Network: Satcom introduction

Satellite dish


Satellite dish, Raisting Germany. CC BY-SA 2.5
Source: https://pl.wikipedia.org/wiki/Plik:Erdfunkstelle_Raisting_2.jpg

A satellite antenna is an essential part of the satellite tract, without which neither the transmitting part nor the receiving part can function. It is a component used to transmit or receive radio signals, usually from telecommunications satellites. It is often used in households to receive satellite television.

The figure above 1 shows a satellite dish (28.5m in diameter) used for transmission by European teleports. Such antennas are rarely used nowadays as semiconductor technology has made it possible to build high-power amplifiers while optimising the cost of such an amplifier. New installations use a maximum antenna diameter of no more than 10 metres.

The appearance of the antenna is due to the fact that at EHF frequencies (30-300 GHz), wave phenomena become much more apparent than at lower frequencies. The satellite dish resembles by far more in its operation a parabolic mirror than a classical antenna based on the half-wave dipole principle. A consequence of this is also that we can easily calculate the gain of such an antenna.

$$ G = \frac{4 \pi A}{\lambda^2}e_A = (\frac{\pi d}{\lambda})^2 e_A$$.

- A: the area of the antenna aperture. Size of the aperture through which electromagnetic waves pass.
- d: Diameter of the antenna if the antenna is circular.
- $lambda$: The wavelength of the electromagnetic wave.
- e_A: Aperture performance parameter, between 0 and 1.

From this formula we can deduce that the larger the diameter of the antenna, the higher its gain. This is why older installations from the 1990s used very large antennas, as high-powered amplifiers for high bandwidth were very energy and cost inefficient.

Construction of an artificial Earth satellite

Mock-up of the ERS 2 artificial Earth satellite
Source: https://commons.wikimedia.org/wiki/File:ERS_2.jpg

An artificial earth satellite is any man-made object that moves in a certain orbit around the earth. The first such object was Sputnik 1, launched into orbit by the USSR in 1957. This chapter describes the main parts that are responsible for the operation of such a satellite. The following sections focus mainly on electronics and data communications, mechanical issues are covered less extensively.

Positioning and orbital control of the satellite

Each of the man-made satellites has not had enough time (Billions of years) to stabilise its orbit, so it needs compensation to keep it in its designated position. The positions of geostationary satellites are denoted by their deviation to the east and west of the zero meridian. For example, a satellite moving over the equator 7 degrees east of the zero meridian would be called 'E7', nowadays, due to the high occupation of positions, sometimes several satellites are sent to one position, this then causes the nomenclature to look like 'E7A', 'E7B', 'E7C', for example.

The compensation of the satellite's position itself is realised by jet engines, which eject a mixture of gas that allows the satellite's orbital movements to be compensated. The amount of fuel is usually limited, which means that satellites have a limited lifespan, e.g. the Eutelsat 7B satellite launched in 2013 is designed to operate for about 15 years, which means it is likely to run out of fuel to carry out the compensation in 2028. The solution in such situations is to use a transmit/receive antenna with satellite tracking, this then allows the satellite to be used for several more years after its expiry date.

