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Zenoh

A Crash Course in Building Cloud-to-Microcontroller Applications

Zenoh Team

SMART FACTORY

An interesting use case...

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What is a smart factory?

An interconnected **network** of **machines**, **communication mechanisms**, and **computing power**

https://www.sap.com/insights/what-is-a-smart-factory.html

Data is key

Smart factories are built around data for **realtime operations**, **monitoring**, **data analytics**, etc.

Data in **motion** and data at **rest** are both crucial

A variegated world

Different devices and systems live together

Sensors, robots, control systems, cloud, etc. need to cooperate and interact

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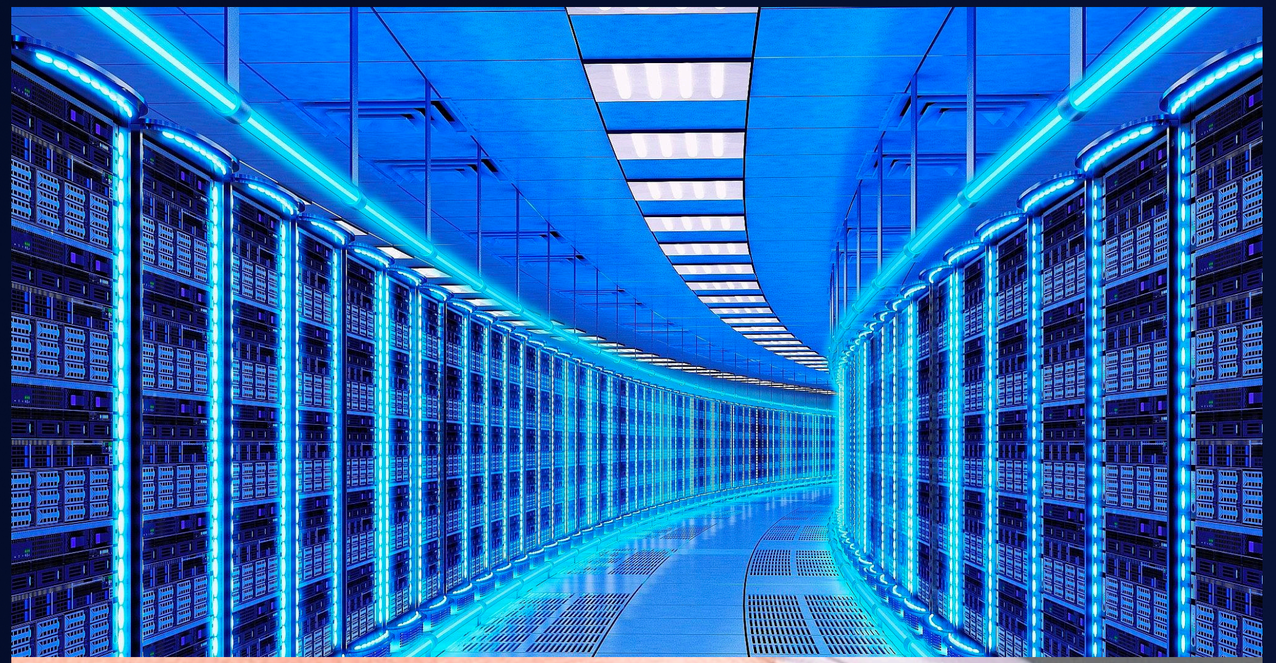
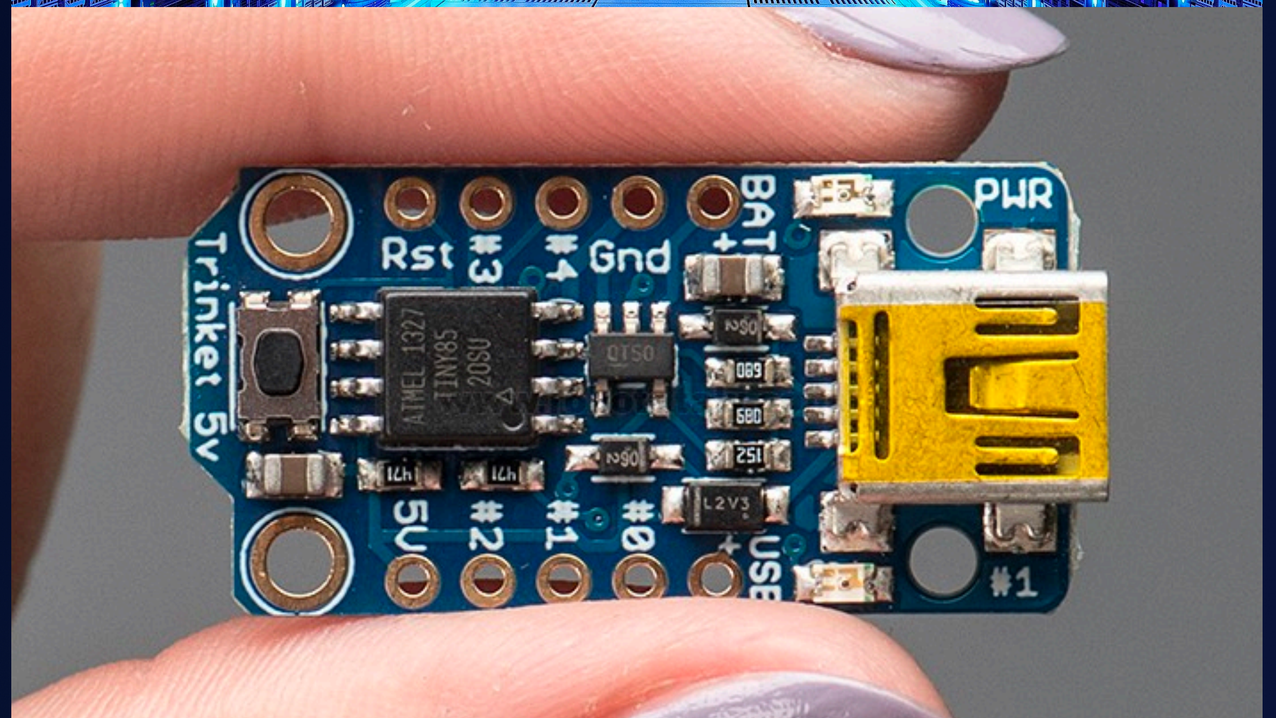
Making big the tiny world



