

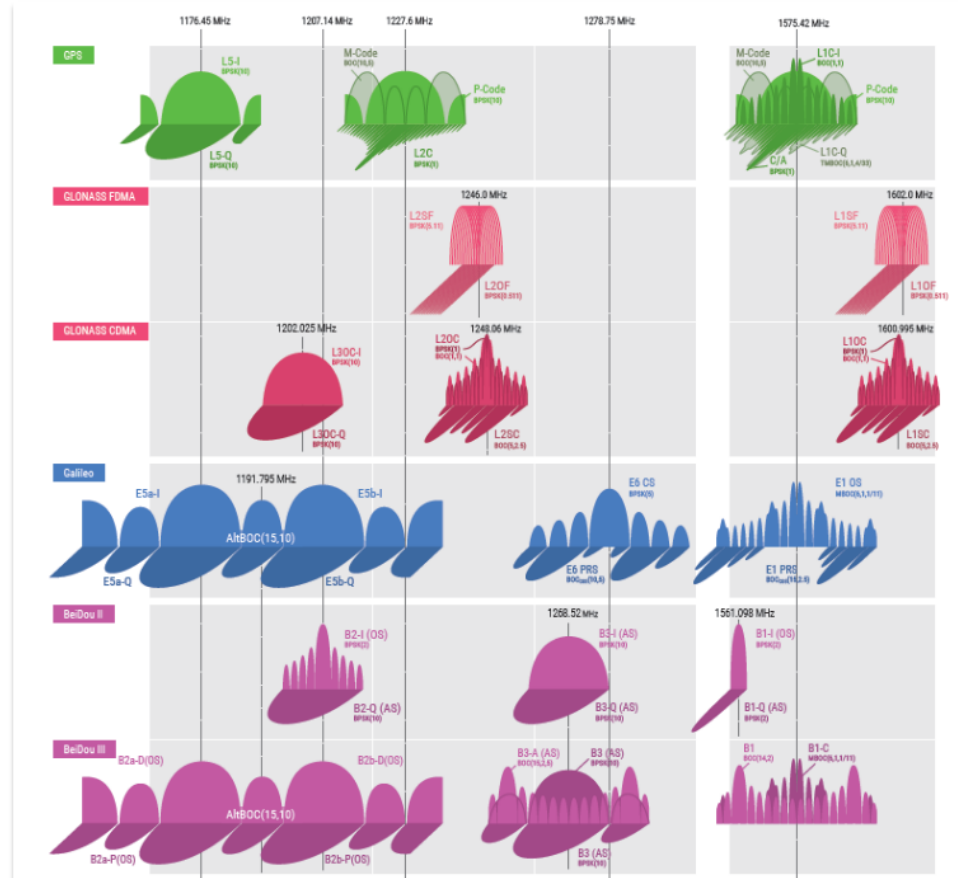
# Centipede-RTK & Millipede Centimeter-Level Outdoor Geolocation

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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)

# Terminology (2) : free OS?

~~Free OS  $\Leftrightarrow$  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

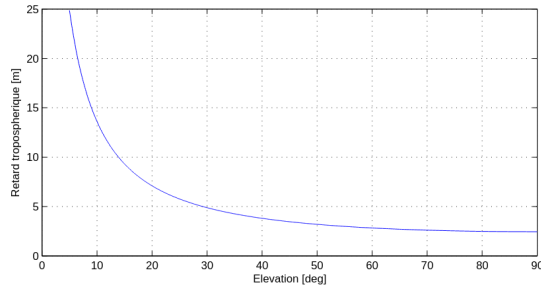
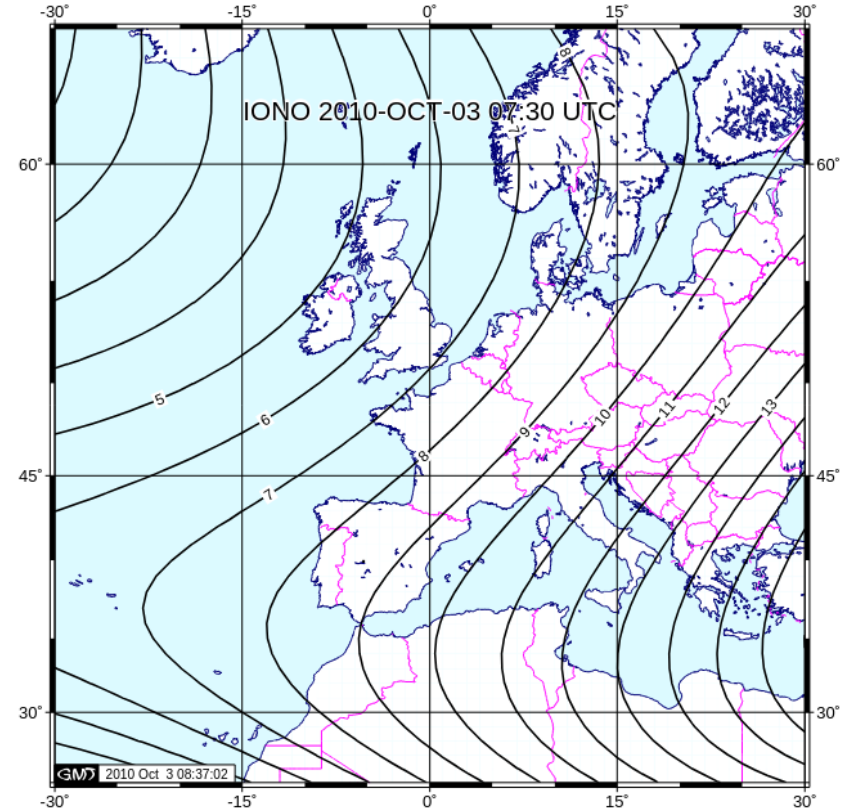
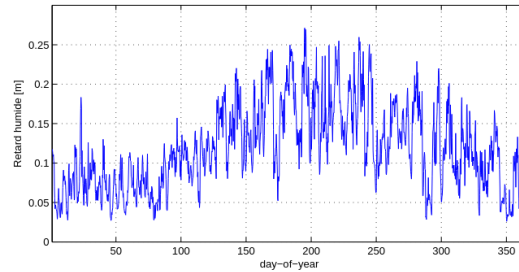
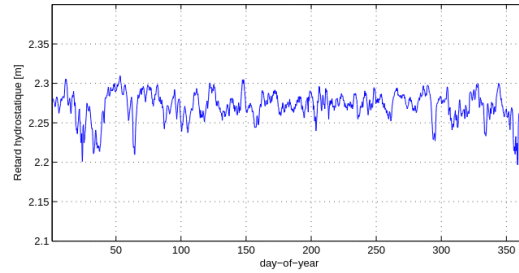
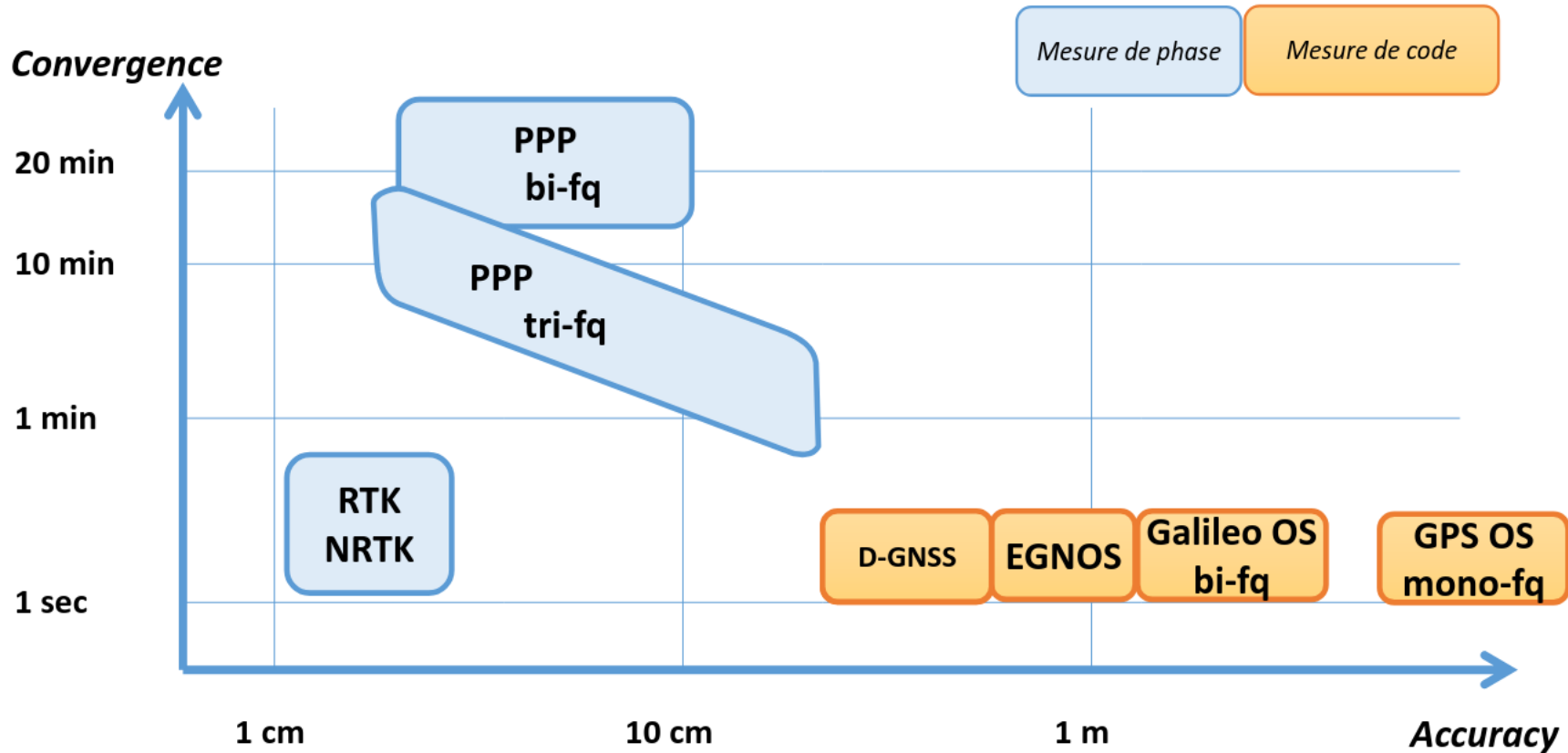


FIG 25 - Évolution du retard troposphérique avec l'élévation du satellite au-dessus de l'horizon.