Transponder

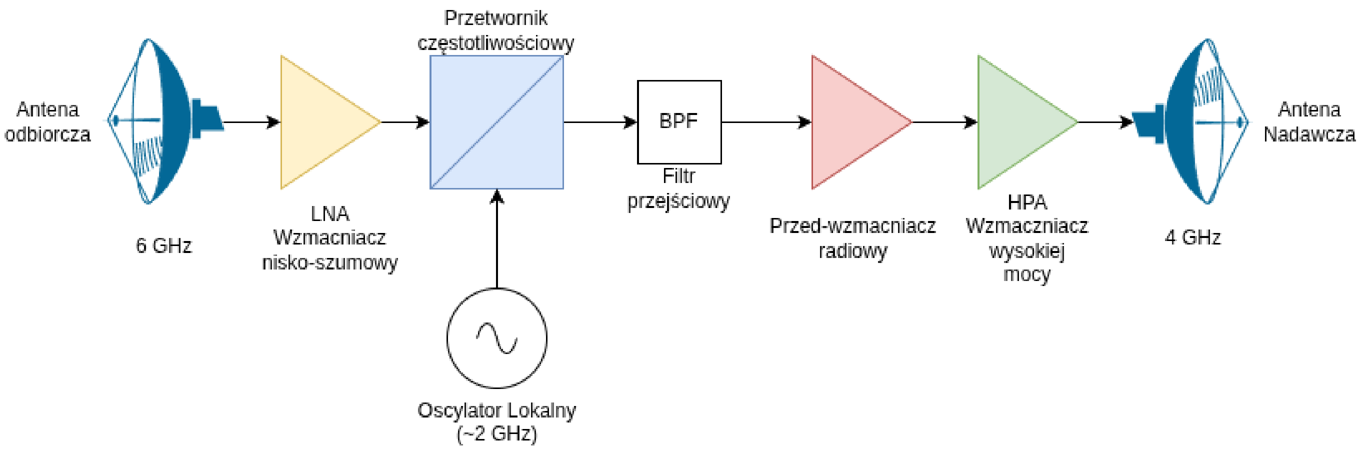


Diagram of an example transponder [own elaboration].

A satellite transponder is a key component of communication systems, responsible for receiving, amplifying and retransmitting signals. Its design includes several key components:

- **Receiving antenna:** Receives signals from Earth.
- **Low noise amplifier (LNA):** Amplifies weak signals to reduce noise and increase power.
- **Frequency converter (and local oscillator):** Converts the frequency of the received signal to another frequency required for transmission.
- **Transient filter (BPF):** Rejects unwanted frequencies, allowing only the expected signal to pass through.
- **Pre radio amplifier:** Further increases the power of the signal before it is transmitted.

- **High-power radio amplifier (HPA):** Ultimately amplifies the signal to a level that can be effectively retransmitted back to Earth.
- **Transmitting antenna:** Emits a signal towards a receiving station on Earth.

Satellite bands and dependence of service availability

The frequency bands used for satellite communications determine not only the nature of the services offered, but also their geographical availability, resistance to atmospheric interference and regulatory requirements. The most important bands, their typical uses and the factors affecting service availability in each region are outlined below.

L-band (1-2 GHz)

- **Applications**: satellite navigation systems (GPS, GLONASS, Galileo), mobile communications in low SNR conditions, some telemetry systems.
- **Advantages**: high resistance to precipitation (rain, snow) and ionospheric interference; relatively low loss of signal strength over long distances.
- **Limitations**: limited throughput compared to higher bands; need for larger antennas to achieve high gain.
- **Availability**: widely available globally as the L-band is allocated to public services and does not require expensive licences.

S-band (2-4GHz)

- **Applications**: weather radar, atmospheric monitoring, some emergency communication systems, observation satellites.
- **Advantages**: moderate sensitivity to precipitation; medium throughput possible with relatively small antennas.
- **Limitations**: the band is partly occupied by military and scientific systems, which may limit availability in some countries.
- **Availability**: available in most regions, but requires coordination with regulators to avoid interference.

C-band (4-8 GHz)

- **Applications**: satellite television (DTH), data transmission in corporate networks, backhaul links.
- **Advantages**: good coverage with moderately sized antennas; relatively low susceptibility to rain compared to higher bands.
- **Limitations**: requires larger antennas than Ku/Ka bands; band is heavily managed, which can lead to spectrum congestion.
- **Availability**: widely used in Europe and North America; availability may be limited in some regions of Asia and Africa due to national allocations.

