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5G BLUEPRINT

Next generation connectivity for enhanced, safe & efficient transport & logistics

D4.1: Barge Use Case

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Abstract

In the domain of vehicle teleoperations, robust network connectivity emerges as a fundamental element. This study delves into the teleoperation of barges, where the vessel, equipped with control systems, tsails in waterways while being remotely operated from a station equipped with visualization tools. The crux lies in the connectivity signals that bridge these components. A critical focus is placed on enhancing connectivity beyond 4G limitations, particularly in high-traffic port areas and cross-border regions. The transition to a 5G Standalone connection is tested in the Port of Antwerp and the cross-border area in Zelzate, showcasing improved video streaming in the port and seamless teleoperation across borders.The automated vessel, part of the Seafar project in the 5G-Blueprint initiative, relies on sensors and devices like cameras, GNSS receivers, and radar. The vessel's data is transferred over the network to a remote operational center (ROC), enabling the remote captain to make informed decisions using joysticks. This deliverable include assessments of 5G Standalone connectivity in the Port of Antwerp and cross-border scenarios. Notable milestones involve SA-NSA switches, operation nd datatransfer over 5G SA connectivity, speed and bandwidth evaluations, and seamless operation at cross border area. In Seafar's exploration of 5G benefits over 4G, emphasis is placed on the high bandwidth requirements for camera streams and low latency crucial for teleoperation. The project signifies a significant leap for automated sailing industries towards 5G adoption.The comprehensive tests, detailed for both the Port of Antwerp and Zelzate cross-border area, opens opportunity for seamless, low-latency connectivity for maritime teleoperations. The results pave the way for potential market adoption of 5G solutions, ushering in a new era of safety and efficiency in teleoperated maritime operations.

Keywords: 5G, teleoperation, cross-border, communication, redundancy, latency, bandwidth, barge operation, remote captains, situational awareness.

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CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to 5G-Blueprint project and Commission Services	

* R: Document, report (excluding the periodic and final reports)

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

EXECUTIVE SUMMARY

Effective network connectivity stands as a foundational pillar in the realm of vehicle teleoperations. A comprehensive analysis of teleoperation scenarios reveals three pivotal components: the remote station, the vehicle (in this case, a barge), and the intricate network connections that bind these two entities. The efficacy of operations conducted remotely is tied to the availability and robust functionality of the network. Without a solution ensuring seamless connectivity, the assurance of safety in a teleoperation scenario remains elusive [1].

In the specific context of teleoperated barges, the vessel, equipped with essential systems and control mechanisms, navigates waterways. Conversely, the remote control station is equipped with visualization tools, human-machine interfaces, and joysticks. The lifeline connecting these two entities is the network's signal integrity.

A critical focus within the teleoperation of barges is the enhancement of connectivity beyond the limitations of a 4G-based connection. Particularly in challenging environments like ports with high barge traffic, situational awareness emerges as a key aspect for the remote captain, ensuring the safety of navigation [2]. Another complex terrain is encountered in cross-border areas, where network devices transition between the providers of different countries. A seamless handover is imperative; any disruption could compromise connectivity, necessitating the presence of a captain on board to resume manual control.

The primary objective of this project centers on testing the capabilities of a 5G Standalone connection in the Port of Antwerp and the cross-border area in Zelzate. The aim is to evaluate how 5G technology can enhance the teleoperation scenario. Results from the study affirm that within the critical port region, the video streaming to the remote control station exhibits sharper images and higher resolutions. In the cross-border area, the 5G connection demonstrates uninterrupted teleoperation while crossing the border.

This deliverable presents the transformative potential of 5G Standalone connectivity in teleoperated maritime operations, specifically in overcoming challenges posed by high-traffic ports and cross-border transitions. The findings not only showcase technological advancements but also point toward a future where enhanced connectivity plays a pivotal role in ensuring the safety and efficiency of teleoperated vehicles, contributing to the evolution of maritime operations. It is highly probable that these solutions enter the market and replace the old methodologies.

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

BW	*Bandwidth*
3GPP	*Third Generation Partnership Project*
4G	*Fourth Generation*
5G	*Fifth Generation*
CAM	*Cooperative Awareness Message*
eNB	*Evolved Node B*
gNB	*Next Generation NodeB*
GNSS	*Global Navigation Satellite System*
IEEE	*Institute of Electrical & Electronics Engineers*
IP	*Internet Protocol*
KPI	*Key Performance Indicator*
LTE	*Long Term Evolution*
MNO	*Mobile Network Operators*
MTU	*Maximum Transmission Unit*
NR	*New Radio*
PLC	*Programmable Logic Controller*
RADAR	*Radio Detection and Ranging*
RF	*Radio Frequency*
ROC	*Remote Operation Center*
SIM	*Subscriber Identity Module*
TCP	*Transmission Control Protocol*
UE	*User Equipment*
UDP	*User Datagram Protocol*
VPN	*Virtual Private Network*
WAN	*Wide Area Network*

1. INTRODUCTION

Seafar is a use case leader in 5G-Blueprint project. This use case is an automated vessel sailing using 5G connectivity. Two main use cases have been considered:

1. Port of Antwerp:

a) 4G and 5G NSA comparison (demonstrated in technical review meeting in July 2022)

b) 5G NSA and 5G SA data collection

2. Zelzate cross border:

Seamless roaming and handover between the two network providers KPN and Telenet

In an automated vessel use case, the vessel is equipped with a variety of sensors and devices. The devices include cameras, GNSS receivers, radar, framegrabber to collect radar and camera frames, sensor processor to communicate and process the collected data, automation processor to communicate with the navigational instruments onboard.

Seafar has been using 4G previously for network connectivity. However, regarding the high bandwidth required for camera streams and low latency in transferring the data, it is highly important for the automated sailing industry to be prepared for an migration to 5G connectivity. In 5G-Blueprint, Seafar investigates the benefits of using 5G over 4G for the teleoperation of the barges in port area of Antwerp.Another significant milestone for Seafar is the experiment of a seamless and low latency handover at cross border areas.

We have done several tests for each part of the use case. The tests for use case 4.1 part 1 are summarized in Table 1 and the tests for use case 4.2 part 2 are summarized in Table 2. More details about each of these tests are given in the next chapter of this deliverable.

Table 1 Summary and IDs of tests done in Port of Antwerp.

Test ID	Test Title	Date	SA/NSA	Additional Information
T1.1	January test	11/01/2023	NSA	Test with new balance
T1.2	Dome test	20/01/2023	SA	Test SA firmware and results
T1.3	NSA-SA Switch	02/05/2023	NSA	NSA – SA Switch
T1.4	Onboard testing Tuimelaar	14/06/2023	SA	Speed and BW testing
T1.5	NSA – SA switch test at Telenet	14/09/2023	NSA/SA	Test together with Telenet for issue solving
T1.6	Remote barge testing	21/09/2023	SA	Testing 5G SA connectivity
T1.7	Remote barge testing	19/09/2023	SA	Testing 5G SA connectivity
T1.8	Remote barge testing	30/10/2023	SA	Testing 5G SA connectivity
T1.9	Remote barge testing	9/11/2023	SA	Testing 5G SA connectivity

Table 2 Summary and IDs of tests done in Zelzate cross border area.

Test ID	Test Title	Date	SA/NSA	Additional Information
T2.1	Border crossing Zelzaten	06/06/2023	SA	Connectivity test (sent the dome to KPN lab no issue with the dome)
T2.2	Test with car	29/08/2023	SA	Connectivity test
T2.3	Test with car	24/10/2023	SA	Handover test
T2.4	Test with car	31/10/2023	SA	Handover test
T2.5	Test with urban barge	6/11/2023	SA	Handover test
T2.6	Test with urban barge	7/11/2023	SA	Handover test
T2.7	Test with car	17/11/2023	SA	Handover Test
T2.8	Test with urban barge	20/11/2023	SA	Barge sailing in cross border area
T2.9	Demo with barge	21/11/2023	SA	Barge sailing in cross border area

2. TECHNOLOGY BEHIND THE USE CASE

The graphical representation of a remote operation use case is shown in figure below.

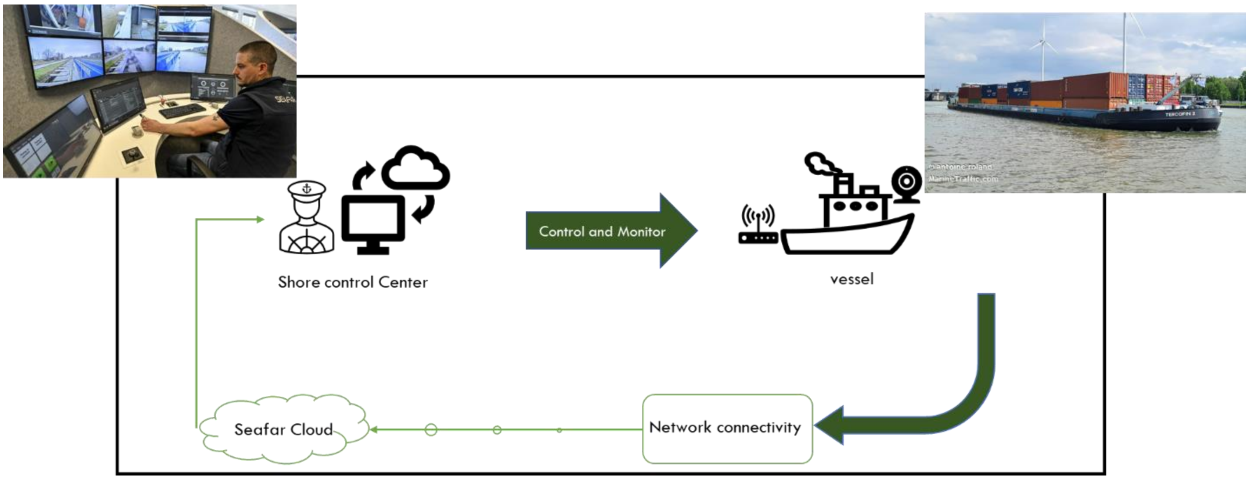

Figure 1 Graphical representation of an automated barge sailing

As shown in Figure 1, the vessel is sailing in the waterway while the captain is at the office. The data from surrounding of the vessels are captured by the cameras and radar, collected by the framegabber and transferred to Seafar cloud over network connectivity. Considering that the area is inland waterway, there is no need for satellite connectivity and terrestrial network would cover those areas. The data in the cloud is then visualized to the remote captain on the monitors in front of him at remote operational center (ROC). At the control station, the captain has access to the joysticks to steer the vessel. When the remote captain is steering the vessel, he is frequently making decisions to change the speed or the heading of the vessel. When the values on joysticks are changing, a command will be sent to the ship over network connectivity. At the vessel the command will be applied by communication of the automation processor and the navigational instruments. The remote control station at Seafar is illustrated in Figure 2.

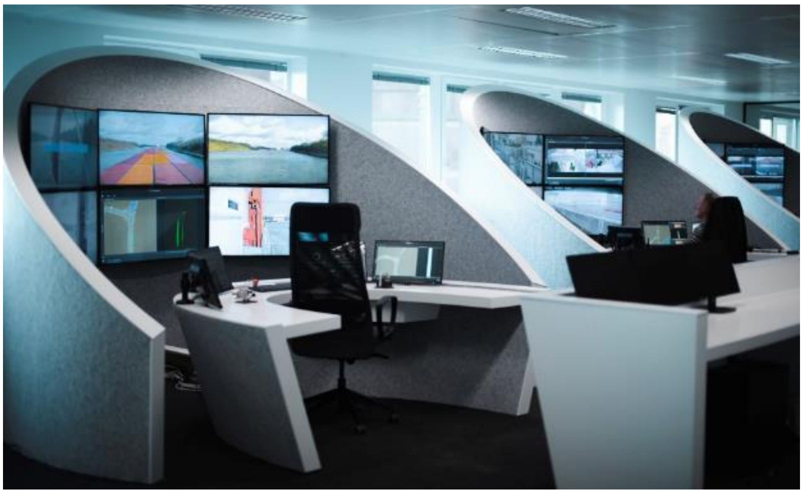

Figure 2 Seafar remote control station in Antwerp.

The new modem is illustrated in Figure 3.

Figure 3 The new modem used for 5G NSA and SA connectivity.

The architecture of connection between different elements on the barge and the remote control station is illustrated in diagram 1.

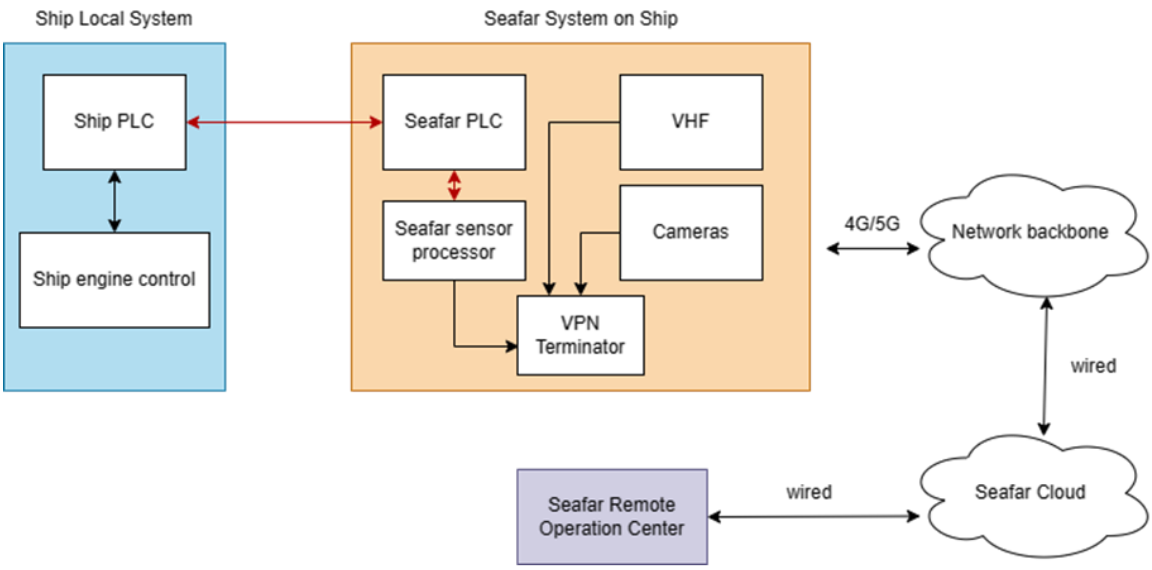

Diagram 1 Architecture of connections between different elements in barge teleoperation

Ship systems include onboard PLC for controlling the vessel and the engine controller, which are also used during onboard navigation. The Seafar system include Seafar PLC and onboard PLC for controlling the Seafar system and interacting with ship PLC. There is VHF radio available onboard for contacting other vessels, locks and port auhorities. Seafar has its interface with the VHF to enable communication with authorities from remote operation center.

Seafar sensor Processor information is a microbox PC and it is utilized for consolidating all sensor information and transfer it to the remote operation center. The cameras are AXIS PTZ cameras and they are used to provide remote captains a situational awareness similar to the captain onboard.The VPN terminator is a network balance used to combine different modems to one VPN for transferring data to the cloud backend. The modem is a Peplink MAX HD1 Dome Pro. Seafar cloud is the backend systems for controlling and steering the vessel. Remote operation center as shown in Figure 2 is the setup for monitoring and controlling the vessel.

The operational vessel used for testing in Port of Antwerp is a commercial barge illustrated in Figure 4.

Figure 4 operational barge by Seafar teleoperation utilized for the tests on 5G SA.

Figure 5 radar and one of the cameras on the barge

This barge is 110 meters length and 11.4 meters breadth. This barge is equipped with Seafar control system which is made of a processor to communicate with the interfaces of navigational instruments onboard. The instruments include propeller, thruster, and the rudders. When a remote captain steer the vessel from control station, the command will be sent to the processor and the processor communicate with the instruments through the interfaces.

On the other hand, the barge is equipped with necessary sensors to collect enough data such as 6 cameras for the video streams from the waterway and all other objects around the vessel, the

GNSS receiver to provide positional map at control station to remote captain, the Automated Identification System (AIS) to transmit identity of the ship to the vessel traffic services. Radar data is also collected by a frame grabber to transfer the data to control station.
The 5G modem which is a dome-shaped device and sometimes called as 5G mushroome or 5G dome, is installed on the barge for enabling data transfer. The operational trajectory of the barge extracted from Marine Traffic is shown in Figure 6.

