Centipede-RTK & Millipede
Centimeter-Level Outdoor Geolocation

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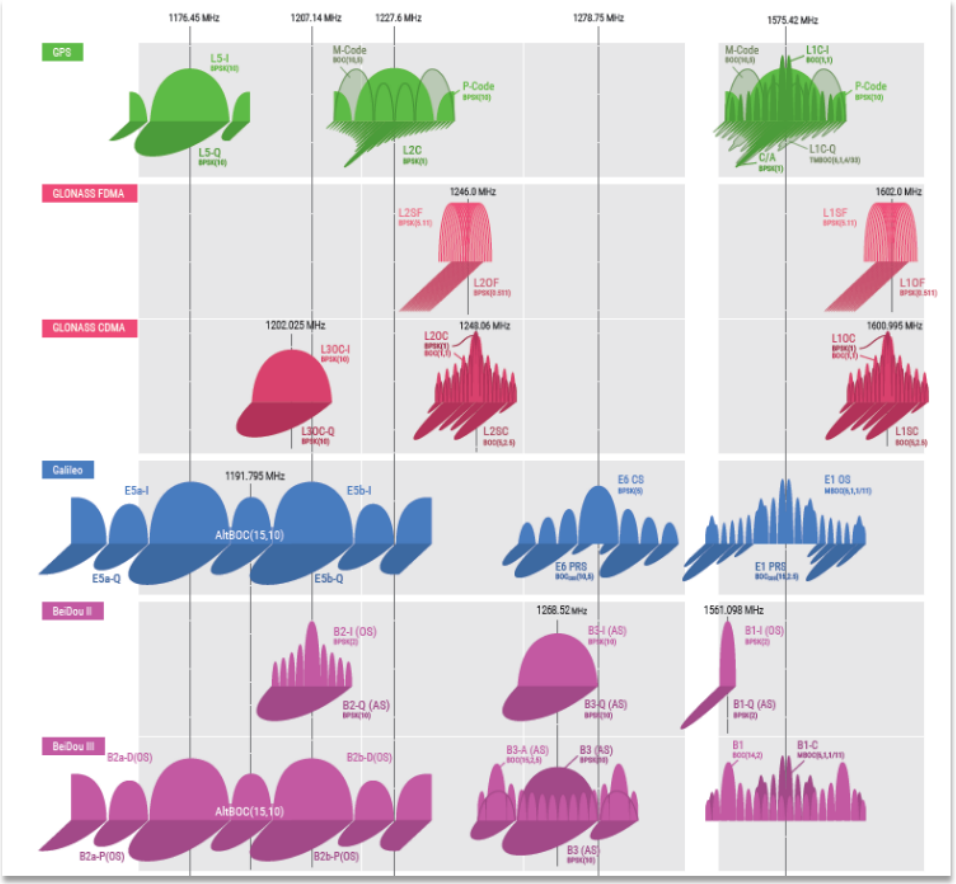
Eriomem.net
Frnog41 – Paris -- 28 March 2025

GNSS frequency bands



https://www.agrotic.org/wp-content/uploads/2019/02/2019-04-23-AgroTic-Geolocalisation-CNES-VP.pdf

Terminology (1): GPS, GNSS ?

GNSS = Global navigation satellite systems

→

- GPS (USA)
- Galileo (EU)
- BeiDu (China)
- Glonass (Russia)

Terminoloy (2) : free OS?

~~Free OS <=> Linux~~

- ~~« Is it running on Linux? »~~
- « Is it running on a free/libre/FOSS Unix system? »
- ~~BSD? Is it a new Linux distribution?~~
- Berkeley Software Distribution (1977-)

Tropospheric and ionospheric delays

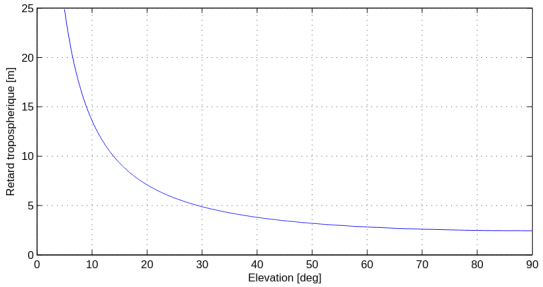
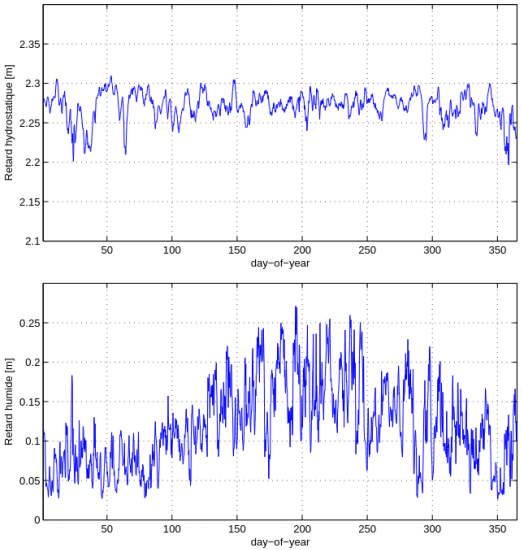
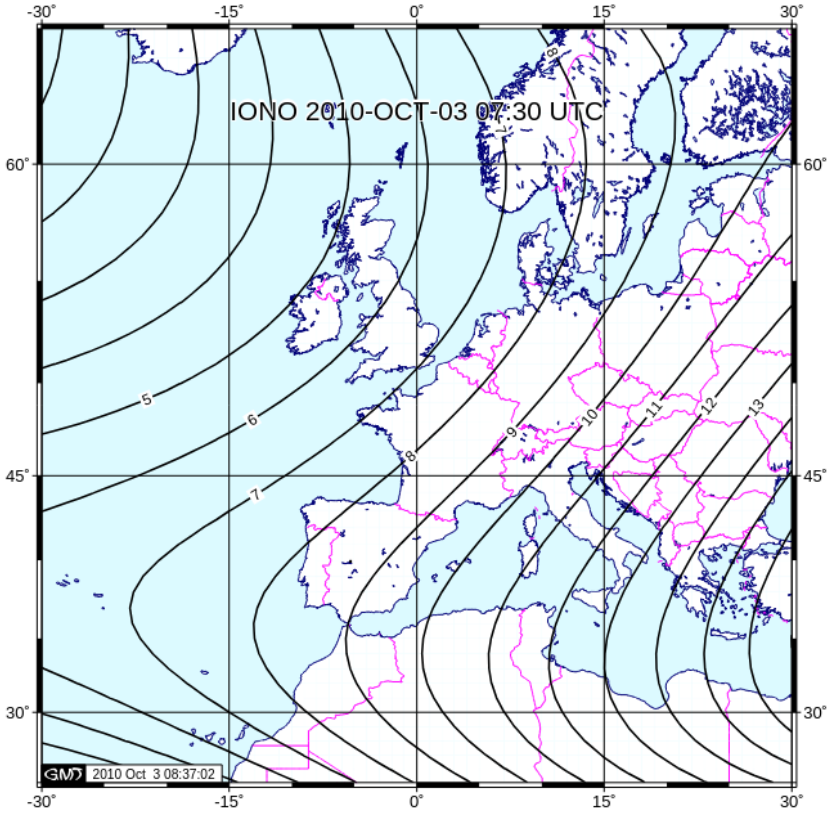


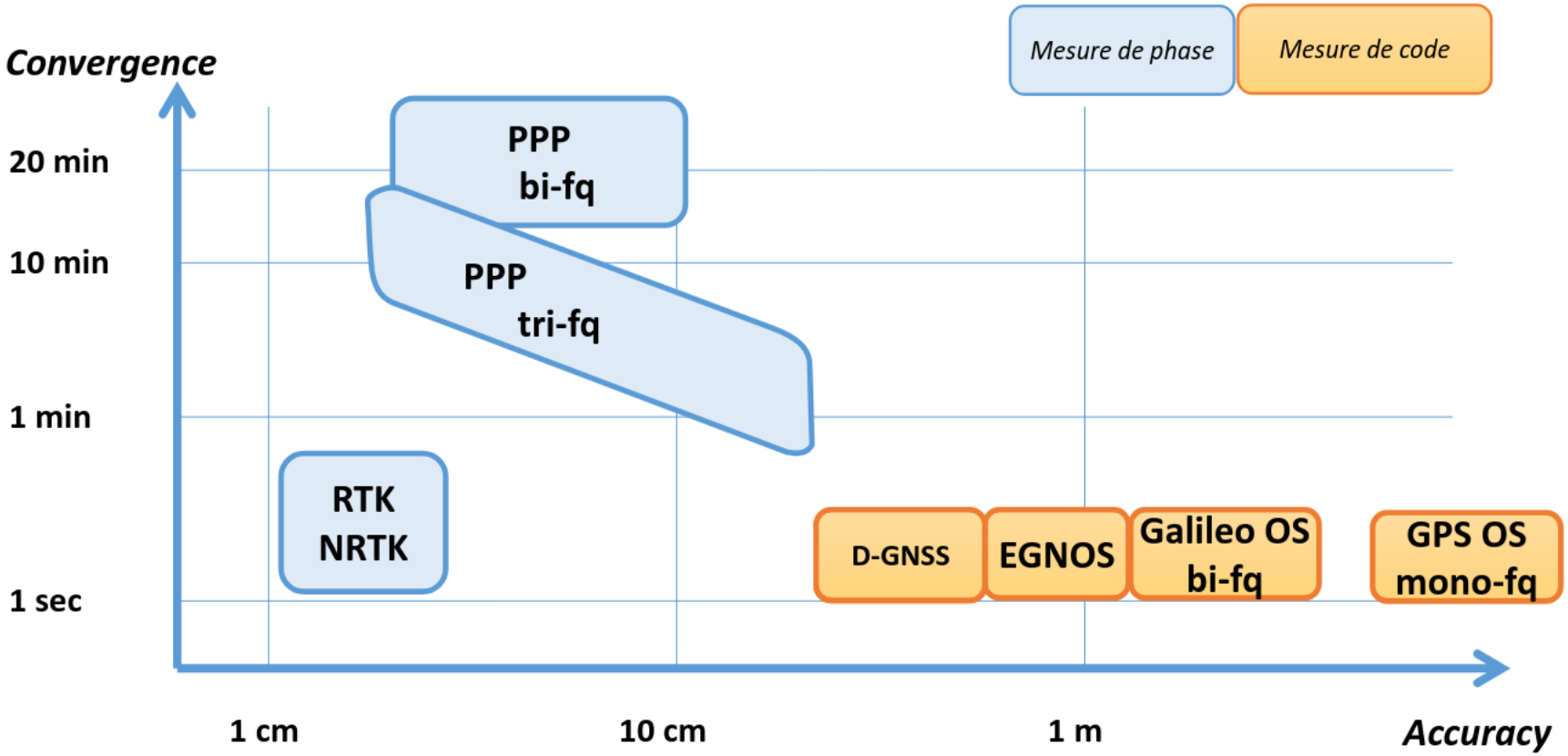
FIG 25 - Évolution du retard troposphérique avec l'élévation du satellite au-dessus de l'horizon.