X-band (8-12 GHz)

- **Applications**: military communications, radar tracking, satellite links in harsh weather conditions.
- **Advantages**: high precision and high throughput capability; better resistance to ionospheric interference than lower bands.
- **Limitations**Strong absorption during heavy rainfall (rain fade). *rain fade*); requires precise aiming of antennas.
- **Availability**: limited to users with appropriate military or government licences; in some countries only available under research programmes.

Ku-band (12-18GHz)

- **Applications**: TV transponders, satellite broadband, VSAT links.
- **Advantages**: relatively high throughput with moderate antenna size; good balance between coverage and susceptibility to *rain fade*.
- **Limitations**: requires precise antenna positioning; quality of service may be reduced in areas of heavy rainfall.
- **Availability**: widely available in Europe, North America and parts of Asia; requires licensing from local regulators in some regions.

Ka-band (26.5-40GHz)

- **Applications**: high-bandwidth satellite links, 5G backhaul, 4K/8K video transmissions, high-bandwidth IoT systems.
- **Advantages**: very high throughput, enabling gigabit data streams; small antennas due to shorter wavelength.
- **Limitations**: Strong susceptibility to *rain fade* and other atmospheric phenomena; requires advanced error correction techniques and adaptive power allocation.
- **Availability**: increasing as new regulations are introduced; only available in pilot projects in some countries.

V-band (40-75 GHz)

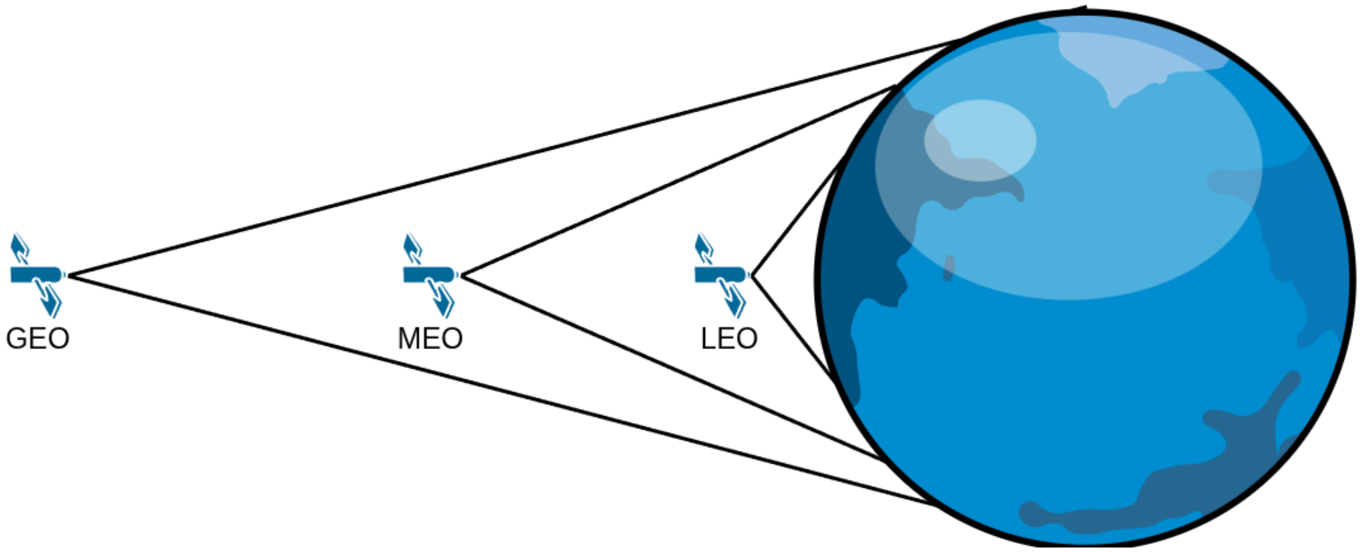
- **Applications**: Experimental satellite communication systems, research on data transmission at very high frequencies, satellite network prototypes for 6G.
- **Advantages**: extremely high throughput (tens of gigabits per second); possibility to use very small antennas and electronics.
- **Limitations**: very strong absorption by the atmosphere (mainly water and oxygen); requires precise beam control and advanced modulation techniques.
- **Availability**: currently limited to research laboratories and demonstration projects; regulations allowing commercial use only in development.

