



Final report of green teleport program from the University of Ljubljana team



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1. Introduction

Abstract - Satellite communication is the key to the development of the modern information and communication society. The rapid proliferation of satellite communication systems over the last decade has led to an increased need for efficient and sustainable satellite teleport facilities. This report examines innovative approaches and technologies aimed at minimizing the environmental footprint and optimizing the operational efficiency of satellite teleports. It focuses on the STN teleport example. By summarizing current research and industry developments, this report provides an overview for satellite communications professionals to working at the intersection of technological advancement and environmental responsibility in the satellite teleport sector.



a. The project and its goals

A telecommunications port, or teleport for short, is a permanent ground station that serves as a connection facility for communication between satellites, usually in geostationary orbit, and the terrestrial telecommunications network. The basic task of the teleport is the continuous transmission of a communication signal from the earth to the satellite. At the same time, the reception of signals from the satellite is also important, on the basis of which the quality control of the transmission is carried out. The goal of satellite communication is to transmit a signal of the best quality with the lowest energy and bandwidth consumption using the simplest hardware. The reliability of operation is also of great importance here, as every second of service downtime has financial consequences for the responsible stakeholder.

After the launch of the first Telstar communication satellite half a century ago, satellite communication technologies have triggered a true communication revolution that has enabled the development of today's information society. Today, the transmission of information data via artificial satellites seems to be taken for granted by all users of telecommunications services. It will come even closer to people in the sixth generation (6G) of public mobile networks, when every user on earth will be able to connect directly to the Non-Terrestrial Network (NTN). As the number of satellites increases, so will the number of teleports, which will have to become even more environmentally friendly.

Satellite systems and networks consume large amounts of resources, from electricity to raw materials. The electrical energy required to operate satellite telecommunications networks is enormous. Although the space-based part of the network is energy self-sustaining at the level of each individual satellite, if we do not take into account the energy consumed for launch, the ground part cannot be operated sustainably at all. Of course, the end users are responsible for most of the energy consumption, as there are many of them around the world. But the satellite teleport itself also needs to be more energy efficient and sustainable in the future. In 2022, for example, the STN teleport consumed 2,000 megawatt hours of electricity.

The sustainability of satellite systems can be viewed from two perspectives. One is how to make the satellite ecosystem more sustainable, and the other is how we can use satellite systems and networks to make other applications and industries more sustainable. In this article, we focus on the first, although the second is also a very important societal factor that utilizes satellite services in combination with artificial intelligence and a large number of user devices.

A sustainable teleport that reduces the environmental impact of satellite communication and ensures a reliable and efficient connection can be designed by using green technologies, introducing energy-efficient telecommunications devices and optimizing cooperation between teleports.

This report presents innovative approaches and technologies aimed at reducing the environmental footprint and optimizing the operational efficiency of satellite teleports. In the next sections, four conceptual designs are presented that cover current research results and industrial developments in the field of sustainable satellite teleports. The report ends with the aforementioned conclusions.

b. Student team members from the University of Ljubljana

Luka Kavčič is a 2nd year student of the Master's programme in Electrical Engineering with a focus on Electronics at the Faculty of Electrical Engineering, University of Ljubljana. He is interested in designing complex and innovative printed circuits and finding optimal solutions. He is involved in the programming of embedded systems and the development of entire products with a focus on low consumption and reliability.

Jaša Vid Meh Peer is a 2nd year student of the Master's program in Electrical Engineering with a specialisation in Electronics at the Faculty of Electrical Engineering, University of Ljubljana. He is interested in work related to new and innovative challenges in the field of photovoltaics, especially in the testing of solar modules. He is involved in the design of switching transducer circuits for tracking the point of maximum power and scanning the U-I characteristic.

Rok Marko Šter is a second-year student of the Master's programme in Electrical Engineering with a focus on Information and Communication Technology (ICT) at the Faculty of Electrical Engineering, University of Ljubljana. He is interested in the development of integrated solutions and web applications, digital processing of image signals, data visualisation and cyber security.

Vid Vrh is a second-year student of the Master's programme in Electrical Engineering with a focus on Information and Communication Technology (ICT) at the Faculty of Electrical Engineering at the University of Ljubljana. He is interested in advanced antenna design.

Neja Flogie is a 3rd-year student of the 1st-level university study programme Geodesy and Geoinformatics at the Faculty of Civil Engineering and Geodesy, University of Ljubljana.

Luka Mlakar is a student in the 3rd year of the 1st degree programme in Geodesy and Geoinformatics at the Faculty of Civil Engineering and Geodesy, University of Ljubljana.

Jan Luka Verček is a 3rd year student of the Bachelor's degree programme in Applied Electrical Engineering with a focus on Information and Communication Technology (ICT) at the Faculty of Electrical Engineering, University of Ljubljana.

Mihael Zeme is a 3rd year student of the Bachelor's degree programme in Applied Electrical Engineering with a focus on Information and Communication Technology (ICT) at the Faculty of Electrical Engineering, University of Ljubljana.

b. Mentors team members from the University of Ljubljana

Marko Jankovec is an associate professor at the Faculty of Electrical Engineering at the University of Ljubljana. He conducts research in the Department of Electronics in the Laboratory of Photovoltaics and Optoelectronics, where he develops electronic measurement systems for the characterization and long-term monitoring of the operation of photovoltaic components under various operating conditions.

Polona Pavlovčič Prešeren is an associate professor at the Faculty of Civil Engineering and Geodesy at the University of Ljubljana. She works in the Department of Mathematical and Physical Geodesy and Navigation, where he deals with the use of global satellite navigation systems for high-precision positioning.

Boštjan Batagelj is an associate professor at the Faculty of Electrical Engineering at the University of Ljubljana. He conducts research in the Department of Information and Communication Technologies in the Laboratory of Radiation and Optics, where he deals with the physical layer of telecommunication networks based on radio and optical technology.

c. STN teleport profile and participating staff

Andraž Pavliha is a telecommunications engineer and works at STN STORITVE d.o.o., where he is a systems engineer responsible for the control and management of technical equipment for reception and transmission chains, playout systems and Network Monitoring Systems (NMS) control.

Grega Blatnik is a trained computer technician and is employed by STN STORITVE d.o.o. as an IT/network technician, where he takes care of the entire IT and network infrastructure and support for all back-end video/audio distribution systems.

2. Planning of an Energy Self-Sufficient Cooling System; Luka Kavčič, Jaša Vid Meh Peer

The use of green technological approaches for powering a teleport, besides renewable sources such as solar and wind energy, can also include fuel cells and hydrogen technologies. Solutions are best implemented together with energy storage systems, such as batteries or capacitors, where excess energy is stored to be used when renewable sources are not available. This allows the system to be less dependent on outside energy sources, which would in turn lead to better reliability and better power consumption efficiency.

Before the introduction of green technologies, it is necessary to study the electricity consumption of the teleport. It makes sense to identify the main power consumers of the system and examine how power consumption varies over time. Goals can vary from reducing electricity consumption to transitioning the entire company or at least a smaller part of it to operate in a self-sufficient manner. In most cases, the main power consumption in a teleport is attributed to the server room, as depicted in Figure 1, and the air conditioning system for cooling the entire hardware.