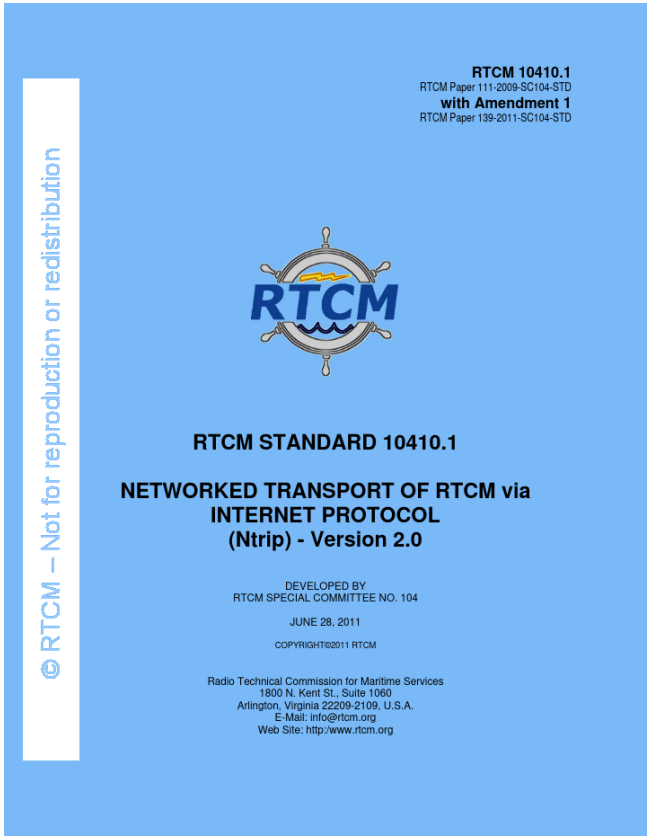
https://cours-fad-public.ensg.eu/pluginfile.php/1501/mod_resource/content/1/gnss.pdf

Precision positioning technologies



https://www.agrotic.org/wp-content/uploads/2019/02/2019-04-23-AgroTic-Geolocalisation-CNES-VP.pdf

Open-closed standards



NTRIP1, NTRIP2

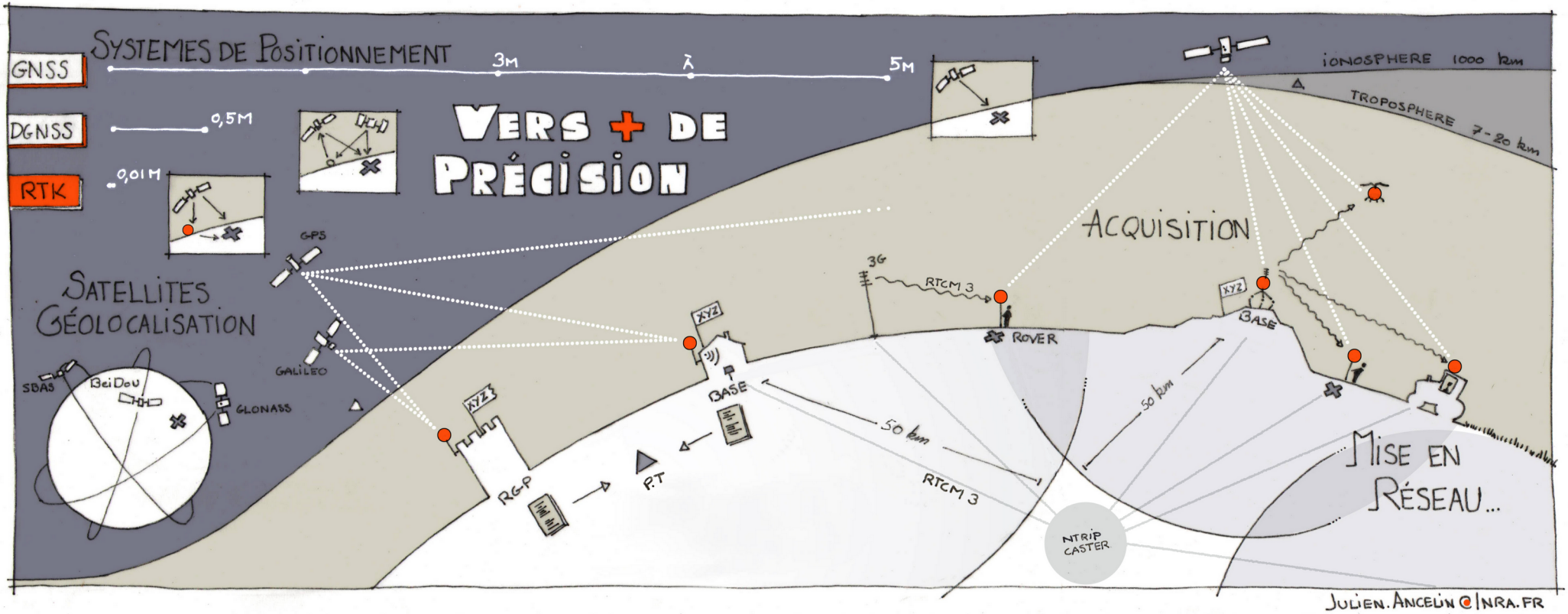
- « Networked Transport of RTCM via Internet Protocol »
- Ntrip1: roughly based on ICECAST, itself roughly based on HTTP 0.9
- Ntrip2: complies with HTTP 1.1
  - Can cross a http proxy → easier handling of https
- Many broken/half cooked client or server implementations
- Transparent: can stream anything, proprietary packets, audio or even video.

Real-time kinematics

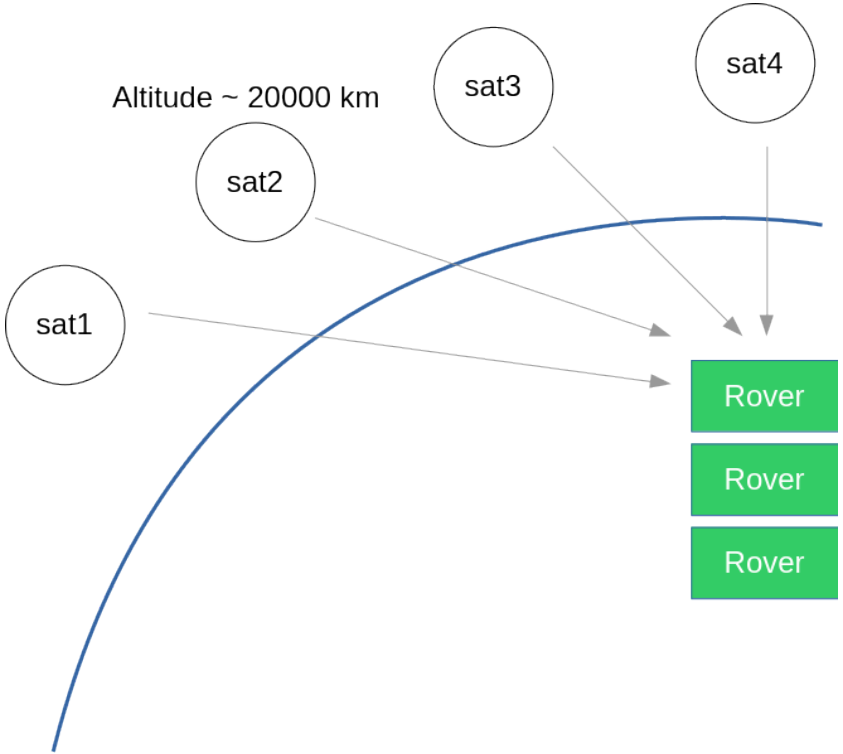
- Absolute positioning
- Relative positioning
- Needs a reference base
- « rovers »

- Local base for local deployment
  - Radio link
  - Internet access for the base + mobile data for the rover
- How about we share the base streams?

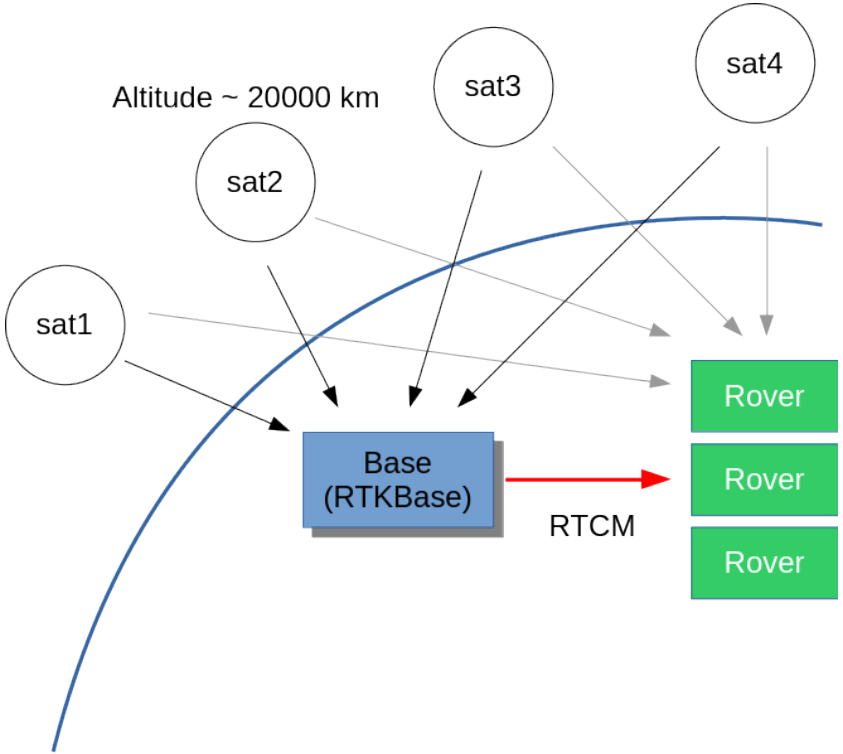
  => Centipede


SYSTEMES DE POSITIONNEMENT
GNSS
3M
À
5M
DGNSS
0,5M
RTK
0,01M
VERS + DE PRÉCISION
IONOSPHERE 1000 km
TROPOSPHERE 7-20 km
ACQUISITION
SATELLITES GÉOLOCALISATION
GPS
GALILEO
SBAS
BeiDou
GLONASS
3G
RTCM 3
ROVER
XYZ
BASE
50 km
RGP
PT
MISE EN RÉSEAU...
NTRIP CASTER
JULIEN.ANCELIN@INRA.FR