Summary of availability dependencies

- **Geographical factors**: in regions with high precipitation (e.g. tropical), higher bands (Ku, Ka, V) may require additional mitigation techniques *rain fade*which increases implementation costs.

- **Regulation and licensing**: some bands (X, V) are reserved for military or research applications, limiting their availability to the commercial sector.
- **Bandwidth requirements**: bandwidth-intensive applications (e.g. 4K video transmissions, 5G backhaul) lean towards Ka and Ku bands, while mission-critical and low-bandwidth systems (e.g. navigation) use L band.
- **Infrastructure costs**: lower frequencies (L, S) require larger antennas, increasing installation costs, while higher frequencies (Ka, V) allow for smaller antennas but increase interference correction costs.

Types of artificial earth satellites



Schematic diagram of the orbits of communication satellites [Own elaboration].

LEO (Low Earth Orbit)

Satellites in low orbit (160-2000 km) are characterised by:

- **Low latency** (20-40ms) - beneficial for real-time applications (VoIP, online applications, teleconferencing).
- **High resolution images** - enable detailed observations of the Earth, monitoring of environmental changes.
- **Short orbital period** (90-120min) - requires a large number of satellites in the constellation to ensure continuous coverage.

Typical applications: broadband constellations (Starlink, OneWeb), Earth observation systems (Sentinel-2, Landsat), research and education missions.

MEO (Medium Earth Orbit)

Medium Earth Orbit (2000-35786km) is mainly used by navigation systems:

- **Fixed altitude around 20200km** - Optimum compromise between range and delay (approx. 70ms).

- **Fixed number of satellites** (e.g. 24 in GPS) provides global coverage with a moderate number of units.
- **Orbital stability** - Less atmospheric influence than in LEO, reducing the need for orbital corrections.

Examples: GPS, GLONASS, Galileo, BeiDou.

GEO (Geostationary Orbit)

Geostationary satellites (35786km) move at an angular velocity equal to the Earth's rotation, giving:

- **Fixed position relative to the surface** - A single ground-based antenna can serve the entire area visible from a single point.
- **Long range** - a single satellite covers approximately $$frac{1}{3}$ of the Earth's surface.
- **Higher latency** (approx. 250ms) - less favourable for applications requiring low RTT, but acceptable for video transmission and telecommunications.

Applications: television broadcasting, satellite broadband, meteorology, emergency communications.