# Precision positioning technologies



# Open-closed standards

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**RTCM 10403.2**  
RTCM Paper 104-2013-SC104-STD



**RTCM STANDARD 10403.2**

**DIFFERENTIAL GNSS  
(GLOBAL NAVIGATION SATELLITE SYSTEMS)  
SERVICES – VERSION 3**


DEVELOPED BY  
RTCM SPECIAL COMMITTEE NO. 104

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Web Site: <http://www.rtcmm.org>

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**RTCM 10410.1**  
RTCM Paper 111-2009-SC104-STD  
**with Amendment 1**  
RTCM Paper 139-2011-SC104-STD



**RTCM STANDARD 10410.1**

**NETWORKED TRANSPORT OF RTCM via  
INTERNET PROTOCOL  
(Ntrip) - Version 2.0**

DEVELOPED BY  
RTCM SPECIAL COMMITTEE NO. 104

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E-Mail: [info@rtcm.org](mailto:info@rtcm.org)  
Web Site: <http://www.rtcmm.org>

# NTRIP1, NTRIP2

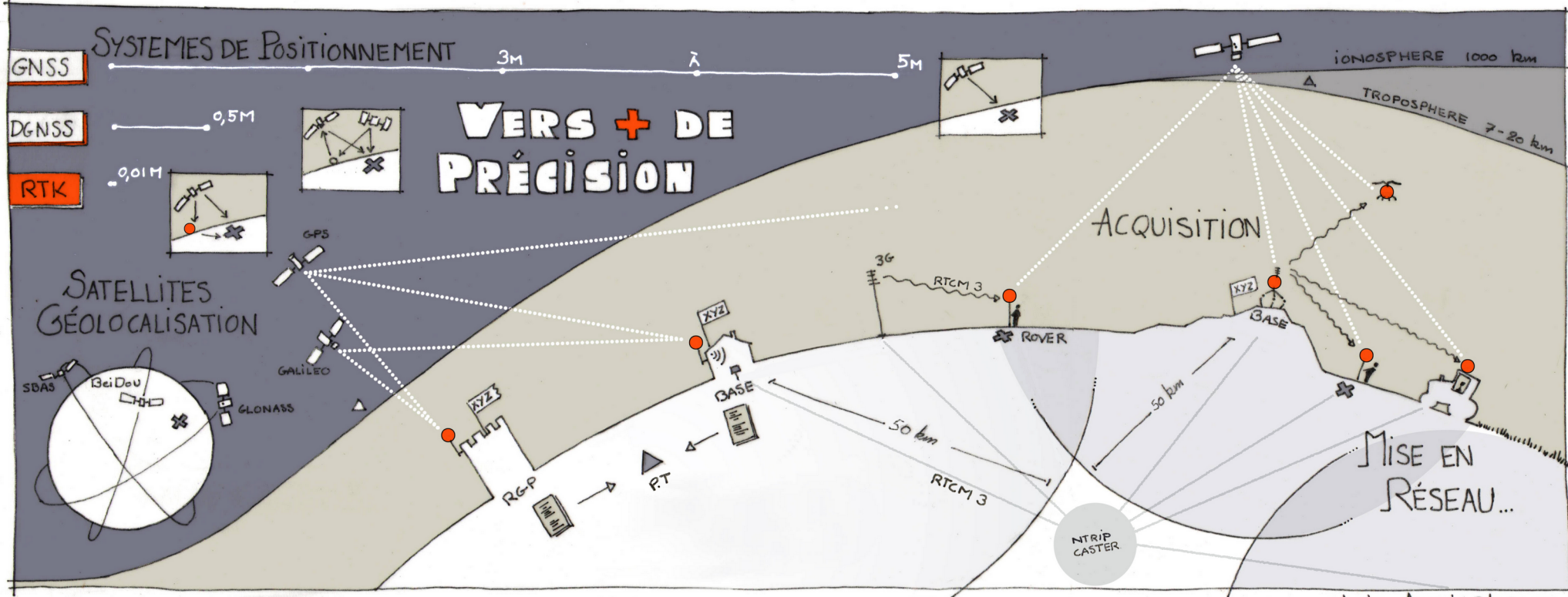
- « Networked Transport of RTCM via Internet Protocol »
- Ntrip1: roughly based on ICECAST, itself roughly based on HTTP 0.9
- Ntrip2: complies with HTTP 1.1
  - Can cross a http proxy → easier handling of https
- Many broken/half cooked client or server implementations
- Transparent: can stream anything,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



# Real-time kinematics

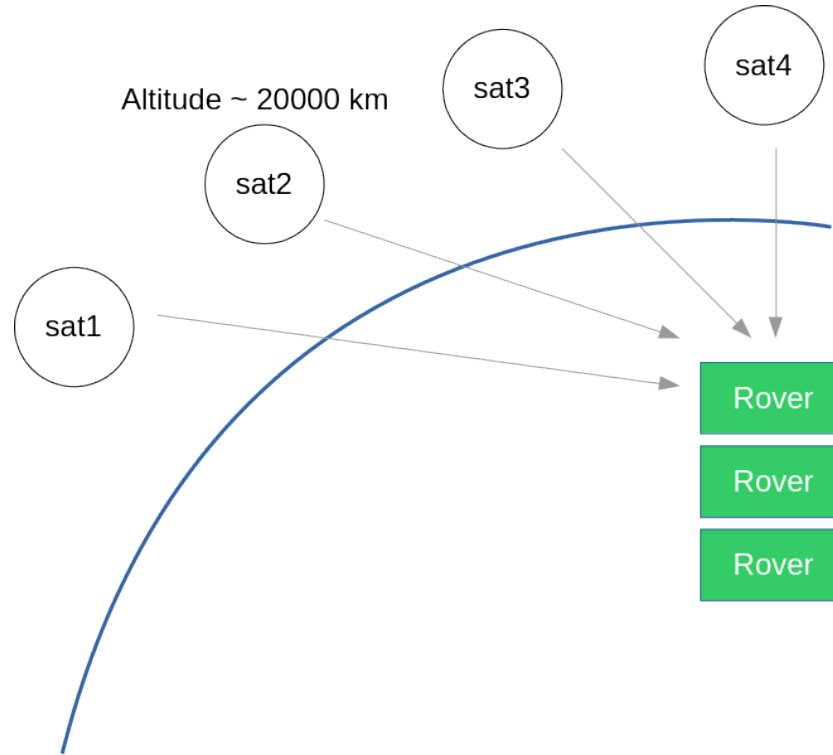
- Absolute positioning
- Relative positioning
- Needs a reference base
- « rovers »

