of view: 120deg Az, 20deg El**
- **Peak power 85 W**
- **Pulse length: 5 – 20ns**
- **Range: 300 meter (car) 70 meter (pedestrian)**
- **Angular accuracy: 0.1-0.5deg**

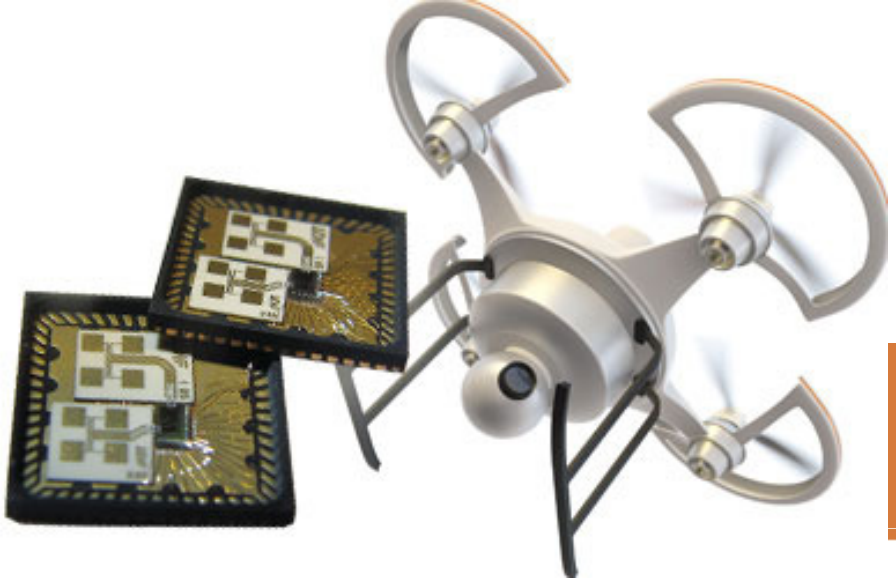
Short range radar



RfBeam 24 GHz radar

- 24 GHz Ka band 24.0 – 24.5 GHz
- 76 GHz automotive
- FMCW and Doppler Radar
- Bandwidth 250 MHz – 4 GHz
- Beamwidth: 7 – 80 degrees
- Range: 5 – 300 meter





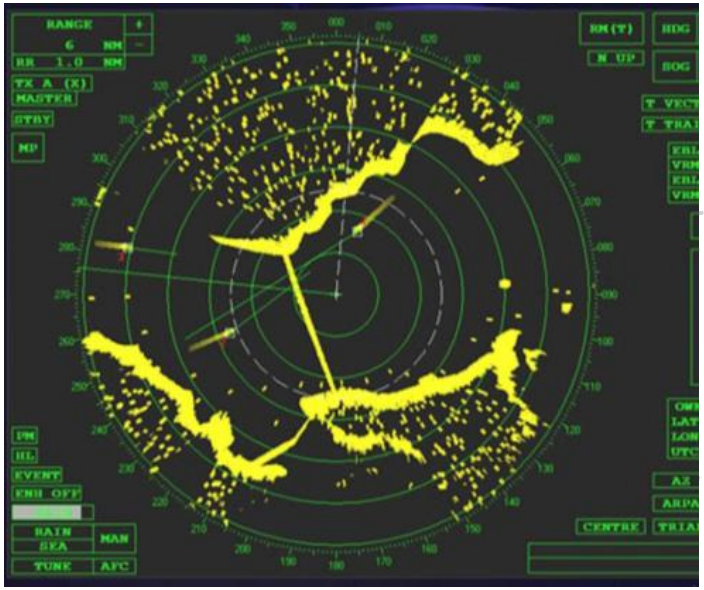
122 GHz mmW Radar

SILICON radar

Features

- Radar frontend (RFE) with antennas in package for 122 GHz ISM band
- Dual supply voltage of 3.3V (RF-part) and 1.2V (CMOS)
- Fully ESD protected device
- Low power consumption of 380mW
- Integrated low phase noise Push-Push VCO
- Receiver with homodyne quadrature mixer
- RX and TX patch antennas
- Large bandwidth of up to 7GHz
- QFN-56 leadless plastic package 8x8mm²
- Pb-free (RoHS compliant) package
- IC is available as bare die as well (without antennas)

Radar



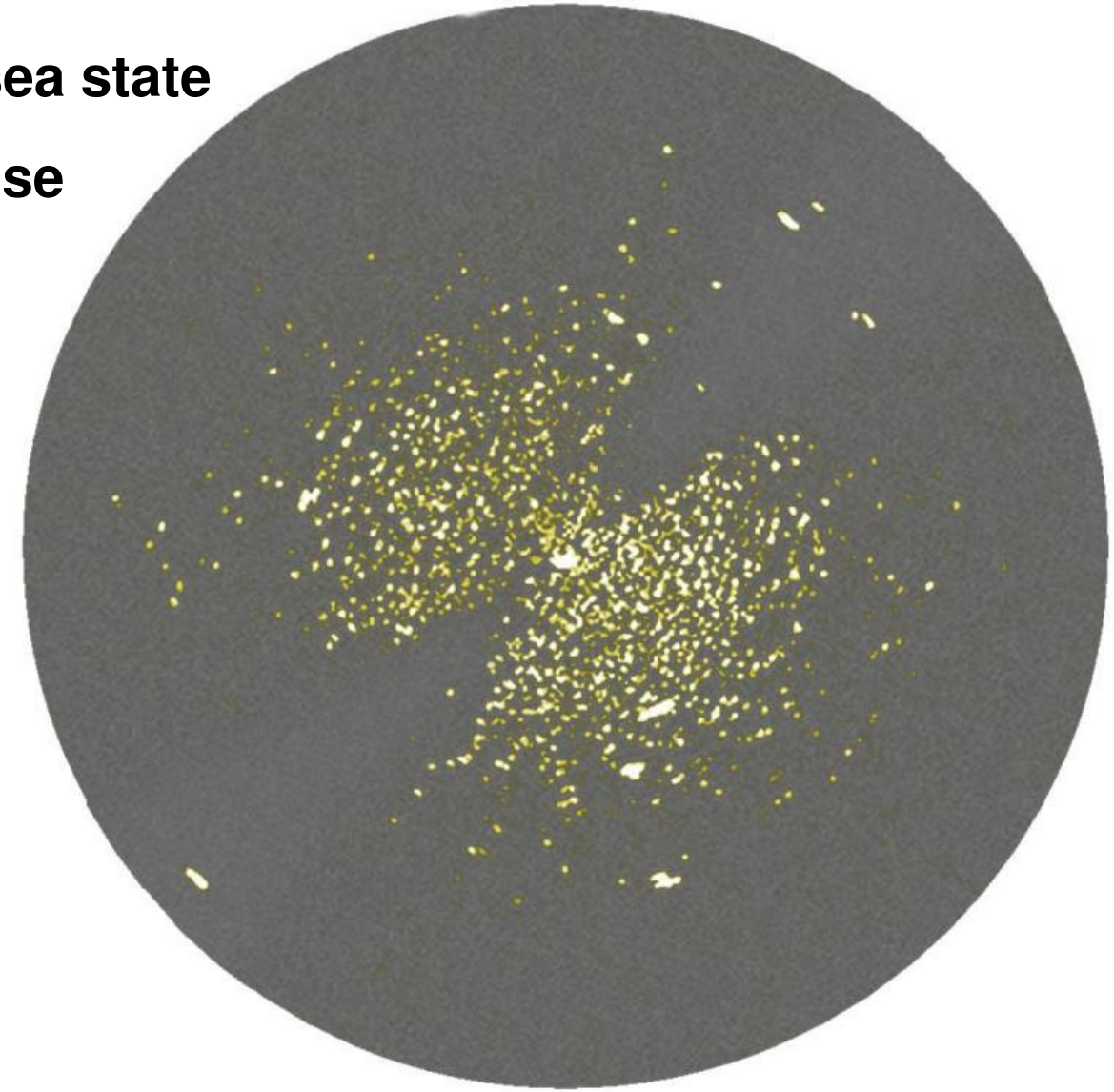
- Well proven technology
- Long range
- Limited resolution

$$\Delta r = \frac{c}{2B}$$

- Sea clutter – rain clutter – operator errors
- «Radar holes» due to multipath during calm sea
- ARPA – only for large installations
- Small ships does not have ARPA
- «Blind zone» – 25m at short ranges
- Low update rate (0.8 – 2.5 updates/sec)