Design applications

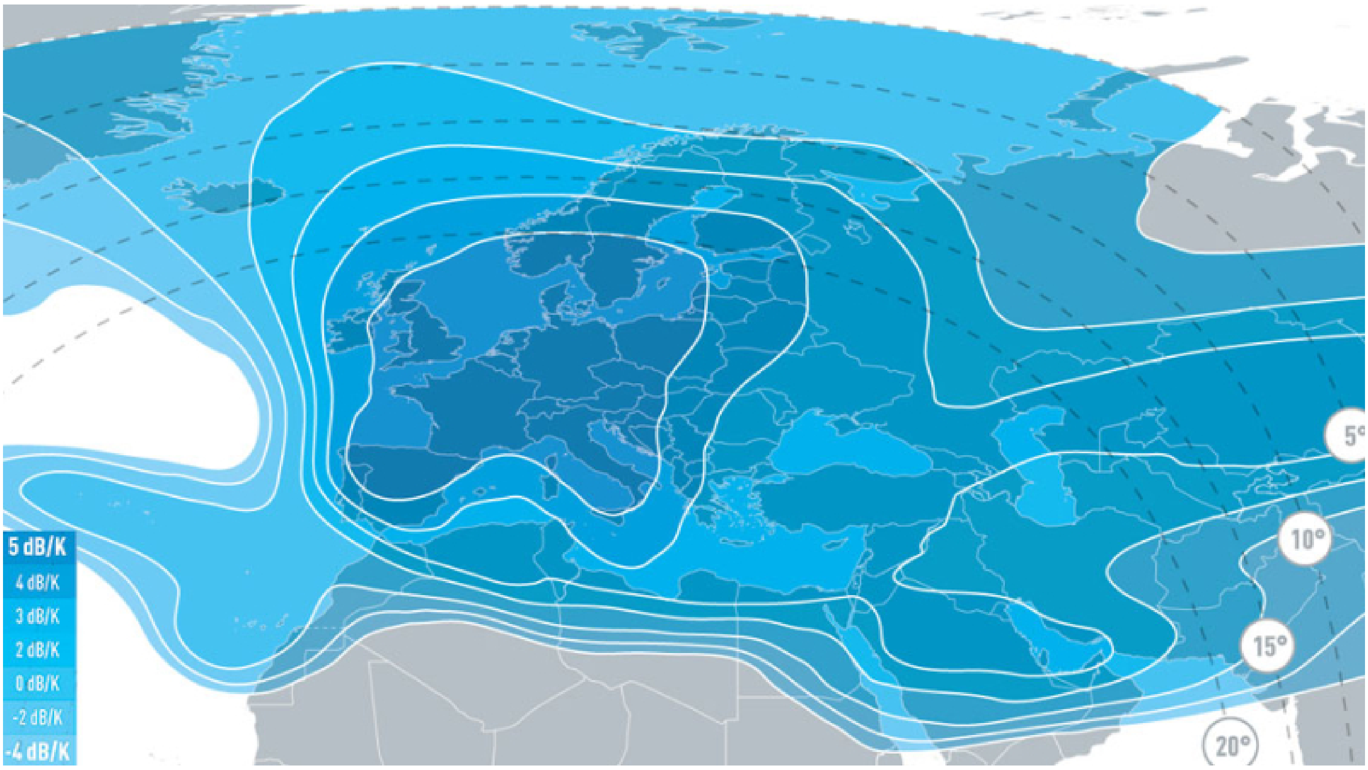
- **The choice of orbit** should depend on the requirements of the application: low latency → LEO; global availability with minimum number of satellites → MEO; wide coverage with a single unit → GEO.

- **Launch and operating costs** increase with orbit altitude (higher propulsion requirements, longer satellite lifetime, more expensive propulsion systems).
- **Interference management** requires consideration of band allocation and international cooperation, especially in the Ku/Ka bands, which are heavily used.
- **Redundancy and reliability** - LEO and HEO constellations provide natural redundancy due to the large number of satellites; in GEO, redundancy requires launching spare satellites in the same orbital position.

Planetary coverage by satellite signals

The satellite signal covers areas of the planet by means of various transmission methods, allowing large-scale delivery of telecommunications and data services.

Receiving map: Represents the range over which the satellite signal can be received on the Earth's surface. In the case of Eutelssatelliteat 7B, the signal covers much of Europe, the Middle East and parts of Africa.



Transmission map (from the ground) of the Eutelsat 7B satellite
Source: https://www.eutelsat.com/satellite-network/GEO-fleet/eutelsat-7-east

- **Transmission map:** Shows the extent of the areas from which the signal can be sent to the satellite. In the case of Eutelsat 7B, users must be in the appropriate zones to effectively use the broadcast services.

Satellite coverage is key to providing broadband internet access, TV broadcasting and communications in hard-to-reach regions where terrestrial infrastructure is not developed.