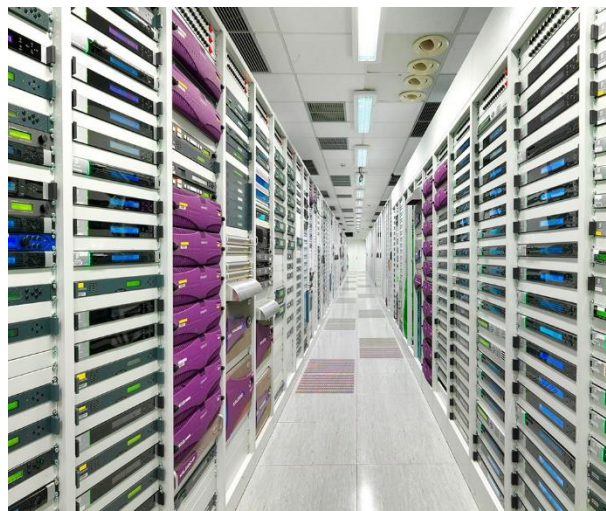


Figure 1: Server room from STN d.o.o.

Our main focus was on planning an energy self-sufficient cooling system, because the savings can be maximized by using solar panels to directly cool servers instead of using power from the grid with rising electricity prices per kilowatt-hour and networking cost per kilowatt. We also tried to incorporate renewable resources and environmentally friendly materials to make the whole process greener and more sustainable.

Since the teleport operates 24/7 with minimal downtime, the overall consumption remains relatively constant over time. Of course, it should be noted that the power consumption of the cooling system is lower in winter months due to lower outside temperatures, requiring less cooling, but while designing a system to accommodate cooling of the servers we should focus more on the worst possible case, which is when the system is under maximum load during hot outside temperatures.

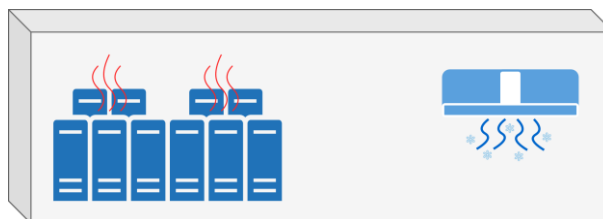


Figure 2: Schematic representation of the current cooling system.

The current cooling system of most teleports around the world consists of using big AC machines to cool the server racks with cooled air, such a system is represented in Figure 2. These systems usually regulate the room temperature between 14 °C to 20 °C. Power for the cooling is supplied from the grid or in rare cases from a UPS system if a power outage occurs. Such a system is very dependent on the grid, and it also has a high power consumption which translates to high electricity bills.

The simplest idea for a sustainable teleport is often to install a solar power plant on the company's buildings as shown in Figure 3, or in the vicinity, a practice already adopted by some providers. Such a power plant can directly generate energy for cooling the hardware or even power the whole system, if it is big enough to supply the necessary power.

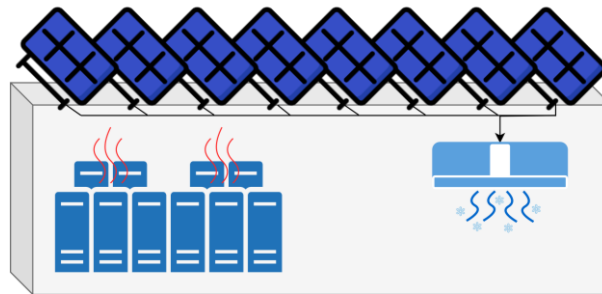


Figure 3: Powering the system using solar panels installed on the roof of the company building.

To do this, an inspection of the roof surface must be carried out initially to assess the feasibility, followed by the selection of suitable areas and calculation of the surface area. In the case of STN teleport, the entire company has approximately 1500 m² of roof surfaces, mostly facing south. The roof surfaces are marked with red on Figure 4. However, due to the fact that the entire surface is composed of much smaller parts with distances of up to 50 meters between them, making it difficult to connect them all into one system, it would be more efficient to build a solar power plant only on the main building of the company, which has approximately 1200 m² of roof surfaces. Connecting solar panels that are further apart would also be incredibly inefficient, because they usually operate at relatively low voltages and high currents, which would lead to big voltage drops on longer cables of wire between them. Solar panel layout planning can be done efficiently using the SolarEdge Designer program, where various orientations of solar panels can be tested and compared.



Figure 4: Inspection of suitable rooftop surfaces for solar panel installation.

For the simulations an arbitrary solar panel was chosen with a surface area of about 2 m² and a standard power rating of 400 W with efficiency of around 21 %. In this part of the project, we didn't want to focus too much on the solar panels themselves, but rather on how their orientation and layout affect their yield.

The first solar panel layout is the simplest one, all the panels are mounted in landscape orientation and tilted at an angle of 37° and aligned with the roof according to figure 5. This poses an issue because some roof surfaces of the STN Teleport company building are not pointing directly to the south, which leads to less power production. Such solar panel layout would, according to the simulation, consist of 308 panels and produce 123 kW DC power.



Figure 5: Solar panel layout 1.

The second layout is shown on Figure 6, it has panels mounted in landscape orientation at 37° and aligned with the roof only on the biggest roof. The smaller ones have panels mounted in a dual tilt configuration in landscape orientation. Dual tilt can increase the power production of solar panels that aren't looking directly south. This layout consists of 295 panels and produces 118 kW DC power.



Figure 6: Solar panel layout 2.

The third layout is mostly the same as the second layout, the only difference is that the orientation of the dual tilt configuration on the smaller roofs was changed. Instead of dual tilt landscape, dual tilt portrait configuration was used as can be seen on the right side of Figure 7. Such a layout can fit 312 panels on the available roof surfaces. It would produce 124 kW DC power.



Figure 7: Solar panel layout 3.

Considering all the shadows on the roof top, we were left with a bit less than 1200 m², but even so all of the simulated orientations were able to produce around 120 kW of DC power. Just from these three different layouts we can see that solar panel orientation impacts the number of panels we can fit on the available roof surfaces and has a big influence on the maximal power produced. Of course, a greater number of panels translates to higher maximal power, but there are compromises that need to be taken into account. These simulations are very rough but give a general idea. For a more detailed report and a layout that would give the best cost to power ratio, more time would have to be invested into placing panels manually and running an analysis.

Since solar panels only provide electricity on suitable sunny days, it is also important to consider how to cool the server room overnight and on days with lower sunlight. Of course, the option of supplying the power from the electrical grid remains, but it is advisable to avoid this as much as possible to be more sustainable and reliable. Typically, in such cases, battery stations would be added to the system to store excess energy on sunny days. The existing 600 kVA battery system of the STN company (Figure 8) serves as an uninterruptible power supply (UPS) and is intended to provide electricity in case of a grid outage. The already installed UPS is intended to provide power for a short period of time.

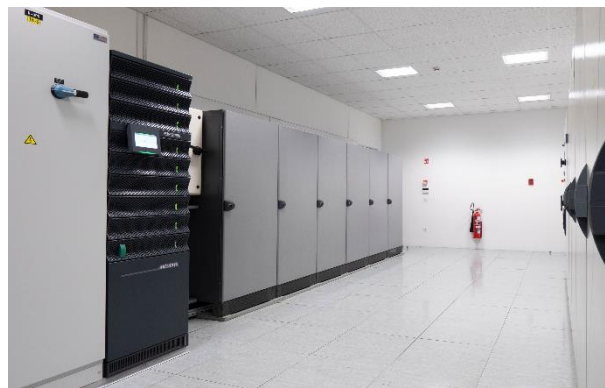


Figure 8: 600 kVA UPS in STN d.o.o.