- 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

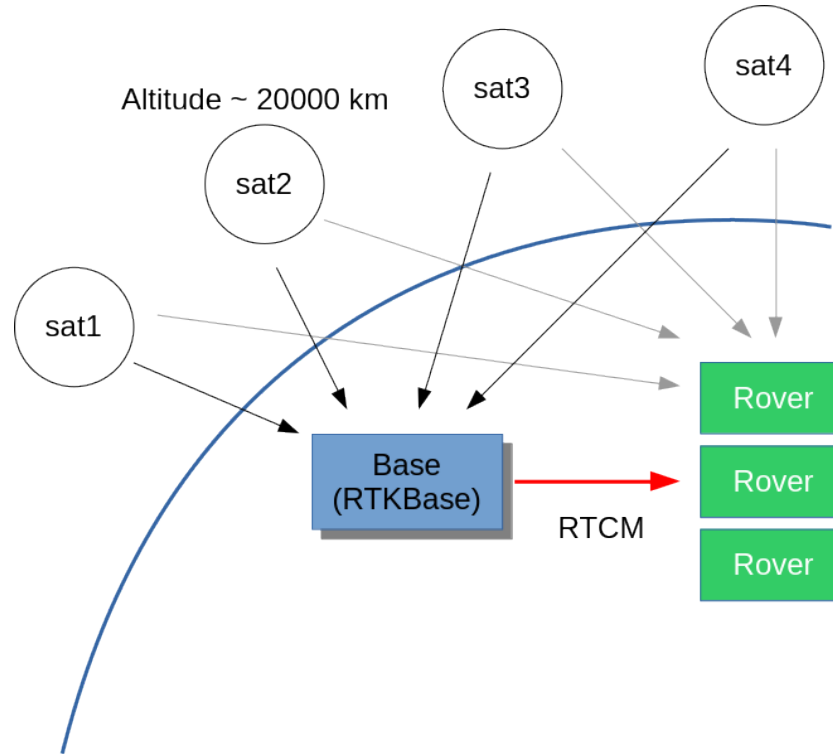


JULIEN.ANCEAUX @INRA.FR

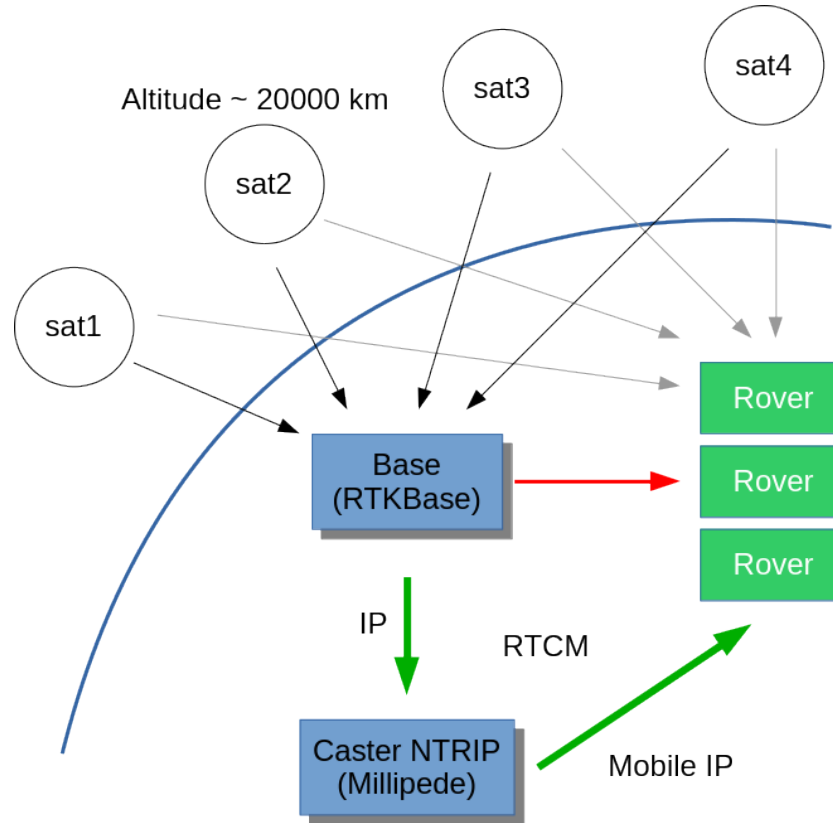
# Basic GNSS reception



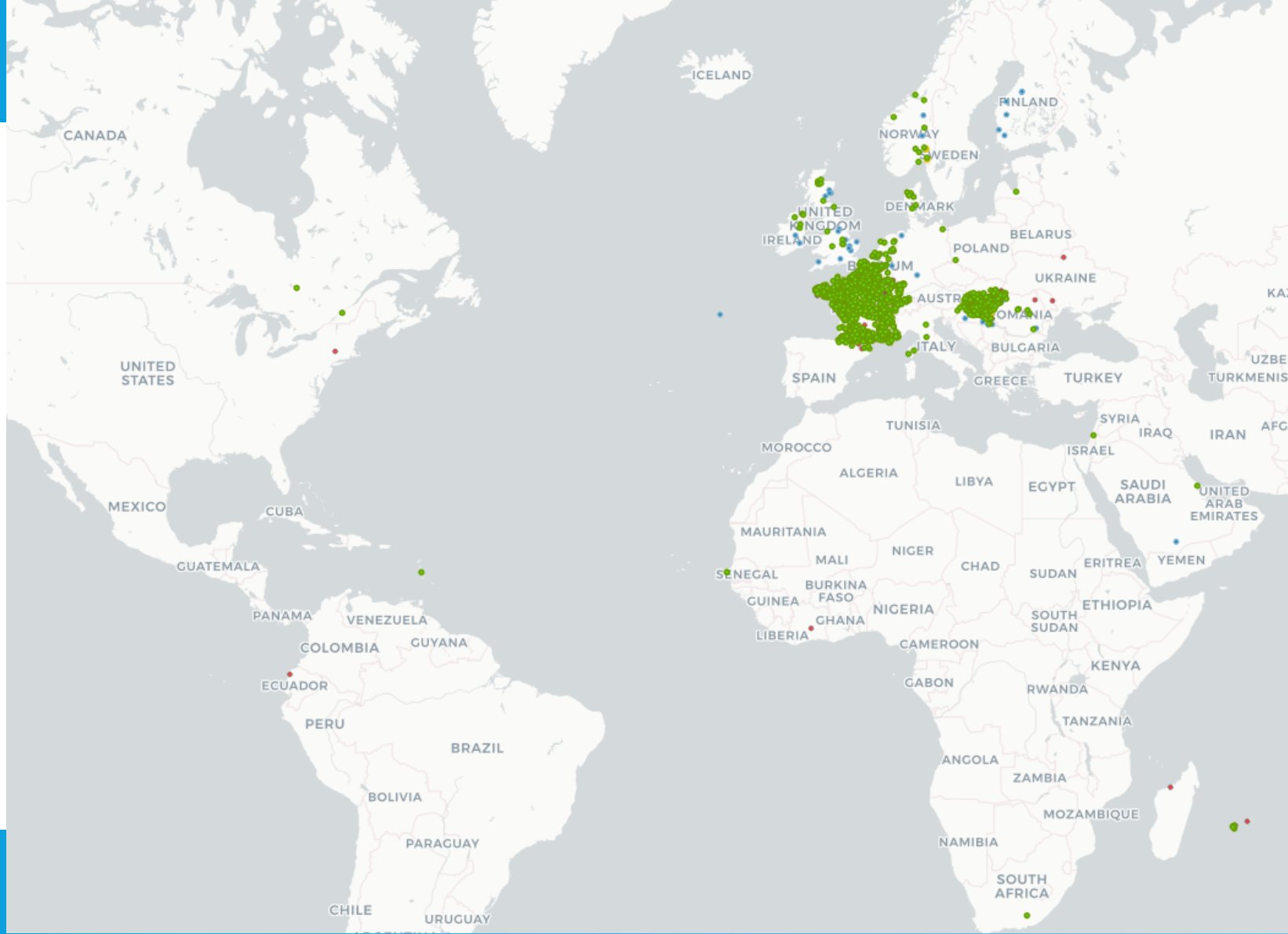
# Adding local corrections



# Distributing source streams



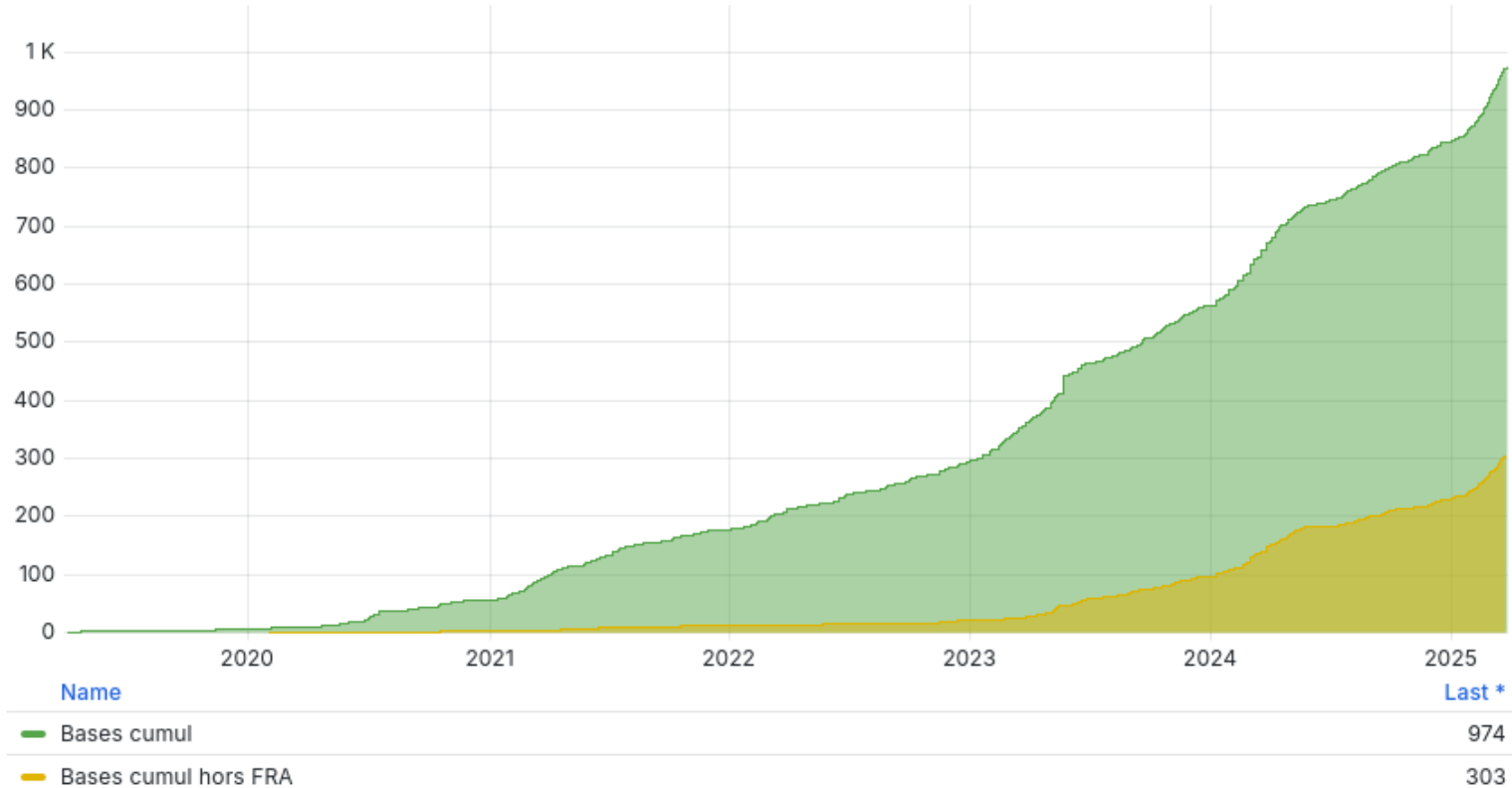






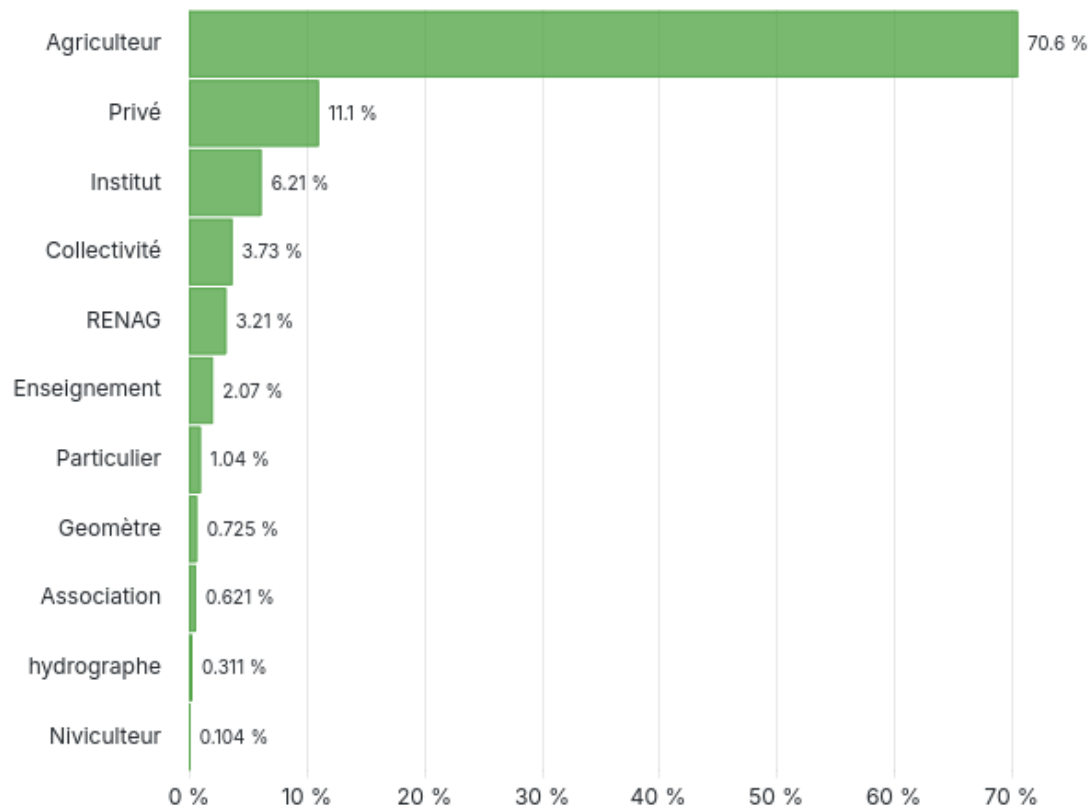
# Centipede bases over time

Number of declared bases ⓘ ⌚ Last 6 years



# Centipede bases by owner type

Type of installer ⓘ



# Centipede clients

## ▼ Clients

client global

2295

client DIRECT

2010

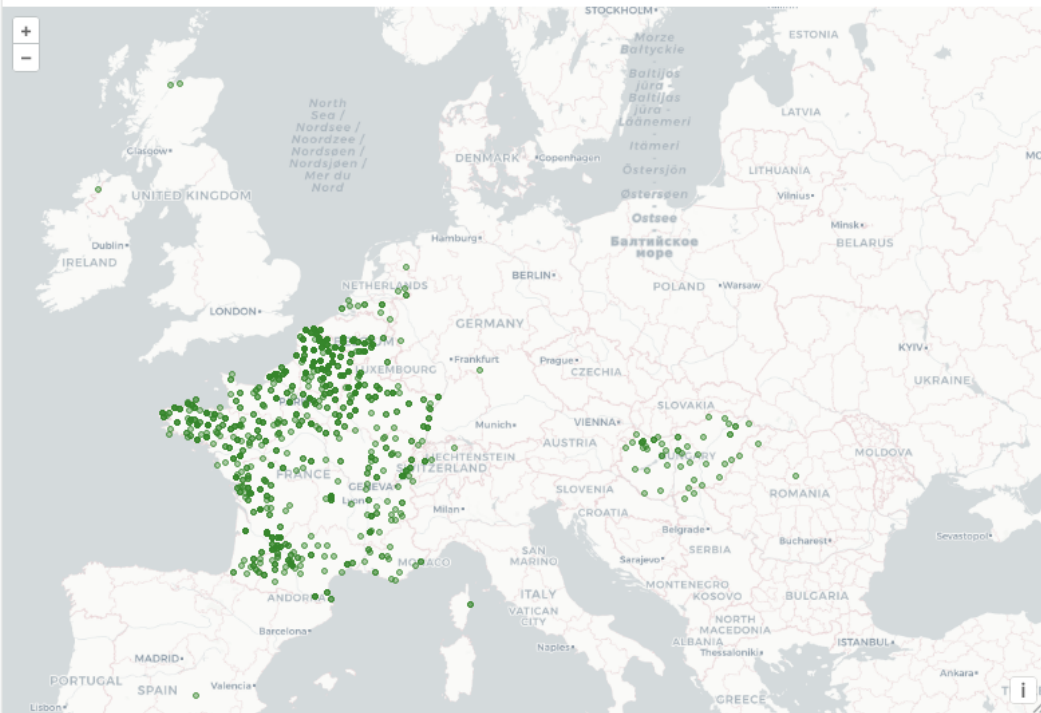
client NEAR

285

Rinex RENAG

569

client / source fetcher .Less RENAG



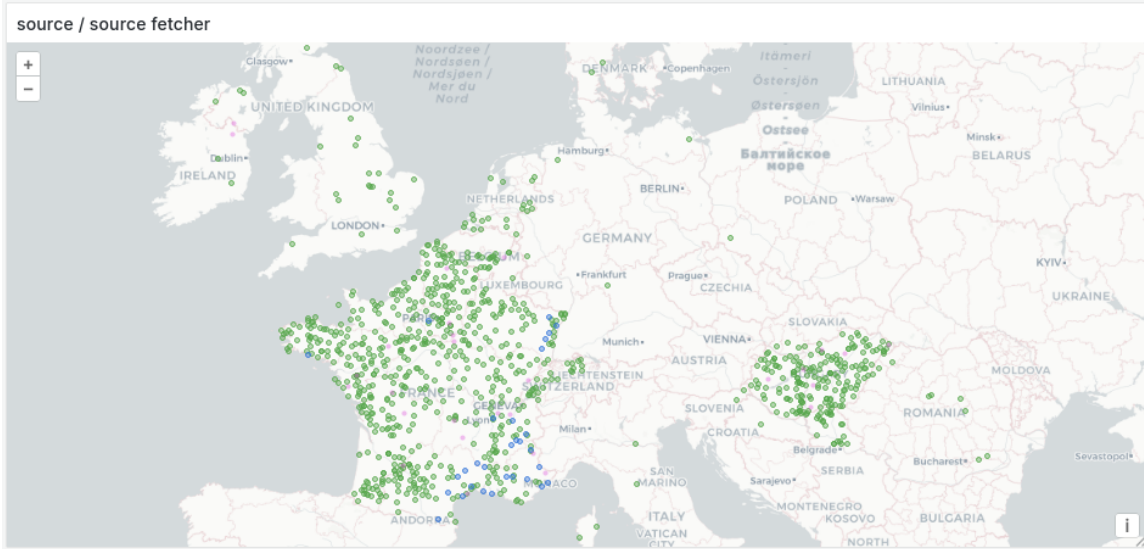
client user\_agent

NTRIP AgcoNtripClient/1.00		588
NTRIP BNC/2.12.18 (LINUX)		569
NTRIP GNSSInternetRadio/		121
NTRIP JOHN DEERE		110
NTRIP TnIAGClient/1.0		100
NTRIP AgOpenGPSCClient/20221020		64
NTRIP TPA Client/0.0.0		55
NTRIP RTKLIB/2.4.3		42
NTRIP LefebureNTRIPClient/20131124		41
NTRIP AgNav/OS-3.9.1.20241017		37
NTRIP GNSSInternetRadio/Accept: */*		35
NTRIP DJI_CSDK_NTRIP_CLIENT/1.4		30
NTRIP ntrip_ros		29
NTRIP AgNav/5.1.1.20250303		27
NTRIP AgOpenGPSCClient/6.4		24
NTRIP ntrip_client_ros		24
NTRIP RV CLIENT		24
NTRIP AgNav/OS-3.9.1.20240403		23
NTRIP rtk_net_service/1.1		19
NTRIP sNTRIP/3.17.00p		19

