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Non-Terrestrial Networks (NTN) / Satellite networks (for applications on Earth)

MARIA KIHLM



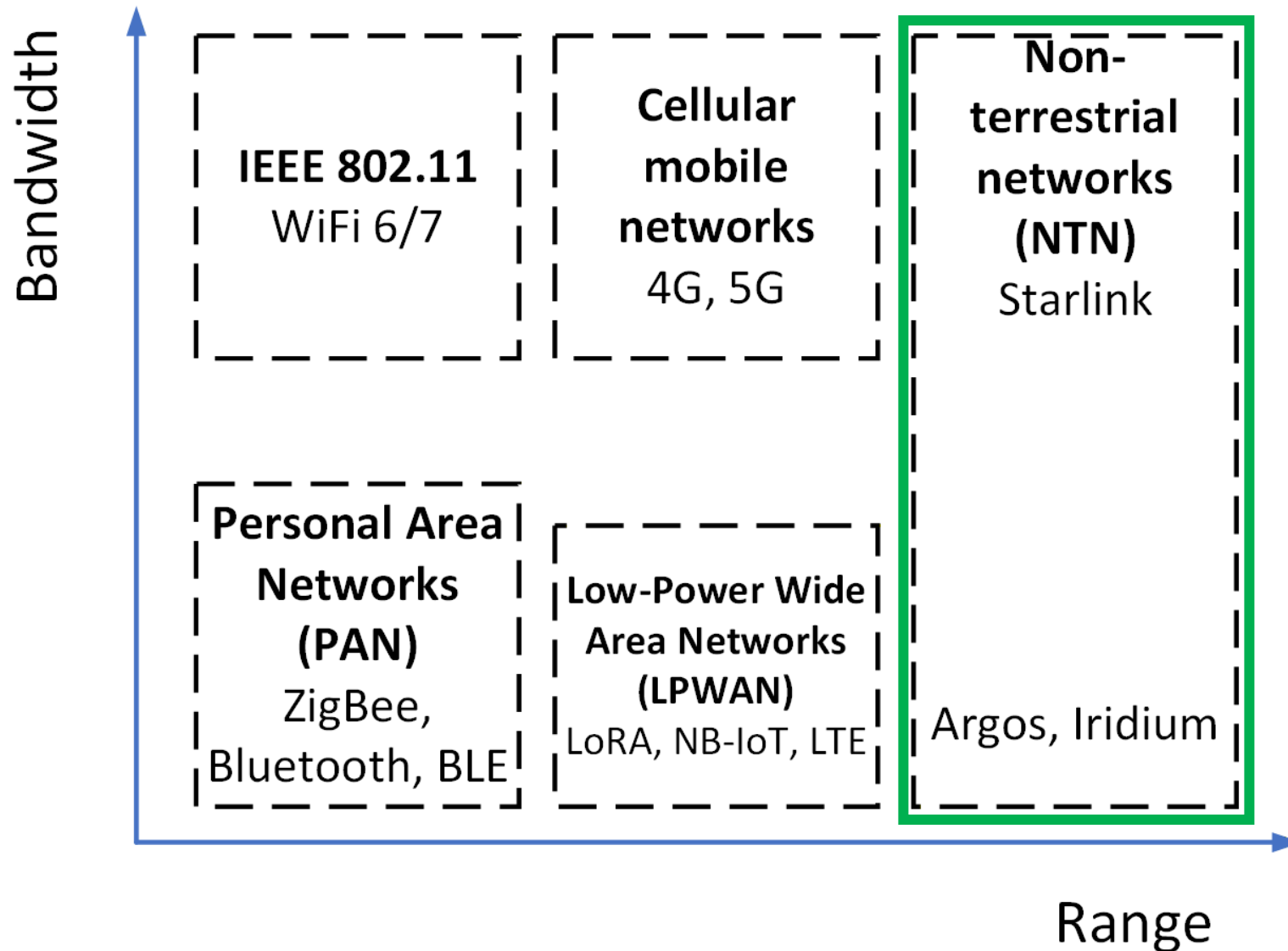
Literature

- O. Kodheli et. al, “Satellite Communications in the New Space Era: A Survey and Future Challenges”, IEEE Communication Surveys & Tutorials, 2021.
 - Sections I-III
- C. Gomez et. al. "On the Energy Performance of Iridium Satellite IoT Technology", *Sensors* 21, no. 21: 7235, 2021
 - Sections 1-3
- <https://www.argos-system.org/about-argos/how-argos-works/>
- [Starlink \(Wikipedia\)](#)
- [Argos satellite system \(Wikipedia\)](#)
- [Iridium satellite system \(Wikipedia\)](#)

To do!

- Project
 - Project meetings week 4-5, do not forget to register.
- Tutorials
 - Arrival processes and queues, on Wednesday

Today's lecture



Today's scenario: Reindeer herding

You have been asked to help a Sami community situated in an area of the most northern parts of Sweden (also called Sápmi). They would like to have a tracking solution for their reindeer herds. Positioning data should be collected about the reindeers' movements and sent to a cloud server. Due to the large distances, the positioning data do not need to be exact. There can be an acceptable error in the positioning of about 1 km.

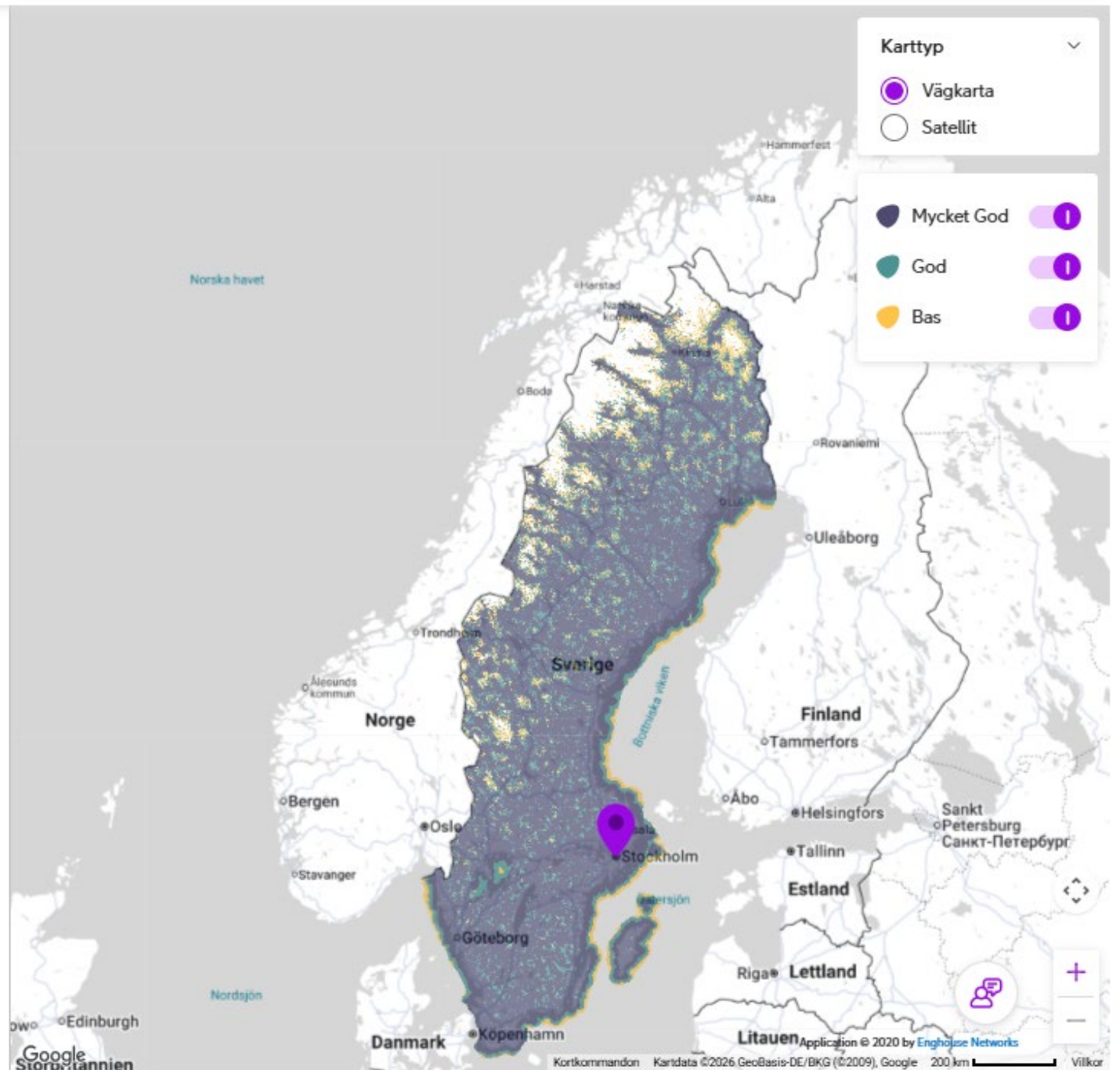
Also, your solution should enable the herders to have access to some basic Internet applications, as sending emails and web browsing, at suitable places. In addition, the reindeer herders should be able to monitor the reindeers through an app on their cell phone or laptop when they have Internet access.

Note: Even if Sweden has good cellular network coverage, there are large parts of Sápmi with very bad connectivity conditions. Your solution must reflect this.