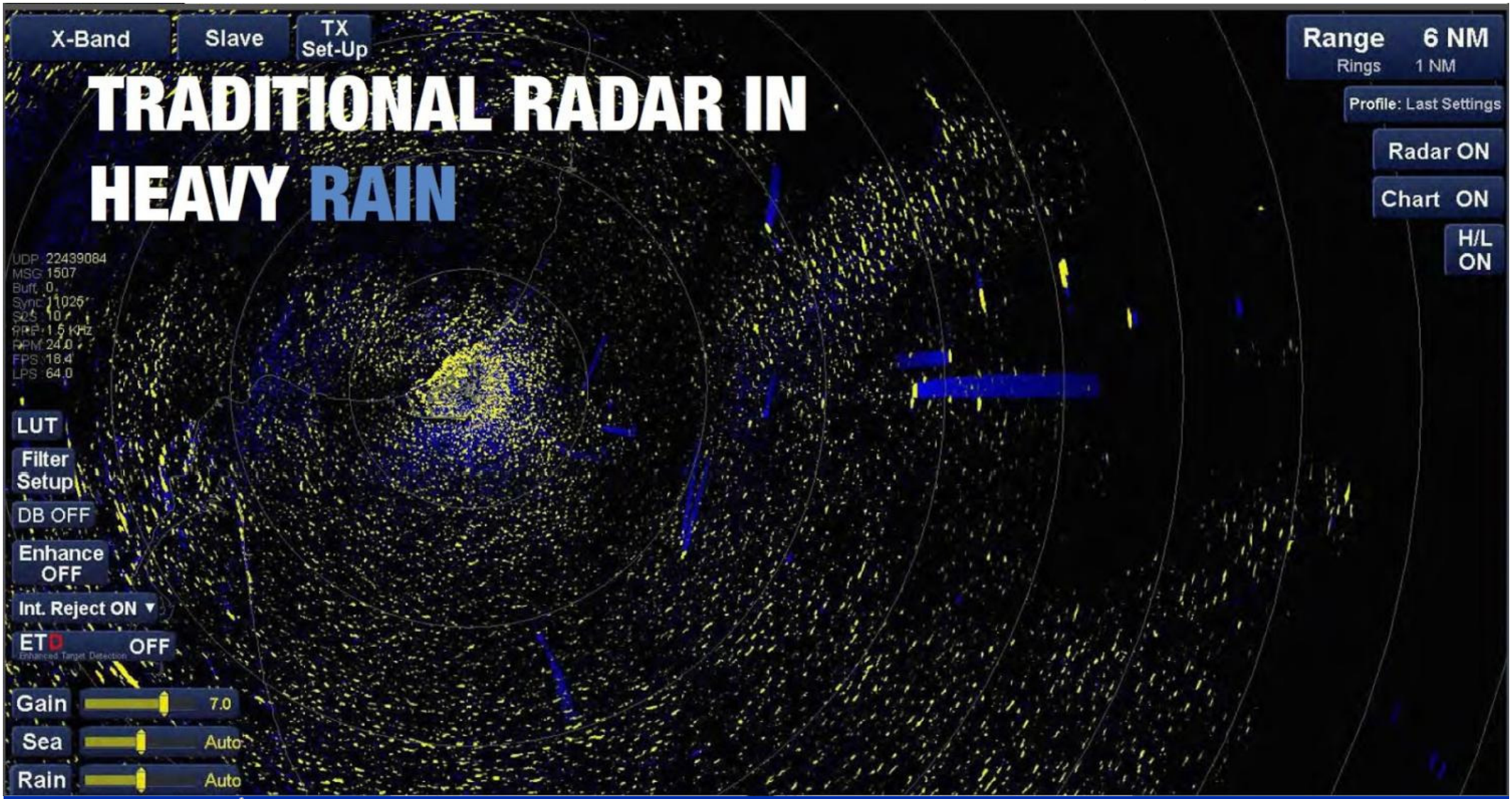
Sea clutter

- Dependent on wind and sea state
- Directional clutter response
- May mask small objects

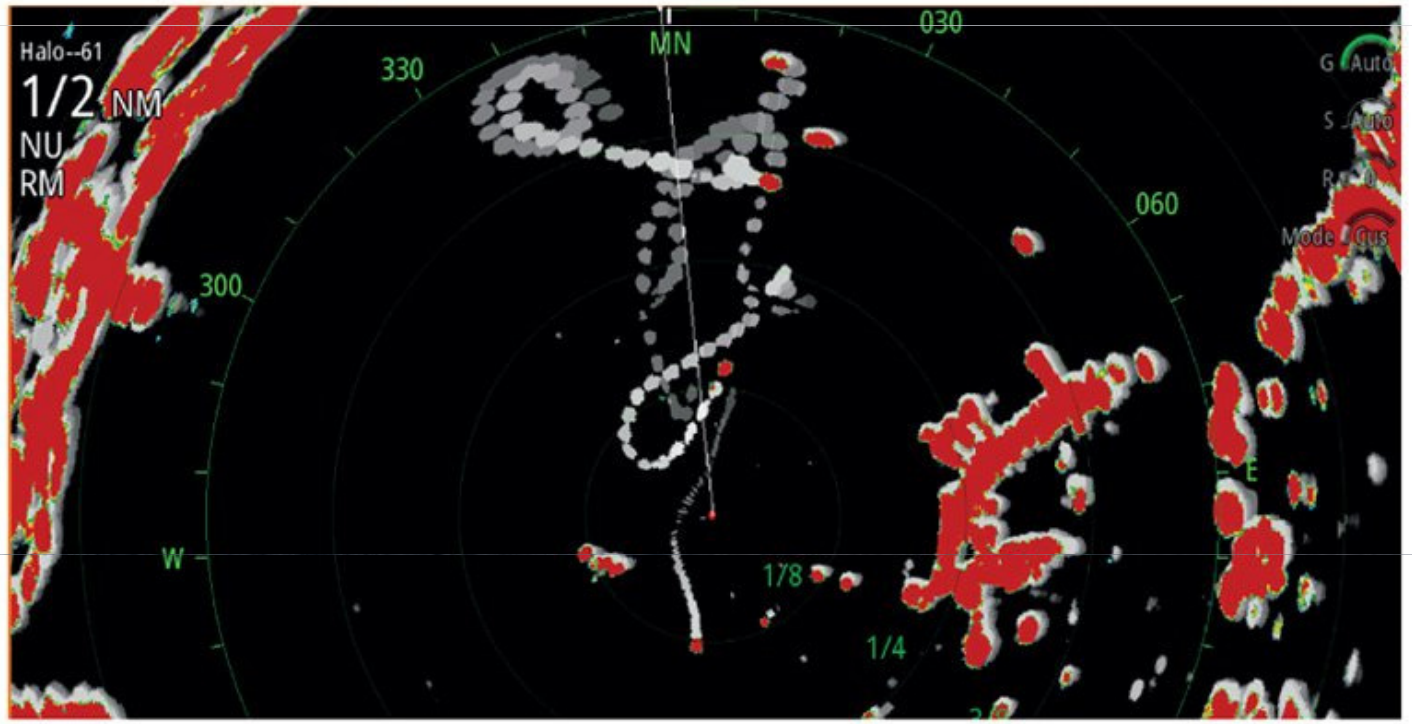


Rain clutter

Highest clutter level at X- band (9.3 – 9.5 GHz)



