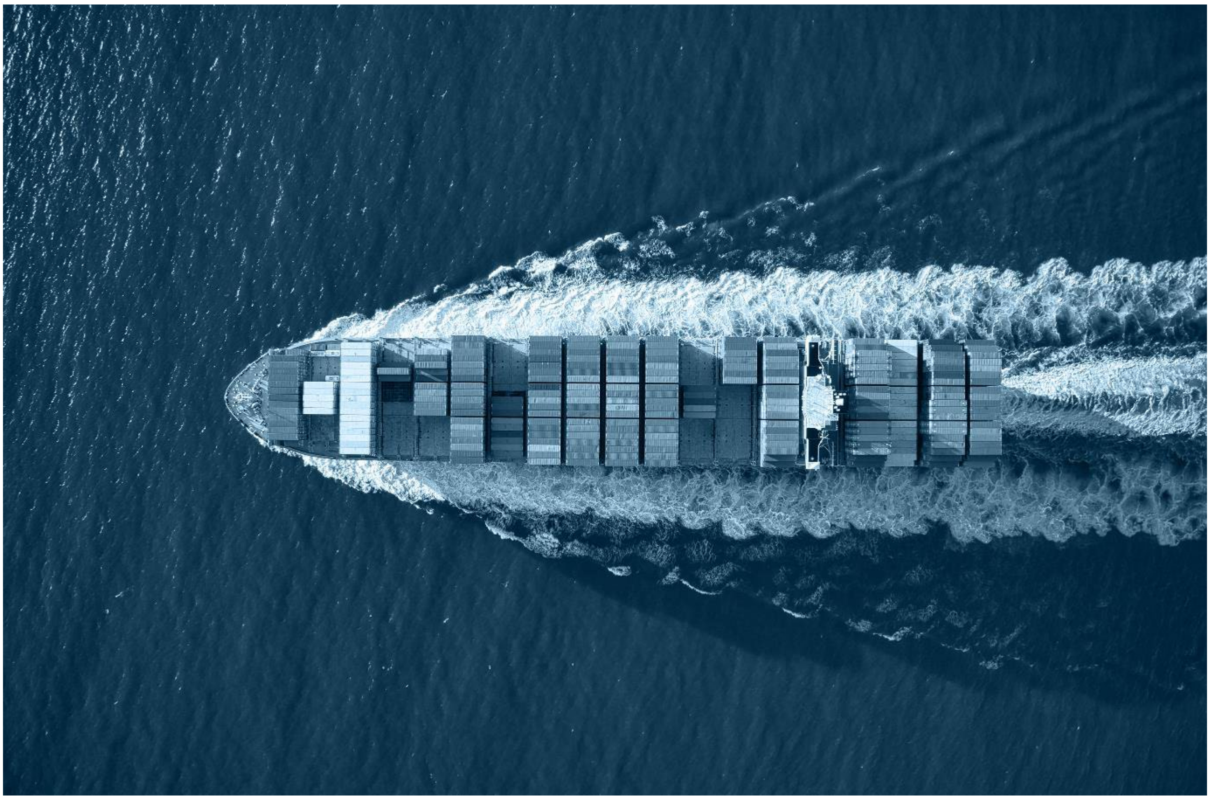
ADMO Deliverable 4.1.- Piloting plan



Introduction

This deliverable presents the infrastructure used in the ADMO project pilots and the initial plan for the actual pilots. We present the test vessel, related remote operations center and considerations on wireless communications in maritime environments and finally the initial piloting plan.

Test vessel

In response to the growing need for advanced testing infrastructure in the maritime industry, a decision was taken to build a test platform dedicated to maritime environments. This innovative endeavor was made possible by applying and receiving additional funding, notably the TEHOTEKO project (January 2022 to August 2023). The primary objective of the TEHOTEKO project is to provide support to Small and Medium-sized Enterprises (SMEs) in tackling the challenges posed by the integration and application of artificial intelligence (AI) algorithms to their operations. TEHOTEKO is financed from the European Regional Development Fund (ERDF).

While TEHOTEKO encompasses a diverse range of AI and machine learning applications, Turku University of Applied Sciences (Turku UAS) has made a strategic decision to specialize in the field of maritime environments. As a result, the test platform of the project was chosen to be a test vessel with advanced sensoring, ICT, and AI capabilities.