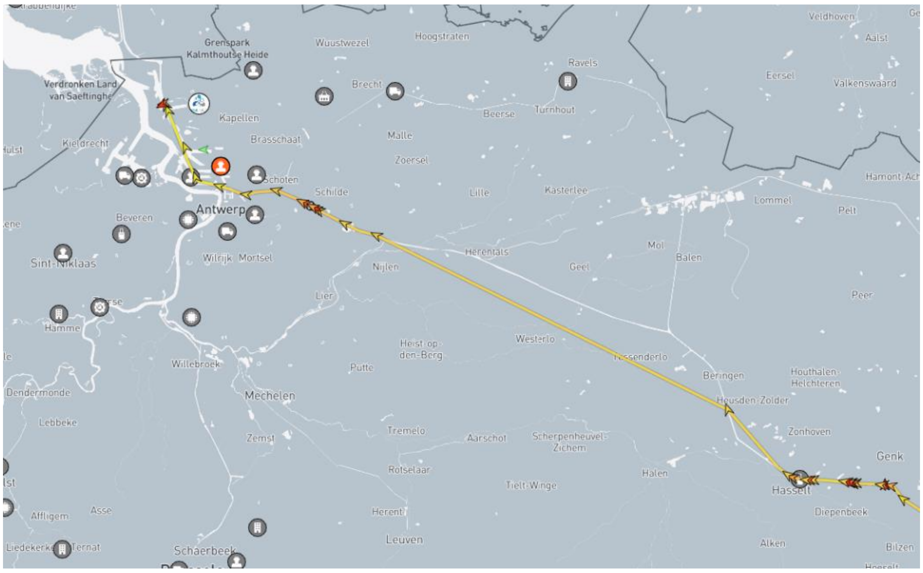

Figure 6 Frequent trajectory of barge sailing in Flemish waterways.

It is good to mention that the trajectory of a vessel is determined by its owner, based on the destination and cargo being transported. Market conditions play a significant role in shaping this trajectory. For instance, the availability of cargo for deliveryi to a specific destination can greatly influence the vessel's route. At times, there may be ample cargo available for transportation to a particular location, while at other times there may be insufficient demand to justify navigating the vessel to that destination. Ultimately, the decision of which route to take is based on a careful consideration of market conditions, cargo availability, and other relevant factors, and is subject to change as circumstances evolve. Considering that Seafar is not the owner of the barges but the operator of them, operations are affected by the decision of the vessel owner. For the duration that barge operation was stopped for a specific period, Seafar considered a boat for more data collection as described in T1.4.

3. TESTS IN PORT OF ANTWERP

A remote operation use case in a critical scenario such as port of Antwerp area require enough bandwidth and low latency. Sufficient bandwidth is required to enable sensorial data to be transferred from vessel to the remote control station and the low latency is important for fast detection of the changes in the environment. For example if a fast boat is passing by the barge, the remote operator should be able to see the boat from the camera streams as fast as possible. With 5G connectivity, as barge teleoperator, we expect higher resolution of camera streams and faster data transfer. In system test report (Minimum Viable Platform), the sharpness of the images and better quality over 5G NSA was reported and also demonstrated during the technical review in 2022. In this deliverable, we investigate a new modem which is compatible with 5G NSA and 5G SA capability for the barge teleoperation.

3.1.Test T1.1

3.1.1. Introduction

The first test is done in Port of Antwerp using a vessel. The test took place on Jan 11th,2023. We have utilized a 5G NSA new modem (Peplink MAX HD1 PRO 5G). The test started on (15:25) and lasted until (15:50). In this test, we were able to do the bandwidth test and collect the signal quality. The collected data are summarized in Appendix.

3.1.2. BW test

This test is executed to check if the bandwidth is higher when we use a new balance on board. The new balance as illustrated in Figure 7 shows almost 3 times the bandwith in comparison to the tests done in previous reporting period (average 150Mbps). The previous balance was "Peplink balance 210". We have done the throughput testing using iperf application. The server of iperf was located on Seafar cloud. The results show that the bandwidth is about 4 Mbps higher in comparison with the tests done in June 2022.

In Figure below we can see that the average bandwidth during the bandwidth test was 35 Mbps for uplink direction, the measurement is done in the time span of 15:28-15:46.

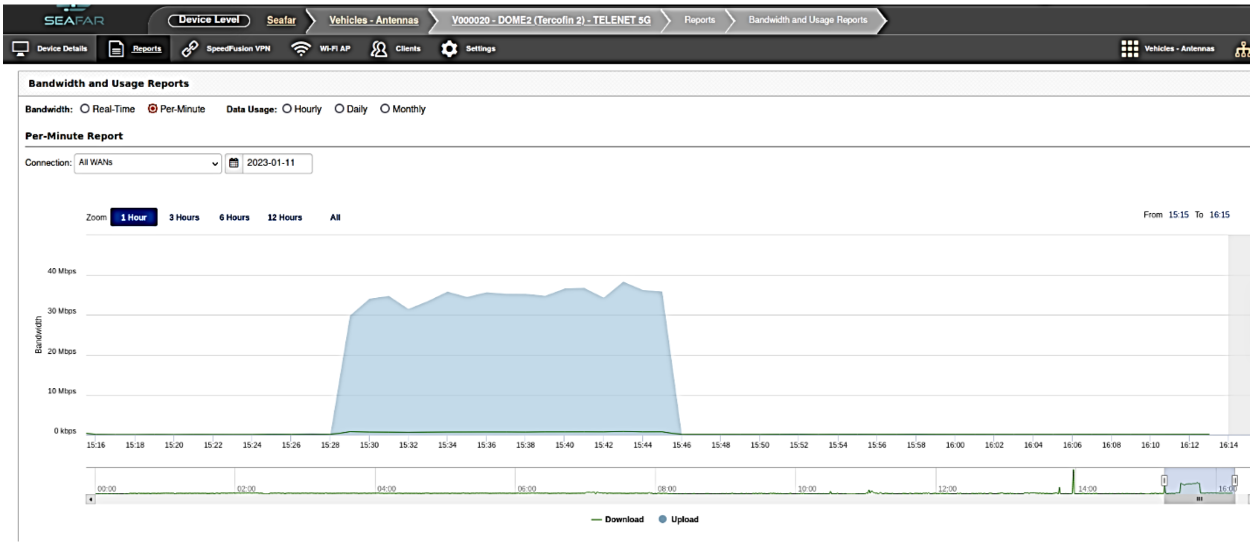

Figure 7 Band Width value during the test

3.1.3. Signal Quality

In this measurement, we have collected the signal quality. The first figure shows the WAN-quality of signal bars which means how many signal bars you have on your signal. Like it is displayed on a phone from 0 to 5 where 5 is the best quality. We can see in the figure that the signal bar remained on level 5 during the test.

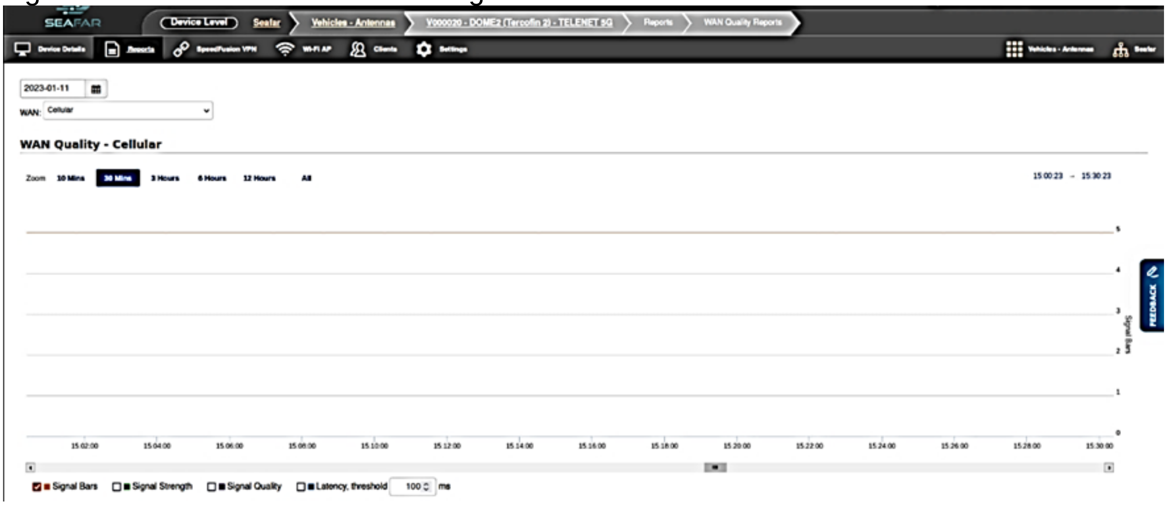

Figure 8 Signal quality during the test

This figure below shows the WAN Quality based on signal strength. The definition of different strengths including "Excellent, Very Good, Good, Fair, Poor, Very Poor" are provided in the appendix.

This figure below shows the WAN Quality of the 5G signal based on SINR and RSRQ .

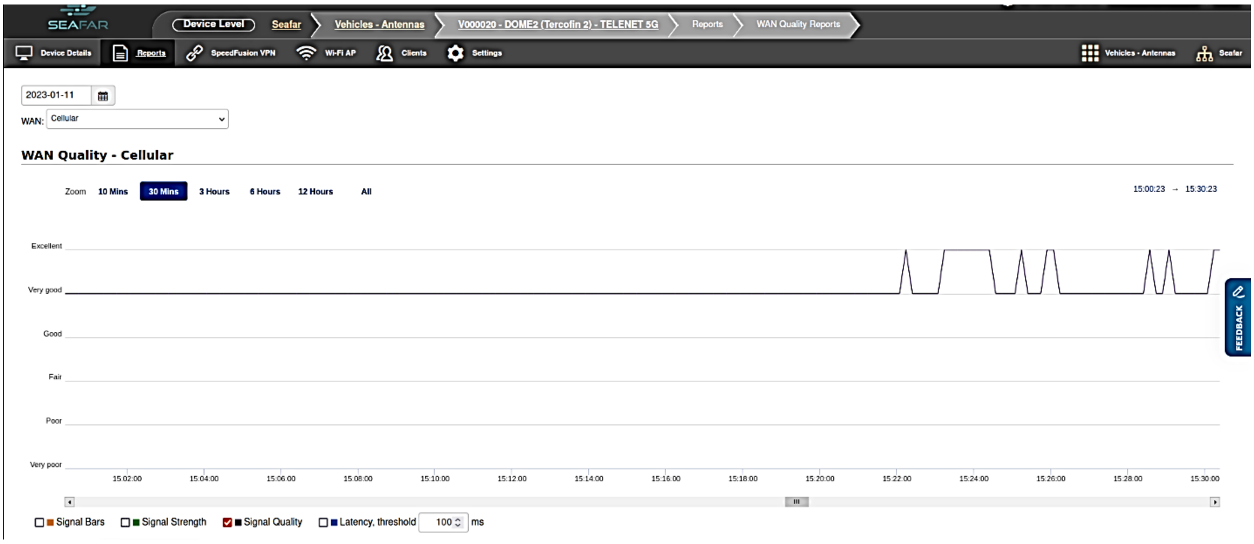

Figure 9 WAN quality during the test

Figure 10 shows the latency between the mast and the 5g antenna. With a threshold of 15 ms. The units of the reported latency values is millisecond. According to Peplink forum, the latency is Round Trip Time (RTT) measurement [3].

Figure 10 latency values during the test

3.1.4. Coverage map

The 5G signals coverage during the measurements is illustrated in Figure 11. Regarding the color code of the signals quality provided, we can see that on the whole path the signal quality is excellent. This test was not a full run as the vessel was moored at port so no operation was happening in the area with coverage so we made a short trajectory next to the mooring area and returned.

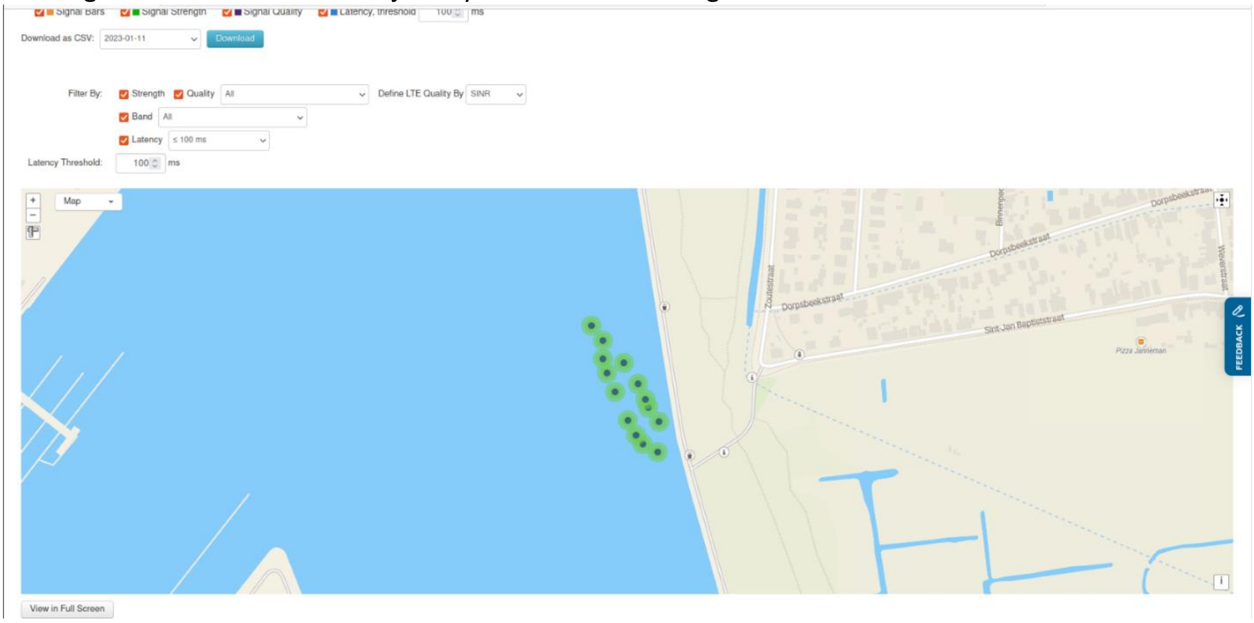

Figure 11 Area of test and 5G NSA coverage.

3.1.5. Remarks

BW seems lower than expected according to the info we got from our MNO Telenet and considering the limits of our 100Mbit switches onboard. We expect to have a bandwidth of around 100Mbps and only reach 35Mbps. However, this BW is sufficient for teleoperation. No other issues encountered.

3.2. Test T1.2

Before switching to 5G SA onboard the barge, we had to first ensure the connectivity and coverage in the area. Thus, we drove to the side of the waterway and tested the connections.

3.2.1. Introduction

This test was to verify the results and report the signal quality of the 5G SA signal. It is executed with the car for testing of the 5G SA dome. The summary of data collected in this test is provided in Appendix.

The trajectory that the car has passed is illustrated in Figure 12.

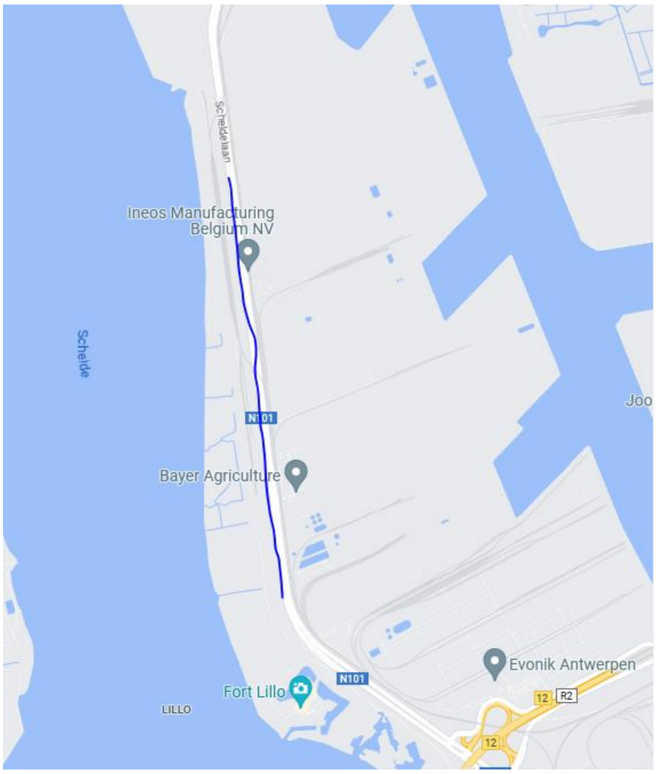

Figure 12 Trajectory of the 5G SA network test with car.

The test is done on Jan 20th, 2023 from (8:55) to (9:23).

3.2.2. BW test

The BW test for 5G SA is done at 9:06. Based on Figure 13, we can see that the maximum BW is almost 252 Mbps downlink which in comparison to 5G NSA is higher. In this test, we used a laptop with online speed test website for testing the BW capabilities (https://www.speedtest.net/nl). We don't use the full Seafar system in this test. The test is done only with the 5G dome being carried by a car. Thus, the system is not transmitting information of camera streams, other sensors and devices which we install onboard a vessel. This is the reason we reach a higher Bandwidth in this scenario. We check this as well on the vessel to see how the presence of other devices using the Bandwidth will affect the test results.