Detection and tracking of small objects

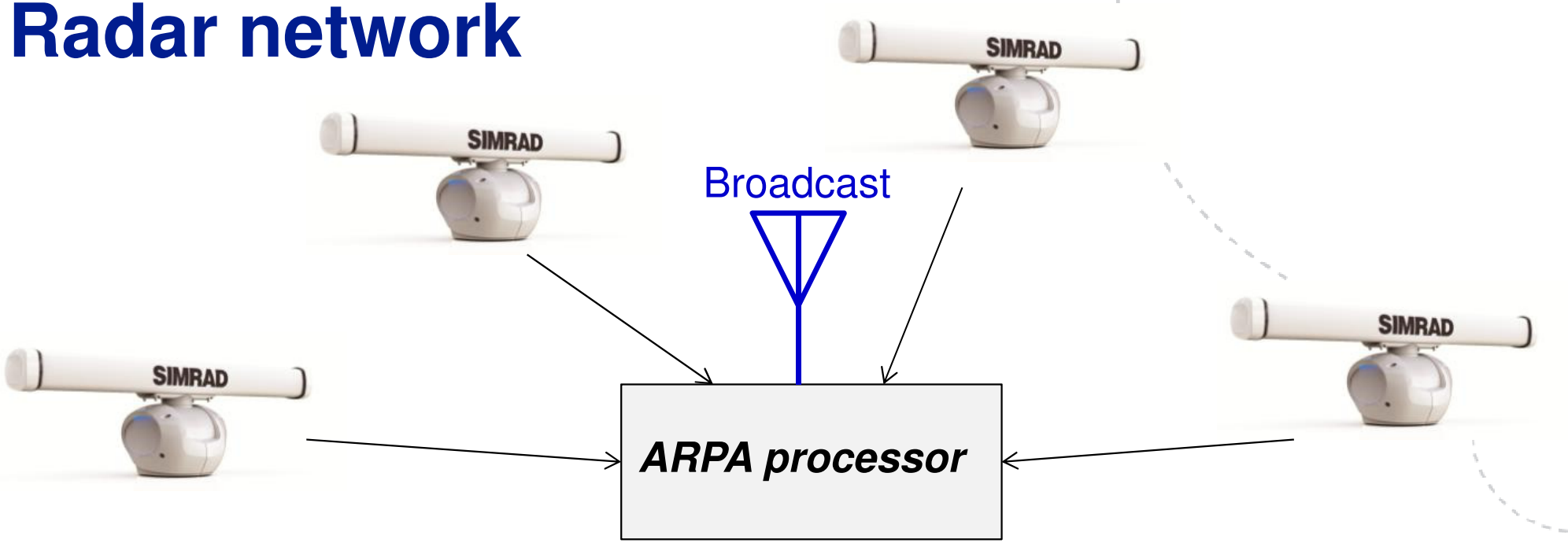


TRACK MULTIPLE HIGH-SPEED TARGETS

With high-speed operation, Halo™ shows target trails of four fast-moving jet skis in Clearwater, Florida harbour.

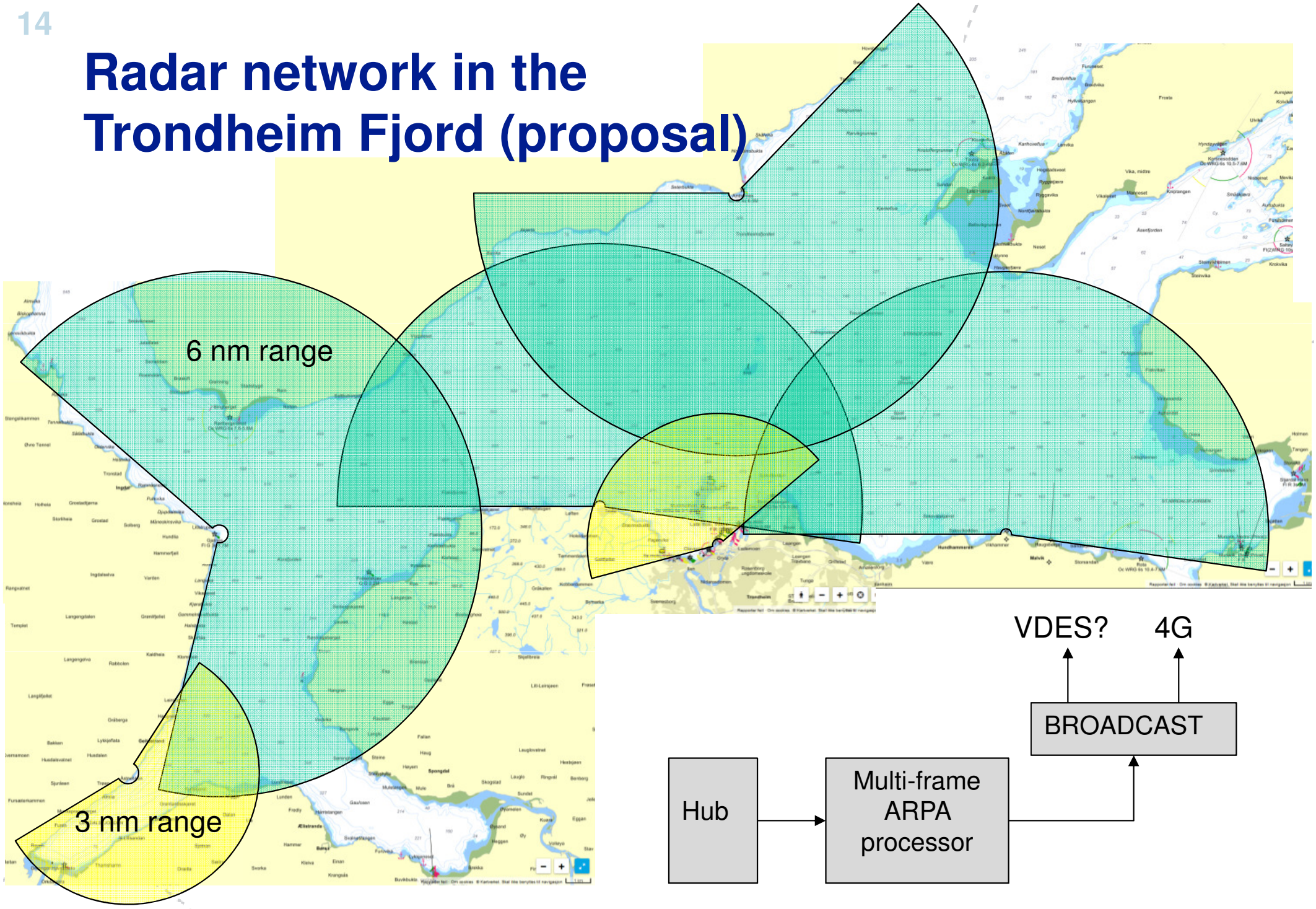
Image: Navico

Radar network



- Several radars cover a common area from different angles
- Sensor fusion on raw data or post detection data
- Centralized ARPA function with high quality
- Broadcasting of tracks to all user in the area
- → ”Augmented AIS”

Radar network in the Trondheim Fjord (proposal)