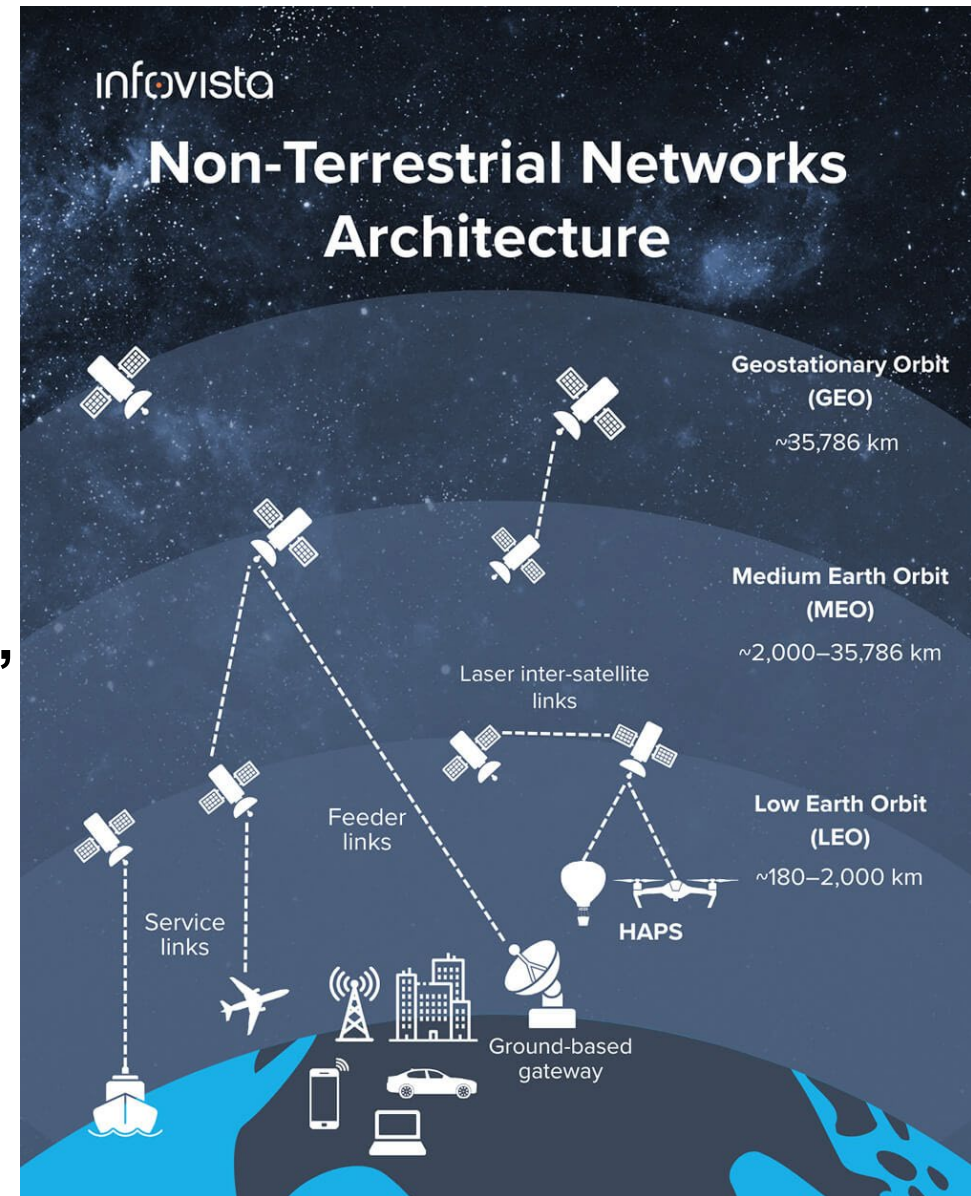
Telia 4G/5G coverage in Sweden

This map shows 4G/5G coverage using Telia's infrastructure (aimed at ordinary 4G/5G, not NB-IoT and LTE-M).



Non-Terrestrial Networks / Satellite Networks

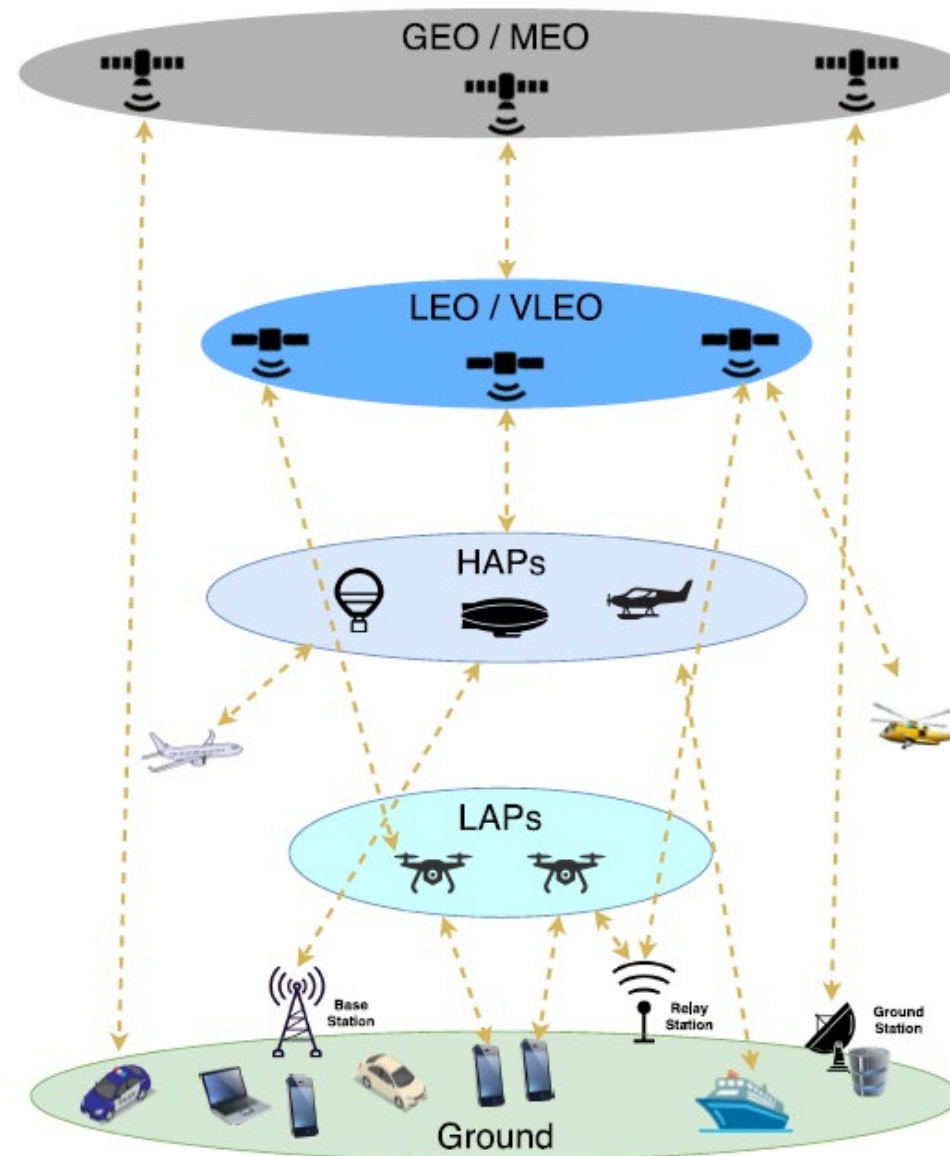
- **Non-Terrestrial Networks (NTNs)** are wireless communication networks that rely on infrastructure not located on the ground, most commonly, satellites.
 - NTN is a concept defined by 3GPP for satellite-based cellular mobile services.
- **Satellite-based NTNs, or Satellite Networks,** are supported by **ground-based gateways** that connect the satellite constellations to the terrestrial internet.