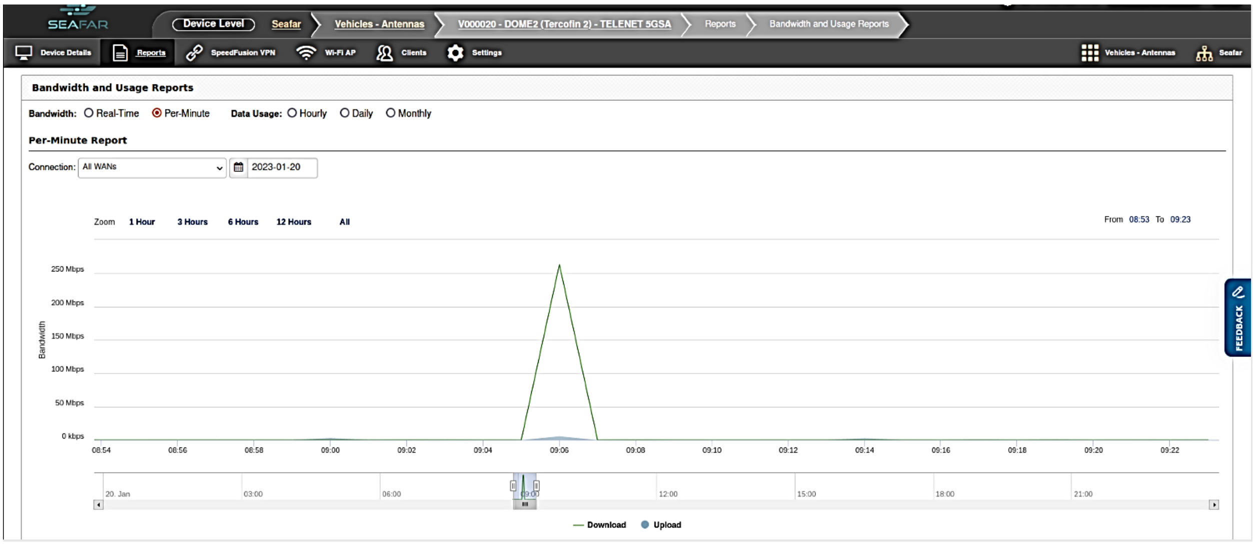

Figure 13 5G SA BW test with car at Port of Antwerp

3.2.3. Signal Bars

In this measurement, we have collected the signal quality. Figure 14 shows the WAN-quality of signal bars which means how many signal bars you have on your signal. Like it is displayed on a phone from 0 to 5 where 5 is the best quality.

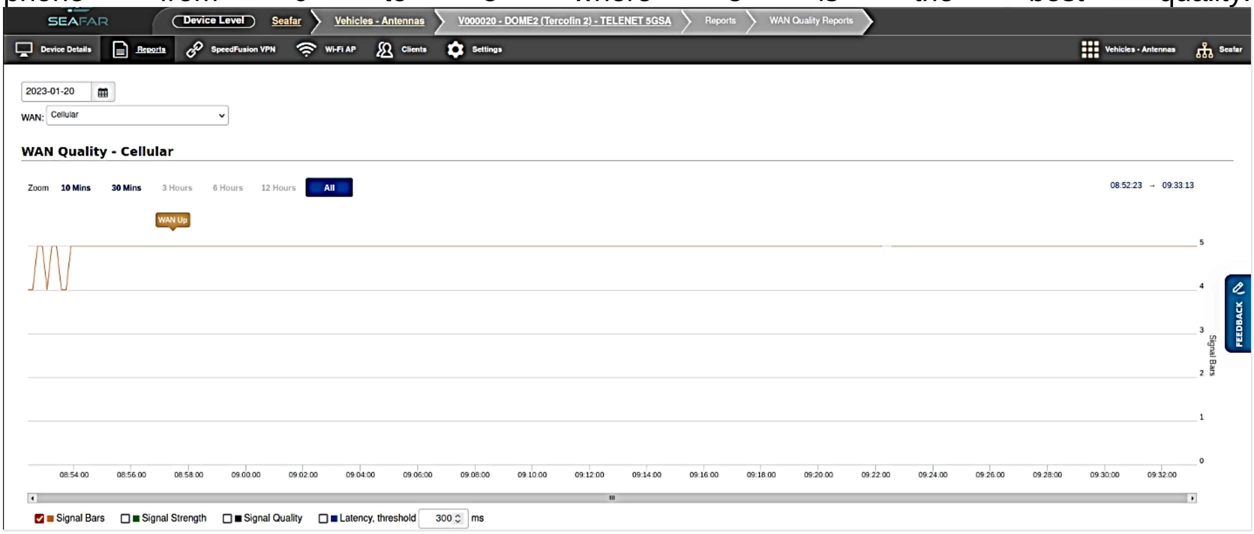

Figure 14 5G SA BW test with car at Port of Antwerp

3.2.4. Wan Quality

The WAN quality based on signal strength for the signals utilizing 5G SA dome is illustrated in Figure 15. Based on the figure, we can see that the signal strength fluctuates among Good, Very Good, and Excellent, while the signal quality using 5G NSA experienced a fixed quality. This problem was solved by Telenet by changing MTU value from 1428 to 1350.

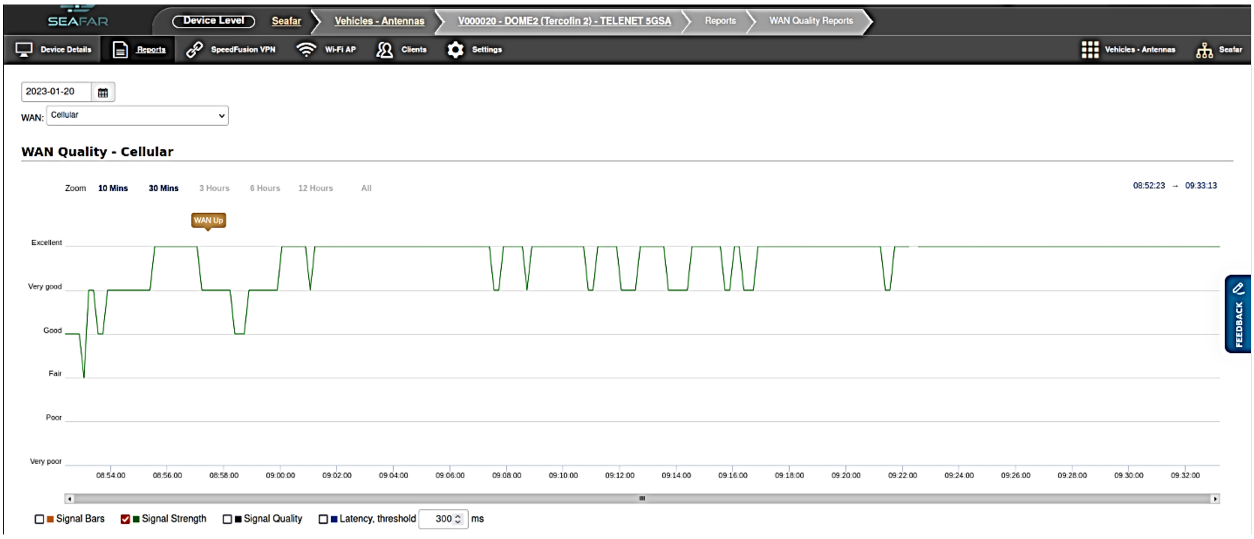

Figure 15 5G SA WAN quality based on signal strength during test with car at Port of Antwerp

The signal quality based on signal quality is provided in Figure 16. We can see that the signal quality fluctuates between different categories. This can be a result of the high distance to the mast at the beginning of the test. We check this quality with the barge in further test scenarios.

Figure 16 5G SA signal quality based on signal quality during test with car at Port of Antwerp

3.2.5. Latency

The latency in the unit of millisecond is illustrated in Figure 17. The green part of the figure means within threshold and the red part means below the threshold. We could see that in the beginning (far from the antenna) we have latency's up to 250 ms and on the end of the test we are around 13ms. We can see that the latency is extremely higher than the reported values for 5G NSA. However, this is a different test scenario. In the further sections we also test the latency for 5G SA on the barge.

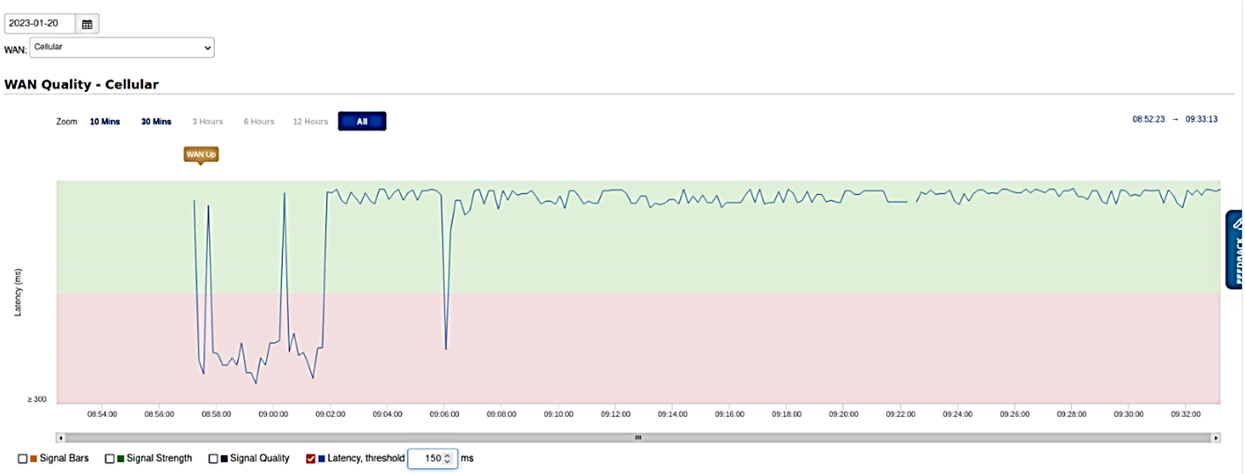

Figure 17 5G SA latency with car at Port of Antwerp

3.2.6. Coverage map

The coverage map during the second test with 5G SA dome is illustrated in Figure 18. We can see that for half of the way, the signal quality was almost poor while in the second half, there was excellent signal quality. This can be a result of NLoS (Non-Line of Sight) propagation of the signals or the relatively far distance to the antenna.

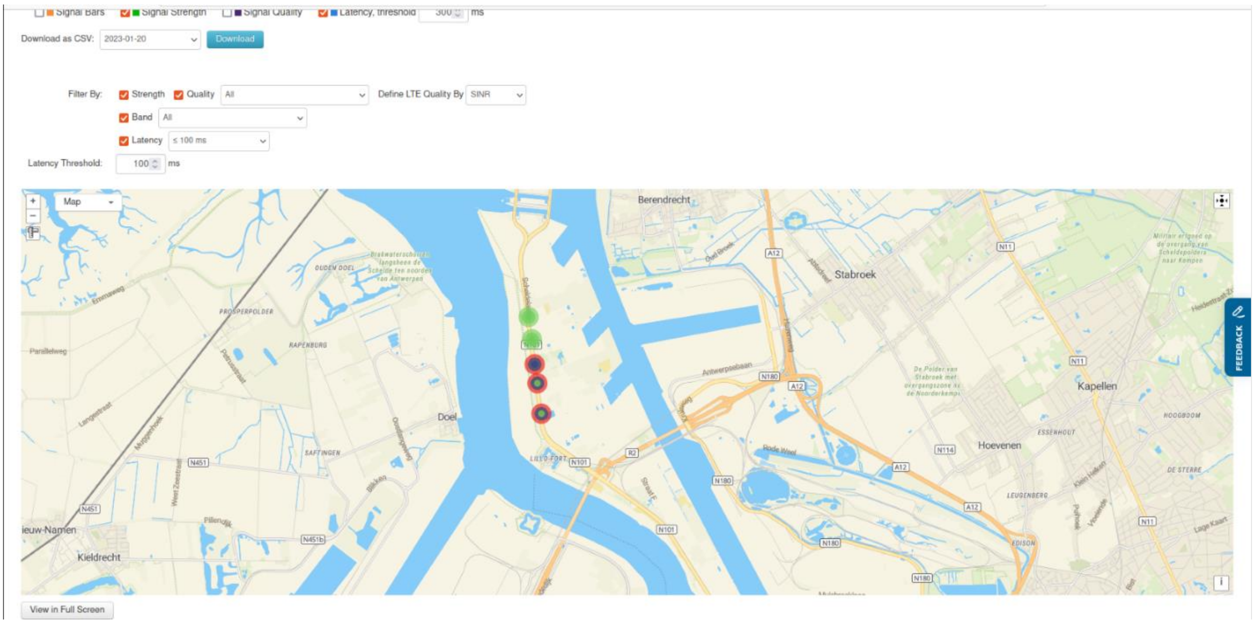

Figure 18 5G SA coverage map during test with car at Port of Antwerp

The coverage map received from Telent later shows the unavailability of coverage in the area where signal reception was poor.

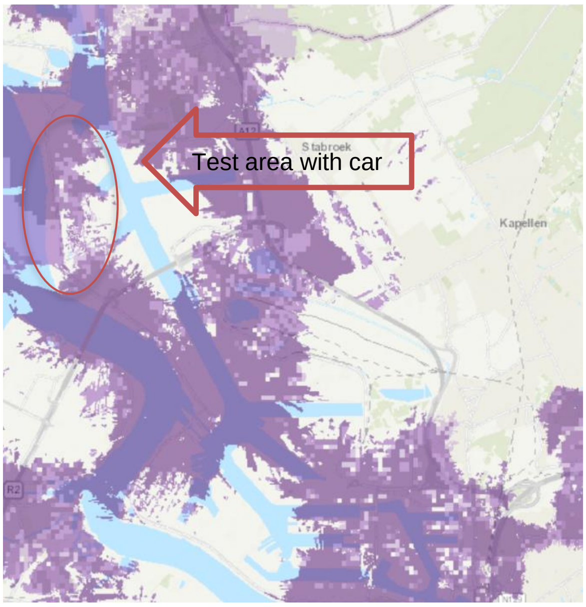

Figure 19 5G SA coverage map received from Telenet

3.2.7. Remarks

The internet access via the SA dome wasn't working fine. Only some types of URLs worked.

3.3. Test T1.3

3.3.1. Introduction

This test was supposed to verify the results and report the signal quality of the 5G SA signal while operating the barge from remote control station. The test was executed in the Port of Antwerp and the test took place on May 2nd, 2023 from (12:38) to (13:15).

3.3.2. Test overview

During the test we have executed multiple actions to switch from 5G NSA simcard to the 5G SA simcard remotely but each time we tried to switch the connection to SA, the NSA simcard reactivated and terminate the SA connection. In the dataset with 11469 samples, there is 155 samples with 5G SA showing signal connections every few minutes after each attempt to switch to 5G SA. To investigate the situation another test was planned onsite with Telenet for extra investigation.

3.4. Test T1.4

Until the arrangements with Telenet for solving the issue on switching from 5G NSA to 5G SA, we had to use a boat for data collection because of two main reasons: 1) remote switching from NSA to SA was not possible on the barge. Thus, first a solution should be found to be able to switch to 5G SA. 2) The barge was not sailing the trajectory to port of Antwerp during that time based on barge owner decision.

Seafar is not a barge owner. Seafar equip the barges of the vessel owners and with their intent or support, provide the use case for remote operation. Therefore, the testing is limited to the time and location that the barge is sailing and whether it is passing the pilot site. It is also not possible to purchase a barge for the tests during a project. A barge has specific high costs such as barge price which can be a few million euros to tens of million euros, there is also cost for renting the docking area, paying the crew and insurance (please see appendix 2 for more information). Therefore, during the time that operations of the barge was terminated for a specific period based on barge owner decision, Seafar received supports from Port of Antwerp Bruges to continue the test on 5G connectivity on a boat. This boat was also utilied in Vital-5G project live demonstration to show the monitoring dashboard as one of the 5G network applications. The boat is illustrated in Figure 19.

Figure 20 Tuimelaar research boat provided by Port of Antwerp

The equipment that Seafar put on the boat include two GNSS receivers in front, one camera in front, one 5G modem (Peplink MAX HD1 PRO 5G) on top of the boat, one demonstration box which include the sensor processor, the frame grabber, and the router. The devices images are provided in Figure 20 and 21.

Figure 21 Two GNSS receivers and one camera installed on the boat.

Figure 22 5G modem installed on top of the boat.

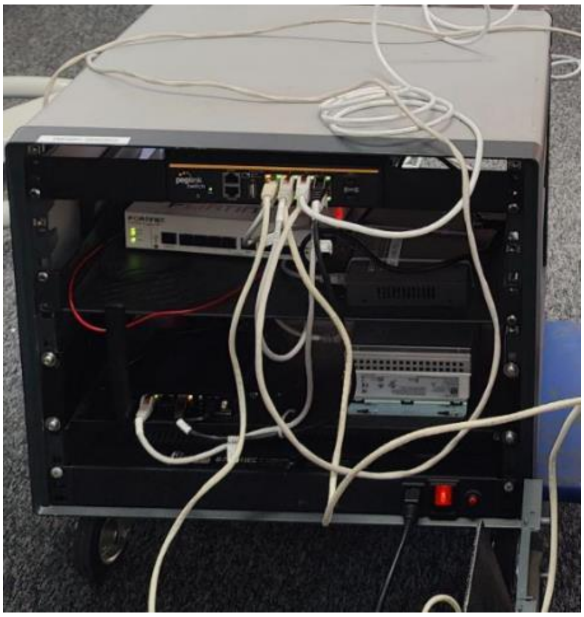

Figure 23 Seafar demonstration box equipped with sensor processor, router, and frame grabber.

It is good to mention that the frame grabber is used for camera streams and radar data collection.

3.4.1. Introduction

This test is done in Port of Antwerp Bruges using a vessel. The test took place on June 14,2023. We have utilized a 5G SA modem (Peplink MAX HD1 PRO 5G). The test started on (13:25) and lasted until (15:30). In this test, we were able to do the bandwidth test and collect the signal quality. The summary of data collected in this test is provided in appendix.