Microcontrollers are as important as **data centres**

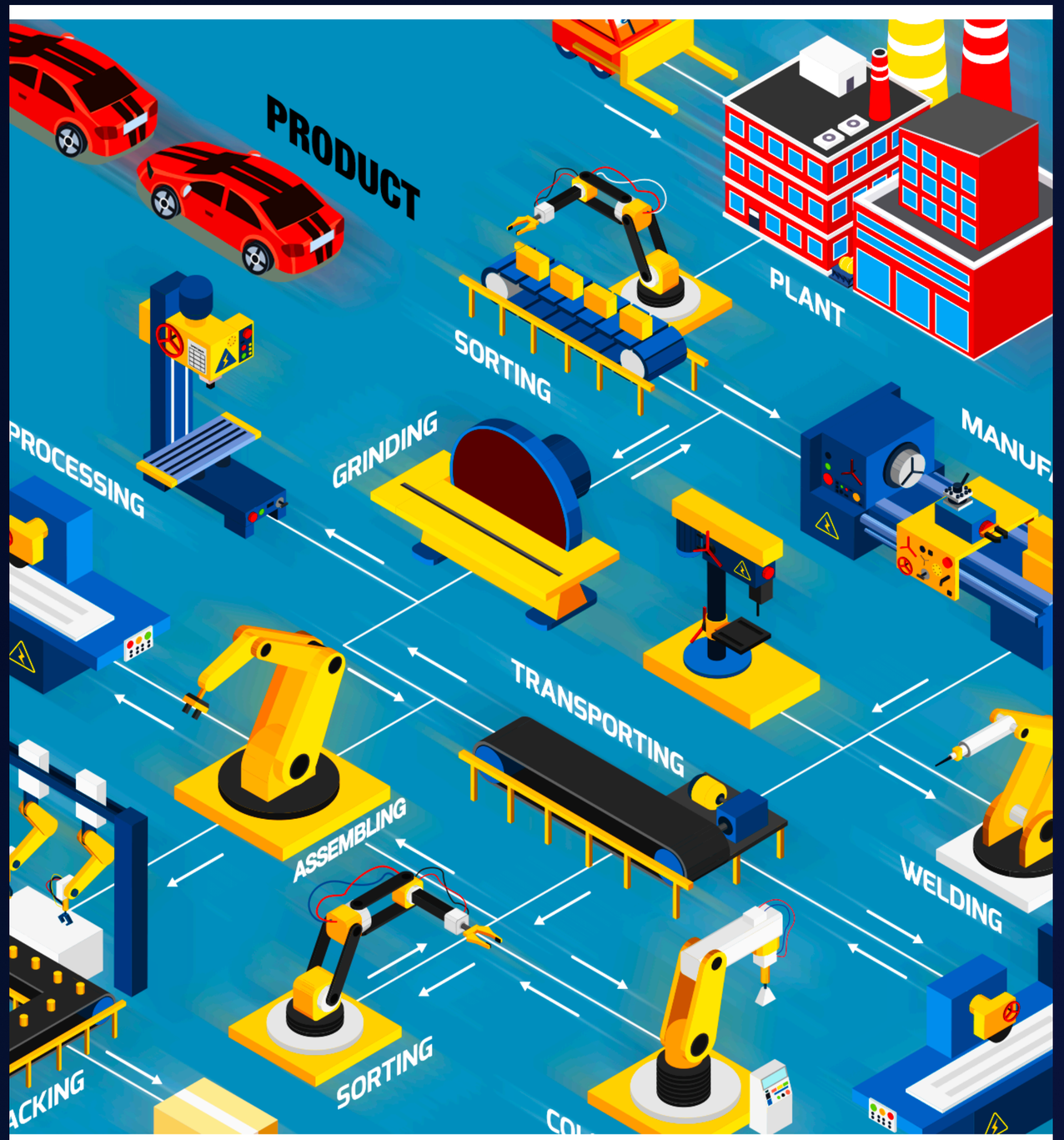
Data are **generated** and **consumed** by sensors, actuators, and apps in data centres



Speaking many languages

Multiple **communication protocols** (e.g. DDS, OPC-UA, MQTT, PROFINET, REST, etc.)

Multiple **network technologies** (e.g. WiFi, 5G, Serial, Bluetooth, etc.)



Talking freely

Communication in smart factories is a mix of

Peer-to-peer (e.g. between robots for coordination)

Infrastructured (e.g. with the control room)

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Let’s build a virtual fence for our smart factory!