Test vessel features

The vessel is equipped to function both manually and autonomously. It boasts a state-of-the-art commercial autopilot implementation, with navigational devices from the Furuno product line. A remote operation center was also built to allow seamless control and monitoring of the vessel.

The autonomous operation is based on Robotic Operating System 2 (ROS2) software architecture. The vessel's multi-satellite navigation system is compatible with GPS, GLONASS, BeiDou, Galileo, and QZSS satellites.

To enhance situational awareness and facilitate the vessel's ability to detect other boats and potential obstacles, it boasts an array of multi-modal sensoring systems. These encompass a comprehensive suite of technologies, including Lidars, RGB and thermal cameras, AIS (Automatic Identification System), radars, and more.

In support of AI algorithm testing, an advanced ICT infrastructure has been integrated to the test vessel. This allows seamless integration and testing of artificial intelligence capabilities within the maritime domain. Moreover, the inclusion of the BHI SmartBox for wireless connectivity guarantees uninterrupted data transmission and communication by aggregating several links from different technologies, such as mobile networks and satellites.

The test vessel serves the Finnish industry in testing and developing their AI and Machine Learning (ML) based solutions in many different application areas. IN ARPA WP2, the test vessel is pivotal in collecting data from the multi-modal sensoring system for ML datasets and in studying the wireless connectivity in maritime environments. The test vessel is shown in Figure 1.

Figure 1. The test vessel eM/S Salama.

Phases in the development of the test vessel

The development of the test vessel is not a trivial task, and it includes several challenging phases. The different phases are described briefly in the following.

1. Defining Requirements and Specifications: The initial phase involved a thorough examination of the vessel's requirements and specifications. This includes crucial parameters like size, weight, speed, power, and the essential regulatory and certification standards that must be adhered to.
2. Electrical System Design: A pivotal aspect of the project was designing the vessel's electrical system. This includes accommodating a variety of electronic devices, necessitating a provision for 12/24/48 V DC and 230 V AC electricity. Overcoming non-trivial challenges related to safety, interference, and grounding

is crucial for ensuring the system's safe and efficient operation. The team also designed the charging system and acquired an aggregate for a reliable backup energy source.

3. CAN Bus Architecture Design: The development of the Controller Area Network (CAN) bus architecture is paramount for seamless communication among the vessel's various devices. The vessel's equipment relies on NMEA2000, J1939, and CANopen messages for effective interaction.
4. Simulations: The team conducted comprehensive simulations to assess both the overall vessel's NMEA2000 system and the vessel's resistance characteristics. This includes evaluating frictional resistance, wave-making resistance, and air/wind resistance.
5. Procurement of Key Components: Sourcing essential components like the hull, motors, and batteries is a critical step. The team acquired these components from established commercial suppliers while ensuring their compatibility with the overall system design.
6. Motor and Rudder Controller Design and Implementation: The design and integration of a motor controller are essential for enabling motor control via NMEA messages, facilitating remote and autonomous operations.
7. Sensor Selection and Integration: The team focused on identifying the most suitable sensors for capturing essential data for ML datasets and to obtain situational awareness.
8. ICT Subsystem Design and Implementation: The development of the Information and Communication Technology (ICT) subsystem is instrumental in facilitating data processing, storage, and seamless communication within the situational awareness system.
9. Electrical System Implementation: This phase involved the installation and integration of electrical system components, including batteries, power distribution panels, wiring, and safety devices, all executed in strict accordance with electrical and safety standards.
10. CAN Bus Integration: Connecting and configuring all pertinent electronic systems, encompassing propulsion, navigation, sensors, and control systems, through the CAN bus system.
11. Rigorous System Testing and Compliance: Thorough system testing is conducted to ensure the vessel complies with all pertinent safety regulations, certifications, and guidelines. This phase also entails the careful preparation of documentation for registration. Notably, this work marks a pioneering milestone, as it represents the first work boat in Finland to utilize electric propulsion.

Figure 2 shows the roadmap for the test vessel development. The vessel launch event was held in June 2023 in Ruissalo, Turku, Finland. The vessel was named eM/S Salama. Test drives were conducted during summer 2023 and data was collected from the sensors for ML purposes. This data will be annotated during winter 2023-2024. The development of the autonomous features is on-going, and the features will be field-tested during summer of 2024. Vessel automation and autonomous operation features will be ready for summer 2024 to trial ADMO use case automated vessel operation.