To supply the cooling system with power for a few days or even just overnight, a very big battery system would be required. Battery systems require significant financial investment and regular inspections and occasional replacements. Their complexity and investment are proportional to their size. A system using a battery system to store energy is shown in Figure 9.

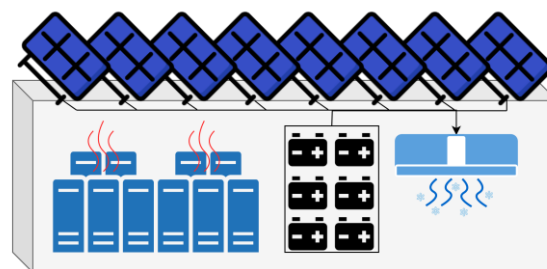


Figure 9: Adding a battery system for energy storage.

Therefore, it is worth considering other methods of energy storage and to research thermal energy storage (TES), which involves storing thermal energy for later use in a medium. There are several implementations differing in size, medium, temperature, and source. In this particular case, the approach is slightly different as it does not store thermal energy but rather pre-cooled water, which would be later used for direct or indirect cooling of the hardware.

The primary source of energy is the sun or solar energy, which would cool the selected medium using a heat pump. Water would be a suitable medium as it has a very high specific heat capacity, $4200 \text{ J}/(\text{kg}\cdot\text{K})$, is inexpensive, and allows for easy storage. Unlike lithium batteries, water is locally available and an environmentally friendly way of energy storage. However, direct water cooling means that the IT equipment in the server room would need to be modified. This requires an initial investment, but newer data centers are already considering such an approach. There is also an option of using indirect cooling, with liquid to air heat transfer.

It is sensible to store cooled water in a water tank as shown in Figure 10. The tank must be appropriately sized according to the server room's consumption so that the water temperature does not exceed the maximum temperature over a certain period, allowing for the necessary cooling of the hardware.

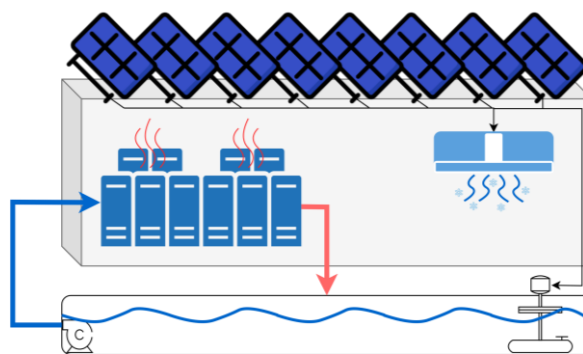


Figure 10: Implementing a pool for storing cooled water used for cooling.

The calculations were made from data for the STN Teleport here in Slovenia. Their cooling system has approximately 60 kW of power consumption and the company building has 1200 m^2 of suitable surfaces for solar panel installation. We can expect about 120 kW DC of installed power on the roof, more than double the cooling system consumption. Their allowed temperature fluctuation is between $16 \text{ }^\circ\text{C}$ and $19 \text{ }^\circ\text{C}$ and for a realistic example we chose to do the calculations for a maximum time of 48 hours without solar power. The pool's lowest temperature is limited due to problems with condensation on cooling equipment. This temperature can be decreased by using a bypass valve. This allows the mixing of cool water from the pool with warm water returning from the servers, allowing control of the temperature while having the pool water at a lower temperature. Lower temperature means smaller pool or longer time till the pool gets too hot.

We created a simulation of the pool temperature in MATLAB. Since it is hard to visualize large volumes, we used length of a side of cube on y-axis. In Figure 11 we can see the size of pool required for any given allowed temperature fluctuations and cooling power.

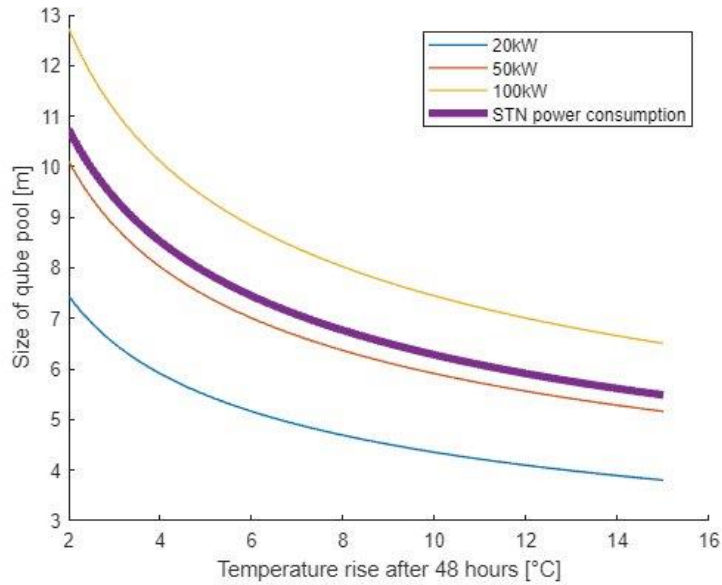


Figure 11: Simulation results 1

We have also done calculations for the given allowed temperature ranges. The first graph in figure 12 shows the pool size for temperature fluctuations currently allowed in STN server room. The reasoning behind the second graph is incorporation of a bypass valve. This allows the minimum temperature to be lowered. For this calculation it was set to 4 °C, so that we can use water and it does not come close to freezing. Both graphs show time until water reaches the upper temperature for given power consumption and pool size.

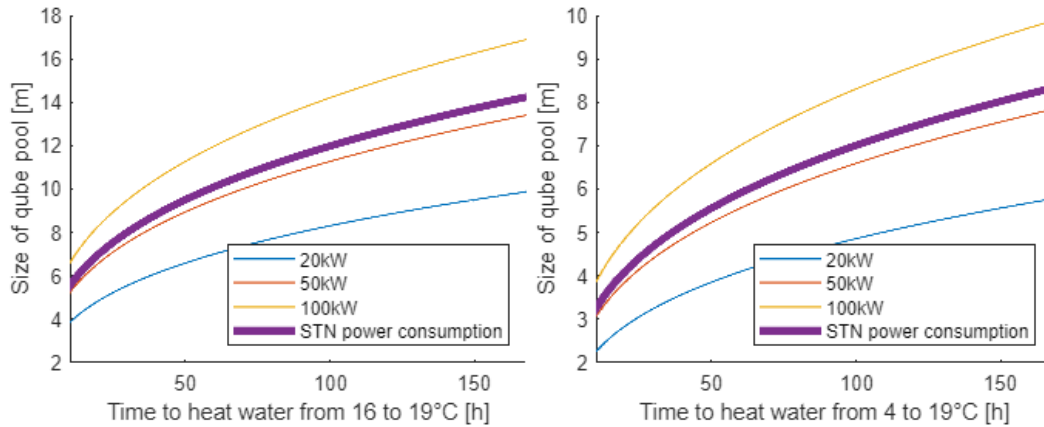


Figure 12: Simulation results 2

Using the above calculations, for water temperature between 16 °C and 19 °C and 48 hours without cooling, required pool size is 9,4 m cube. Building a more conventionally shaped pool equates to 5 m x 10 m x 17 m. In our opinion, this is a reasonable size, that could be built next to or under the facility. Using the bypass valve and lowering minimum temperature to 4 °C makes the pool 5,5 m cube, therefore reducing the size 5 times.

A reason for not having the minimum temperature set too low is heat pump efficiency, which is higher when the temperature difference is smaller. But the heat pump itself does not affect the size of the pool, since it only affects the cooling time and power required for cooling. Heat exchange efficiency tells us how much heat gets transferred from the heat source to the cooling medium. While also important, it does not affect pool size since all heat budget not transferred to the source returns to the pool and can be used again.