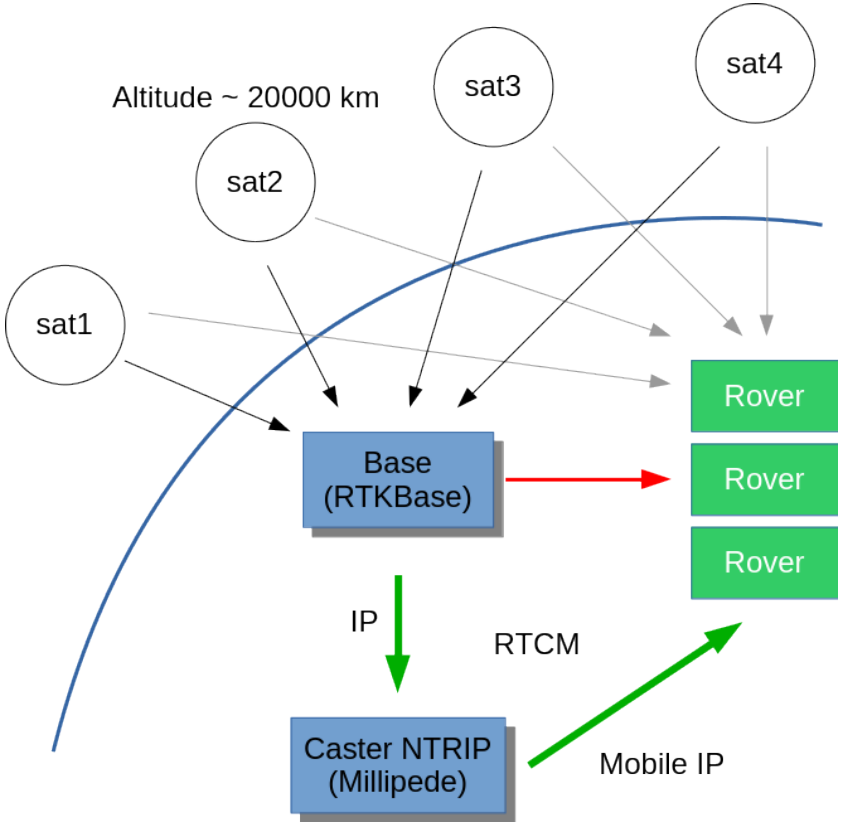
Basic GNSS reception

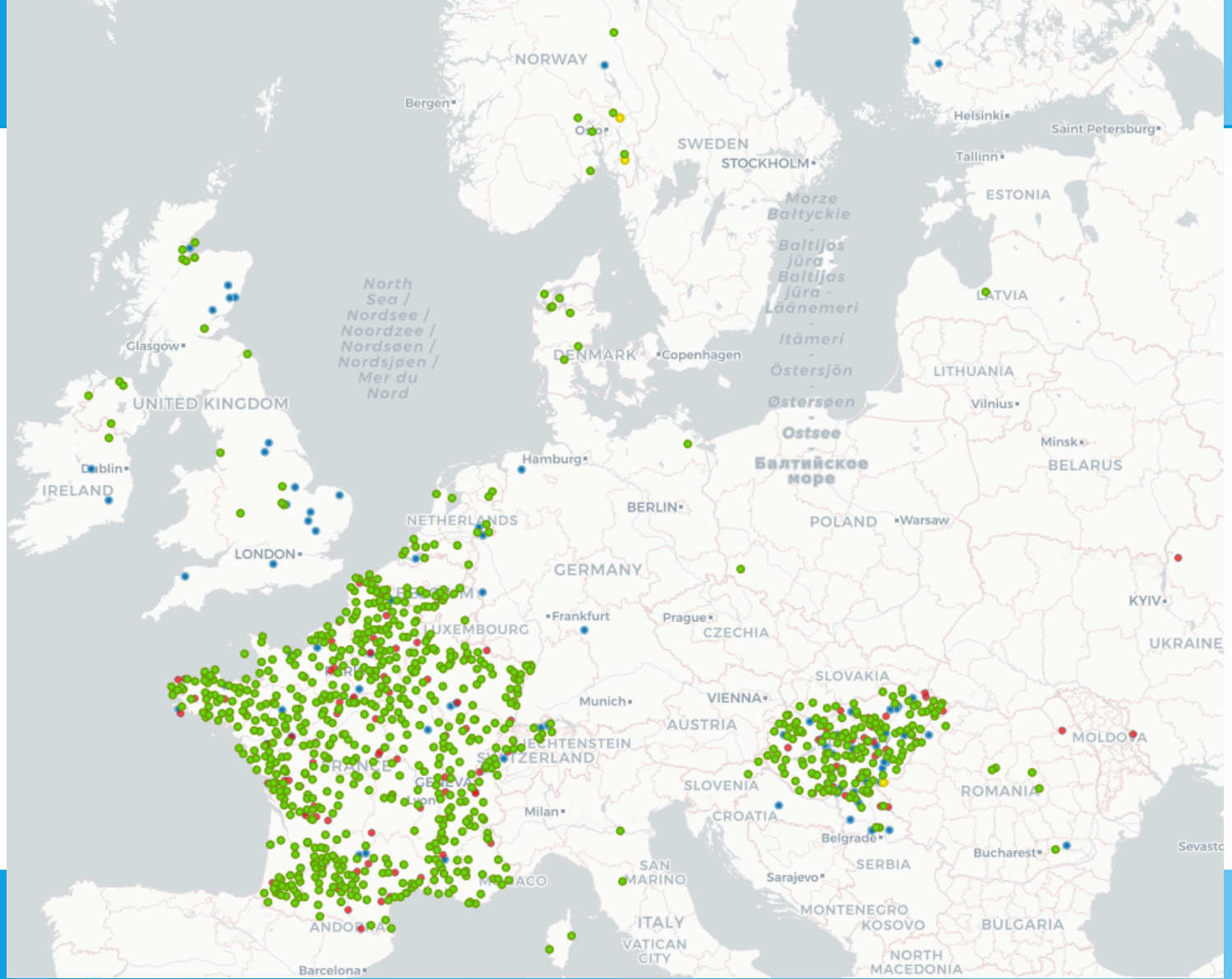


Adding local corrections



Distributing source streams




NORWAY
Bergen
Oslo
SWEDEN
STOCKHOLM
Helsinki
Saint Petersburg
Tallinn
ESTONIA
LATVIA
LITHUANIA
Vilnius
Minsk
BELARUS
Morze Bałtyckie
Baltijos jūra
Baltijas jūra
Läänemeri
Itämeri
Östersjön
Østersøen
Ostsee
Балтийское море
North Sea / Nordsee / Noordzee / Nordsøen / Nordsjøen / Mer du Nord
DENMARK
Copenhagen
Glasgow
UNITED KINGDOM
Dublin
IRELAND
LONDON
Hamburg
BERLIN
NETHERLANDS
POLAND
Warsaw
GERMANY
Frankfurt
Prague
CZECHIA
LUXEMBOURG
KYIV
UKRAINE
SLOVAKIA
Munich
VIENNA
AUSTRIA
LIECHTENSTEIN
SWITZERLAND
MOLDOVA
ROMANIA
SLOVENIA
CROATIA
Milan
