ARESIBO

HORIZON 2020

D3.1 A stable and reliable network for border security operations

ARESIBO

Augmented Reality Enriched Situation awareness for Border security
ARESIBO – GA 833805

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Abstract: This report presents the network architecture and its main components, as well as the results obtained from system tests performed in the lab and on the field.

Document History

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24/11/20	0.1	**First draft**
01/12/20	0.2	**Added Sections 2.3, 3.3, 4.1, addressed comments**
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Table of Contents

List of Acronyms

Acronym	Meaning
PC	Project Coordinator
D#.#	Deliverable number #.# (D1.1 deliverable 1 of work package 1)
DoA	Description of Action of the project
EC	European Commission
EU	European Union
GA	Grant Agreement
H2020	Horizon 2020 Programme for Research and Innovation
IPR	Intellectual Property Rights
M#	#th month of the project (M1=May 2019)
WP	Work Package
IPR	Intellectual Property Rights
PSC	Project Steering Committee
PIC	Project Implementation Committee
PSB	Project Security Board
AB	Advisory Board
TL	Task Leader
WPL	Work Package Leader
MANET	Mobile Ad Hoc Network
AMR	Adaptive Multi-Rate
AES	Advanced Encryption Standard
MJPEG	Motion Joint Photographic Experts Group
SIMO	Single-Input and Multiple-Output
KaLMA	Ka-band Land Mobile Antenna
UL/DL	Uplink/Downlink

1 Executive summary

This deliverable presents a detailed description of the network architecture and the network security system, as well as an update on Viasat's achievements so far in the ARESIBO project. In addition, it contains a description of the lab and on-field tests performed to evaluate the performance of the proposed network architecture with the obtained results.

The purpose of this document is to provide to ARESIBO a fully described communication system architecture and definition that will serve as a communication platform for field demonstrations. Since this is a task that impacts all the involved partners, it is of great significance for everybody involved in the project to understand the capabilities and limitations of the communication system.

1.1 Scope

The scope of this deliverable covers:

- Network architecture presentation
- Network functional description
- Network test results
- Security architecture presentation
- Security functional description
- Security Test Results
- Satellite communications mobile antenna architecture presentation
- Satellite communications mobile antenna test results
- Satellite communications nomadic antenna presentation
- Last mile technology presentation
- Last mile technology test results

2 User requirements

This section presents the user requirements for the on-field demonstrations obtained during several technical discussions with some of the end-users. The following subsections present several examples of user requirements.

2.1 Robotnik

- Number of devices: Several UGVs.
- BW needed between UGV and GCS: Managed by the partner
- BW needed between GSC and Viasat Communication Hub:
  - Control messages and teleoperation: 100 KB/s
  - LIDAR: 80 Mbps
  - HD Camera: 2 Mbps
- Protocols: TCP for command and teleoperation, UDP for sensor streaming.
- Distance between UGV and GCS: Managed by the partner
- Distance between GCS and the Viasat Communication Hub: depends on the demonstration ground ensuring LOS with the UGV.
- Latency: less than 1 sec
- LOS / NLOS: UGV may lose line of sight

2.2 Tekever

- Number of devices: One UAV
- BW needed between UGV and GCS: Managed by the partner
- BW needed between GSC and Viasat Communication Hub:
  - HD Camera: 2 Mbps (up to 4 Mbps)
  - LIDAR: 80 Mbps
  - HD Camera: 2 Mbps
- Protocols: TCP for command and teleoperation, UDP for sensor streaming.
- Distance between UGV and GCS: Managed by the partner
- Distance between GCS and the Viasat Communication Hub: depends on the demonstration ground ensuring LOS with the UGV.
- Latency: less than 1 sec
- LOS / NLOS: LOS

2.3 CERTH

- Activity: Video stream processing for object detection
- Number of devices: No on-field devices
- BW needed between UGV and GCS: Managed by the partner
- Bandwidth: CERTH needs to get several 720p video streams at the same time so that implies approximately 4 Mbps.
- Protocols: Preference for RTP type video stream protocols / based both on UDP/TCP - maybe UDP for faster delivery of data
- Video stream resolution: >= 720p (HD)
- Segmented streaming: If provided

3 Pilot use cases

This subsections presents the four pilot use cases (PUCs) discussed during the meetings held in Gorizia. As explained in Section 6.1, Viasat will deploy a nomadic satellite antenna system) for the on-field demonstrations. This nomadic satellite system will have the same functionalities as the communication hub and will be deployed at the location of the GCS in the pilot use cases. Therefore, in the diagrams presented in Figure 1, Figure 2, Figure 3 and Figure 4 the nomadic antenna system has the role of a communication hub GCS and is collocated with the GCS. The links contained in the legend framed in red are provided by Viasat.

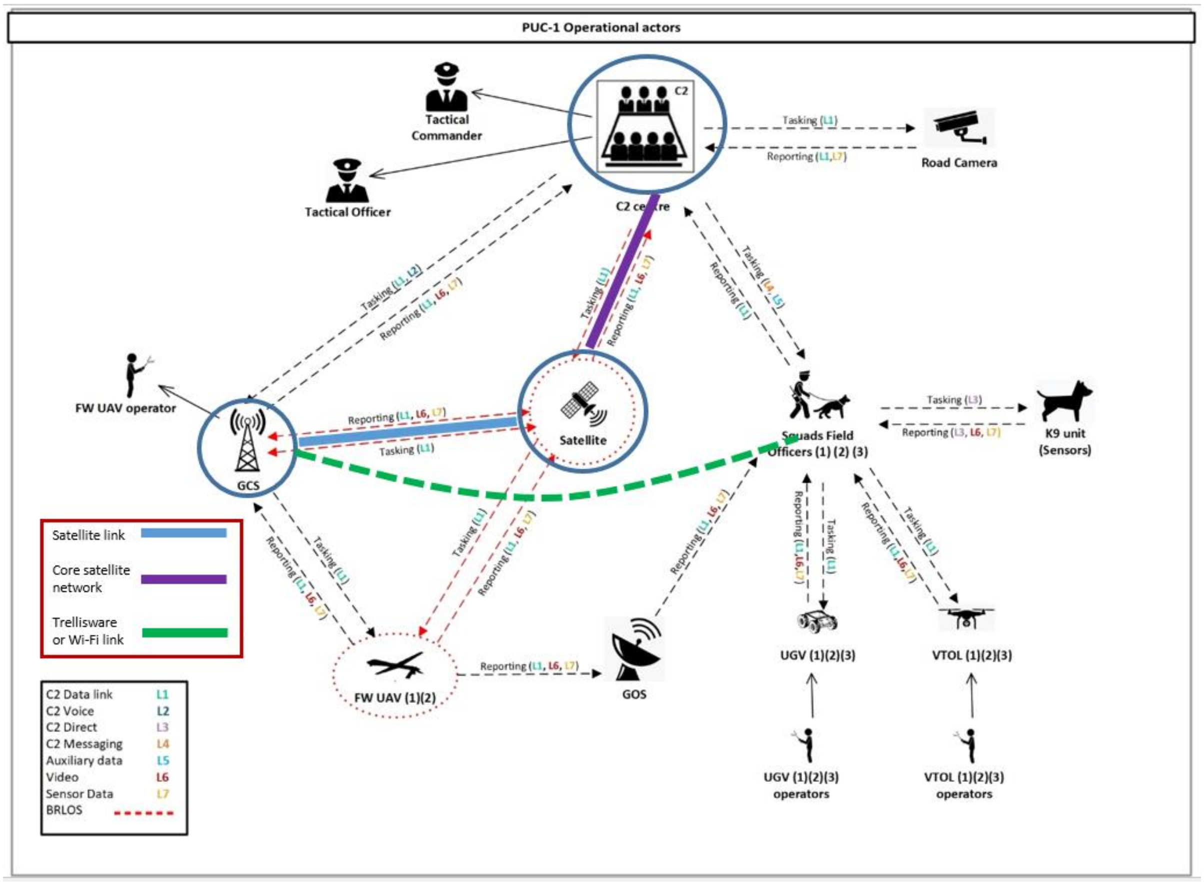


Figure 1 - Links provided by Viasat for PUC 1

The diagram for PUC 1 where the communication hub (Viasat land vehicle) is deployed instead of the nomadic antenna system is shown in Figure 5. This diagram corresponds to the PUC 1 shown in Fig with the only difference being that the nomadic antenna system is replaced by the communication hub (Viasat land vehicle).

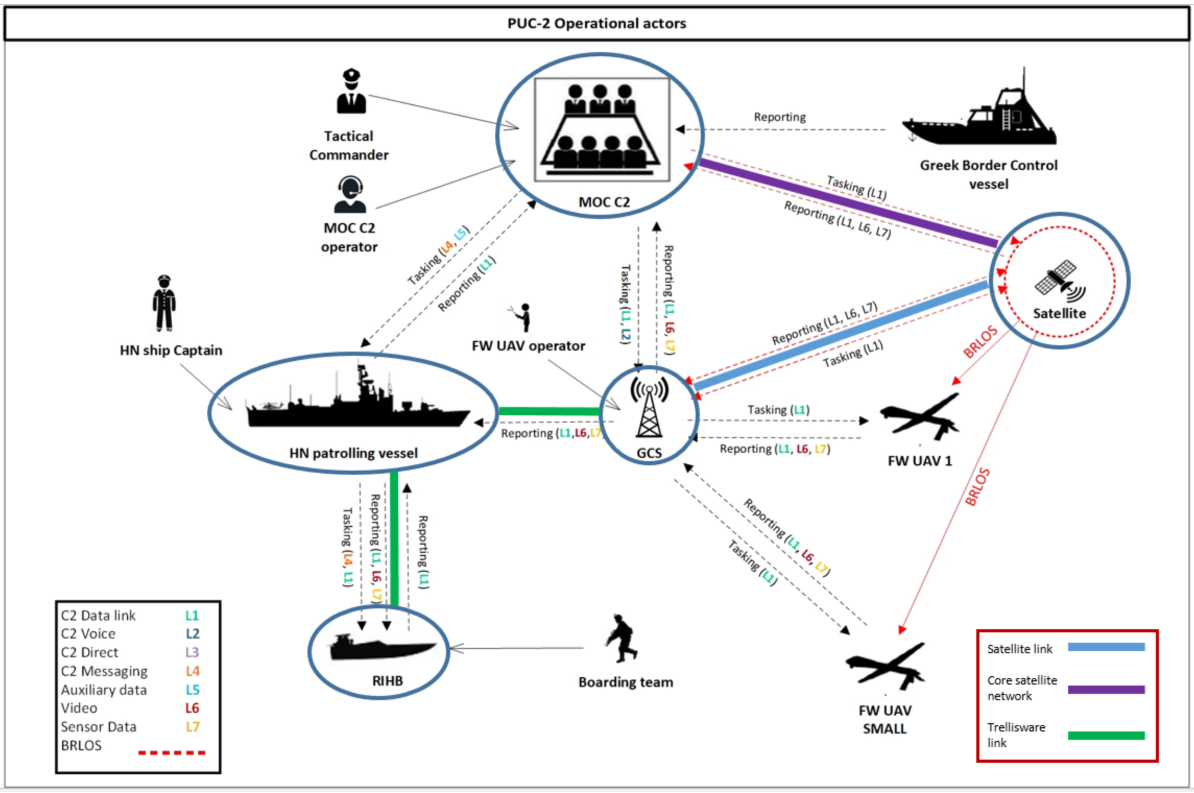


Figure 2 - Links provided by Viasat for PUC 2

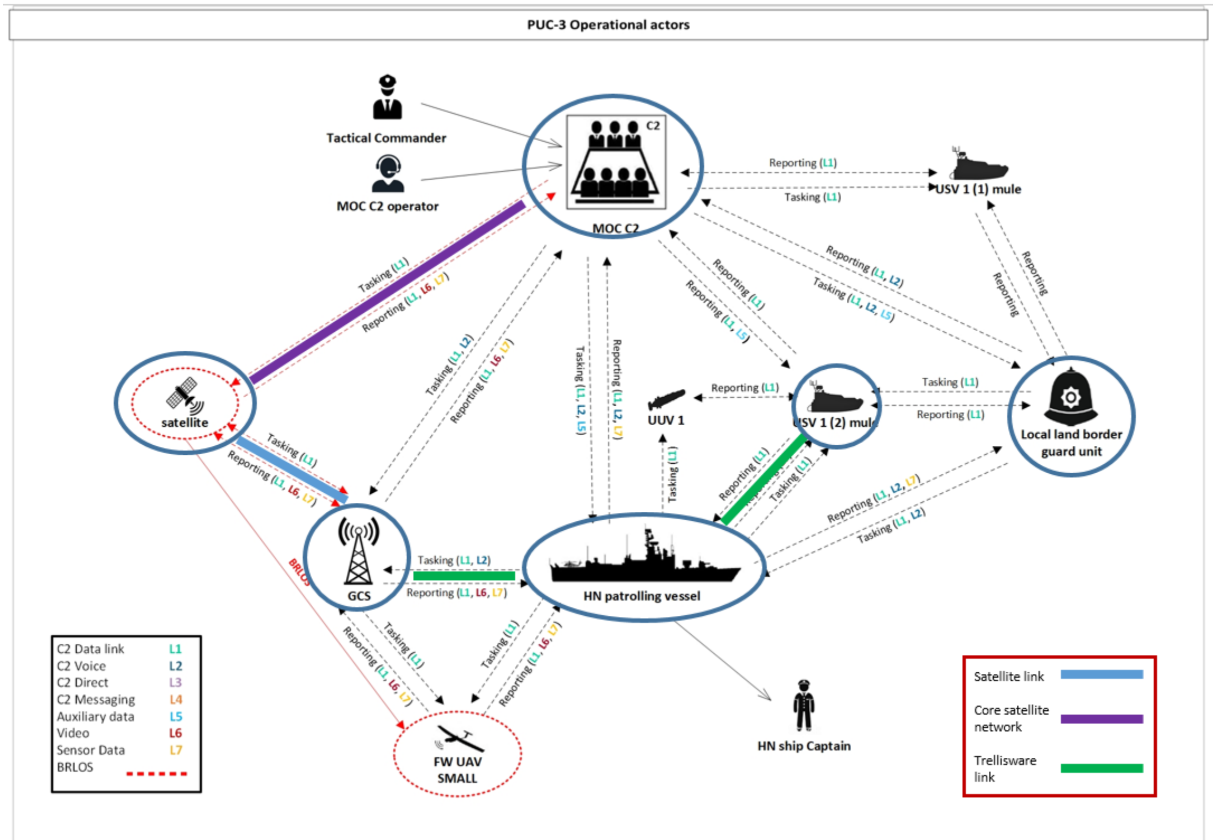


Figure 3 - Links provided by Viasat for PUC 3

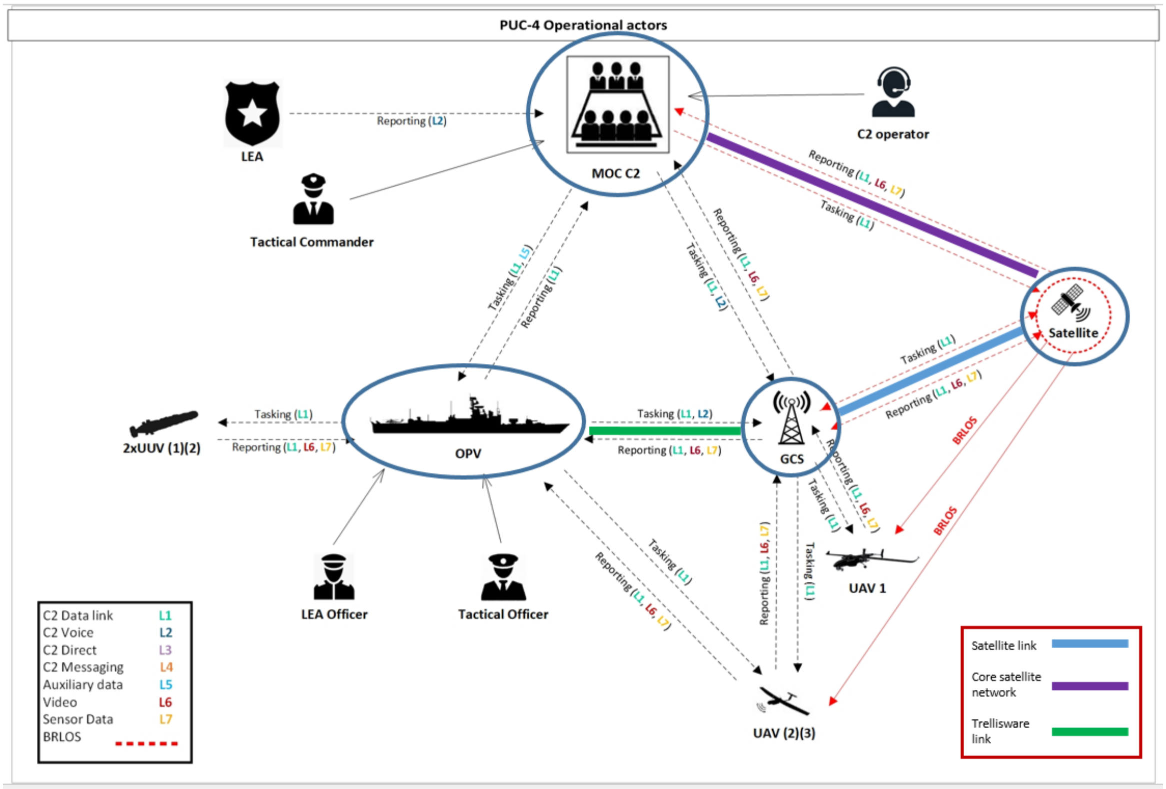


Figure 4 - Links provided by Viasat for PUC 4

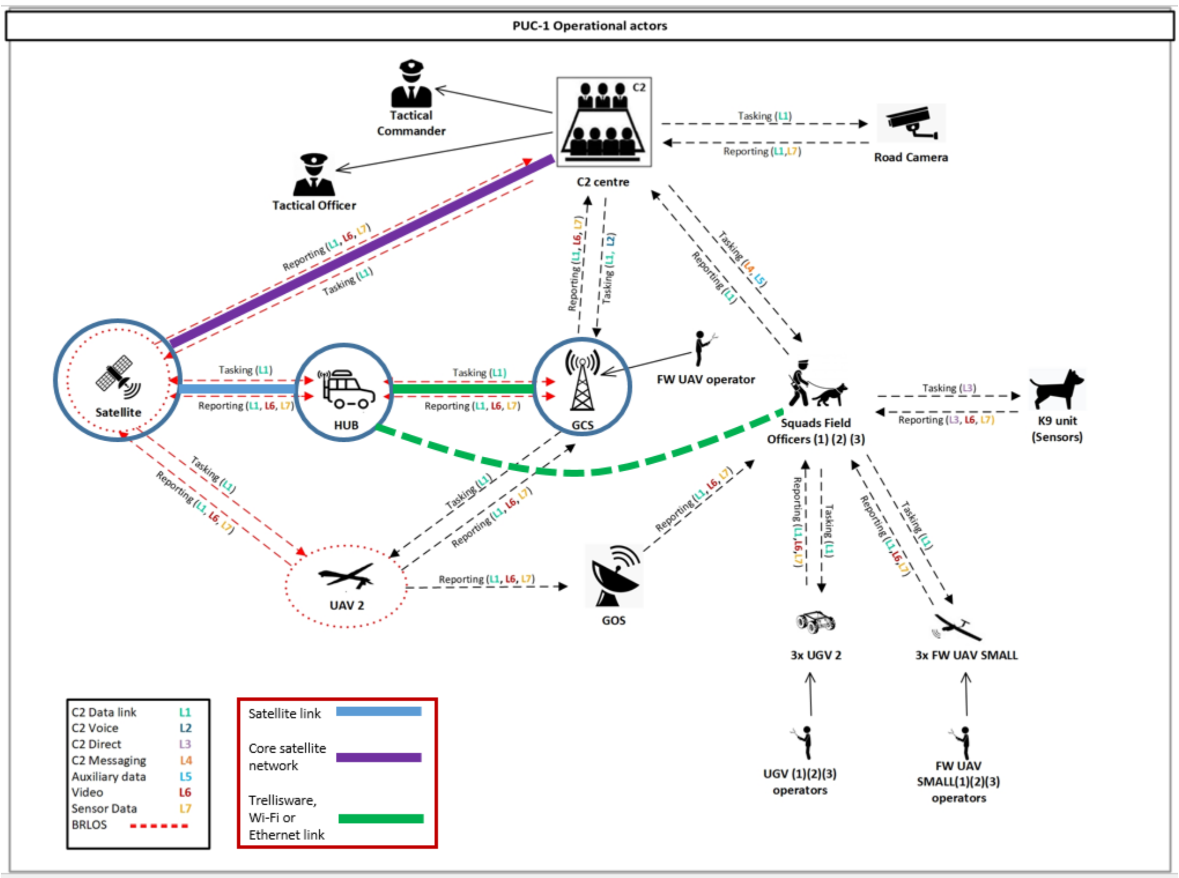


Figure 5 - Links provided by Viasat for PUC 1 with communication hub

4 ARESIBO network architecture description

One of the main goals of ARESIBO is to establish reliable and secure connectivity between the field units, field commanders (operational level) and the C2 centres (tactical level). The overall ARESIBO communication solution is based on a secure hybrid network approach that will provide high availability in remote areas outside of the coverage area of traditional communication networks or areas where these networks have been disrupted due to an emergency. The hybrid network will provide the necessary availability and data rates within the latency constraints in order to support the large set of interactions and augmented reality applications between the field units and C2 centres in time-critical missions.

4.1 Network architecture description

This section presents a detailed description of the ARESIBO network architecture with Figure 6 presenting a high-level overview of the three main segments:

- **Radio network** presents the last-mile network that connects the field units and UxVs to the communication hub.
- **Communication hub** is the land vehicle that acts as the backhaul to the radio network, i.e. the communication node which connects the radio network to the C2 centre. The goal of this nomadic communication hub is to provide network coverage to areas where the ordinary land communication systems are not available due to lack of coverage, unreliability or disruption.
- **ARESIBO Command and Control centre** is the entity that has a global view and control of all the components of the ARESIBO project.

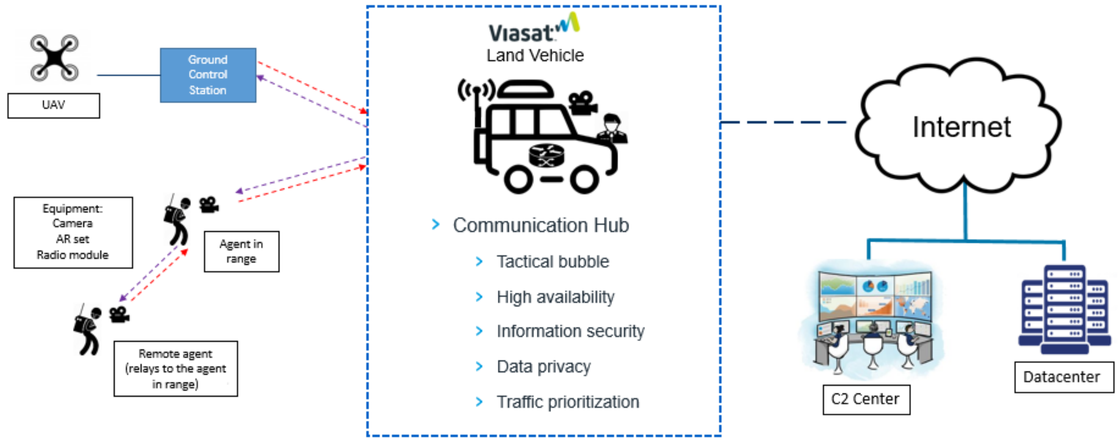


Figure 6 - ARESIBO Network Architecture schema

In the following paragraphs the main components of the ARESIBO network architecture will be described in more details.

4.2 Radio Network

The main goal of the radio network is to provide connectivity to field units (first responders) and UxVs in remote operation areas which are out of coverage of traditional communication networks. Furthermore, this radio network has to provide high range connectivity to stationary and highly mobile units with low latency for time-critical missions.

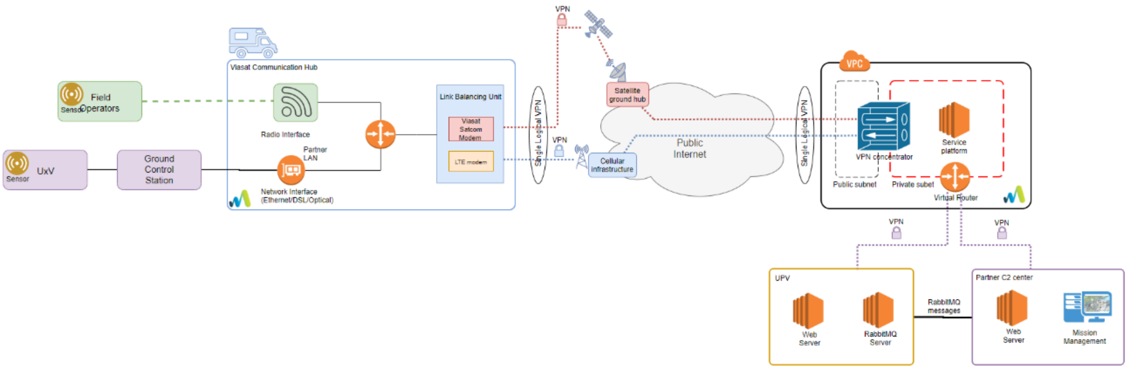


Figure 7 – ARESIBO Detailed network architecture diagram

This can be accomplished by deploying a self-forming/self-healing Mobile Ad Hoc Network (MANET), which provides mission critical video, voice, situational awareness, and data sharing without depending on an established infrastructure. The MANET is established between TrellisWare radios which are available in full-featured handheld (equipped on the first responders) and vehicular configurations, as well as small form factor modules for easy integration into unmanned systems (equipped on the UAVs).

4.2.1 Trellisware MANET

In addition to the audio channels, each radio module supports H.264 video streams with 8 Mbps IP Throughput per channel. Depending on the model of the radio terminal and the resolution of the video streams, the MANET can support multiple video streams simultaneously. Furthermore, the Trellisware radio terminal can act as a relay to other radios in range, thus creating a mesh radio network with a large range (20 km LOS per network Hop). The radio modules (equipped on first responders and UAVs) will send or relay all the data streams to the communication hub where the traffic will be routed to the C2 centre.
The Trellisware tactical mobile ad-hoc network has the following features:

- Not dependent on a fixed infrastructure - no towers needed.
- No central control points, programmed routes or tables, access points, or directional antennas (as needed for cellular or Wi-Fi networks).
- No restrictions on topology.
- No restrictions on the number of radios to host in a single network.
- No special setup required to connect to a computer or existing network.
- Every radio is a receiver, transmitter, and relay – all in one.
- Each radio directly communicates with other radios for all network traffic.
- Reliable communications with low latency and low overhead.

An important feature of the Trellisware MANET is that the entire MANET increases in robustness, area of coverage, and path diversity as more radios are deployed.

Figure 8 - Trellisware MANET in an urban environment

The Trellisware tactical mobile ad-hoc network provides the following advantages:

Network Benefits

- Self-forming, Self-healing - Infrastructure-less Mobile Ad-hoc Networking
- Scalable - Large and small network capability, 200+ node network in actual user deployment
- Fast re-entry - Less than one second
- Transparent IP routing - IP devices are plug and play

Services of Network

- Voice, Data, PLI - Simultaneous voice, IP data, GPS, gateway, video encoding, external devices
- Cellular quality voice - 12 channels, AMR5.9 (GSM), or MELPe
- Video - Capable of multiple simultaneous video streaming (H.264, MJPEG)
- Data rate - 8 Mbps IP throughput
- Multi-hop - Up to 8 hops
- Mobility - Instantaneous network anywhere at any time - (vehicle to
- ground to air)
- Harsh RF Environments - Urban, ship, building, tunnels, etc.

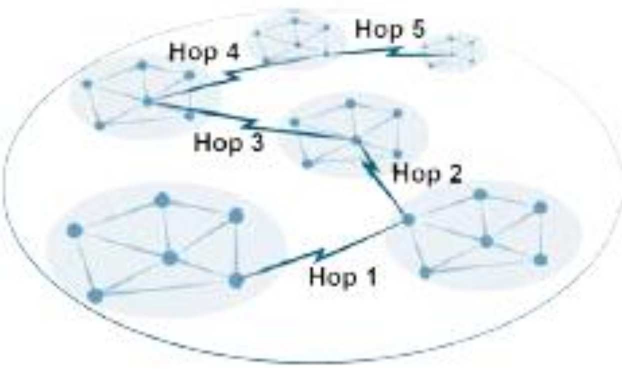


Figure 9 - Trellisware MANET with multiple hops

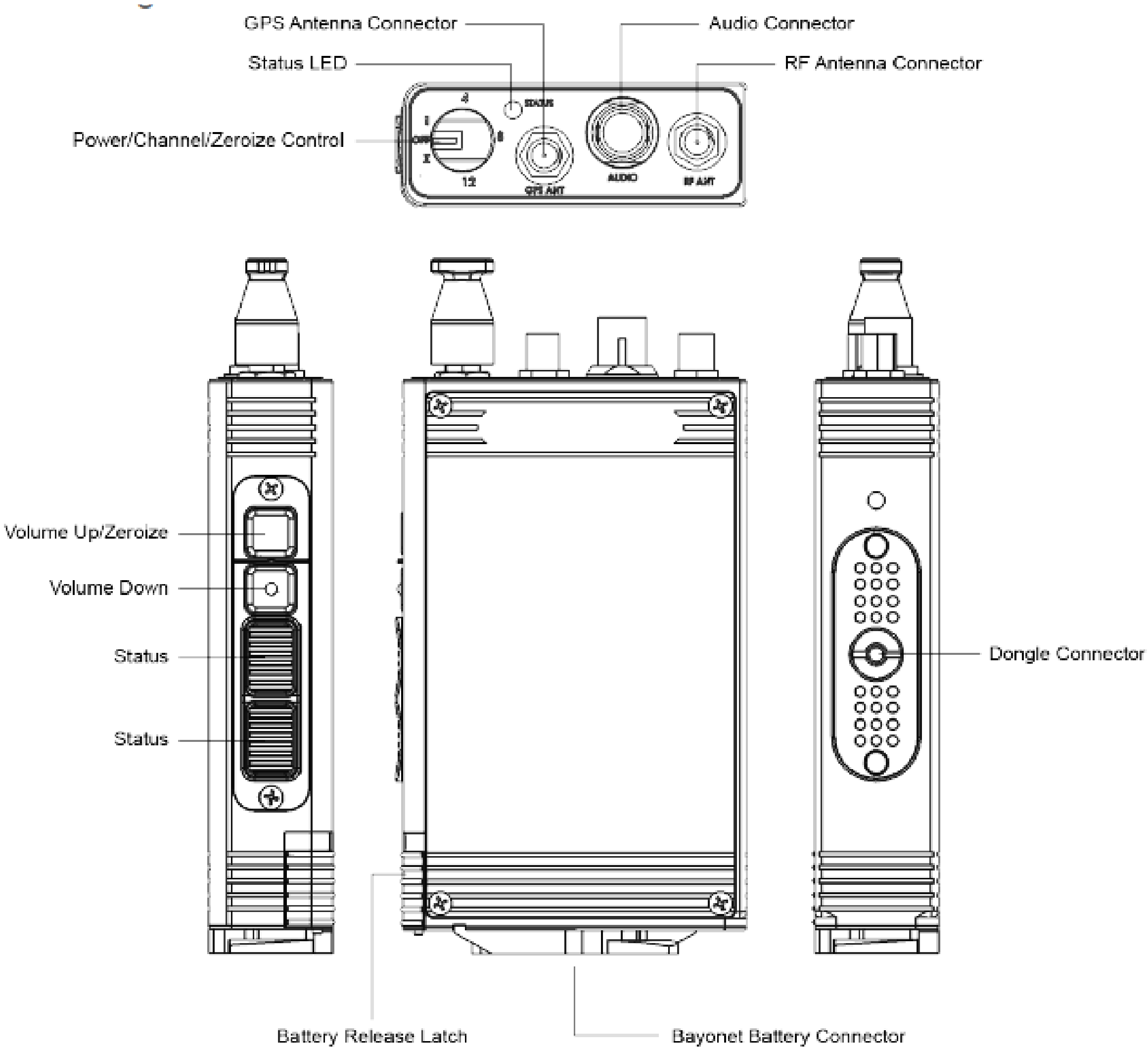


Figure 10 - Trellisware Cub diagram

The radio terminal used in the ARESIBO project is the Trellisware “Cub” with the functional diagram and specifications shown in Figure 10 and Figure 11 respectively.