3.4.2. BW Test

This test is executed to check the maximum bandwidth we can get with a total new configuration and switch setup. The new balance is the same as with T1.2 test a "peplink MAX BR1 Pro." The used switch was a “Peplink SD Switch 8-Port Rugged”with 1Gbps ports instead of the 100Mbps ports we use on the barge. We have done the throughput testing using iperf application. The server of iperf was located on Seafar cloud. We noticed that the iperf is limited to 40Mbps per session. For this reason we did tests with multiple simultaneous Iperf sessions.

For upload or Iperf test was only reaching about 1Mbps. For this reason, we have used multiple sessions to the onboard camera stream. The results show that the download is dubble of what we had in previous tests now up to 80Mbps and the upload is similar to the tests with NSA 40Mbps. The BW values are provided in Figure 23.

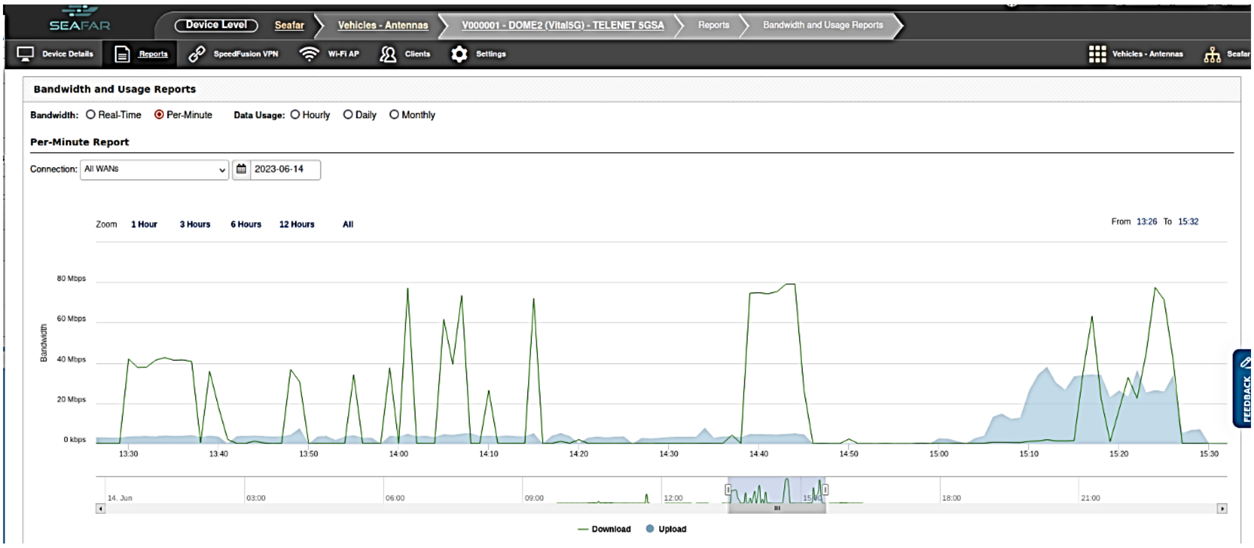

Figure 24 BW test on boat at Port of Antwerp

In this diagram you can see that we can do download speed tests up to 80Mbps and upload test up to 38Mbps. We will repeat this tests again to follow-up on the evolution and will ad extra Iperf servers and sessions for this.

3.4.3. Signal Bars

In this measurement, we have collected the signal quality. Figure 24 shows the WAN-quality of signal bars which means how many signal bars you have on your signal. Like it is displayed on a phone from 0 to 5 where 5 is the best quality.

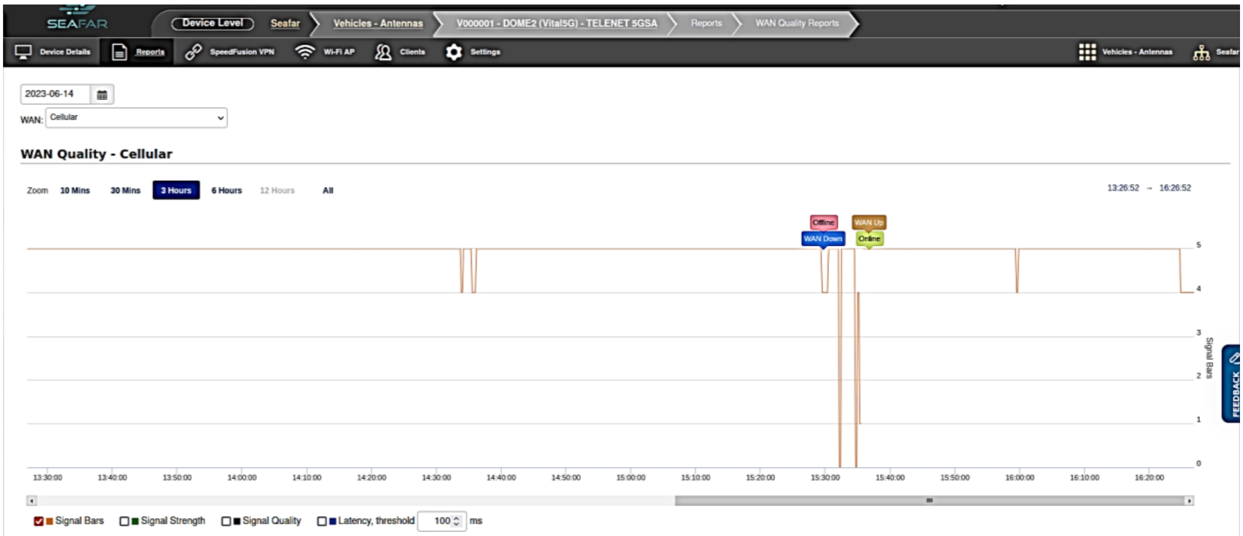

Figure 25 5G SA signal bars on boat at Port of Antwerp

Figure 25 shows the WAN Quality based on signal strength. The definition of different strengths including "Excellent, Very Good, Good, Fair, Poor, Very Poor" are provided in the appendix.

Figure 26 5G SA WAN quality based on signal strength on boat at Port of Antwerp

Figure 26 below shows the WAN Quality of the 5G signal based on SINR and RSRQ .

Figure 27 5G SA WAN quality based on signal quality on boat at Port of Antwerp

Figure 27 shows the latency between the mast and the 5g antenna. With a threshold of 15 ms. The units of the reported latency values is in millisecond. According to Peplink forum, the latency is Round Trip Time (RTT) measurement [1].

Figure 28 5G SA latency on boat at Port of Antwerp

3.4.4. Coverage Map

The 5G signals coverage during the measurements is illustrated in Figure 28. Regarding the color code of the signals quality provided in the appendix, we can see that on the whole path the signal quality is excellent.

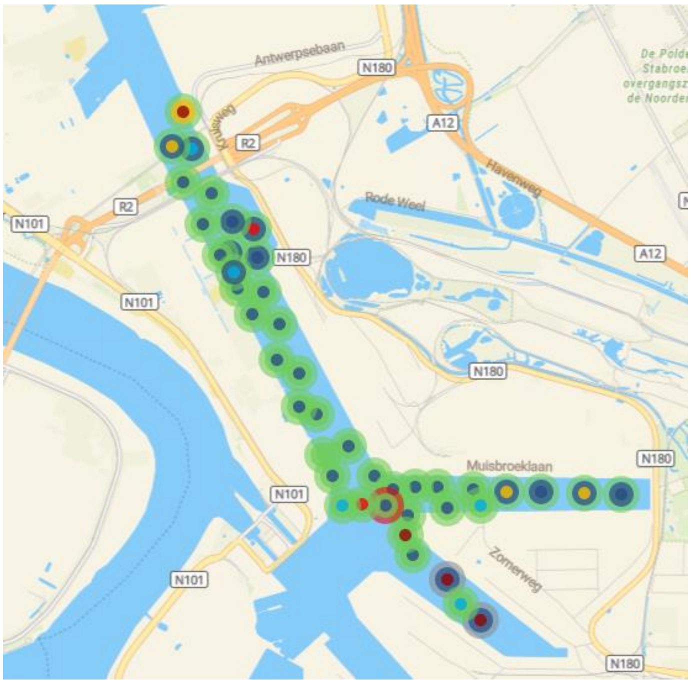

Figure 29 5G SA signal coverage during sailing on boat at Port of Antwerp

3.4.5. Remarks

BW seems lower than expected according to the info we got from our MNO Telenet. Furthermore, there is 100Mbit switches onboard. However, we reach 35Mbps uplink bandwidth. No other issues encountered.

3.5. Test T1.5

Regarding the test attempt in T1.4 when switching to SA on the barge failed, we had to test together with Telenet to find the issue. So we drove to Telenet base station with a car and tested the connectivity while the antenna was on top of the car.

3.5.1. Introduction

This test was to verify the SA connection and the switch from SIM1 with 4G/5G NSA to SIM2 with 5G SA. The summary of collected data is provided in the appendix.

The test is done on September 14th , 2023 from (10:00) to (13:00). The car was parked near the cellular tower of Telenet as illustrated on Figure below.

Figure 30 Car equipped with 5G modem parked under Telenet base station to test the connectivity.

3.5.2. BW test

For testing the bandwith capabilities we have used online speed test from ookla (www.speedtest.net) The result form the site can be seen in Figure 30.

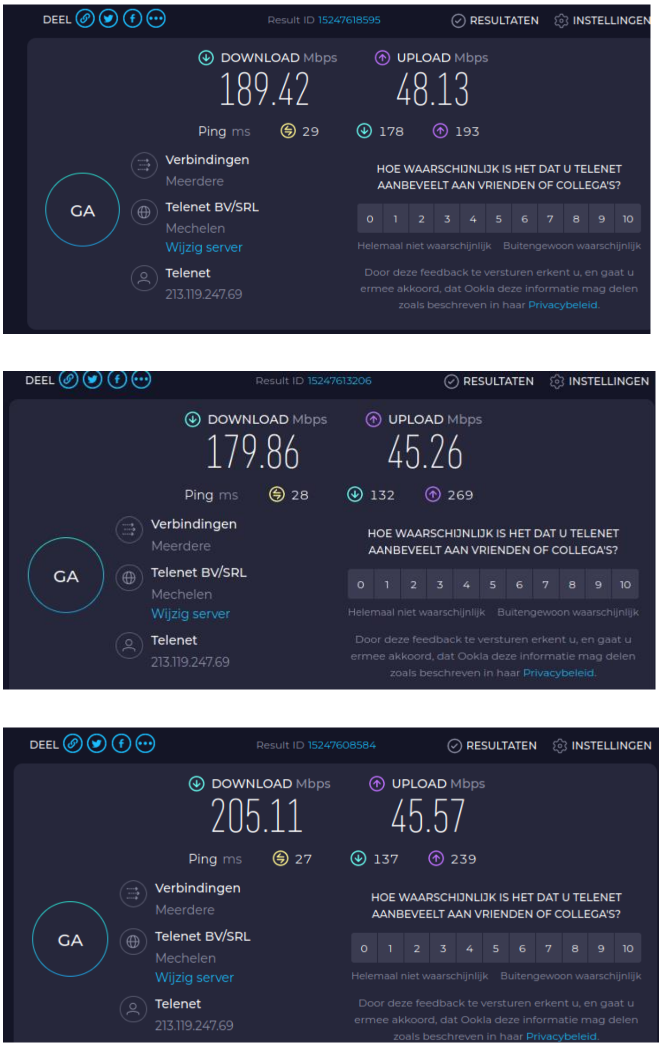

Figure 31 3 BW test under Telenet 5G SA base station

After the modification of simcard by Telenet, we then tried to get connected to 5G NSA/4G.

Figure 32 BW test after switching to 4G/5G NSA sim

Then again we switched to 5G SA. This time the BW was lower because of high load on cellular tower during test window.

Figure 33 BW test after switching to 5G SA sim

Again we switched to NSA Sim and it worked well.

Figure 34 BW test after switching to 4G/5G NSA sim

After conducting this test together with Telenet and repeating the switching several times, the problem of switching from NSA to SA and SA to NSA was solved.

3.5.3. Signal Bars

In this measurement, we have collected the signal quality. Figure 34 and 35 shows the WAN-quality of signal bars with 5G SA and NSA, respectively. The value means how many signal bars we had on the connection (The bars as shown as it is displayed on a phone from 0 to 5 where 5 is the best quality.)

During the test the car was parked near the Telenet cell tower. Due to this we had 5 Bars for each test.

The online and offline is shown for the moments the dome is no longer able to connected to the user interface of peplink which we used for data collection.

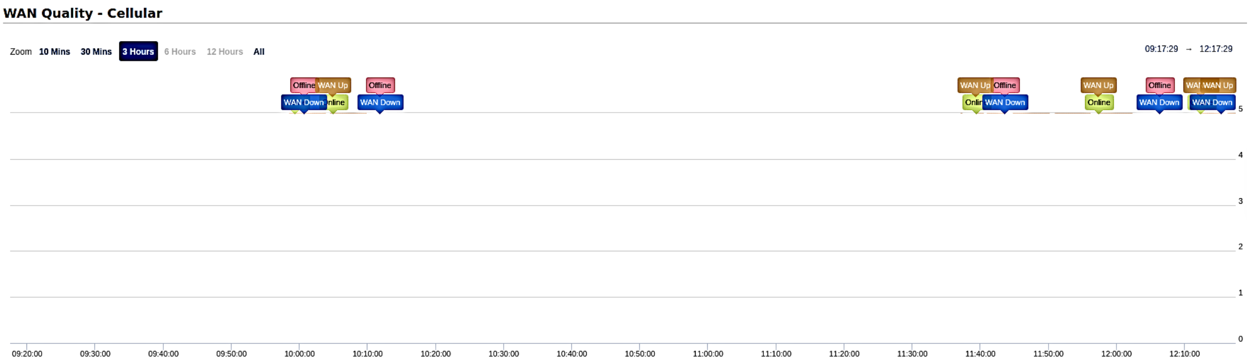

Figure 35 Signal bars when connected to 5G SA on test T1.5

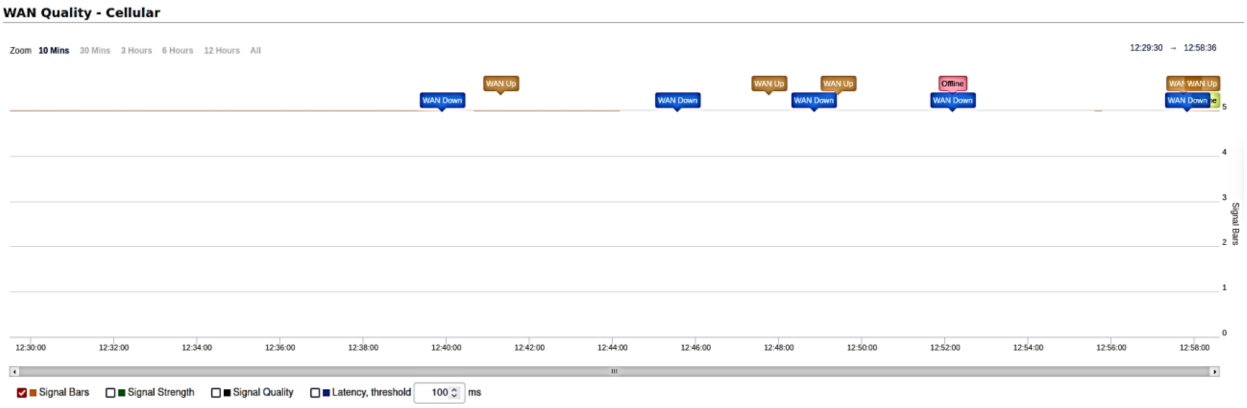

Figure 36 Signal bars when connected to 5G NSA/4G sim on test T1.5

3.5.4. Wan Quality

The WAN quality based on signal strength for the signals utilizing 5G SA and NSA dome is illustrated in Figure 36. Based on the figure, we can see that the signal strength fluctuates among Poor, Fair, Good, Very Good, and Excellent. Most of the fluctuations take place each time the modem is restarted.

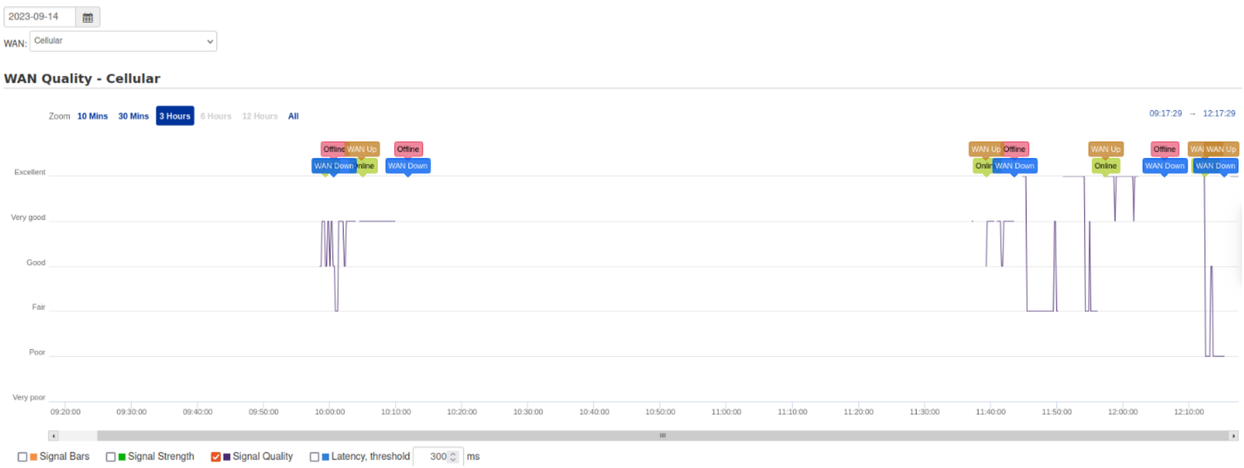

Figure 37 WAN quality when connected to 5G SA sim on test T1.5

Figure 38 WAN quality when connected to 4G/5G NSA sim on test T1.5

3.5.5. Latency

The latency in the unit of millisecond is illustrated in Figure 38. The green part of the figure means within threshold and the red part means below the threshold. We can see that the Latency on average is around 30ms. During the startup and shut down of the dome we have spikes up to

200ms.