To test the feasibility of the idea and test heat losses we created a model shown in Figure 13. It contains a water reservoir with 2-5 L of liquid, a water pump, an external heatsink with two fans and a waterblock for heat transfer. It is surrounded with 5 cm thick polystyrene insulation. The server heat load is simulated using a 50 W 5 Ohm resistor. While the full-scale implementation would use a heat pump for efficient cooling of the water, we are using two peltier modules with combined power draw of 84 W. The system is controlled by an STM32G4 microcontroller on MIŠKO3 development board and a shield for accompanying electronics and connectors. Temperature is measured using three thermometers located in the water reservoir measuring water temperature, inside the insulated box measuring inside air temperature, and outside the box measuring ambient temperature. MIŠKO3 has multiple buttons and LCD touchscreen, which we use to set controlling parameters and display measurements.



Figure 13: Subscale model

The measurements can be transmitted to PC over USB C for further analysis. In Figure 14 we can see three different modes of operation. In the first 35 minutes the load is turned on and the cooling. Next, the cooling turns on while the load is still active. In the last part, the load and cooling are turned off.

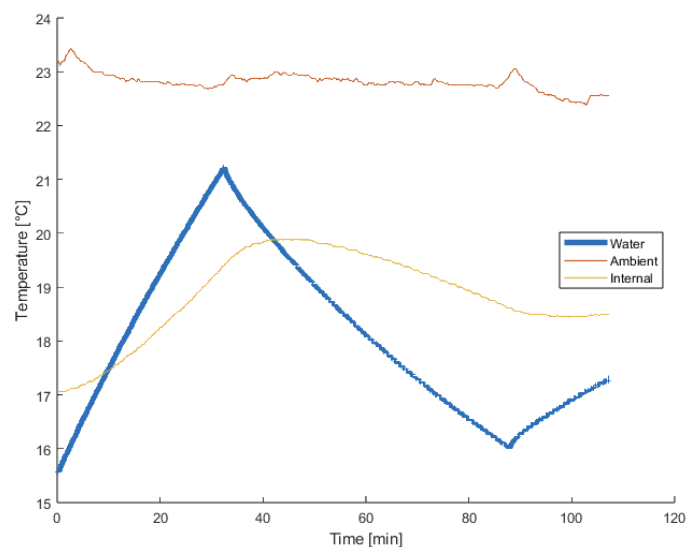


Figure 14: Measurements

Using these measurements and measuring load power at 22.5 W, we can calculate that the peltiers cooled the water with 45.9 W and heat losses were at 6.2 W. If the system were larger, the losses would represent a smaller percentage of total power, since the volume of water would increase faster than surface area of the enclosure. Therefor a real system could have quite thin insulation (our system has 5 cm) and would not lose much energy.

To conclude this chapter, we found out that a cooling pool would reduce the complexity of the system and add reliability. It should also be mentioned that a battery system that would power the cooling system for 48 hours is too expensive to be economical. Storing energy in a cooled pool and using water as a cooling medium simplifies the system and is a green alternative to lithium batteries or lead acid batteries. Some batteries would still be required to power the servers and water pumps however they could be much smaller. Additional cooling hardware is required, but we believe the cost is worth for the added reliability, flexibility of the system and lower electricity bills. In the case of direct cooling, we need compatible hardware and a redesign of the server system. Indirect cooling with liquid to air heat transfer would allow for the server system to stay as it is, but heat exchangers would be required.

3. Satellite Tracking Improvements; Vid Vrh

The objective of this project is to explore energy and emissions savings on satellite tracking and uplink transmissions. With proposed satellite tracking method the number of antennas on satellites could be reduced to reduce energy consumption, or they could be repurposed for data transmissions instead of tracking. This way, satellites would be more sustainable by increasing their lifetime, and thus making savings in operating expenses. On the side of the teleport, more precise tracking could mean lower required transmitting power, which would reduce teleport's total energy consumption, and consequently teleport's operating expenses. Since the recommendations in this project are about replacing the satellite tracking system with already existing technologies, the only cost would be on the side of teleports, where the satellite tracking system would have to be replaced with minimal cost.

When sending data to the satellite, it is important to consider the direction of the transmitting antenna. For that reason, satellites use a beacon signal, which is usually a narrow continuous wave (CW) signal, that is received by a specialized ground antenna and then used by satellite tracking system. By turning the antenna, the satellite tracking system is searching for the maximum received power of the beacon signal, which indicates the most optimal antenna orientation for the satellite.

Received power of the beacon signal is, among other things, dependent on the radiation pattern of the receiver antenna. When searching for the maximum received signal strength, antenna is oriented in a way that the antenna's axis of the maximum gain is aligned with the direction of the satellite. Since the main lobe of the radiation pattern is wide, the differences between received power around its maximum are small, which makes it harder to find the optimal antenna position. Since the radiation pattern minimums are much narrower, the differences in received power around the desired position are bigger, which makes finding the optimal position much easier.

Therefore, in order to track a satellite by searching for the minimum of received power, an antenna with low directivity and radiation pattern consisting of wide main lobe and deep minimum in the middle should be used instead of antennas with high directivity and narrow main lobe should be used. Since we are no longer tracking the maximum of a known signal, the beacon is no longer needed. Instead, the satellite downlink signal can be used for tracking as well as for providing the satellite service for users. With that the resources needed for transmitting the beacon signal could be repurposed for additional uplink or downlink transmissions. If the equipment needed for beacon signal transmission was simply left out, it would improve the lifetime of the satellite both in terms of power consumption and resources needed to maintain the satellite orbit.

Shutting down the beacon transmitter would reduce the energy consumption. For power, satellites are dependent on solar panels and on board batteries, which are becoming less and less efficient with time, less required power would also mean longer satellite lifetime, as estimated below:

$$P_{\text{beacon}} = 0,08\text{W} [1]$$

$$P_{\text{data}} = 16\text{W} [2]$$

$$\% \text{ energy saved without beacon} = \frac{P_{\text{beacon}}}{P_{\text{data}}} = 0,5\%$$

In addition to reducing the number of transmitting antennas on the satellite, this solution could also help reduce the power needed to transmit the data from the ground station to the satellite. Since the tracking system, which would be searching for signal minimum instead of maximum, could be more precise, this would in turn mean that the transmitting antenna could have better directivity and lower transmitting power. This is proven by Friis transmission equation:

$$P_{RX} = P_{TX} \frac{A_{effRX} * D_{TX} * \eta_{RX} * \eta_{TX}}{4\pi r^2} [3]$$

To implement such satellite tracking system in combination with transmitting antenna, I propose a patch-monopole antenna feed. Such feed uses a monopole antenna, which has a deep minimum in the center of its radiation pattern and is thus suitable for tracking the signal source using the minimum of received signal power. The second antenna the feed is composed of is a patch antenna, which has better directivity and serves as transmitting antenna.