Belgrade
Bucharest
SERBIA
Sarajevo
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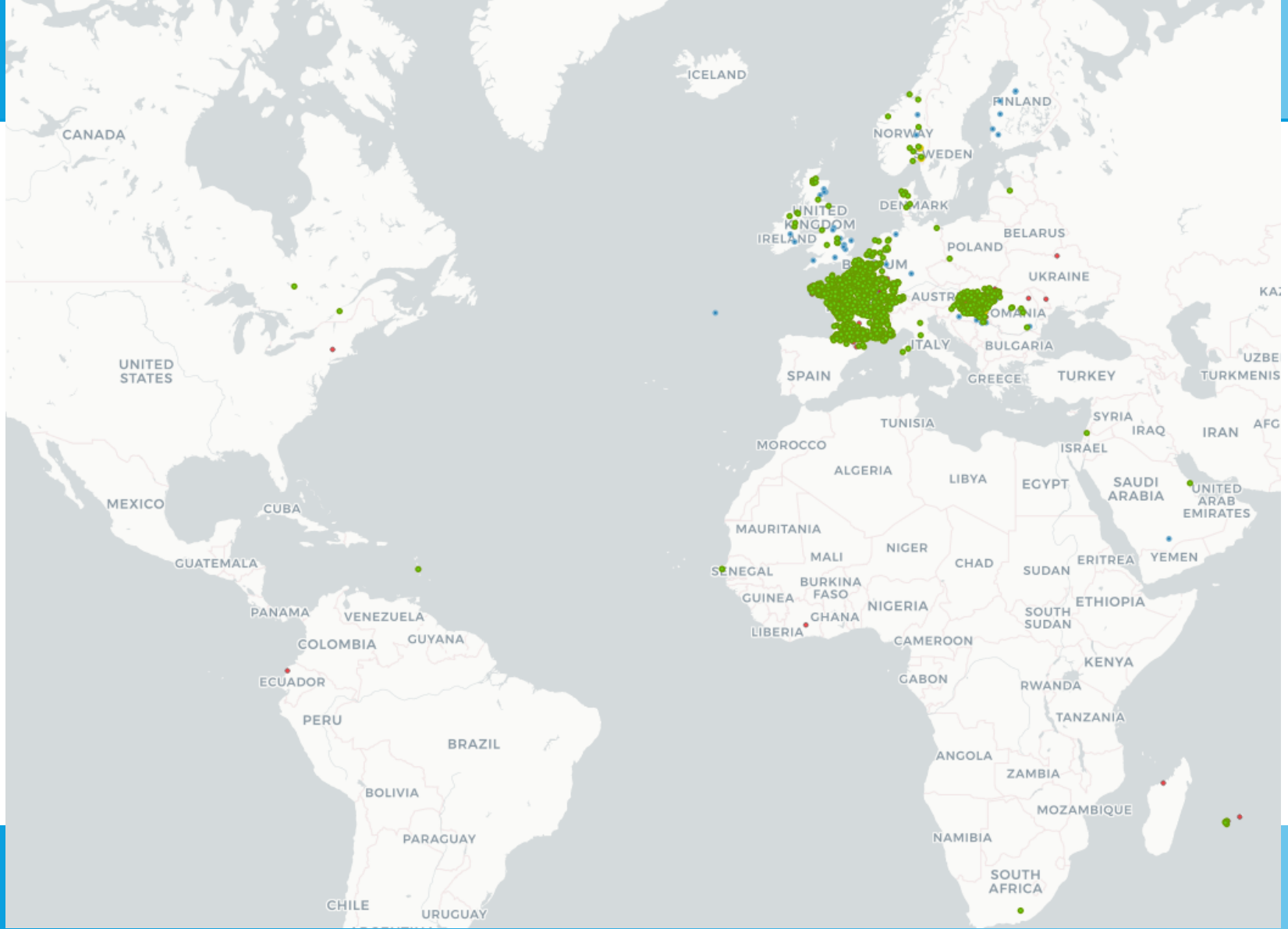
ITALY
VATICAN CITY
MONTENEGRO
KOSOVO
BULGARIA
NORTH MACEDONIA
ANDORRA
Barcelona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BULGARIA
GREECE
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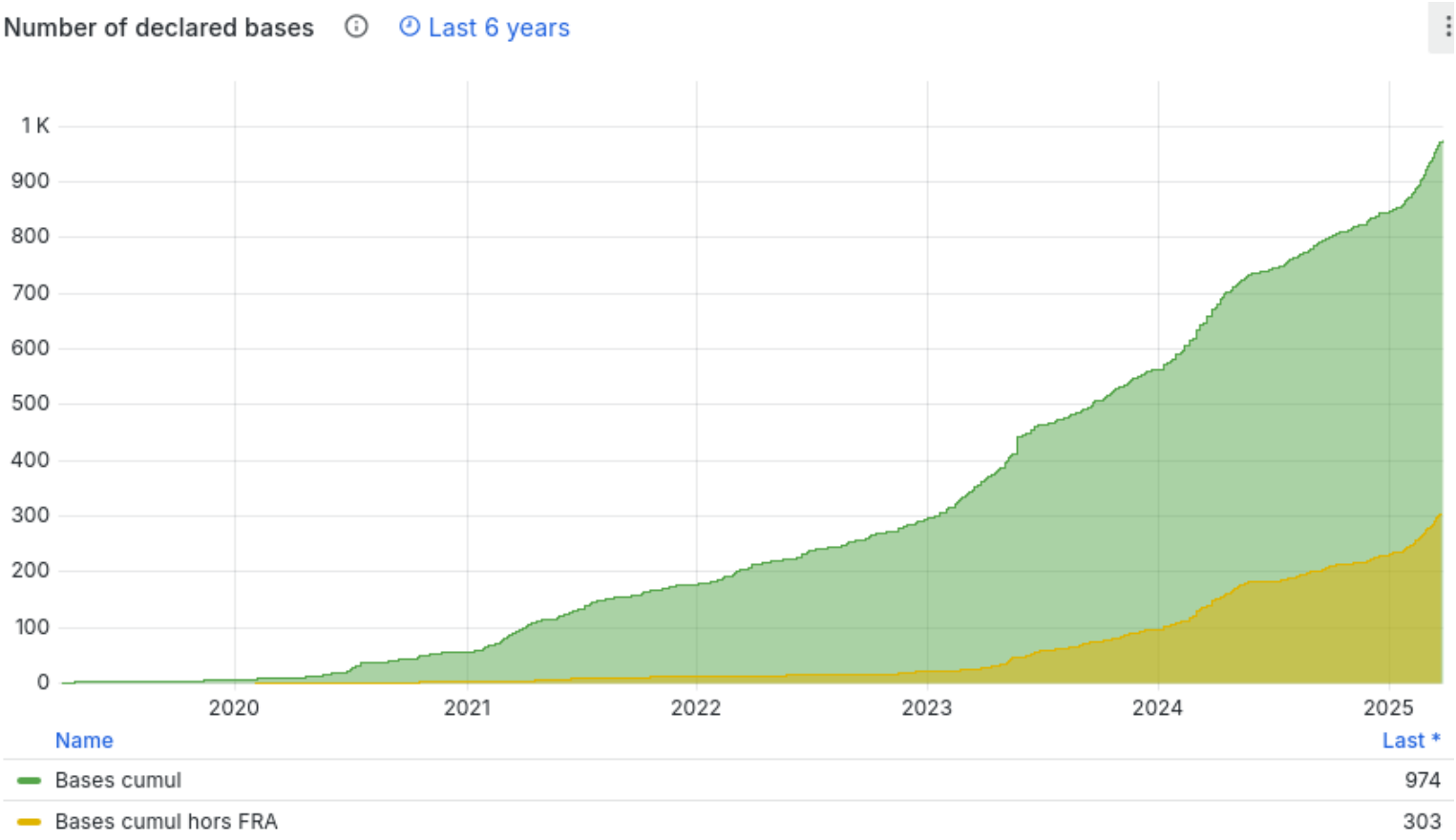
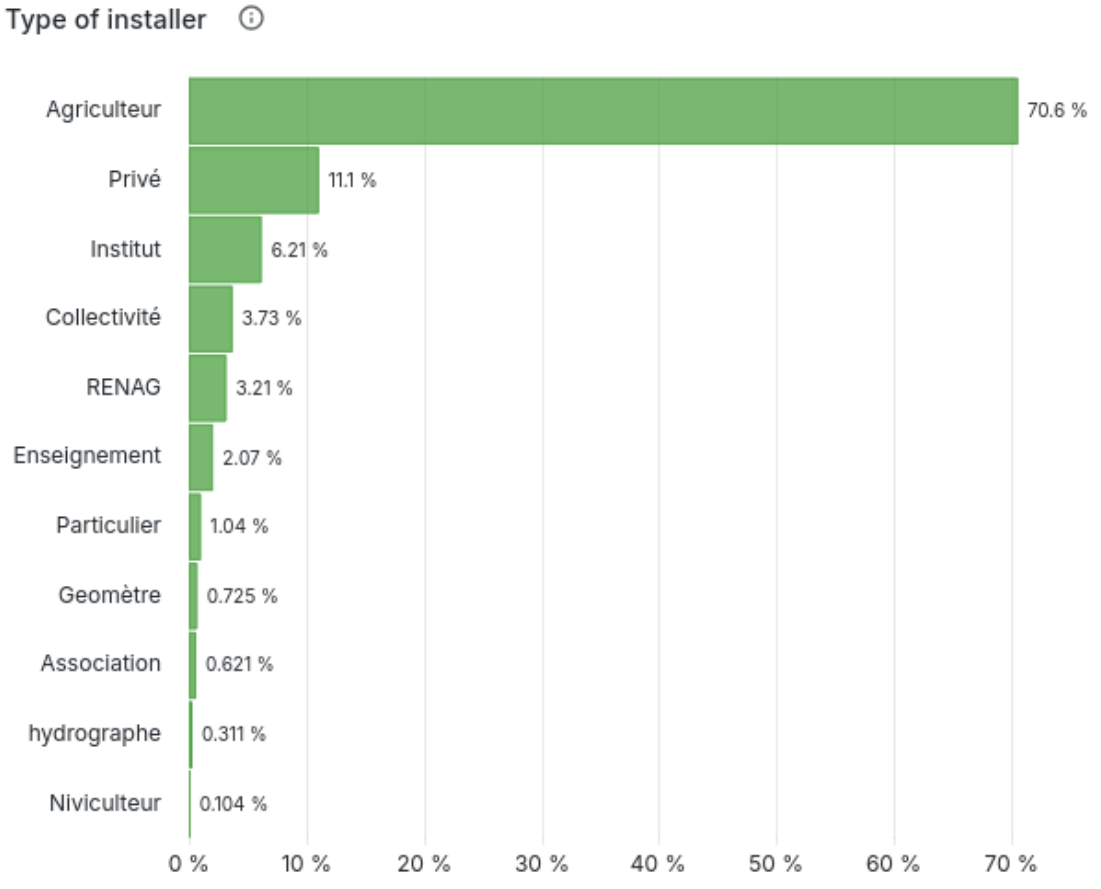
CUBA
MAURITANIA
MALI
NIGER
CHAD
SUDAN
ERITREA
YEMEN
GUATEMALA
SENEGAL
BURKINA FASO
GUINEA
NIGERIA
ETHIOPIA
PANAMA
VENEZUELA
GHANA
SOUTH SUDAN
LIBERIA
COLOMBIA
GUYANA
CAMEROON
KENYA
ECUADOR
GABON
RWANDA
TANZANIA
PERU
BRAZIL
ANGOLA
ZAMBIA
BOLIVIA
MOZAMBIQUE
PARAGUAY
NAMIBIA
SOUTH AFRICA
CHILE
URUGUAY