Satellite technologies used in the work

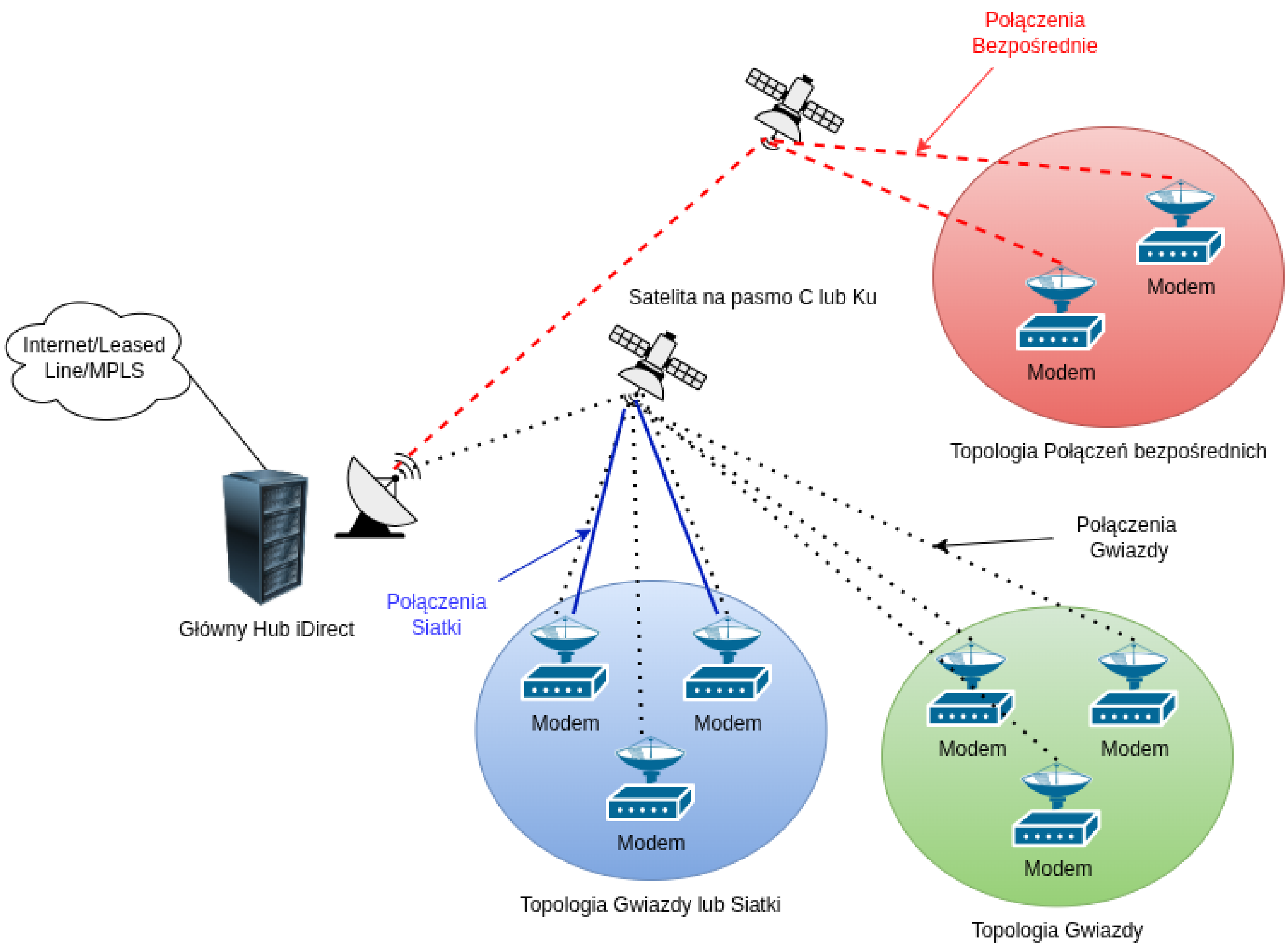
In the following section, we discuss the satellite technologies that are key to building a network supporting satellite terminals. Such networks play an important role in the transmission of IP data, making them indispensable in situations where traditional links, such as wired Internet connections, are not available.