Advantages

- Stationary radars
- Solid state coherent radar (Chirp/FMCW) with Doppler filtering
- More suitable antenna patterns – less rain clutter
- Observations from many angles – reduction of sea clutter
- Combined S + X band processing (2.9 – 3.1 GHz) (9.3 – 9.5 GHz)
- Sensor fusion at raw data level
- Processed tracks can be broadcasted with low data rate

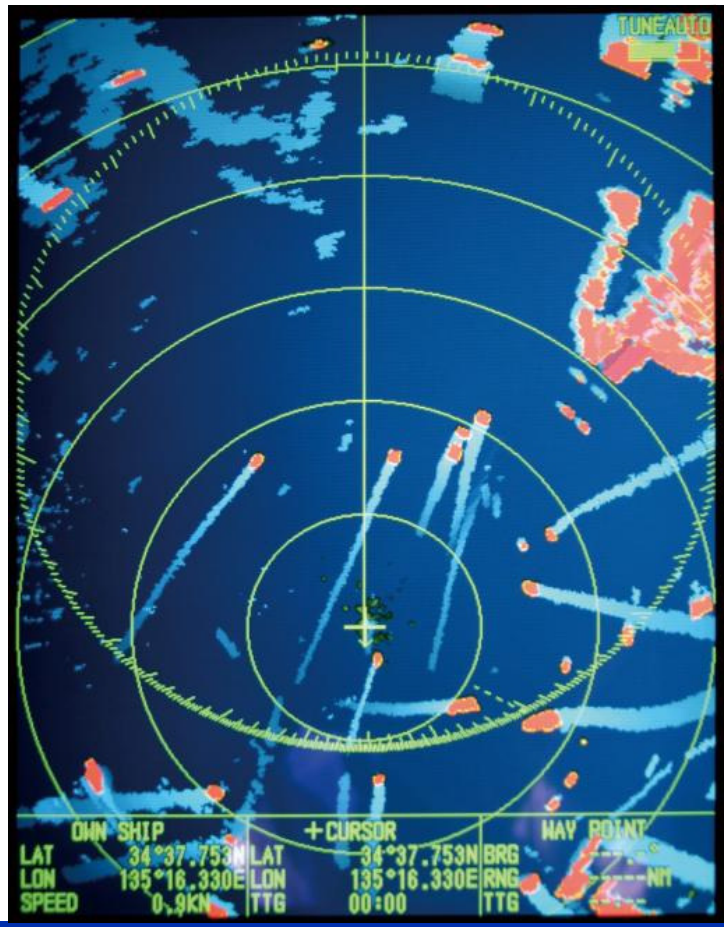
Technological challenges

- High capacity – low latency data transfer from radar to central
- Fast multi-frame processing of large amounts of data
- Low total latency: < 1 sec (from recording to distributed tracks)
- Raw data transfer: ~50 Mbit/s
- PPI transfer: ~0.3 Mbit/s
- Broadcasting of tracks: ~50bytes/track

Solid State

Operational advantages

- **Augmented AIS – full ARPA functionality even for small vessels**
- **Tracking of small objects (small boats, kayaks etc)**
- **High reliability detection**
- **Avoid shadows behind headlands**
- **VTS functionality**
- **Better safety on sea**
- **Less risk of accidets**



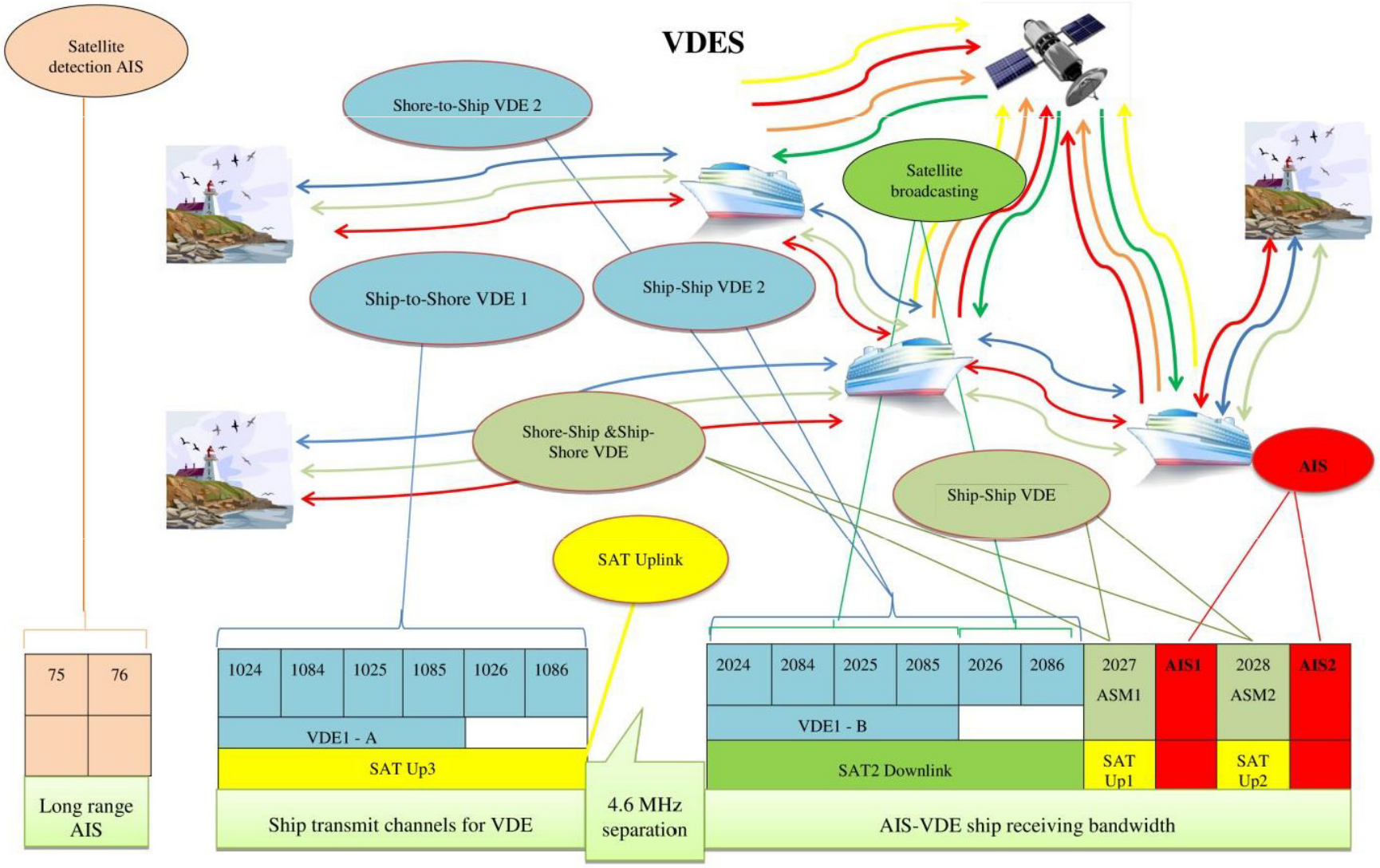
Autonomous ships and communication

- Need secure and robust communications system
- Authentication and encryption (resilient against hacking)
- Redundancy: several frequency bands – several systems
- Correction data for GNSS (RTK)
- Commands from shore station (VTS)
- Narrowband telemetry (AIS - VDS) status updates
- Ship – ship communication (collaborative navigation)
- Broadband telemetry, video, radar, lidar
- Voice relay (maritime VHF)
- Remote control during docking operations

VDES (VHF Data Exchange System)