Figure 39 Latency when connected to 5G SA sim on test T1.5

Figure 40 Latency when connected to 4G/5G NSA sim on test T1.5

3.5.6. Coverage map

Since we have tested only in a static environment this is not applicable.

3.5.7. Remarks

During the test the main goal was to switch between 2 simcards and the 4G/5G NSA and the 5G SA simcard. The switch between the sims worked fine. Only on the 4G/5G NSA sim our dome failed to connect to 5G NSA and stayed on 4G.

3.6. Test T1.6

After solving the issue with switching from 5G NSA to SA remotely, we were able to collect data from the commercial barge sailing in the waterway. This test describes the results on this test.

3.6.1. Introduction

This test was to verify the results and report the signal quality of the 5G SA signal. The collected data in this test is provided in the appendix.

The test is done on September 19th , 2023 from (14:50) to (15:30). The operational barge is the same as the one used in T1.1 and trajectory of sailing is in Port of Antwerp.

3.6.2. BW test

For bandwith testing we have enabled all our video streams with 40% compression instead of the default 75% compression. During the test we can see that we reach a maximu of 3.5Mbps. This was due to the bad 5G reception at the test location.

For the upload test we used a file copy via scp. The upload was blocked on 1.6Mbps.

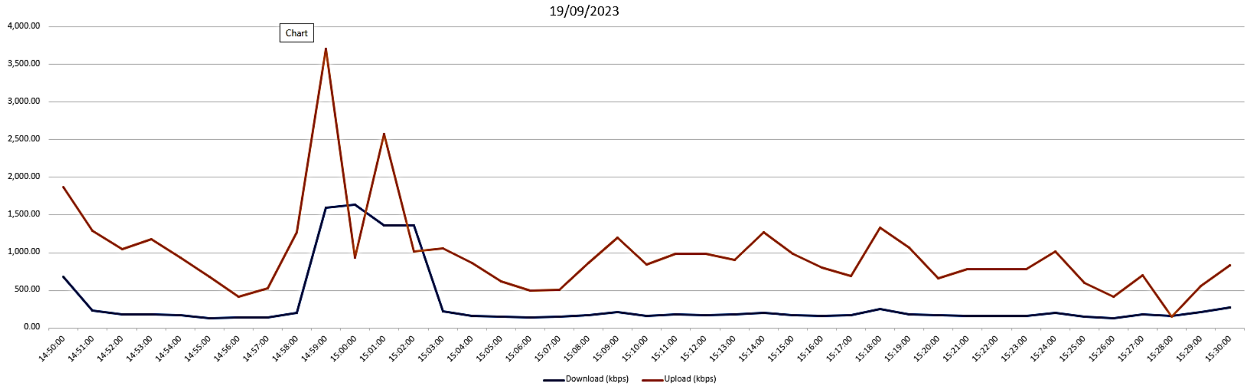

Figure 41 The upload and download BW during T2.6

3.6.3. Signal Bars

In this measurement, we have collected the signal quality. The first figure shows the WAN-quality of signal bars. The dome has been disconnected for a short amount of time after our test. The rest of the test duration we had 5 signal bars as shown in Figure 41.

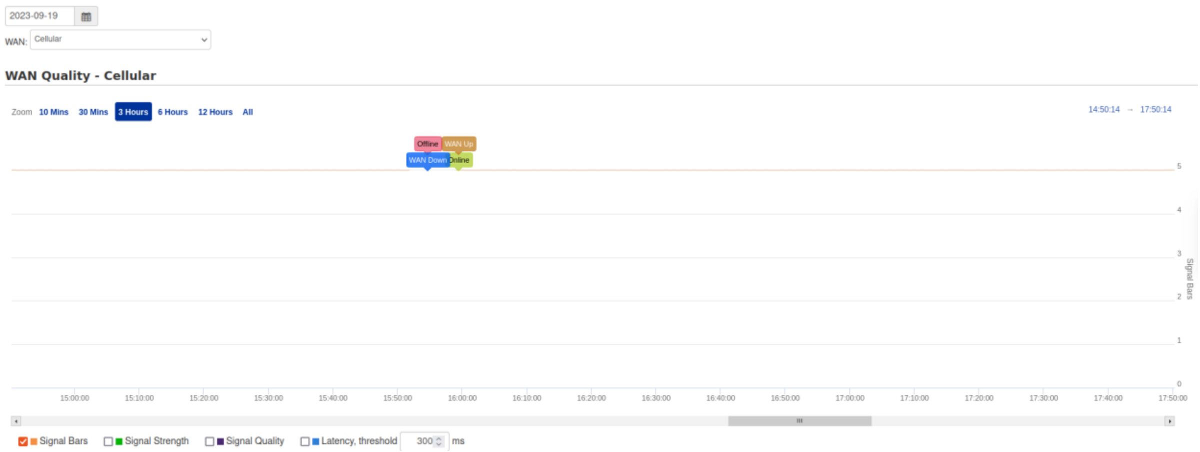

Figure 42 5G SA signal bars during sailing in T2.6

3.6.4. Wan Quality

The WAN quality based on signal strength for the signals utilizing 5G SA dome is illustrated in Figure 42. Based on the figure, we can see that the signal strength fluctuates among Poor, Fair, Good, Very Good, and Excellent during the start of the test and stays on Verry Good and Excellent during the rest of the test window.

Figure 43 5G SA signal quality during sailing in T2.6

3.6.5. Latency

The latency during the test is between 21 and 50ms as shown in Figure 43. The average is 25ms.

Figure 44 5G SA latency during sailing in T2.6

3.6.6. Coverage map

On coverage map provided in Figure 44, we can see that there were some moments with less reception quality but overall, the coverage was excellent.

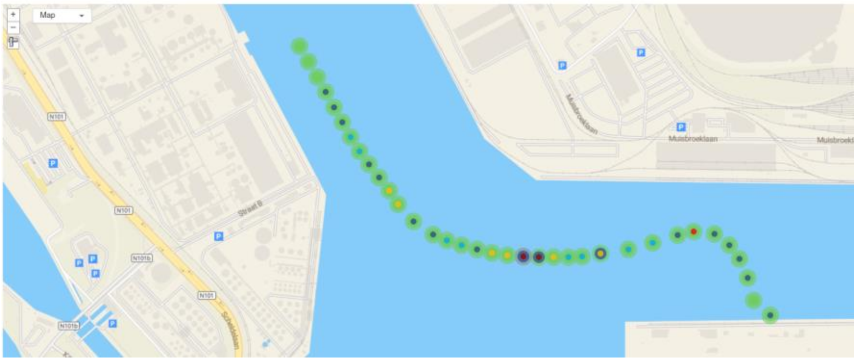

Figure 45 5G coverage map during sailing in T2.6

3.6.7. Remarks

This test shows sailing over 5G SA. We can see that at some point the signal is lost. During this failure, out network balance onboard switches to another network provider to keep the teleoperated sailing smooth and seamless.

3.7. Test T1.7

This test took place on Sep 19, 2023 similar to previous test using the same barge as in T1.1. Based on Figure 45 and 46 we can see that near the base station of Telenet there is good to fair coverage, some fluctuations in signal quality but also good latency with an average of 30 ms.

Figure 46 5G SA signal quality and latency in T1.7.

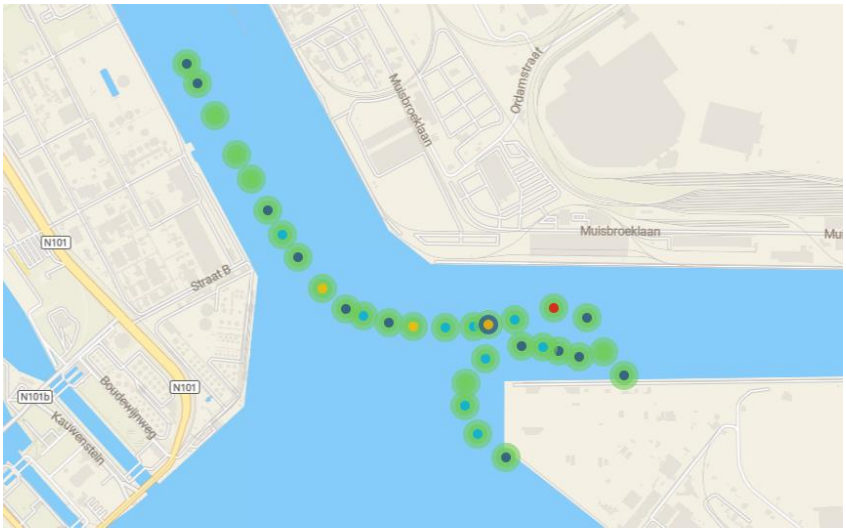

Figure 47 5G SA coverage and trajectory in T1.7.

3.8. Test T1.8

This test took place on Oct 30, 2023 similar to previous test using the same barge as in T1.1. Considering Figures 47 and 48, we can see that far from the SA base station there are low signal quality, high fluctuations in signal quality and latency happened. Even at some part, the latency was more than 600 ms.

Figure 48 5G SA signal quality and latency in T1.8.

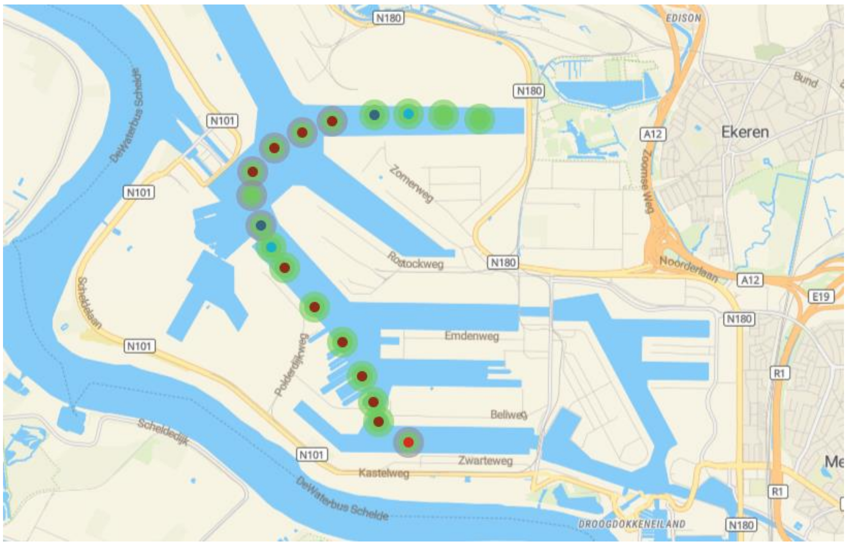

Figure 49 5G SA coverage and trajectory in T1.8.

3.9. Test T1.9

This test took place on Nov 9, 2023 similar to previous test using the same barge as in T1.1. We can see similar results as two previous tests. Near Telenet base station there is good connectivity and coverage as shown in Figure 50. However, in the parts far from the base station, the signal quality fluctuates severely. The latency stayed more or less the same in all the tests.

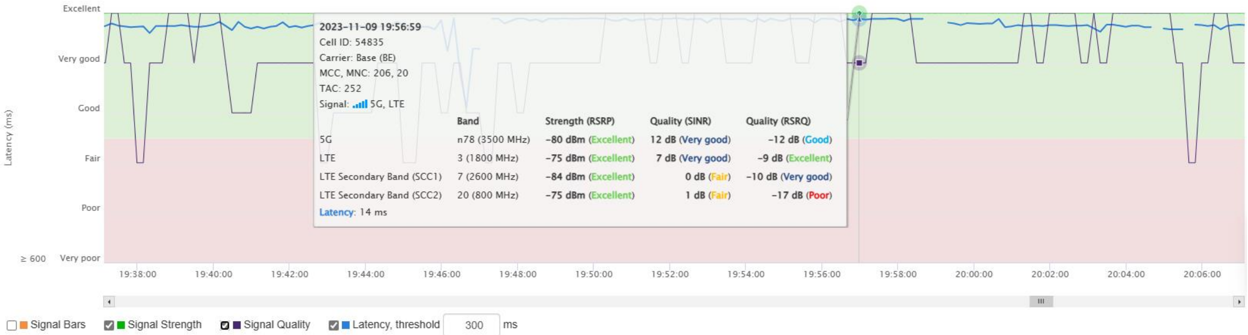

Figure 50 5G SA signal quality and latency in T1.9.

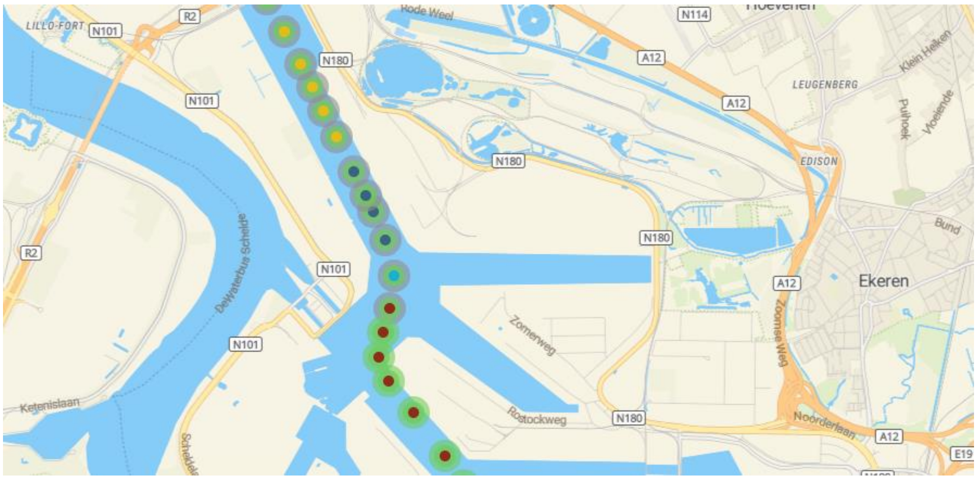

Figure 51 5G SA coverage and trajectory in T1.9.

4. TESTS IN ZELZATE

Today, with the 4G connectivity, there are some specific issues which prevent international operations. It is possible that in cross border area the 4G modem requires a remote reset to get connected to base station of the second country. Sometimes, the roaming over 4G happens automatically. However, the latency can be up to a few minutes which is not tolerable for a remote operation of a ship. These limitations prevents the journey toward fully autonomous sailing. It also reduces the operational hours as the ships sail into cross border area, the network engineer must be always accessible to control and monitor network connectivity or the captain onboard must be present to take over control of the vessel if a problem occurs. By deploying 5G, Seafar investigates the seamless roaming at cross border area, Zelzate. Moreover, the presence of the Zelzate bridge in this region adds complexity to obtaining teleoperation permits. Ensuring seamless connectivity is pivotal to facilitating the authorization process from relevant authorities. By establishing robust and uninterrupted connectivity, the likelihood of expeditious approval for teleoperation permits can be significantly improved, addressing the challenges posed by the infrastructure, particularly the Zelzate bridge, and streamlining the authorization process for enhanced operational efficiency. The area of testing is illustrated in the map below.

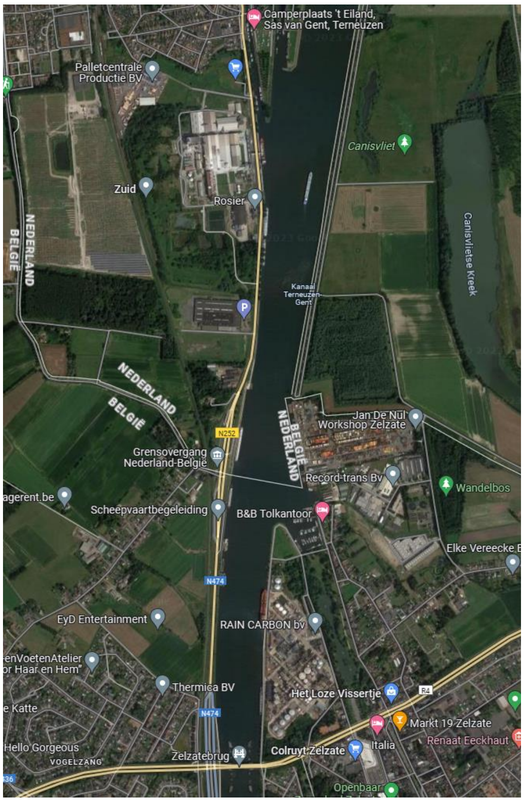

Figure 52 Area of testing during cross border experience in Zelzate.