The NTN concept includes more than satellites

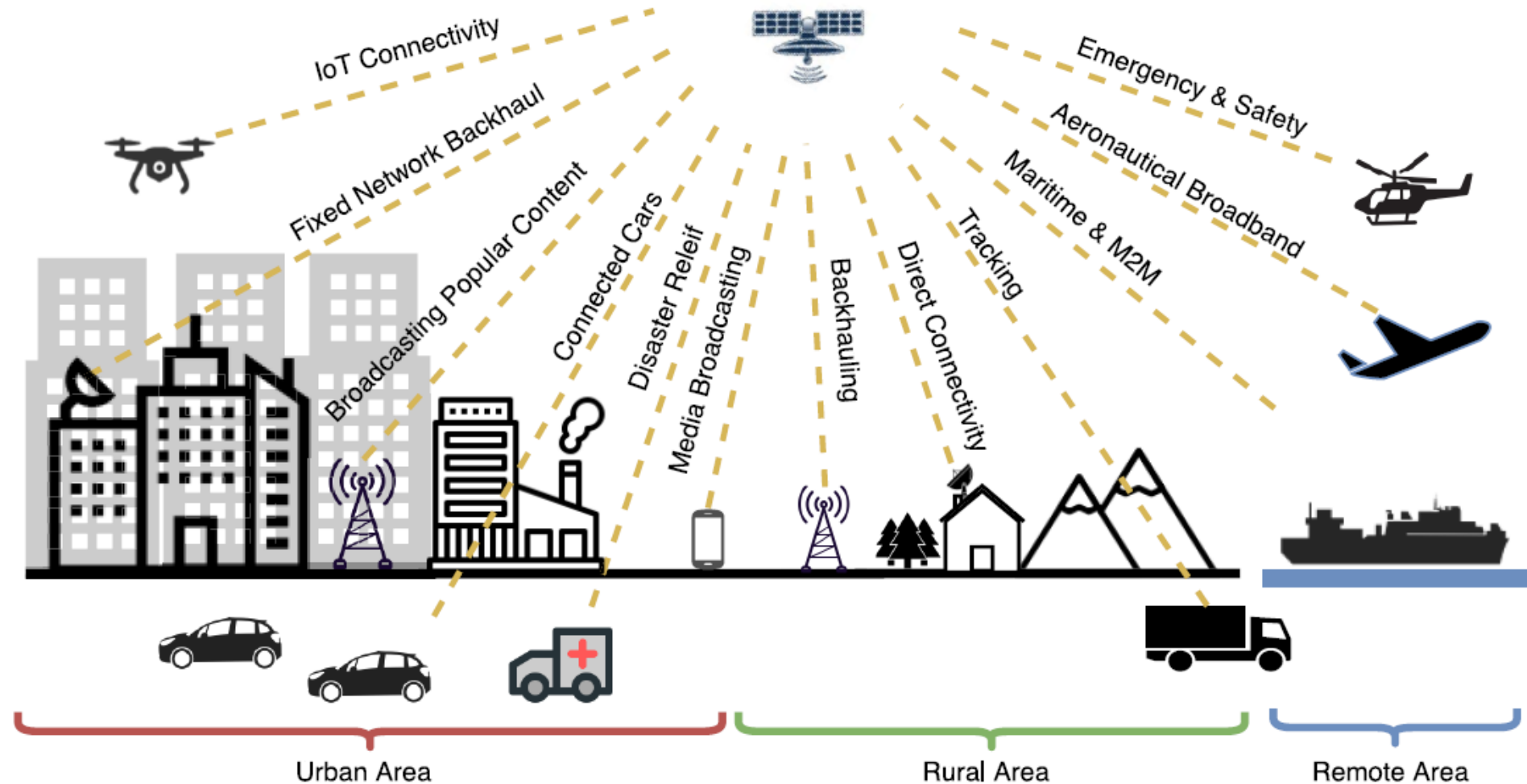
HAP: High Altitude
Platforms

LAP: Low Altitude
Platforms



Source: Satellite Communications in the New Space Era:
A Survey and Future Challenges

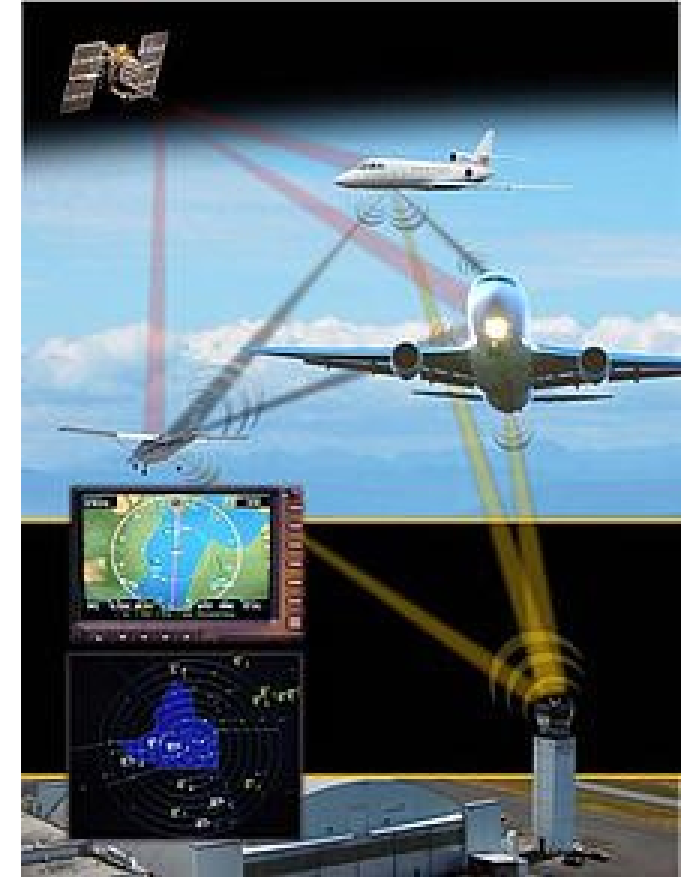
Main use cases for Satellite networks (on Earth)



Example:

Automatic Identification System (AIS)

- The **Automatic Identification System (AIS)** is an automatic tracking system that uses transceivers on ships and is used by vessel traffic services.
- The **Automatic Dependent Surveillance–Broadcast (ADS-B)** is an aviation surveillance technology with the same function as AIS.



https://en.wikipedia.org/wiki/Automatic_identification_system

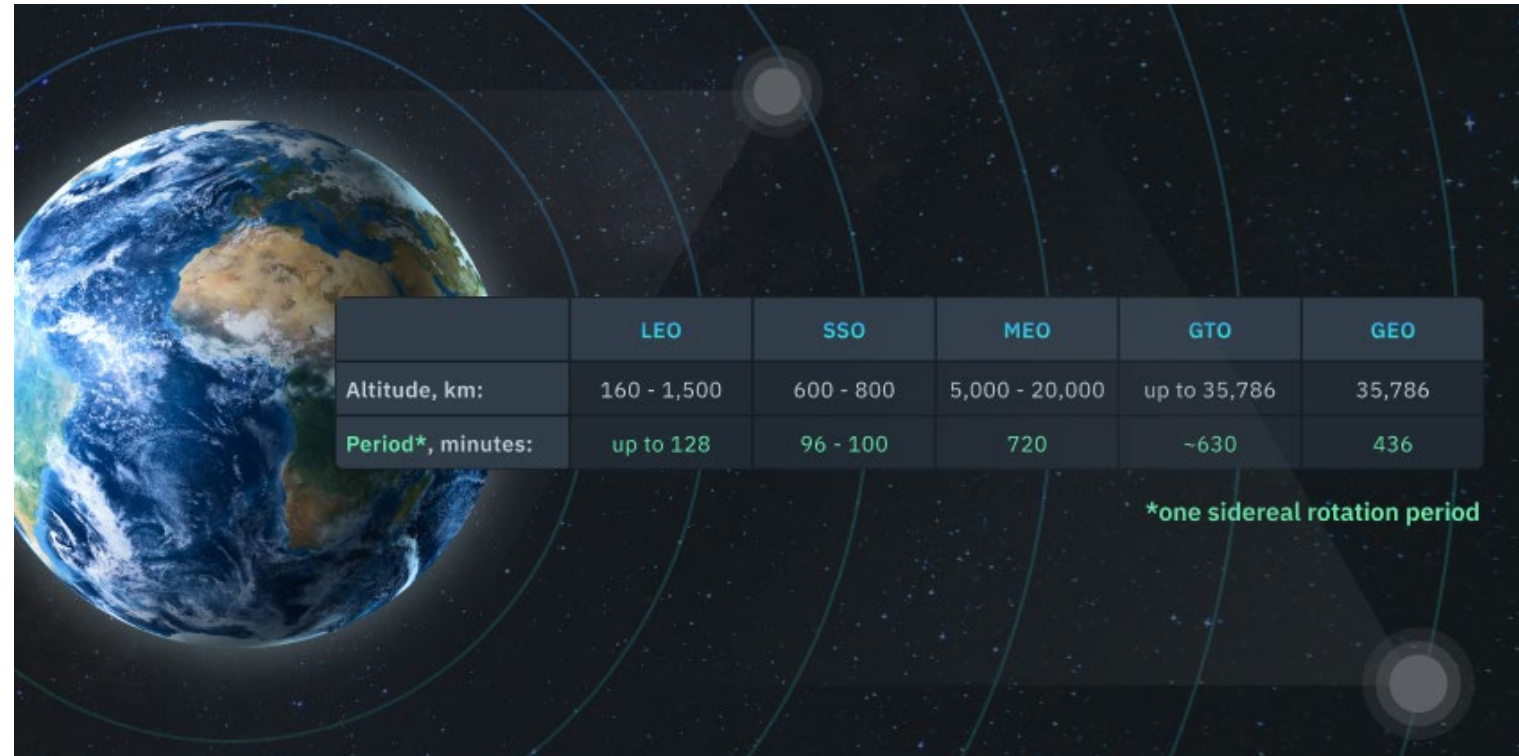
https://en.wikipedia.org/wiki/Automatic_Dependent_Surveillance%E2%80%93Broadcast