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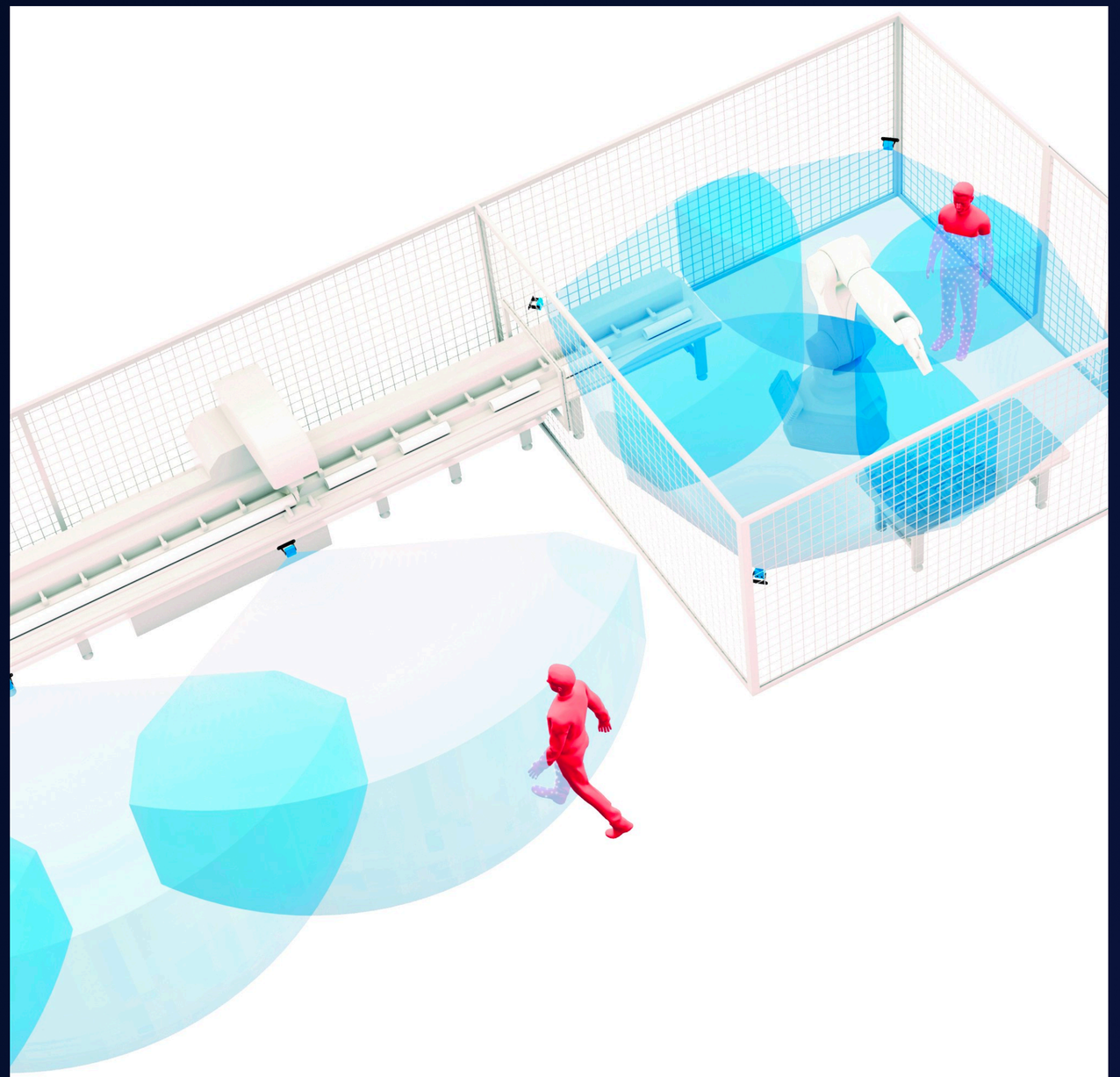
Virtual fence and robots

Sensors and **actuators** are ubiquitous: from the **building** to the **robots**