For demonstrational purposes a patch-monopole antenna feed for frequencies around 2.4 GHz. was built. It consists of two antennas, a patch antenna and a monopole antenna, in a circular cavity, as pictured below:

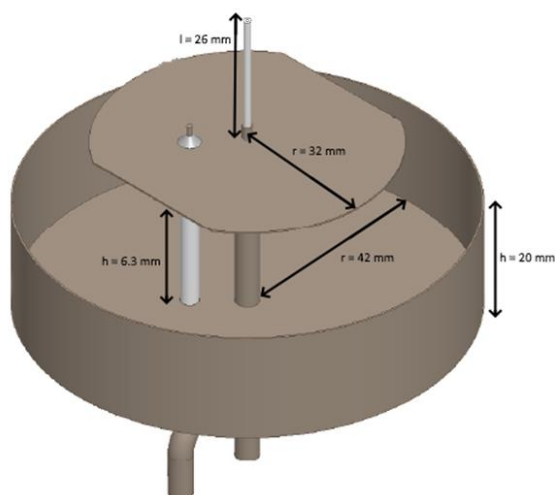


Figure 1: demonstrational patch-monopole antenna feed

For the demonstrational antenna feed the radiation pattern of the monopole antenna was measured. From the measurements, the desired deep minimum of radiation pattern, which could be used for satellite tracking.

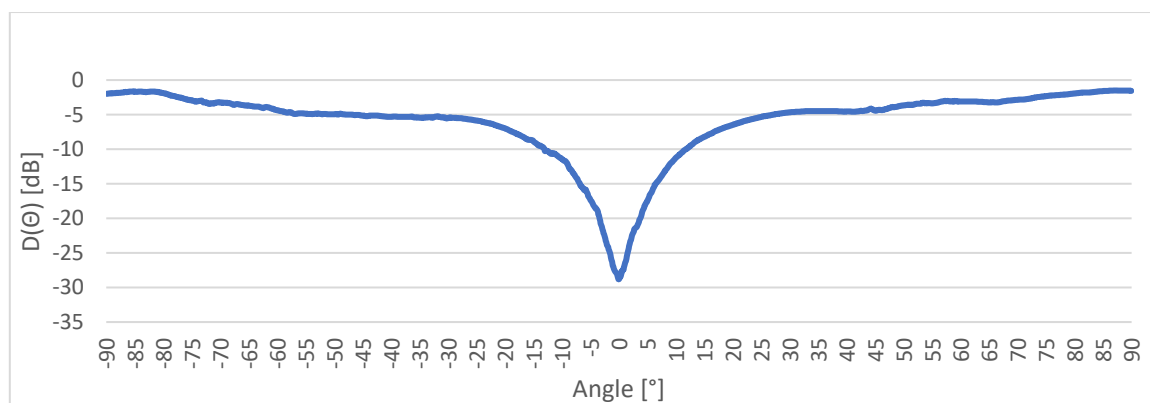


Figure 2: measured radiation pattern of proposed antenna feed

Sources:

- [1] S. Kawase, Radio Interferometry and Satellite Tracking. Artech, 2012.
- [2] ITU, "Handbook on satellite communications."
- [3] Vidmar, Matjaž, "Antene in razširjanje valov." (Antenna and wave propagation) Accessed: Jan. 02, 2024. [Online]. Available: <http://antena.fe.uni-lj.si/literatura/ar.pdf>

4. Global Network of Teleports; Jan Luka Verček, Mihael Zeme, Neja Flogie, Luka Mlakar

Currently, there are more than fifty teleports in the World Teleport Association – WTA and our idea was to unite them into a network. Sometimes stations malfunction, experience stormy weather, or are overwhelmed with data. In such times of need, stations could depend on this network to transmit their data to satellites. A teleport in need could choose optimal teleports based on different data available and conditions on other teleports. Our goal in this project was to create different programs that utilize different kinds of data to facilitate such cooperation, making it easier and more straightforward. We focused on weather data and rain attenuation because during stormy weather and heavy rain, additional power needs to be added for the transmission to reach the satellites. With this information, operators would know how much power is added and from which teleports they could transmit. Additionally, we also focused on the visibility between satellites and teleports to determine which satellites are visible from each teleport. With all this data, operators could calculate from which teleports the transmission would be the most efficiently transferred.

The first program we created was an interactive weather map, which operators could check weather predictions. The map uses quickly accessible data to facilitate the planning of transferring the transmissions to other teleports easier. It features weather data, allowing to anticipate incoming bad weather and decide when and to which station to transmit. When bad weather is imminent, operators can opt for another teleport that currently experiences clear skies. Once a teleport is chosen, operators can access information about that station to plan the data transmission accordingly. This map provides operators with a more transparent view of teleports and weather predictions, aiding them in their planning processes. Moreover, the map is designed to be straightforward and easy to use.

We created the interactive map in QGIS, an open-source program, and this feature that was created is easy to use and requires little basic knowledge of the program. The program is very simple; first, the operators would check the weather using the action button. That would take them to a webpage for weather predictions Weather Online (Weather Online UK - current weather and weather forecast worldwide). If the weather prediction were bad, they would choose another station with nice weather to transmit the data. When the station is chosen, they could check the information about that station. This would take them to the teleport webpage in the WTA website (World Teleport Association). Additionally, we developed an interactive web map with identical features (see Figure 1).

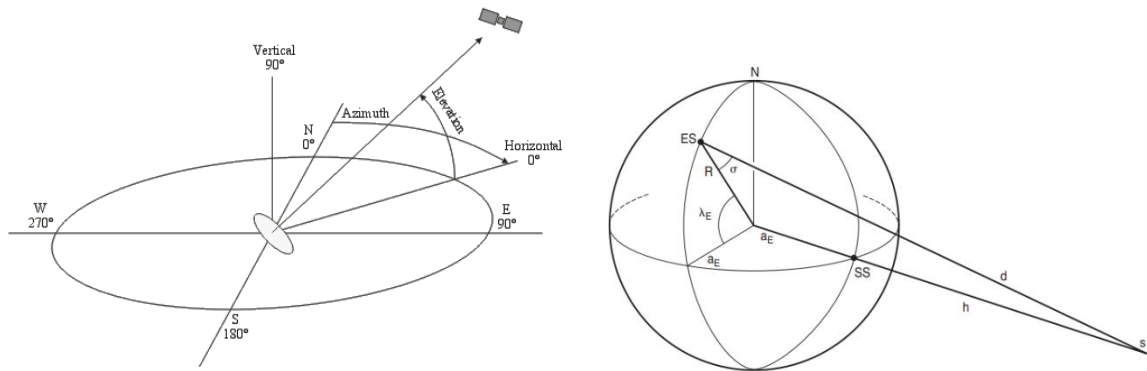


Figure 1: Interactive web-map with locations of teleports in Europe.

If we aim to establish a network of teleports, within which we can switch between stations in case of excessive power consumption during signal transmission due to inclement weather, one of the key requirements is the condition that the same satellite is visible from both selected stations. Satellite visibility is primarily described using two basic parameters: azimuth and elevation angle. The azimuth, within on the interval $[0^\circ, 360^\circ]$, tells us the angle between north and the selected satellite, while the elevation angle, within the interval $[0^\circ, 90^\circ]$, indicates how many degrees above the horizon the satellite is positioned. If the satellite is visible, the angle is always positive; a negative angle indicates that the satellite is below the horizon.

For easier analysis of satellite visibility, we developed a computer program into which we imported the geographic coordinates of all Earth teleports that are part of the World Teleport Association (WTA). Thus, the input data consisted of many sets of teleport coordinates (φ, λ, h) . The program also needs our input of the geographic longitude of the chosen geostationary satellite, and then it automatically calculates the parameters of satellite visibility from each Earth station. The most crucial output is the elevation angle, needing to be greater than 0° (or 15°) if we intend for the satellite to be visible above the horizon.