2 VHF channels (25 kHz) QPSK → 156 kbit/s (shared)

ITU-R M.2092-0



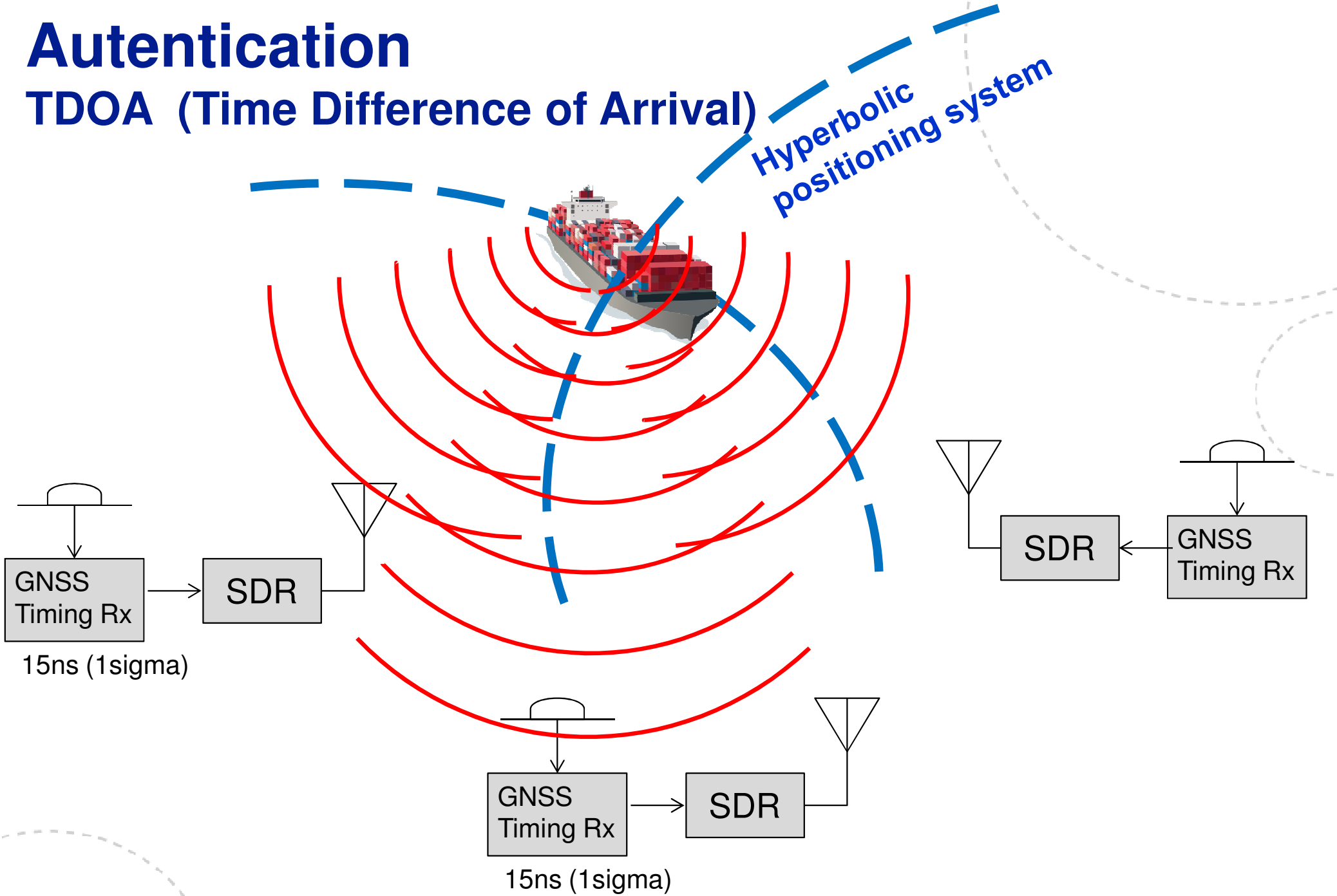
Broadband Radio:

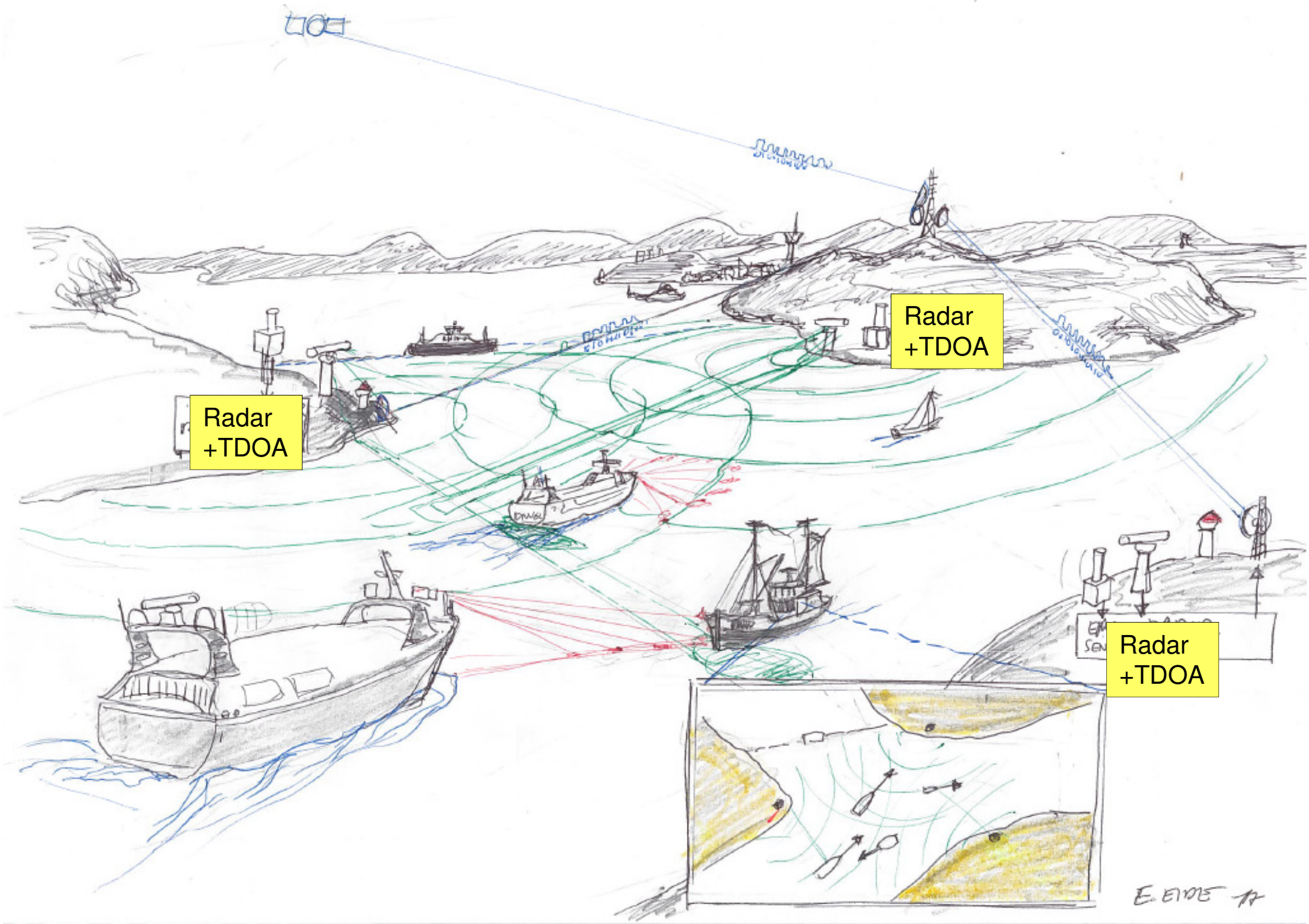
Kongsberg Maritime Broadband Radio (5 GHz band)

- adaptive beamforming
- up to 60 antennas in an array

Autentication

TDOA (Time Difference of Arrival)