# Base monitoring

Sources

total direct source	total fetcher source
943	30



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
<b>Total</b>				<b>2244</b>

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



RÉNAG Website

RÉseau National GNSS permanent - doi:10.15778/resif.rg

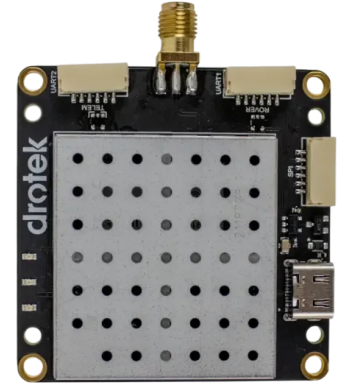
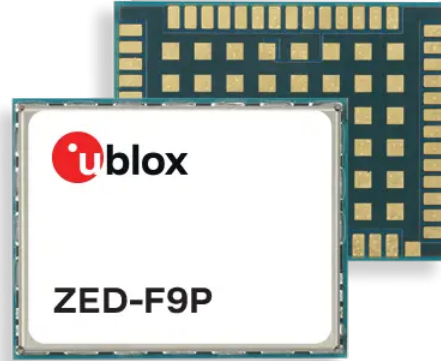


Stations map



News

- 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)



### Bluetooth GNSS

Connect RTK/NTRIP

GNSS Device read stats

Lat: 48,8869694

Lon: 2,6714679

Time from GNSS: 11:02:49+00:00

Ellipsoidal Height: 99,61

Orthometric (MSL) Height: 53,38

Geoidal Height: 46,23

Fix status: ACTIVE

Fix quality: RTK

UBLOX Fix Type: D3

UBLOX XY Accuracy(m): 0.016

UBLOX Z Accuracy(m): 0.019

HDOP: 0.69

Course: 25.19

N Sats used TOTAL: 25

N Galileo in use/view: 6 / 9

N GPS in use/view: 9 / 13

N GLONASS in use/view: 4 / 9

N BeiDou in use/view: 6 / 6

N QZSS in use/view: 0 / 0

Location sent to Android: 0.490 Seconds ago

Alt type used: ellipsoidal

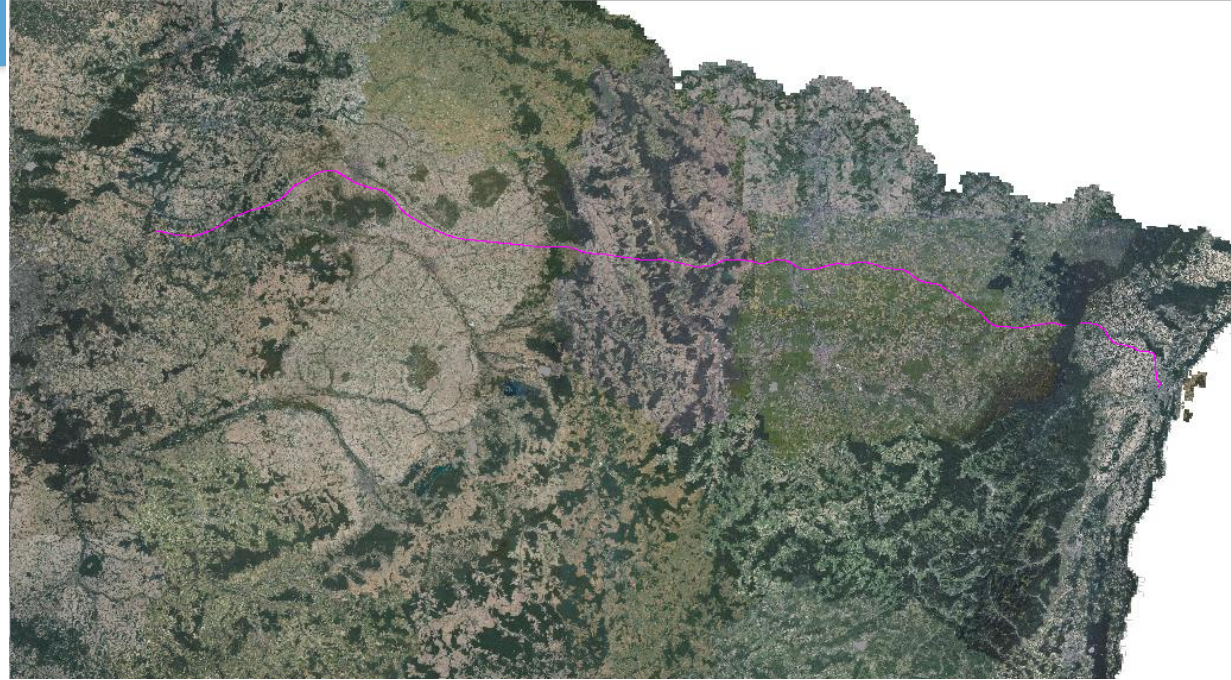
Total GGA Count: 222

Total RMC Count: 223

Current log folder: No data

Current log name: No data

Current log size (MB): No data



# 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)

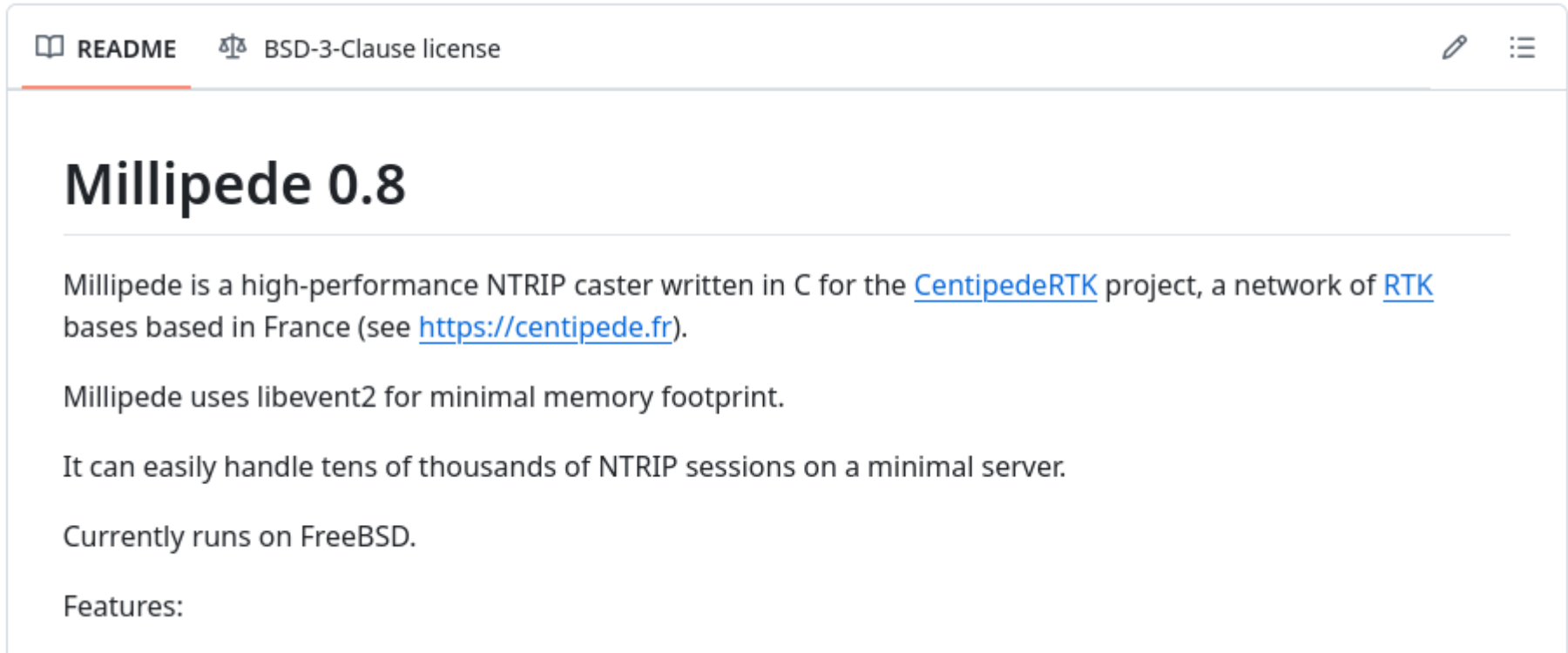
# V/NEAR

- 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)



The image shows a screenshot of a GitHub repository page for 'Millipede 0.8'. At the top, there are navigation links for 'README' and 'BSD-3-Clause license', along with icons for editing and a menu. The main content area features the title 'Millipede 0.8' in a large, bold font. Below the title, there is a horizontal line. The text describes Millipede as a high-performance NTRIP caster written in C for the CentipedeRTK project, a network of RTK bases based in France. It mentions that Millipede uses libevent2 for minimal memory footprint and can handle tens of thousands of NTRIP sessions on a minimal server. It also states that it currently runs on FreeBSD. The section 'Features:' is partially visible at the bottom.