The sailing tests in Zelzate area are done with an urban barge called AVATAR. This vessel is illustrated in Figure 52.

Figure 53 AVATAR urban barge.

Like the operational barge in Port of Antwerp, AVATAR is also equipped with all the sensors necessary for remote operations. Furthermore, Seafar control system is installed and integrated with AVATAR to enable teleoperation of this urban barge. Seafar control system inside the urban barge is shown in Figure 53.

Figure 54 Seafar control system inside AVATAR urban barge.

4.1.Test T2.1

Seafar has received 2 simcards of SA connectivity from TNO in May, 2023. One of them is KPN and the other one is Telenet.

4.1.1. Introduction

This test window was foreseen for initial testing of the Peplink dome and roaming test. Goal was to test the simcards, firmware, end user device and if all working the hand over between KPN and Telenet. Thus, for this test we drove with a car to the area and put the modem in the car to check network connectivity. The test is done on June 6th , 2023 from (9:00) to (12:00).

4.1.2. Test results

First test has been done with KPN simcard. The modem kept trying to get connected but connection failed. The second part of the test was done with Telenet simcard. The same issue happened. For the trouble shooting, the modem was sent to TNO, which provides the core of the network.

The signal strength is illustrated in Figure 54.

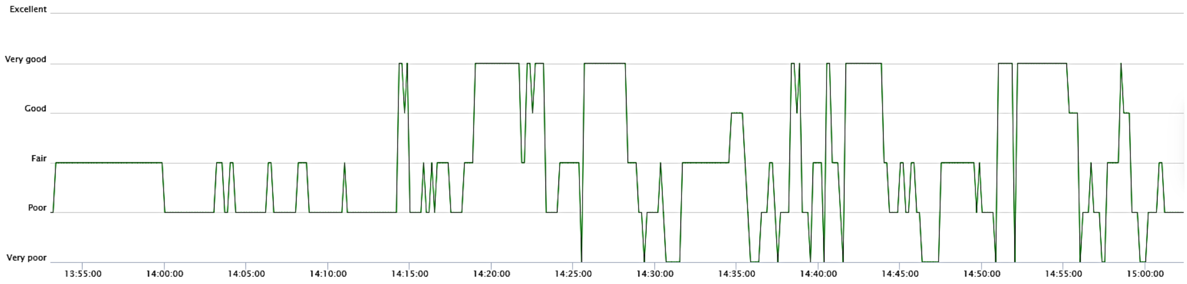

Figure 55 Signal strength during first test in Zelzate cross border area

4.1.3. Remarks

After analysing the traces TNO confirmed the peplink devices is responding differently than other SA devices. Decision was made to send over the test dome to TNO for Lab testing. After this testing, we realized that there is no issue with the modem so we planned more tests together with network providers to find the issues.

4.2. Test T2.2

4.2.1. Introduction

This test was for checking the TNO simcards for KPN and Telenet with the Peplink dome at Zelzate cross border area. The test is done on August 31st, 2023 from (8:25) to (9:47). Considering the unsuccessful network connectivity in previous test, we still continued the test with the car to make sure the connection is good enough for teleoperated sailing. The devices present during this test are illustrated in Figure 55. These devices include Seafar demonstration box with processor, camera, framegrabber, router, and network balance. The 5G modem was also on top for enabling Line of Sight communication with the base station. A UPS was also utilized to provide the required power for communication.

Figure 56 Seafar devices and equipment for test T2.2 with car.

4.2.2. Test overview

During the test window we have been testing with connection to KPN and Base on a regular basis. At this test we could not get connected to KPN as MNO. We restarted used multiple sim cards and the issue kept returning. A summary of steps taken during this test are as follows.

Internet Connection Test

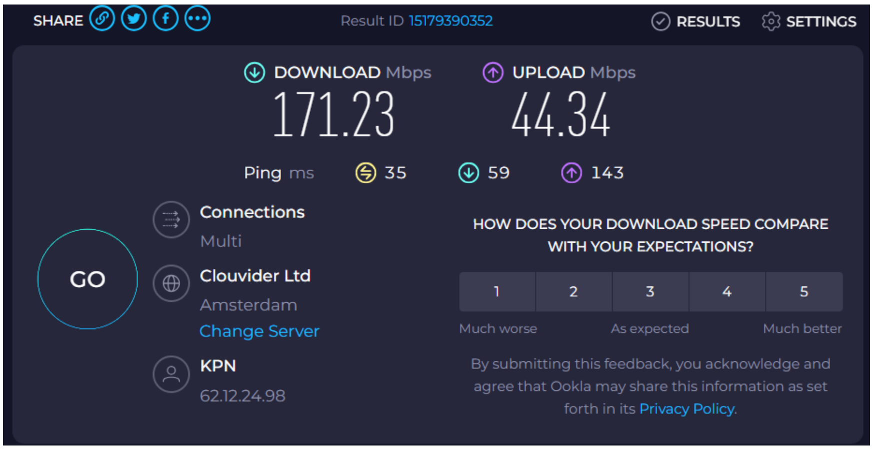

Figure 57 Internet connection with KPN sim card in the Netherlands

Test a: BE to NL SIM KPN (SIM A)

8:25- 8:28

The device started to try connection. However, due to a settings configuration , the Dome didn't Roam. Roaming not activated. The detail of cellular network setting, connectivity, and ping test in this step is illustrated in Figures 57, 58, and 59 respectively.

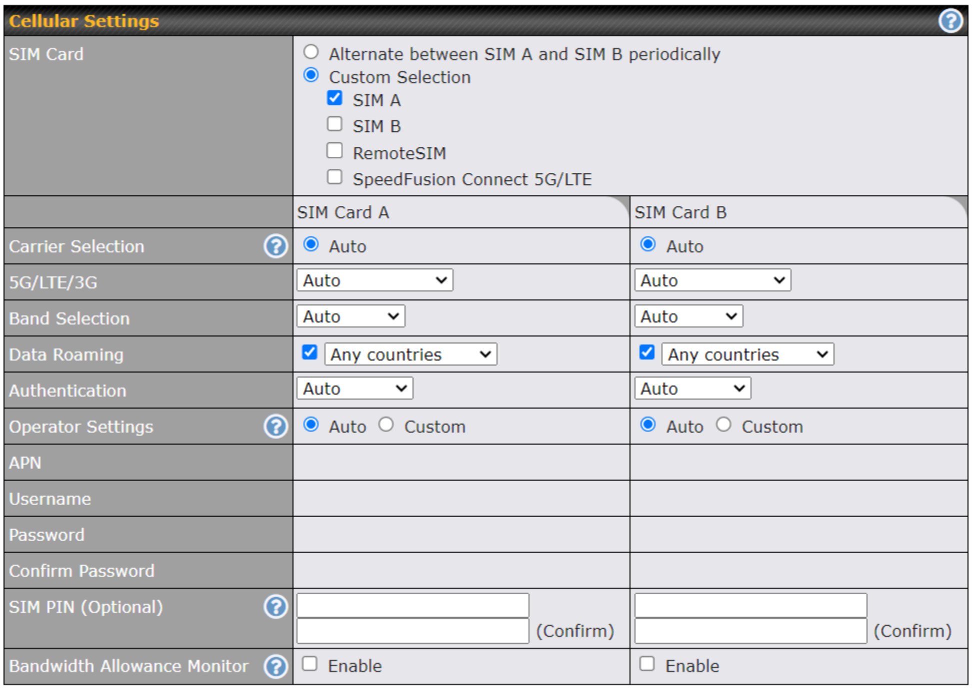

Figure 58 Cellular setting of the modem at first attempt in T2.2

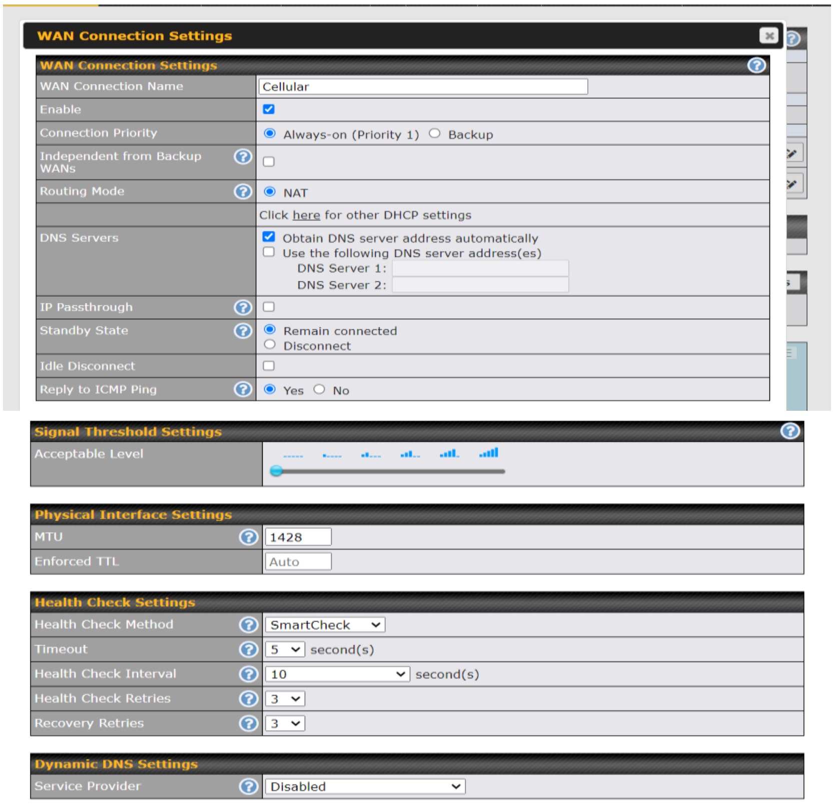

Figure 59 WAN connection setting on the modem.

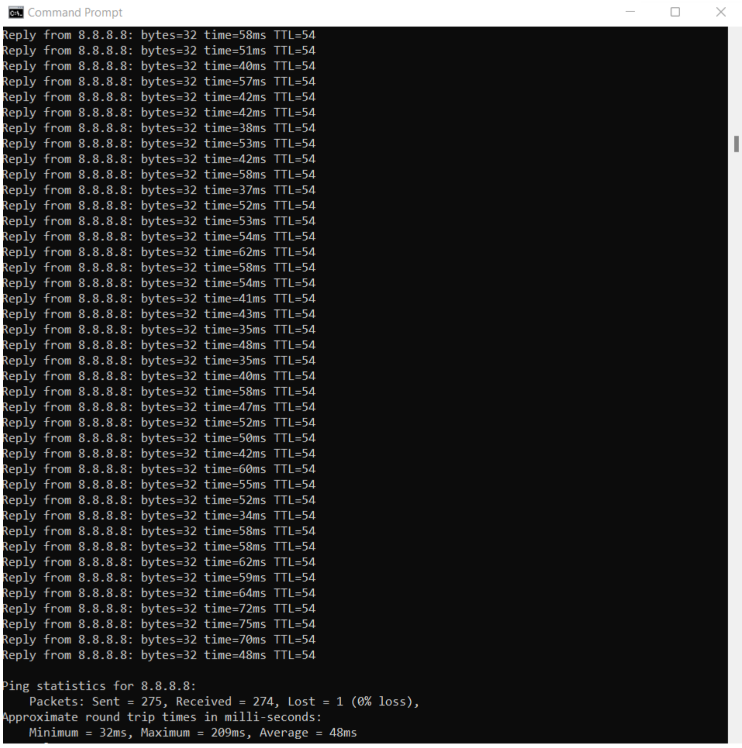

Figure 60 ping test results while connected with KPN 5G SA sim card.

Test b: NL to BE SIM KPN (A)

8:30- 8:47

Got connection arriving to BE

TEST c: BE to NL SIM KPN (SIM A)

8:49- 8:55

Ping lost one time, when crossing the border. SIM kept connected on KPN base station.

TEST d: NL to BE SIM KPN (SIM A)

9:00- 9:11

APN changed to default. No internet access, error message WAN failed SmartCheck. This error appeared when changing the APN to default, then there was not connection until crossing the border to BE. Finally got the WAN message back.

TEST e: BE KPN (SIM A)

9:17

Configuration of 5g/LTG/3g =5g SA , SIM didn't connect.

9:20 Auto and APN=auto and Configuration of 5g/LTG/3g =Auto, got connection to KPN base station

9:22 change APN to default, no connection.

9:26 change APN to auto and 5G/LTE/3G =5G SA, connected to KPN base station

9:30 change APN to default and 5G/LTE/3G =5G SA at 9:31 we got connection to KPN base station, still in BE

TEST f: BE KPN (SIM A)

9:39 9:47

9:30 change APN to default and 5g/LTG/3g =5g SA at 9:31 we got connection to KPN base station while the modem was still in BE. While crossing the border the connection didn't get lost, stay connected to KPN base station. The detail of cellular network connectivity in this step is illustrated in Figure 60.

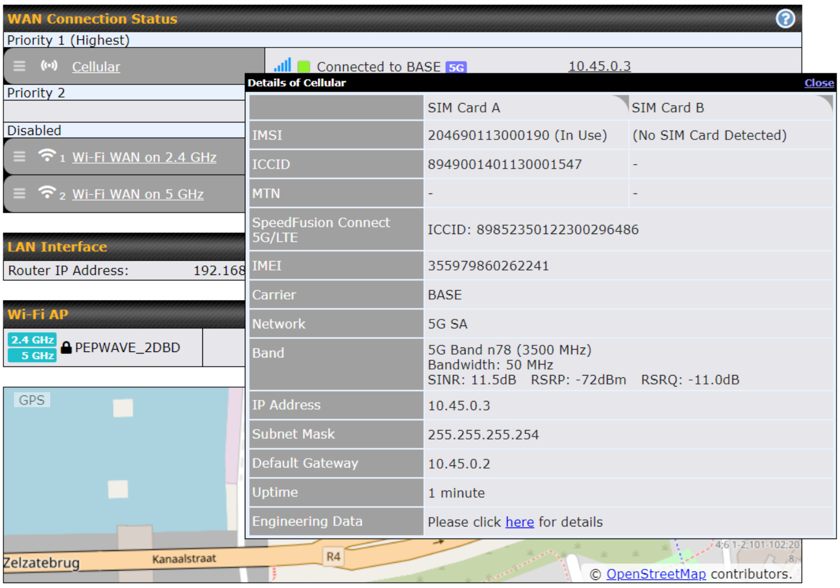

Figure 61 Details of Cellular network connectivity.

4.2.3. Remarks

Test failed due to handover and connection issues. After this test other partners testing the network connectivity arrived in cross border area and experienced similar issues. We ended the test since there was a more general issues than the seafar Peplink dome.

After this test, we provided list of IP addresses to be whitelisted by Telenet.

4.3. Test T2.3

The tests stopped until second week of October when the networks from MNOs and handover was ready for testing by use case leaders. After the confirmation, on the first dry-run event on Oct 24, 2023, we arranged another test with car to check network behaviour (The plan was to test network with the barge. The AVATAR barge is a green vessel running on battery instead of the fuel. However, we received a message from the vessel owner that the battery is not working properly so we switched to test with a car.)

We utilized KPN simcard, which was supposed to have the seamless roaming when we enter Belgium from the Netherlands. As illustrated in Figure 61, we experienced a lot of fluctuations and disconnections during this test. The signal coverage and quality are illustrated in Figure 62.

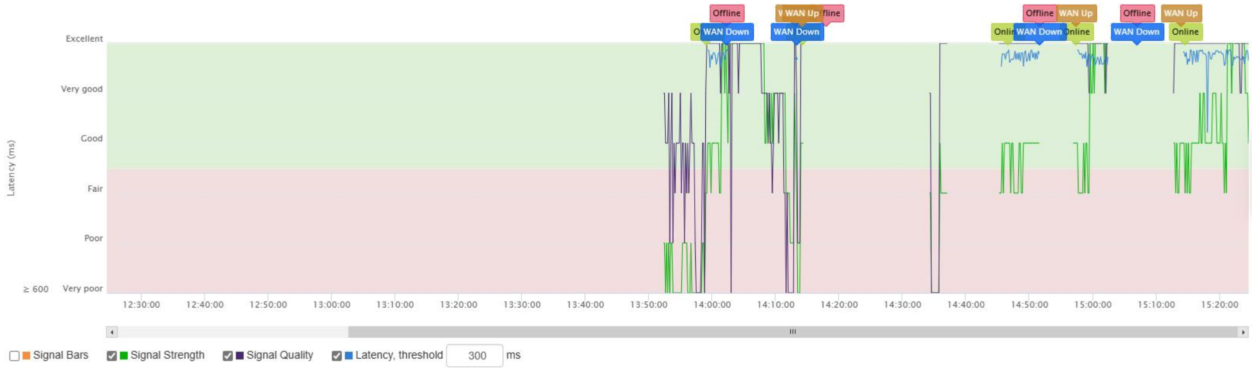

Figure 62 5G SA signal quality and latency while connected to KPN base station.