Distributed control system using a **virtual fence** to stop **robots**



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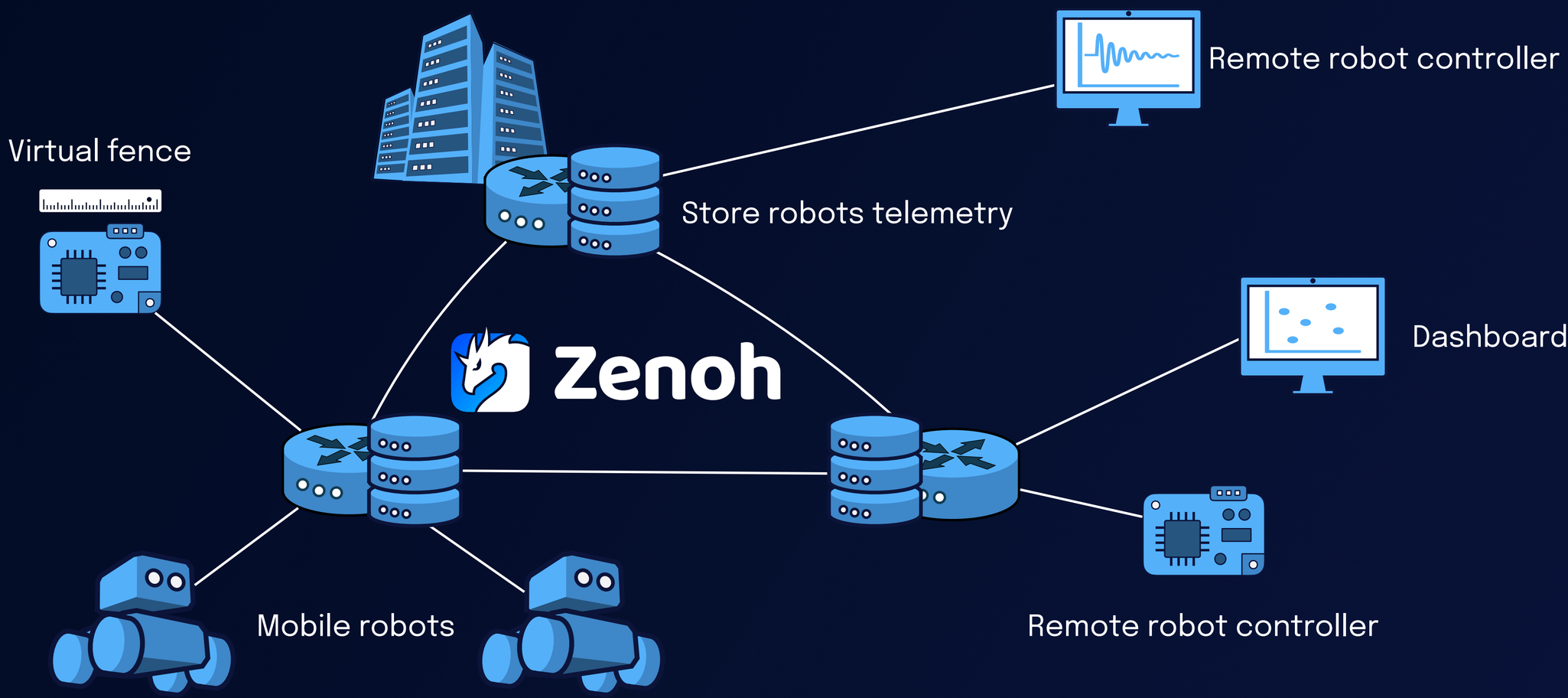
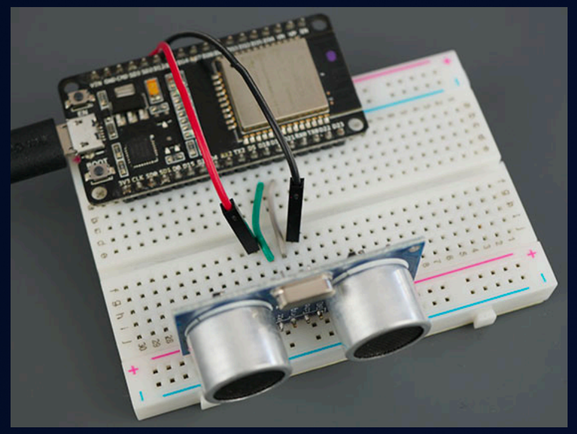
What we are going to build

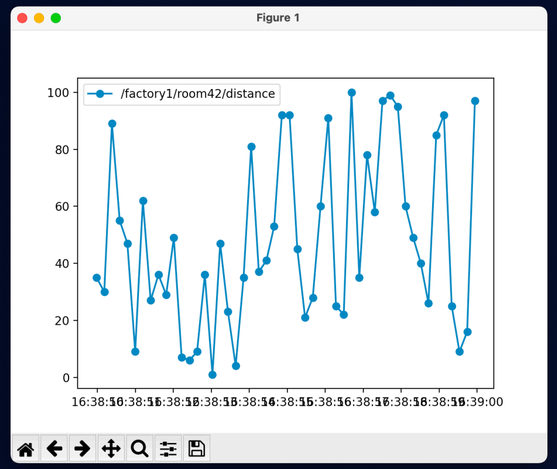


Virtual fence: let’s sense

ESP32 with ultrasonic sensor



Pub distance
factory1/room42/distance



Sub distance

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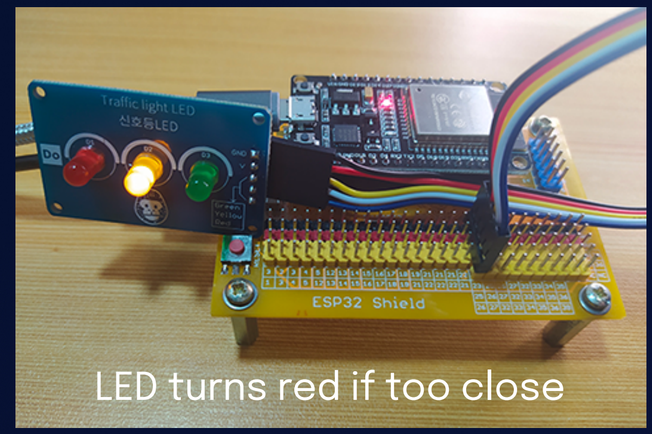
WiFi