Centipede bases over time



Centipede bases by owner type



Centipede clients

Clients

client global

2295

client DIRECT

2010

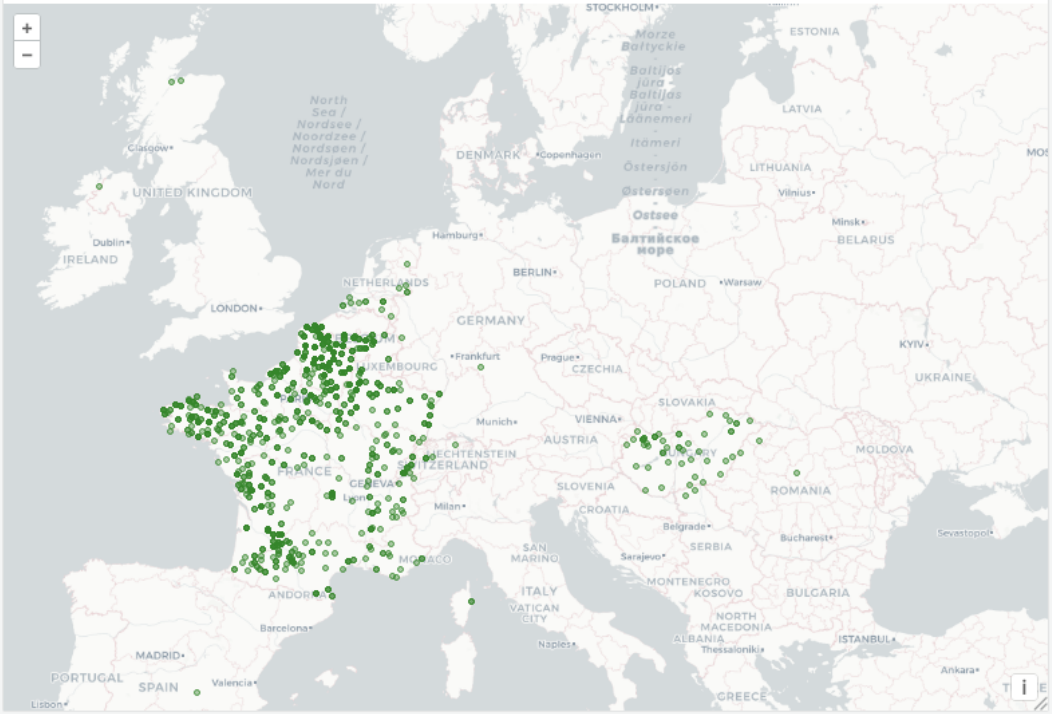
client NEAR

285

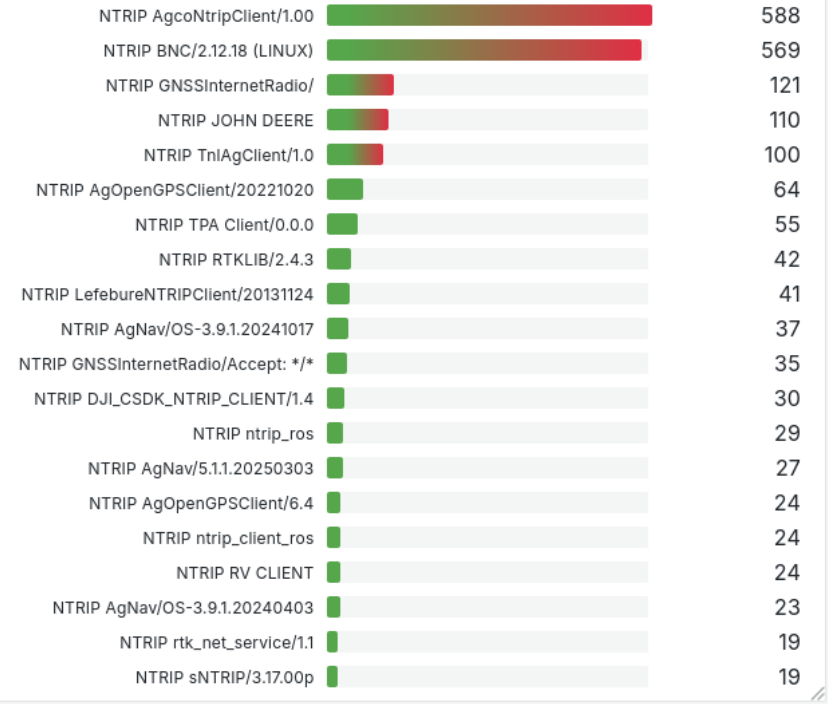
Rinex RENAG

569

client / source fetcher .Less RENAG



client user_agent



Base monitoring

Sources

total direct source	total fetcher source
943	30

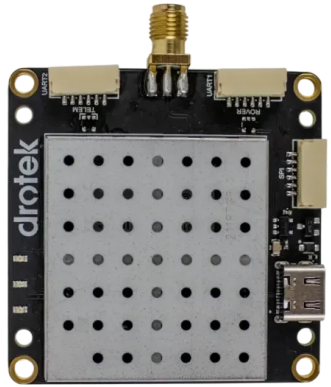
source / source fetcher

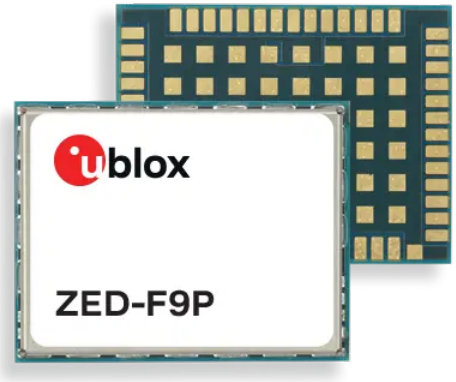
livesources/rtcm

mountpoint	state	type	timestamp	nsubscribers
STPOL	RUNNING	DIRECT	27-03-2025 11:46:03	53
DECAL	RUNNING	DIRECT	27-03-2025 11:46:02	42
MVITRY	RUNNING	DIRECT	27-03-2025 11:46:03	32
CODAR	RUNNING	DIRECT	27-03-2025 11:45:57	27
BEAUR	RUNNING	DIRECT	27-03-2025 11:45:55	26
VILBO	RUNNING	DIRECT	27-03-2025 11:46:01	20
SABI	RUNNING	DIRECT	27-03-2025 11:46:00	19
SBOIS	RUNNING	DIRECT	27-03-2025 11:45:53	19
Total				2244

- Base position checks
- Used and archived by RENAG (French Réseau National GNSS permanent)

- GNSS/USB module: Drotek, France
- GNSS/USB chip: u-blox, Switzerland
- Chip: STM32, France





RTK, what for?

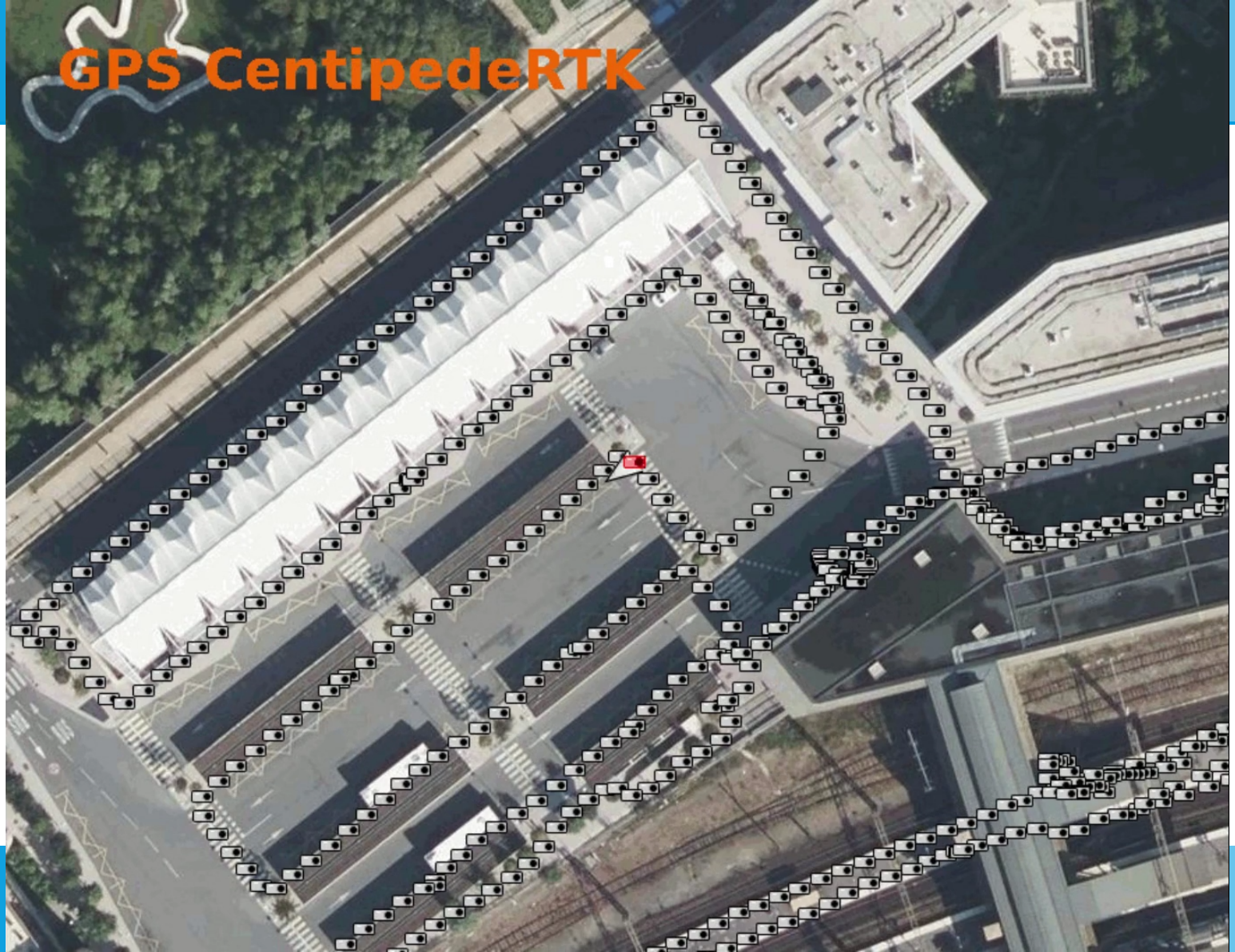
- C'est un GPS d'appartement. Ça vous indique à 2 millimètres près où sont les différentes pièces et comment y aller.

Sidewalk surfaces

=> locate telecom cables and assets easily

=> kiss « alerte pelleteuz » good bye?


GPS GoPro Max


GPS CentipedeRTK

IPv6? (Philippe's idea)

- 31 bits for latitude, resolution 11,1 mm
- 32 bits for longitude, resolution 7.3 mm (at 48.87° latitude)

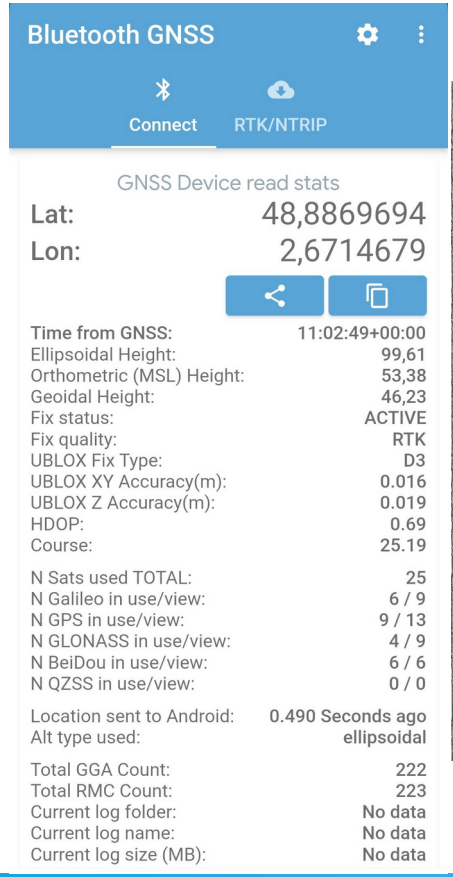
Here = (48.8710098, 2.3309497)