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>

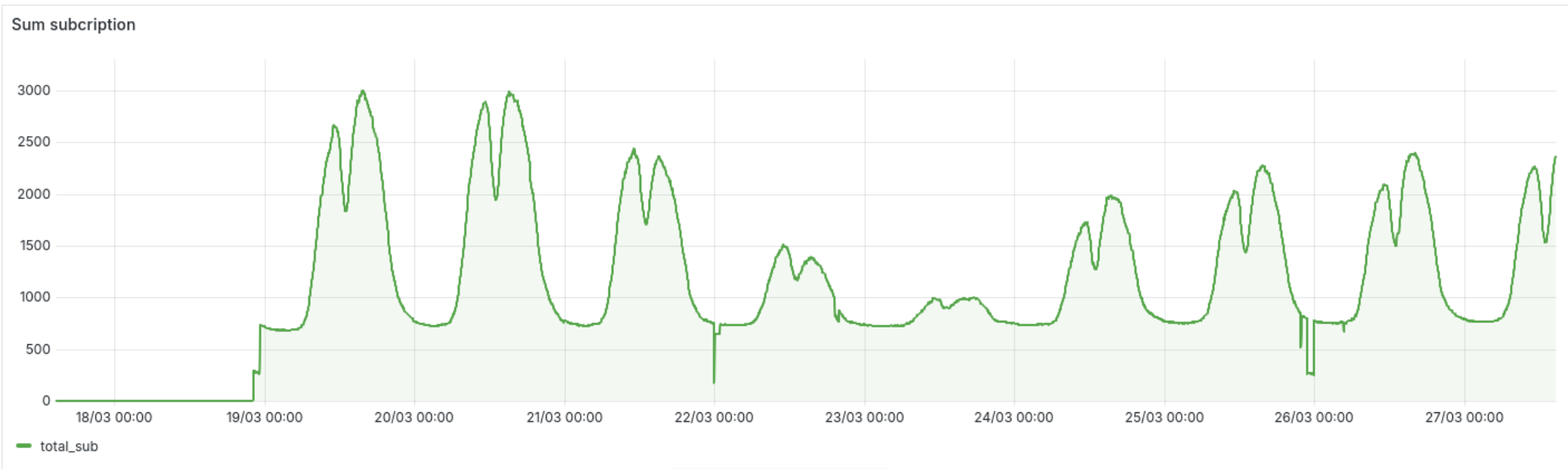
18 March 2025

- 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

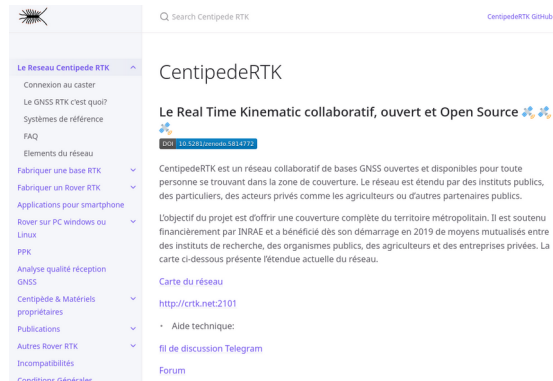


# Next?

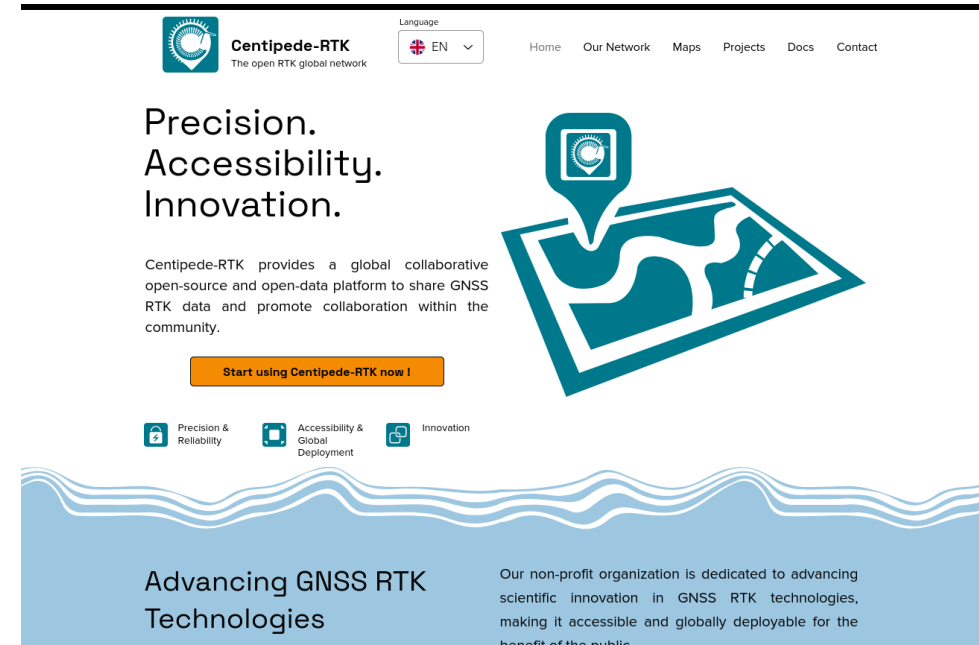
- Now hosted by pch.net
- Anycast service, perfect fit
  - Lower latency between RTCM sources (bases) and rovers
  - vs DNS: NTRIP benefits from lower latency from sources in the same region
  - Transparent failover for NTRIP clients
  - Simplify rover configuration
- Scaling to 10k international clients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

# Thanks!

- Web site: [centipede-rtk.org](http://centipede-rtk.org)
- Caster: [crtk.net:2101](http://crtk.net:2101)  
Bluesky: [@pierreb.bsky.social](https://bsky.app/profile/pierreb.bsky.social)  
Fediverse: [@pb@mast.eu.org](https://mastodon.social/@pb)



The screenshot shows the CentipedeRTK website. The header includes a search bar and the text "CentipedeRTK Global". The main content area features the title "CentipedeRTK" and a sub-header "Le Real Time Kinematic collaboratif, ouvert et Open Source". Below this, there is a paragraph in French describing the network as a collaborative GNSS network. A sidebar on the left contains a navigation menu with items like "Le Réseau Centipede RTK", "Connexion au caster", "Le GNSS RTK c'est quoi?", "Systèmes de référence", "FAQ", "Éléments du réseau", "Fabriquer une base RTK", "Fabriquer un Rover RTK", "Applications pour smartphone", "Rover sur PC Windows ou Linux", "PPK", "Analyse qualité réception GNSS", "Centipède & Matériels propriétaires", "Publications", "Autres Rover RTK", and "Incompatibilités".



The screenshot shows the Centipede-RTK website home page. The header includes the Centipede-RTK logo, the text "The open RTK global network", a language selector set to "EN", and navigation links for "Home", "Our Network", "Maps", "Projects", "Docs", and "Contact". The main content area features the text "Precision. Accessibility. Innovation." and a large graphic of a map with a location pin. Below this, there is a paragraph in English describing the platform as a global collaborative open-source and open-data platform to share GNSS RTK data. A prominent orange button says "Start using Centipede-RTK now!". At the bottom, there are three icons representing "Precision & Reliability", "Accessibility & Global Deployment", and "Innovation". The footer area contains the text "Advancing GNSS RTK Technologies" and "Our non-profit organization is dedicated to advancing scientific innovation in GNSS RTK technologies, making it accessible and globally deployable for the benefit of the public."

## 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

# 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

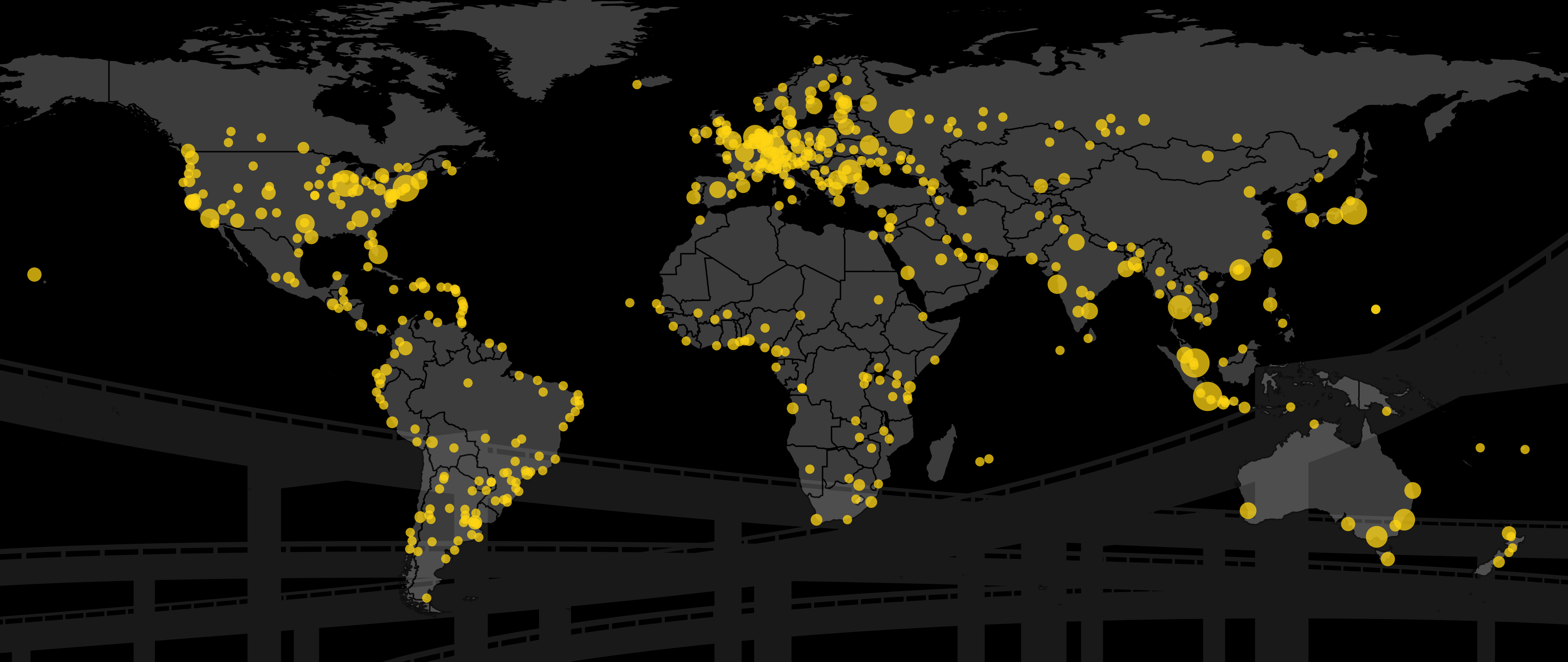
Develop 3rd-gen reference station hardware

## PCH's Involvement with the Project

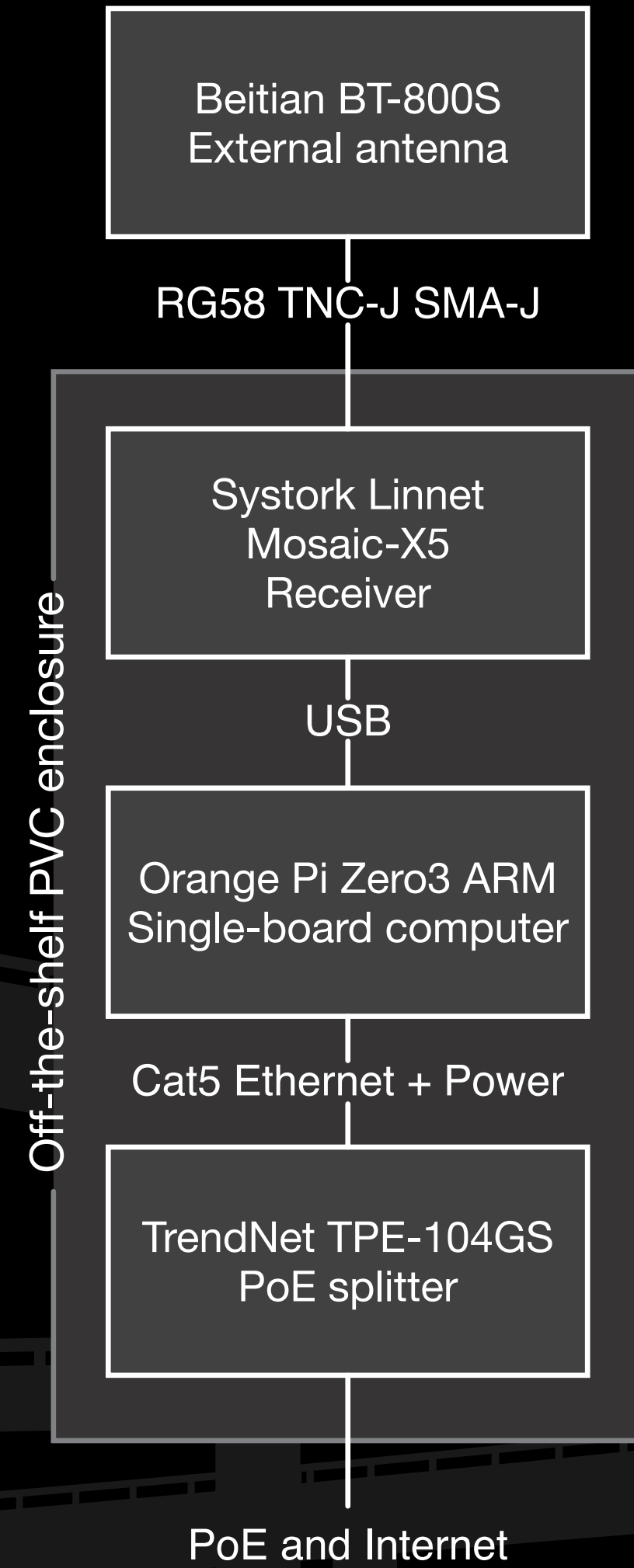
- Host and anycast NTRIP caster network globally ✓ In beta
- Deploy RTK ground reference stations globally ✓ Started
- Port all software components to RISC-V ✓ Done
- Develop 2nd-gen reference station hardware ✓ Near completion
- Develop 3rd-gen reference station hardware ✗ Just starting