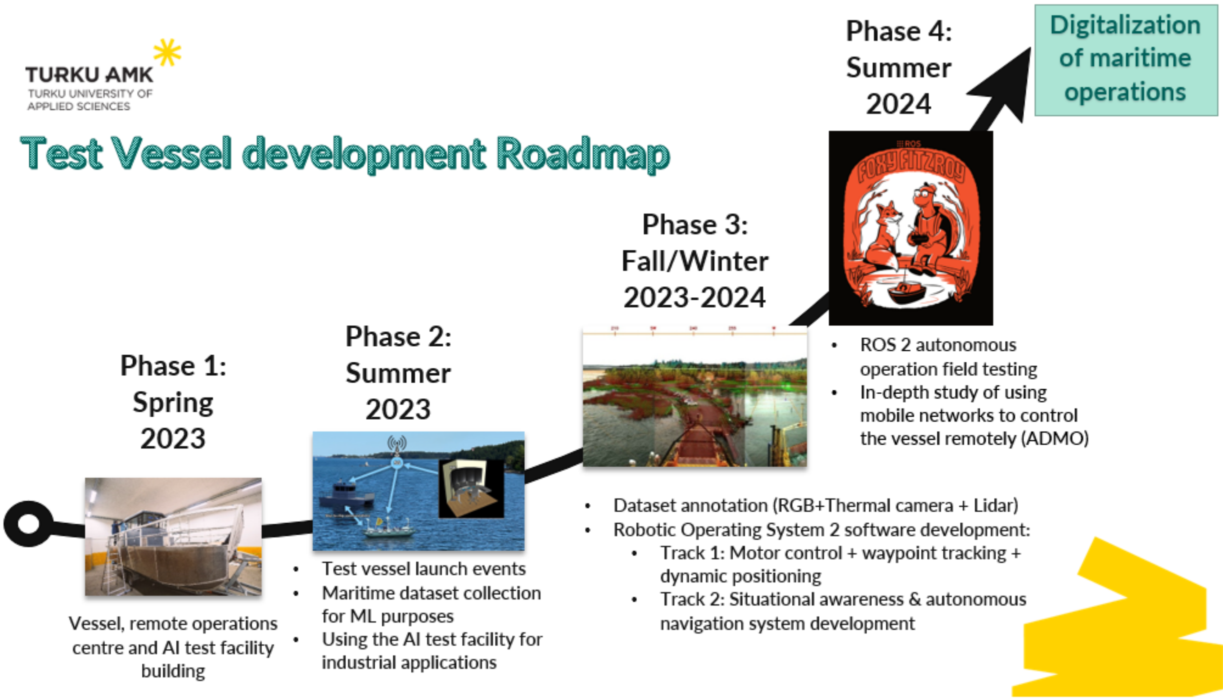


Figure 2. Test vessel development roadmap.

Remote Operations Center

To monitor the operation of the test vessel, a center is needed from which the operation can be controlled and monitored without being physically on board. For this purpose, an additional investment funding was received from European Regional Development Fund (ERDF) for TEHOTEKO-ROC project, where a remote operations center (ROC) was built.

The ROC represents a critical component in the test vessel's advanced operational infrastructure, designed to enable both remote monitoring and remote operation of the vessel, both of which are ADMO project use cases. The ROC's software, procured from a reputable commercial supplier, has entered its final testing phase, with plans for a launch scheduled for late 2023.

One of the ROC's core functions is the handling and visualizing telemetry data from the vessel. This data is transmitted efficiently through the utilization of NMEA2000 messages, ensuring a seamless flow of essential information. Moreover, video streams are transmitted via the Real Time Streaming Protocol (RTSP). Notably, the ROC is set to elevate its capabilities with the introduction of surround sound during the autumn of 2023.