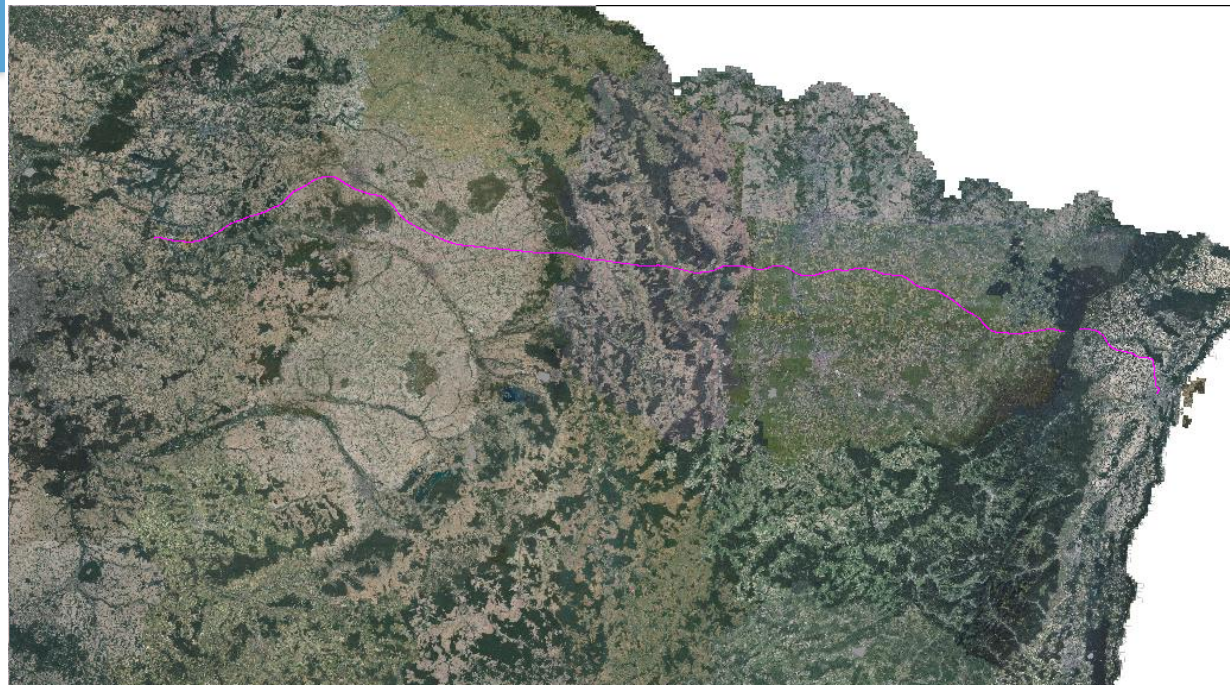
Latitude 488710098 → 1d211fd2

Longitude 23390497 → 163acb9

2001:db8::1d21:1fd2:0163:acb9

RTK at high speed (TGV Est)





Precise speed measurement

$$V = \frac{d}{t}$$

$$\frac{\Delta V}{V} = \frac{\Delta d}{d} + \frac{\Delta t}{t}$$

$$d = p_2 - p_1$$

$$\Delta d = \Delta p_2 + \Delta p_1$$

Uncertainty on speed, example at 100 km/h (= 27.8 m/s)

Standard GNSS precision ~2x5 m = ...
- 1 s interval: 36 % uncertainty
- 10 s interval: 3.6 % uncertainty

RTK precision ~2x2 cm = ...
- 1 s interval: 0.14 %
- 10 s interval: 0.014 %

Uncertainty on time can be neglected (under 1 ppm)

Millipede

- V/NEAR base
- Json API, YAML configuration
- TLS supported
- Proxy and « on-demand » features to include third-party networks
- IPv6 and IPv4 support (→ 129k connections possible)
- Low memory and CPU footprint: could run on a Raspi for personal use (NEAR proxy)

V/NEAR

- Based on rover-announced geolocalization to the caster
  - $G*GGA lines (NMEA)
- Caster sends the stream of the nearest known base
- Rover can cross 1000s of kilometers while staying with mostly-centimetric precision, switching from base to base

- C
- FreeBSD or Linux
- Event-driven with libevent

  => less state per session: ~600 bytes instead of 250 KB => less memory used
- Json API, YAML configuration
- TLS supported
- Experimental threaded version (workers) for multicore CPUs
- Quality assurance:
  - regression tests
  - valgrind for memory leaks & thread contention debugging

Source code on github (BSD license)

README BSD-3-Clause license

Millipede 0.8

Millipede is a high-performance NTRIP caster written in C for the CentipedeRTK project, a network of RTK bases based in France (see https://centipede.fr).

Millipede uses libevent2 for minimal memory footprint.

It can easily handle tens of thousands of NTRIP sessions on a minimal server.

Currently runs on FreeBSD.

Features:

https://github.com/pbeyssac/millipede-caster

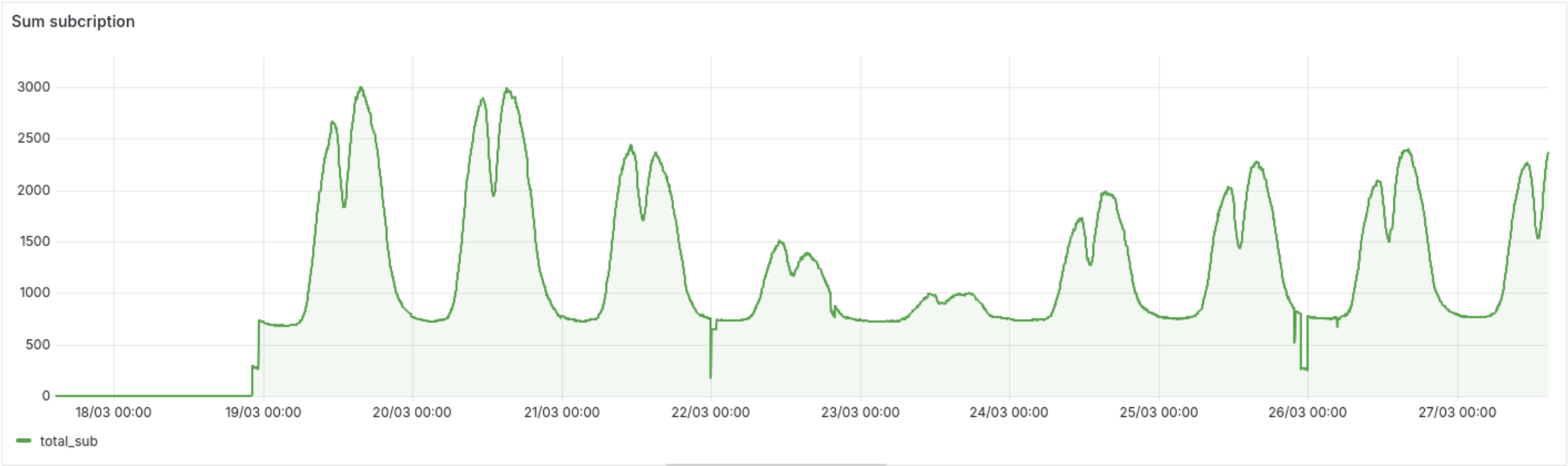
18 March 2025

- Deployed on crtk.net:2101 (caster.centipede.fr:2101)
- From ~2000 connections with the former caster software (overloaded) to over 4000 and counting

On 3000 connections:

- Memory: about 60-70 MB / 30-40 MB resident
- CPU: ~15% monothread = 1 core used

Clients over time



Next?

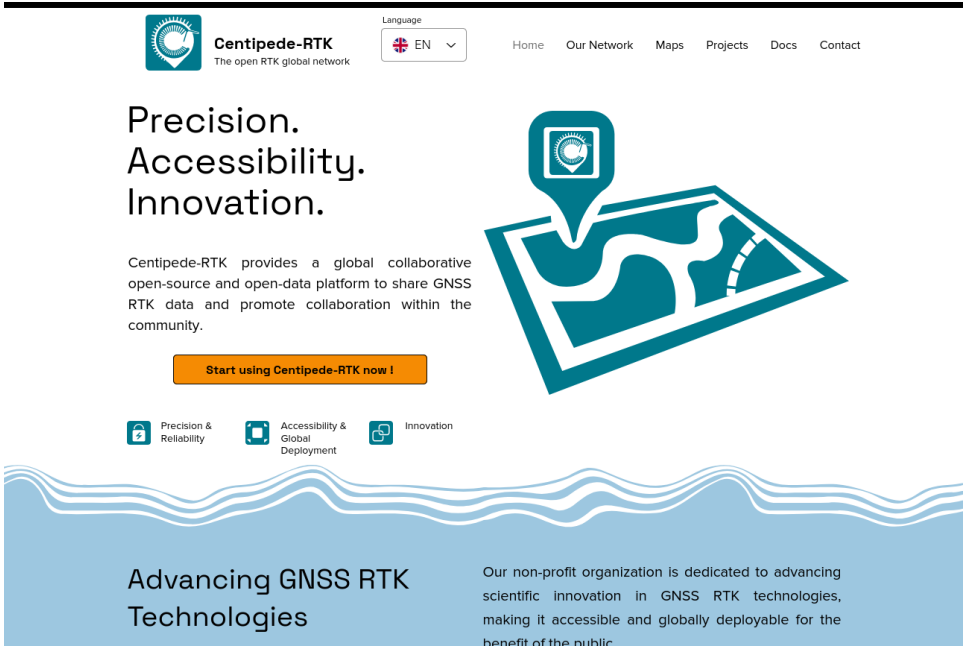
- Now hosted by pch.net
- Anycast service, perfect fit
  - Lower latency between RTCM sources (bases) and rovers
  - vs DNS: NTRIP benefits from lower latency from sources in the same region
  - Transparent failover for NTRIP clients
  - Simplify rover configuration
- Scaling to 10k international clients in 3 years
- RTCM filtering for low-bandwidth clients?

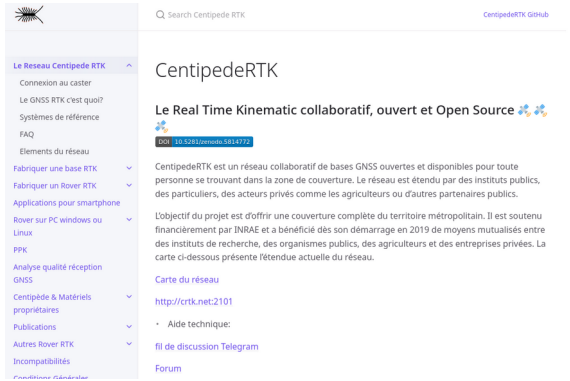
Thanks!