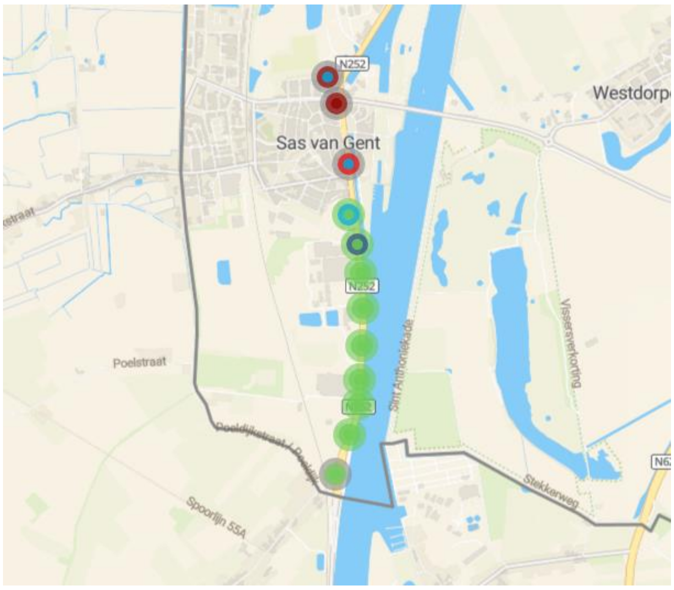

Figure 63 5G SA signal coverage and trajectory of the driving while staying in the Netherlands.

We also realized that we cannot get connections to Telenet base station. Neither with the Telenet Sim card, nor with seamless roaming. As a result, we decided to do another test with the car.

4.4. Test T2.4

This test took place with the car again. We drove for several rounds on the road from Netherlands to Belgium and the opposite. There was good signal coverage on the side of the canals as illsutrated in Figure 64. However, there were many fluctuations in signal quality as shown in Figure 63 which resulted in a not safe enough condition for remote operations of the barge. Meanwhile, MNOs were working on the issues to be solved.

Figure 64 5G SA signal quality while connected with KPN sim card and crossing the border with car.

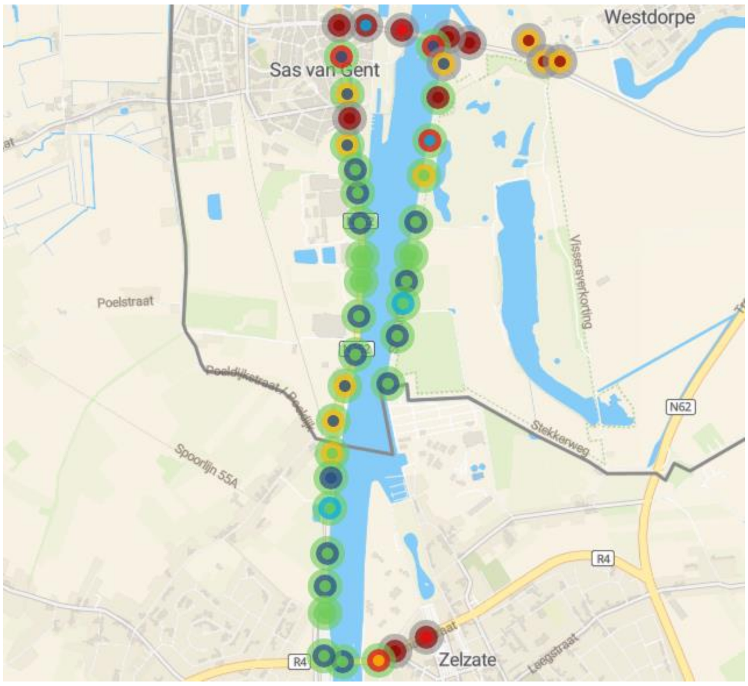

Figure 65 5G SA signal quality while connected with KPN simcard and crossing the border with car.

During this test, we were not still able to get connected to Telenet simcard. Thus, we were in communication with Telenet for solving the issue to have a chance to start our test from Belgium to Netherlands with connectivity over Telenet base station and then the seamless roaming to KPN base station. Meanwhile, we were also in discussion with KPN for the low signal quality and throughput.

4.5. Test T2.5

The barge was repaired and ready for test on Nov 6th, 2023. The results showed an improved connectivity to KPN base station. However, near the Telenet base station the connection was not good enough. We faced lags in video qualities at Remote control stations. The signal quality is illustrated in Figure 65 and the coverage is shown in Figure 66.

Figure 66 5G SA signal quality connected with KPN simcard and sailing across the border.

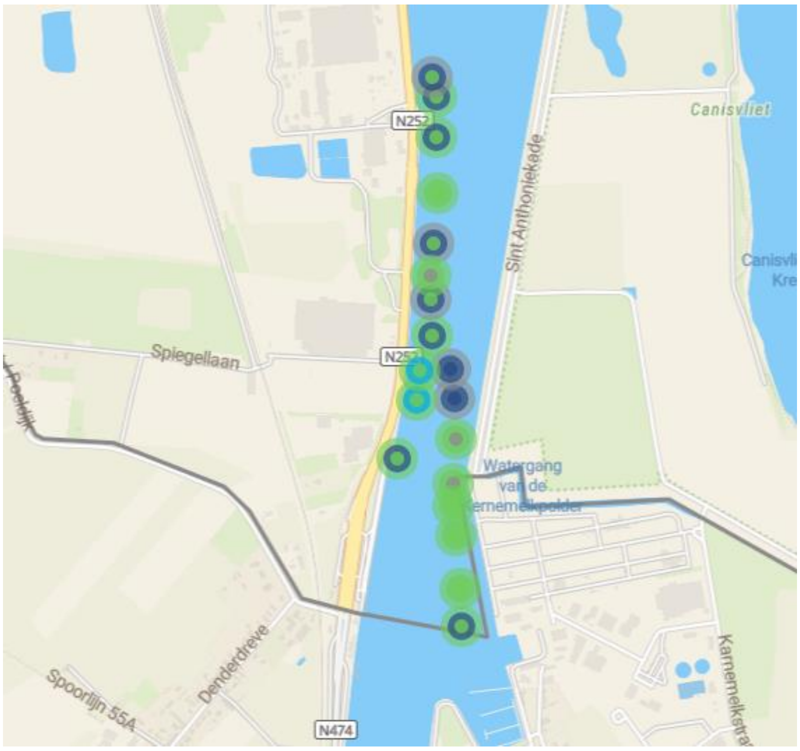

Figure 67 5G SA signal quality connected with KPN simcard and sailing across the border.

The video quality for test purposes, while the captain is onboard and ready to take over control of the vessel if connection is lost, is ok. However, based on the reviews by the traffic controller, the video quality is not high enough for a safe remote operation with no captain onboard. We communicated these results with MNOs and partners in the project.

4.6. Test T2.6

Another test was conducted on Nov 7th with the urban barge while sailing in the cross border area. During this test, we switched the Sim cards and used Telenet simcard instead of KPN and started the sailing from Belgium to the Netherlands. The results showed an improved connectivity. Videos were recorded from remote control station and the barge sailing in the waterway. The latency is shown in Figure 67 and the 5G SA signal coverage is shown in Figure 68.

Figure 68 5G SA signal quality connected with Telenet simcard and sailing across the border.

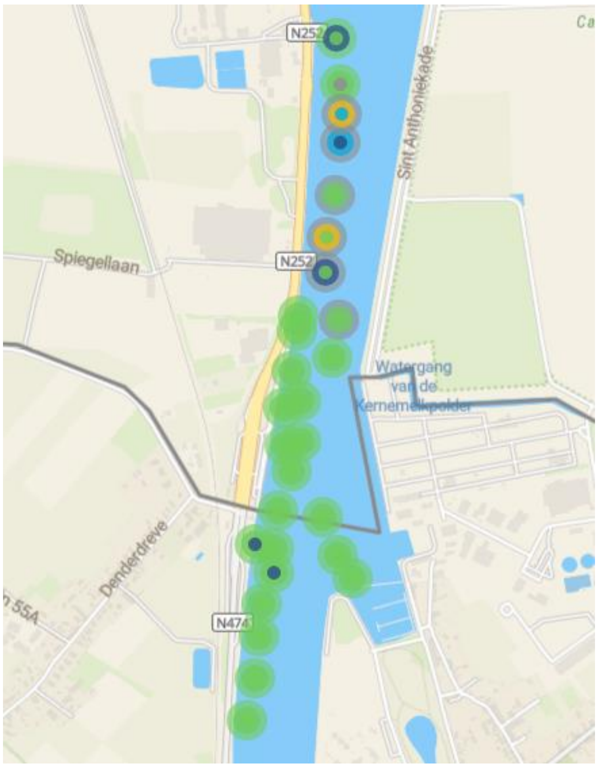

Figure 69 5G SA signal quality connected with Telenet simcard and sailing across the border.

One remark is that with Telenet connectivity we experienced higher throughput and signal quality. Our assumption is that it is a result of beamforming capability of Telenet base stations [4].

4.6.1. Challenges and Solutions

After this test, we recognized two issues: 1. The height of the antenna affecting the communication of our modem with the base station, as shown in Figure 69.

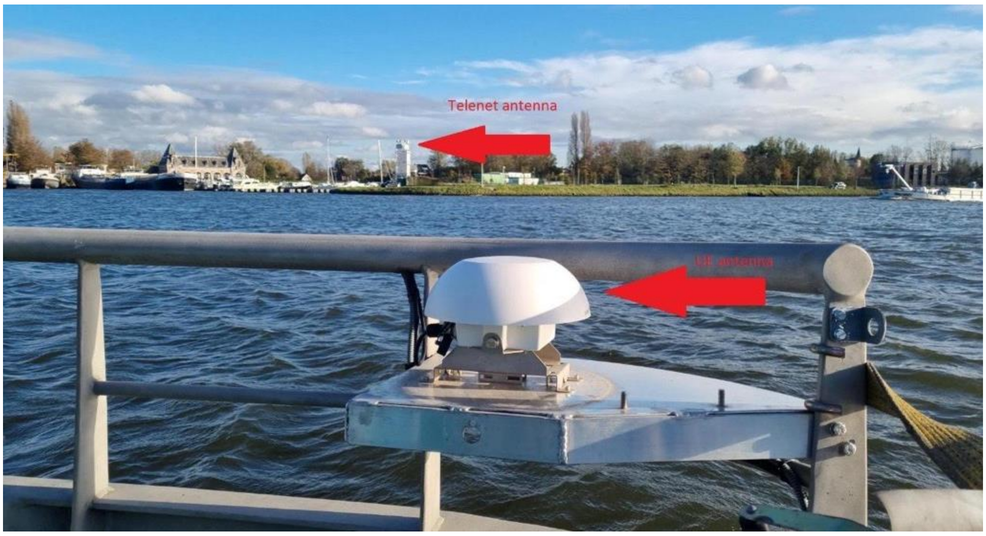

Figure 70 Railing of the urban barge preventing the LoS communication with the base station.

To solve this issue we increased the height of antenna with a temporary solution as illustrated in Figure 70.

Figure 71 Increased height of communication to provide LoS links.

The reason that we considered a temporary solution is that AVATAR barge usually sails in Ghent waterways where there are very low bridges. Any object above the railing might stuck with the side of the bridge and get broken.

2.The disconnection with the base station at some parts of the trajectory.

We realized that our modem loses network connectivity in areas where there should be network coverage. To find the reason, we arranged another test with car which is described in

T2.7.

4.7. Test T2.7

To find out about the reason behind the disconnection of modem during previous sailing test, we arranged another test with car while TNO was monitoring our network connection remotely to help us solve this issue. After driving the car in the following trajectory, TNO realized that our modem is trying to get connection to some IP addresses. Considering the private network of Telenet, without whitelisting those IP addresses the connection was not possible. Therefore, all those IP addresses were extracted and provided to Telenet to whitelist them for the next test. The trajectory that car drove during this test is shown in Figure 71.

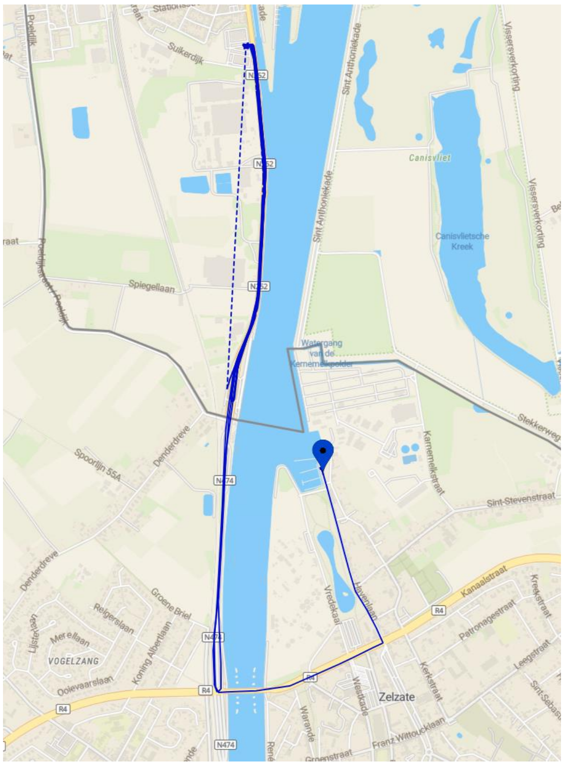

Figure 72 Trajectory of the car in Zelzate.

4.8.Test T2.8

This test was done during the dry-run test on Nov 20, 2023. The AVATAR barge was sailing in the cross border area from the NL to BE and the opposite direction. The remote captain was making continuous U-Turns so the connections can be tested sufficiently. In this test we realized that after increasing the height of the antenna and whitelisting all relevant IPs, solved our issues in previous tests. The connection was overall good and we were able to sail remotely from the office facing no issue around the border.

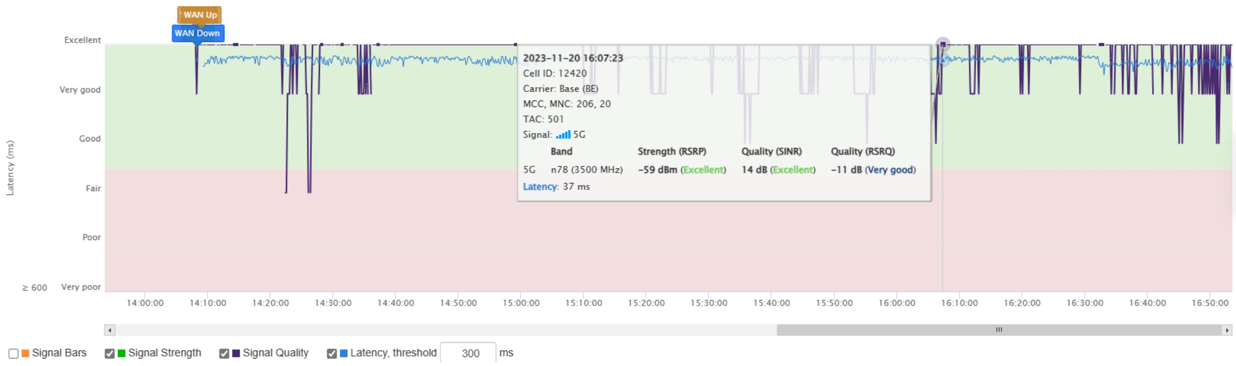

Figure 73 5G SA signal quality and latency during dry-run test.

Figure 74 5G SA signal coverage and trajectory during dry-run test.

4.9.Test T2.9

This test was done during the day of demonstration on Nov 21, 2023. The results show successful connection to remote control station over 5G SA when crossing the border from Belgium to the Netherlands and the opposite direction. In figures below we can see that there was very good signal quality on most the trajectory of sailing as shown in Figure 74. The poor connection only happened at a single point which can be a result of many big barges around our barge during the day of demonstration. The signal coverage is shown in Figure 75.

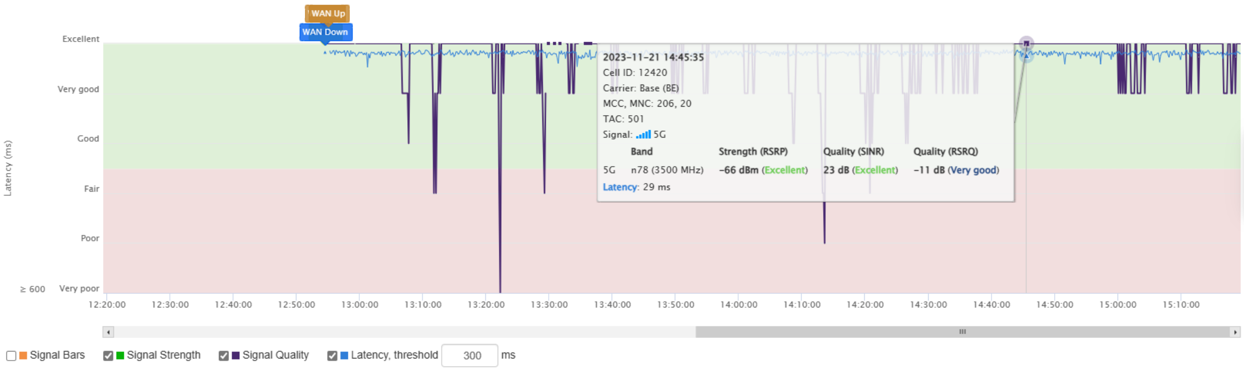

Figure 75 5G SA signal quality and latency during final demonstration.