Features	Specifications
Transmit Power	2 Watt peak
Frequency Range	1775-1815 MHz, 2200-2250 MHz
Hop Reach	26 miles per hop (up to 8 hops)
Security	AES-256, remote disable, RSA-2048 and SHA-256 authentication
Size (w/o accessories)	4"(H) x 2.5" (W) x 0.9" (D)
Weight	10 oz (R/T only)
Throughput	Up to 8 Mbps
Environmental Compliance	MIL-STD-810F with 2 meter immersion (R/T)
Host Interface	Ethernet, USB, Wi-Fi, BNC analog video, trigger-in/out, power out
Connectors	LEMO audio, SMA RF and GPS antennas, 24-pin for dongles
Input Power	12-16 V DC
Video/Audio Encoding	MJPEG or H.264 video, AAC audio, AMR 5.9 or MELPe for PTT voice
Audio Channels (and latency)	Up to 12 independent channels (3 hop <250 ms, 8 hop <400 ms)
Net Entry Time	Less than 1 second
Battery Life/Power Conservation	1+ week continuous idle, 30+ days Wake on Wireless, 10+ months Wake on Trigger (on dual BA 5590's)
Occupied Bandwidth	20 MHz, tunable down to 4 MHz
IP Support	Unicast, multicast, broadcast

Figure 11 - Trellisware Cub specifications

Figure 12 - Trellisware Cub radio terminal

4.3 Communication Hub

This section describes each of the components of the communication hub and their functionalities in the setup. The detailed diagram of the setup inside the communication hub is illustrated in Figure 13. The communication hub connects the radio network to the C2 centre by using two different networks: LTE network and satellite network. This allows the communication hub to use the LTE network with low latency when the vehicle is in LTE coverage area and switch to using the Viasat satellite network in cases when there is no LTE coverage, which is very common for the use cases in the ARESIBO project. This will ensure high reliability and availability even in rough terrains and changing conditions. The components in the communication hub are described in the following subsections.

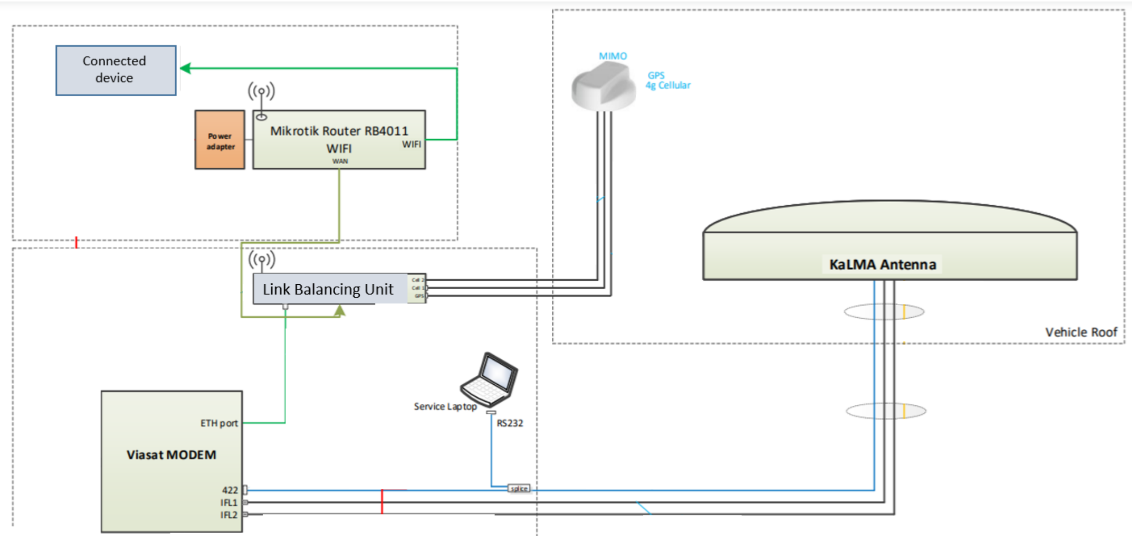


Figure 13 - Communication hub diagram

4.3.1 Network Camera

The camera mounted on the vehicle is an IP surveillance camera – "AXIS Q6215-LE PTZ" which is robust network camera specially designed with high precision pan, tilt and zoom and long-range IR to cover wide and long-distance surveillance. The camera can recognise and identify objects in large open areas even in poor light or complete darkness which makes it very useful for the use cases covered in ARESIBO.

The real time video stream from the camera can be played by accessing the Axis web interface with HTTP through the IP address of the camera. The user can modify all the parameters of the camera and configure the RTSP stream on the camera such that it can be played by any video player hosted on a device which has access to the camera's subnet.

Figure 14 - AXIS Q6215-LE PTZ network camera

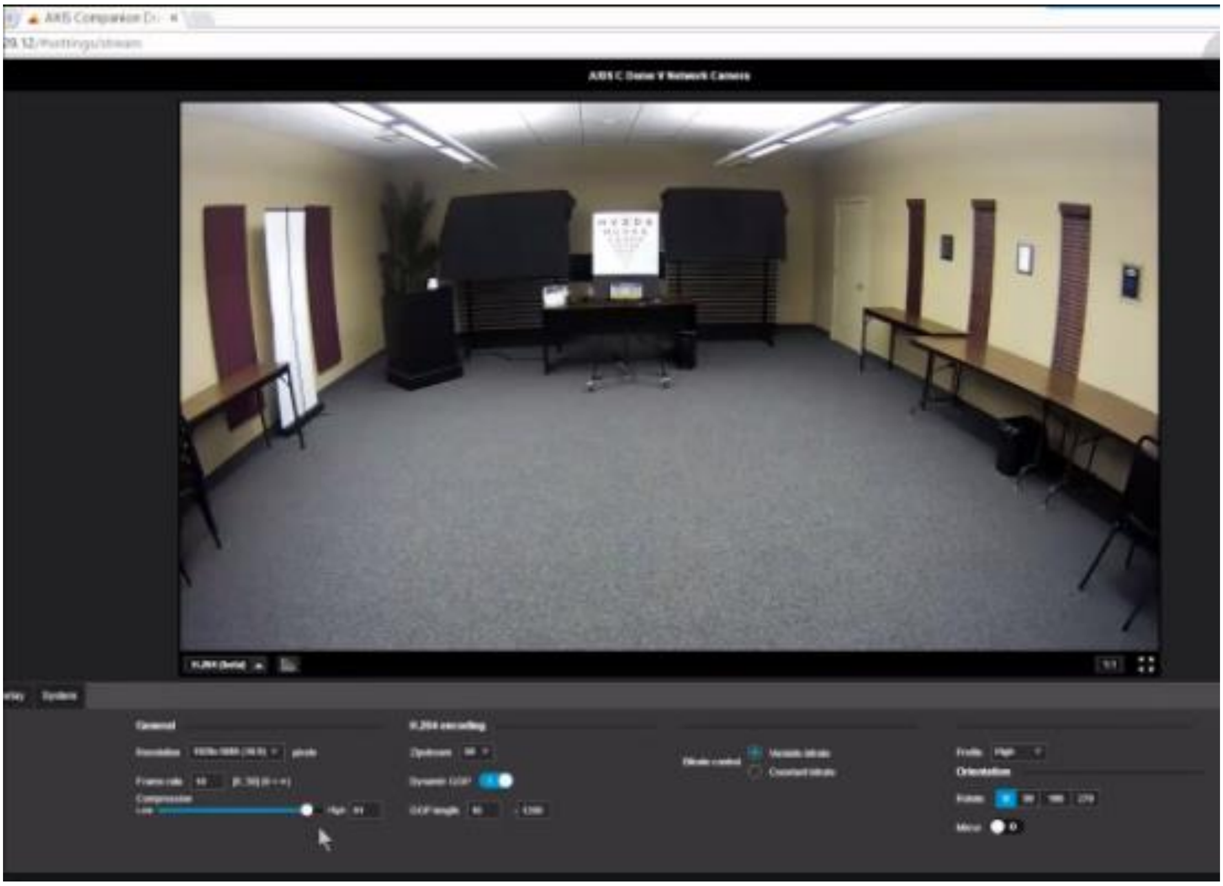


Figure 15 - Axis web interface

Figure 16 - Axis network camera mounted on the communication hub

4.3.2 MikroTik RB4011 router

The MikroTik RB4011 router is used in the communication hub to interconnect all the devices. In addition, it provides Wi-Fi connectivity to users and devices located in a close proximity to the communication hub. The router and its detailed schema are illustrated in Figure 17.

Figure 17 - MikroTik RB4011 router

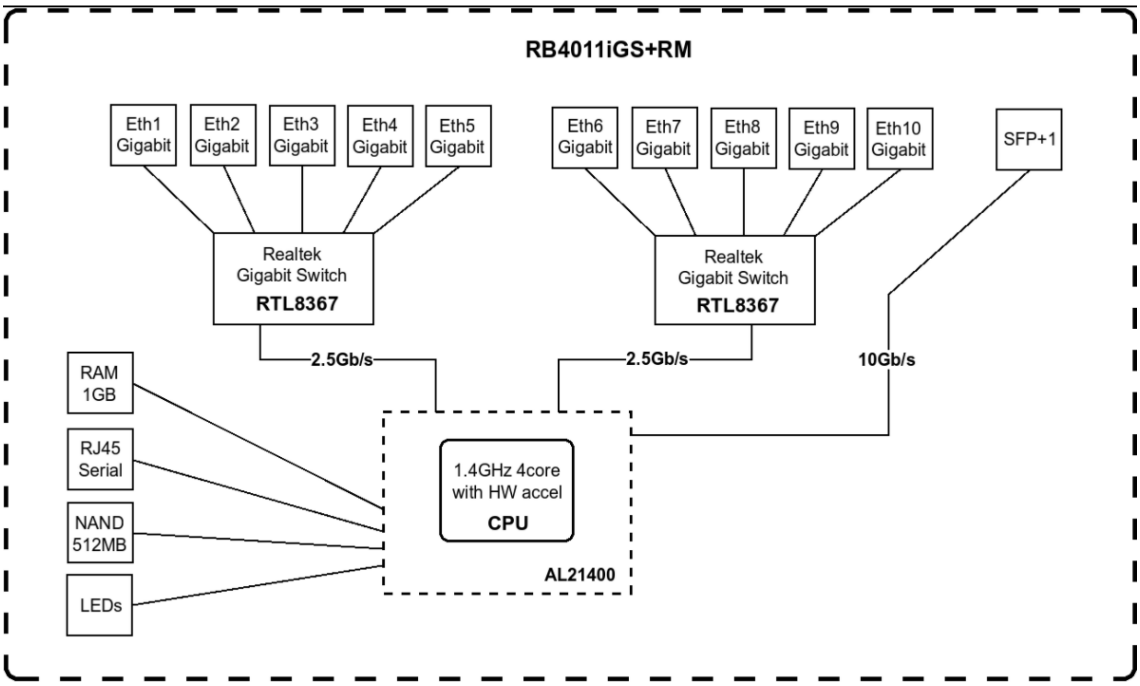


Figure 18 - MikroTik RB4011 schema

4.3.3 Link balancing unit

The link balancing unit has the functionality of utilizing several links to connect the on-field agents and the C2 centre. In the current setup, the link balancing unit utilizes two backhaul links (satellite and LTE). In order to ensure reliability and availability in different network scenarios, two separate VPN tunnels (one over LTE and the other over the satellite link) are established between the Link Balancing Unit on-board the Viasat communication hub (vehicle) and the VPN concentrator hosted in a virtual private cloud which terminates the VPN tunnels. The Link Balancing Unit and VPN concentrator manage the VPN tunnels to provide Active/Standby failover between the two links (LTE and satellite). The VPN tunnels act as a single logical VPN tunnel by performing packet-based fail-over between the links.

Figure 19 - Link Balancing Unit

The communication hub can establish the satellite link by utilizing the self-pointing Viasat “KaLMA” satellite antenna or the Dawson “Dawson SC Zero 70 KA-SAT” fully automated system.

4.3.4 Dawson satellite antenna system

The Dawson SC Antenna is a fully automatic flyaway antenna system that operates on the satellite Eutelsat KA-SAT as well as other Viasat networks around the world.
Figure 21 presents the system in a lab setting and is used solely for illustration purpose (the system shown in the figure is not powered on). The full system specifications are presented in Figure 22. Dawson produces in partnership with Viasat Inc. a set of auto pointing antennas for outdoor nomadic applications.

These antennas come on two different setups:

1. Vehicle mounted, equipped with all the necessary kit to be setup on top of a van or any other capable vehicle. It has advanced stowing capacities to reduce the stow size and reduce aerodynamic drag.

2. Ground based, with appropriate tripod for field deployment, this antenna can be disassembled in parts and can be carried in appropriate flight cases for remote site setup.

This antenna set, also, can be accompanied by an appropriate energy module able to provide electrical power in quantity sufficient for 24h operations on locations where no other source is available.

The antenna pointing system is able to discover the given satellite position dialoguing directly with the SATCOM modem and getting the relative information from the standard “satinfo” file available on the modem file system.

Figure 20 - Dawson antenna system deployed in the EMSA project

The antenna control unit is able to dialogue with both the TRIA module and the modem to ensure correct pointing and beam selection, plus is able to keep memory of the latest position where the satellite had been fund in order to speed up the antenna pointing in case the vehicle/field of operation had not been moved. (E.g: multi day operation with overnight stowing) Some application for this antenna:

- Provide field internet connectivity to a mobile pilot station to operate an UAV from a remote and unconnected field. (Project “Viadrone”).
- Provide connectivity to an emergency deployed control station to operate “on field” remote sensor image treatment to prevent pollution in the Mediterranean Sea caused by illegal oil tanker spill (Project EMSA shown in Figure 20).

Figure 21 - Dawson SC Zero 70 KA-SAT antenna system in the Viasat lab (powered off)

Section	Item	Specification
Power requirement	Prime power Power consumption	220 V AC (12 V DC optional) Approximately 100W
Physical	Antenna box Equipment box Positioner box	850 H x 820 W x 180 D (mm) Wt 14 Kg 240 H x 560 W x 620 L (mm) Wt 19 Kg 410 H x 360 W x 1120 L (mm) Wt 34 Kg
Operation	Set up / Pointing time Pointing system	<4 minute typical Fully automatic Manual over ride and emergency stow
Environmental	Temperature (use) Wind speed Rain	Minus 40 to Plus 60 C 70 Kph use 160 Kph stow (with ballast) Fully waterproof in use
Construction	Antenna system Reflector Base	Aluminium and stainless steel ViaSat OEM part Stainless steel tripod
Positioner	Elevation range Azimuth range Polarisation range	10 - 90 Degrees fully motorised 200 degrees +/- fully motorised Automatic switching of polarity
Performance	BUC size Data rate TX Data rate RX	Standard ViaSat E TRIA KA-SAT services supported KA-SAT services supported
RF	Antenna	Eutelsat KaSat
	Frequency	KaBand
	Compatibility	Eutelsat KA-SAT
	Antenna size Feed	75 cm nominal Circular Polarised KaBand

Figure 22 - Dawson SC Zero 70 KA-SAT technical specifications

4.3.5 KaLMA satellite antenna

The KaLMA antenna is a self-pointing Ka-band satellite antenna mounted on the communication hub (Viasat Land Vehicle). This antenna is used to establish a link to the satellite, thus creating the backhaul link through the Viasat core satellite network.

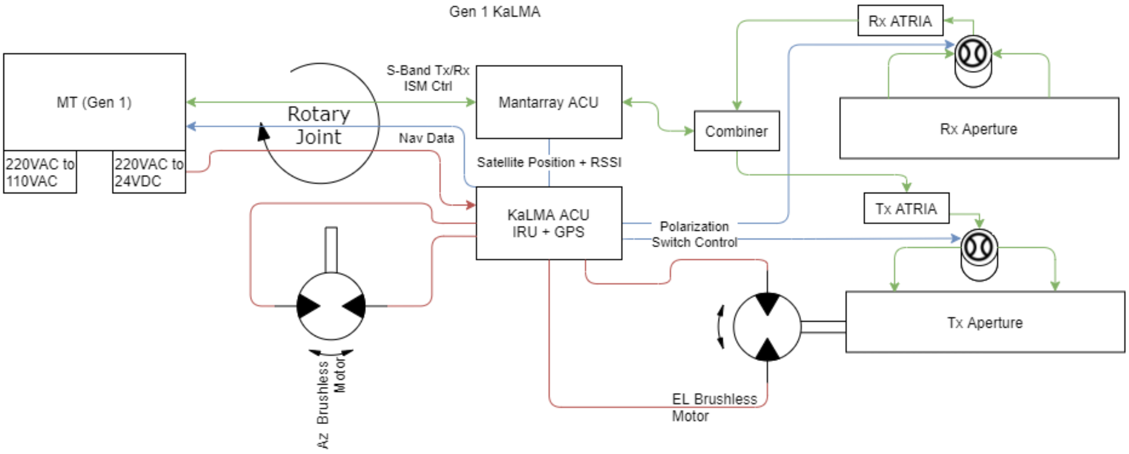


Figure 23 - Architecture diagram of the KaLMA antenna

Figure 24 - KaLMA antenna mounted on the roof of the Viasat Land Vehicle

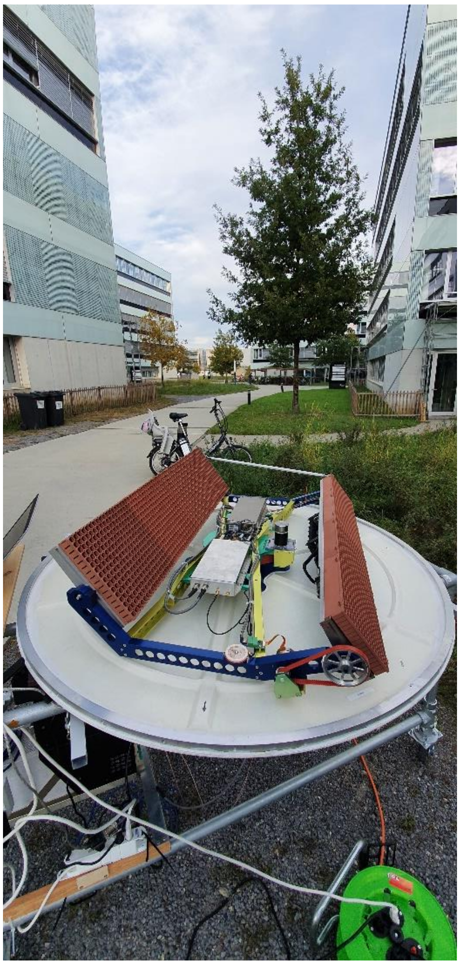


Figure 25 - Testing with the KaLMA antenna

Figure 26 - Viasat mobile terminal (modem) and ACU power source

4.3.6 Panorama MIMO Antenna

The LGMMFFR-7-27 is a high performance MIMO antenna covering 698-2700MHz mounted on the roof of the communication hub (Viasat land vehicle). The LGMMFFR-7-27 consists of up to 5 elements; two isolated high performance antenna elements covering 698-2700MHz offer MIMO/diversity at cellular/LTE frequencies, up to 2 optional dual band elements covering 2.3-2.7 & 4.9-6GHz support MIMO/diversity operation for WIFI and WiMAX and a high performance GPS antenna with an integrated 26dB gain LNA.

Figure 27 - Panorama LGMMFFR-7-27 antenna in the lab

Electrical Data	
LTE Frequencies	698-960/1710-2700MHz
Global Positioning	Optional GPS L1 1575; GPS L1 1575
Wifi Frequencies	MiMo - 2.4/5.0GHz - (Optional)
Peak Gain (dBi)	5
LTE MiMo	2x2
WiFi MiMo	Optional 2x2;
Max Input Power (W)	20
Pattern	Omni-directional
Ground Plane Independent	Yes

Figure 28 - Panorama LGMMFFR-7-27 technical specifications

5 Terminals for the future – phased antenna arrays

The combination of growing number of on-board critical and non-critical connected devices in vehicles is resulting in a strong demand for a resilient broadband on-the-move solution. This demand will just keep growing as investment towards autonomous technologies intensify and adoption rates of automated vehicles spike. That is why it is important to envisage the integration of phased antenna arrays for land mobile application in the future.
Phased antenna arrays have become of high interest in the recent years due to the technology advancement that makes electronic chips needed for their production more affordable. Compared to the currently widely used mechanically steered arrays, phased antenna arrays offer several advantages.
Firstly, due to the purely electronically steering and therefore the lack of the motors used for azimuth and elevation pointing, phased antenna arrays offer significantly better reliability of the service provided. Even if some of the chips are dead, the redundancy and large number of radiating elements make the performance slightly affected but service remains.
Another strong point is significantly reduced thickness of the terminal. The phased antenna arrays can serve in many applications where height of the antenna terminal is critical, for example for installations on top of the vehicles, like busses and trains, and even vans and cars. The flatness of the terminal is highly beneficial for the aerodynamics of the vehicles, no matter if they are moving on the ground, on the water or in the air.

5.1 Phased antenna array architecture

The difference between mechanically and electronically steered arrays is shown via several top-level diagrams below. Namely, the mechanically steered arrays have two apertures (receive and transmit) that are controlled with two motors, one for elevation, the other one for azimuth scanning (as shown in Figure 29**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**). On the contrary, the phased antenna array is fixed flat terminal where all the steering is done through the change of phase and amplitude for each of the radiating elements as seen in Figure 30, Figure 31 and Figure 32.

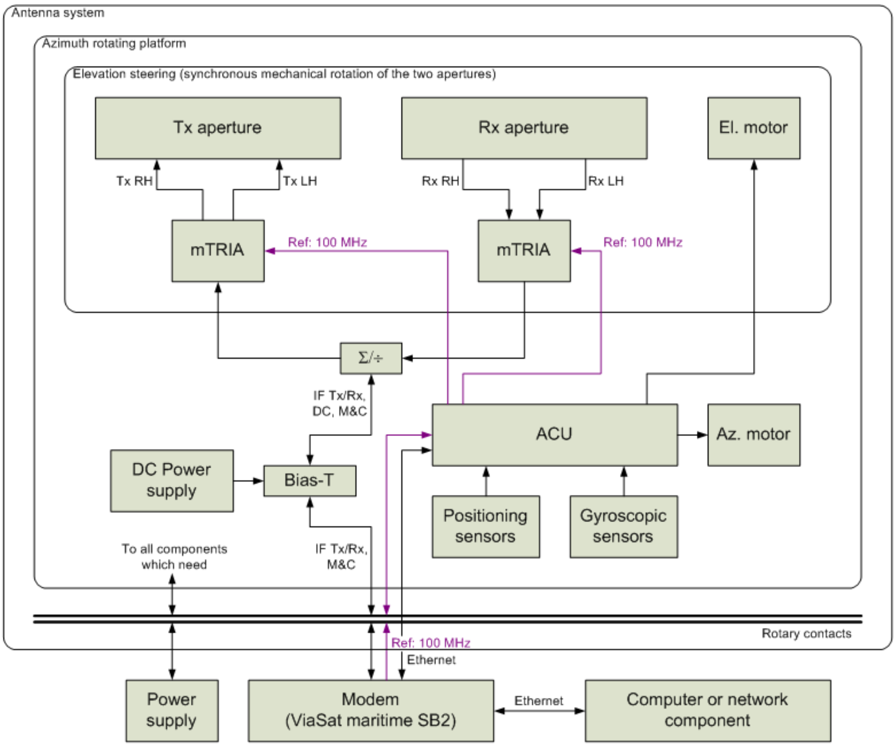


Figure 29 - Current solution: Directive array on mechanical platform - block diagram

In simple words, the phased antenna array terminal is basically made of a Rx and a Tx radiating aperture mounted on a common support, and with independent RF, DC and control interfaces (Figure 30).

A radiating aperture (Figure 31) is a complete Rx or Tx antenna array made of three key building blocks:

- Radiating (functional) tiles, defined by grouping to a single RF, DC, and control input/output.
- Control board, which connects the radiating tiles together, as well as interfacing with the ATRIA and modem.
- Interposer providing electrical interconnections between the tiles and the control board, mechanical support, as well as assisting in the conduction of heat away from critical components (not shown in the block diagram).

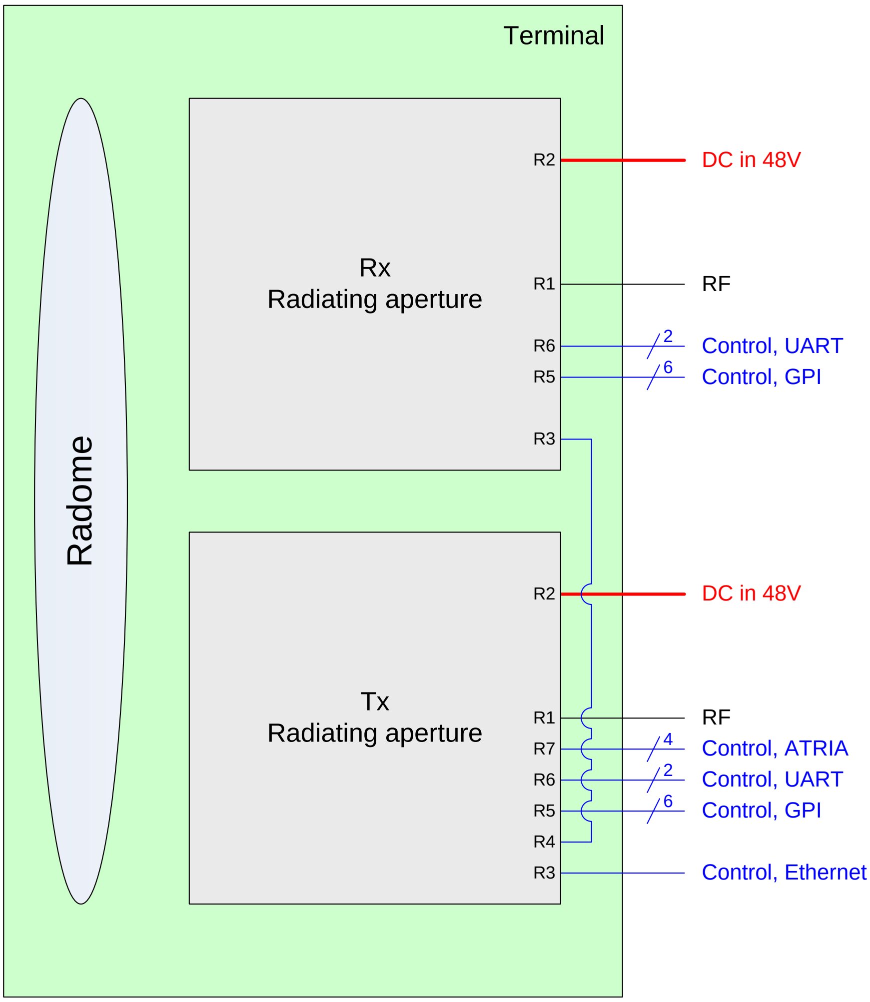


Figure 30 - High level block diagram of the phased array antenna terminal.

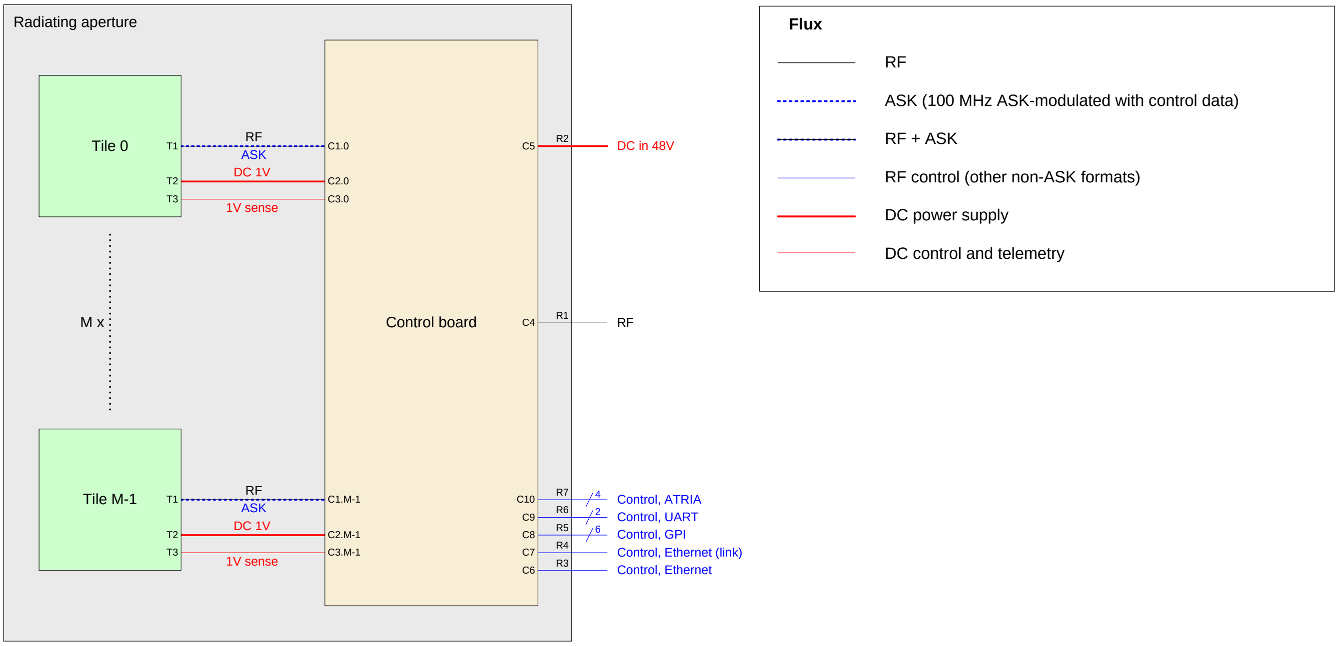


Figure 31 - Block diagram of the radiating apertures for M tiles used. M is defined according to the performance needed.