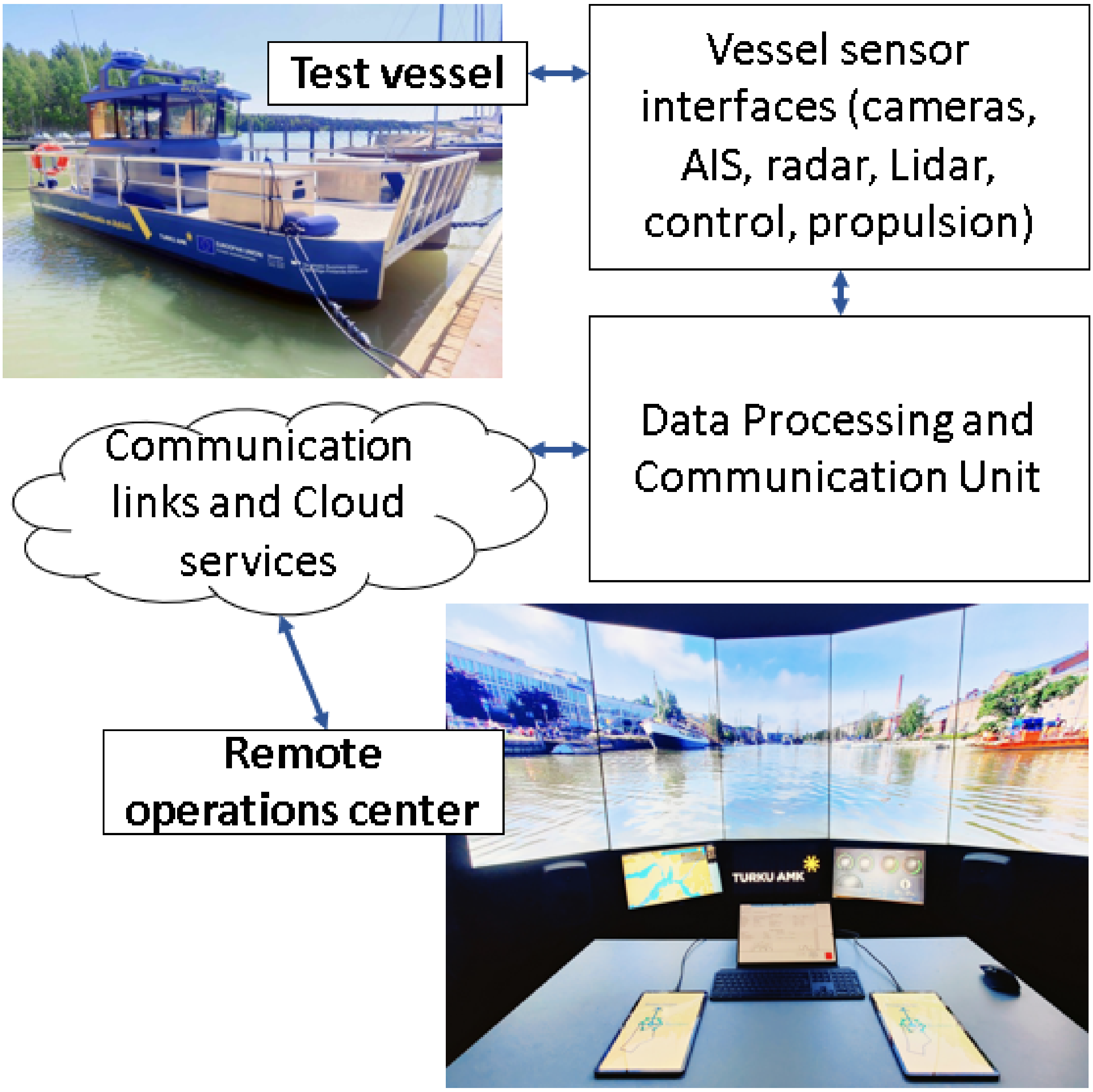


Figure 3. high-level illustration of the ROC implementation.

Figure 3 shows a high-level illustration of the ROC implementation. The data from vessel interfaces is transmitted to a data processing and communication unit, which transmits the data wirelessly to the ROC-PC through a cloud service. The ROC itself boasts a display setup featuring five 55-inch screens and three 24-inch screens. This extensive array of screens serves various purposes, including providing a 180-degree view of the vessel's surroundings, displaying telemetry data, and showcasing map data. For operational control, tablets are employed, offering a user-friendly and versatile means of modifying and testing various control systems. This approach offers greater adaptability and efficiency compared to traditional physical controllers or exact replicas of the vessel's dashboard. Furthermore, the ROC is designed with scalability in mind, enabling the seamless addition of extra screens to display information from various sensors, such as side-view cameras, thermal imaging devices, and Lidar sensors. This adaptability further enriches the vessel's capabilities and operational flexibility. The ROC is located at Turku UAS campus in Kupittaa, Turku.

The vessel’s motors and rudder are operated using an ESP32 microcontroller unit (MCU) -based dynamic control unit (DCU), which communicates with the vessel’s NMEA2000 bus. The motor and rudder controller architecture are shown in Figure 4.