ESP32 with LED



Sub distance

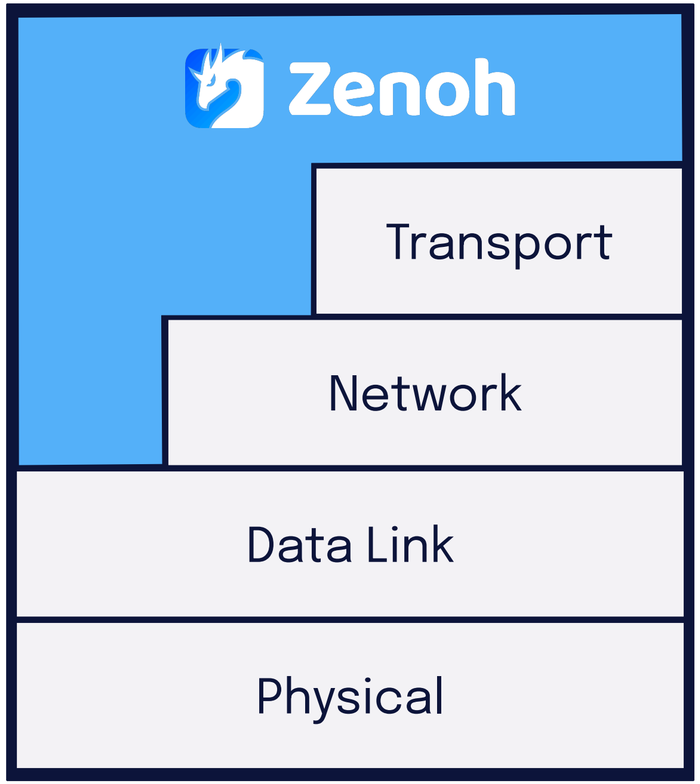
Pub alarm light
factory1/room42/led/green
factory1/room42/led/red

Zenoh runs everywhere

Native libraries and **API bindings** for many programming languages

Over various **network technologies**: from **transport layer** to **data link**

On **embedded** and **constrained devices**



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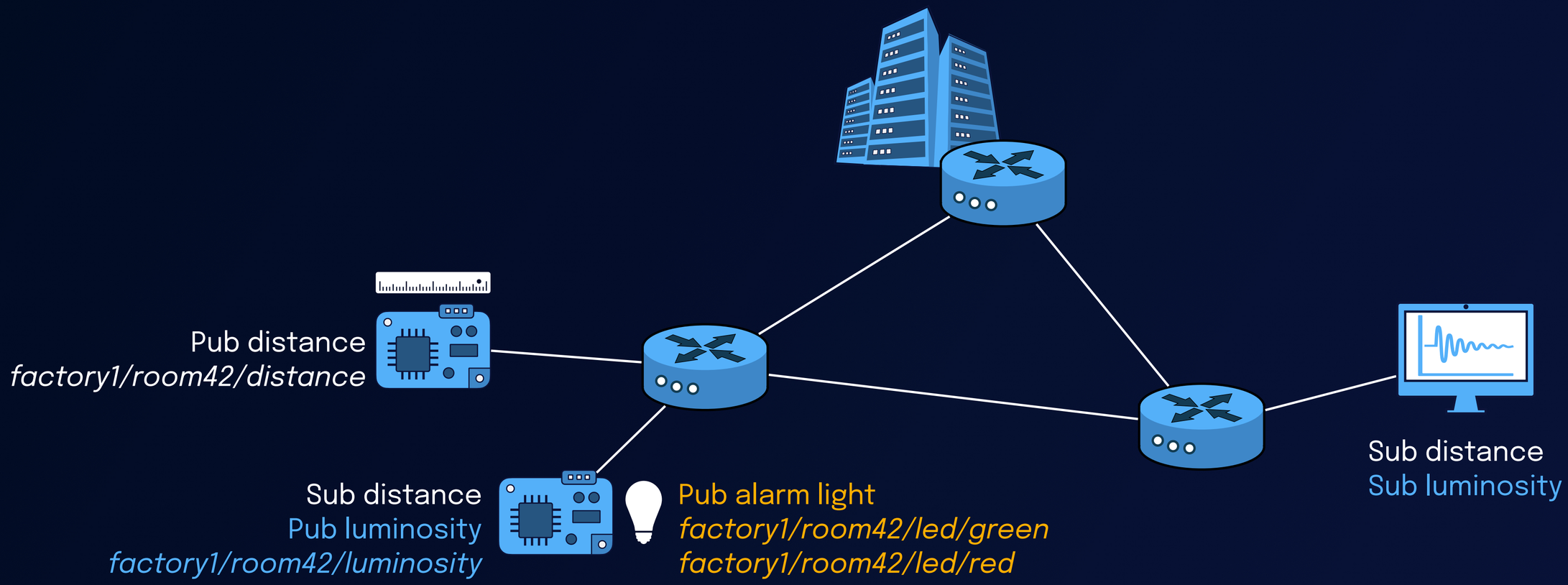
Extending beyond a LAN