The control board serves the purpose of electrically combining the radiating tiles, as well as, providing the relevant DC supplies and control sequences. It furthermore interfaces with the remaining system.
This steering unit generates all the needed signals to control the RFICs in the tiles, the RF amplifiers, and the power supplies, from the input commands sent through one of the possible protocols.
The term tile refers to here as functional tile or subarray. The tiles consist of the radiating elements and their associated RFICs, as well as the beam forming network (BFN) upon which is also modulated the 100 MHz control signal. The top-level architecture of both the Rx and Tx tiles are represented by Figure 32.

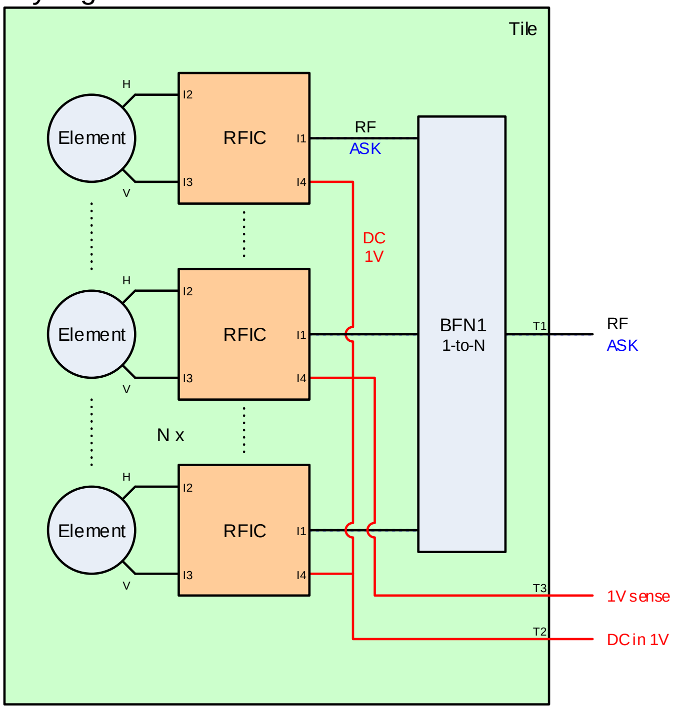


Figure 32 - Block diagram of the functional tile for N numbers of elements

5.2 RFIC development

Each of the elements is controlled through the Radio-Frequency Integrated Circuit (RFIC) that amplifies signal either in receive or in transmit direction and applies the required phase, so that the beam scan can be performed completely electronically. The number of the RFICs used in the antenna is equal to the numbers of antenna elements, and it goes from few hundreds to several thousand depending on the requirements and data rates needed. Even if some percentage of the RFICs dies, the antenna continues to transmit and receive with lightly reduced performances.

The RFIC represented the major cost for the antenna terminal so far. That is why Viasat has developed internally RFIC in Ka band specifically designed to have the optimal size and the performance for its terminals. The RFIC design is done in symbiosis with antenna element and therefore improves the overall efficiency of the array.

The major point is certainly that cost reduction with internally developed chip is significantly lower than what could be achieved with OTS components and it makes the product competitive in the market.

5.3 Modular concept

The main issue when producing the large PCB panels for antenna arrays is the production limitations of the PCB manufacturer. On top of that the board assembly houses have difficulties to assemble large boards especially with dense population of the components like RFICs.

The modular approach we use to overcome this problem assumes many identical smaller PCBs, named tiles which we combine as in one large panel. The distribution of the Rx and Tx tiles for one configuration is shown in Figure 33.

The drawback of this approach is the need for external combination of the RF signal on additional board while minor gaps between the tiles have an influence on the radiation pattern. However, the advantages are mainly in feasible production and high yield. On top of this, the large quantities of the very same radiating tiles can be produced for various applications and different market needs. The change from airborne to maritime or land mobile application would be only in the enclosure and certifications needed for thermal and mechanical requirements, while the core technology remains the same. In Figure 34 different enclosers for different application are shown, from single user small footprint terminals to large arrays for broadband applications.

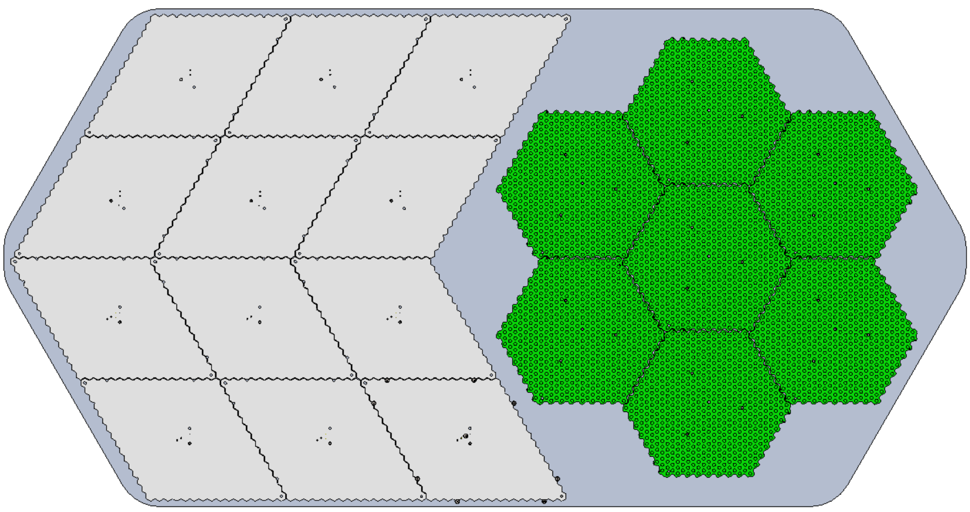


Figure 33 - Rx and Tx radiating tiles distribution

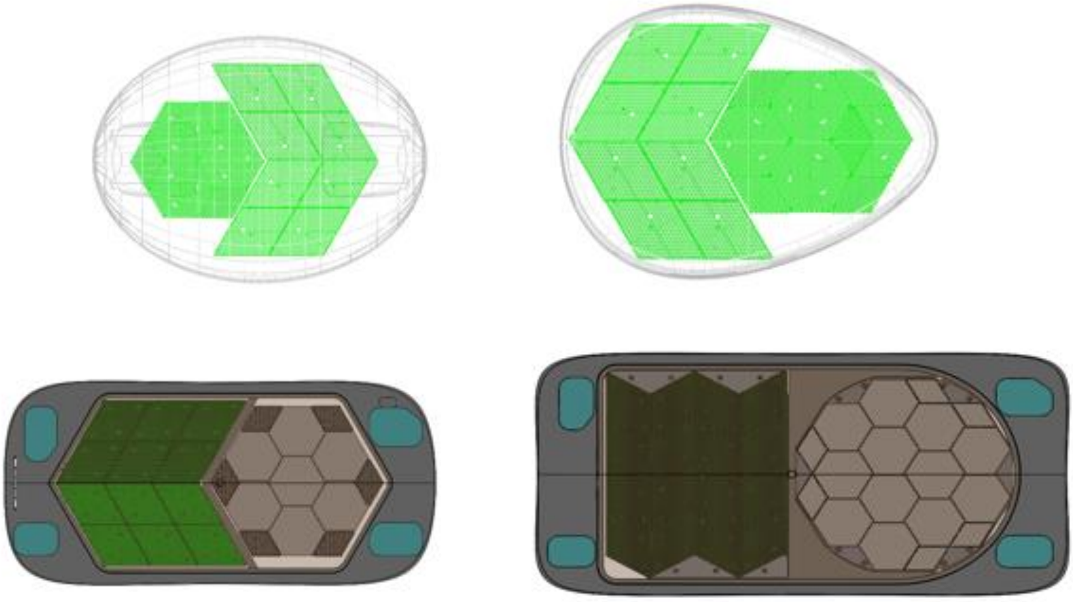


Figure 34 - Modular approach for phased antenna arrays: using the same tiles (hexagonal for Tx and rhomboidal for Rx) to achieve desired size and performance for various markets and applications.

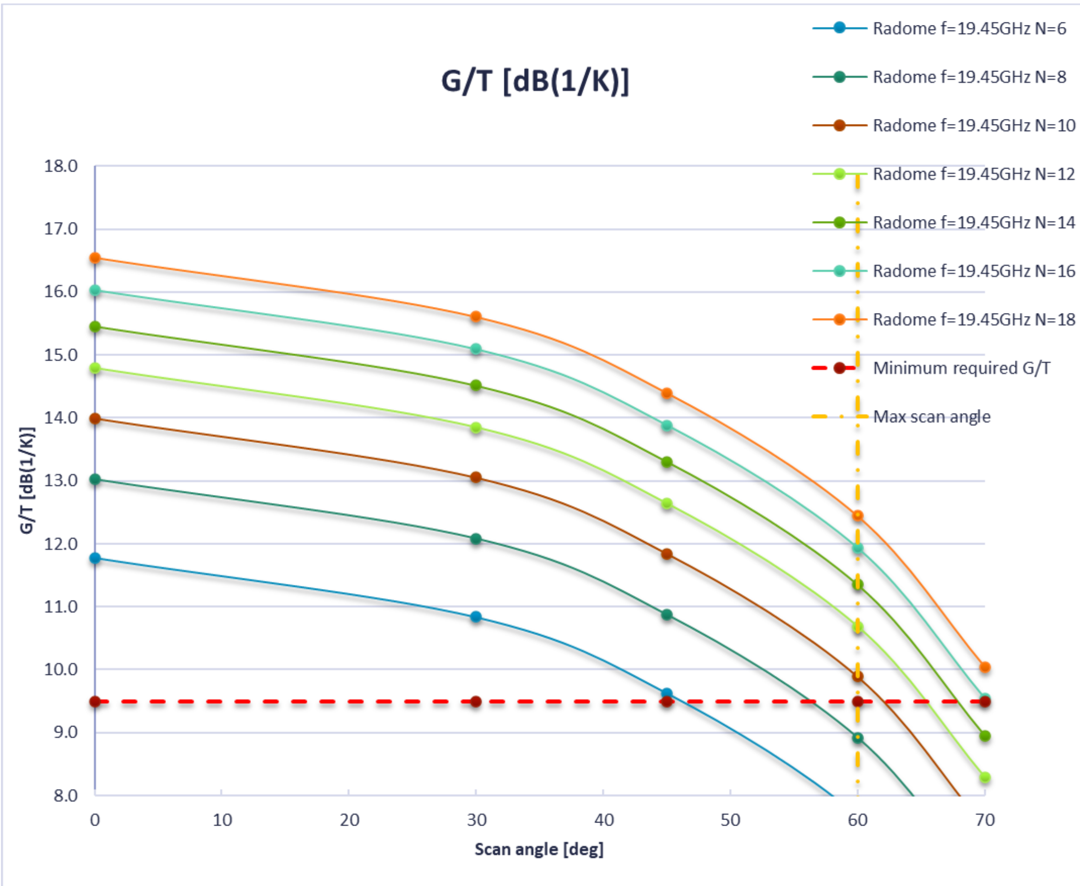


Figure 35 - Receive aperture performance depending on the number of tiles used. In the example given, if we want to have Gain over Temperature at least 9.5dB/K and to be able to scan down to 60 degrees, we need to combine 10 Receive tiles for the antenna.

5.3.1 RF performance for various antenna size

When deciding the size of the aperture needed we can have a look at discrete performance for various number of tiles as shown in the receive aperture example in Figure 35. The performance for central Rx frequency (19.45GHz) for various number of tiles and different scan angles are shown.
For example, we see that if we want to have Gain over Temperature at least 9.5dB/K and to be able to scan to 60 degrees, we need to combine 10 Receive tiles for the antenna. Then, if we want to have more performing terminal we can scale it up or, on the contrary if we want a terminal for single user with low scanning capabilities and lower cost, we can scale it down in size having in mind that link with satellite has to be closed. No matter the configuration, we use the existing tiles and architecture.

5.4 Phased antenna array terminal

In Figure 36 the possible phased antenna array terminal for land mobile application is presented. The tiles for receive and transmit aperture are thin green boards laying on the metallic interposer that serves as a heatsink for thermal dissipation but also for mechanical support. The plastic radome is on the top and aluminum enclosure on bottom and side of the terminal.

Figure 36 - Phased antenna array for land mobile applications - exploded view. The total height of the terminal is below 11cm, but it can go even lower for the future designs.

6 Lab tests

6.1 *Connectivity tests*

Test description

The connectivity between a remote unit and the C2 centre has been tested by establishing a TCP session between a remote unit (Trellisware radio terminal) which will have the role of a client, and a TCP server hosted in an AWS cloud infrastructure which has the role of the C2 centre. The lab tests were performed in the Viasat communications lab in the Lausanne office during the months of April, May and June. The connection is initiated by the client and the exchanged messages can be observed together with the percentage of lost packets and the latency. The same test will be performed using UDP. These tests will be performed for four separate cases:

- **TST_COMS_001_1**: TCP connection between the remote unit and C2 centre using LTE as backhaul.
- **TST_COMS_001_2**: UDP messages between the remote unit and C2 centre using LTE as backhaul.
- **TST_COMS_001_3**: TCP connection between the remote unit and C2 centre using satellite as backhaul.
- **TST_COMS_001_4**: UDP messages between the remote unit and C2 centre using satellite as backhaul.

The detailed setup of the testing scenario is illustrated in Figure 37.

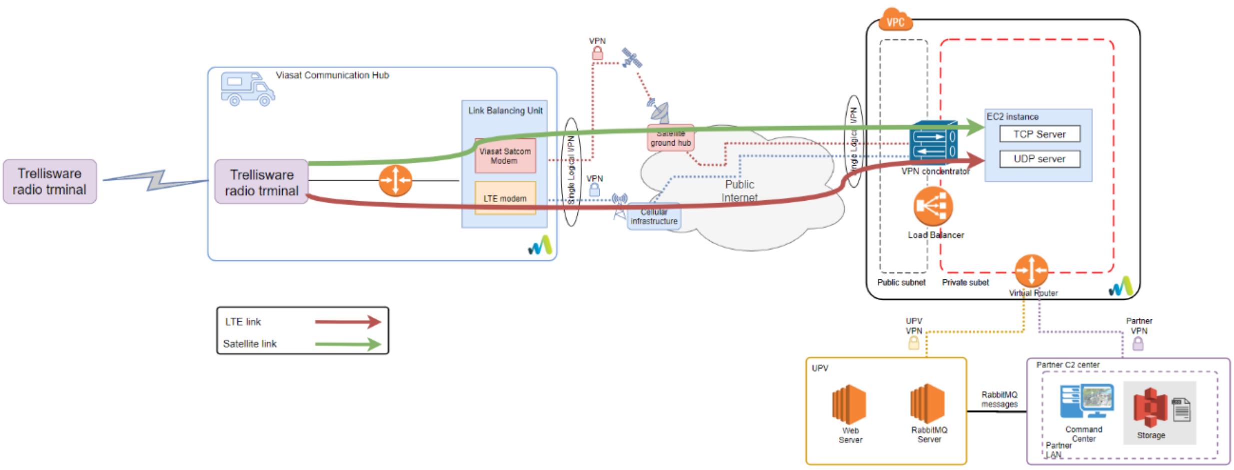


Figure 37 - Diagram for the 'Telecommunication full reachability' tests

6.1.1 TST_COMS_001_1: TCP connection between the remote unit and C2 centre using LTE as backhaul

Test case ID	
TST_COMS_001_1	
Test description	TCP connection between the remote unit and C2 centre using LTE as backhaul.
Test Scenario	
This test is performed to evaluate the connectivity between a remote unit (in this case, a laptop connected to a Trellisware radio terminal) and the C2 centre (EC2 instance hosted in AWS) using LTE as backhaul. The test is performed by pinging the EC2 instance from the remote laptop, as well as starting a TCP client using Iperf on the remote laptop and a TCP server on the EC2 instance using Iperf.	
Test Results	
Latency	Minimum = 19ms, Maximum = 78ms, Average = 32ms
Bandwidth	DL: 19.3 Mbps, UL: 9.2 Mbps

6.1.2 TST_COMS_001_2: UDP messages between the remote unit and C2 centre using LTE as backhaul

Test case ID	
TST_COMS_001_2	
Test description	UDP messages between the remote unit and C2 centre using LTE as backhaul.
Test Scenario	
This test is performed to evaluate the connectivity between a remote unit (in this case, a laptop connected to a Trellisware radio terminal) and the C2 centre (EC2 instance hosted in AWS) using LTE as backhaul. The test is performed by pinging the EC2 instance from the remote laptop, as well as starting a UDP client using Iperf on the remote laptop and a UDP server on the EC2 instance using Iperf.	
Test Results	
Latency	Minimum = 19ms, Maximum = 78ms, Average = 32ms
Bandwidth	DL: 27.3 Mbps, UL: 13.8 Mbps

6.1.3 TST_COMS_001_3: TCP connection between the remote unit and C2 centre using satellite as backhaul

Test case ID	
TST_COMS_001_3	
Test description	TCP connection between the remote unit and C2 centre using satellite as backhaul.
Test Scenario	
This test is performed to evaluate the connectivity between a remote unit (in this case, a laptop connected to a Trellisware radio terminal) and the C2 centre (EC2 instance hosted in AWS) using a satellite network as backhaul. The test is performed by pinging the EC2 instance from the remote laptop, as well as starting a TCP client using Iperf on the remote laptop and a TCP server on the EC2 instance using Iperf	
Test Results	
Latency	Minimum = 617ms, Maximum = 1278ms, Average = 732ms
Throughput	DL: 5.8 Mbps, UL: 3.2 Mbps

6.1.4 **TST_COMS_001_4:** UDP messages between the remote unit and C2 centre using satellite as backhaul

Test case ID	
TST_COMS_001_4	
Test description	UDP messages between the remote unit and C2 centre using satellite as backhaul.
Test Scenario	
This test is performed to evaluate the connectivity between a remote unit (in this case, a laptop connected to a Trellisware radio terminal) and the C2 centre (EC2 instance hosted in AWS) using the satellite network as backhaul. The test is performed by pinging the EC2 instance from the remote laptop, as well as starting a UDP client using Iperf on the remote laptop and a UDP server on the EC2 instance using Iperf.	
Test Results	
Latency	Minimum = 617ms, Maximum = 1278ms, Average = 732ms
Throughput	DL: 9.4 Mbps, UL: 6.2 Mbps

6.2 RT video tests

Test description

The goals of this test is to evaluate the capability of the communication network to transport real time video streams with different video resolutions and how the video continuity, quality and latency is affected by the fail-over between the backhaul links. The video source is the 'AXIS Q6215-LE' IP camera on-board the communication hub (Viasat Land Vehicle).

The tests defined in this category are separated into 3 test scenarios. The first test scenario consists of tests where the real time video stream from the Axis camera is played by accessing the web interface of the camera from an EC2 instance. The second tests scenario consists of tests where the real time video stream is played using a VLC player hosted in an AWS EC2 instance using RTSP pull. The detailed setup of the testing scenarios is illustrated in Figure 38.

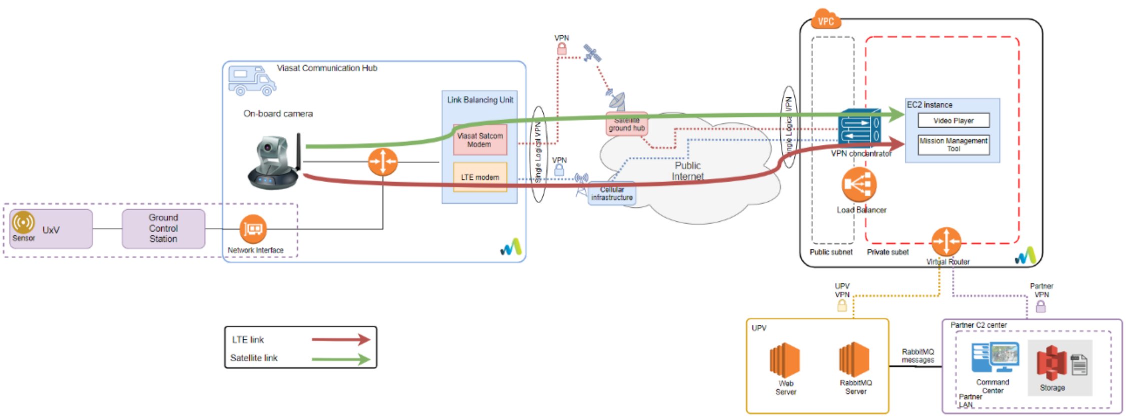


Figure 38 - Diagram for the RT video tests

HTTP tests

- **TST_COMS_003_1**: Real-time HD video stream with H.264 compression using HTTP with LTE as backhaul.
- **TST_COMS_003_2**: Real-time HD video stream with H.264 compression using HTTP with satellite as backhaul.

VLC tests

- **TST_COMS_003_3**: Real-time HD video stream with H.264 compression using RTSP and VLC with LTE as backhaul.
- **TST_COMS_003_4**: Real-time HD video stream with H.264 compression using RTSP and VLC with satellite as backhaul.
- **TST_COMS_003_5**: Real-time HD video stream with H.264 compression using HTTP and VLC during a fail-over from LTE to satellite.
- **TST_COMS_003_6**: Real-time HD video stream with H.264 compression using HTTP and VLC during a fail-over from satellite to LTE.

6.2.1 TST_COMS_003_1: Real-time HD video stream with H.264 compression using HTTP with LTE as backhaul

Test case ID	
TST_COMS_003_1	
Test description	Real-time HD video stream with H.264 compression using HTTP with LTE as backhaul.
Test Scenario	
This test is performed to evaluate the ability of the communication network to transport an H.264 real time video stream with a resolution of HD using LTE as backhaul. The main goals of the test are to observe the quality of the video (whether there are any disruptions to the video) and the latency. In order to do this, we play the video from the Axis camera using HTTP by accessing the camera web interface by its IP address: 192.168.10.11 from an EC2 instance and observe the difference in the timestamps between the shown video in the EC2 instance and the video shown on a laptop connected physically in the same subnet as the Axis camera.	
Test Results	
Video quality	Video is played without disruption
Latency	0.5-1s

6.2.2 TST_COMS_003_2: Real-time HD video stream with H.264 compression using HTTP with satellite as backhaul.

Test case ID	
TST_COMS_003_2	
Test description	Real-time HD video stream with H.264 compression using HTTP with LTE as backhaul.
Test Scenario	
This test is performed to evaluate the ability of the communication network to transport an H.264 real time video stream with a resolution of HD using LTE as backhaul. The main goals of the test are to observe the quality of the video (whether there are any disruptions to the video) and the latency. In order to do this, we play the video from the Axis camera using HTTP by accessing the camera web interface by its IP address: 192.168.10.11 from an EC2 instance and observe the difference in the timestamps between the shown video in the EC2 instance and the video shown on a laptop connected physically in the same subnet as the Axis camera.	
Test Results	
Video quality	Video is played without disruption
Latency	2-3s

6.2.3 **TST_COMS_003_3:** Real-time HD video stream with H.264 compression using RTSP and VLC with LTE as backhaul.

Test case ID	
TST_COMS_003_3	
Test description	Real-time HD video stream with H.264 compression using RTSP and VLC with LTE as backhaul.
Test Scenario	
This test is performed to evaluate the ability of the communication network to transport an H.264 real time video stream with a resolution of HD using RTSP and LTE as backhaul. The main goals of the test are to observe the quality of the video (whether there are any disruptions to the video) and the latency. In order to do this, we play the video from the Axis camera using an RTSP pull with VLC from an EC2 instance. In addition, we observe the difference in the timestamps between the shown video in the EC2 instance and the video shown on a laptop connected physically in the same subnet as the Axis camera.	
Test Results	
Video quality	Video is played without disruption
Latency	0.3-0.5s

6.2.4 **TST_COMS_003_4:** Real-time HD video stream with H.264 compression using RTSP and VLC with satellite as backhaul.

Test case ID	
TST_COMS_003_4	
Test description	Real-time HD video stream with H.264 compression using RTSP and VLC with satellite as backhaul.
Test Scenario	
This test is performed to evaluate the ability of the communication network to transport an H.264 real time video stream with a resolution of HD using RTSP and satellite as backhaul. The main goals of the test are to observe the quality of the video (whether there are any disruptions to the video) and the latency. In order to do this, we play the video from the Axis camera using an RTSP pull with VLC from an EC2 instance. In addition, we observe the difference in the timestamps between the shown video in the EC2 instance and the video shown on a laptop connected physically in the same subnet as the Axis camera.	
Test Results	
Video quality	Video is played without disruption
Latency	1-1.5s

6.2.5 **TST_COMS_003_5:** Real-time HD video stream with H.264 compression using HTTP and VLC during a fail-over from LTE to satellite.

Test case ID	
TST_COMS_003_5	
Test description	Real-time HD video stream with H.264 compression using HTTP and VLC during a fail-over from LTE to satellite.
Test Scenario	
This test is performed to evaluate the behaviour of the system during a fail-over from LTE to satellite and the effects on the video continuity and quality. The main goals of the test are to observe the quality of the video (whether there are any disruptions to the video), the latency and the packet loss rate before, during and after the fail-over. In order to do this, we play the video from the Axis camera using an RTSP pull with	

VLC from an EC2 instance using LTE as backhaul and then we disable the LTE link in order to force the fail-over to the satellite link. We observe the impact of the fail-over on the continuity of the video (whether there is a disruption) and the latency of the real time video. In order to do that, we observe the difference in the timestamps between the shown video in the EC2 instance and the video shown on a laptop connected physically in the same subnet as the Axis camera.

Test Results	
Video quality	Short degradation of the video quality lasting for 1-2s during the failover
Latency	Increase in latency from 0.5s to 1-1.5s after failover to satellite

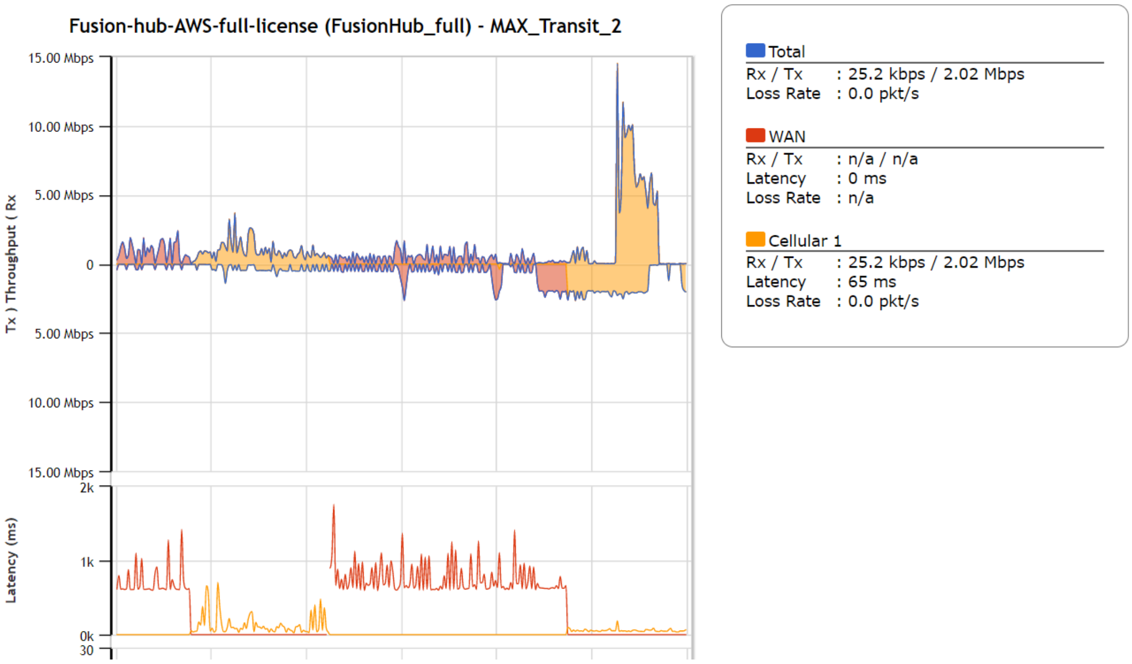


Figure 39 - Failover between LTE and satellite

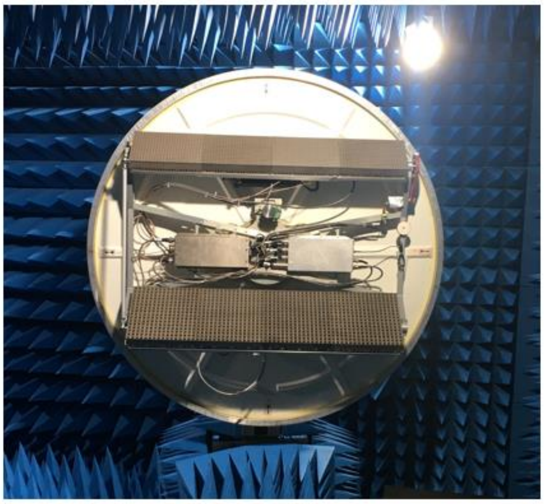
1.1.1. **TST_COMS_003_6**: Real-time HD video stream with H.264 compression using HTTP and VLC during a fail-over from satellite to LTE.