Satellite orbits

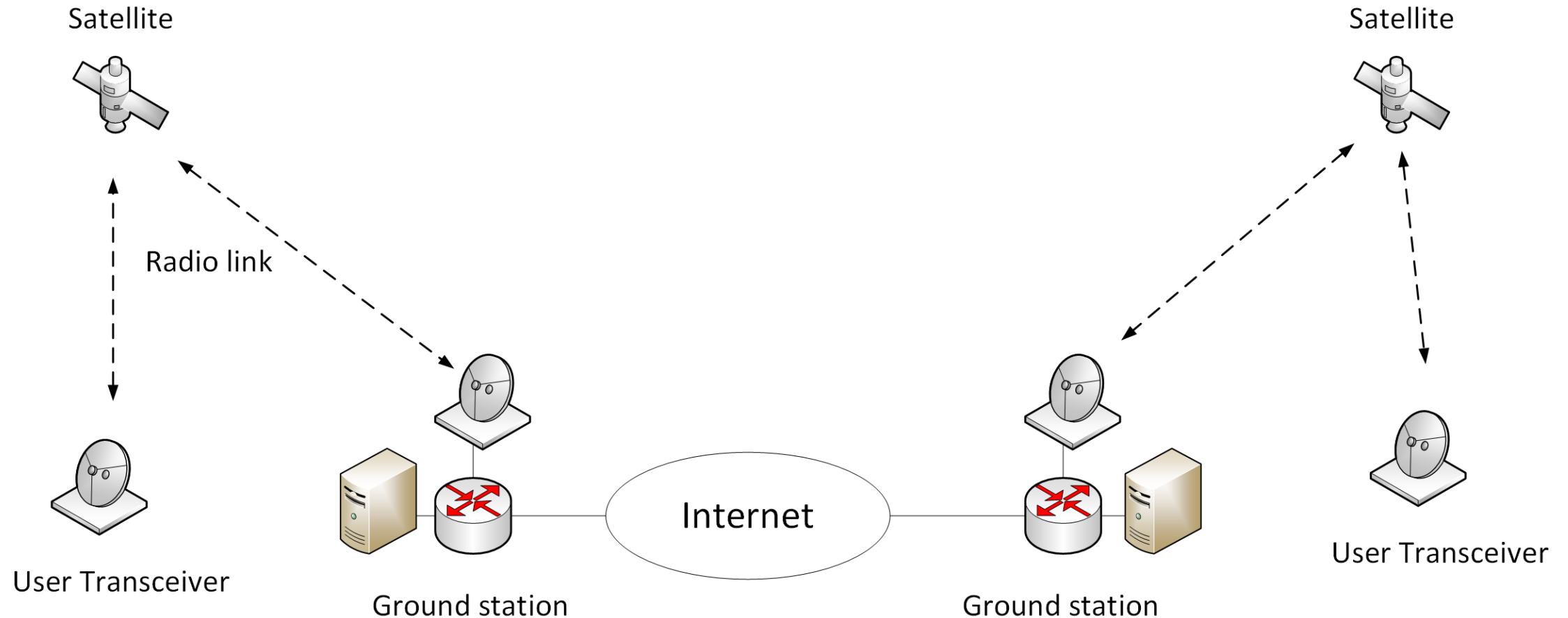
Satellites are usually classified based on their orbital altitude (distance from the Earth's surface), which directly affects their coverage and the speed at which they travel around the planet.

The 5 main types of satellites based on their orbits are:

- Low Earth orbit (LEO);
- Medium Earth orbit (MEO);
- Geostationary orbit (GEO);
- Sun-synchronous orbit (SSO);
- Geostationary transfer orbit (GTO).



Satellite networks – Basic infrastructure and communication



Internet access via Satellite networks is always expensive in comparison with, for example, cellular mobile networks and IEEE 802.11!

Starlink

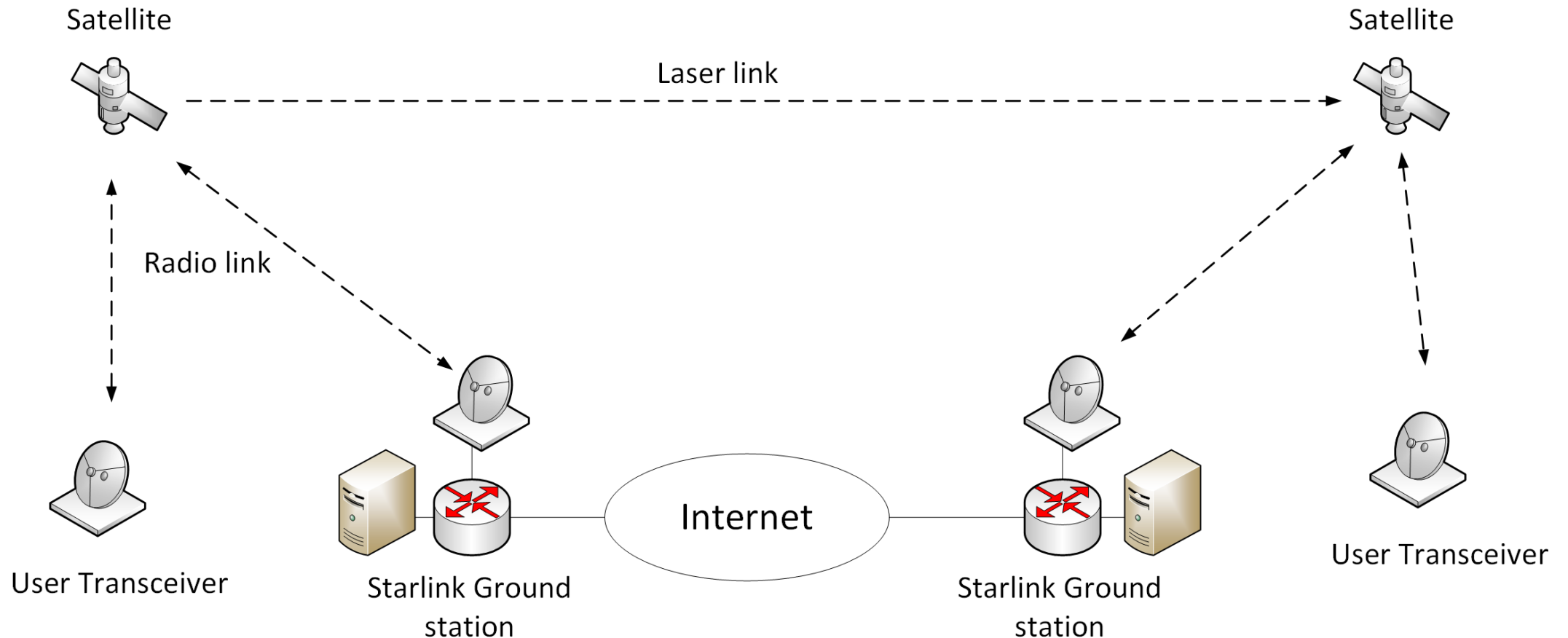
Starlink

- Starlink is a satellite broadband network operator owned by SpaceX, providing satellite Internet access coverage in about 160 countries.
- Starlink consists of over 10.000 mass-produced small satellites in Very Low Earth orbit (VLEO) and SSO, which communicate with designated ground transceivers.
- All Starlink communication protocols are proprietary and not openly published.
- Starlink utilizes the Ku-band (10.7–12.7 GHz for downlink) and Ka-band (17.8-19.3 GHz for uplink).
- A special transceiver (see images) is required to get access with Starlink.



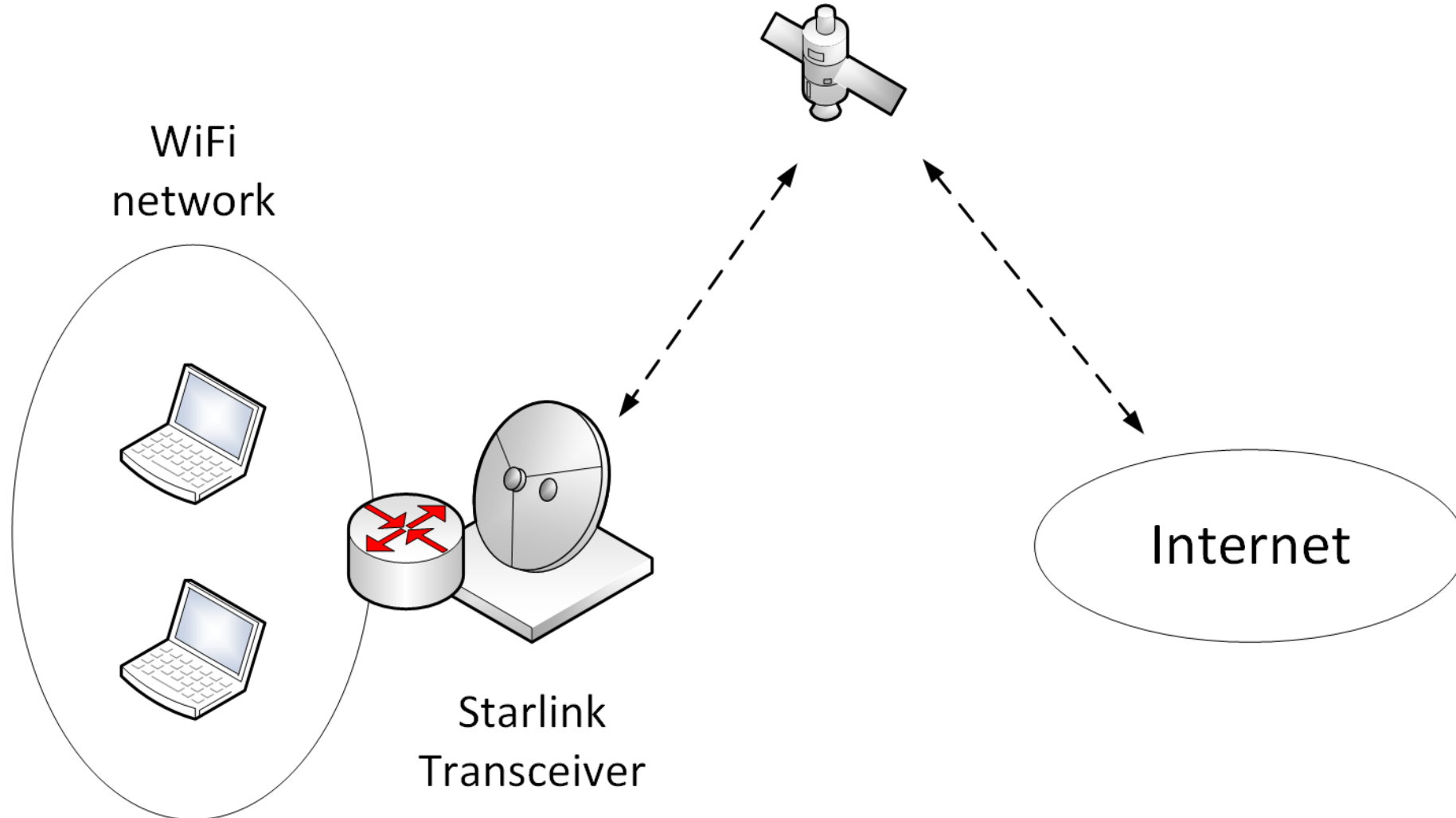
Starlink – basic communication infrastructure