Radar
+TDOA
Radar
+TDOA
Radar
+TDOA

LTE, WIFI and 5G Massive MIMO Communications in Maritime Propagation Environments

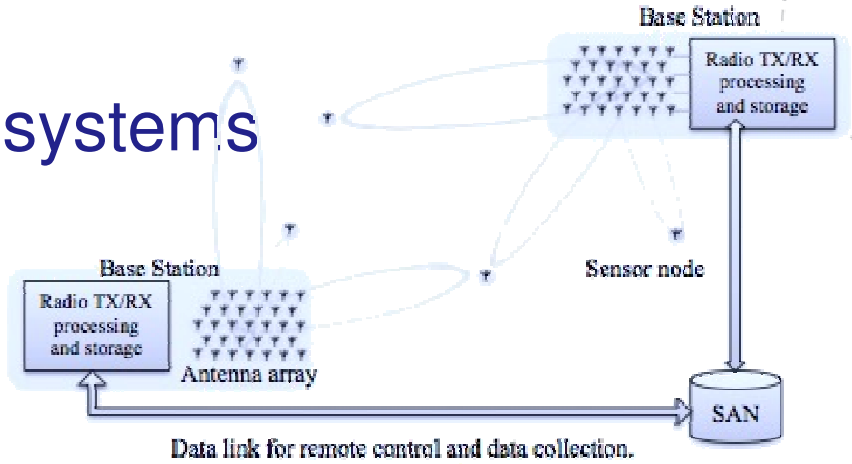
- **MaMIME**
  - How to Make This Work in a Maritime Scenario
- Understand propagation
  - Continue activity on channel modeling
- Antennas
  - Large arrays
  - Spatially distributed
- Measurement campaign
  - From shore to ship
- **Partners**
  - NTNU
  - Kongsberg Seatex
  - Teleplan
  - Witelcom
  - ZTE
  - Super Radio

ReRaNP Reconfigurable Radio Network Platform

"All the proof of a pudding is in the eating."

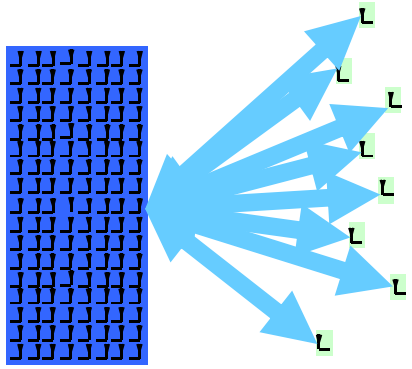
- Enabling research infrastructure for
  - exploration
  - validation
  - demonstration

  of the next generation of radio systems

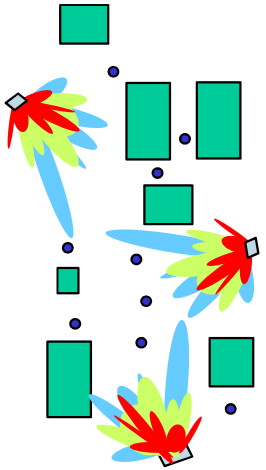


- Implement and test in environments of Norwegian interest
  - Large cells, rural regions
  - **Maritime** and **Arctic** environments

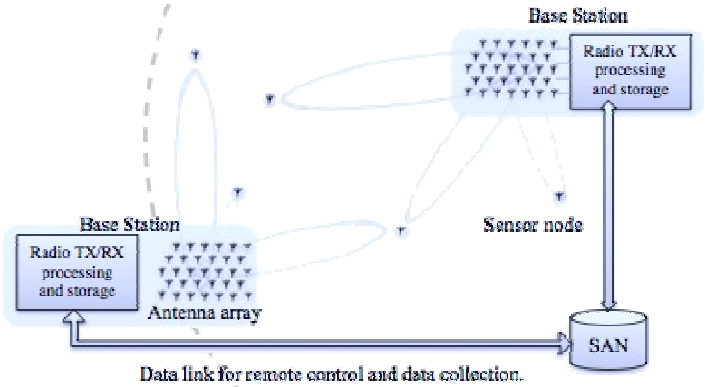
What is the Reconfigurable Radio Network Platform?



- National infrastructure project
  - Funded by the Research Council of Norway
- A Software Defined Radio (SDR) lab
  - Massive MIMO capabilities at NTNU
    - 64 SDR units in a rack give a BS with 128 antennas
    - 4 racks with 16 SDR units each gives 4 BS with 32 antennas
    - 5G demonstrator
  - Roof-lab with 4 sites provided by Wireless Trondheim
    - 4 BS with 32 antennas each
    - 5G demonstrator in city environment



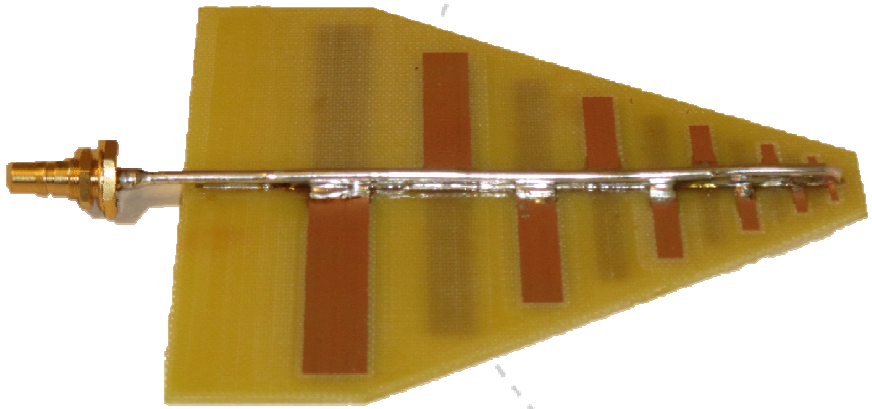
The SDR in ReRaNP



- NI USRP-2943R
  - 64 units in racks
  - 40MHz BW
  - 1.2 GHz TO 6 GHz
  - Kintex-7 FPGA
  - PXI Express
  - GPS disciplined oscillators
- NI USRP-2953R
  - As nodes (7 units)
  - Same as above with inbuilt GPS Clock

- PHY programmed with
  - LabVIEW Communications System Design Suite
  - GNU Radio

Antenna array



- Log-periodic antenna elements
  - Gain 6 dBi
- Array made of 4 sub-arrays
  - 32 elements in a 4x8 grid
- One array for the frequency range from 1.4 - 6GHz

NTNU
Kunnskap for en bedre verden

Department of Electronics Systems
Department of Engineering Cybernetics
Department of Marine Technology

NTNU AMOS
Centre for Autonomous Marine Operations and Systems


Illustration: Svein Aa Aanondsen, NTNU

Concept

- **”On-demand ferry”** - push the button for the ferry to come
- Traveling time: **1 minute** → low latency
- Passengers: **12 persons**
- **Electrical propulsion**, **Automatic charging** of batteries
- Navigation: **RTK GNSS compass with IMU** plus backup system
- **Anti-collision system** **(Lidar/camera/radar)**

A new entrance for cruise tourists

Autonomous shuttle bus

Ferry

To Nidaros Cathedr


Fosenkaia
←New bridge for pedestrians
Vestre Kanalkai
Ravnkloa
706
Vestre Kanalkai
Kai 19
Kai 20
Kai 21
Frostakaia
Fjordgata
Jomfrugata
Munkegata
Taraldsgårdsveita
Credoveita
Olav Tryggvasons gate
E 6