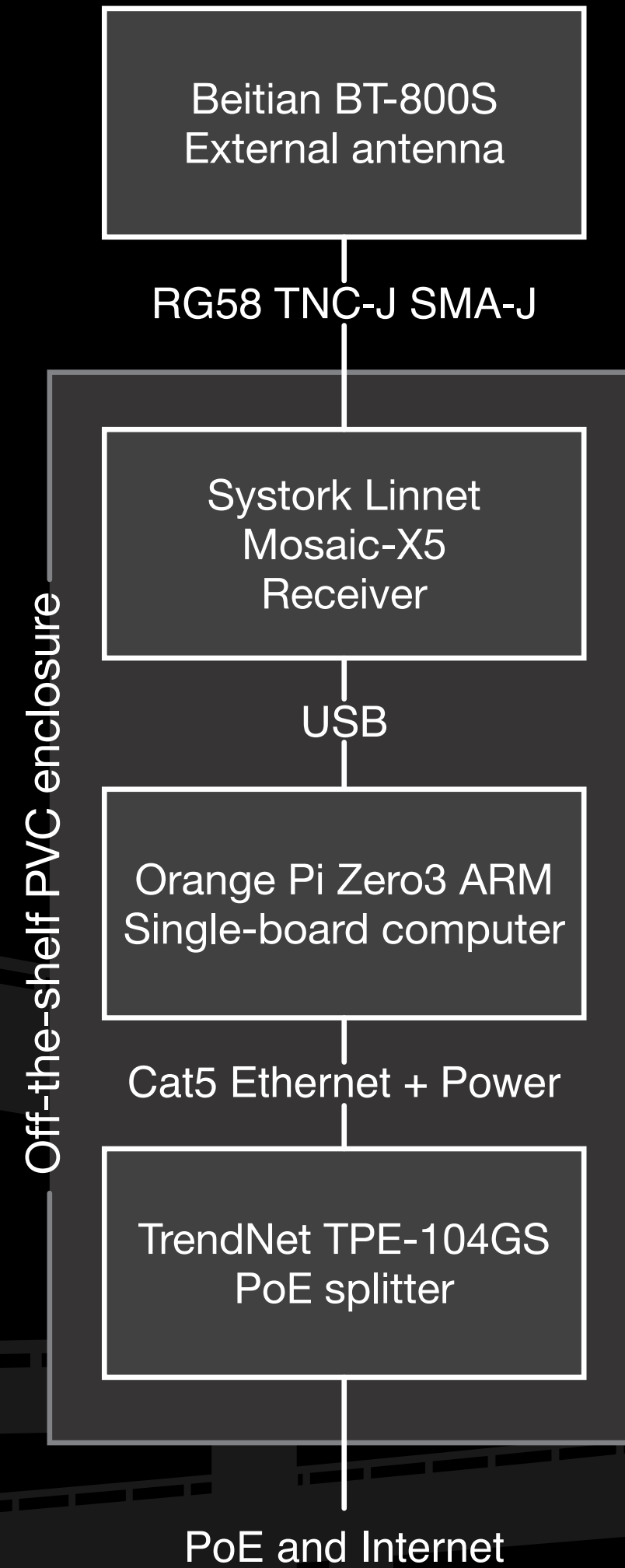
# NTRIP casters in 330 IXPs in 136 countries