Satellite networks are extremely valuable in areas where telecommunications infrastructure is limited. Examples include rural locations or remote areas that lack access to fibre optic cables or radio links such as 4G/LTE mobile networks. In such cases, satellite technologies offer flexible solutions that enable users to obtain stable and fast internet access.

Geostationary satellite communications

Due to its popularity and ease of implementation, geostationary connectivity has been used in this work, as the GEO orbit provides a fixed position of the satellite relative to a ground point, which eliminates the need for complex antenna tracking and significantly simplifies network configuration under field conditions. The simulations and all associated configurations were developed with Ku-band in mind, which is the most widely used band for IP data transmission in satellite networks due to its favourable ratio of bandwidth to susceptibility to the phenomenon of *rain fade*. Ku-band (12-18GHz) offers sufficient bandwidth to support transport protocols (TCP/UDP) and adaptive coding and modulation (ACM) techniques, allowing transmission parameters to be dynamically adapted to current atmospheric conditions. In addition, the band is widely supported by numerous satellite platforms, including iDirect solutions, which provide turnkey terminals, bandwidth management software and diagnostic tools, significantly reducing deployment time and operating costs. This makes GEO-Ku connectivity the optimal solution both for backup connectivity and as the main internet connection in locations without available wired or radio links (e.g. 4G/LTE).

The iDirect platform



Schematic of the satellite network based on the iDirect platform [Own elaboration].

The iDirect satellite platform was used in the implementation of the network design. The following comparison uses the concept of satellite hopping. A satellite hop is the transmission of a signal from the transmitting site and then receiving it at the receiving site, the following comparison uses the concepts of single hop and double hop. An explanation of these concepts follows.

A single satellite hop occurs when, the transmitted signal is only processed once by the satellite. That is, for example, in a situation where two terminals communicate together via satellite bandwidth. The signal is first transmitted by one terminal then received by the other.

Satellite double hopping occurs when the signal is processed twice by the satellite. When, for example, a terminal wants to access the internet and needs to pass through a master point i.e. a hub. The terminal executes the command `ping 8.8.8.8`, the packet is first sent to the hub, the hub then decodes the satellite packet and sends it to the destination address `8.8.8.8`, waits for a reply `ECHO REPLY` when it receives the reply, it encodes it into a satellite packet, sends it to the satellite and then the terminal receives it. In this way, a so-called double hop occurs.

The iDirect platform allows satellite networks to be implemented in the following configuration modes:

- Star or mesh topology.
  - Allows each terminal to be connected to each other (after a double hop).
  - Additionally, it allows defining connections between terminals (after a single hop).
- Star topology

Allows any terminal to be connected to any terminal (double hop) * Allows any terminal to be connected to any terminal (double hop) * Allows any terminal to be connected to any terminal (double hop)

- Does not allow mesh connections between terminals (no double hop)
- Direct connection topology
- Allows only direct connections between two or more satellite terminals on a dedicated, dedicated only band, the so-called SCPC single channel per carrier.

In this work, the network and satellite platform were configured for network operation in 'Star Topology' mode. The consequence of this is that all network traffic that occurs, either between terminals or to the Internet, must pass through a central point (so-called hub).

Using a TX-RX loop to simulate a satellite link

During the tests before the satellite network is put into operation, functional tests must be carried out. As satellite bandwidth is a high-priced service, this causes solutions to be sought and developed to test the operation of the network without satellite bandwidth. In Figure 8 we can see, a comparison of what are the most important components of a real satellite network, and how we can simplify this in order to test a network without satellite bandwidth.