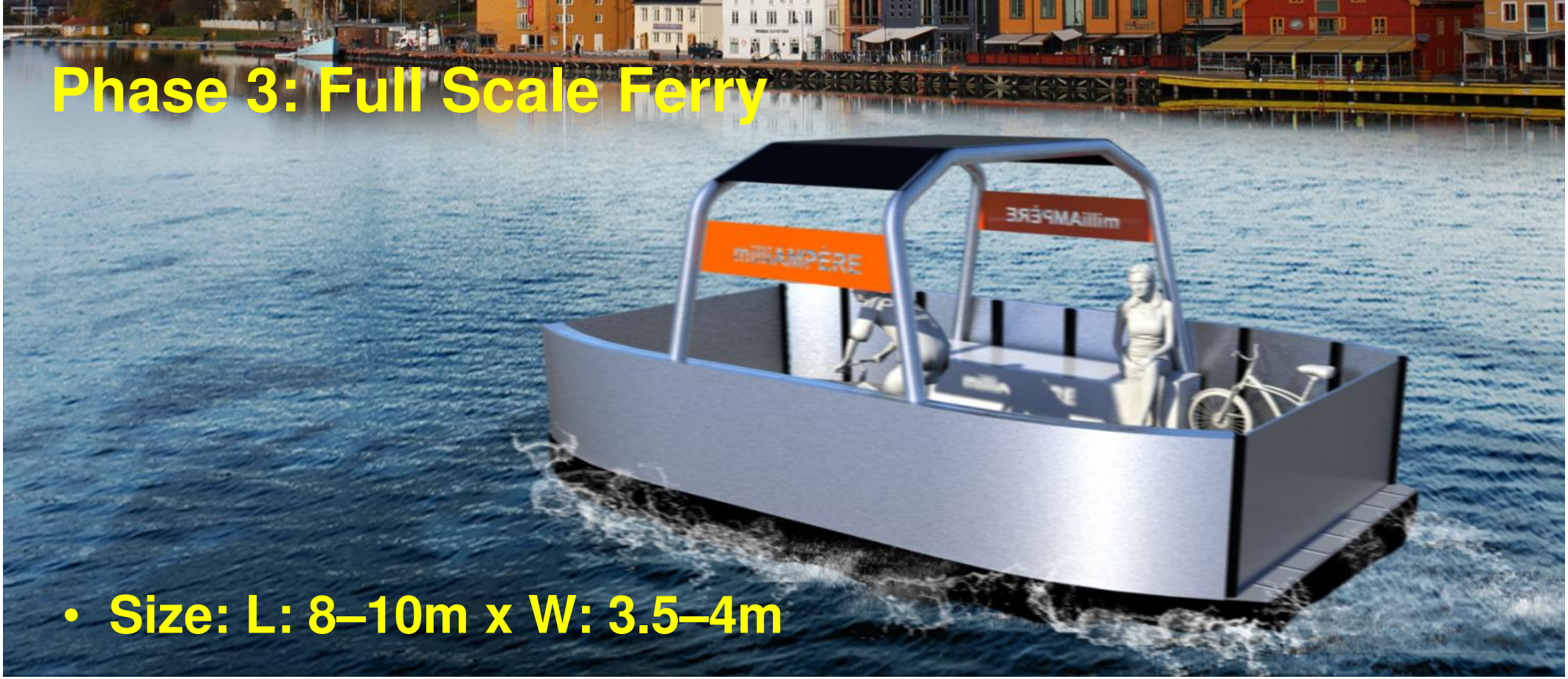
Illustration: Anders Engebakken, NTNU

Automatic docking and passenger access system

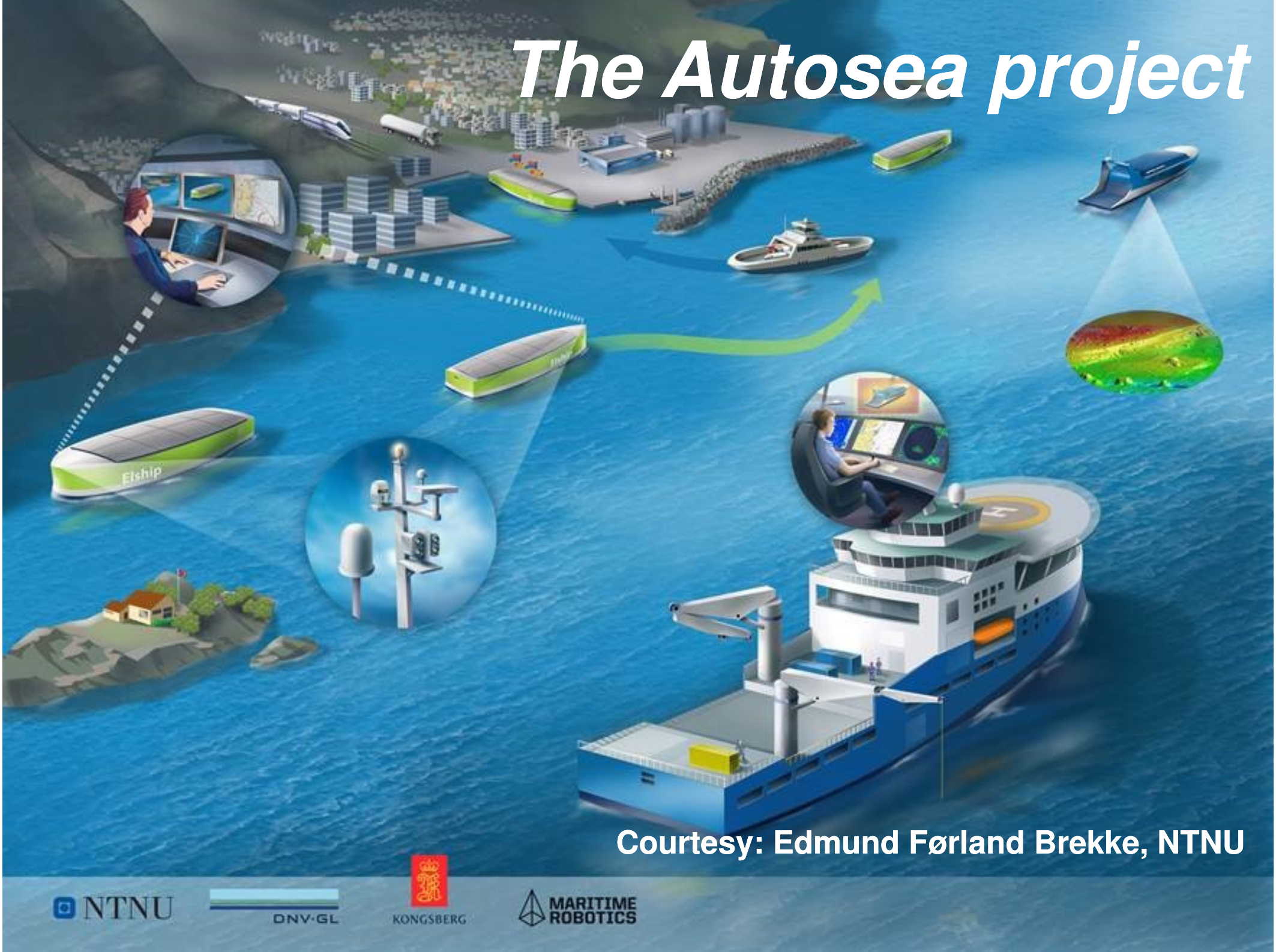
- Passenger registration using smartphone app
- On board camera + IR for verification
- Fail-safe gate sytem

Illustration: Anders Engebakken, NTNU

Phase 3: Full Scale Ferry



- **Size: L: 8–10m x W: 3.5–4m**
- **12 passengers**
- **Automatic battery charging (induction or plug connector)**
- **Propulsion: 2 x 10kW azimuth thrusters**
- **RTK GNSS-compass + LIDAR system**
- **AIS and 2-way wireless communication including video**


The Autosea project
Elship
Courtesy: Edmund Førland Brekke, NTNU
NTNU
DNV·GL
KONGSBERG
MARITIME ROBOTICS

The AUTOSEA project

- Funded under the MAROFF programme of the Research Council of Norway.
- Budget 11MNOK, with contributions from DNV GL, Kongsberg Maritime and Maritime Robotics.
- Duration: August 2015-Spring 2019.
- Competence building project: The aim is to educate PhDs with expertise on maritime collision avoidance.
- The project funds 2 PhD candidates and one postdoctoral fellow. In addition, 2 PhD candidates and several MSc candidates are affiliated with the project.
- Project is owned by the Department of Engineering Cybernetics at NTNU.