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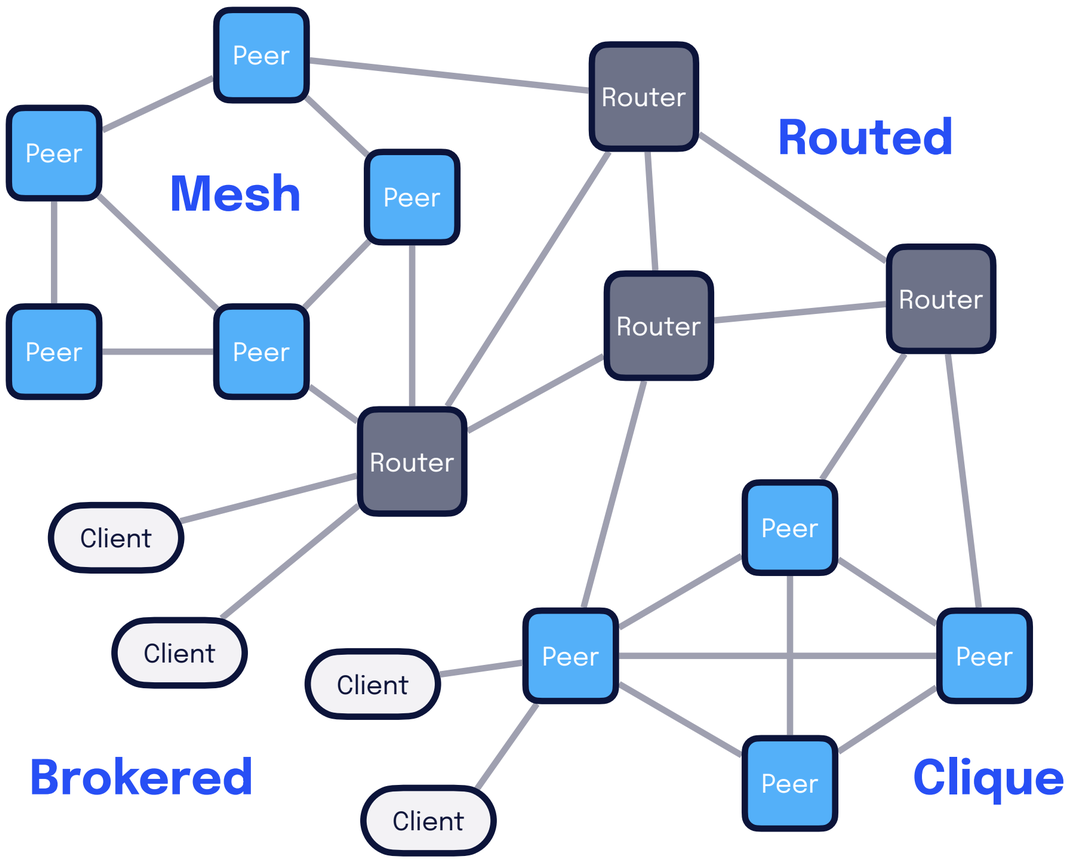
Zenoh supports many topologies



Peer-to-peer

Clique and mesh topologies

Brokered

Clients communicate through a router or a peer

Routed

Routers forward data to and from peers and clients

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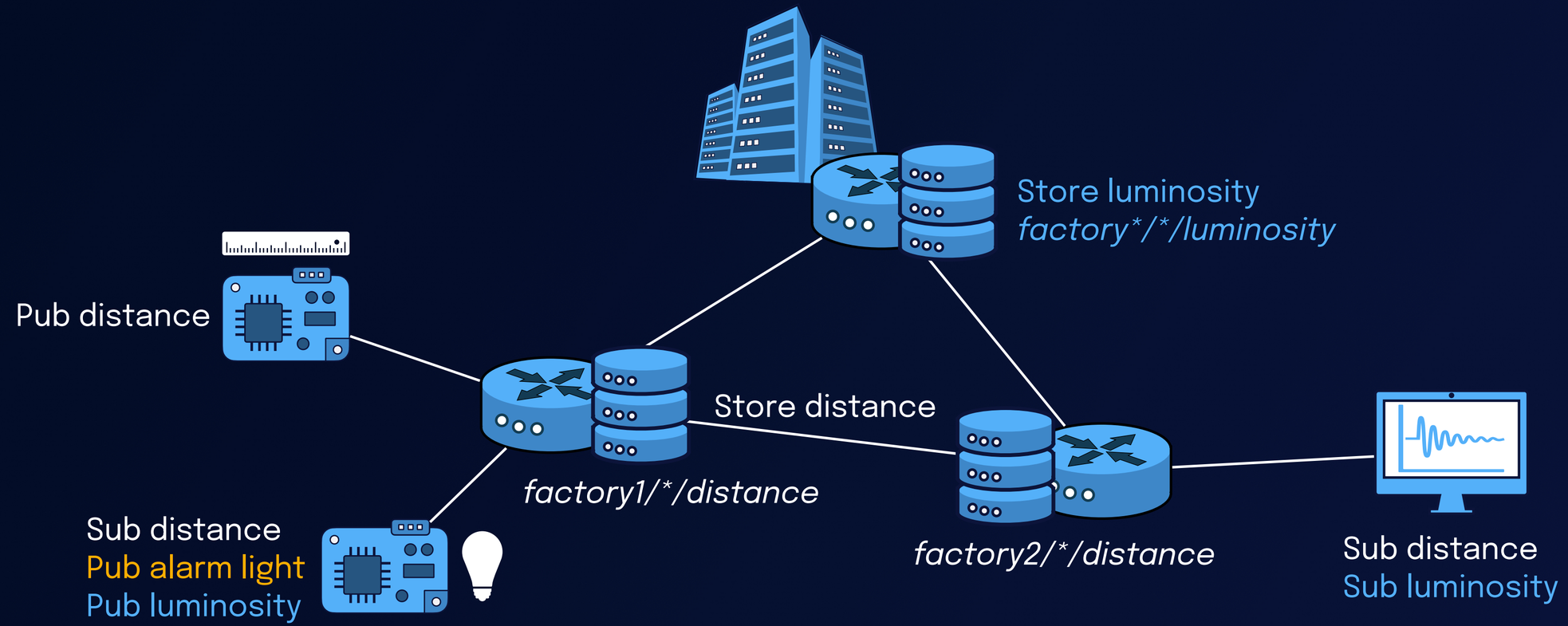
Storing data