The program operates based on mathematical formulas derived using Napier's equations and other fundamental mathematical relations of spherical trigonometry.



$$Az = \arcsin \left(\frac{\sin(|\Delta\lambda|)}{\sin(\arccos(\cos(\Delta\lambda) * \cos(\varphi_E)))} \right) (\pm\pi)$$

$$El = \arccos \left(\frac{a_{GSO}}{\sqrt{R^2 + a_{GSO}^2 - 2 * R * a_{GSO} * \cos(\arccos(\cos(\Delta\lambda) * \cos(\varphi_E)))} * \sin(\arccos(\cos(\Delta\lambda) * \cos(\varphi_E)))} \right)$$

Thus, the final output of the program is a list of all 44 teleports from which it is possible to transmit a signal to the selected satellite. These Earth stations can then collectively form a subnetwork for signal transmission in case of adverse conditions at any station. Stations of a subnetwork can also be displayed on a map.



Visibility of Eutelsat 53A

Additionally, besides the parameters of satellite visibility, the program is further enhanced to compute, as a third output, the distance between each Earth station and the selected satellite. This parameter is crucial in calculating the signal power needed for transmission and is therefore essential to include in determining from which Earth station it is most sustainable to transmit a signal at any given time.

$$d = \sqrt{R^2 + a_{GSO}^2 - 2 * R * a_{GSO} * \cos(\arccos(\cos(\Delta\lambda)) * \cos(\varphi_E))}$$

The length calculated with the program thus forms the basis for future calculations of the required signal transmission power.

Teleport: Aflenz (47.554466, 15.324985)
Azimuth: 133.699883 deg
Elevation angle: 24.376777 deg
Distance: 39133.219 km

Teleport: Ljubljana (46.149324, 14.631131)
Azimuth: 132.329710 deg
Elevation angle: 25.030062 deg
Distance: 39071.432 km

Teleport: Rome (41.975809, 13.601840)
Azimuth: 129.155382 deg
Elevation angle: 27.350788 deg
Distance: 38855.471 km

Part of the final output

One of the ideas we have been investigating is the attenuation of radio communication between a geostationary satellite and a ground teleport. The concept involves a global network or coverage of teleports aimed at improving energy efficiency and reducing bandwidth when sending data to satellites. Specifically, we envision a scenario where a ground teleport experiencing high signal attenuation due to the satellite's considerable distance and/or adverse weather conditions redirects traffic to a teleport with a better connection. Through theoretical calculations concerning a teleport situated at the equator, we have determined that a geostationary satellite positioned at a 15° elevation receives 20% less signal power compared to its zenith position directly above us. Utilizing the given parameters—frequency = 11.5 GHz, satellite distance directly above the equator = 36,000 km, transmit power = 20 kW, transmit

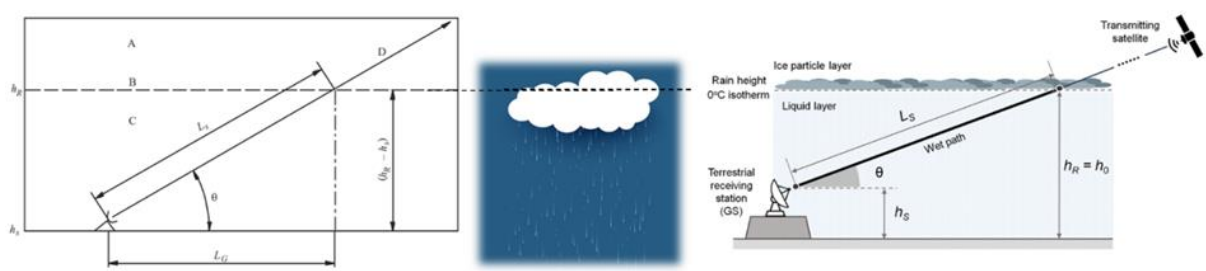
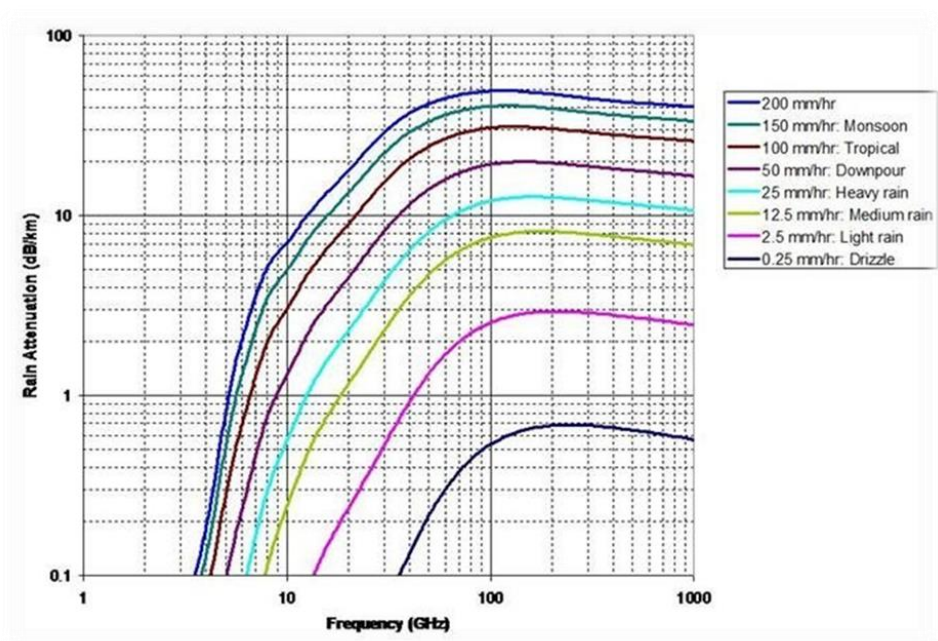
antenna gain (G_o) = 27.3 dBi, and an assumed receive antenna gain (G_s) = 22.7 dBi—we computed the

following results using the formula:
$$P_s = P_o G_o G_s \frac{\lambda^2}{4\pi d^2}$$

These calculations yielded a received power of 6.6 pW when the satellite is directly overhead and 5.28 pW at a 15° elevation. These values assume equal gain for both antennas and no weather-related attenuation, with the teleports being identical in composition and components.

Currently, we anticipate that due to real-world conditions on Earth, teleports should be strategically positioned at locations selected based on geographical location and weather patterns. It is advisable to avoid excessively high frequencies, as rain can block them, necessitating careful consideration of suitable transmit frequencies. While increasing power at both teleports and geostationary satellites would improve results, efficiency and energy conservation are paramount. Our aim is to contribute to sustainability and reduce wear and tear on terrestrial resources and assets.

The next challenge arises from rain, as precipitation hampers signal transmission through the air. Rain attenuation is addressed using the formula: $A_{RAIN} = \gamma_R * L_e$, where γ_R represents specific attenuation (in dB/km) and L_e denotes the effective path length of the wave in the rain (in km). The graph illustrates rain attenuation (dB/km) as a function of frequency (GHz) and rainfall rate (mm/h), showing that higher rainfall rates result in greater attenuation, especially as frequencies increase.



Effective path length of the wave in the rain: L_e

Specific attenuation can also be determined using coefficients k and α , which are associated with the frequency at which horizontal and vertical polarization occur. For calculations and weather data, cloud heights in Slovenia, typically ranging from 500m to 6000m, were considered. The primary challenge in satellite communications lies in high-density clouds with intense rain showers.