Test case ID	
TST_COMS_003_6	
Test description	Real-time HD video stream with H.264 compression using HTTP and VLC during a fail-over from satellite to LTE.
Test Scenario	
This test is performed to evaluate the behaviour of the system during a fail-over from satellite to LTE and the effects on the video continuity and quality. The main goals of the test are to observe the quality of the video (whether there are any disruptions to the video), the latency and the packet loss rate before, during and after the fail-over. In order to do this, we play the video from the Axis camera using an RTSP pull with VLC from an EC2 instance using satellite as backhaul and then we enable the LTE link in order to force the fail-over to the LTE link. We observe the impact of the fail-over on the continuity of the video (whether there is a disruption) and the latency of the real time video. In order to do that, we observe the difference in the timestamps between the shown video in the EC2 instance and the video shown on a laptop connected physically in the same subnet as the Axis camera.	
Test Results	
Video quality	Short degradation of the video quality lasting for 1-2s during the failover
Latency	Decrease in latency from 1-1.5s to 0.5s after failover to LTE

6.3 KaLMA antenna tests

6.3.1 Radiation Patterns

These tests were performed in order to analyse the radiation patterns of the KaLMA antenna, as well as the effect of the radome for both Rx and Tx.



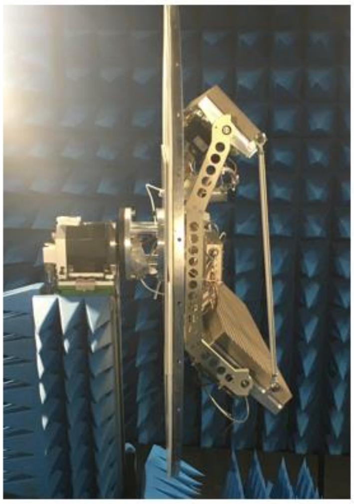


Figure 40 - Antenna pattern test setup

6.3.2 Antenna pattern measurements

- Rotating aperture elevation produces results in-line with expected test uncertainty (± 0.25 dB)
- Radome loss :1.08 (Tx) 0.28 dB (Rx)

Aperture	Elevation	Radome	Peak Gain†	Peak Directivity	Radiated power	XPD
Tx	~90°	No	36.80 dB	36.06 dBi	0.000 dBW‡	15.8 dB
Tx	~45°	No	37.03 dB	36.29 dBi	-0.001 dBW	10.0 dB
Tx	~45°	Yes	35.57 dB	35.91 dBi	-1.079 dBW	7.3 dB
Rx	~90°	No	47.53 dB	39.90 dBi	-0.192 dBW	18.9 dB
Rx	~45°	No	47.84 dB	40.02 dBi	0.000 dBW‡	15.8 dB
Rx	~45°	Yes	47.27 dB	39.73 dBi	-0.278 dBW	20.1 dB

† *Not gain referenced*
‡ *Normalisation reference*

Elevation effect (90°→ 45°) (no radome)

Aperture	Δ Gain	Δ Directivity
Tx	+0.23 dB	+0.23 dB
Rx	+0.31 dB	+0.11 dB

Radome effect (off → on) (elevation ~45°)

Aperture	Δ Gain	Δ Directivity	Δ Gain Attributed to radome loss
Tx	-1.46 dB	-0.38 dB	-1.08 dB
Rx	-0.57 dB	-0.29 dB	-0.28 dB

Figure 41 - Peak gain and directivity measurements

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~90°
Radome	No

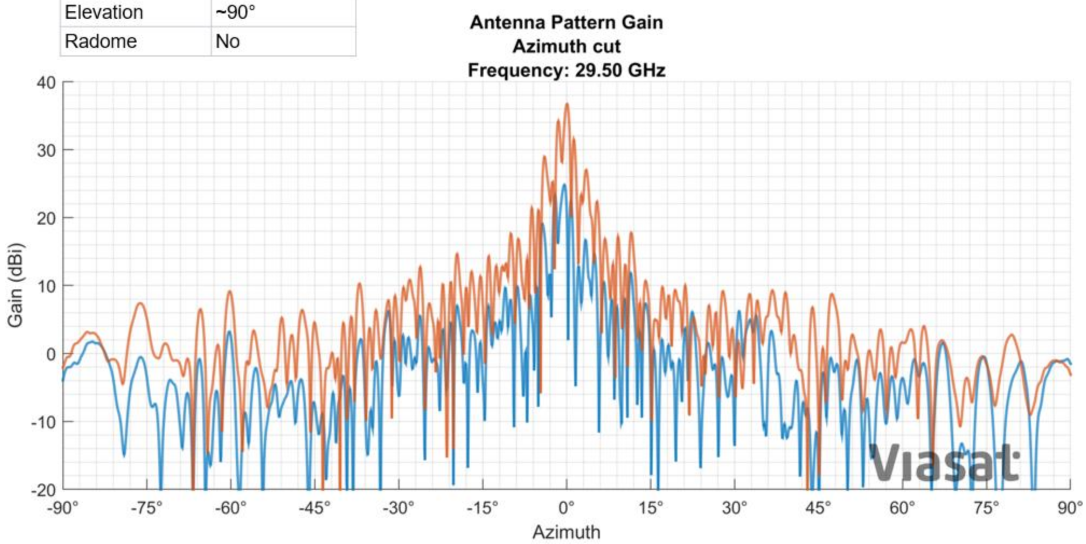


Figure 42 - Antenna Pattern Gain at 29.5 GHz - Azimuth cut at 90 degree elevation

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~90°
Radome	No

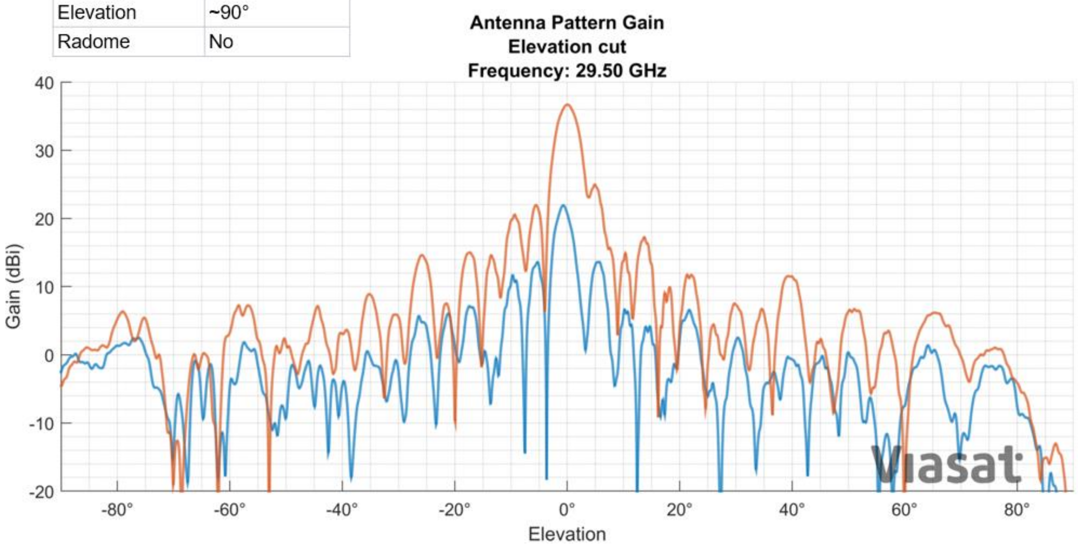


Figure 43 - Antenna Pattern Gain at 29.5 GHz - Elevation cut at 90 degree elevation

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~45°
Radome	No

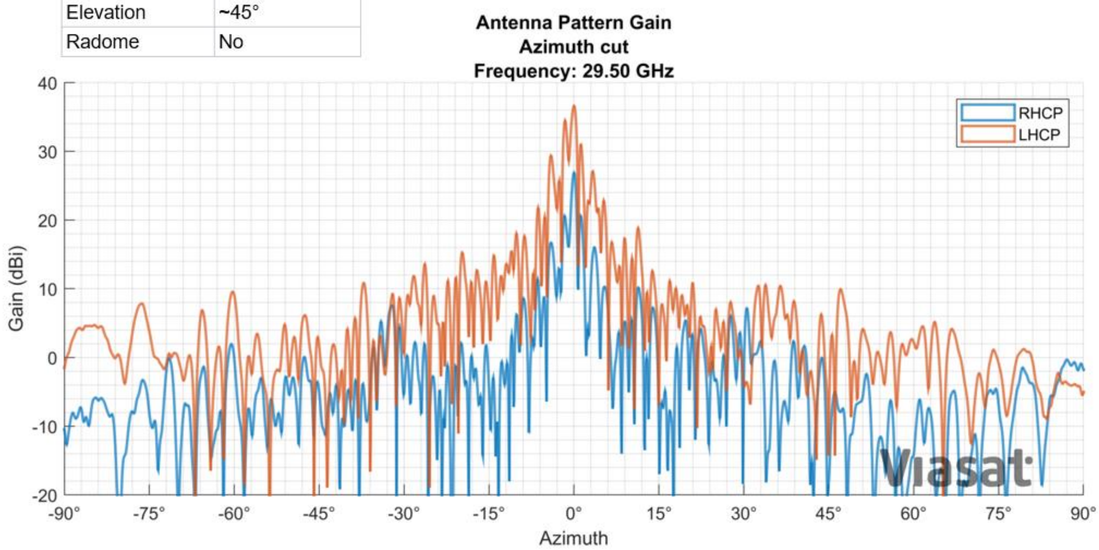


Figure 44 - Antenna Pattern Gain at 29.5 GHz - Azimuth cut at 45 degree elevation

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~45°
Radome	No

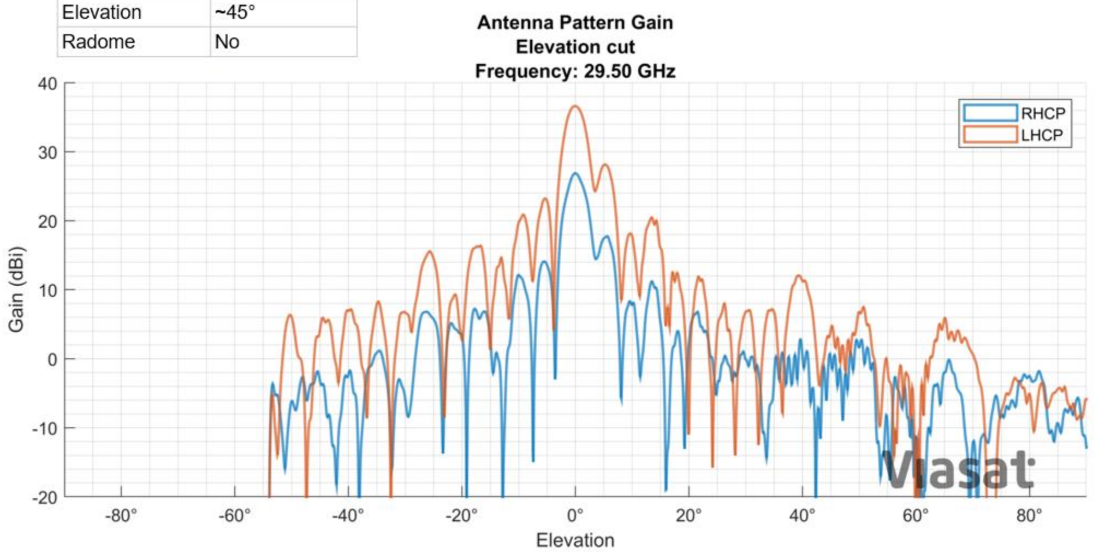


Figure 45 - Antenna Pattern Gain at 29.5 GHz - Elevation cut at 45 degree elevation

6.3.3 Antenna Pattern Measurements Comparisons

Test Parameter	Value
Band	Rx
Coating	Nickel
Elevation	~90° and ~45°
Radome	No

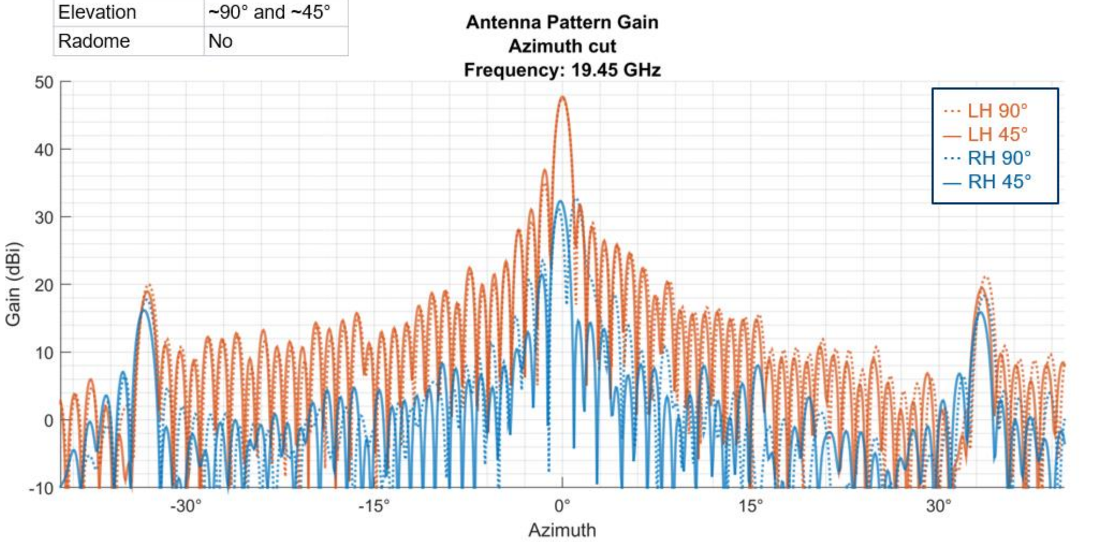


Figure 46 - Comparison of the Antenna Pattern Gain - Azimuth cut at elevation of 45 and 90 degrees at 19.45 GHz

Test Parameter	Value
Band	Rx
Coating	Nickel
Elevation	~90° and ~45°
Radome	No

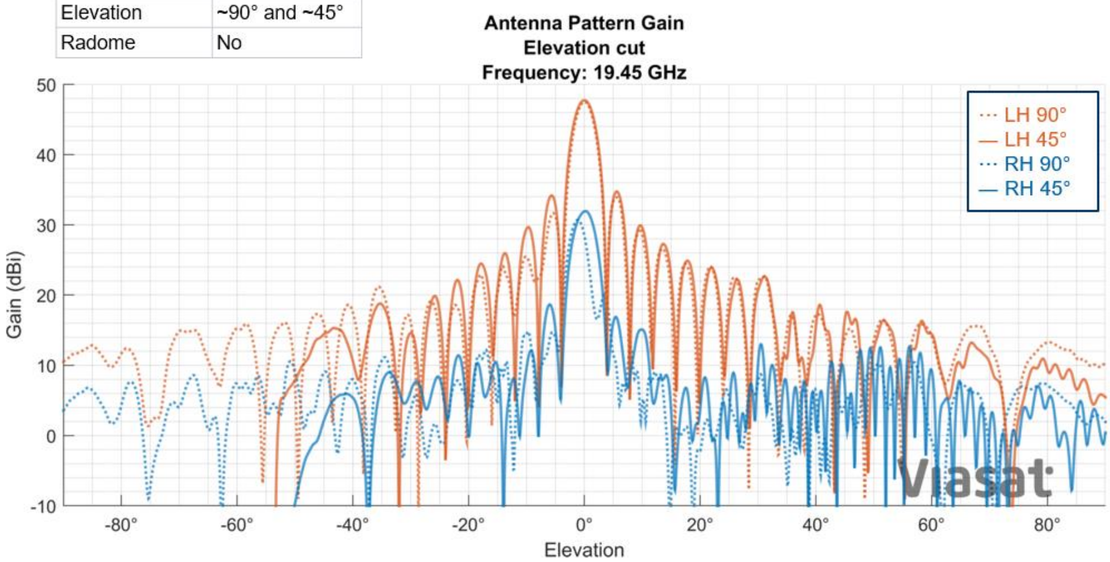


Figure 47 - Comparison of the Antenna Pattern Gain - Elevation cut at elevation of 45 and 90 degrees at 19.45 GHz

Test Parameter	Value
Band	Rx
Coating	Nickel
Elevation	~45°
Radome	No and Yes

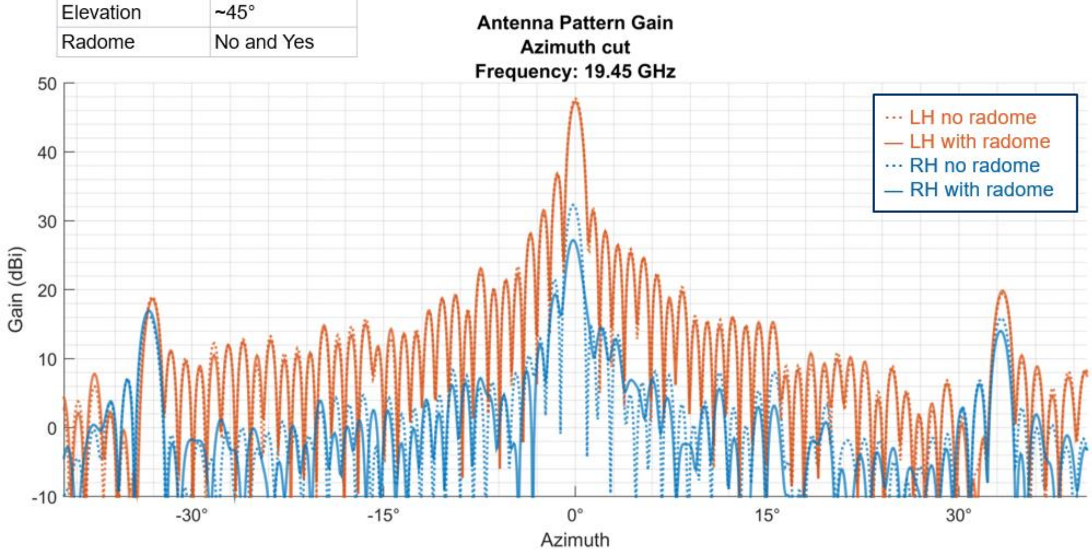


Figure 48 - Evaluation of the effect of the radome on the Antenna Pattern Gain - Azimuth cut at 19.45 GHz

Test Parameter	Value
Band	Rx
Coating	Nickel
Elevation	~45°
Radome	No and Yes

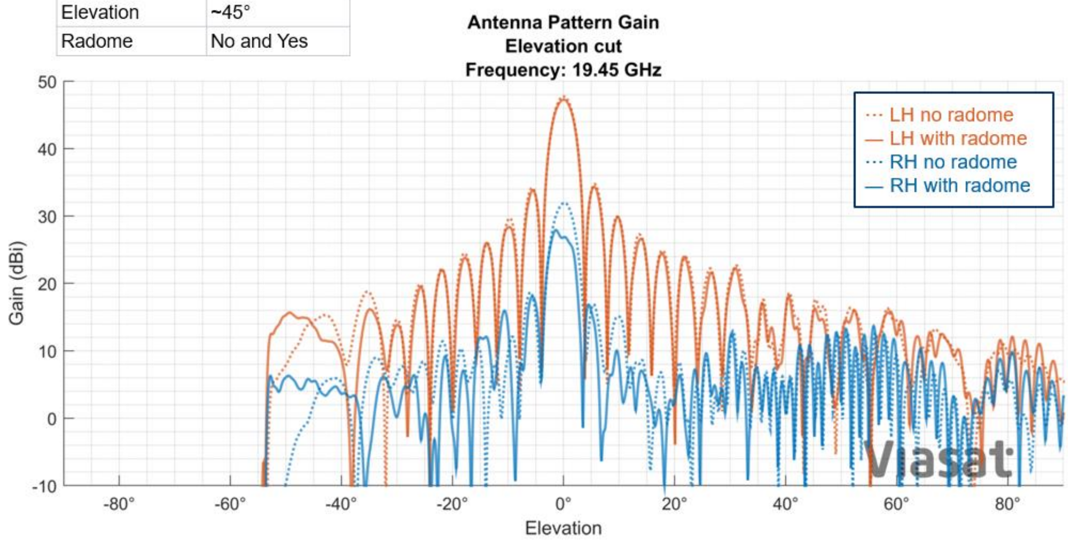


Figure 49 - Evaluation of the effect of the radome on the Antenna Pattern Gain – Elevation cut at 19.45 GHz

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~90° and ~45°
Radome	No

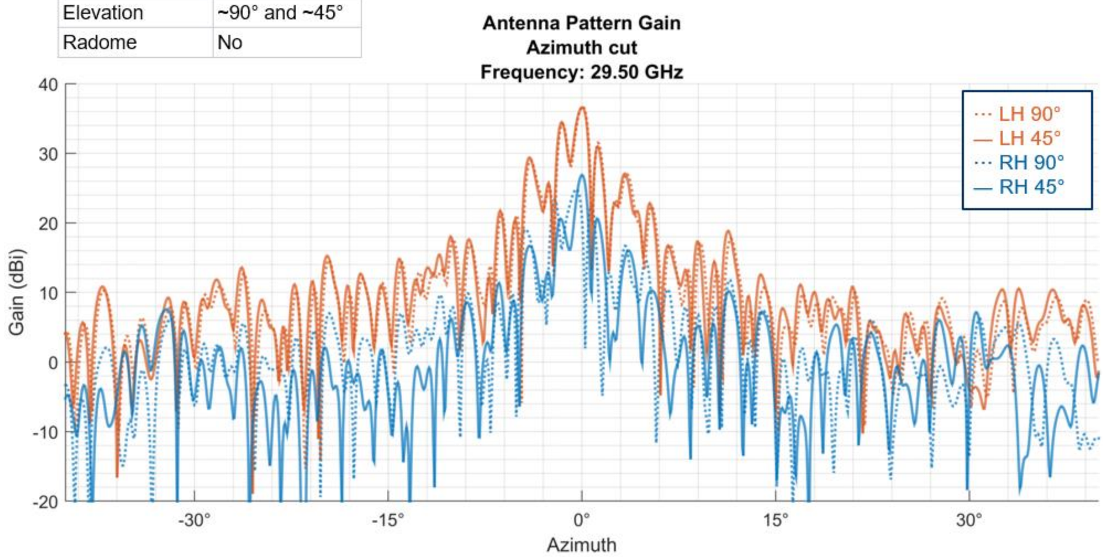


Figure 50 - Comparison of the Antenna Pattern Gain - Azimuth cut at elevation of 45 and 90 degrees at 29.5 GHz

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~90° and ~45°
Radome	No

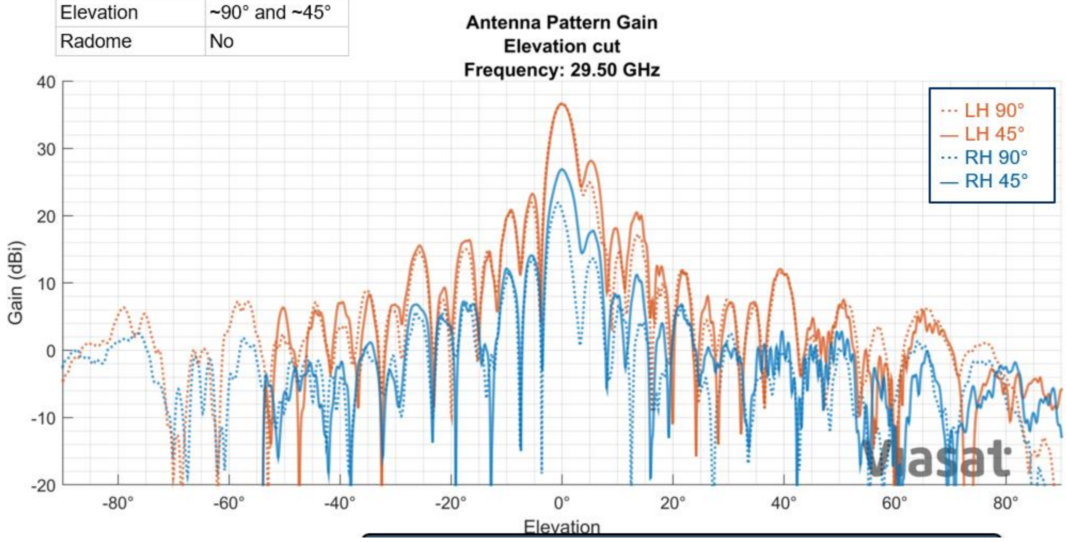


Figure 51 - Comparison of the Antenna Pattern Gain - Elevation cut at elevation of 45 and 90 degrees at 19.45 GHz

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~45°
Radome	No and Yes

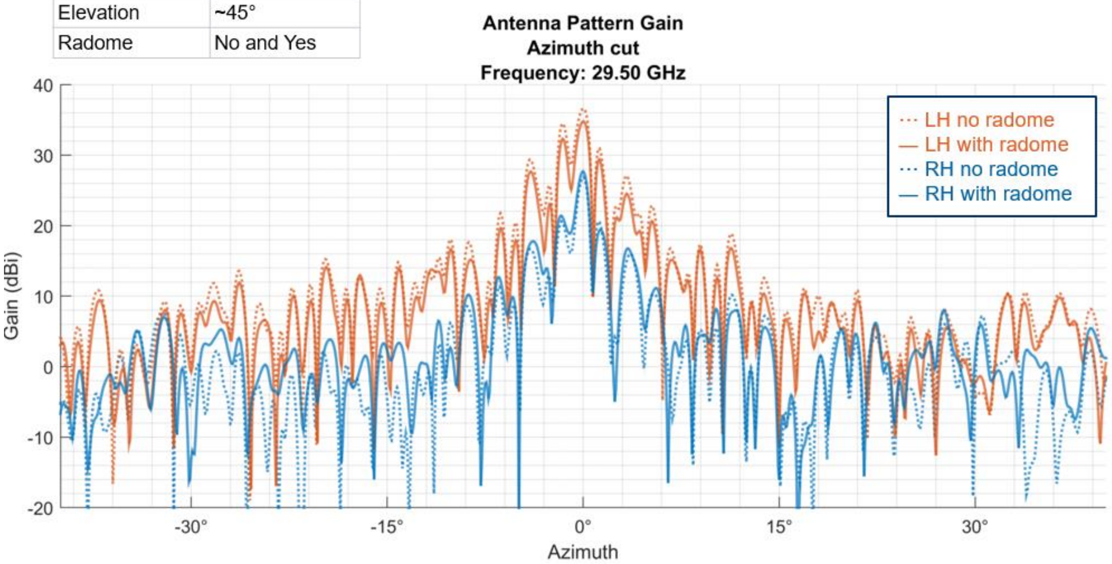


Figure 52 - Evaluation of the effect of the radome on the Antenna Pattern Gain - Azimuth cut at 29.5 GHz

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~45°
Radome	No and Yes

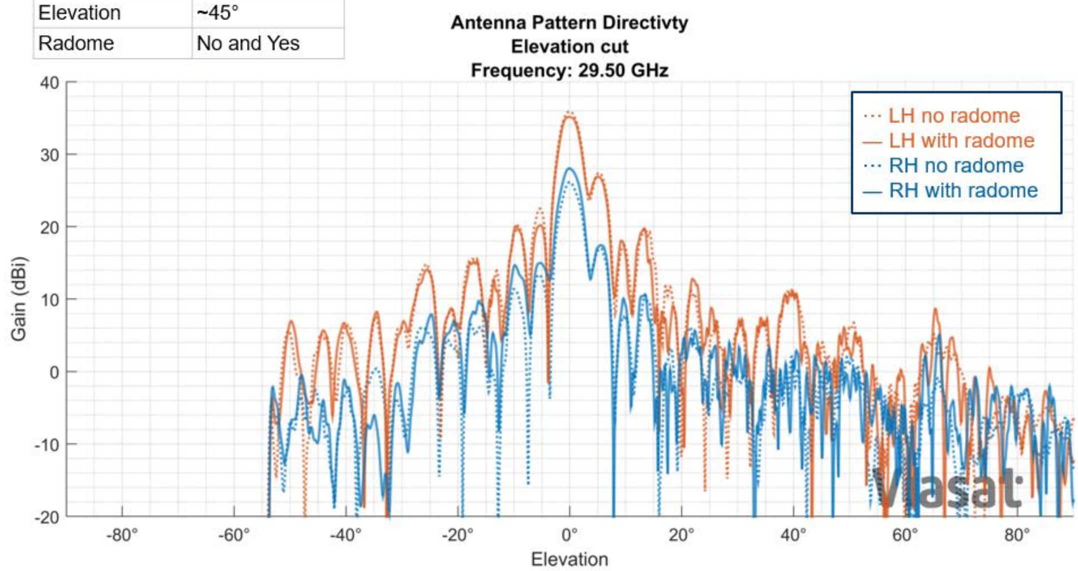


Figure 53 - Evaluation of the effect of the radome on the Antenna Pattern Gain - Elevation cut at 29.5 GHz

6.3.4 Antenna Pattern Measurements: Zoom-in of main beam

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~90°
Radome	No
Frequency	29.5 GHz

XPD within 1dB contour

Test Parameter	Value
@beam peak	16.8 dB
typical	15.8 dB
Worst case	11.7 dB

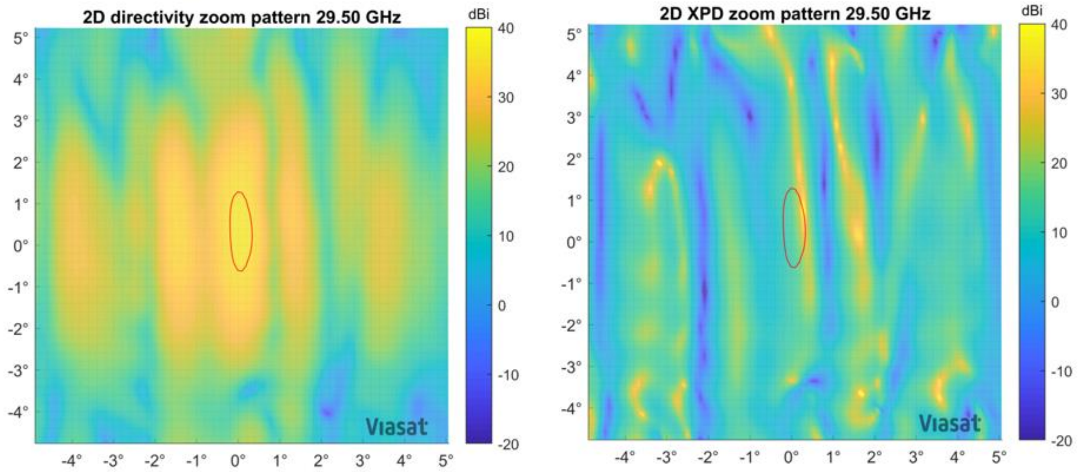


Figure 54 - Antenna pattern main beam detail at 29.5 GHz at 90 degree elevation

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~45°
Radome	No
Frequency	29.5 GHz