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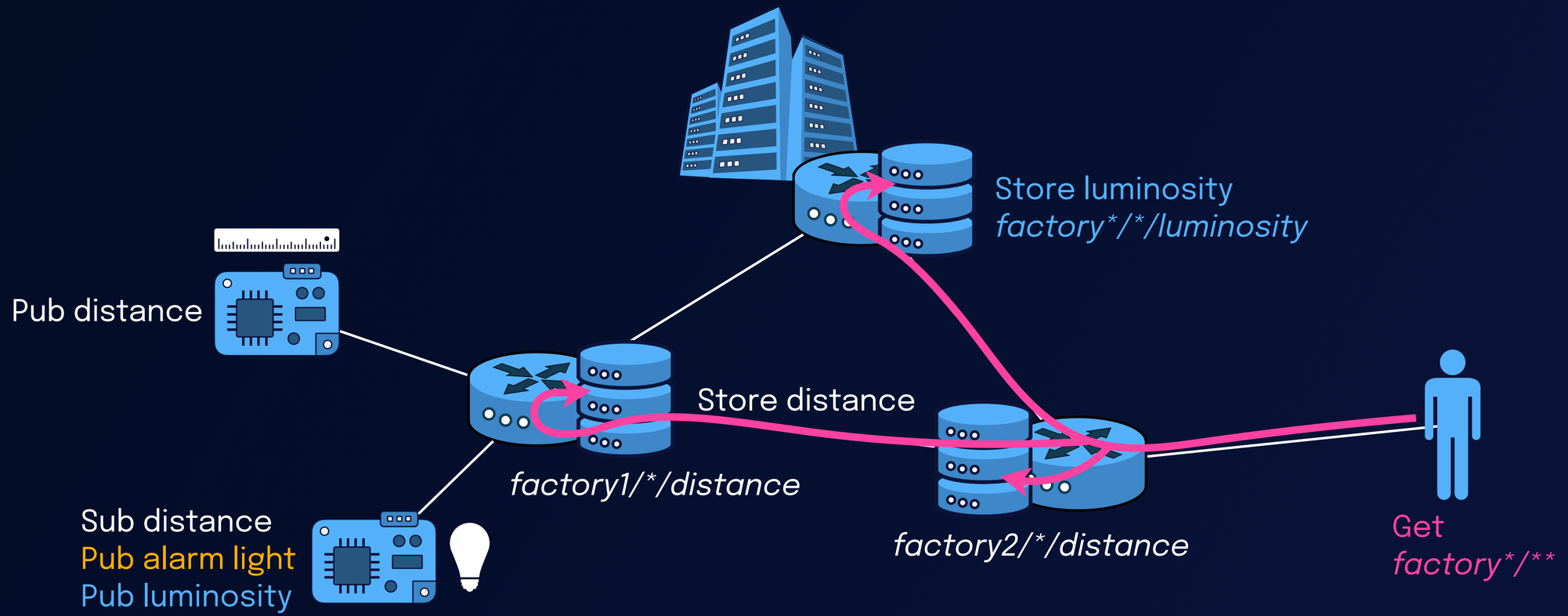
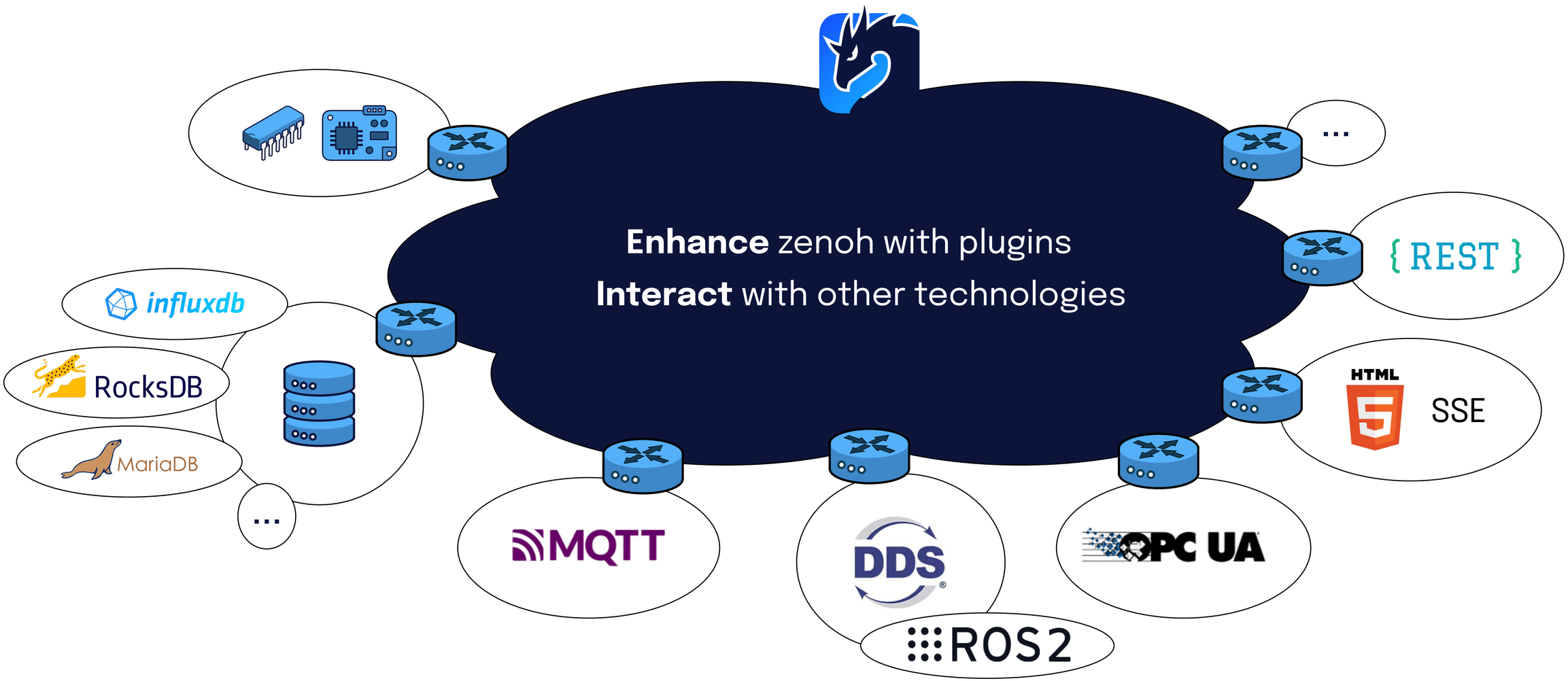
Retrieving data