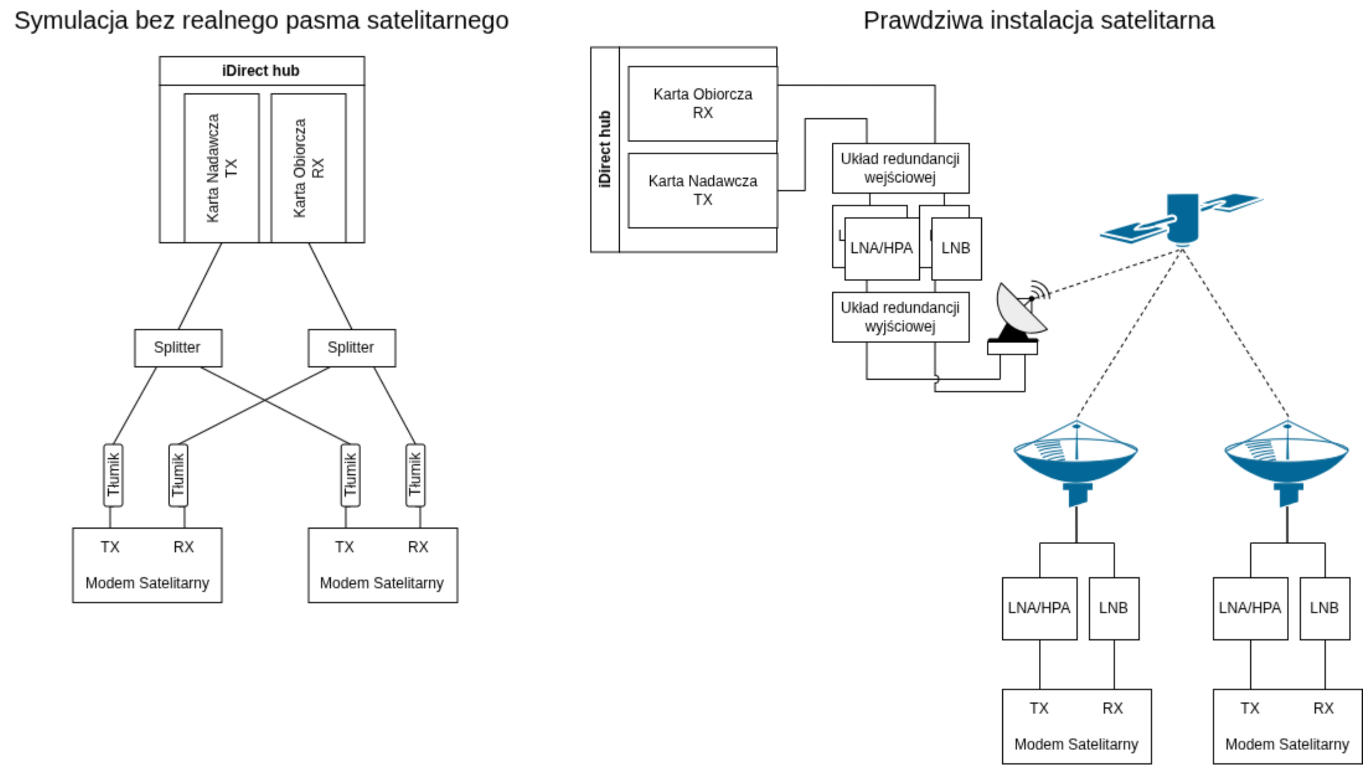


Diagram of TXRX loop simulation and comparison with a real installation [Own elaboration].

The satellite network when using real satellite bandwidth requires us to use full receive and transmit tracts for the terminal side as well as the hub side. The transmit tract should also be redundant, so we need to use dual transmit and receive equipment on the hub side.

For functional tests, however, it is sufficient to use dividers to which we can connect the transmitting and receiving sides of the terminals, and after attenuating the signal to a suitable level, we can connect the signals prepared in this way to the terminals. This will allow us to connect and authenticate to the satellite network without first renting satellite bandwidth.

Tests performed in this way do not allow us to investigate the delay and bandwidth limitations due to the satellite bandwidth. Therefore, the next section presents a method for testing and simulating such conditions using open source software.