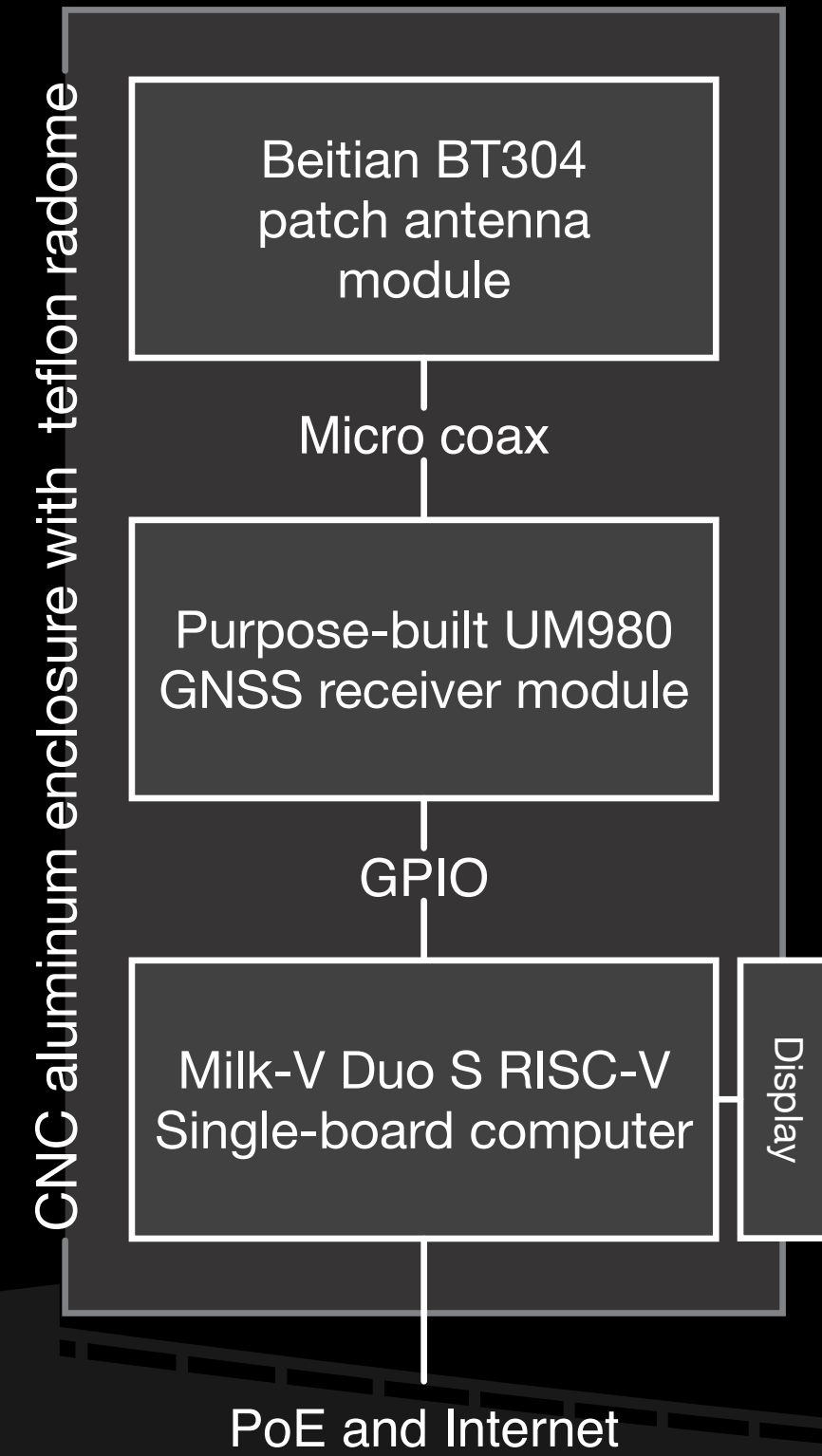
## Generation One



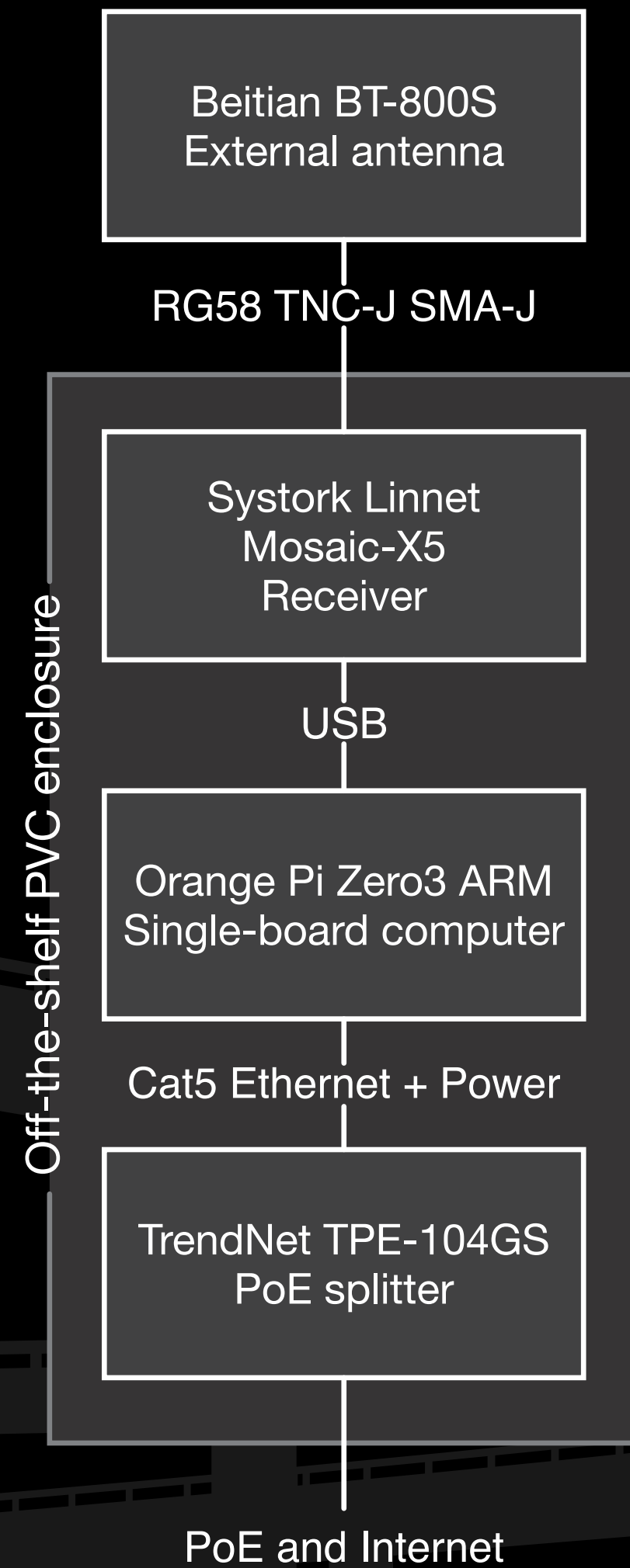
## Generation One



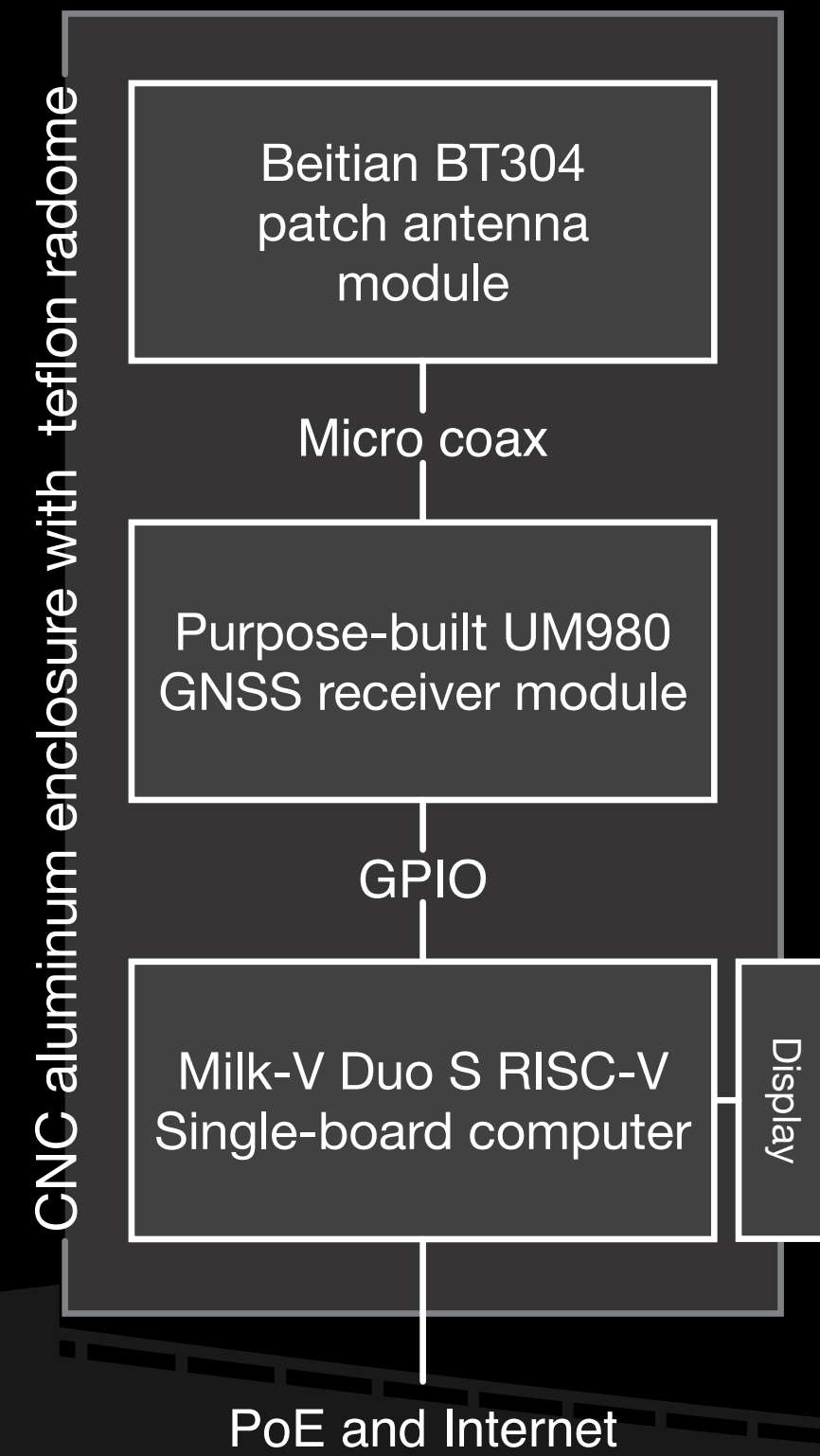
## Generation Two



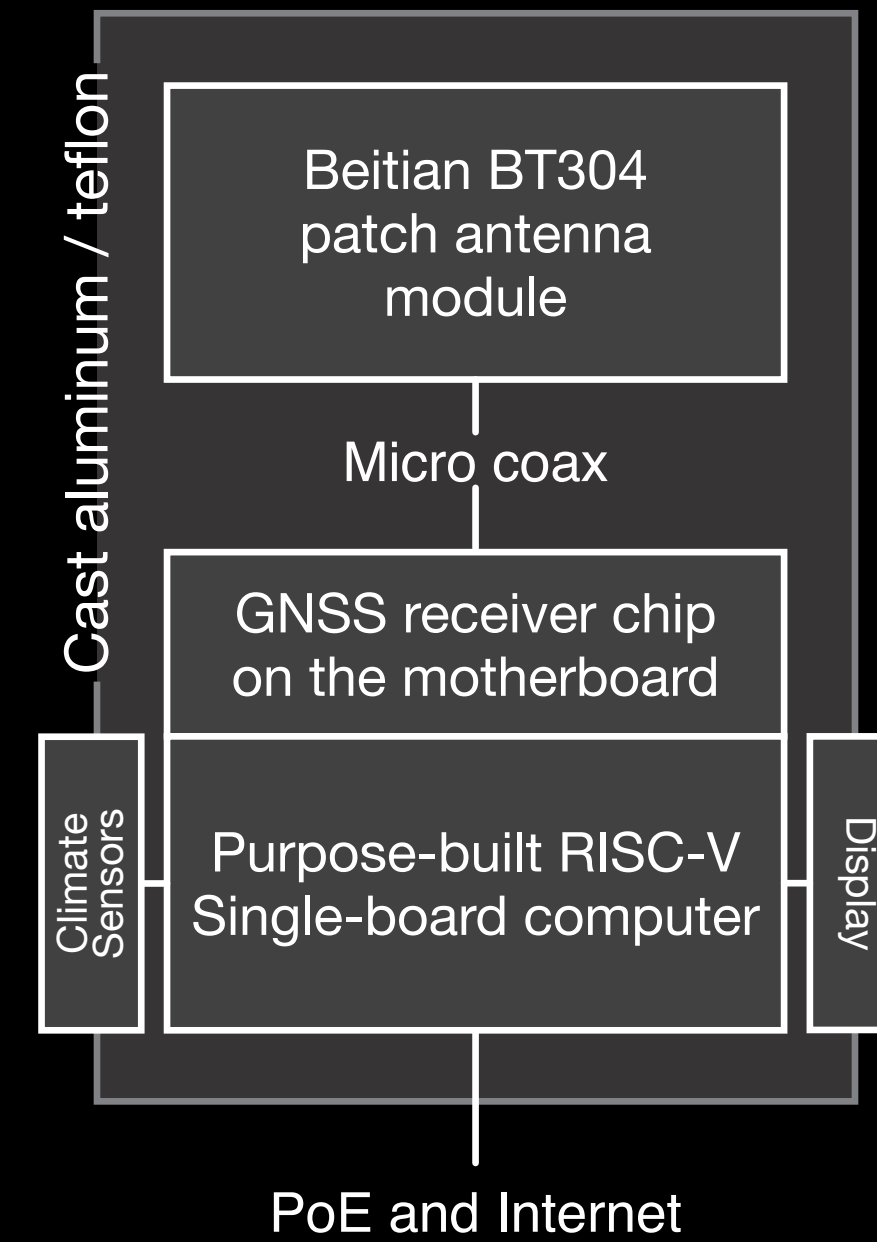
## Generation One



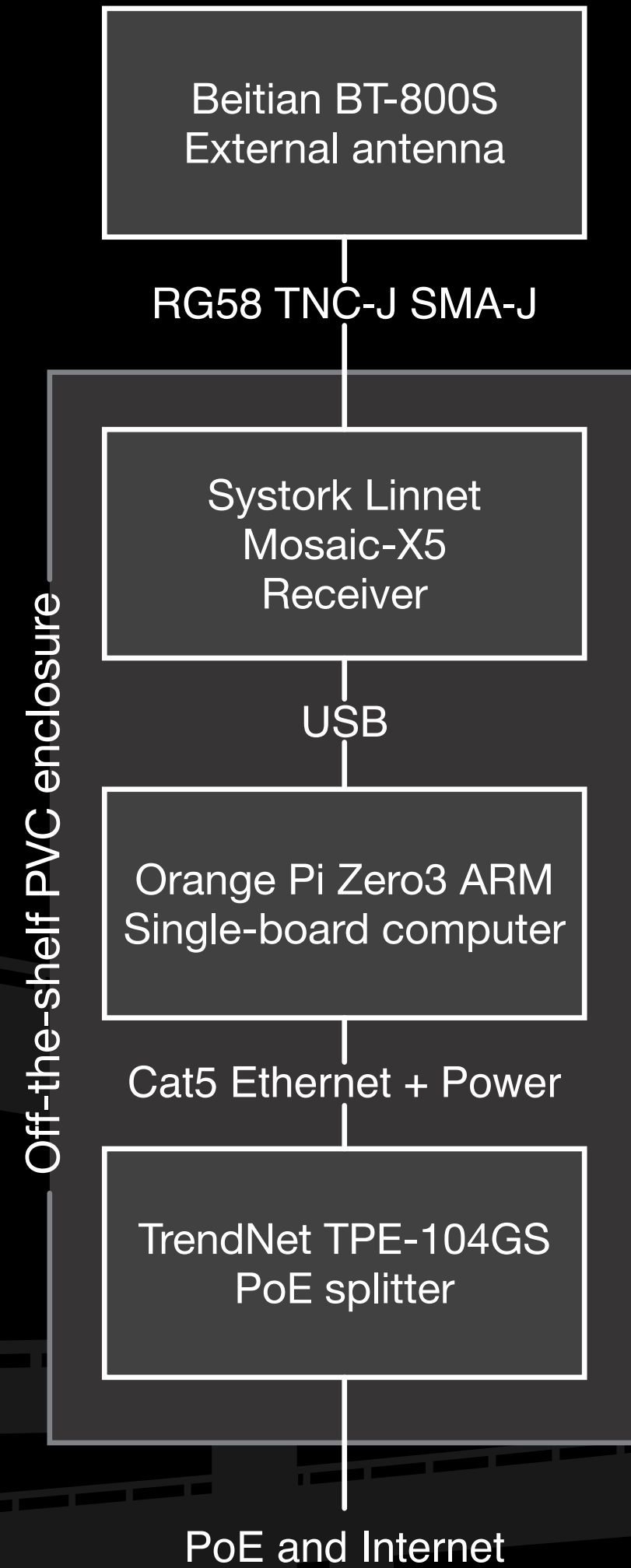
## Generation Two



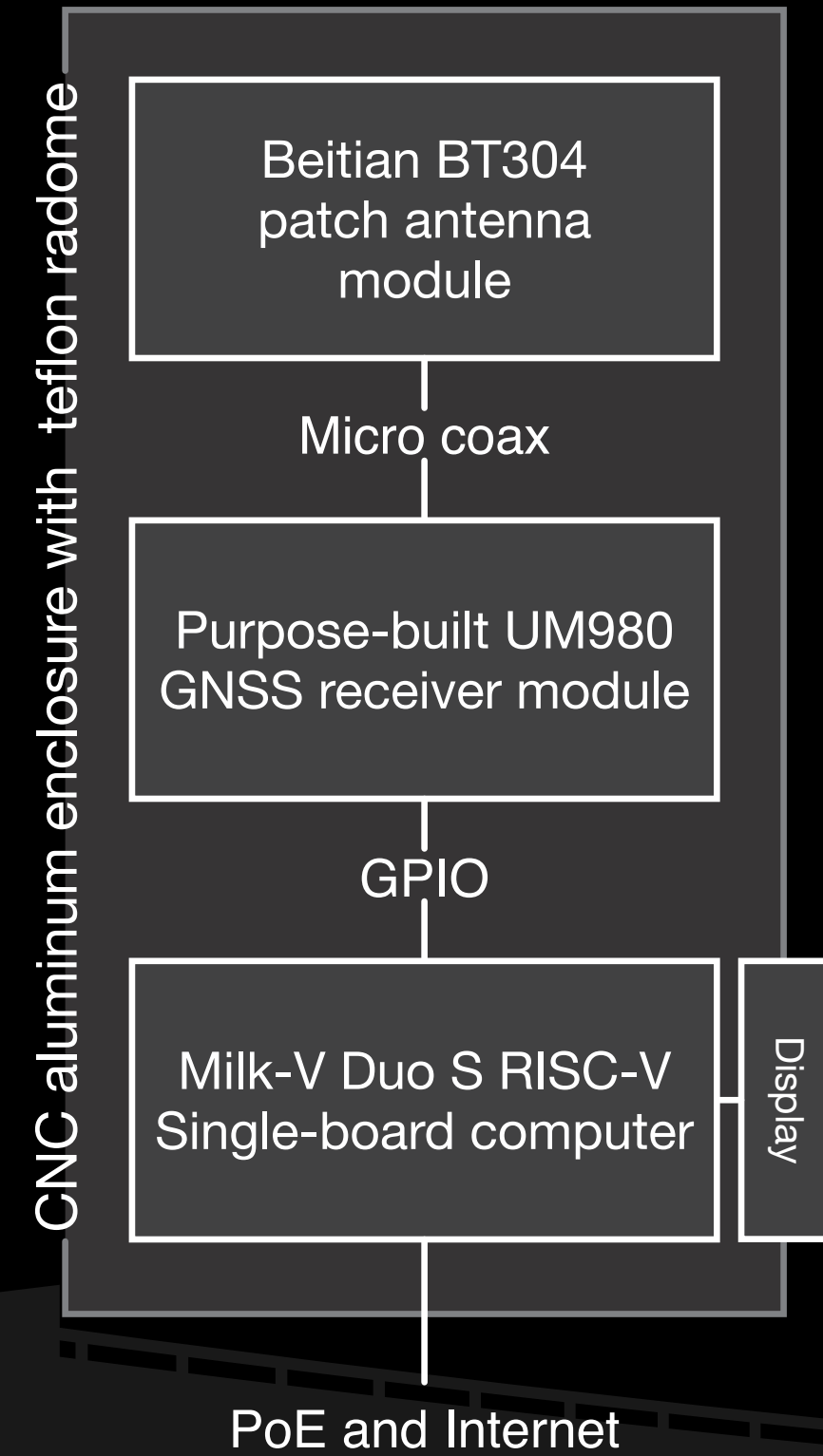