Frequency (GHz)	k_H	α_H	k_V	α_V
1	0.0000259	0.9691	0.0000308	0.8592
1.5	0.0000443	1.0185	0.0000574	0.8957
2	0.0000847	1.0664	0.0000998	0.9490
2.5	0.0001321	1.1209	0.0001464	1.0085
3	0.0001390	1.2322	0.0001942	1.0688
3.5	0.0001155	1.4189	0.0002346	1.1387
4	0.0001071	1.6009	0.0002461	1.2476
4.5	0.0001340	1.6948	0.0002347	1.3987
5	0.0002162	1.6969	0.0002428	1.5317
5.5	0.0003909	1.6499	0.0003115	1.5882
6	0.0007056	1.5900	0.0004878	1.5728
7	0.001915	1.4810	0.001425	1.4745
8	0.004115	1.3905	0.003450	1.3797
9	0.007535	1.3155	0.006691	1.2895
10	0.01217	1.2571	0.01129	1.2156
11	0.01772	1.2140	0.01731	1.1617
12	0.02386	1.1825	0.02455	1.1216
13	0.03041	1.1586	0.03266	1.0901
14	0.03738	1.1396	0.04126	1.0646
15	0.04481	1.1233	0.05008	1.0440
16	0.05282	1.1086	0.05899	1.0273
17	0.06146	1.0949	0.06797	1.0137
18	0.07078	1.0818	0.07708	1.0025

Specific attenuation $\gamma_R = kR^\alpha$

Coefficients k and α : $k = [k_H + k_V + (k_H - k_V) \cos^2 \theta \cos 2\tau]/2$ $\alpha = [k_H\alpha_H + k_V\alpha_H + (k_H\alpha_H - k_V\alpha_H) \cos^2 \theta \cos 2\tau]/2k$

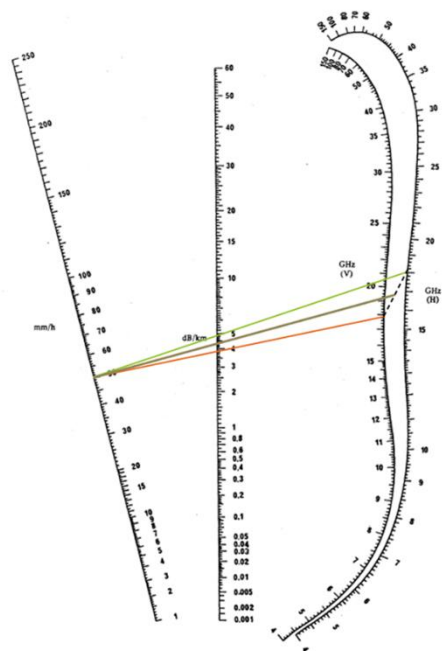
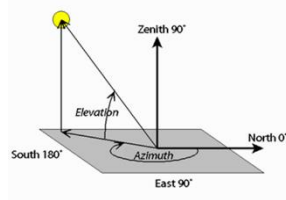
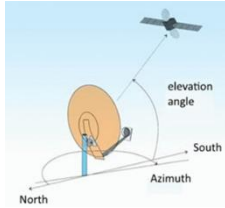


FIGURE 2 - Specific attenuation due to rain

In this figure we mapped out for a frequency of 18GHz, Rainfall rate: R [mm/h] = 50 mm/h, and Cloud height = 2.74km, Ellevation = 37° which means the Actual path through rain & cloud: $L_e = 4.548$ km.

We calculated:

Specific attenuation: $\gamma_R = 4.33$ dB/km; Attenuation due to rain: $A_{RAIN} = 17.78$ dB in which the loss of signal power is 98.3%.



In another example we took rainfall rate at 50mm/h, frequency 6GHz, cloud height 2.74km and elevation at 37° which means the actual path through rain & cloud is 4.548km. The calculated results were specific attenuation = 0.3 dB/km, attenuation due to rain = 1.327dB which meant that the loss of signal power is 27%.

All of this data shows that heavy rain and higher frequencies have a powerful impact on signal loss, so it would be best to redirect data information from a teleport struggling to properly transmit data to geostationary satellite to another teleport which has as little of obstacles as possible such as rain to be the main transmitter or receiver of data. The saved energy as it is valuable in this day and age could be used in another part of the circuit of teleports.

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ITU-R recommendations:

Propagation data and prediction methods required for the design of Earth-space telecommunication systems (itu.int)

RECOMMENDATION ITU-R P.839-4 - Rain height model for prediction methods

RECOMMENDATION ITU-R P.838-3 - Specific attenuation model for rain for use in prediction methods

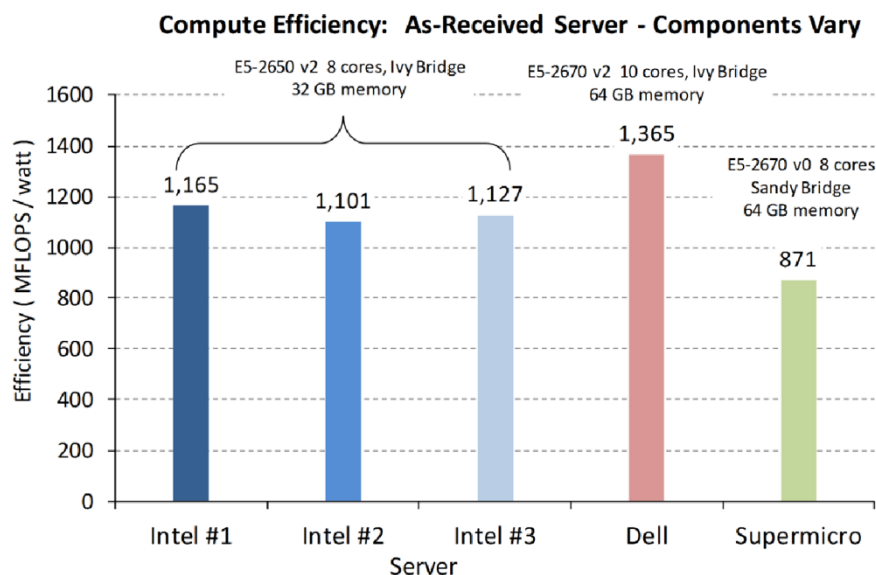
CCIR report 721-3:

Reports of the CCIR (Düsseldorf, 1990): Annex to Volume V (itu.int)

5. IT Sustainability; Rok Marko Šter

In the ICT industry, it is best practice to maximize resource utilization through server virtualization and orchestration with a hypervisor. A hypervisor is a type of embedded software or hardware that creates and runs virtual machines. Its primary functions include automating the management of virtual servers on host machines, simplifying scalability, efficiently distributing processes across hardware, leading to lower power consumption, and reducing the server footprint. Hypervisors can temporarily deactivate idle hosts of virtualized servers, further reducing energy consumption. Dynamic allocation of virtual memories assigns memory to virtual servers as needed, making it easier to manage disk arrays while allowing smooth data movement from one physical memory device to another, with the goal of automatically deactivating underutilized servers.

Defining Server Power Usage Effectiveness (SPUE) as the ratio between the total energy required to operate server equipment and the actual energy consumed by the server equipment, the unequivocal goal is to reduce server energy consumption since reducing consumption for power supplies and cooling falls under the previous subsection. Server equipment consumption can be achieved by upgrading to newer and more efficient server equipment. A review of studies shows that due to technological advancements in processor units, energy efficiency can improve by up to 50% in two years. Therefore, it makes sense to regularly review server equipment on the market and assess how quickly an investment in newer, more energy-efficient equipment would pay off.