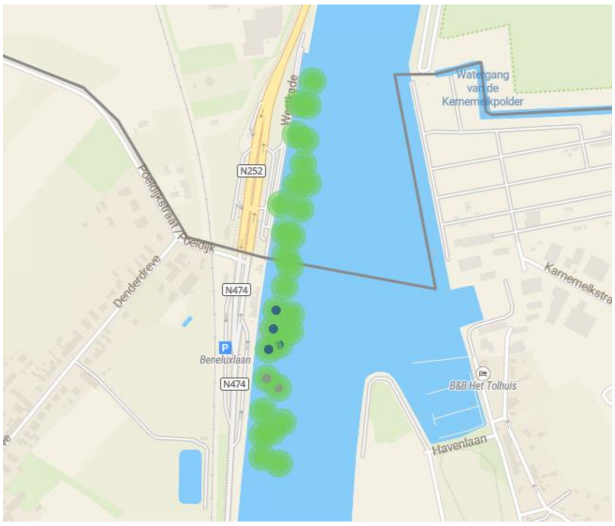

Figure 76 5G SA signal coverage and trajectory during final demonstration.

5. TEST RESULTS

The results prove that the video streams over 5G NSA and SA connectivity are better than 4G. Therefore, in general 5G connectivity result in higher situational awareness of the captain, who is sailing the vessel remotely from the office. The higher awareness will result in safer operations. Furthermore, 5G SA connectivity at cross border area results in lower latency in connections. Specifically with the presence of Zelzate bridge in the infrastructure it becomes highly important to prove seamless connectivity for automated sailing in the area. In our extensive testing of 5G NSA, we observed that the available bandwidth surpasses that of 4G, providing an opportunity for enhanced video quality in remote navigation scenarios. While the latency for 5G NSA remains comparable to 4G, the reduced jitter results in a smoother video feed, contributing to a safer remote navigation experience compared to 4G. However, the current limited coverage of 5G NSA raises concerns about network stability, as reflected in the variability of link quality, which exhibits more fluctuations between quality levels than observed in 4G. Shifting our focus to 5G SA, our tests revealed a significantly higher bandwidth than 4G, enabling improved video quality and diverse angles for remote navigation. This heightened capability ensures safer navigation, especially in port locations with heavy maritime traffic. Although the latency in 5G SA mirrors that of 4G for remote barge use cases, the reduced jitter further refines the video feed, enhancing the overall experience.

The solution has demonstrated exceptional performance within the designated test area throughout the project. Nevertheless, akin to the observations made with 5G NSA, the restricted coverage of 5G SA prompts us to carefully evaluate its impact on network stability in contrast to the well-established robustness of 4G networks. While the functionality has proven effective within the test parameters, the broader application of 5G SA and its potential challenges associated with limited coverage warrant a thorough examination to ensure its reliability and stability align with the high standards set by 4G networks.

6. CONCLUSIONS

We have acquired proficiency in utilizing 5G modems, encompassing configuration processes and establishing connections with 5G Standalone (5G SA) networks. This expertise was put into action through testing in the critical environment of the Port of Antwerp, verifying the robustness of our connections. In the subsequent phase of our use case, we extended our acquired knowledge to another barge, validating the transferability and applicability of our lessons to different vessels. Rigorous testing procedures were implemented, particularly in the critical and challenging area of Zelzate cross-border, where we tested the connectivity in detail. The teleoperated sailing functionality was tested multiple times, ensuring the reliability and adaptability of our approach across various operational scenarios.

The executive summary accentuates the pivotal role of connectivity in the barge teleoperation use case. It places a strong emphasis on the safety implications associated with potential network interruptions, particularly underscoring the significance of critical zones such as cross-border operations and port areas. By drawing attention to these safety considerations, the summary underscores the critical need for a resilient and uninterrupted connectivity framework to ensure the secure and efficient functioning of barge teleoperation, especially in areas where safety is significant, such as cross-border operations and busy port environments.

In conclusion, this report has comprehensively examined the teleoperation of the barge, delving into its elements and the diverse devices employed. The study meticulously presented the outcomes of 18 tests conducted during the reporting period, detailing the tests in both the Port of Antwerp and Zelzate cross-border area. The challenges, methodologies, solutions, and results were thoroughly explored in each location, shedding light on the operational challenges and success factors. Chapter four encapsulates the key lessons learned from the entirety of the tests, underscoring the significance of collaborative efforts with MNOs and the strategic utilization of communication channel in overcoming challenges associated with 5G implementation for teleoperation. The findings of this study hold substantial value for the practical application of 5G technology, paving the way for enhanced connectivity across crucial sectors.

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APPENDIX1

Wan quality map

The map below illustrates the strength and the quality of signals during the first test.

The WAN quality on the map is coloured in 3 circles Depending on the values of Latency, signal strength and signal quality.

- The outer circle is indicating the latency.
  - Green: Lower than threshold. The threshold value is 30ms
  - Red: higher than threshold
- The middle circle signal strength.
  - Green: excellent
  - Dark Blue: very good
  - Light Blue: good
  - Orange: Fair
  - Red: poor
  - Dark Red: very poor
- The inner circle is the signal quality.
  - Green: excellent
  - Dark Blue: very good
  - Light Blue: good
  - Orange: Fair
  - Red: poor
  - Dark Red: very poor

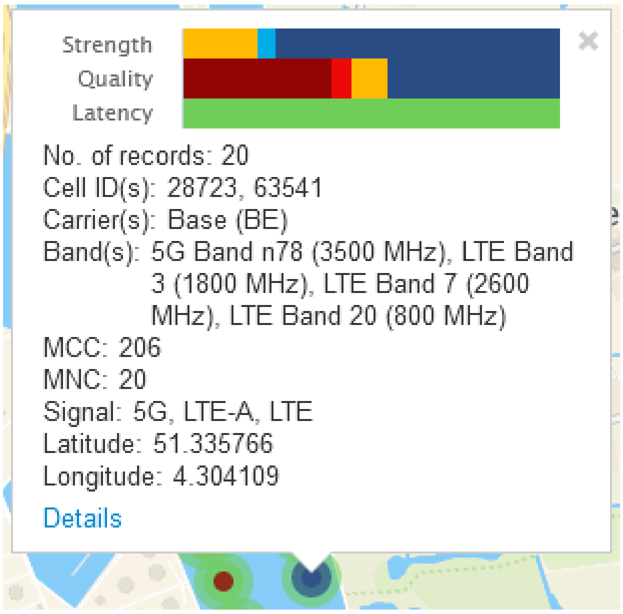

Figure 77 Detailed example of one dot on the map.

Table of Data Collected in T1.1

Name of Dataset	Description	Number of Samples	Header of the samples
20230111-Bw.csv	Time of sample	22	Minute
20230111-Bw.csv	Bandwidth usage	22	Download (kbps)

	download		
20230111-Bw.csv	Bandwidth usage upload	22	Upload (kbps)
20230111-WANQ.csv	Connection Type LTE/5G	552	Type
20230111-WANQ.csv	Cell tower ID	552	Cell ID
20230111-WANQ.csv	MNO name	552	Carrier
20230111-WANQ.csv	Mobile Band	552	Band
20230111-WANQ.csv	Signal Latency	552	Latency
20230111-WANQ.csv	Sample Time	552	Time
20230111-WANQ.csv	GPS location Latitude	552	Latitude
20230111-WANQ.csv	GPS location Longitude	552	Longitude
20230111-WANQ.csv	GPS location Altitude	552	Altitude

Table of Data Collected in T1.2

Name of Dataset	Description	Number of Samples	Header of the samples
20230120-Bw.csv	Time of sample	31	Minute
20230120-Bw.csv	Bandwidth usage download	31	Download (kbps)
20230120-Bw.csv	Bandwidth usage upload	31	Upload (kbps)
20230120-WANQ.csv	Connection Type LTE/5G	186	Type
20230120-WANQ.csv	Cell tower ID	186	Cell ID
20230120-WANQ.csv	MNO name	186	Carrier
20230120-WANQ.csv	Mobile Band	186	Band
20230120-WANQ.csv	Signal Latency	186	Latency
20230120-WANQ.csv	Sample Time	186	Time
20230120-WANQ.csv	GPS location Latitude	186	Latitude
20230120-WANQ.csv	GPS location Longitude	186	Longitude
20230120-WANQ.csv	GPS location Altitude	186	Altitude

Table of data collected in T1.4

Name of Dataset	Description	Number of Samples	Header of the samples
20230614-Bw.csv	Time of sample	126	Minute

20230614-Bw.csv	Bandwidth usage download	126	Download (kbps)
20230614-Bw.csv	Bandwidth usage upload	126	Upload (kbps)
20230614-WANQ.csv	Connection Type LTE/5G	756	Type
20230614-WANQ.csv	Cell tower ID	756	Cell ID
20230614-WANQ.csv	MNO name	756	Carrier
20230614-WANQ.csv	Mobile Band	756	Band
20230614-WANQ.csv	Signal Latency	756	Latency
20230614-WANQ.csv	Sample Time	756	Time
20230614-WANQ.csv	GPS location Latitude	756	Latitude
20230614-WANQ.csv	GPS location Longitude	756	Longitude
20230614-WANQ.csv	GPS location Altitude	756	Altitude

Table of Data collected in T1.5

Name of Dataset	Description	Number of Samples	Header of the samples
20230914-Bw-Dome1.csv	Time of sample	16	Minute
20230914-Bw-Dome1.csv	Bandwidth usage download	16	Download (kbps)
20230914-Bw-Dome1.csv	Bandwidth usage upload	16	Upload (kbps)
20230914-WANQ-Dome1.csv	Connection Type LTE/5G	339	Type
20230914-WANQ-Dome1.csv	Cell tower ID	339	Cell ID
20230914-WANQ-Dome1.csv	MNO name	339	Carrier
20230914-WANQ-Dome1.csv	Mobile Band	339	Band
20230914-WANQ-Dome1.csv	Signal Latency	339	Latency
20230914-WANQ-Dome1.csv	Sample Time	339	Time
20230914-WANQ-Dome1.csv	GPS location Latitude	339	Latitude

20230914-WANQ-Dome1.csv	GPS location Longitude	339	Longitude
20230914-WANQ-Dome1.csv	GPS location Altitude	339	Altitude
20230914-Bw-Dome2.csv	Time of sample	2	Minute
20230914-Bw-Dome2.csv	Bandwidth usage download	2	Download (kbps)
20230914-Bw-Dome2.csv	Bandwidth usage upload	2	Upload (kbps)
20230914-WANQ-Dome2.csv	Connection Type LTE/5G	158	Type
20230914-WANQ-Dome2.csv	Cell tower ID	158	Cell ID
20230914-WANQ-Dome2.csv	MNO name	158	Carrier
20230914-WANQ-Dome2.csv	Mobile Band	158	Band
20230914-WANQ-Dome2.csv	Signal Latency	158	Latency
20230914-WANQ-Dome2.csv	Sample Time	158	Time
20230914-WANQ-Dome2.csv	GPS location Latitude	158	Latitude
20230914-WANQ-Dome2.csv	GPS location Longitude	158	Longitude
20230914-WANQ-Dome2.csv	GPS location Altitude	158	Altitude

Table of data collected in T1.6

Name of Dataset	Description	Number of Samples	Header of the samples
20230120-Bw.csv	Time of sample	41	Minute
20230120-Bw.csv	Bandwidth usage download	41	Download (kbps)
20230120-Bw.csv	Bandwidth usage upload	41	Upload (kbps)
20230120-WANQ.csv	Connection Type LTE/5G	246	Type
20230120-WANQ.csv	Cell tower ID	246	Cell ID
20230120-WANQ.csv	MNO name	246	Carrier

20230120-WANQ.csv	Mobile Band	246	Band
20230120-WANQ.csv		246	LTE/5G - RSRP
20230120-WANQ.csv		246	LTE/5G - SINR
20230120-WANQ.csv		246	LTE/5G - RSRQ
20230120-WANQ.csv	Signal Latency	246	Latency
20230120-WANQ.csv	Sample Time	246	Time
20230120-WANQ.csv	GPS location Latitude	246	Latitude
20230120-WANQ.csv	GPS location Longitude	246	Longitude
20230120-WANQ.csv	GPS location Altitude	246	Altitude

APPENDIX2

Grant Agreement N°: 952189

Topic: ICT-53-2020

Next generation connectivity for enhanced, safe & efficient transport & logistics

Analysis of Utilizing Customer-Owned Barges: Factors Influencing the Decision and Potential Advantages and Disadvantages

Abstract

Barge teleoperation is one of the main use-cases in 5G-Blueprint project with Seafar leading the charge. Seafar is a highly skilled SME specializing in automated vessel navigation, and their vision is to centralize and optimize the workforce through remote operations. This will enhance the competitiveness of waterborne transport, reduce operational costs by reducing onboard crew, and strengthen the business case for increasing green investments.

Seafar's service is divided into three main parts: equipment installation, vessel operation (updates, and data on the vessel's condition, and navigation analysis), and remote navigation. In the 5G-Blueprint project, Seafar leverages innovative 5G solutions for vessel-to-shore control centre communication, providing a real-world scenario for 5G standalone and non-standalone usage. The customer-owned vessel navigates by remote captain of Seafar in a specific area, highlighting the potential of 5G technology for remote navigation.

Rationale Behind Project

Seafar's investigation of 5G connectivity between vessels and shore control centers has provided them with valuable insights and improvements for future services. Through the lessons learned in this project, it has become clear that 5G communication offers low-latency and higher bandwidth, leading to significant benefits.

Low-latency communication ensures that remote sailing is safer, as it takes less time for the system to transmit the remote captain's decisions to the vessel. This ensures that any commands issued are executed more quickly, minimizing the risk of accidents or delays. Higher bandwidth communication also provides the opportunity to transmit more data from the vessel's surroundings to the shore control center, enhancing situational awareness for the captain and crew. With more comprehensive data available, the captain can make more accurate decisions, leading to safer and more efficient navigation.

Overall, Seafar's use of 5G technology in this project has highlighted the significant benefits of this communication standard for vessel navigation and control, providing a valuable case study for the wider industry. However, there are two primary challenges when testing 5G connectivity throughout a vessel's trajectory. The first challenge is network coverage, as the coverage area is only a small part of the vessel's overall navigation route. The second challenge is the impact of market conditions on the vessel's trajectory, which will be explained further in the following section.

Reasons Affecting the Vessel Navigation Trajectory

The trajectory of a vessel is determined by its owner, based on the destination and cargo being transported. Market conditions play a significant role in shaping this trajectory. For instance, the availability of cargo for delivery to a specific destination can greatly influence the vessel's route. At times, there may be ample cargo available for transportation to a particular location, while at other times there may be insufficient demand to justify navigating the vessel to that destination. Ultimately, the decision of which route to take is based on a careful consideration of market conditions, cargo availability, and other relevant factors, and is subject to change as circumstances evolve.

One possible idea to overcome this challenge for R&D projects is to have a self-owned barge by Seafar. And the other possible idea is to ask the vessel owner to navigate in a specific area for R&D project purposes. However, barge ownership or intervening in the barge trajectory come with a lot of cost and additional challenges which are mentioned in the next section.

Cost-Benefit Analysis of Owning a Vessel for R&D Projects

Seafar's services, as mentioned previously, take the form of remote navigation and one-off installations of equipment. However, owning or running self-owned vessels is not in Seafar's roadmap. The cost of the barges that Seafar navigates is enormously high. For instance, the cost of a second-hand model of the barge used for part of the data collection in this project was 2.5 million EUR two years ago, while other barges that Seafar is sailing at the moment cost between 3 to 7 million EUR.

Furthermore, the barge itself is not the only cost involved. The following costs should be also considered:

- Monthly navigation costs between 15k~20k EUR
- Fuel costs
- Laying the vessel up in the docking area for the time not being used
- Onboard crew costs
- Vessel insurance (in addition to Seafar technology, equipment and remote operation insurance)
- Maintenance costs
- Barge ownership management

Thus, if we want to intervene in the trajectory and timeline of the customer-owned vessel navigation for R&D purposes, we have to pay all of the above costs to the vessel owner. Additionally, it is important to note that the vessel owner might earn about 10k profit each day by navigation of the vessel for delivering cargo. In case of navigation in another specific route only for Seafar R&D project purposes, we are obliged to pay the loss of profit to the vessel owner.

It is also worth mentioning that if we want to consider a very small barge just to test innovative activities, the cost would be a minimum of between 150k~200k only for the vessel. The costs of insurance, laying the vessel up/moore the vessel in a docking area, running, and maintenance will be added to this price. These significant costs and efforts required just to own a vessel for innovations are beyond Seafar's scope, which is focused on innovative technologies utilized in a real-world scenario for barge-shore communication and teleoperation.

In addition to all of the above, for the remote sailing of each vessel, there are lots of efforts required to collect agreements from the relevant authorities. Each waterway and each port has its own regulations. To allow Seafar to remotely navigate each vessel, Seafar should provide an adequate report detailing why remote sailing with that specific vessel and in a specific trajectory with reduced crew will be safe. Then the authorities investigate this report and decide whether to provide an exemption from the regulations of normal operation or not. Therefore, the manhours of negotiation and collecting agreements from authorities for additional vessel, will be added to the above costs.

For these reasons, Seafar does not invest in vessel ownership. Seafar places its great focus of research and development on the remote shore control center, the equipment to be installed onboard the customer-owned vessel, and the communication required between the shore control center and the vessel. Seafar concentrates on methodologies involved in sensing the environment around the vessel and transferring this information to the captain onshore for situational awareness as well as sending commands from the remote captain to the vessel in the waterway fast and accurately.