The ROC can send commands to change the RPM of the motors and change the rudder angle. Motor and rudder control relay send status change requests motor and rudder controller units, which include the functionalities needed to change the RPM of the motors and the angle of the rudder. Status messages from the motors and rudder are sent to the onboard NMEA2000 bus.

Functionalities of the DCU are divided into two devices with custom printed circuit boards (PCBs). One device is controlling motors mimicking throttle inputs and the other is controlling rudder as a remote for the Furuno autopilot. Both devices incorporate a CAN controller for NMEA2000 and a digital to analog converter (DAC) and relays. DACs provide throttle input and the rudder remote input. Relays are used for changing throttle input provider and used as a switch for the autopilot. The DCU includes several fail-safe functions. A heartbeat signal must be sent by the commanding unit at set intervals to maintain operational mode. The vessel’s local operator can also revert to manual operating mode by moving the engine control lever from idle or pressing an emergency button.

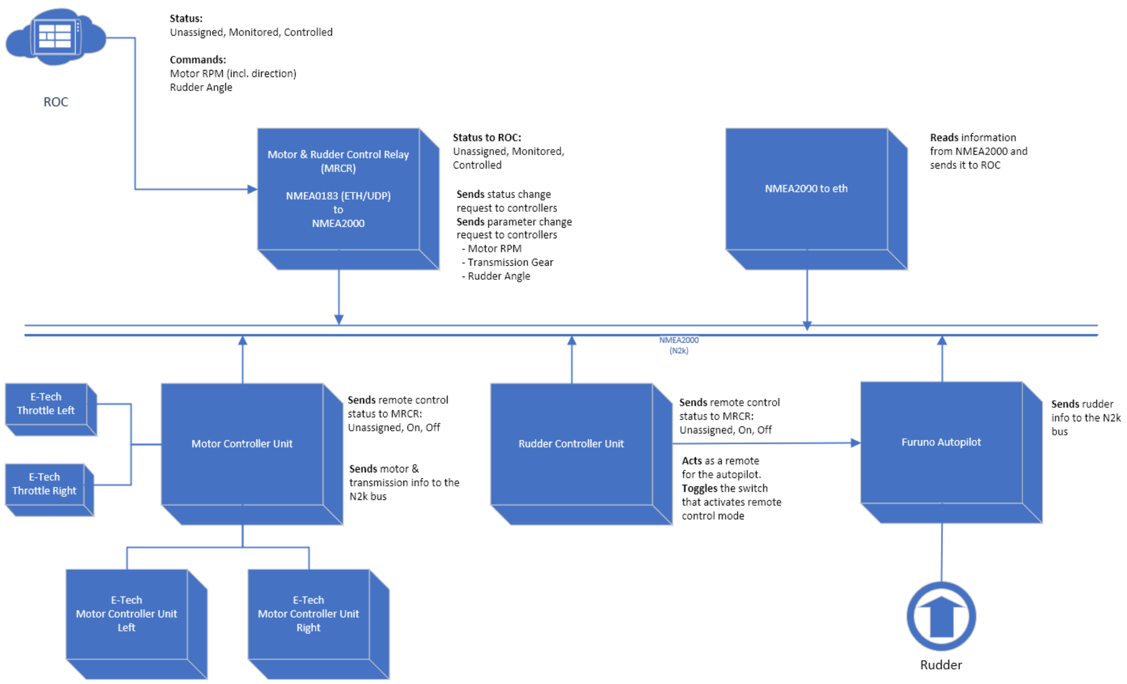


Figure 4. Motor and rudder controller architecture.

The ROC serves as an indispensable counterpart to the test vessel, seamlessly complementing its capabilities. By enabling remote monitoring and operation, the ROC augments the vessel's functionality, making it a dynamic and multifaceted platform.

For future development, the ROC could see improvements in several aspects. First, the introduction of advanced AI and machine learning algorithms could enhance the ROC's ability to process and interpret data, further optimizing decision-making and safety protocols. Additionally, integrating advanced cybersecurity measures would ensure the robust protection of sensitive vessel data.

Moreover, the incorporation of augmented reality (AR) and virtual reality (VR) technologies within the ROC could provide operators with immersive and interactive control interfaces, thereby revolutionizing vessel operation. Further improvements in real-time data analytics and predictive maintenance capabilities could enhance the vessel's efficiency and reduce downtime.