Starlink satellites can communicate directly with each other using laser links, thereby creating a mesh network. This enables global coverage, not only areas close to ground stations.



Starlink – the Backhaul link

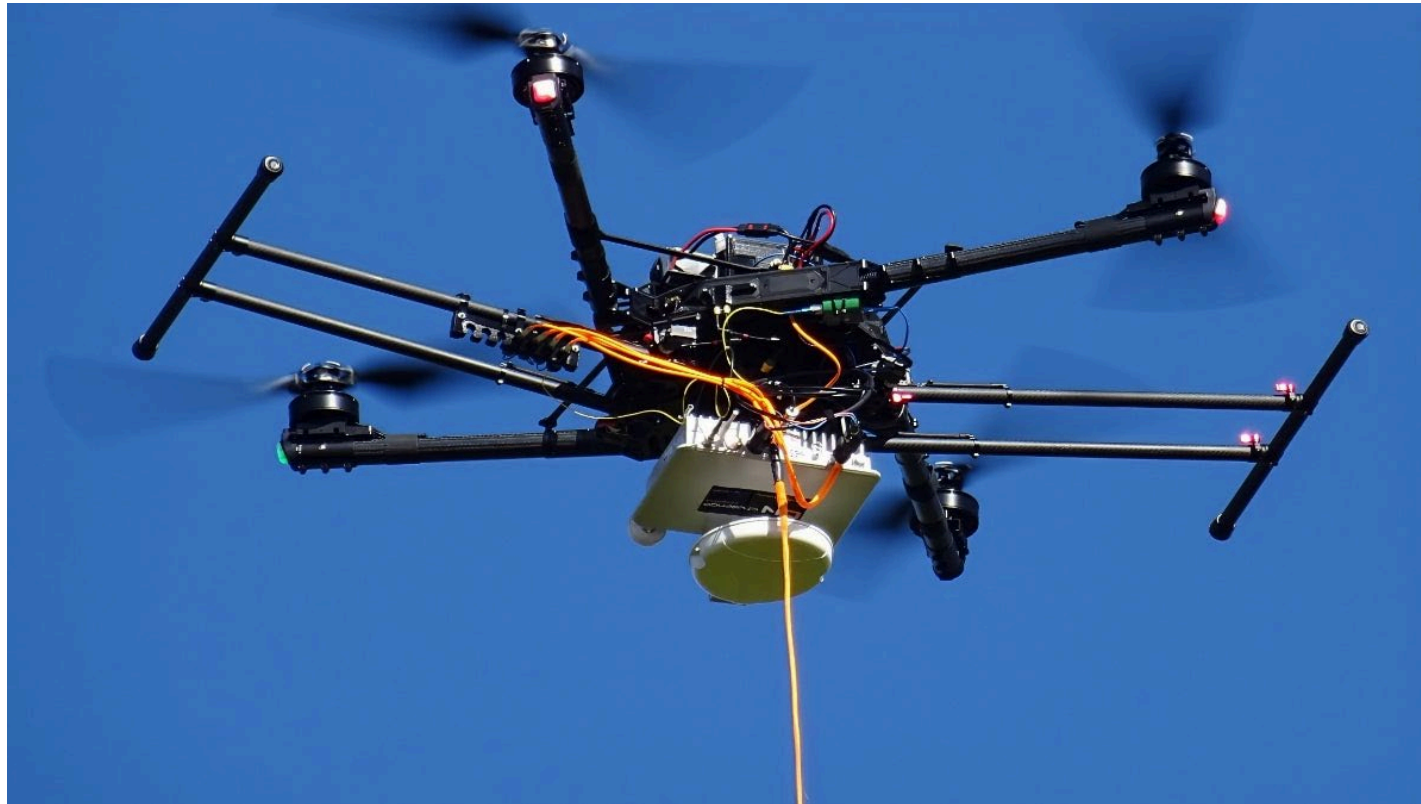
In practice, Starlink acts as a backhaul link. Usually, you access Starlink via a WiFi.



Starlink as backhaul - Example

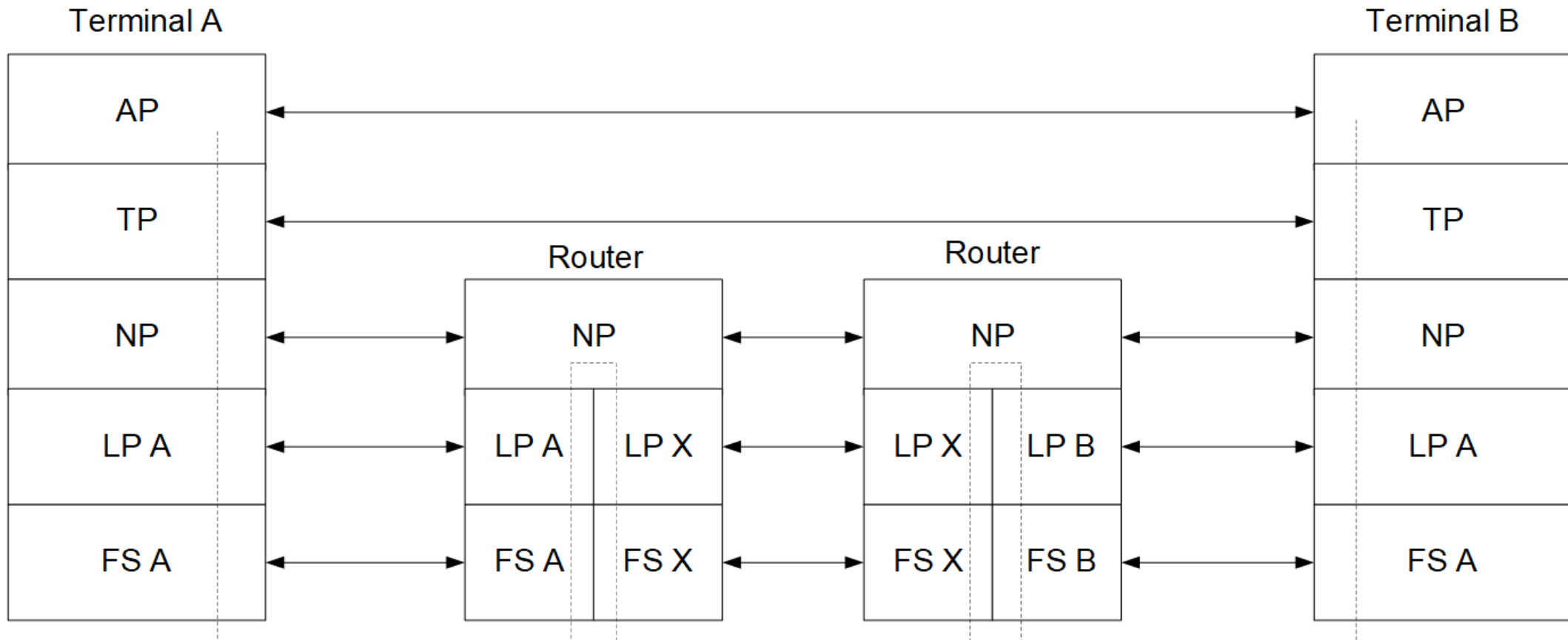
A drone can be equipped with Starlink and then used as a temporary WiFi access point, for example during rescue operations.

The drone in the picture is mains powered, for better power supply.