DNV·GL

KONGSBERG

MARITIME ROBOTICS

Photo: Egil Eide

Time schedule

Phase 1 (2016): Concept study, student projects. **Webcamera and radar** to monitor boat traffic i the harbour. Dynamic Position system to be tested onboard **ReVolt** from DNV-GL in Trondheim Harbour.

Phase 2 (2017): Autonomous **pilot ferry** for concept testing and to study behaviour of the other boat traffic.

Phase 3 (2018/2019): Full scale ferry certified for passengers.

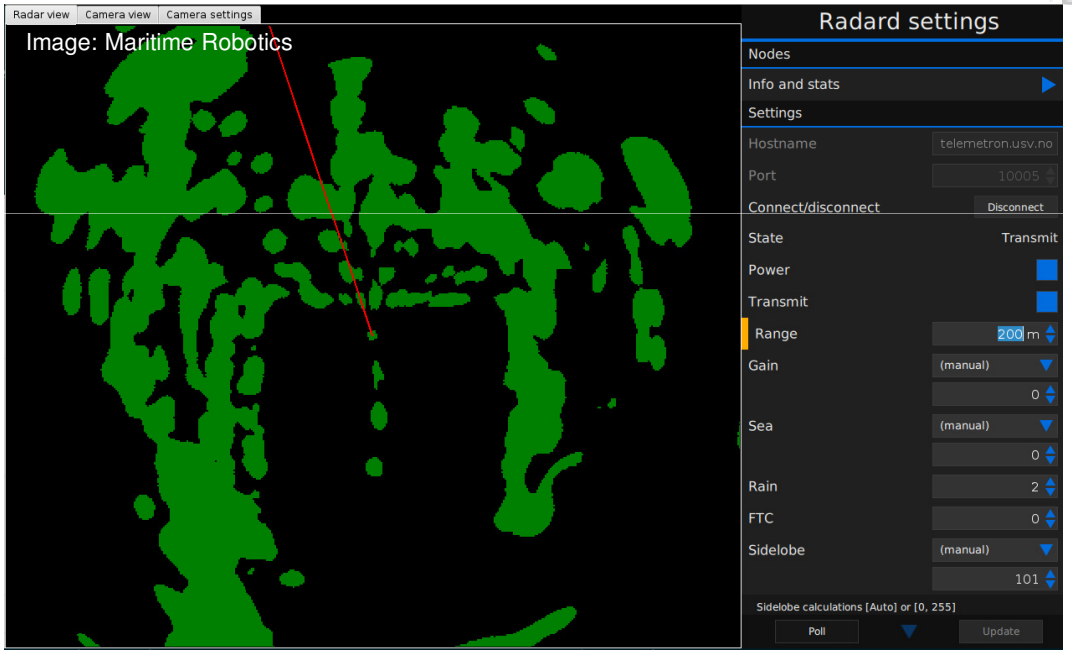
Phase 1: Monitoring of boat traffic

(Collaboration with Maritime Robotics)

Photo: Egil Eide

Radar + webcam

- boat traffic statistics
- kayaks and small wooden boats
- study behaviour of boaters



Phase 1: Monitoring of boat traffic

(Collaboration with Maritime Robotics)

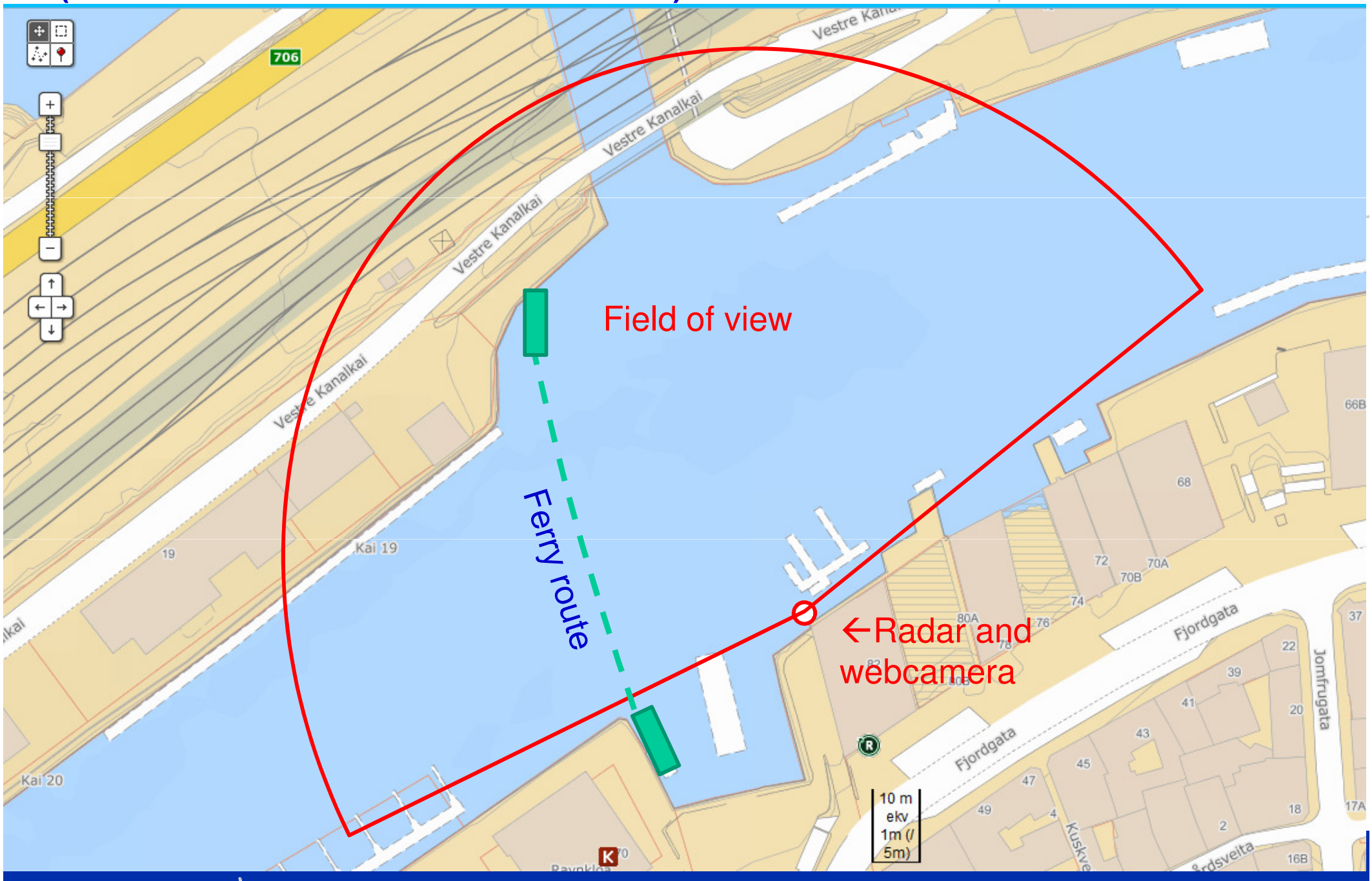


Photo: Egil Eide