In the future, the ROC may evolve to become an even more pivotal hub for real-time decision-making and enhanced situational awareness, harnessing the full potential of cutting-edge technology to push the boundaries of maritime operations.

Maritime wireless connectivity

To enable digitalization and efficient maritime operations, we need wireless communication systems and different types of sensors. Data from sensors can be used for decision making support, smart diagnostics, monitoring and remote operation. Digitalization presents many opportunities and advantages for industry players, but it can only reach its full potential when data flows are seamless.

In the maritime environment, no single connectivity technology provides stable enough connection to allow for seamless data flow in every location. Therefore, a combination of different technologies with different capabilities is required. For example, mobile networks provide high capacities close to shoreline, while no connectivity may be available at the open sea. Therefore, for example, connectivity over a satellite network is required in this situation.

The maritime domain, one of the 5G vertical domains in 3GPP, is moving forward with the digitalization and mobilization of commercial as well as safety fields. Legacy 3GPP-based technologies and solutions can be used for the digitalization and mobilization of the maritime domain, but the legacy 3GPP technologies and solutions may not be able to fully support the requirements of the digitalized maritime services. The maritime radio environment was not originally considered by 3GPP when the technical specifications and solutions were standardized for LTE and 5G.

Satellite access is one of the 3GPP radio access networks supported over the 5G system, so it is possible to provide seamless maritime mobile services at open sea by integrating multiple access technologies including satellite access, depending on the service scenarios. However, satellite access has very different latency and bandwidth characteristics compared to terrestrial 5G, and thus it needs to be carefully analyzed how the satellite access can meet the demands of remote control and other relevant use cases.

Maritime mobile networks

4G (LTE) and more recently 5G have revolutionized mobile (and even fixed) data communication on land based terrestrial use providing in best case hundreds of Mbit/s bit rates and almost universal coverage. This has increased interest in using mobile networks also for maritime, especially due to increased requirements for high-speed data in many new applications like remote operations.

LTE is using OFDM for downlink and SC-FDMA for uplink with maximum bandwidth of 20 MHz giving theoretical bit rates of 300 Mbit/s for DL and 75 Mbit/s uplink. However, in practice the maximum bitrates are lower, in many cases in the order of 100 Mbit/s and 20 Mbit/s for a 20 MHz bandwidth. In addition, these are maximum bitrates of a cell and are shared with all the users in the cell area and in a congested cell the bit rates may drop to a few Mbit/s or even lower. LTE can use FDMA or TDMA depending on the used frequency band. LTE has been deployed on many different bands from 700/800 MHz (B20/B28), 1800 MHz (B3), 2100 (B1), 2300 (B40) to 2600 MHz (B7). For maritime use (as for any rural area) probably the most important are the low frequencies (700/800 MHz) as the propagation is much better than at higher frequencies, which are mainly used to cover densely populated areas with smaller cell sizes. For large rural and archipelago areas the lower frequencies provide possibilities for much larger cell sizes thus resulting in more economical network deployment. The downside of this is that in a large cell the number of users can also be high and the bitrate per user drops. Especially if a large passenger ship, with thousands of users comes to a coverage area of a single cell, the drop of bitrates can be dramatic.

5G is in many ways very similar to 4G/LTE, but has more flexibility, many improvements and new features. Bandwidths up to 100 MHz and higher are used increasing the theoretical bitrates up to 1 Gbit/s (3.5 GHz band), although in practice the maximum bitrates are lower in the order of few hundred Mbit/s. 5G was deployed first in the 3.5 GHz band (n77, n78), now going also to 26 GHz band and more importantly from the maritime use point to 700 MHz band (n28). However, the larger bandwidths in the order of 100 MHz are not available at the 700 MHz band, and 5G is using the same 10 MHz bandwidth as the low frequency LTE. Therefore, the advertised high bitrates are not available on the 700 MHz rural deployments. Still 5G will give an improvement over the LTE.

Although radio propagation over the water is typically better than over the land and in many cases line of sight (LOS) conditions apply, the available range from the base station is limited to a few tens of kilometers even using the 700/800 MHz bands. The consequence of this is that mobile network service is limited to coastal waters, giving less range than for example VHF communication. The situation is somewhat different if there is an archipelago, where the mobile networks can be built using the islands. In this case the backhaul network may be more critical than finding places for the base stations. Population in the islands also forms a basic customer base, so building the network is economically more viable. A good example of this is the archipelago between Turku and Åland, which makes it possible to have an almost full coverage for the sea route between Turku and Stockholm, having only a short gap between Åland and Stockholm archipelago. In general Finnish coastal waters are fairly well covered due to large number of islands. Table 1 gives some properties of the different mobile bands. For the range of the lower 700/800 MHz frequencies a higher upper limit has been added to reflect the better propagation over water.