XPD within 1dB contour

Test Parameter	Value
@beam peak	9.7 dB
typical	10.0 dB
Worst case	9.7 dB

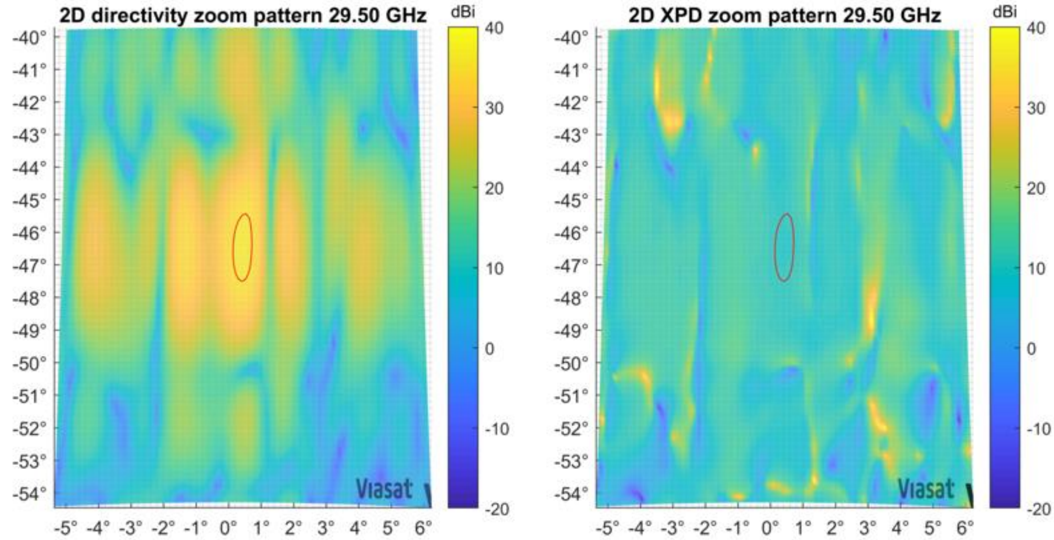


Figure 55 - Antenna pattern main beam detail at 29.5 GHz at 45 degree elevation

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~45°
Radome	Yes
Frequency	29.5 GHz

XPD within 1dB contour

Test Parameter	Value
@beam peak	7.1 dB
typical	7.3 dB
Worst case	7.1 dB

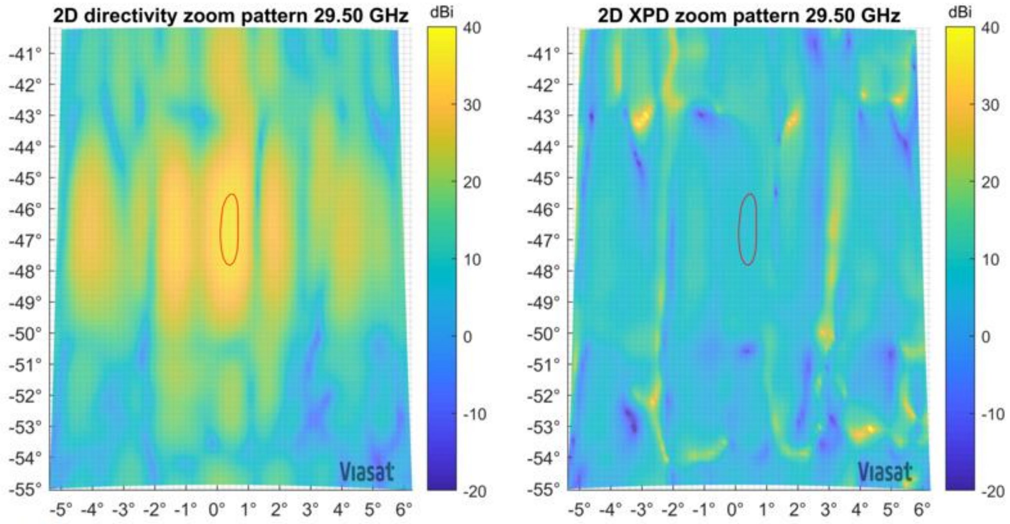


Figure 56 - Antenna pattern main beam detail at 29.5 GHz at 45 degree elevation with radome

Test Parameter	Value
Band	Rx
Coating	Nickel
Elevation	~90°
Radome	No
Frequency	19.45 GHz

XPD within 1dB contour

Test Parameter	Value
@beam peak	19.3 dB
typical	18.9 dB
Worst case	14.9 dB

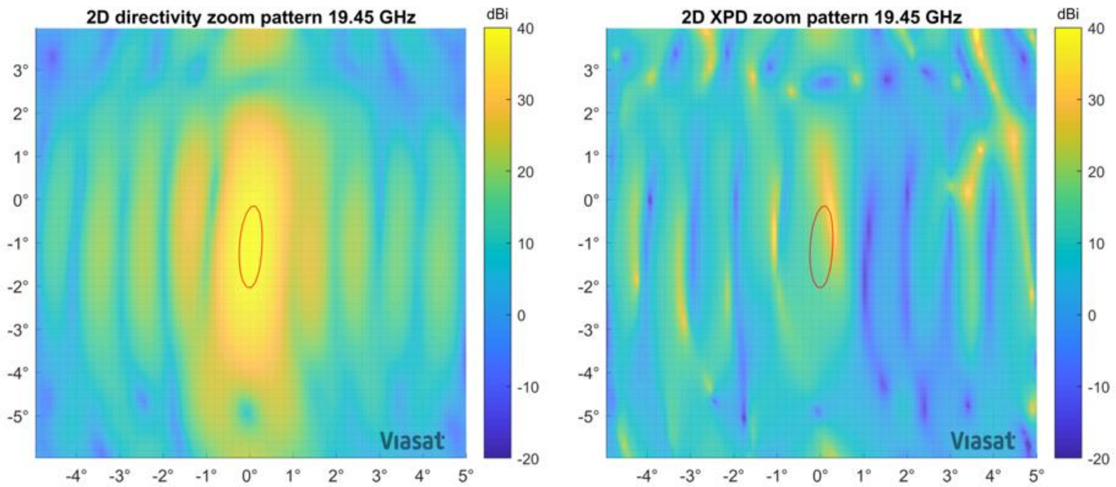


Figure 57 - Antenna pattern main beam detail at 29.5 GHz at 90 degree elevation with radome

6.3.5 Transformations to Near-field

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~90°
Radome	No
Frequency	29.25 GHz

Test Parameter	Value
Band	Tx
Coating	Nickel
Elevation	~45°
Radome	No
Frequency	29.25 GHz

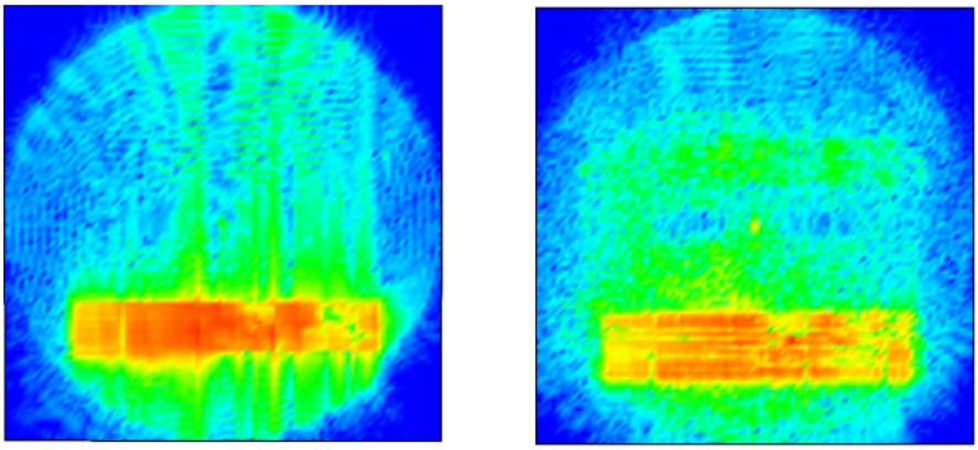


Figure 58 - Transformations to near-field at 29.25 GHz

Test Parameter	Value
Band	Rx
Coating	Nickel
Elevation	~90°
Radome	No
Frequency	19.45 GHz

Test Parameter	Value
Band	Rx
Coating	Nickel
Elevation	~45°
Radome	No
Frequency	19.45 GHz

Test Parameter	Value
Band	Rx
Coating	Nickel
Elevation	~45°
Radome	Yes
Frequency	19.45 GHz

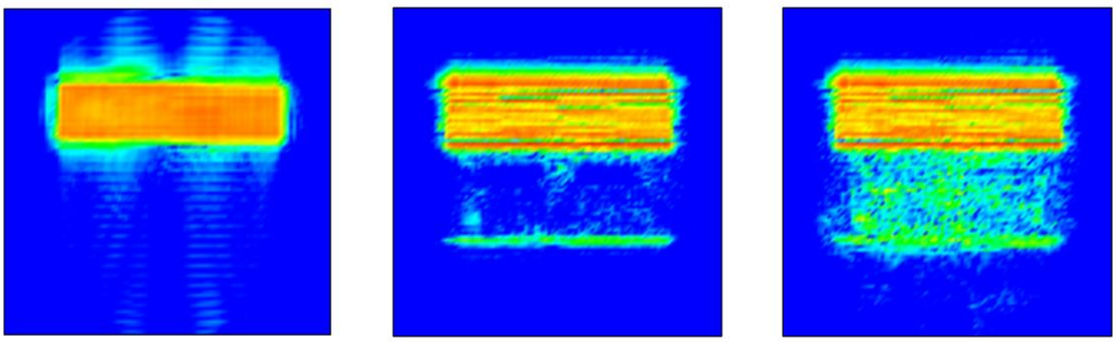


Figure 59 - Transformations to near-field at 19.45 GHz

7 On-field Tests

7.1 Long driving tests

This section presents the tests that have been performed with the presented system and the obtained results. The goal of the test was to drive along pre-defined routes with the communication hub for 72 hours in order to evaluate the performance of the system during a long period of active use. The routes for the testing are presented in Figure 60, Figure 61 and Figure 62 respectively.

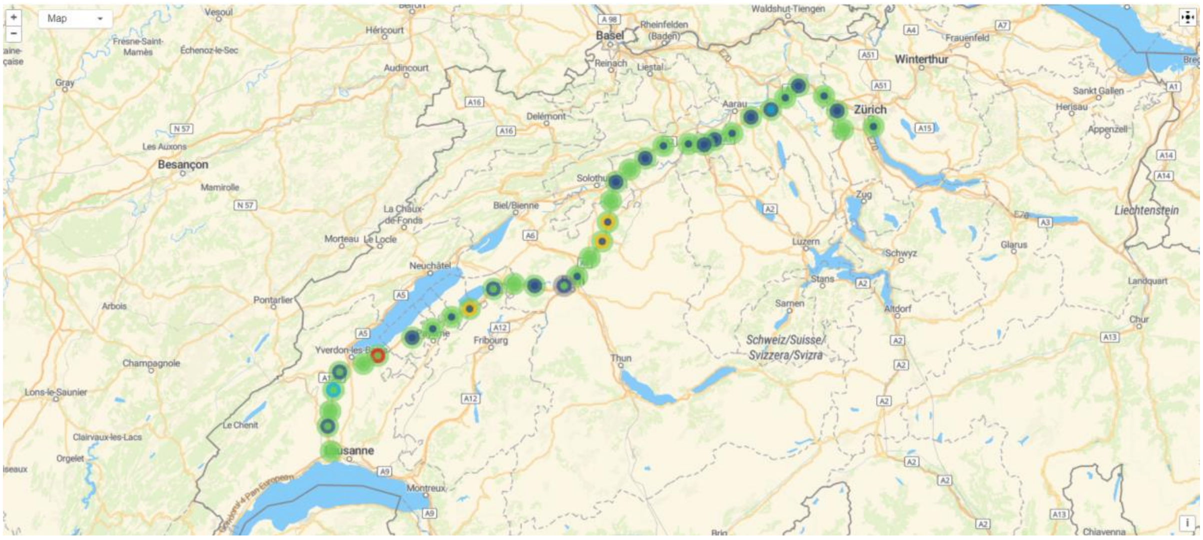


Figure 60 - Driving route taken on 13.11.2020 (230 km)

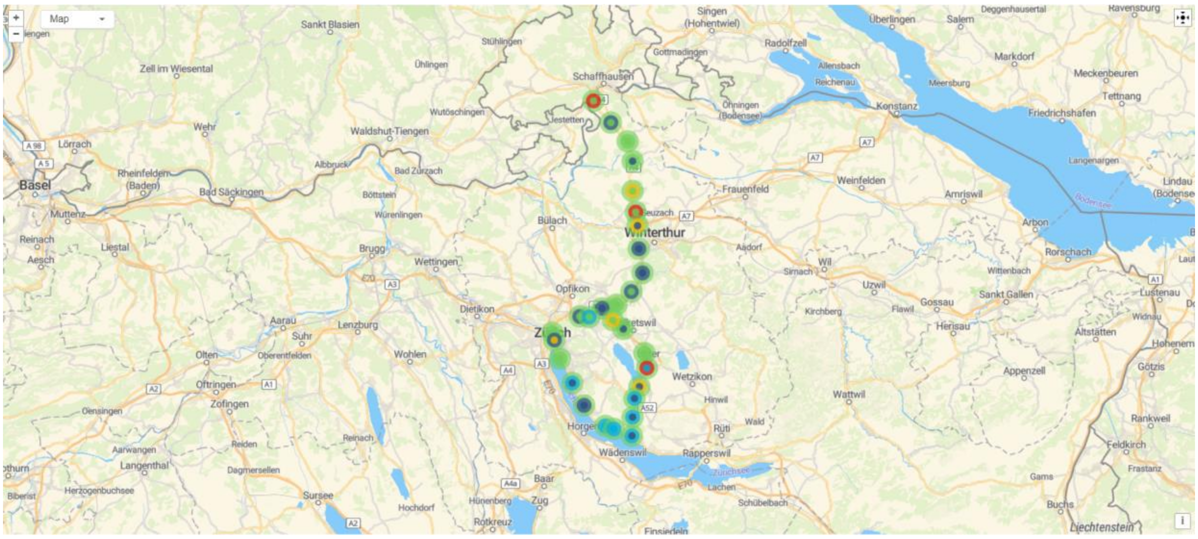


Figure 61 - Driving route taken on 14.11.2020 (40 km)

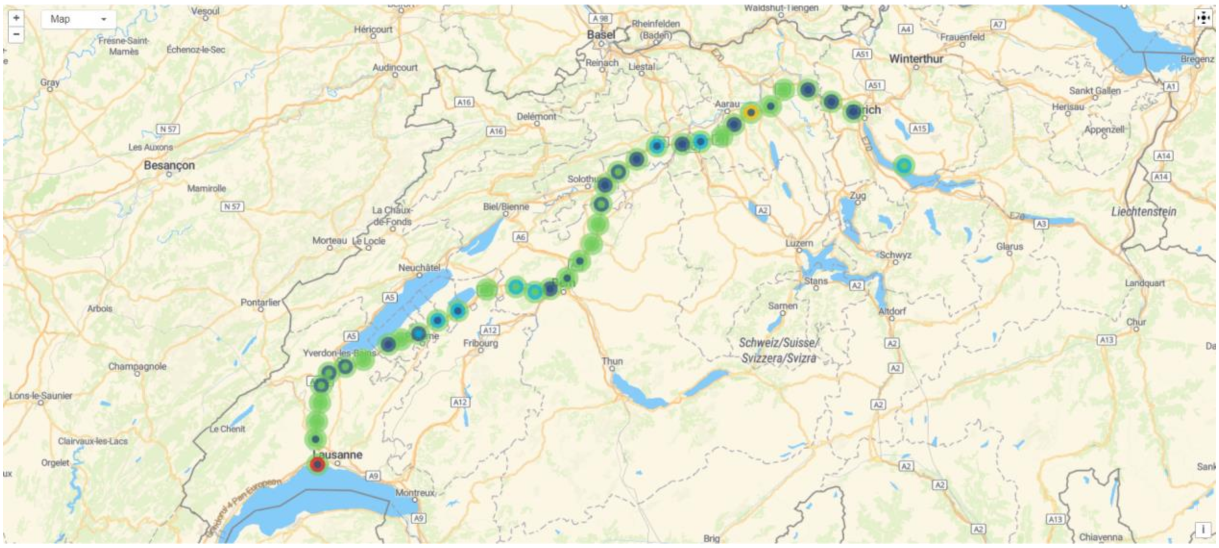


Figure 62 - Driving route taken on 15.11.2020 (230 km)

7.1.1 Link quality monitoring

One of the main goals of the test was to monitor the quality of each link (satellite and LTE) at every 10 seconds along the test route and evaluate the dependence between the quality of the links and the performance of the system. The link balancing unit has the ability to monitor each link with its signal parameters at an interval of 10 seconds. This provides us with the ability to observe the quality of the links in near real-time, as well as store the obtained results for further analysis.

LTE link

The system can record the following parameters on the LTE link:

- SNR – The signal-to-noise ratio of the given signal.
- RSRP – The average power received from a single reference signal, and its typical range is around -44dbm (good) to -140dbm (bad).
- RSRQ – Indicates quality of the received signal, and its range is typically -19.5dB (bad) to -3dB (good).
- Represents the entire received power including the wanted power from the serving cell as well as all co-channel power and other sources of noise.

Since Switzerland is relatively well covered when it comes to LTE, we can observe in Figure 63 that the LTE signal quality (indicated by the blue and green circles) is high along the test route with very few drops in quality in some spots. This can be confirmed by observing the timeline graph of the LTE signal parameters in Figure 64. The graph shows a very brief time interval of 5 minutes where the LTE signal drops and the LTE connection is completely lost which is shown in Figure 65. The map with the exact location of the signal drop is illustrated in Figure 66 showing the values of the LTE signal parameters before the signal is completely dropped and the location where the LTE signal is regained a few minutes later. It is important to note that when the LTE signal was dropped, the system performed a failover to the satellite link without any disruption to the performance of the system.

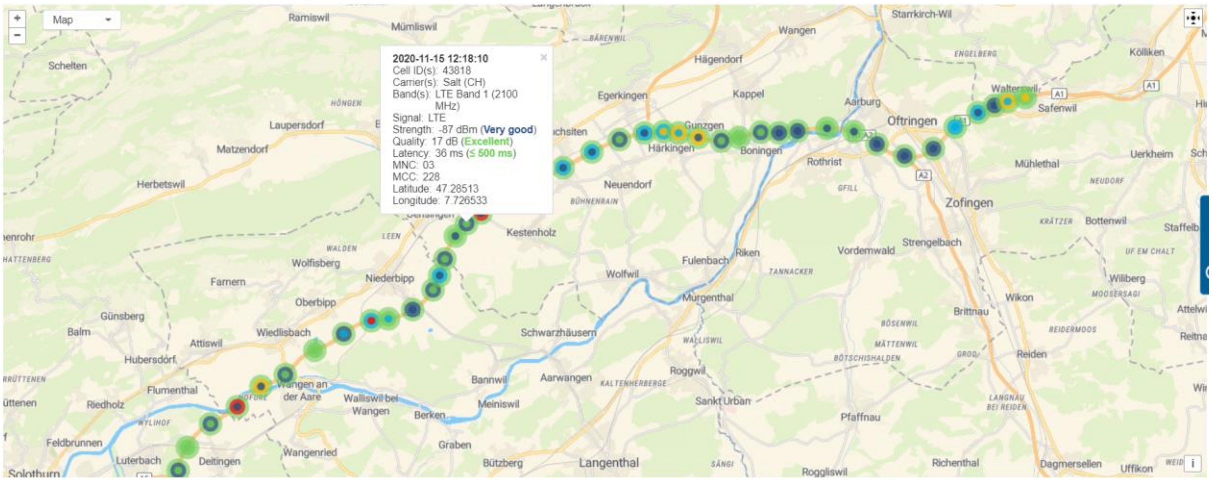


Figure 63 - Map of the LTE link quality during the long driving test

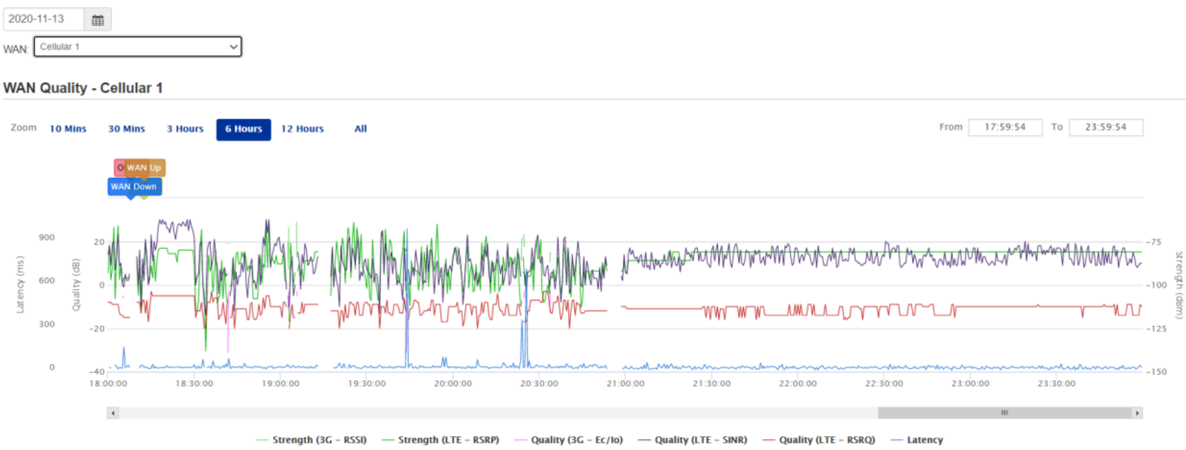


Figure 64 - Timeline graph of the LTE signal parameters

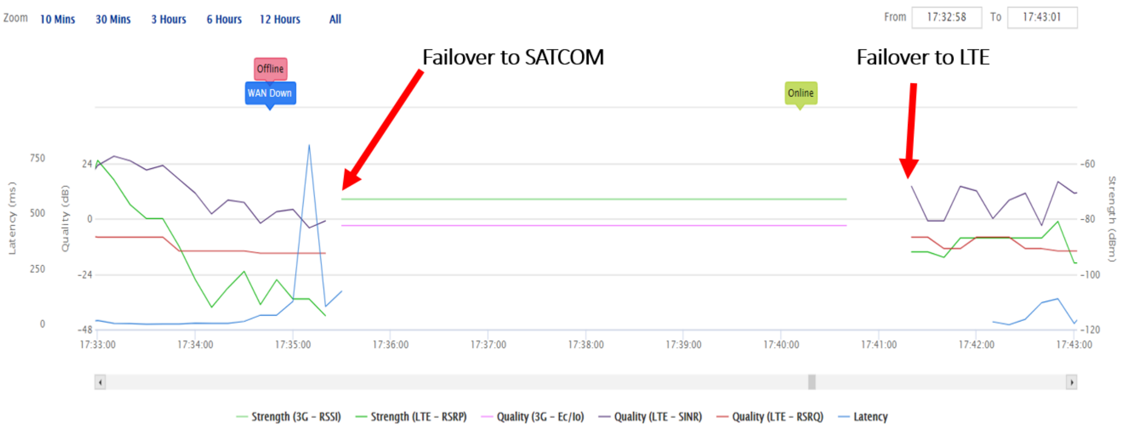


Figure 65 - Timeline graph of the LTE signal drop

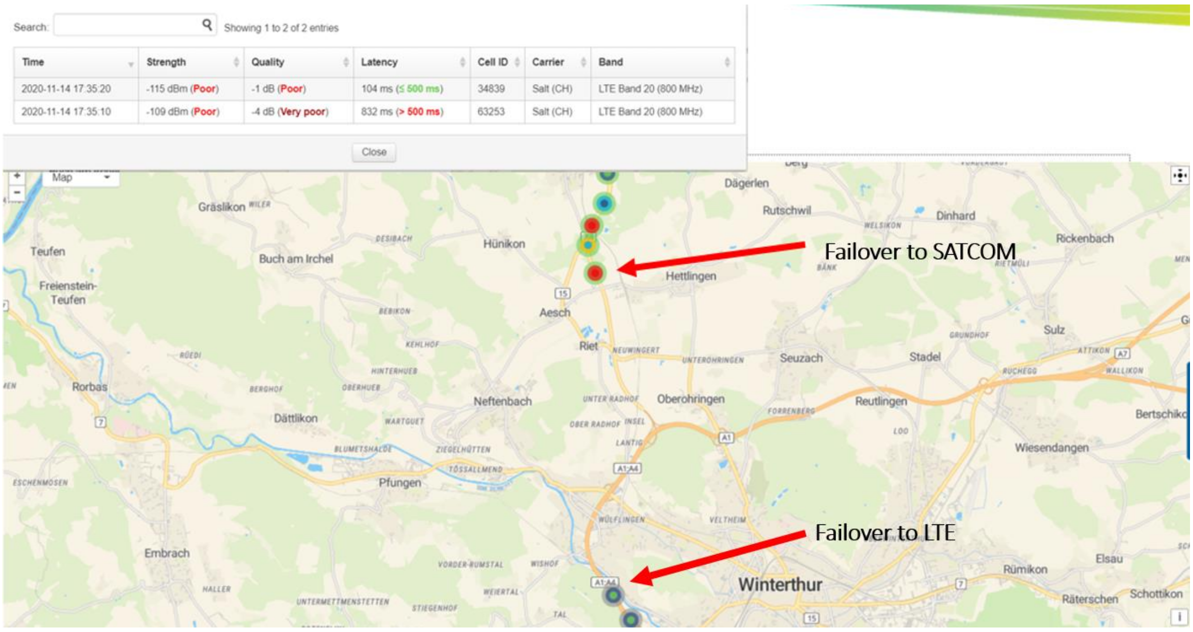


Figure 66 - Map of the LTE signal drop

Satellite link

Similar to the LTE link, we have also observed the satellite link status at intervals of 10 seconds. The map shown in Figure 67 illustrates the status of the Satellite link along the test route during the long driving test. The red circles on the map show the location where the satellite link was active and the system is using the link as backhaul. It is important to note that each circle on the map corresponds to approximately 10 data points since each data point is taken at an interval of 10 seconds and not every data point can be shown on the map when it is not zoomed in. The map shows that the satellite link is active along most of the test route with some disruptions due to the many physical obstacles on the road that prevent the KaLMA antenna from maintaining LOS with the satellite. The timeline graph of the latency on the satellite link corresponding to the map shown in Figure 67 is illustrated in Figure 68. The timeline graph shows only the latency measurements when the satellite link is active meaning that the blank spots correspond to the points in time when the satellite link was down. During those points in time, the system performs a failover to the LTE link with no loss of data.

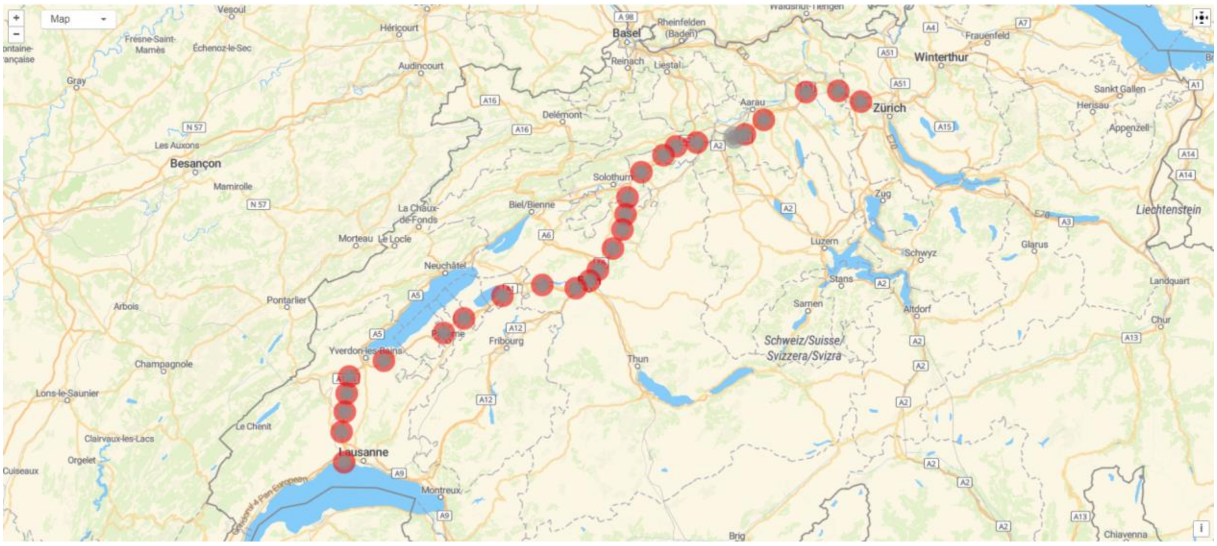


Figure 67 - Map of the Satellite link status during the long driving test

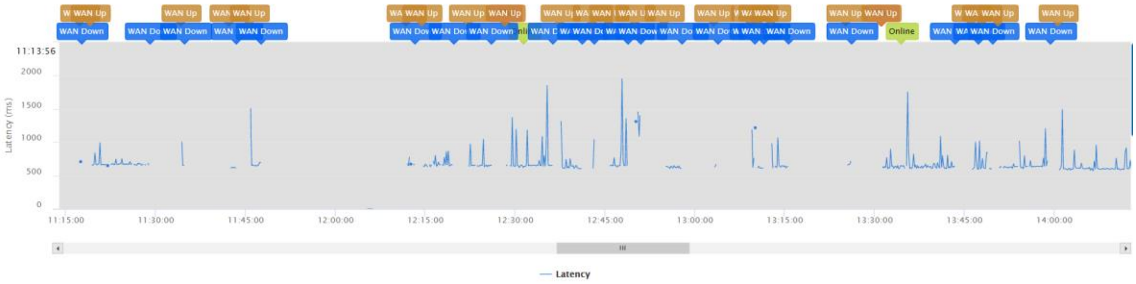


Figure 68 - Timeline graph of the latency on the Satellite link during the long driving test

7.1.2 Deployment Test

This subsection presents a testing scenario where the communication hub is deployed to the field of operation and remains static during the mission defined in ARESIBO. To simulate this scenario, we have monitored the system during driving before stopping at a pre-defined location for 1 hour in order to analyse if the system performs in a stable manner after the deployment. The map of this test is illustrated in Figure 69 where we can see the route taken to reach the deployment location, as well as the location of the deployment with its 302 entries for the latency measurements. The corresponding timeline graph is presented in Figure 70 where we can observe the satellite link latency during the test. We can observe that the satellite link is going back and forth between online and offline during the driving to the deployment location which is expected due to the physical obstacles encountered along the route. It is important to point out that the satellite link is stable after the communication hub reaches the defined location and while the communication hub is no longer moving. This shows that the communication hub provides a reliable backhaul link in the scenario where it needs to be deployed in an area outside of cellular coverage which is common for the ARESIBO use-cases.