- Web site: centipede-rtk.org
- Caster: crtk.net:2101

Bluesky: @pierreb.bsky.social

Fediverse: @pb@mast.eu.org





PCH
Packet Clearing House

A Short History of PCH

Started building IXPs in 1994
Started anycasting TLD nameservice globally in 1997
Anycasted the first root nameservice in 2000
Began providing services over IPv6 in 2001
Built the INOC-DBA infrastructure protection hotline in 2002
Became fully IPv4/IPv6 dual-stack in 2009
Started providing FIPS 140-2 L4 DNSSEC signing in 2011
Deployed world’s largest protective recursive nameserver in 2017

Packet Clearing House

PCH's Involvement with the Project

Host and anycast NTRIP caster network globally

Deploy RTK ground reference stations globally

Port all software components to RISC-V

Develop 2nd-gen reference station hardware

Develop 3rd-gen reference station hardware

PCH
Packet Clearing House

PCH's Involvement with the Project

Host and anycast NTRIP caster network globally	✓ In beta
Deploy RTK ground reference stations globally	✓ Started
Port all software components to RISC-V	✓ Done
Develop 2nd-gen reference station hardware	✓ Near completion
Develop 3rd-gen reference station hardware	x Just starting

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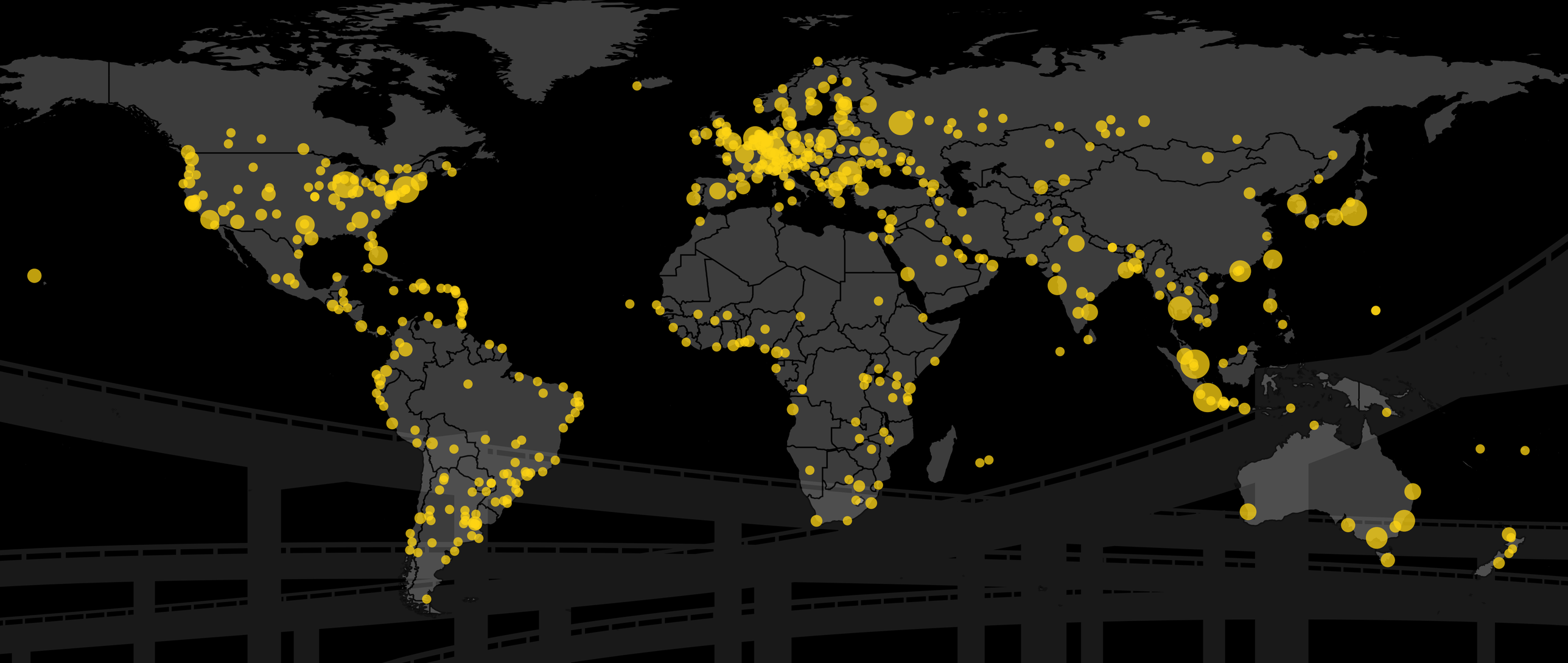
NTRIP casters in 330 IXPs in 136 countries



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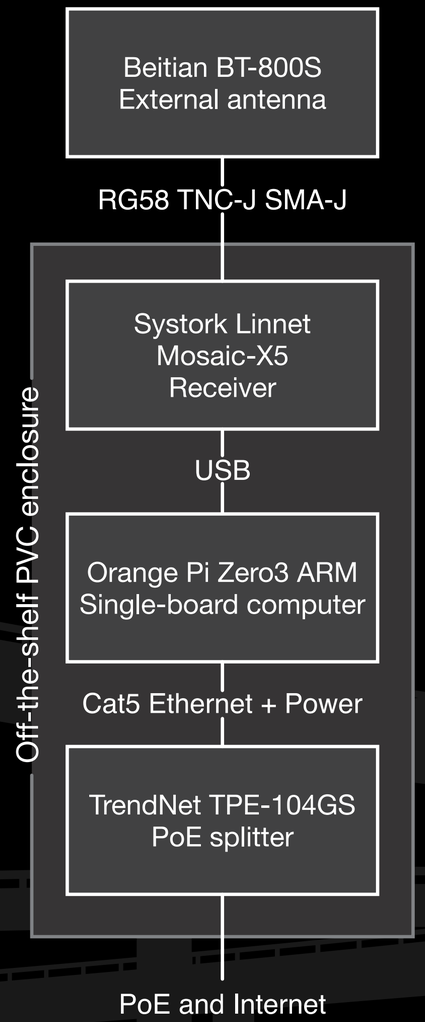
Generation One



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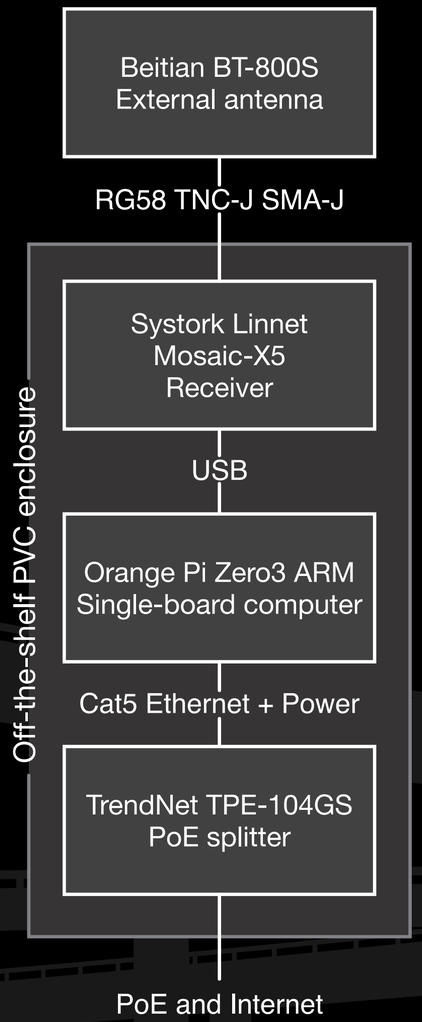
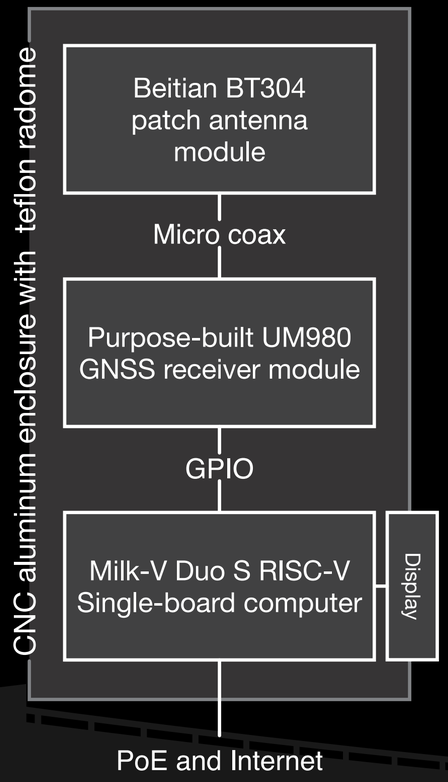
Generation One



Generation Two



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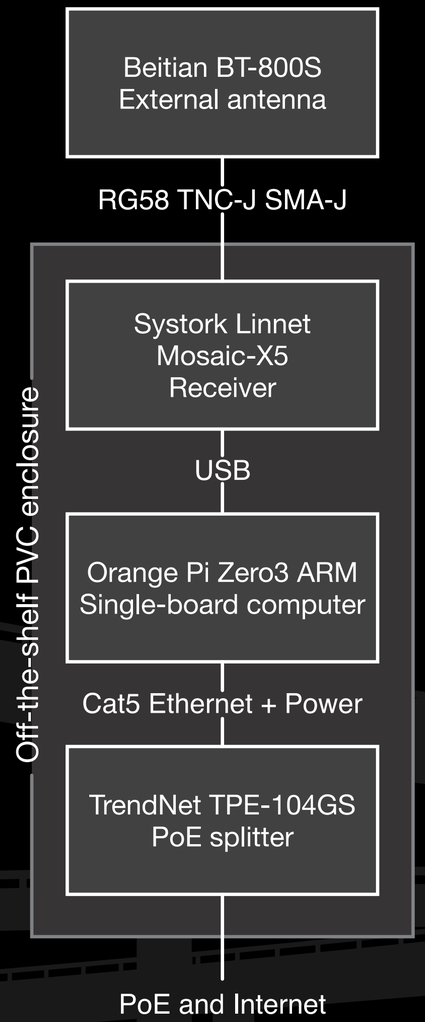
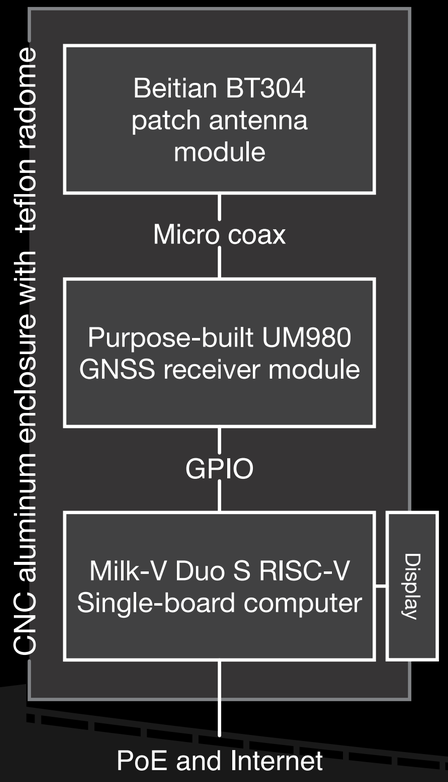
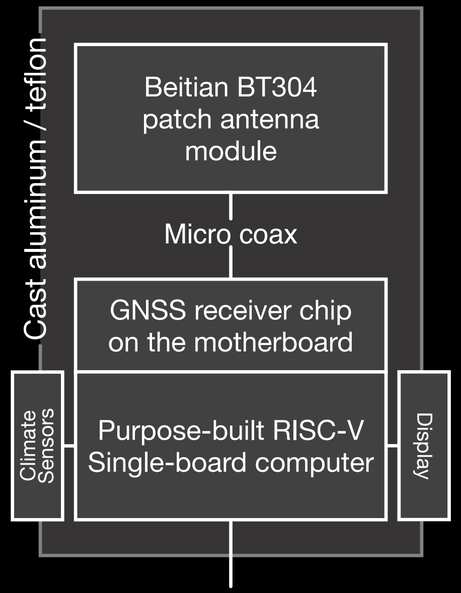
Generation One