Comparison of Compute Efficiency of different CPU generations,

Source: H. Coles, Y. Qin, and P. Price, Comparing server energy use and efficiency using small sample sizes, 2014. doi:10.2172/1163229

To further understand the practical benefits of virtualization and orchestration in the ICT industry, we conducted extensive tests, including comparing different workloads distributions across multiple Docker containers and their management with Kubernetes. This approach allowed us to evaluate the efficiency, scalability, and flexibility of different virtualization technologies. We began by establishing an experimental environment in which we implemented multiple Docker containers on two host machines. Each container hosted different applications or services, enabling us to simulate a heterogeneous IT infrastructure common in modern data centres. Our testing focused on analysing the performance of each container in processing various types of workloads, from computationally intensive tasks to those requiring high bandwidth or response speed. We then utilized Kubernetes, a popular tool for automating the deployment, scaling, and management of applications in containers, to

assess its ability to manage workloads distributed across different containers. With Kubernetes, we could automate and optimize the scheduling of applications based on available resources and application requirements. We paid special attention to features like automatic healing, automatic load measuring, and horizontal auto-scaling, which enable Kubernetes to dynamically adjust the amount of resources allocated to individual applications or services based on their current needs. During testing, we noted key performance indicators, such as response time, transaction success rates, and resource utilization. We compared these measurements in scenarios using only Docker containers and in scenarios where container management was taken over by Kubernetes. This comparison allowed us to identify the advantages and limitations of each approach and assess how well each technology can meet the specific needs of modern data centres.

The test results showed that the combination of Docker and Kubernetes provided exceptional flexibility and efficiency in managing workloads and resources. Kubernetes stood out in ensuring high availability and resilience of applications, even in the event of hardware failures or software bugs in applications. Docker containers enabled rapid deployment and easy portability of applications across different environments. Together, these two tools enabled better resource utilization and greater agility in developing and deploying applications, which is crucial for the rapidly changing business environment. It is important to note that with a small added overhead, resource utilization is increased, leading to the golden point of energy efficiency in power supplies.

In the context of our research and testing of virtualization and orchestration, we also focused on the theoretical understanding of VMware vSphere, although we did not implement it in practice, since the participating company already uses it. VMware vSphere is an industry-recognized virtualization solution that enables centralized management of physical servers and virtual machines (VMs) and optimizes available resources. Although we did not directly use vSphere in our tests, we studied documentation and analysed numerous videos to understand how vSphere could impact our findings and how it compares with the tools we used. vSphere would play a key role in providing a more in-depth virtualization platform in our context, enabling better isolation, security, and resource management. One of the key components of vSphere is ESXi, a type 1 hypervisor installed directly on physical hardware, providing a high level of efficiency and control over physical and virtual resources. vSphere also offers advanced features, such as vMotion for moving running VMs between physical servers without interruption, Storage vMotion for moving VM files between data stores, and High Availability to ensure minimal service downtime.

The shift of IT infrastructure from on-premises to the cloud represents a significant step in the digital transformation of organizations, with important sustainability implications. When evaluating the environmental impact of this shift, it is crucial to understand the different categories of greenhouse gas emissions, which are often divided into Scopes 1, 2, and 3.

Scope 1 emissions are direct emissions from sources owned or controlled by the organization, such as emissions from burning fuel in buildings or emissions from company vehicles. In local IT operations, this includes emissions resulting from the direct operation of data centres, such as generators and cooling systems. When an organization migrates its IT infrastructure to the cloud, direct emissions related to its data centre operations are significantly reduced or even completely eliminated. This is due to the transfer of responsibility for physical infrastructure, including cooling systems and backup generators, to the cloud service provider. Thus, the organization can focus on its core activities without directly contributing to emissions from data centre operations, leading to a reduction in Scope 1 emissions.

Scope 2 emissions are indirect emissions resulting from the consumption of purchased energy, such as the electricity consumed by the data centre. These emissions are a consequence of the production and delivery of energy used by the organization and can be significantly reduced by migrating to the cloud, where large and efficient data centres are typically more energy efficient. Migration to the cloud also

optimizes Scope 2 emissions. Cloud data centres are often optimized for energy efficiency and can leverage economies of scale to reduce energy consumption per unit of service. Additionally, many cloud service providers invest in renewable energy sources to power their operations, further reducing the carbon footprint associated with energy consumption. Organizations implementing their services in the cloud indirectly reduce their Scope 2 emissions by relying on greener and more efficient energy sources, granted that we do our due diligence and review and assess the cloud provider's eco-friendliness.

Scope 3 emissions are all other indirect emissions resulting from the organization's entire value chain, including the production and disposal of products the organization uses, such as servers and other IT equipment. When moving to the cloud, the responsibility for e-waste associated with IT infrastructure is transferred to the cloud service provider. This reduces the e-waste burden on individual organizations but requires careful examination of cloud providers' disposal and recycling practices. The shift to the cloud also impacts Scope 3 emissions. The responsibility for the production, maintenance, and end-of-life disposal of physical IT equipment shifts to the cloud service provider. This transfer of responsibility requires organizations to carefully select providers with robust e-waste policies and sustainable practices. By relying on providers that efficiently manage e-waste and recycle or reuse equipment, organizations can reduce their Scope 3 emissions associated with IT infrastructure. Additionally, using cloud services can reduce the need for business travel and transportation, which also contributes to reducing Scope 3 emissions. The existing infrastructure of the company after a successful migration to the cloud can be repurposed for other needs.

The shift to the cloud also brings other sustainable benefits. The scalability of the cloud allows organizations to precisely adjust their resource usage to their needs, reducing excess and improving energy efficiency. This dynamic allocation of resources reduces unnecessary energy consumption and associated greenhouse gas emissions.

To summarize everything, it should be noted that data centres of large cloud providers are often designed with energy efficiency and sustainability in mind, using advanced cooling technologies, renewable energy sources, and other innovations to reduce their carbon footprint. This approach not only improves the sustainability of operations but also reduces operational costs, benefiting both cloud providers and their customers.

It should be noted that ensuring that the shift to the cloud contributes to sustainability goals, it is crucial for organizations to choose cloud providers committed to sustainable practices and transparently report their environmental impacts. This includes verifying how cloud providers manage e-waste, their use of renewable energy sources, and efforts to reduce greenhouse gas emissions throughout their operational chain. Thus, organizations can ensure that their move to the cloud not only improves operational efficiency and reduces costs but also supports their broader sustainability goals.

6. Conclusion

The rapid development of satellite services requires an ever faster introduction of environmentally friendly technologies and the updating of existing solutions in teleports.

Of all the known solutions for sustainable teleports explored in this report, the introduction of green environmental technologies undoubtedly contributes the most, with the introduction of a renewable solar energy source with suitable electrical energy storage capabilities leading the way. The contribution also offers the possibility of storing cooling liquid, which is an innovative approach to data center construction. The introduction of the green technologies presented contributes to greater teleport autonomy, reducing the likelihood of service outages and increasing the reliability of operations.

In the field of information and communication technology, optimization can also extend to IT and telecommunications equipment. The energy efficiency of IT equipment can be achieved through virtualization and reduction of server consumption. The energy efficiency of telecommunications equipment can be achieved through innovative antenna systems.

A change in business approaches between teleports can also help to achieve sustainable goals. Today, teleports act as competitors in the market, although they should cooperate with each other to reduce power consumption. Optimizing the minimum distance between teleport and satellite and taking over transmission during extreme weather events, which unfortunately have been increasing recently, are particularly important here.