Figure 69 - Map of the deployment test

Figure 70 - Timeline graph of the satellite link latency during the deployment test

7.1.3 Failover Tests

This subsection presents the tests focusing on evaluating the ability of the system to perform failovers between the two links without affecting the performance of the system. Therefore, we have configured the satellite link as the priority link meaning that it will be used when both links are active. The goal is to observe the performance of the system when the satellite link is offline and the system needs to perform a failover to the LTE link. In addition, the system needs to be able to perform another failover back to the satellite link once the satellite link is back online. The map of the first failover example is shown on Figure 71 where the red circles represent the locations where the satellite link is active and the blank spots represent the locations where the satellite link is down and the system has performed a failover to the LTE link. The same map representing the LTE link signal parameters during the same time is shown in Figure 72 where we can observe that the LTE link is online during the whole time interval.

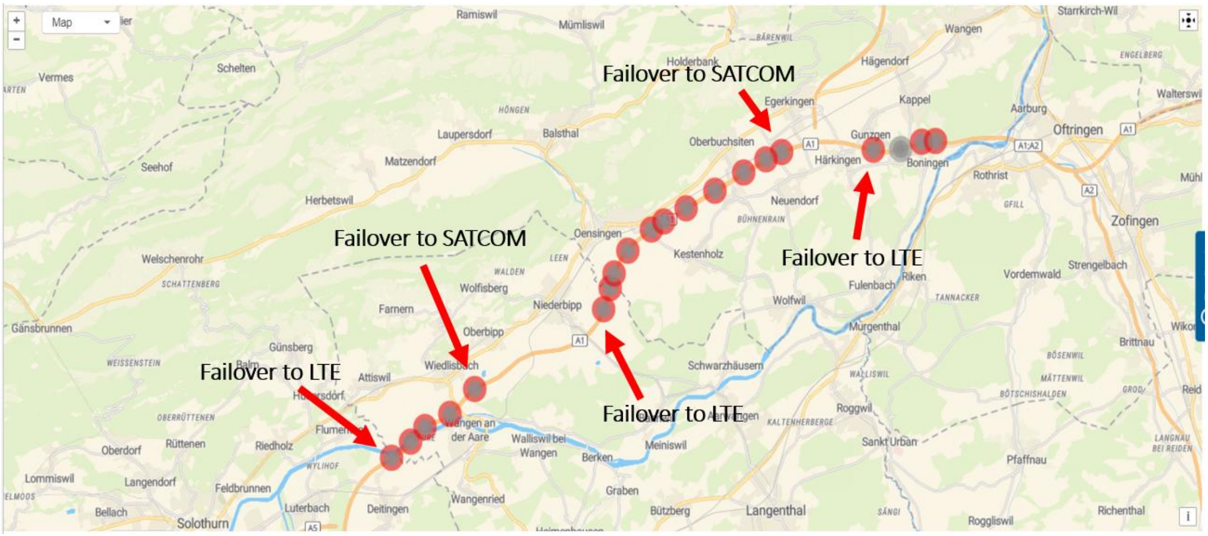


Figure 71 - Map of the Satellite link latency during the failover

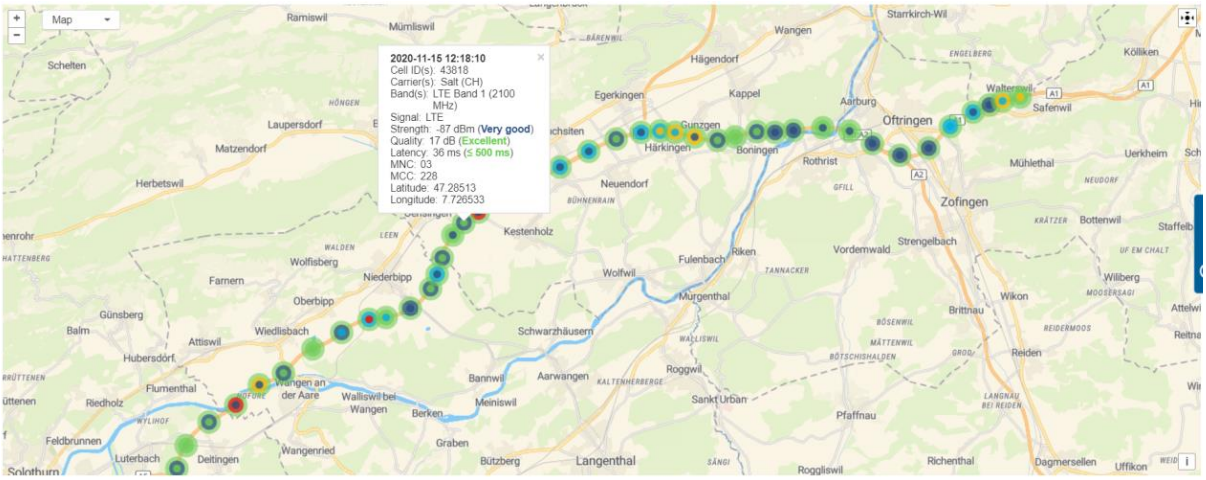


Figure 72 - Map of the LTE link signal parameters during the failover

The data rates on both links during the time interval of 24 minutes (each block on the graph corresponds to 4 minutes) is shown in Figure 73. The upper graph represents the data rate on the satellite link and the lower graph shows the data rate on the LTE link. As shown in the graph, the system performs several failovers between the links depending on the availability of the satellite link since it has priority. The conclusion of these tests is that the system is able to perform failovers between the links without any degradation in performance which ensures that the system provides high availability and reliability which is crucial for the use-cases defined in ARESIBO.

Figure 73 - Data rates on the satellite and LTE link

7.1.4 Long activity Test

The goal of this test is to test the performance of the system using the satellite link during an interval of 12 hours. The test consists of keeping the system to be active for 12 hours while downloading at a constant rate of 750 kbps in order to observe whether the system will experience any disruptions. The SNR measured on the upstream and downstream link of the KaLMA satellite antenna during the 12 hours of active use is shown on Figure 74. This test is relevant for ARESIBO since the use-cases require the communication hub to be deployed on the field and be operational for a longer time.

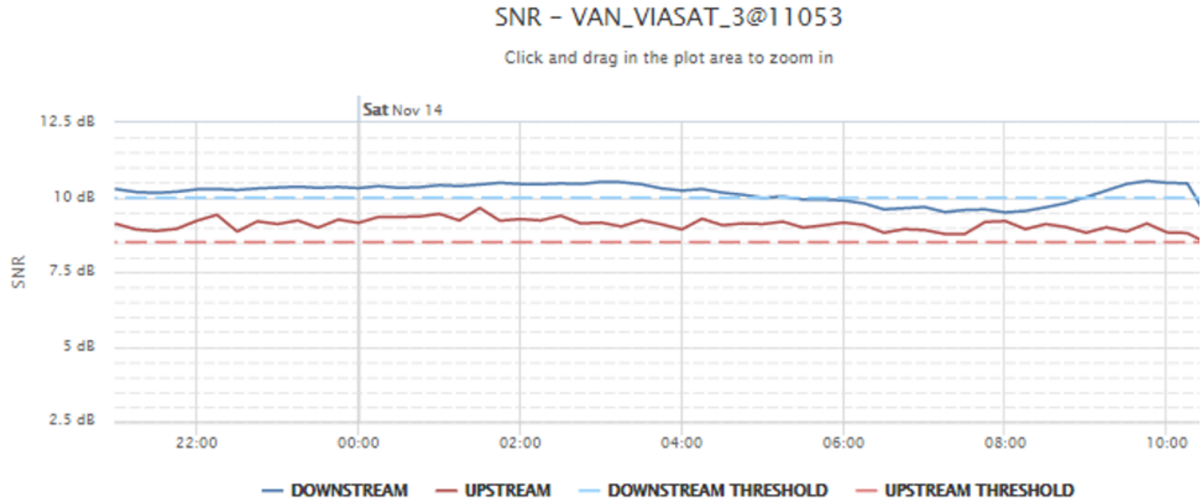


Figure 74 - SNR on the upstream and downstream link on the KaLMA

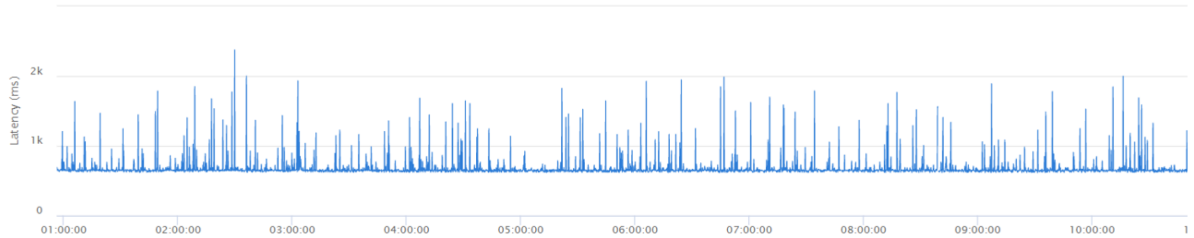


Figure 75 - Timeline graph of the satellite link latency during the long activity test

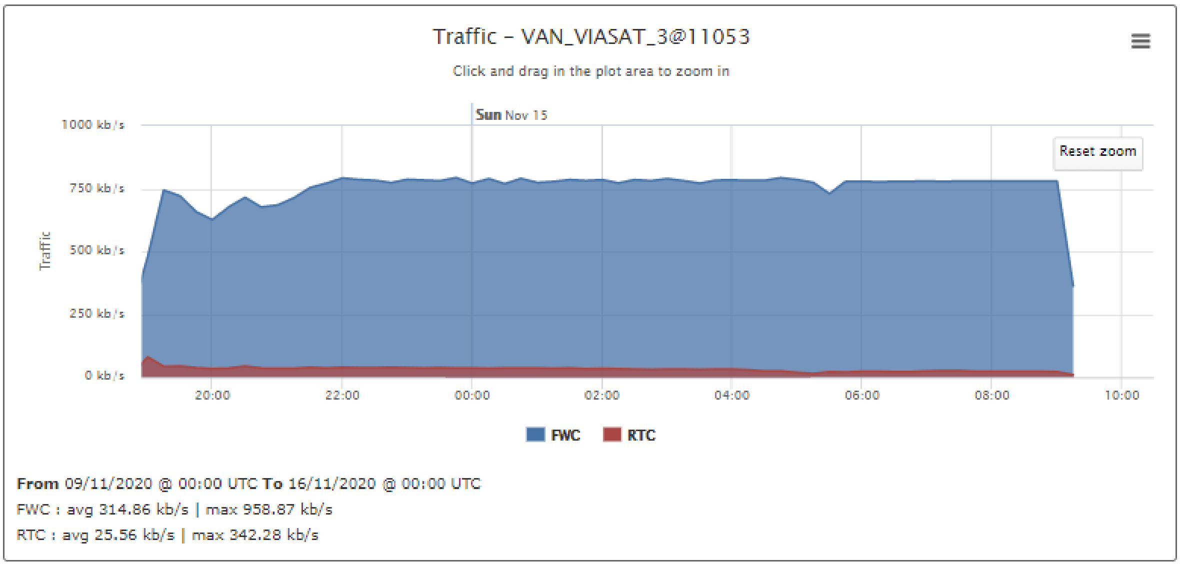


Figure 76 - Download data rate on the satellite link during the long activity test

We can observe that the SNR is stable during the whole time interval except for a brief drop on the upstream link in the morning which is quickly regained. The timeline graph of the satellite link latency illustrated in Figure 75 shows that the satellite link is stable during the whole 12-hour time interval. Furthermore, we can observe in Figure 76 that the download data rate on the satellite link is stable at the desired 750 kbps during the whole time interval. This set of tests proves that the system ensures stable performance during a long period of activity.

7.2 Short Driving Tests

This section presents the tests performed by driving around in the communication hub (Viasat Land Vehicle) with the KaLMA antenna mounted on the roof of the vehicle. The antenna's control unit (ACU) is able to log up to 150 parameters at an interval of 0.1 s which can then be illustrated on a map, thus allowing the visualization of the major antenna parameters at every point in the test path. The screenshots presented in this section use the colour of the icon (in this case a circle) to represent the RSSI of the antenna at the given point with green colour representing a high RSSI (above 8 dB) and orange and red representing lower RSSI values respectively. The goal of this test is to evaluate the pointing capabilities of the antenna and observe which specific scenarios cause the RSSI to drop.
The screenshots illustrate two different routes, but the same conclusions can be drawn from both scenarios. The antenna is able to maintain a high RSSI despite a lot of sharp turns along the paths with some instances of decreased RSSI mostly due to physical obstacles at the given location.

7.2.1 Test at EPFL campus – Lausanne

The same tests were performed by driving around the EPFL campus in Lausanne, Switzerland. Figure 77 illustrates the RSSI at every point along the path where it is clear that the RSSI drops at the points where tall objects like buildings and trees block the satellite signal thus resulting in a very low RSSI. However, the KaLMA antenna is able to quickly recover the signal once LOS with the satellite is established.

Figure 77 - RSSI at every point along the path

Figure 78 - Connectivity at every single point along the path

In order to evaluate the relationship between the RSSI and the connectivity (status of the connection) of the modem, we observe Figure 78 where the network status is illustrated. The modem has 4 different states:

- **Scanning** which means that the KaLMA antenna is tracking the satellite in order to establish the link.
- **Network entry** which means that the antenna has established a link with the satellite with a satisfactory RSSI and the modem is negotiating the network entry with the satellite core network.
- **DHCP** which means that the core satellite network is assigning an IP address to the modem.
- **Online** which means that the system is online and data can be transferred using the satellite network.

We can see from both Figure 77 and Figure 78 that there is a clear alignment between the connection status and RSSI since the system is in Scanning state when the RSSI is low meaning that the KaLMA antenna is still tracking the satellite. Once the antenna establishes the link with the satellite, the system goes to the status Network entry and if it is successful, the system proceeds with DHCP and after receiving an IP address, the system is Online.
Figure 79 and Figure 80 illustrate the relationship between the driving speed of the vehicle and the RSSI obtained by the KaLMA antenna. The plots show that the driving speed does not affect the satellite tracking of the KaLMA antenna which is able to establish and maintain the satellite link at variable driving speed.

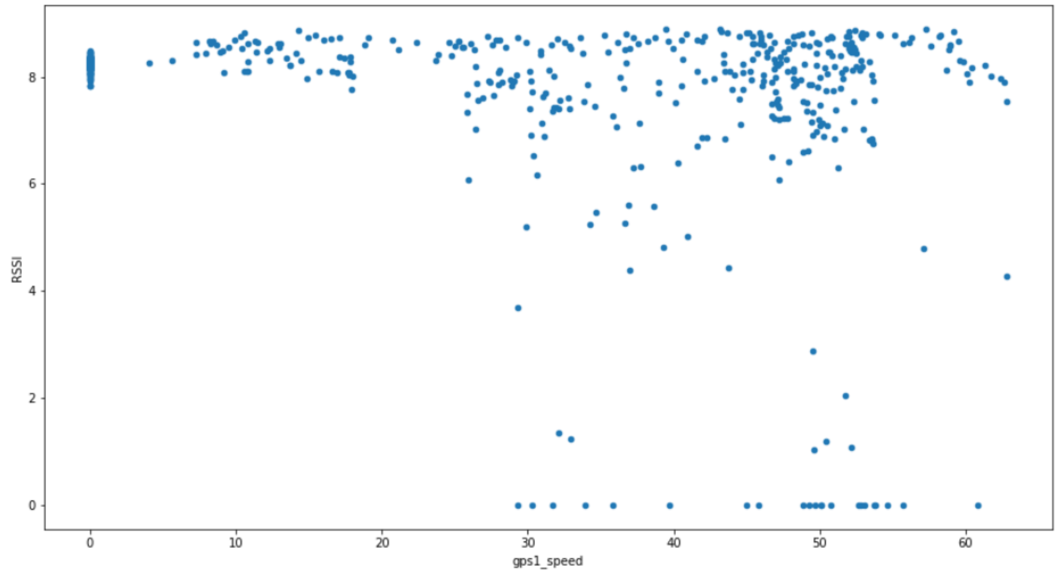


Figure 79 - Relationship of the driving speed (kmph) and the RSSI (1)

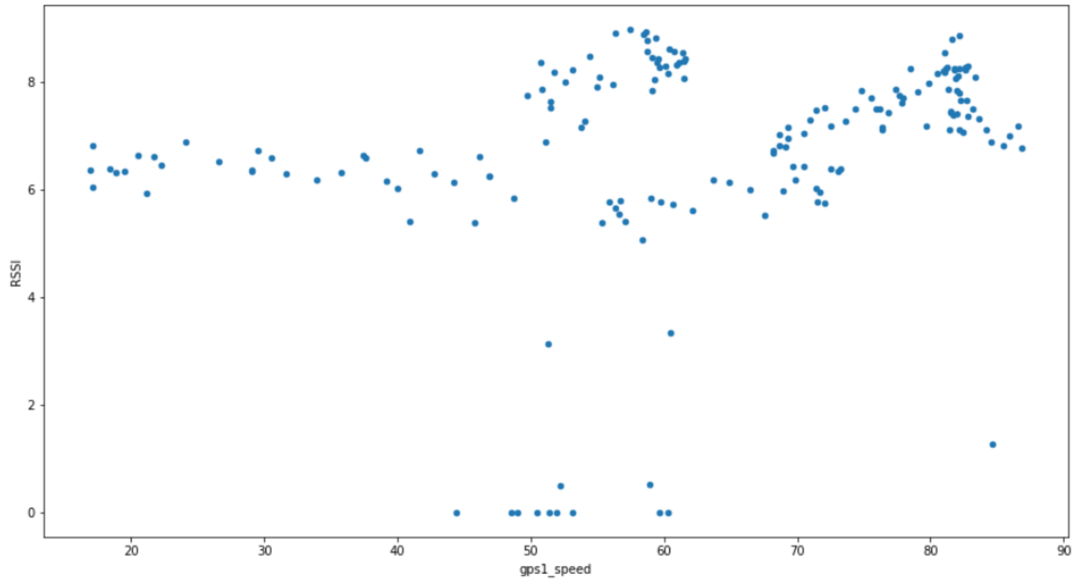


Figure 80 - Relationship of the driving speed (kmph) and the RSSI (2)

7.3 *Trellisware tests*

Test description

Trellisware radio terminals create a self-forming, self-healing, infrastructure-less tactical Mobile Ad-hoc Network (MANET) capable of connecting a large number of devices across a large area. In addition to the audio channels, each radio module supports H.264 video streams. Depending on the model of the radio terminal and the resolution of the video streams, the MANET can support multiple video streams simultaneously. Furthermore, the Trellisware radio terminal can act as a relay to other radios in range, thus creating a mesh radio network with a large range. The radio modules (equipped on first responders and UAVs) will send or relay all the data streams to the communication hub where the traffic will be routed to the ARESIBO C2 centre.

Figure 81 - Trellisware testing setup

The goal of these tests is to evaluate the range and throughput of the Trellisware MANET in different scenarios in order to have an insight into the capabilities and limitations of the radio terminals, as well as to verify the integration of the Trellisware MANET into the developed hybrid network infrastructure.

1. **TST_TRLS_001**: Test the connectivity between two 'Cub' terminals in lab conditions.
2. **TST_TRLS_002**: LOS range test between two 'Cub' terminals.

7.3.1 **TST_TRLS_001:** Test the connectivity between two 'Cub' terminals in lab conditions

Test case ID	
TST_TRLS_001	
Test description	Test the connectivity between two 'Cub' terminals in lab conditions.
Test Scenario	
The goal of this test is to evaluate the connectivity and throughput between two 'Cub' terminals in lab conditions. In order to do this, two laptops are connected to a separate Trellisware 'Cub' radio terminal and a TCP session is established between the laptops using Iperf. The same test is also performed for UDP messages. The test was performed in the communications lab in Viasat's Lausanne office.	
Test Results	
Link SNR	52 dB
Bandwidth	TCP: 3.31 Mbps, UDP: 8.02 Mbps
Packet losses (UDP)	0.012%
Latency	Minimum = 67ms, Maximum = 391ms, Average = 142ms

7.3.2 **TST_TRLS_002:** LOS range test between two 'Cub' terminals

Test case ID	
TST_TRLS_002	
Test Scenario	
The goal of this test is to evaluate the range, throughput and latency between two 'Cub' terminals by placing them at various distances from each other ensuring LOS. In order to do this, we keep one radio terminal at a fixed position and move the other radio to different positions relative to the first. At each designated distance, we evaluate the throughput and latency of the connection between the two radios. We repeat the tests for the following distances between the radios: 50m, 100m, 1km, 3km, 5.5km, 10km. The tests presented in this table have been performed in "Zmeevo military base" in Bulgaria from 09.09.2020 until 12.09.2020 with the support of the Bulgarian Defence Institute "Professor Tsvetan Lazarov".	
Test Results	
50m	
Link SNR	53 dB
Bandwidth	TCP: 3.24 Mbps, UDP: 7.92 Mbps
Packet losses (UDP)	0.13%
Latency	Minimum = 82ms, Maximum = 380ms, Average = 157ms
100m	
Link SNR	52 dB
Bandwidth	TCP: 3.12 Mbps, UDP: 8.04 Mbps
Packet losses (UDP)	0.21%
Latency	Minimum = 73ms, Maximum = 305ms, Average = 135ms
1.3km	
Link SNR	53
Bandwidth	TCP: 2.56 Mbps, UDP: 6.75 Mbps
Packet losses (UDP)	2.3%
Latency	Minimum = 92ms, Maximum = 396ms, Average = 178ms
3km	
Link SNR	53 dB
Bandwidth	TCP: 2.31 Mbps, UDP: 7.12 Mbps
Packet losses (UDP)	3.7%
Latency	Minimum = 74ms, Maximum = 297ms, Average = 133ms
5.5km (over lake)	
Link SNR	34 dB
Bandwidth	TCP: 3.23 Mbps, UDP: 8.02 Mbps
Packet losses (UDP)	0.041%
Latency	Minimum = 67ms, Maximum = 282ms, Average = 128ms
10km	
Link SNR	6 dB
Bandwidth	TCP: 1.02 Mbps, UDP: 2.48 Mbps
Packet losses (UDP)	6.7%
Latency	Minimum = 70ms, Maximum = 292ms, Average = 138ms

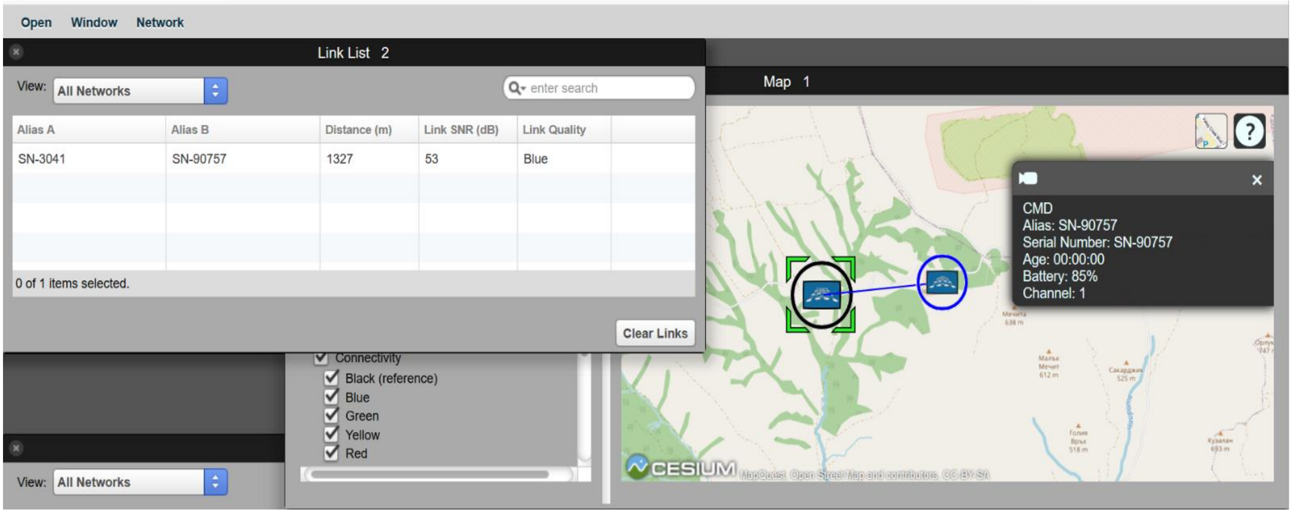


Figure 82- Range test at 1.3 km (map)

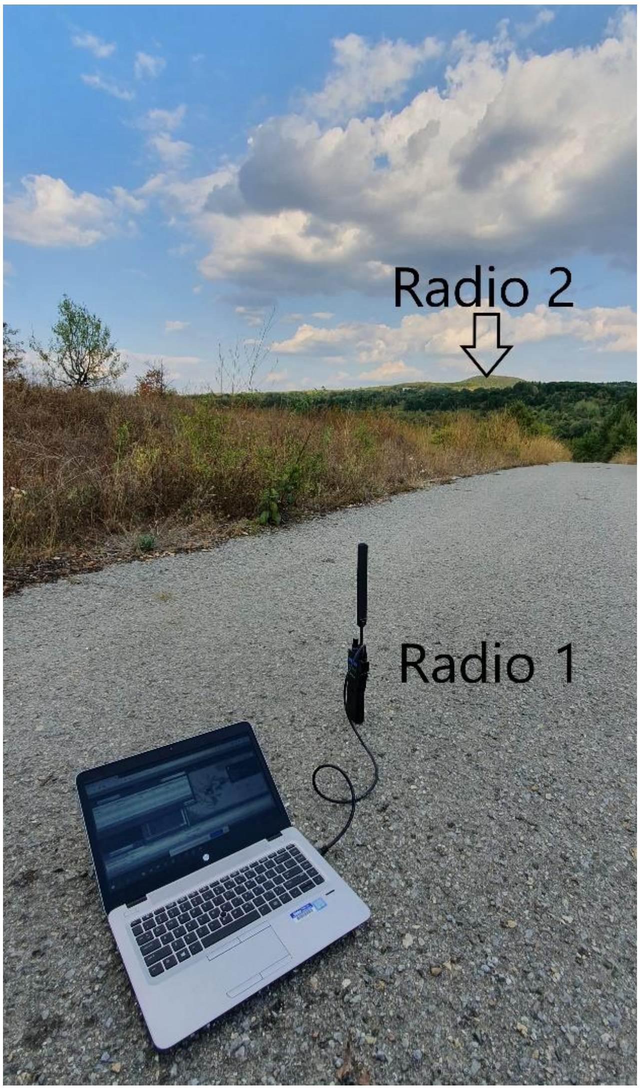


Figure 83 - Range test at 1.3km (terrain)

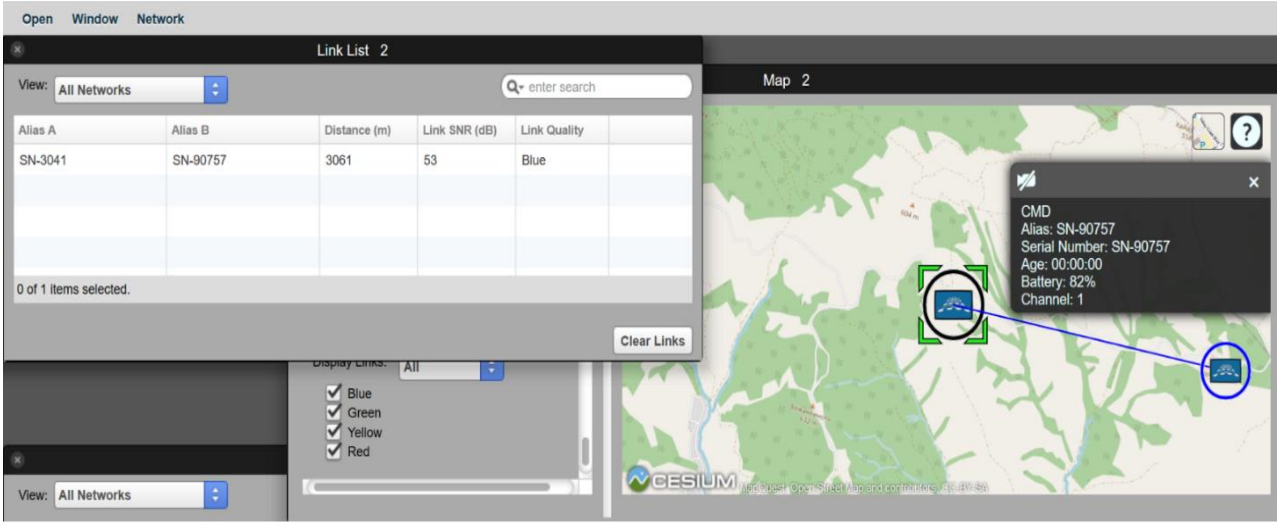


Figure 84 - Range test at 3 km (map)

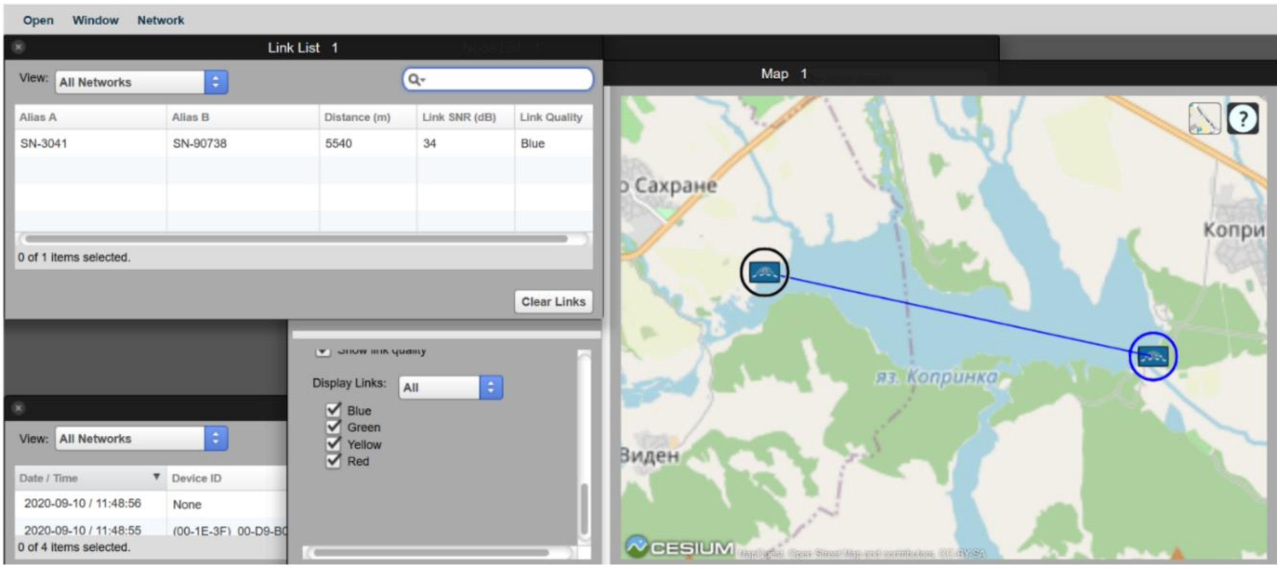


Figure 85 - Range test at 5.5 km (map)