Table 1: 4G/5G properties at different bands [2].

Band [MHz]	Technology [4G/5G]	Range [km]	Bandwidth [MHz]	Mode [FDD/TDD]	DL bitrate [Mbit/s]	UL bitrate [Mbit/s]
700	5G	10-30	10	TDD	110	55
800	4G	10-20	10	FDD	75	25
900	4G	10	10	FDD	75	25
1800	4G	5	20	FDD	150	50
2100	4G	4	20	FDD	150	50
2600	4G	2	20	TDD	150	50
3500	5G	2	130	TDD	1200	400
26000	5G	0.5	800	TDD	8800	3000

Remote Operations Center trials

The sensors and actuators on TUAS research vessel will be connected to TUAS remote operations center using mobile networks or Starlink to enable remote operations of the test vessel. We will integrate the AI algorithms developed in ADMO to evaluate the state of the wireless communications links to our research vessel and develop all the software components needed to pilot the remote operations.

The trials target exploring and showcasing the benefits and opportunities of 5G in a real operational environment. This allows for analysis of additional value of 5G for the maritime digitalization. Figure 5 illustrates how the test vessel is connected to the remote operations center through a 5G network. It also shows other ADMO project use cases like ship-to-ship communications and ship internal communications.

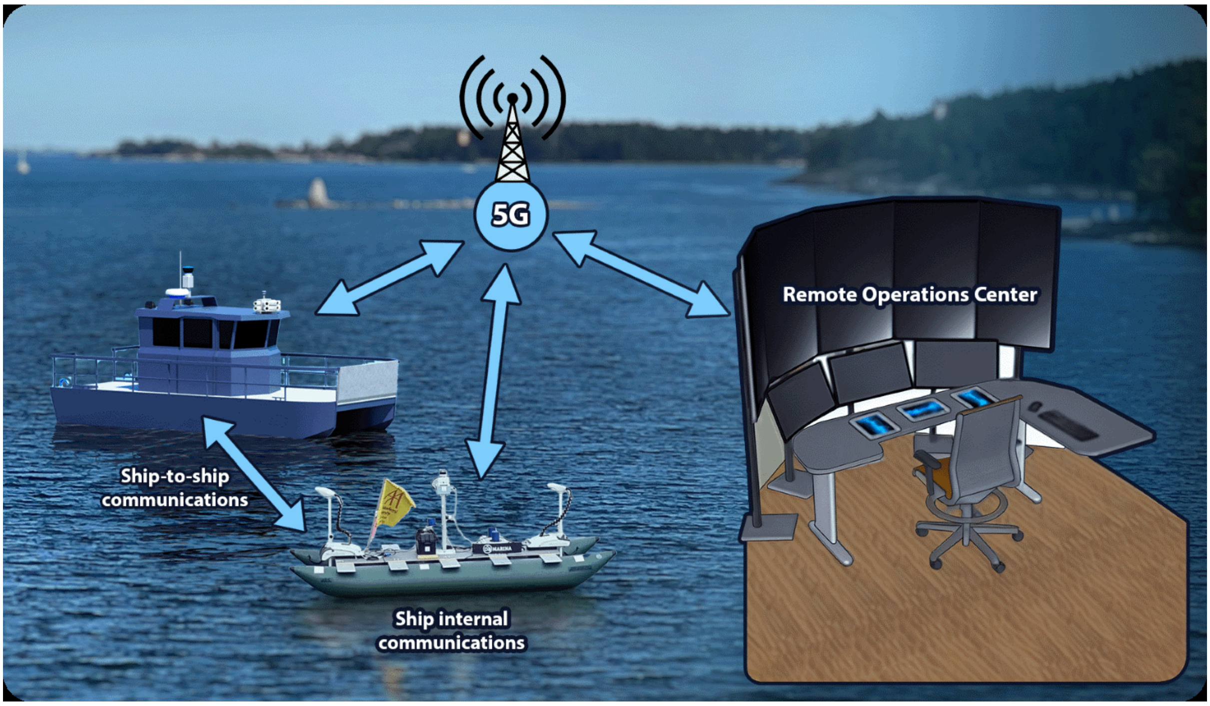


Figure 5: The trial setup for remote operations. 5G will be used to connect the ship to ROC and 5G Sidelink will be used for ship-to-ship communications.