Information flow

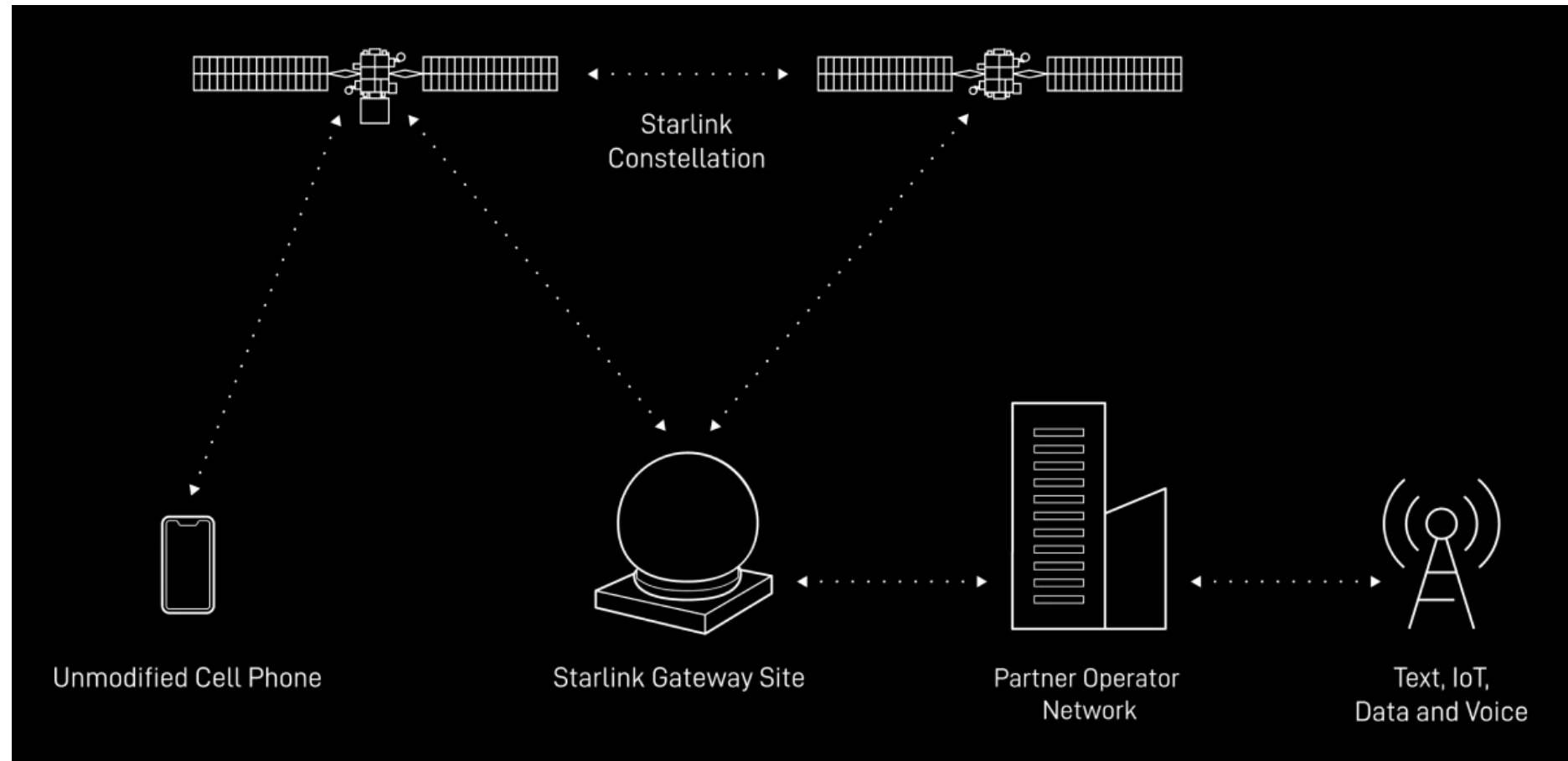
Starlink provides a low-latency, high-speed (full duplex) connection, suitable for time-critical applications requiring end-to-end reliable data transfer.



AP = Application Protocol; TP = Transport Protocol; NP = Network Protocol;
LP = Data link protocol; FS = Physical layer

Starlink Mobile – 4G NTN

In some countries (not Sweden), Starlink Mobile is available. Starlink Mobile works with existing 4G phones. The satellites have an antenna that acts like a mobile base station in space.



Other Satellite operators for fast-speed Internet access

- **Eutelsat OneWeb** is an operator with a LEO satellite broadband network, and its services cover most of Europe and the US.
- **Amazon Leo** is a LEO satellite broadband network company owned by Amazon. The deployment of satellites started during 2025.

Reindeer herding – Type of application?

You have been asked to help a Sami community situated in an area of the most northern parts of Sweden (also called Sápmi). They would like to have a tracking solution for their reindeer herds. Positioning data should be collected about the reindeers' movements and sent to a cloud server. Due to the large distances, the positioning data do not need to be exact. There can be an acceptable error in the positioning of about 1 km.

Also, your solution should enable the herders to have access to some basic Internet applications, as sending emails and web browsing, at suitable places. In addition, the reindeer herders should be able to monitor the reindeers through an app on their cell phone or laptop when they have Internet access.

Note: Even if Sweden has good cellular network coverage, there are large parts of Sápmi with very bad connectivity conditions. Your solution must reflect this.



Solution suggestion - Reindeer herding – Type of application

The scenario includes two different applications:

Reindeer monitoring

- Monitor positions of reindeers that move around in a large geographic area
- Position errors are tolerated
- Latencies are not that critical
- Sensors must be battery-powered
- **Typical non-critical application with resource-constrained communication**

Internet access for herders

- Basic Internet applications
- No requirement on availability everywhere
- **Time-critical application, but only at some places**

Argos

Argos

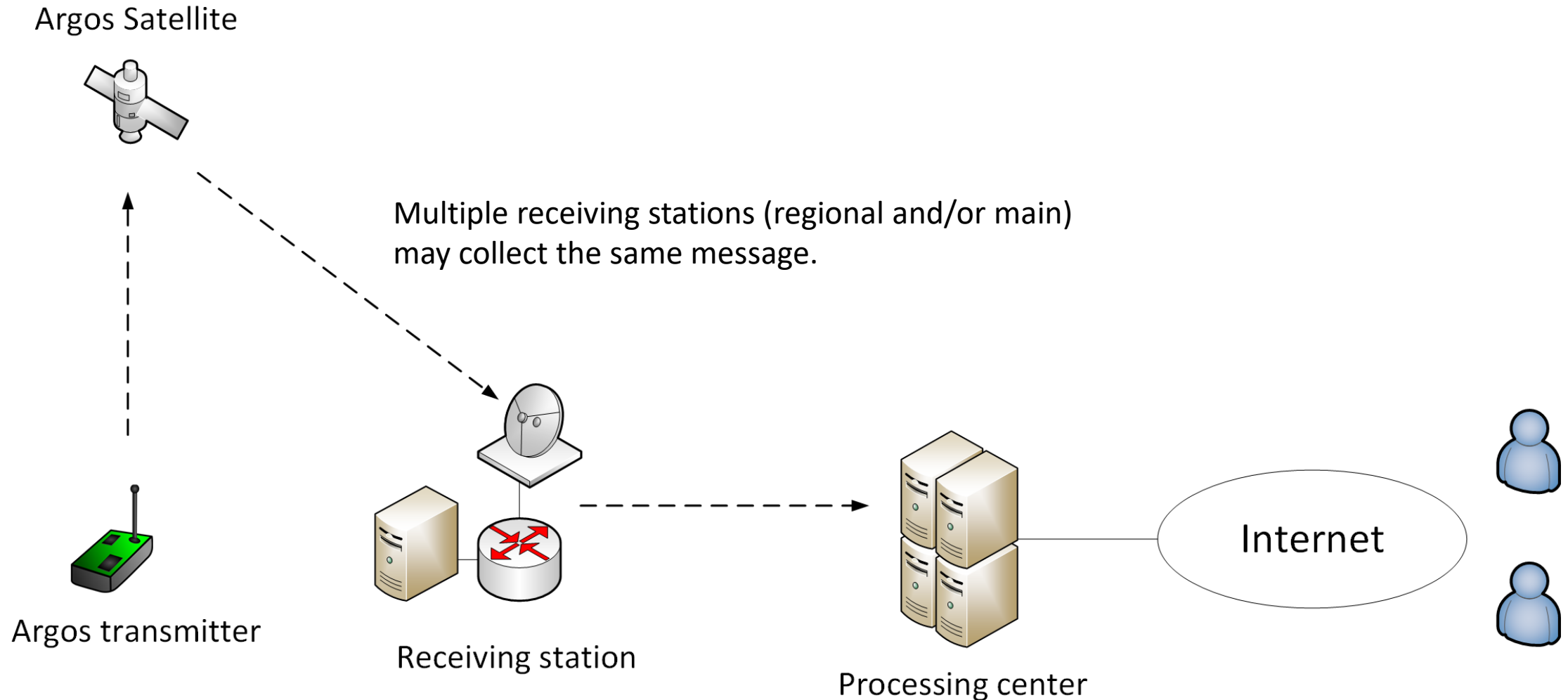
- Argos is a global satellite-based system specifically aimed at **resource-constrained applications**.
- Argos collects, processes, and disseminates data from fixed and mobile devices around the world.
- The system enables **one-way data transmission** (from devices to the back-end) on the frequency band 401.650 MHz.
- A main feature in Argos is the ability to geographically locate the data source (**positioning**) from any location on Earth using the Doppler effect.
- **The user pays fees per active transmitter and for the data transmission.**