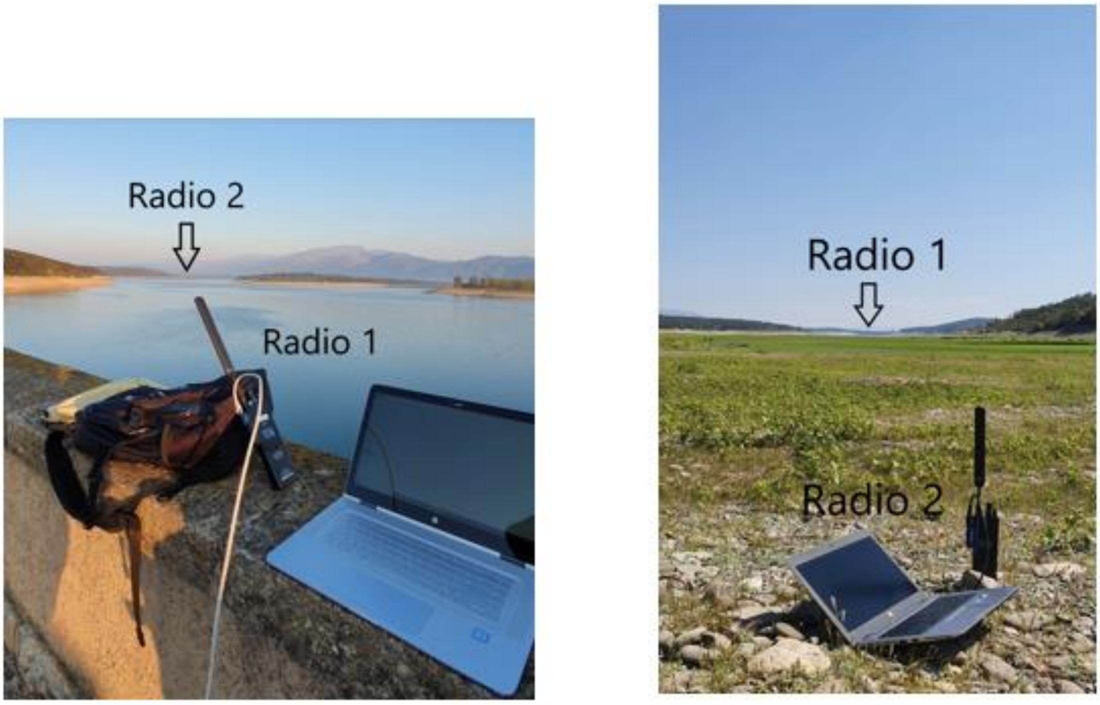


Figure 86 - Range test at 5.5 km (terrain)

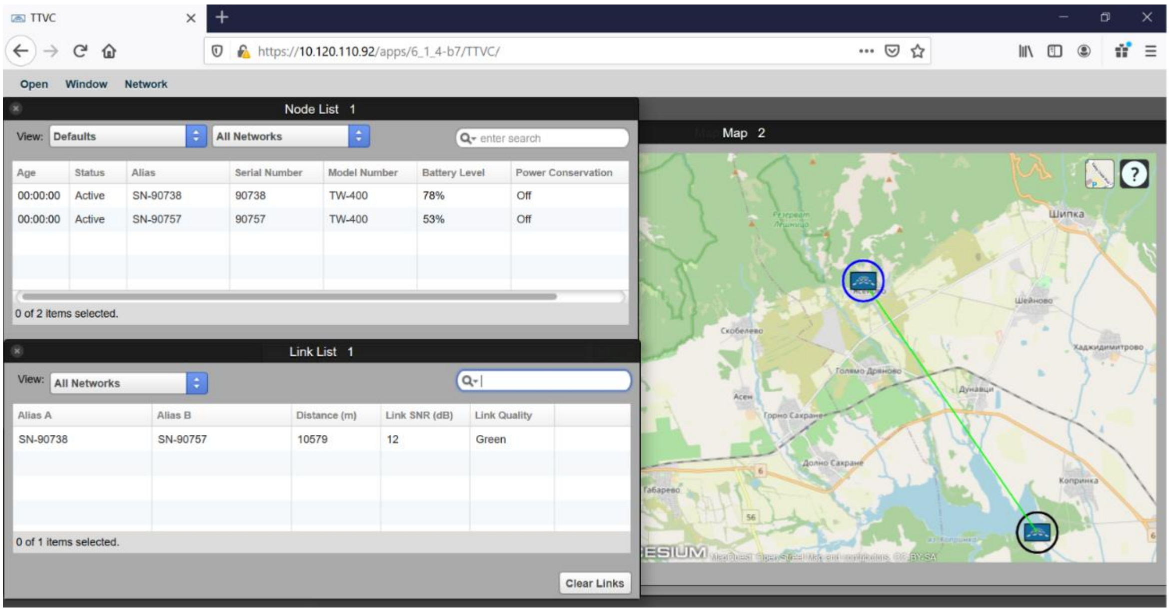


Figure 87 - Range test at 10km (map)

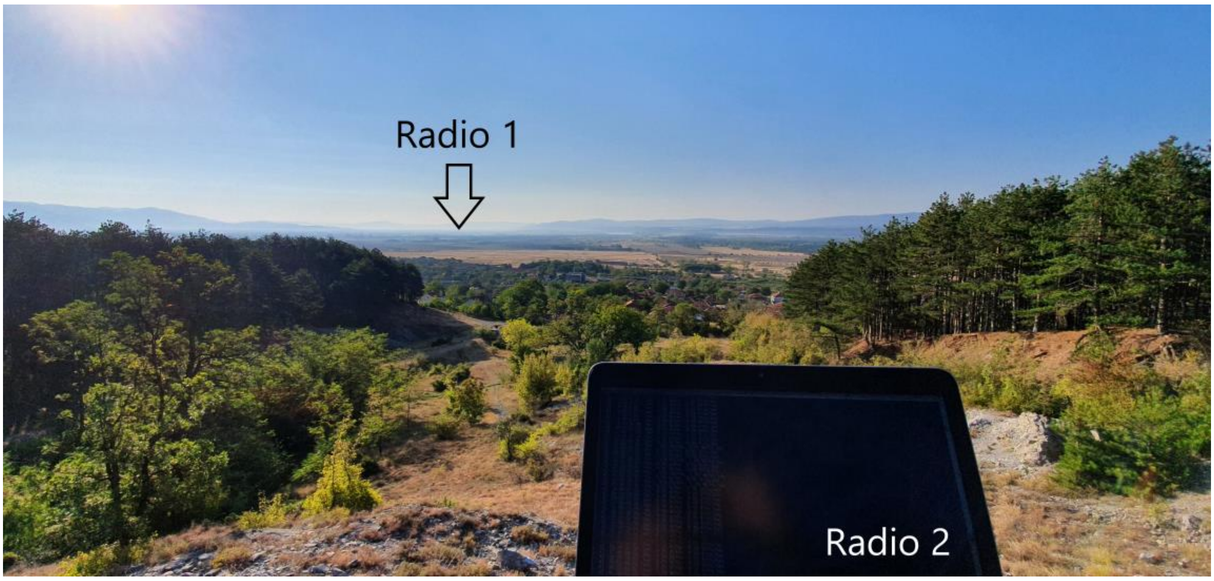


Figure 88 - Range test at 10km (terrain)

Test Logs

```
Pinging 10.120.254.84 with 32 bytes of data:
Reply from 10.120.254.84: bytes=32 time=239ms TTL=128
Reply from 10.120.254.84: bytes=32 time=207ms TTL=128
Reply from 10.120.254.84: bytes=32 time=180ms TTL=128
Reply from 10.120.254.84: bytes=32 time=177ms TTL=128
Reply from 10.120.254.84: bytes=32 time=131ms TTL=128
Reply from 10.120.254.84: bytes=32 time=116ms TTL=128
Reply from 10.120.254.84: bytes=32 time=92ms TTL=128
Reply from 10.120.254.84: bytes=32 time=74ms TTL=128
Reply from 10.120.254.84: bytes=32 time=84ms TTL=128
Reply from 10.120.254.84: bytes=32 time=111ms TTL=128
Reply from 10.120.254.84: bytes=32 time=79ms TTL=128
Reply from 10.120.254.84: bytes=32 time=143ms TTL=128
Reply from 10.120.254.84: bytes=32 time=130ms TTL=128
Reply from 10.120.254.84: bytes=32 time=99ms TTL=128
Reply from 10.120.254.84: bytes=32 time=101ms TTL=128
Reply from 10.120.254.84: bytes=32 time=83ms TTL=128
Reply from 10.120.254.84: bytes=32 time=74ms TTL=128
Reply from 10.120.254.84: bytes=32 time=102ms TTL=128
Reply from 10.120.254.84: bytes=32 time=107ms TTL=128
Reply from 10.120.254.84: bytes=32 time=99ms TTL=128
Reply from 10.120.254.84: bytes=32 time=110ms TTL=128
Reply from 10.120.254.84: bytes=32 time=103ms TTL=128
Reply from 10.120.254.84: bytes=32 time=237ms TTL=128
Reply from 10.120.254.84: bytes=32 time=176ms TTL=128
Reply from 10.120.254.84: bytes=32 time=113ms TTL=128
```

Figure 89 - Latency test at 3km

```
Connecting to host 10.120.254.84, port 5201
[  4] local 10.120.160.139 port 57166 connected to 10.120.254.84 port 5201
[ ID] Interval           Transfer     Bandwidth
[  4]   0.00-1.01   sec   256 KBytes  2.08 Mbits/sec
[  4]   1.01-2.01   sec   256 KBytes  2.10 Mbits/sec
[  4]   2.01-3.01   sec   256 KBytes  2.10 Mbits/sec
[  4]   3.01-4.01   sec   256 KBytes  2.10 Mbits/sec
[  4]   4.01-5.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   5.01-6.00   sec   256 KBytes  2.10 Mbits/sec
[  4]   6.00-7.00   sec   128 KBytes  1.05 Mbits/sec
[  4]   7.00-8.00   sec   128 KBytes  1.05 Mbits/sec
[  4]   8.00-9.00   sec   256 KBytes  2.10 Mbits/sec
[  4]   9.00-10.00  sec   128 KBytes  1.05 Mbits/sec
[  4]  10.00-11.00  sec   256 KBytes  2.10 Mbits/sec
[  4]  11.00-12.00  sec   256 KBytes  2.09 Mbits/sec
[  4]  12.00-13.02  sec   128 KBytes  1.04 Mbits/sec
[  4]  13.02-14.02  sec   128 KBytes  1.04 Mbits/sec
[  4]  14.02-15.02  sec   256 KBytes  2.11 Mbits/sec
[  4]  15.02-16.02  sec   256 KBytes  2.10 Mbits/sec
[  4]  16.02-17.02  sec   128 KBytes  1.05 Mbits/sec
[  4]  17.02-18.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  18.01-19.01  sec   256 KBytes  2.11 Mbits/sec
[  4]  19.01-20.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  20.01-21.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  21.01-22.01  sec   256 KBytes  2.10 Mbits/sec
[  4]  22.01-23.01  sec   128 KBytes  1.04 Mbits/sec
[  4]  23.01-24.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  24.01-25.01  sec   256 KBytes  2.10 Mbits/sec
[  4]  25.01-26.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  26.01-27.00  sec   128 KBytes  1.05 Mbits/sec
[  4]  27.00-28.00  sec   256 KBytes  2.10 Mbits/sec
[  4]  28.00-29.00  sec   128 KBytes  1.05 Mbits/sec
[  4]  29.00-30.00  sec   256 KBytes  2.10 Mbits/sec
```

Figure 90 - TCP test at 3km

```
Connecting to host 10.120.254.84, port 5201
[  4] local 10.120.160.139 port 64354 connected to 10.120.254.84 port 5201
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.02   sec   896 KBytes  7.23 Mbits/sec  112
[  4]   1.02-2.01   sec   976 KBytes  8.03 Mbits/sec  122
[  4]   2.01-3.01   sec   984 KBytes  8.10 Mbits/sec  123
[  4]   3.01-4.00   sec   976 KBytes  8.03 Mbits/sec  122
[  4]   4.00-5.00   sec   968 KBytes  7.92 Mbits/sec  121
[  4]   5.00-6.01   sec   984 KBytes  8.00 Mbits/sec  123
[  4]   6.01-7.00   sec   976 KBytes  8.06 Mbits/sec  122
[  4]   7.00-8.00   sec   976 KBytes  8.00 Mbits/sec  122
[  4]   8.00-9.01   sec   976 KBytes  7.90 Mbits/sec  122
[  4]   9.01-10.01  sec   984 KBytes  8.09 Mbits/sec  123
[  4]  10.01-11.00  sec   968 KBytes  7.97 Mbits/sec  121
[  4]  11.00-12.01  sec   976 KBytes  7.99 Mbits/sec  122
[  4]  12.01-13.01  sec   984 KBytes  8.03 Mbits/sec  123
[  4]  13.01-14.00  sec   968 KBytes  7.97 Mbits/sec  121
[  4]  14.00-15.00  sec   976 KBytes  8.01 Mbits/sec  122
[  4]  15.00-16.02  sec   984 KBytes  7.97 Mbits/sec  123
[  4]  16.02-17.00  sec   976 KBytes  8.10 Mbits/sec  122
[  4]  17.00-18.01  sec   976 KBytes  7.94 Mbits/sec  122
[  4]  18.01-19.01  sec   992 KBytes  8.08 Mbits/sec  124
[  4]  19.01-20.01  sec   960 KBytes  7.90 Mbits/sec  120
[  4]  20.01-21.00  sec   976 KBytes  8.05 Mbits/sec  122
[  4]  21.00-22.01  sec   976 KBytes  7.94 Mbits/sec  122
[  4]  22.01-23.01  sec   984 KBytes  8.09 Mbits/sec  123
[  4]  23.01-24.00  sec   968 KBytes  7.96 Mbits/sec  121
[  4]  24.00-25.00  sec   976 KBytes  7.99 Mbits/sec  122
[  4]  25.00-26.01  sec   984 KBytes  8.03 Mbits/sec  123
[  4]  26.01-27.00  sec   968 KBytes  7.95 Mbits/sec  121
[  4]  27.00-28.01  sec   984 KBytes  8.01 Mbits/sec  123
[  4]  28.01-29.01  sec   984 KBytes  8.04 Mbits/sec  123
[  4]  29.01-30.00  sec   968 KBytes  8.02 Mbits/sec  121
```

Figure 91 - UDP test at 3km

```
Pinging 10.120.162.105 with 32 bytes of data:
Reply from 10.120.162.105: bytes=32 time=187ms TTL=128
Reply from 10.120.162.105: bytes=32 time=149ms TTL=128
Reply from 10.120.162.105: bytes=32 time=129ms TTL=128
Reply from 10.120.162.105: bytes=32 time=67ms TTL=128
Reply from 10.120.162.105: bytes=32 time=137ms TTL=128
Reply from 10.120.162.105: bytes=32 time=91ms TTL=128
Reply from 10.120.162.105: bytes=32 time=119ms TTL=128
Reply from 10.120.162.105: bytes=32 time=101ms TTL=128
Reply from 10.120.162.105: bytes=32 time=114ms TTL=128
Reply from 10.120.162.105: bytes=32 time=94ms TTL=128
Reply from 10.120.162.105: bytes=32 time=68ms TTL=128
Reply from 10.120.162.105: bytes=32 time=111ms TTL=128
Reply from 10.120.162.105: bytes=32 time=282ms TTL=128
Reply from 10.120.162.105: bytes=32 time=248ms TTL=128
Reply from 10.120.162.105: bytes=32 time=236ms TTL=128
Reply from 10.120.162.105: bytes=32 time=257ms TTL=128
Reply from 10.120.162.105: bytes=32 time=237ms TTL=128
Reply from 10.120.162.105: bytes=32 time=201ms TTL=128
Reply from 10.120.162.105: bytes=32 time=223ms TTL=128
Reply from 10.120.162.105: bytes=32 time=146ms TTL=128
Reply from 10.120.162.105: bytes=32 time=126ms TTL=128
Reply from 10.120.162.105: bytes=32 time=99ms TTL=128
Reply from 10.120.162.105: bytes=32 time=130ms TTL=128
Reply from 10.120.162.105: bytes=32 time=114ms TTL=128
Reply from 10.120.162.105: bytes=32 time=87ms TTL=128
Reply from 10.120.162.105: bytes=32 time=78ms TTL=128
Reply from 10.120.162.105: bytes=32 time=120ms TTL=128
Reply from 10.120.162.105: bytes=32 time=79ms TTL=128
Reply from 10.120.162.105: bytes=32 time=113ms TTL=128
Reply from 10.120.162.105: bytes=32 time=100ms TTL=128
Reply from 10.120.162.105: bytes=32 time=79ms TTL=128
```

Figure 92 - Latency test at 5.5km

```
Connecting to host 10.120.162.105, port 5201
[  4] local 10.120.160.139 port 56031 connected to 10.120.162.105 port 5201
[ ID] Interval           Transfer     Bandwidth
[  4]   0.00-1.01   sec   256 KBytes  2.08 Mbits/sec
[  4]   1.01-2.00   sec   256 KBytes  2.11 Mbits/sec
[  4]   2.00-3.00   sec   384 KBytes  3.14 Mbits/sec
[  4]   3.00-4.00   sec   384 KBytes  3.16 Mbits/sec
[  4]   4.00-5.01   sec   512 KBytes  4.16 Mbits/sec
[  4]   5.01-6.00   sec   256 KBytes  2.12 Mbits/sec
[  4]   6.00-7.01   sec   384 KBytes  3.12 Mbits/sec
[  4]   7.01-8.01   sec   384 KBytes  3.15 Mbits/sec
[  4]   8.01-9.01   sec   512 KBytes  4.17 Mbits/sec
[  4]   9.01-10.01  sec   384 KBytes  3.17 Mbits/sec
[  4]  10.01-11.04  sec   384 KBytes  3.04 Mbits/sec
[  4]  11.04-12.01  sec   384 KBytes  3.25 Mbits/sec
[  4]  12.01-13.01  sec   512 KBytes  4.18 Mbits/sec
[  4]  13.01-14.02  sec   384 KBytes  3.14 Mbits/sec
[  4]  14.02-15.00  sec   256 KBytes  2.12 Mbits/sec
[  4]  15.00-16.01  sec   512 KBytes  4.18 Mbits/sec
[  4]  16.01-17.01  sec   384 KBytes  3.12 Mbits/sec
[  4]  17.01-18.02  sec   256 KBytes  2.09 Mbits/sec
[  4]  18.02-19.00  sec   384 KBytes  3.19 Mbits/sec
[  4]  19.00-20.01  sec   384 KBytes  3.13 Mbits/sec
[  4]  20.01-21.00  sec   384 KBytes  3.16 Mbits/sec
[  4]  21.00-22.00  sec   384 KBytes  3.14 Mbits/sec
[  4]  22.00-23.02  sec   384 KBytes  3.11 Mbits/sec
[  4]  23.02-24.01  sec   384 KBytes  3.16 Mbits/sec
[  4]  24.01-25.02  sec   384 KBytes  3.13 Mbits/sec
[  4]  25.02-26.01  sec   384 KBytes  3.17 Mbits/sec
[  4]  26.01-27.01  sec   512 KBytes  4.18 Mbits/sec
[  4]  27.01-28.02  sec   384 KBytes  3.14 Mbits/sec
[  4]  28.02-29.02  sec   512 KBytes  4.19 Mbits/sec
[  4]  29.02-30.01  sec   256 KBytes  2.11 Mbits/sec
```

Figure 93 - TCP test at 5.5km

```
Connecting to host 10.120.162.105, port 5201
[  4] local 10.120.160.139 port 50626 connected to 10.120.162.105 port 5201
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.01   sec   912 KBytes  7.38 Mbits/sec  114
[  4]   1.01-2.00   sec   968 KBytes  8.01 Mbits/sec  121
[  4]   2.00-3.01   sec   976 KBytes  7.93 Mbits/sec  122
[  4]   3.01-4.00   sec   968 KBytes  7.99 Mbits/sec  121
[  4]   4.00-5.00   sec   984 KBytes  8.06 Mbits/sec  123
[  4]   5.00-6.00   sec   968 KBytes  7.91 Mbits/sec  121
[  4]   6.00-7.01   sec   976 KBytes  7.96 Mbits/sec  122
[  4]   7.01-8.01   sec   984 KBytes  8.08 Mbits/sec  123
[  4]   8.01-9.01   sec   976 KBytes  7.98 Mbits/sec  122
[  4]   9.01-10.01  sec   984 KBytes  8.05 Mbits/sec  123
[  4]  10.01-11.02  sec   968 KBytes  7.86 Mbits/sec  121
[  4]  11.02-12.01  sec   976 KBytes  8.07 Mbits/sec  122
[  4]  12.01-13.00  sec   984 KBytes  8.10 Mbits/sec  123
[  4]  13.00-14.00  sec   968 KBytes  7.96 Mbits/sec  121
[  4]  14.00-15.00  sec   984 KBytes  8.03 Mbits/sec  123
[  4]  15.00-16.00  sec   968 KBytes  7.93 Mbits/sec  121
[  4]  16.00-17.00  sec   976 KBytes  8.00 Mbits/sec  122
[  4]  17.00-18.02  sec   976 KBytes  7.83 Mbits/sec  122
[  4]  18.02-19.00  sec   984 KBytes  8.25 Mbits/sec  123
[  4]  19.00-20.00  sec   976 KBytes  7.98 Mbits/sec  122
[  4]  20.00-21.00  sec   976 KBytes  8.00 Mbits/sec  122
[  4]  21.00-22.00  sec   976 KBytes  7.99 Mbits/sec  122
[  4]  22.00-23.00  sec   984 KBytes  8.05 Mbits/sec  123
[  4]  23.00-24.00  sec   968 KBytes  7.95 Mbits/sec  121
[  4]  24.00-25.00  sec   976 KBytes  7.99 Mbits/sec  122
[  4]  25.00-26.01  sec   976 KBytes  7.96 Mbits/sec  122
[  4]  26.01-27.00  sec   976 KBytes  8.03 Mbits/sec  122
[  4]  27.00-28.00  sec   976 KBytes  8.01 Mbits/sec  122
[  4]  28.00-29.00  sec   984 KBytes  8.06 Mbits/sec  123
[  4]  29.00-30.00  sec   976 KBytes  7.98 Mbits/sec  122
```

Figure 94 - UDP test at 5.5km

7.3.3 **TST_TRLS_003:** Test the connectivity between three 'Cub' terminals on the field using radio relaying

<table>
<tr><th colspan="2">Test case ID</th></tr>
<tr><td colspan="2">TST_TRLS_003</td></tr>
<tr><th colspan="2">Test Scenario</th></tr>
<tr><td colspan="2">The goal of this test is to test the radio relaying capability of the Trellisware Cub radio terminal. This functionality allows the radio terminal to act as a relay for two radios that are out of range of each other but within range of the radio acting as a relay. Therefore, this functionality of the Trellisware Cub allows it to drastically increase the range of the Trellisware MANET since it can support up to 8 hops between radio relays in the MANET.
The test was performed by placing two radios at the distance of 10 km with established LOS (same as in TST_TRLS_002) and a third radio at the distance of 100m and LOS to the second radio, without LOS to the first radio. This means that the second radio will act as a relay for the communication between the first and third radio.</td></tr>
<tr><th colspan="2">Test Results</th></tr>
<tr><th colspan="2">Radio 1 : Radio 2</th></tr>
<tr><td>Link SNR</td><td>6 dB</td></tr>
<tr><td>Bandwidth</td><td>TCP: 1.16 Mbps, UDP: 2.14 Mbps</td></tr>
<tr><td>Packet losses (UDP)</td><td>4.2%</td></tr>
<tr><td>Latency</td><td>Minimum = 82ms, Maximum = 302ms, Average = 142ms</td></tr>
</table>

Radio 2 : Radio 3	
Link SNR	51 dB
Bandwidth	TCP: 3.12 Mbps, UDP: 7.83 Mbps
Packet losses (UDP)	0.21%
Latency	Minimum = 76ms, Maximum = 387ms, Average = 147ms
Radio 1 : Radio 3	
Link SNR	No direct link
Bandwidth	TCP: 0.78 Mbps, UDP: 1.97 Mbps
Packet losses (UDP)	6.4 %
Latency	Minimum = 81ms, Maximum = 343ms, Average = 147ms

Figure 95 - Radio relay test (Radio 2 Point of View)

Figure 96 - Radio relay test (Radio 3 Point of View)

7.3.4 **TST_TRLS_004:** LOS range test between two 'Cub' terminals over sea

Test case ID	
TST_TRLS_004	
Test Scenario	
The goal of this test is to evaluate the range, throughput and latency between two 'Cub' terminals by placing them at various distances from each other ensuring LOS over the sea in order to evaluate the effect of the water surface and waves on the radio transmission. In order to do this, we keep one radio terminal at a fixed position and move the other radio to different positions relative to the first. At each designated distance, we evaluate the throughput and latency of the connection between the two radios. We repeat the tests for the following distances between the radios: 50m, 2.3km, 5.5km, 7.5km and 10km. The tests presented in this table have been performed in The Portuguese Navy base in Lisbon, Portugal from 30.09.2020 until 02.10.2020 with the support of the Portuguese Navy (Marinha Portuguesa).	
Test Results	
2.3 km	
Link SNR	35 dB
Bandwidth	TCP: 3.45 Mbps, UDP: 7.96 Mbps
Packet losses (UDP)	0.11%
Latency	Minimum = 82ms, Maximum = 387ms, Average = 159ms
5.5 km	
Link SNR	24 dB
Bandwidth	TCP: 3.12 Mbps, UDP: 7.68 Mbps
Packet losses (UDP)	0.27%
Latency	Minimum = 73ms, Maximum = 317ms, Average = 145ms
7.5 km	
Link SNR	26 dB
Bandwidth	TCP: 2.56 Mbps, UDP: 6.75 Mbps
Packet losses (UDP)	2.3%
Latency	Minimum = 92ms, Maximum = 396ms, Average = 178ms
10 km	
Link SNR	16 dB
Bandwidth	TCP: 1.72 Mbps, UDP: 6.23 Mbps
Packet losses (UDP)	4.7%
Latency	Minimum = 74ms, Maximum = 291ms, Average = 142ms

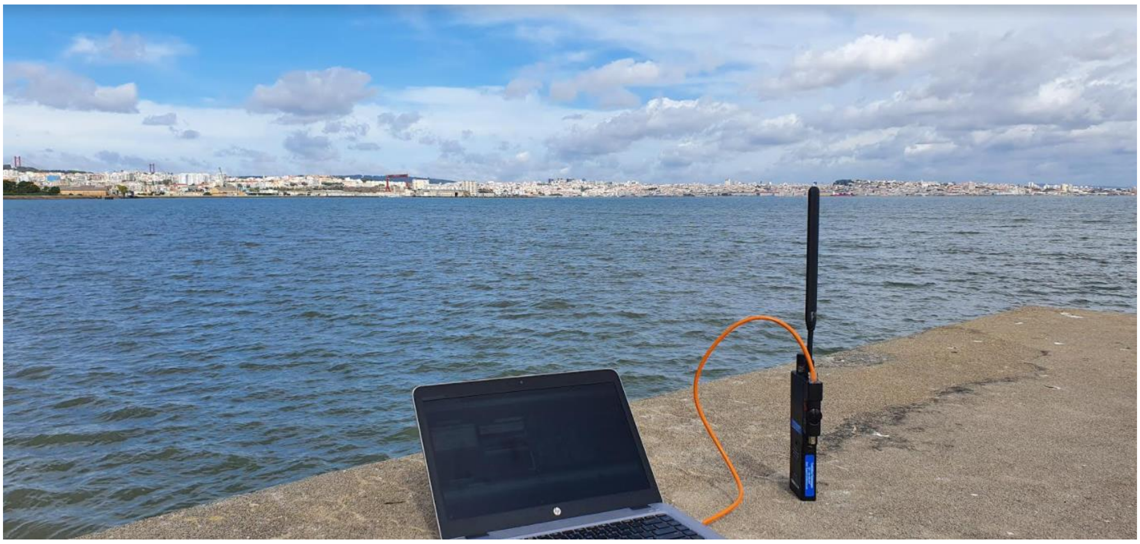


Figure 97 - Range test at 2.3 km (terrain)