Generation Two



Generation Three Hardwired



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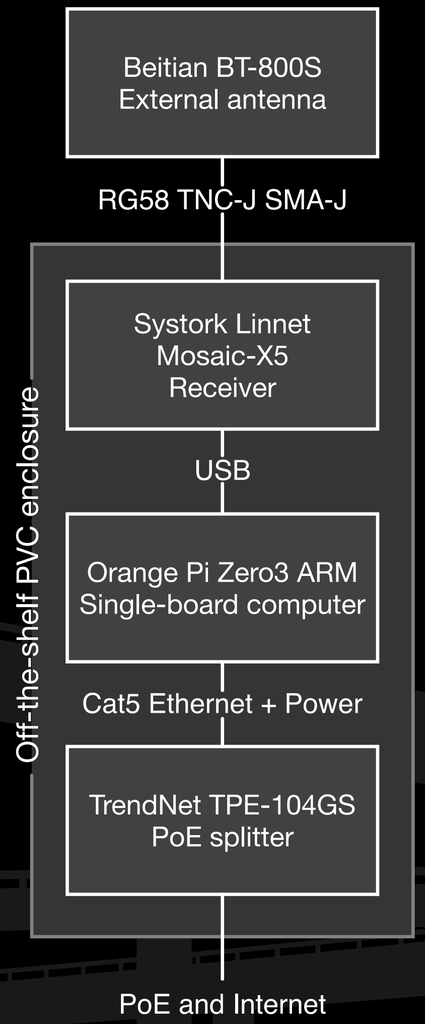
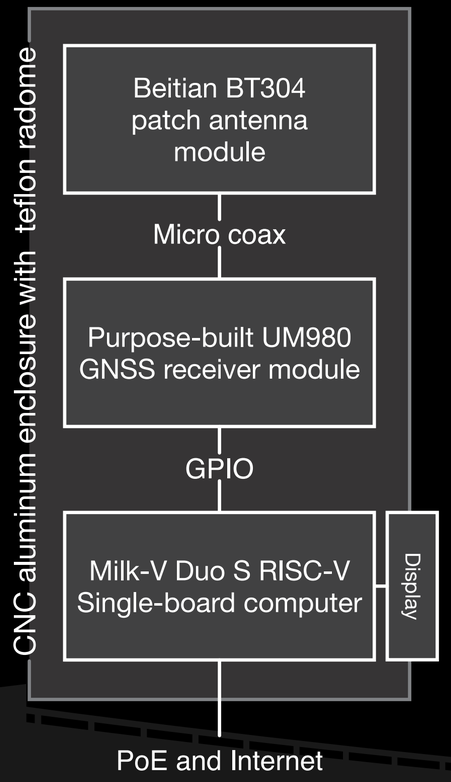
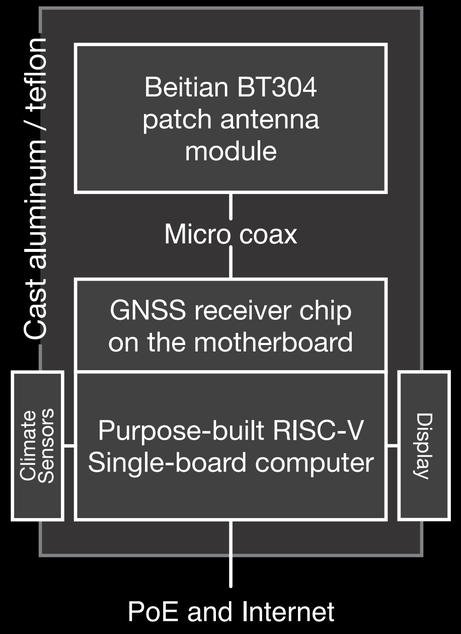
Generation One



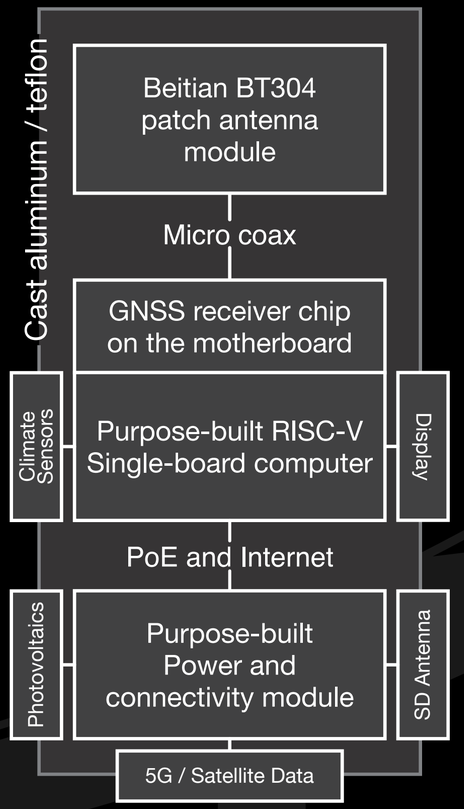
Generation Two



Generation Three Hardwired



Generation Three Standalone



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First-Generation Hardware

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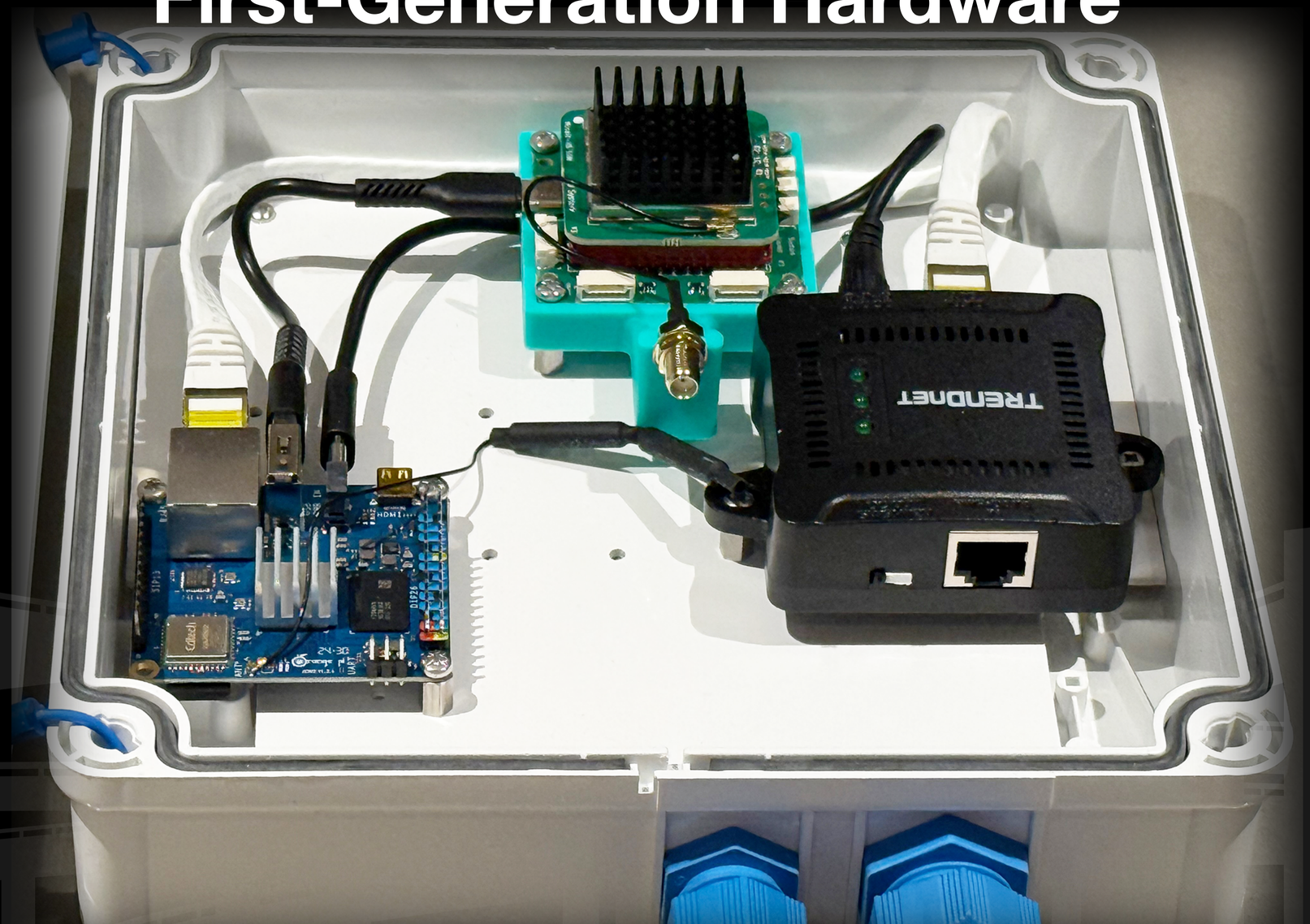
First-Generation Hardware



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Second-Generation Hardware