Argos satellite system

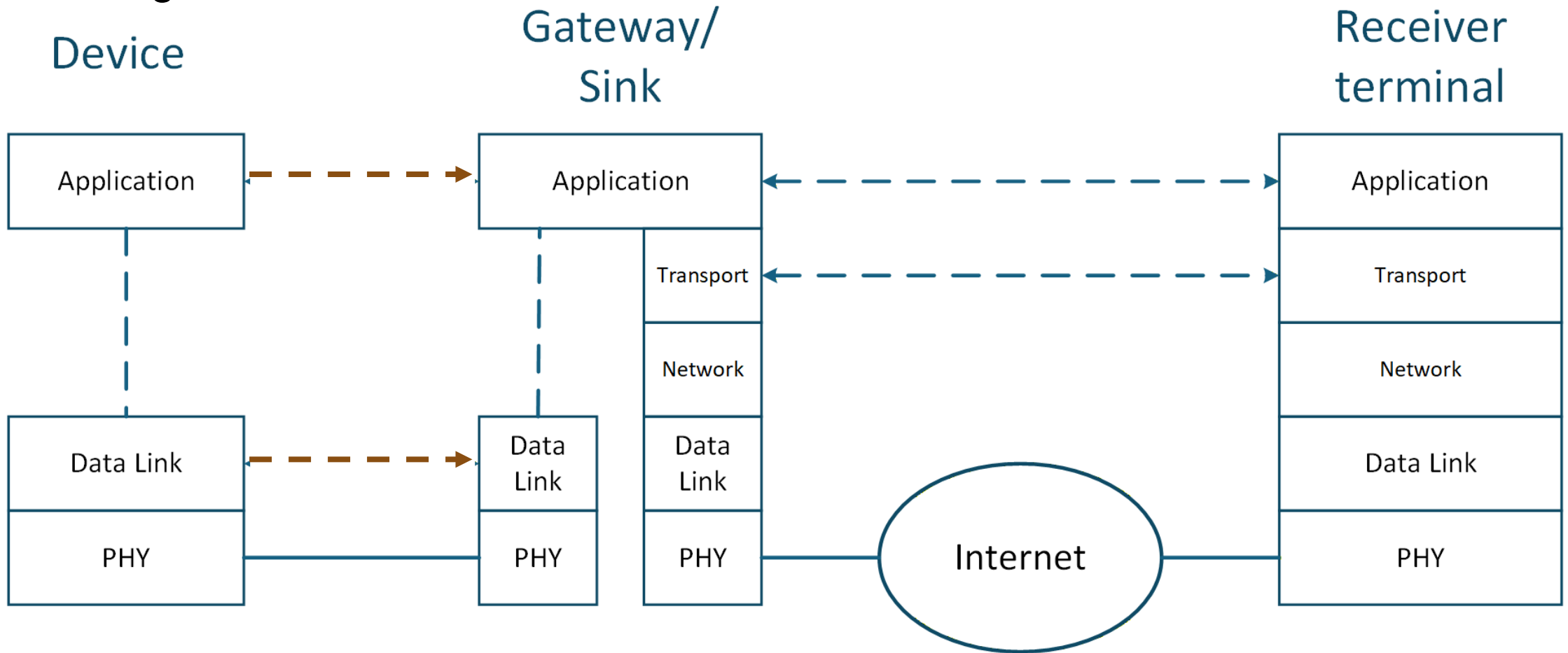
- The Argos System is served by 7 polar orbiting satellites at an altitude of 850 km and completes a revolution around Earth approximately every 100 minutes.
 - The satellites collect the uploaded data, store the data on-board, and then relay the data back to receiving stations on Earth.
- Nearly **70 receiving stations** receive data from the satellites and retransmit them to processing centers. This distribution network provides worldwide coverage.
 - There are **three main receiving stations** that collect **all the messages** recorded by the satellites during an orbit, thus providing coverage of the entire Earth.
- Data received by the satellites are retransmitted to **regional stations** if the station is within satellite visibility.
- There are **two global Argos processing centers**. When data arrive at a processing center, locations are automatically calculated and the information is made available to users.

Argos – basic network architecture



Information flow

Argos provides a low-bit rate (one-way) connection, suitable for resource-constrained networking.



Argos transmitters

- The **Argos transmitters** (powered by batteries or solar energy) upload short duration messages (of less than one second) to Argos satellites.
 - A transmitter can be really small and lightweight so that it can be attached to, for example, a bird or a fish without disturbing them.
- Each Argos transmitter (platform) features a unique 28-bit ID.
- An Argos transmitter can **transmit a short 3 to 31 bytes message** for each transmission.
- Each transmitter is **restricted to a specified interval**, such as every 60 seconds, allowing for a few hundred bytes total per satellite pass.



Argos MAC protocol: E-ALOHA

- **Enhanced ALOHA (E-ALOHA)** is used in several **sensor node systems** for telemetry applications with **periodical data transmissions** (telemetry = sensors only collect data, no two-way communication).
- The sensor transmits data periodically and ALOHA is used when the sensor transmits data.
- Potentially, some sensors can end up with exactly the same time intervals for data transmission, which would mean that there would be permanent data collisions.
- Therefore, E-Aloha defines a time window—considerably longer than the packet transmission time—located around the fixed sending time. Within this window, each node selects randomly a new sending time, thus reducing the chances of permanent collisions among nodes using the same time interval.