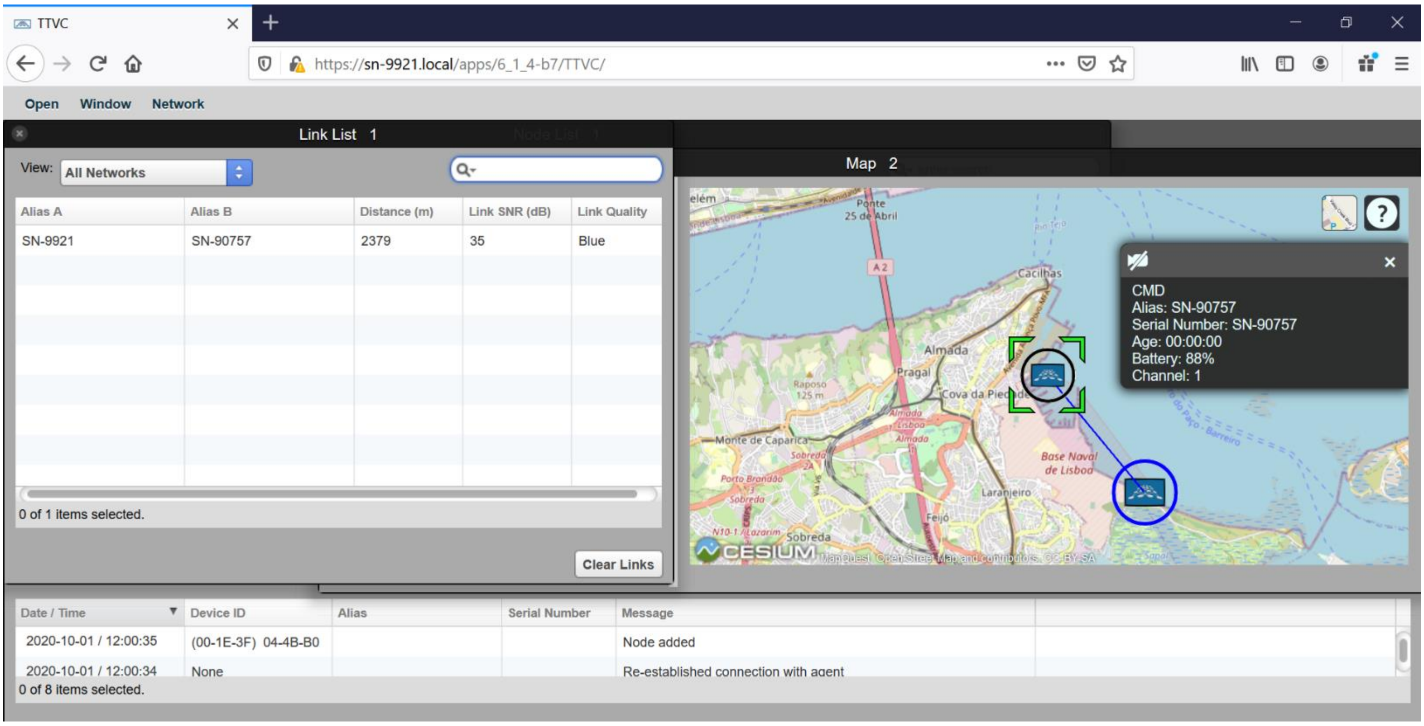


Figure 98 - Range test at 2.3 km (map)

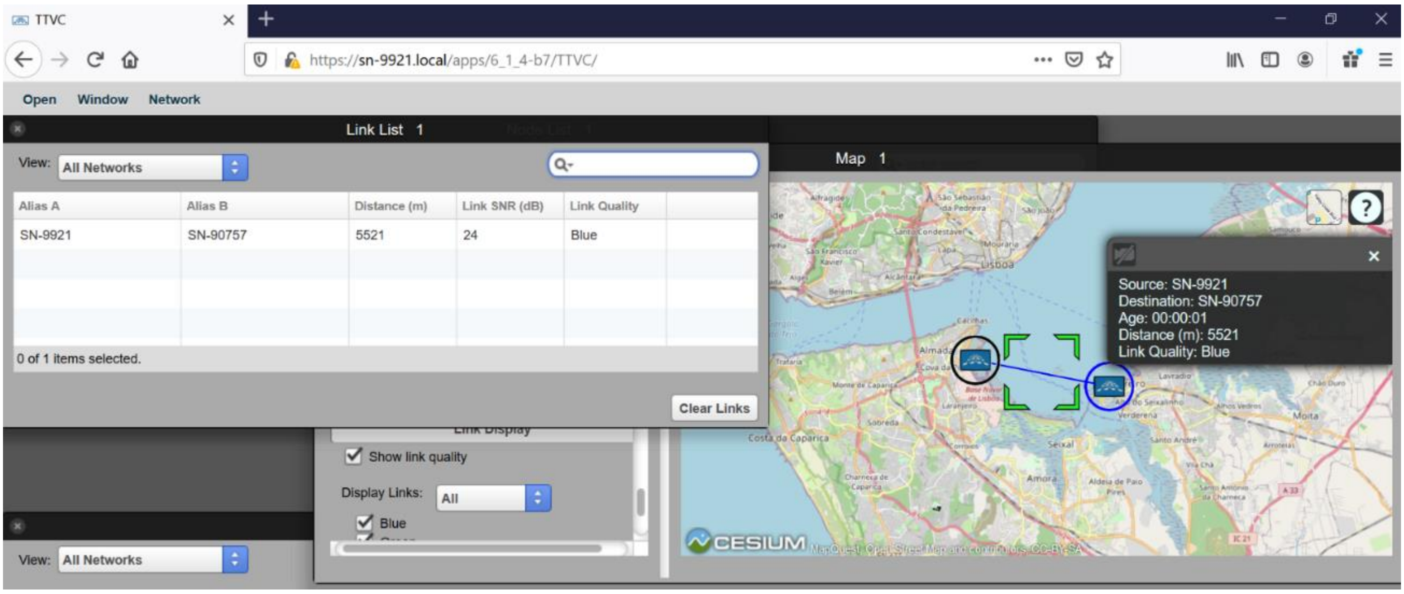


Figure 99 - Range test at 5.5km (map)

Figure 100 - Range test at 5.5km (terrain)

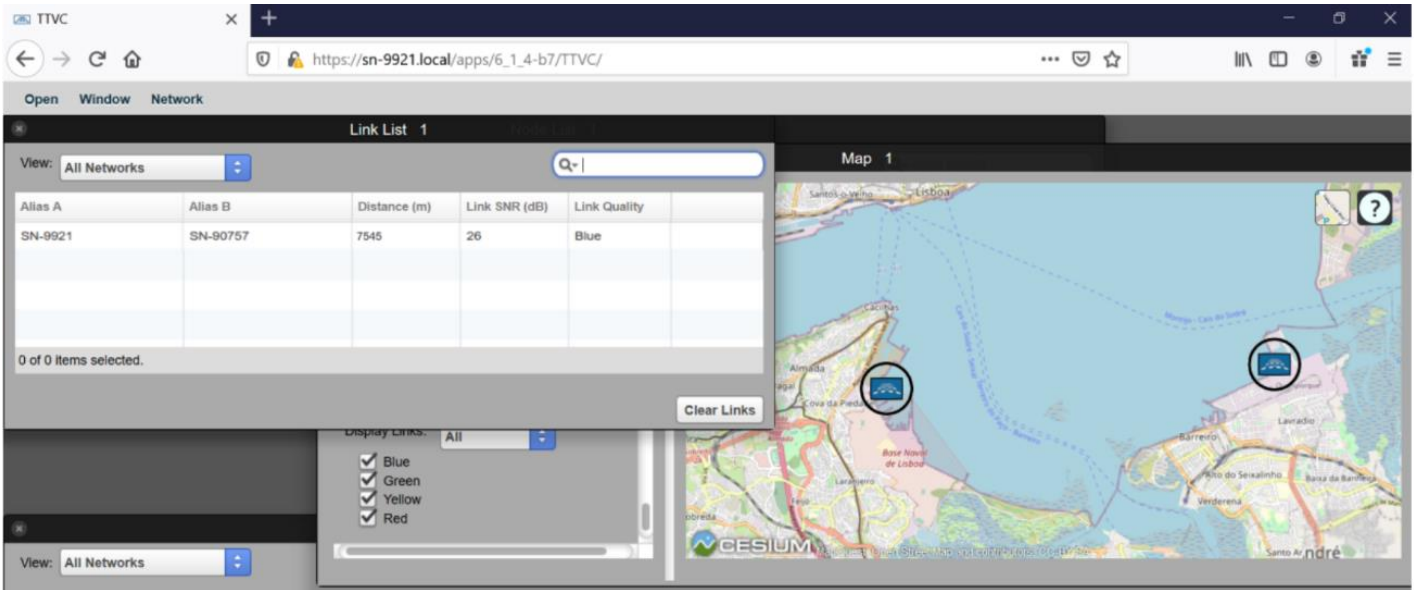


Figure 101 - Range test at 7.5km (map)

Figure 102 - Range test at 7.5km (terrain)

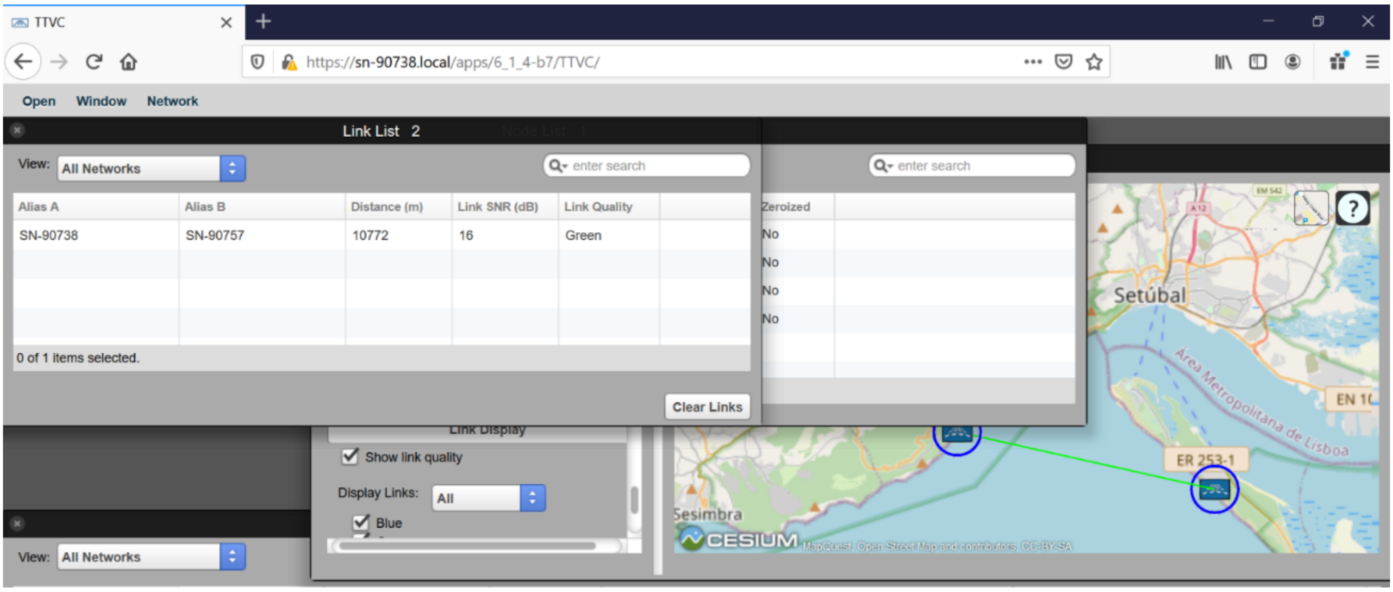


Figure 103 - Range test at 10km (map)

Figure 104 - Range test at 10km (terrain)

Test Logs

```
Pinging 10.120.254.88 with 32 bytes of data:
Reply from 10.120.254.88: bytes=32 time=71ms TTL=128
Reply from 10.120.254.88: bytes=32 time=106ms TTL=128
Reply from 10.120.254.88: bytes=32 time=101ms TTL=128
Reply from 10.120.254.88: bytes=32 time=91ms TTL=128
Reply from 10.120.254.88: bytes=32 time=83ms TTL=128
Reply from 10.120.254.88: bytes=32 time=116ms TTL=128
Reply from 10.120.254.88: bytes=32 time=106ms TTL=128
Reply from 10.120.254.88: bytes=32 time=98ms TTL=128
Reply from 10.120.254.88: bytes=32 time=127ms TTL=128
Reply from 10.120.254.88: bytes=32 time=275ms TTL=128
Reply from 10.120.254.88: bytes=32 time=80ms TTL=128
Reply from 10.120.254.88: bytes=32 time=269ms TTL=128
Reply from 10.120.254.88: bytes=32 time=251ms TTL=128
Reply from 10.120.254.88: bytes=32 time=191ms TTL=128
Reply from 10.120.254.88: bytes=32 time=166ms TTL=128
Reply from 10.120.254.88: bytes=32 time=147ms TTL=128
Reply from 10.120.254.88: bytes=32 time=167ms TTL=128
Reply from 10.120.254.88: bytes=32 time=127ms TTL=128
Reply from 10.120.254.88: bytes=32 time=149ms TTL=128
Reply from 10.120.254.88: bytes=32 time=90ms TTL=128
Reply from 10.120.254.88: bytes=32 time=84ms TTL=128
Reply from 10.120.254.88: bytes=32 time=116ms TTL=128
Reply from 10.120.254.88: bytes=32 time=81ms TTL=128
Reply from 10.120.254.88: bytes=32 time=111ms TTL=128
Reply from 10.120.254.88: bytes=32 time=113ms TTL=128
Reply from 10.120.254.88: bytes=32 time=108ms TTL=128
Reply from 10.120.254.88: bytes=32 time=84ms TTL=128
Reply from 10.120.254.88: bytes=32 time=77ms TTL=128
Reply from 10.120.254.88: bytes=32 time=74ms TTL=128
Reply from 10.120.254.88: bytes=32 time=159ms TTL=128
```

Figure 105 - Latency test at 5.5km

```
Connecting to host 10.120.254.88, port 5201
[  4] local 10.120.160.139 port 52887 connected to 10.120.254.88
[ ID] Interval           Transfer     Bandwidth
[  4]   0.00-1.00   sec   256 KBytes  2.10 Mbits/sec
[  4]   1.00-2.00   sec   384 KBytes  3.14 Mbits/sec
[  4]   2.00-3.00   sec   384 KBytes  3.15 Mbits/sec
[  4]   3.00-4.00   sec   384 KBytes  3.15 Mbits/sec
[  4]   4.00-5.00   sec   384 KBytes  3.15 Mbits/sec
[  4]   5.00-6.00   sec   384 KBytes  3.14 Mbits/sec
[  4]   6.00-7.00   sec   256 KBytes  2.10 Mbits/sec
[  4]   7.00-8.00   sec   512 KBytes  4.18 Mbits/sec
[  4]   8.00-9.00   sec   512 KBytes  4.20 Mbits/sec
[  4]   9.00-10.00  sec   256 KBytes  2.10 Mbits/sec
[  4]  10.00-11.00  sec   512 KBytes  4.20 Mbits/sec
[  4]  11.00-12.00  sec   256 KBytes  2.10 Mbits/sec
[  4]  12.00-13.00  sec   384 KBytes  3.14 Mbits/sec
[  4]  13.00-14.00  sec   384 KBytes  3.15 Mbits/sec
[  4]  14.00-15.00  sec   384 KBytes  3.15 Mbits/sec
[  4]  15.00-16.00  sec   384 KBytes  3.14 Mbits/sec
[  4]  16.00-17.00  sec   384 KBytes  3.15 Mbits/sec
[  4]  17.00-18.00  sec   512 KBytes  4.20 Mbits/sec
[  4]  18.00-19.00  sec   256 KBytes  2.10 Mbits/sec
[  4]  19.00-20.00  sec   384 KBytes  3.15 Mbits/sec
[  4]  20.00-21.00  sec   256 KBytes  2.09 Mbits/sec
[  4]  21.00-22.00  sec   384 KBytes  3.15 Mbits/sec
[  4]  22.00-23.00  sec   384 KBytes  3.15 Mbits/sec
[  4]  23.00-24.00  sec   384 KBytes  3.14 Mbits/sec
[  4]  24.00-25.00  sec   384 KBytes  3.15 Mbits/sec
[  4]  25.00-26.00  sec   384 KBytes  3.15 Mbits/sec
[  4]  26.00-27.00  sec   384 KBytes  3.14 Mbits/sec
[  4]  27.00-28.00  sec   512 KBytes  4.19 Mbits/sec
[  4]  28.00-29.00  sec   384 KBytes  3.14 Mbits/sec
[  4]  29.00-30.00  sec   384 KBytes  3.15 Mbits/sec
```

Figure 106 - TCP test at 5.5km

```
Connecting to host 10.120.254.88, port 5201
[  4] local 10.120.160.139 port 63883 connected to 10.120.254.88 port
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.00   sec   912 KBytes  7.47 Mbits/sec  114
[  4]   1.00-2.00   sec   976 KBytes  8.00 Mbits/sec  122
[  4]   2.00-3.00   sec   960 KBytes  7.86 Mbits/sec  120
[  4]   3.00-4.00   sec   984 KBytes  8.06 Mbits/sec  123
[  4]   4.00-5.00   sec   976 KBytes  7.99 Mbits/sec  122
[  4]   5.00-6.00   sec   968 KBytes  7.93 Mbits/sec  121
[  4]   6.00-7.01   sec   992 KBytes  8.05 Mbits/sec  124
[  4]   7.01-8.00   sec   960 KBytes  7.94 Mbits/sec  120
[  4]   8.00-9.01   sec   984 KBytes  7.95 Mbits/sec  123
[  4]   9.01-10.00  sec   976 KBytes  8.11 Mbits/sec  122
[  4]  10.00-11.00  sec   984 KBytes  8.06 Mbits/sec  123
[  4]  11.00-12.00  sec   968 KBytes  7.93 Mbits/sec  121
[  4]  12.00-13.00  sec   976 KBytes  7.99 Mbits/sec  122
[  4]  13.00-14.00  sec   992 KBytes  8.13 Mbits/sec  124
[  4]  14.00-15.00  sec   960 KBytes  7.86 Mbits/sec  120
[  4]  15.00-16.00  sec   976 KBytes  8.00 Mbits/sec  122
[  4]  16.00-17.00  sec   984 KBytes  8.06 Mbits/sec  123
[  4]  17.00-18.00  sec   968 KBytes  7.92 Mbits/sec  121
[  4]  18.00-19.00  sec   992 KBytes  8.13 Mbits/sec  124
[  4]  19.00-20.00  sec   984 KBytes  8.06 Mbits/sec  123
[  4]  20.00-21.00  sec   976 KBytes  8.00 Mbits/sec  122
[  4]  21.00-22.00  sec   960 KBytes  7.86 Mbits/sec  120
[  4]  22.00-23.00  sec   992 KBytes  8.13 Mbits/sec  124
[  4]  23.00-24.00  sec   968 KBytes  7.93 Mbits/sec  121
[  4]  24.00-25.00  sec   976 KBytes  8.00 Mbits/sec  122
[  4]  25.00-26.00  sec   984 KBytes  8.06 Mbits/sec  123
[  4]  26.00-27.00  sec   960 KBytes  7.85 Mbits/sec  120
[  4]  27.00-28.00  sec   976 KBytes  8.01 Mbits/sec  122
[  4]  28.00-29.00  sec   992 KBytes  8.13 Mbits/sec  124
[  4]  29.00-30.00  sec   968 KBytes  7.93 Mbits/sec  121
```

Figure 107 - UDP test at 5.5km

7.3.5 **TST_TRLS_005:** NLOS range test between Trellisware terminals with radio relaying using an aerostat

Test case ID	
TST_TRLS_005	
Test Scenario	
The goal of this test is to test the radio relaying capability of the Trellisware Cub radio terminal. This functionality allows the radio terminal to act as a relay for two radios that are out of range of each other but within range of the radio acting as a relay. Therefore, this functionality of the Trellisware Cub allows it to drastically increase the range of the Trellisware MANET since it can support up to 8 hops between radio relays in the MANET. The test was performed by placing a stationary Trellisware Cub radio at the ground (football pitch) and mounting a radio relay (Trellisware Ghost terminal) on an aerostat flying over the football pitch at a height of 35m. The third radio is a Trellisware Cub radio terminal mounted on a vehicle which is driving along a path with many obstacles that ensures that the two Cub radios do not have LOS. We evaluate the throughput and latency of the connection between the two Trellisware Cub radios using the Trellisware Ghost mounted on the aerostat as relay at the following distances: 100m, 230m, 600m and 1.2km.	
Test Results	
100 m	
Link SNR (Cub-Ghost)	48 dB
Bandwidth	TCP: 2.38 Mbps, UDP: 6.34 Mbps
Packet losses (UDP)	0.29%

Latency	Minimum = 72ms, Maximum = 487ms, Average = 171ms
230 m	
Link SNR (Cub-Ghost)	41 dB
Bandwidth	TCP: 2.1 Mbps, UDP: 5.32 Mbps
Packet losses (UDP)	0.37%
Latency	Minimum = 73ms, Maximum = 317ms, Average = 195ms
600 m	
Link SNR (Cub-Ghost)	40 dB
Bandwidth	TCP: 1.67 Mbps, UDP: 5.75 Mbps
Packet losses (UDP)	1.3%
Latency	Minimum = 92ms, Maximum = 396ms, Average = 178ms
1.2 km	
Link SNR (Cub-Ghost)	36 dB
Bandwidth	TCP: 1.49 Mbps, UDP: 4.78 Mbps
Packet losses (UDP)	3.7%
Latency	Minimum = 91ms, Maximum = 491ms, Average = 212ms

Figure 108 - Radio relay test with aerostat (map)

Figure 109 - Setting up the aerostat

Figure 110 - Aerostat flying at the height of 35m

Figure 111 - Aerostat flying at the height of 35m after the set-up

8 On-field demonstrations

This section summarizes the technical specifications, limitations and regulations for the on-field demonstrations in the ARESIBO project. There is a distinction between the specifications and the setup for the on-field demonstrations and the eventual operational solution.

8.1 Technical specifications

Table 1 Technical specifications of the last mile solutions

Setup	On-field demonstration		Operational	
Last mile solution	Wi-Fi	MANET	Wi-Fi	MANET
Number of users	20	4	60 (to be tested)	60 (to be tested)
Total bandwidth LTE	20 Mbps	20 Mbps	40 Mbps (to be tested)	40 Mbps (to be tested)
Total bandwidth SATCOM (nomadic)	2 Mbps	2 Mbps	5 Mbps (to be tested)	5 Mbps (to be tested)
Total bandwidth SATCOM (communication hub)	1 Mbps	1 Mbps	5 Mbps (to be tested)	5 Mbps (to be tested)

There are several notes concerning the on-field demonstrations:

- Due to the complexity and cost of deploying the Viasat land vehicle to the demonstration location, Viasat will deploy a nomadic antenna system for the on-field demonstrations.
- The number of users and total bandwidth for the operational solution are based on estimations and require further testing.

8.2 Radio transmission and aerostat regulations

The radio terminals and the aerostat used in the ARESIBO network architecture require a permission to operate. Therefore, we have contacted several partners in the project with the goal of obtaining a permit to operate the equipment in each country.

Table 2 - Status of permits

Point of Contact	Partner	Status
Vítor Fernando Plácido da Conceição	Portuguese Naval Academy	Permit granted and testing performed onsite
Major Dr. Iliyan Hutov	Bulgarian Defence Institute	Permit granted and testing performed onsite (only radio)
Andreas Tsigkopoulos	Hellenic Naval Academy	Permit granted
Lauri Haasto	Finnish Border Guard	Permit process clarified and request to be submitted before due date

Equipment specifications:

1. Aerostat

- Diameter: 3m
- Volume: 6.5m3
- Material: PVC
- Color: white and red
- Wiring: 5mm rope with a maximum length of 200m.
- Fixing stakes: 40cm high

2. Trellisware radio terminals

- Frequency: 2250 MHz (adjustable)
- Channel bandwidth: 4MHz
- Transmitting power 2-4W

8.3 Maritime scenario with Cobham Sailor antenna (concept)

The proposed solution for the maritime scenario consists of the Trellisware MANET for the radio communication between the field units and a satellite link as backhaul. The satellite link is established by a Cobham Sailor satellite antenna mounted on a ship that will act as the communication hub for the other field unites (vessels, UAVs and helicopters). The Cobham Sailor satellite antenna, shown in Figure 112, operates in Ku-Band and Ka-Band (Rx: 10.70 to 12.75 GHz, Tx: 13.75 to 14.50 GHz) and has overall dimensions: Height: 150 cm and Diameter: 130 cm, which makes it ideal for deployment on a larger ship.

Figure 112 - Cobham Sailor satellite antenna

The network architecture diagram is shown in Figure 113. As shown in the diagram, the ship acts as the communication hub and all the field units are equipped with Trellisware radio terminals. These terminals have a single hop range of 30km with the ability to relay signals from other terminals for up to 8 hops, thus providing a large covering range. This means that if a field unit equipped with a Trellisware terminal is not in range to directly communicate with the communication hub, it can use another field unit in range as a relay to communicate with the communication hub. The communication hub receives the data streams from the field units and uses the satellite link to establish a bidirectional connection with the ARESIBO C2 centre via the Viasat satellite network.
The complexity of the installation of the Cobham Sailor satellite antenna and the requirements for the vessel that it infers, make this solution very difficult to demonstrate on the field. In order for the demonstration to be possible, several modifications need to be made:

- Update the design of the vessel with static and dynamic structural verification

- Cabling of the area where the antenna will be installed providing:
    - Power
    - Ethernet
    - Compass and Gyroscope data
    - RF coaxial cabling
- Testing the vessel equipment for non-interference with actual systems.

A demonstration of ship SATCOM capabilities may be set in place using existing SATCOM-ready vessels even if the installed equipment will not be as capable in terms of data throughput as the Viasat one.

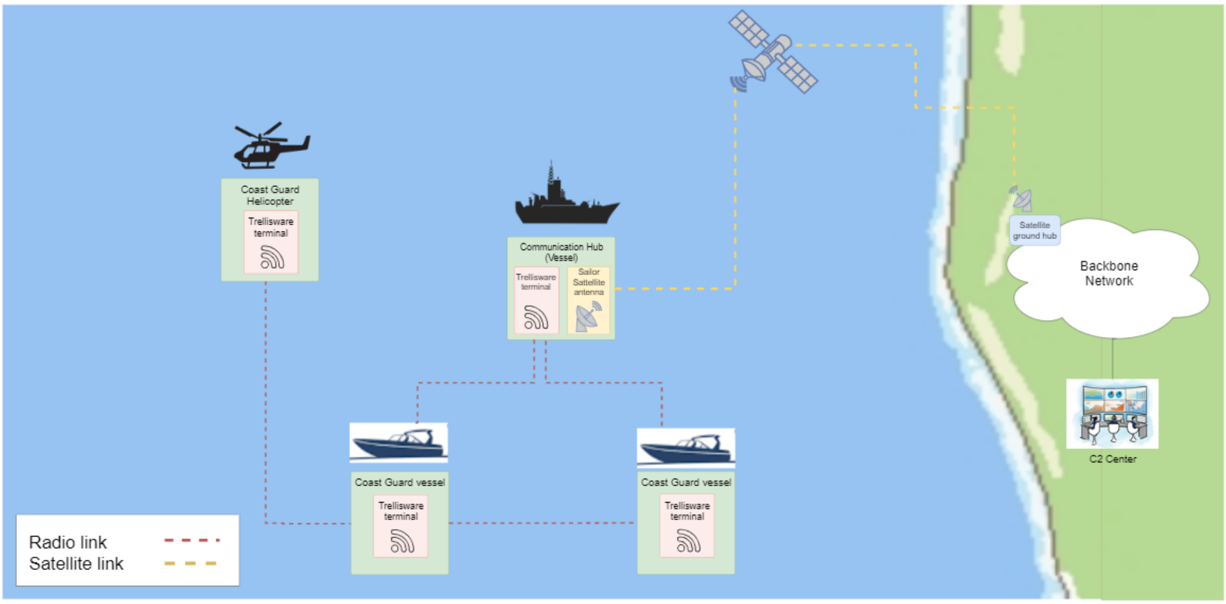


Figure 113 - Network architecture for the maritime scenario

9 Brazilian test campaign

Viasat is planning to perform extensive tests of the system as part of an internal project in Brazil. Viasat has identified both a technical and commercial potential on running tests in Brazil. Viasat currently operates the government satellite SDGC1 owned by the public entity Telebras. Telebras has expressed a strong interest in our mobile communication hub for public first responder applications and other public safety agencies. These synergies combined with the challenging environmental will help to take a significant step forward towards validating both the technical and commercial viability of our solution. These tests can be extended and adapted to the ARESIBO setup and provide valuable insights into the system performance in conditions that cannot be tested in Switzerland, but can be met by some partners in ARESIBO during their operations. These conditions and their effect on the system are explained in more detail in this section.

Antenna angle of elevation

Due to the lower latitude of the testing locations in Brazil and their relative position to the satellite, the KaLMA antenna will have to perform with a higher angle of elevation compared to Switzerland when pointing to the satellite. The goal of these tests is to evaluate the capability of the system to maintain a high level of performance while constantly pointing at a higher angle of elevation. These tests are relevant for the ARESIBO project since there are partners in ARESIBO operating in locations with different latitudes and these tests will provide an answer whether the angle of elevation of the satellite antenna has an effect on the system performance.

Weather conditions

The weather conditions in Brazil are vastly different to the ones in Switzerland, mainly in terms of the temperature and humidity. Therefore, the goal of this test is to evaluate the effect of the weather conditions (mostly temperature and humidity) on the satellite antenna and the whole system. This test is relevant for the ARESIBO project as it will provide valuable insight on the system performance for partners that operate in similar weather conditions.

Beam handovers

Since Brazil covers a significant land area, there is a large number of satellite beams used to provide coverage to the whole area of Brazil. Therefore, having a mobile communication hub would require the system to perform many handovers between different beams. This test will focus on observing the impact of the beam handovers on the overall system performance and it will be relevant for ARESIBO since there are many beams over Europe and handovers will be very common in the ARESIBO use-cases.

Availability and reliability

The tests in Brazil will require the system to be active for long periods of time (i.e. weeks of uninterrupted activity) which will provide valuable insight into the system's availability and reliability. This test will is relevant for the ARESIBO project since the use-cases defined in ARESIBO require the system to be operational for long periods of time.

Border surveillance

The main goal of the ARESIBO project is to provide a stable and reliable network infrastructure to support border security operations. Therefore, testing in the Brazilian border with the French territory of French Guiana might provide significant insight into the ability of the network system to fulfil the requirements for border security operations.

10 Conclusion

The goal of this activity has been reached at this point of the program. VIASAT has designed a communication hub, capable of operating statically, nomadically or on the move. This communication node has been adapted to cover all ARESIBO program requirements and it has been presented and reviewed with all partners since day zero, and due to this fact, the success of the design.

This system has two key elements: KALMA mechanical steering horn array antenna and PEPLINK Seamless Failover System. To the main communication features, some security features have added and explained in previous sections, considering this as a relevant system characteristic to enable the system to be commercialized in near future.

As a final strength of our work, we are proud of the successful design, implementation and test of the last mile technologies that would allow field units to operate in remote locations always connected to our hub and consequently to their remote locations.

The complete design has been built in our lab at our premises in Switzerland, tested and optimized before its migration to the actual vehicle.

The developments are right now in the last phase of the work concerning this specific topic, where we have progressed substantially on our field testing as you could have understood along this document. At this point we can state that there are no remaining activities that could put at risk the physical demonstrations of ARESIBO, however there is still a long way to go until we complete the testing of all the components as well as the optimization of the system configuration for our specific ARESIBO use cases.

At this point we can state that we have designed, set up and tested (not fully) the Robust Mobile Communication System that was due in this specific Deliverable D3.3 and we have minimized the Program Risks related to this specific topic.