Trial plan

Winter 2023-24

The test vessel cannot be operated during the icy winter season and thus the measurements focus on the cases that stem from needs of the companies.

- Coverage measurements between Naantali and Kapellskär

  The target of the measurements is to study the coverage of all operators in the route from Naantali to Kapellskär. This way, it is possible to evaluate the best combination of operators for maximal coverage and data rates. Reducing the need for the use of satellite communications reduces the connectivity costs.

- Indoor coverage measurements at a large cruise boat.

  The target is to measure the coverage of the Finnish mobile network operators inside the cruise ship. Cruise ships have technology to extend the coverage of the mobile networks inside the ship, and the coverage provided by this technology is measured. As the cruise ship is very challenging propagation environment, the signal quality can vary very much in different locations inside the ship.

- Lab scale measurement on wireless sensor -type communication

  Target to get an overview of typical availability and capabilities of prototyping IoT boards equipped with 5G connectivity. These boards are AVR IoT board, 5G NB Click. An RF meter board is used for simple signal strength measurement. The connectivity is verified using Ettus research and software radio UE / base-station.

Summer 2024

- **Coverage measurements at ferries**

  Initial measurements in Parainen – Nauvo were done in autumn 2023 to test the measurement setup acquired in ADMO and get initial results for analysis. It was observed that the coverage of the mobile networks in that area are very good. The Archipelago ring route seems to be rather well covered with mobile networks. The connection ships to outer archipelago on the other hand, suffer from poor network connectivity at some points on the routes. The target for the summer 2024 is to perform measurements on these routes.

- **Trials of ROC with commercial mobile networks**

  The target of the trials is to demonstrate the remote operations on eM/S Salama using commercial 5G mobile networks. The available capacity and latency will be measured and how well the remote operations can be executed using current commercial networks is studied.

- **Trials of ROC with Starlink**

  This trial demonstrates the remote operations on eM/S Salama using Starlink connectivity. The available capacity and latency will be measured and how well the remote operations can be executed using Starlink is studied. Especially, the latency provided by the system and its suitability for remote operations is of interest.

- **Mobile base station at eM/S Salama**

  The 5G base station will be installed onboard eM/S Salama. The target with respect to ship external connectivity is to study the performance of ship to shore connectivity. Having the base station on the vessel has more favorable UL/DL ratio, as now the DL is towards the shore. Also, the base station on the vessel could enable fleet operations, where the vessel with base station would act as a “leading ship” orchestrating the operations. The regulation does not allow moving base stations, but initial discussions have been held with Traficom to obtain a trial spectrum license for this pilot.

- **Wireless sensor / IoT measurements onboard test vessels**

  Test campaigns for IoT-type communication using IoT test boards equipped with 5G connectivity, utilizing both 5G infrastructure and 5G local test equipment (setup determined during lab tests during winter)

- **Smart fairway service trials in collaboration with MaDaMe**

  MaDaMe project stated at 11/2023. The project will study VDES connectivity to deliver smart fairway services. ADMO project will collaborate on the VDES connectivity trials and also analyzes how mobile networks could be used to deliver smart fairway services. As the MaDaMe project is at its initial stage, depending on the developments in the project it may be that these trials will happen in summer 2025.

Conclusions

The ADMO project has established a robust test infrastructure, including a test vessel and a remote operations center, to facilitate project trials.

The winter trials will focus on coverage measurements between Naantali and Kapellskär, and indoor coverage measurements at a large cruise boat. These measurements aim to evaluate the best combination of operators for maximal coverage and reduce the need for the use of satellite communications.

The summer trials will include coverage measurements at ferries and connection ships in outer archipelago, trials of the ROC with commercial mobile networks and Starlink, installation and trials of a mobile base station at eM/S Salama, and VDES trials in collaboration with the MaDaMe project.

The trials aim to demonstrate the feasibility of remote operations using different connectivity solutions and study the performance of ship-to-shore connectivity. The project also aims to explore the potential of using a vessel-based base station.

The collaboration with the MaDaMe project on VDES connectivity trials for distributing navigational information is a significant step towards enhancing maritime safety.