E-ALOHA

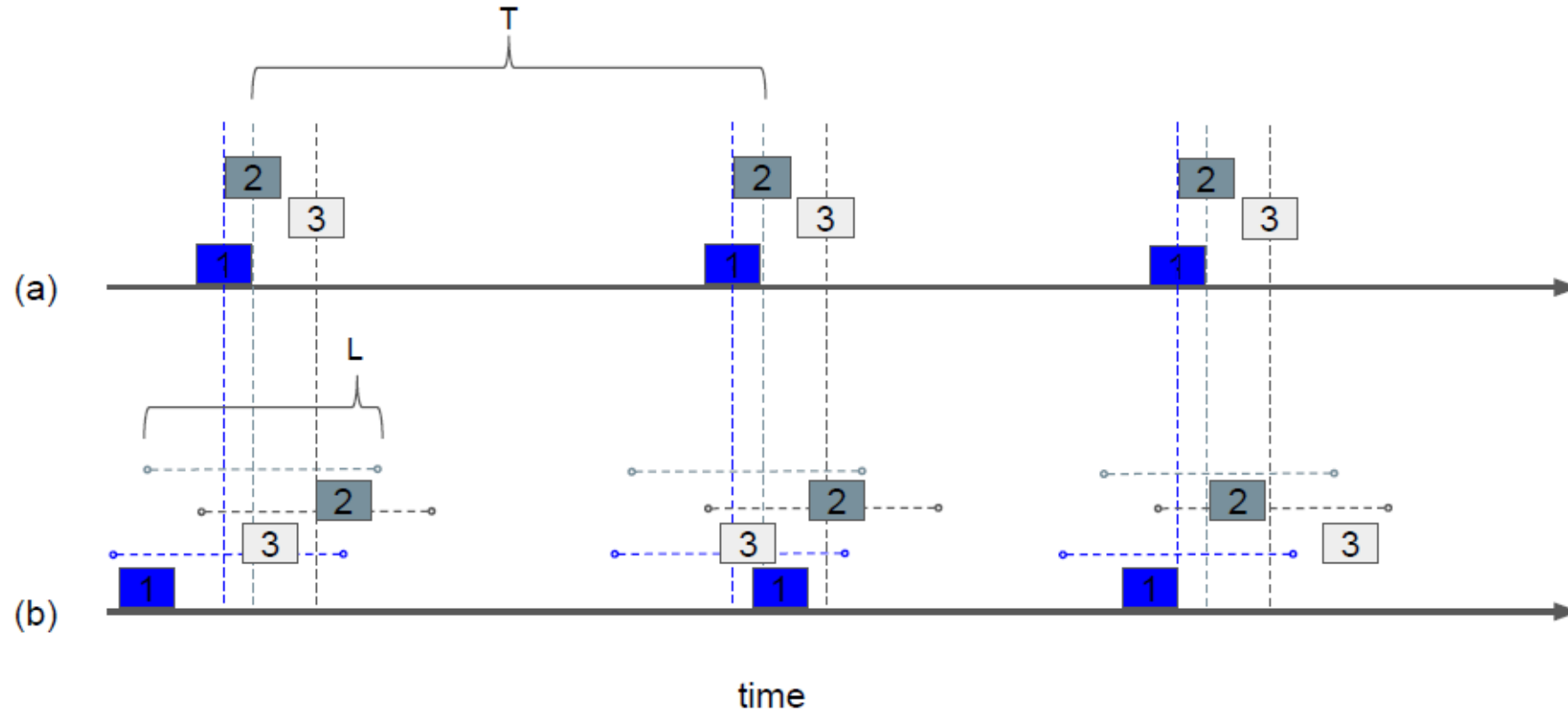


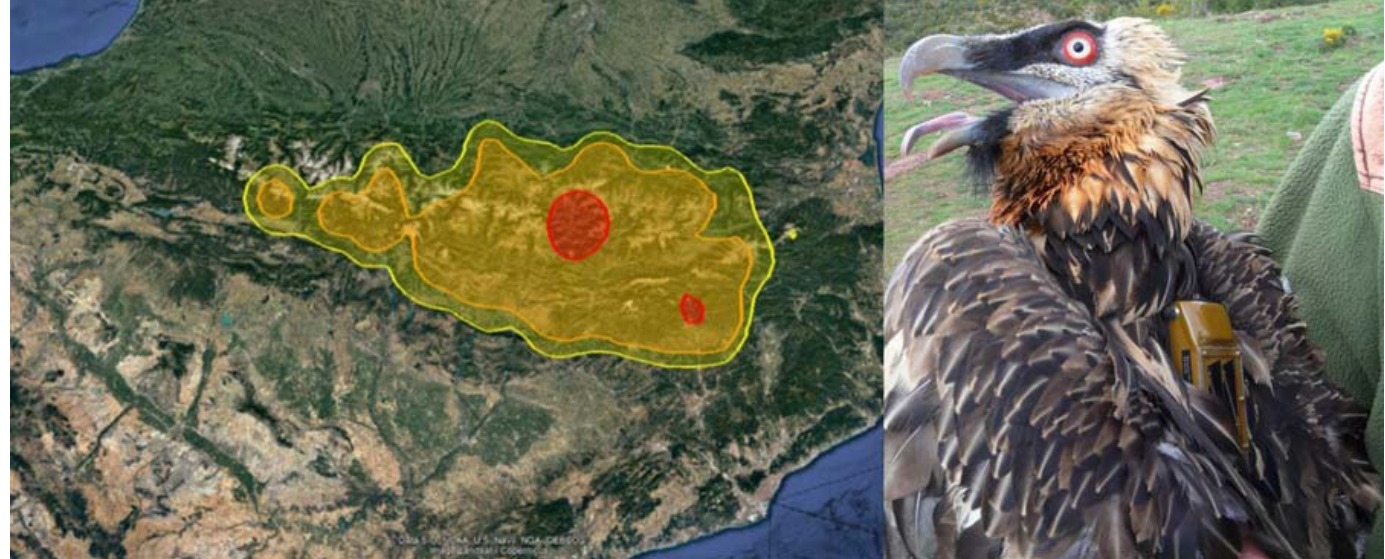
Figure 6. Example of E-Aloha operation where three users send packets at a rate of $\frac{1}{T}$ packets/s. In (a), the users wait a fixed time (T), in consequence, there is a permanent collision between the users 1 and 2; whereas in (b) there is a time window (L) for selecting a new random sending time in order to avoid permanent collisions. Figure adapted from [43].

Argos example: Bearded vulture tracking

Bearded vultures have been monitored for a better understanding and protection in the Pyrenees mountains for about 30 years now.

Several individuals were tagged with 70-g solar-powered Argos sensors. One of those individuals, nicknamed Adrian, a four-year-old subadult male, was localized from 2009 up to 2023 with the same Argos transmitter.

The image shows the home range estimates from Adrian's tracking. The red large area corresponds to his territory when breeding in 2013, the small red area in 2019.



Iridium

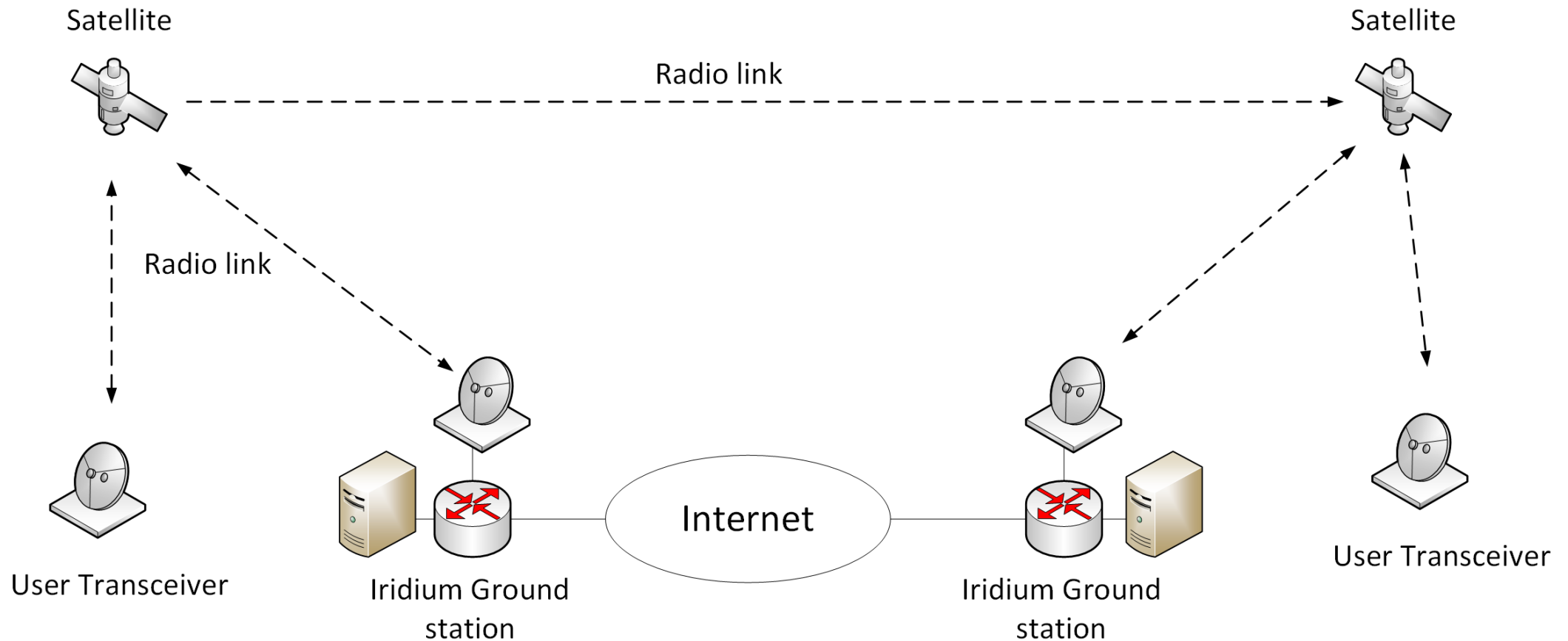
Iridium

- Iridium is a global satellite network operator, providing **global voice and data communication services**.
- The Iridium system uses 66 operational satellites in low Earth orbit, with 14 additional satellites serving as in-orbit spares.
- Iridium uses radio communication on the Ka band (27 – 40 GHz), the K-band (18 – 27 GHz)
 - Ka-band frequencies are used for feeder links between the satellites and Iridium's ground stations.
 - K-band frequencies are used for intersatellite communications.
- Communication between satellites and end devices is done using a TDMA and FDMA based system on the L-band (1-2 GHz)
- Iridium can provide **data rates up to 1.4 Mbps**.



Iridium – basic network infrastructure

Iridium satellites can communicate directly with each other, thereby creating a mesh network. This provides global coverage for Iridium applications.



Iridium based applications

Iridium can be used for several types of applications:

- Satellite phones
 - Classical Iridium application, aimed at users in extremely remote regions.
- IoT applications (M2M communication)
 - Iridium Certus is a global platform for IoT connectivity.
- Pagers and messengers, for example Garmin inReach.
- WiFi hotspots
 - Iridium Go provides global WiFi hotspots.



Iridium example: Garmin inReach

inReach is a brand of satellite communications devices, which is developed by Garmin.

- All inReach devices feature texting, remote location tracking. Some devices have the ability to send images and voice messages.
- All devices have so called **SOS via satellite**.
 - When a user hits the SOS button, the device broadcasts the user's location every minute for 10 minutes, then falls back to a 10 minute interval.
 - A conversation is initiated between the user and the Garmin Response Team, who notifies emergency contacts, determines an appropriate course of action, and facilitates communication between the user and responders.
- inReach requires **an active subscription**. Usage may also incur metered pricing, depending on the subscription.



Reindeer herding – System design?

You have been asked to help a Sami community situated in an area of the most northern parts of Sweden (also called Sápmi). They would like to have a tracking solution for their reindeer herds. Positioning data should be collected about the reindeers' movements and sent to a cloud server. Due to the large distances, the positioning data do not need to be exact. There can be an acceptable error in the positioning of about 1 km.

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Reindeer herding – Solution suggestions

Reindeer monitoring

- IoT technology suitable for resource-constrained networking, for example:
 - LoRa, LTE-M, Argos, Iridium
- LoRa requires gateways, network server, application server and a backhaul link, or the availability of a public LoRa operator.
- LTE-M requires cellular connectivity (longer ranges than ordinary 4G/5G)
- Argos and Iridium are quite expensive but work well in very remote areas.
- NB-IoT does not support mobility
- Positioning using GNSS
- Power supply for potential gateways and sensors

Internet access

- Herders have Internet access on their cell phones when there is 4G/5G coverage.
 - Use WiFi-direct for creating a WiFi hotspot.
- Herders bring a Iridium Go WiFi hotspot to use when they are out of 4G/5G connectivity. Requires power supply.
- Starlink as WiFi hotspot. Requires power supply.
- Ordinary WiFi where there is electricity. Backhaul link is required.



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