## Generation Three Hardwired



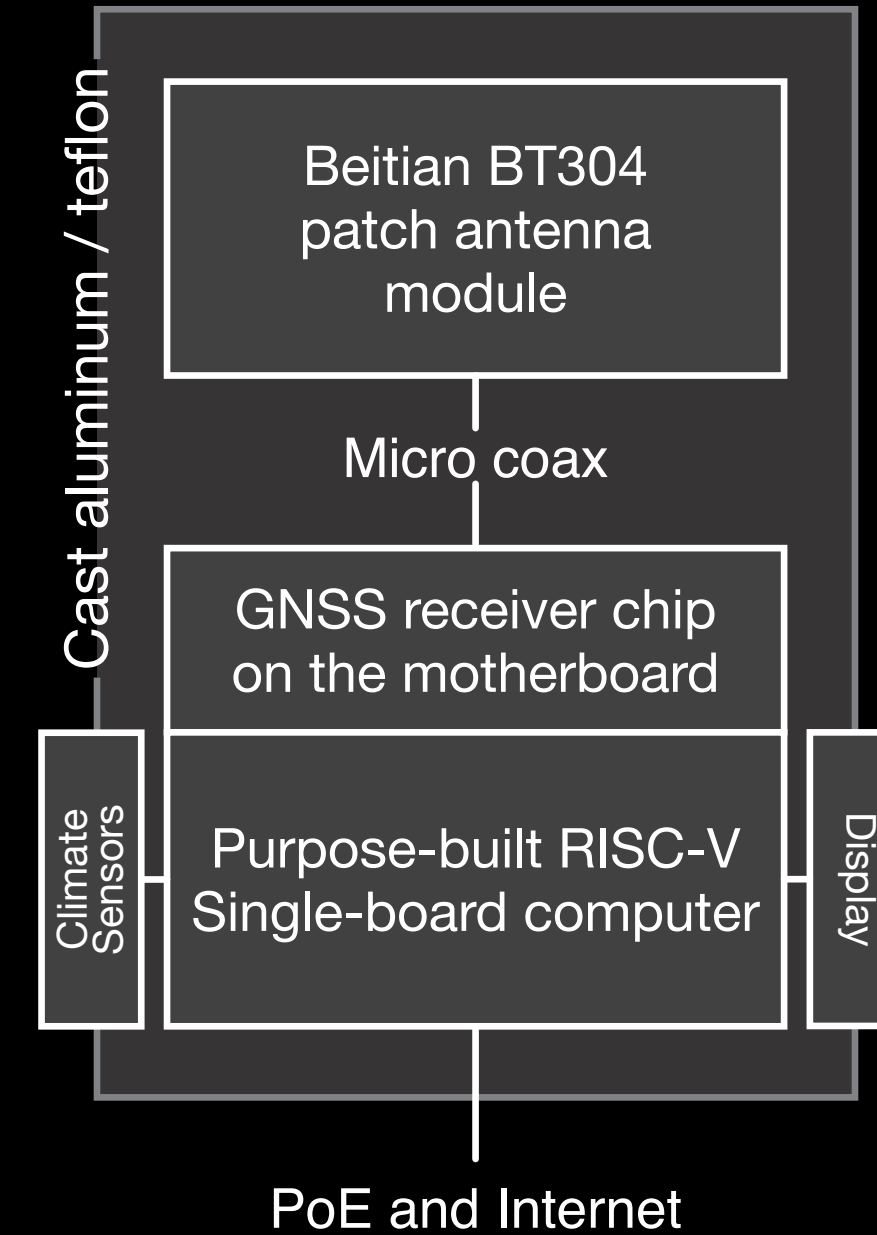
## Generation One



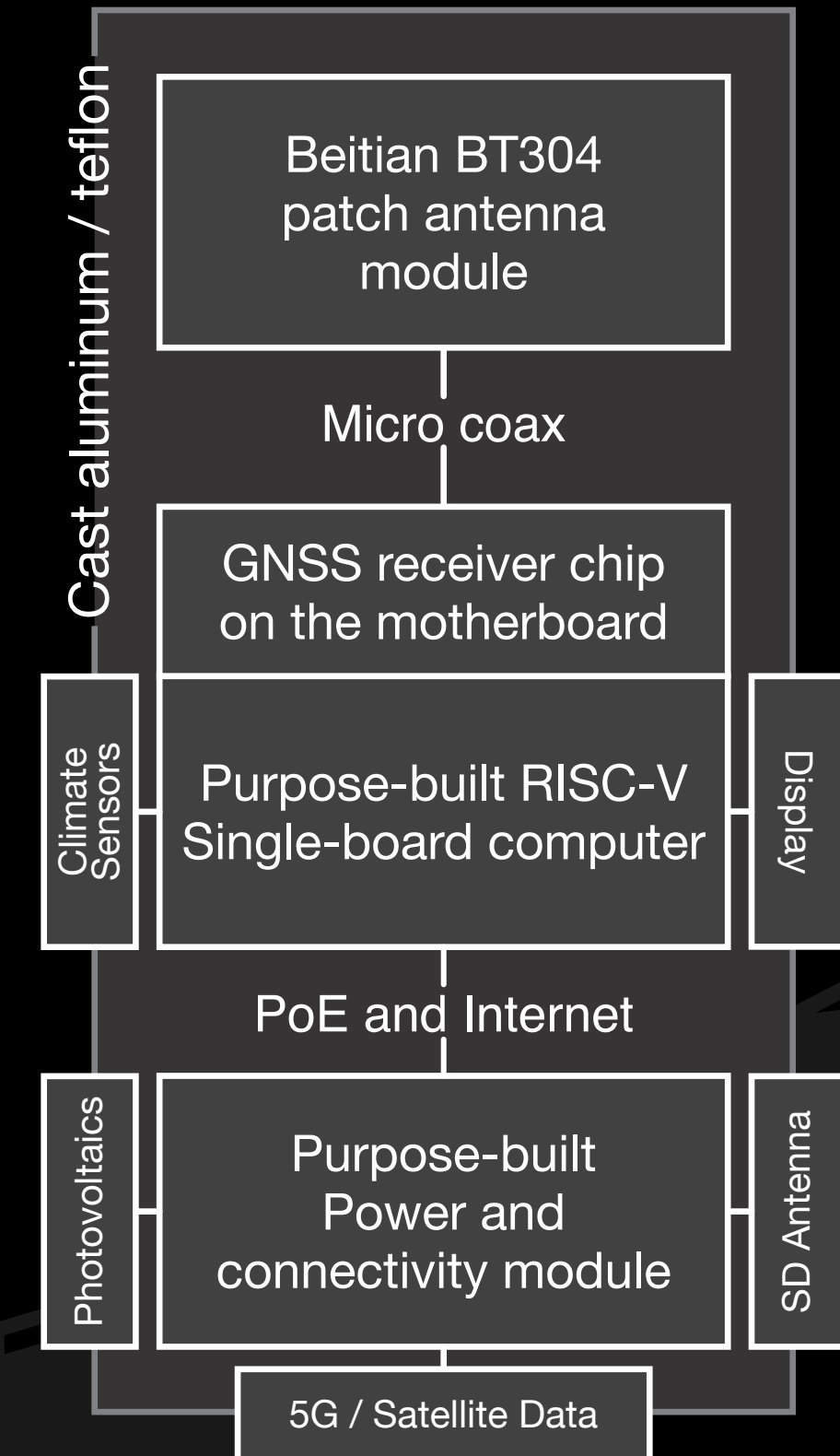
## Generation Two



## Generation Three Hardwired



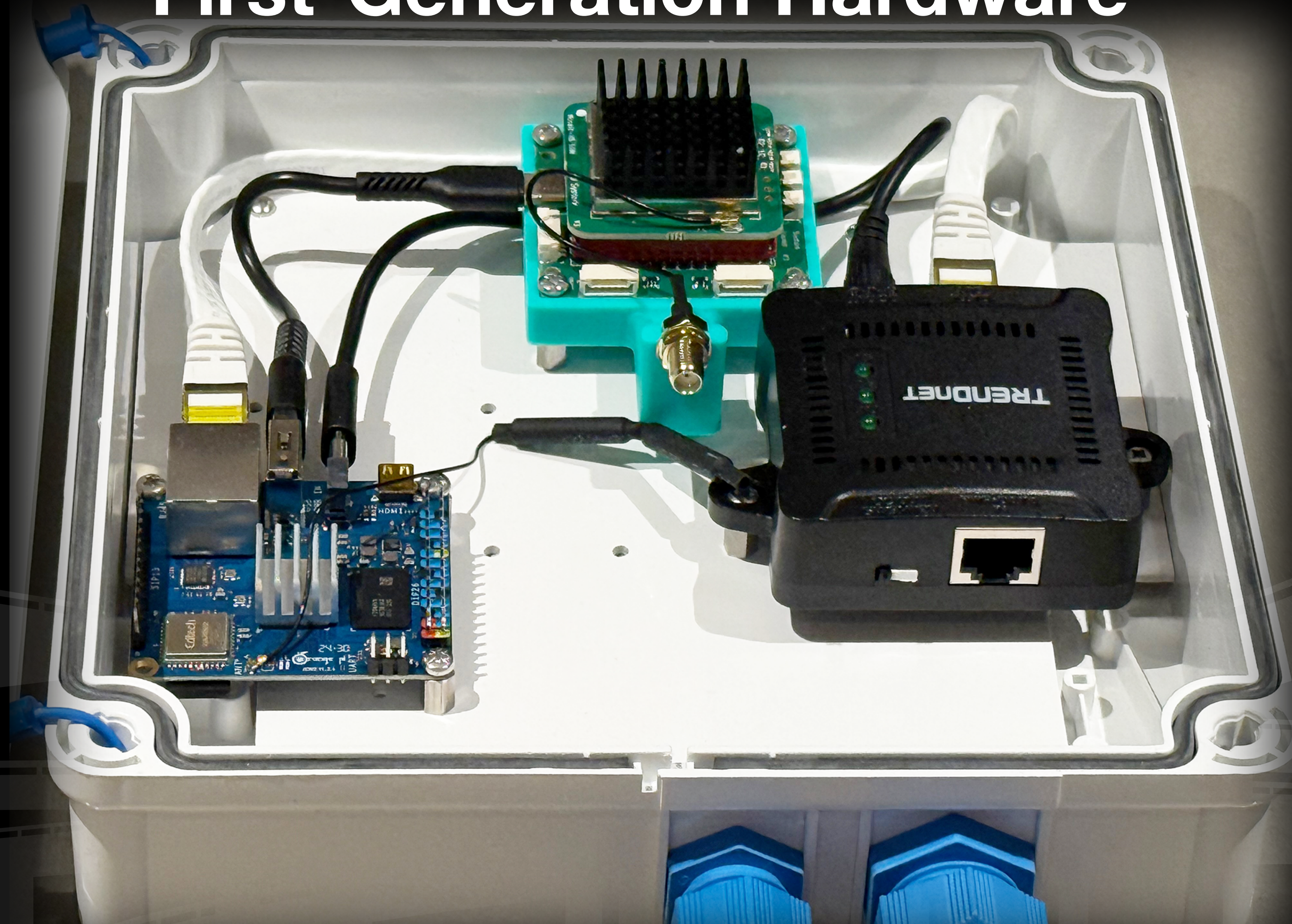
## Generation Three Standalone



# First-Generation Hardware



# First-Generation Hardware



# Second-Generation Hardware