Zenoh is extensible



"Coming together is a beginning; keeping together is progress; working together is success." - Edward Everett Hale

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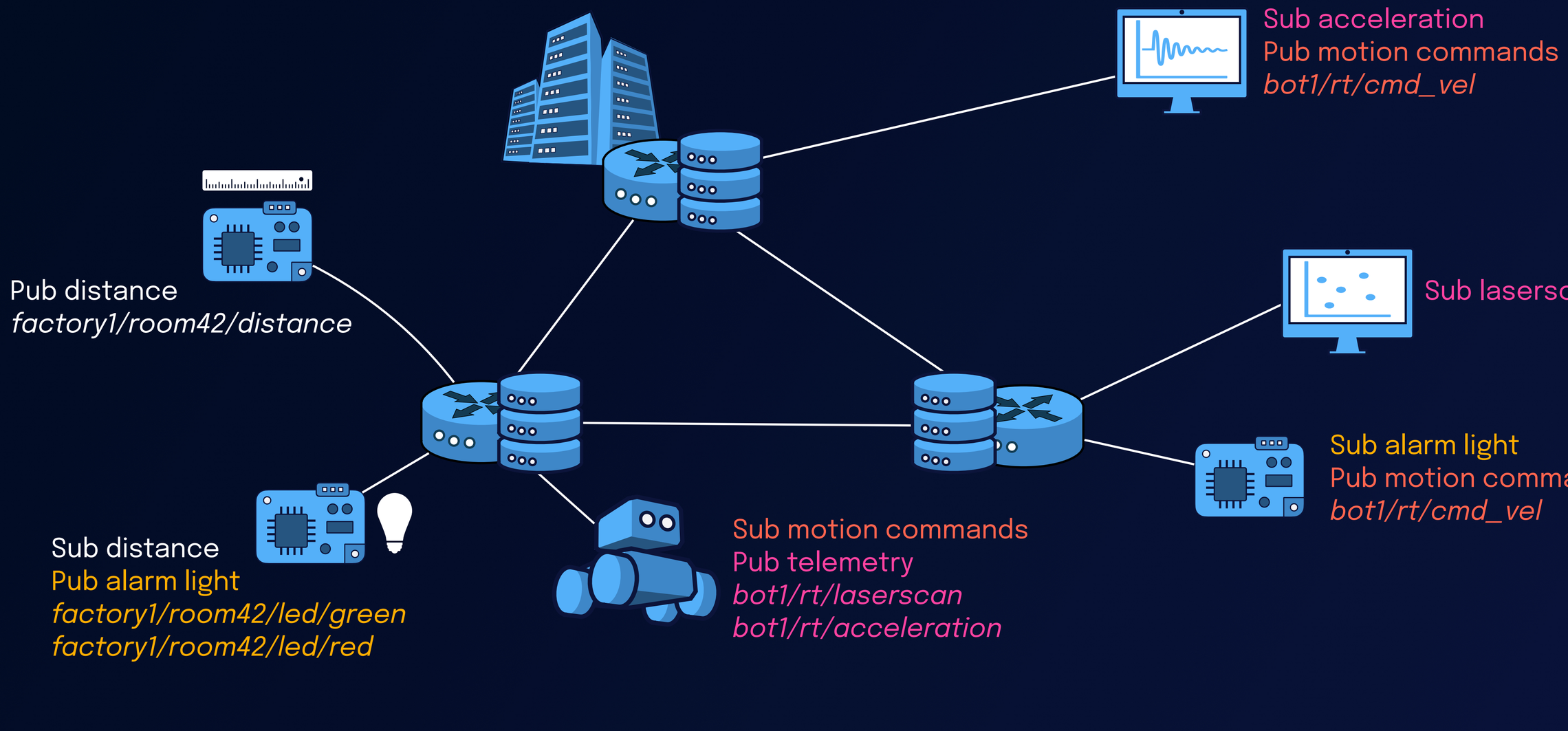
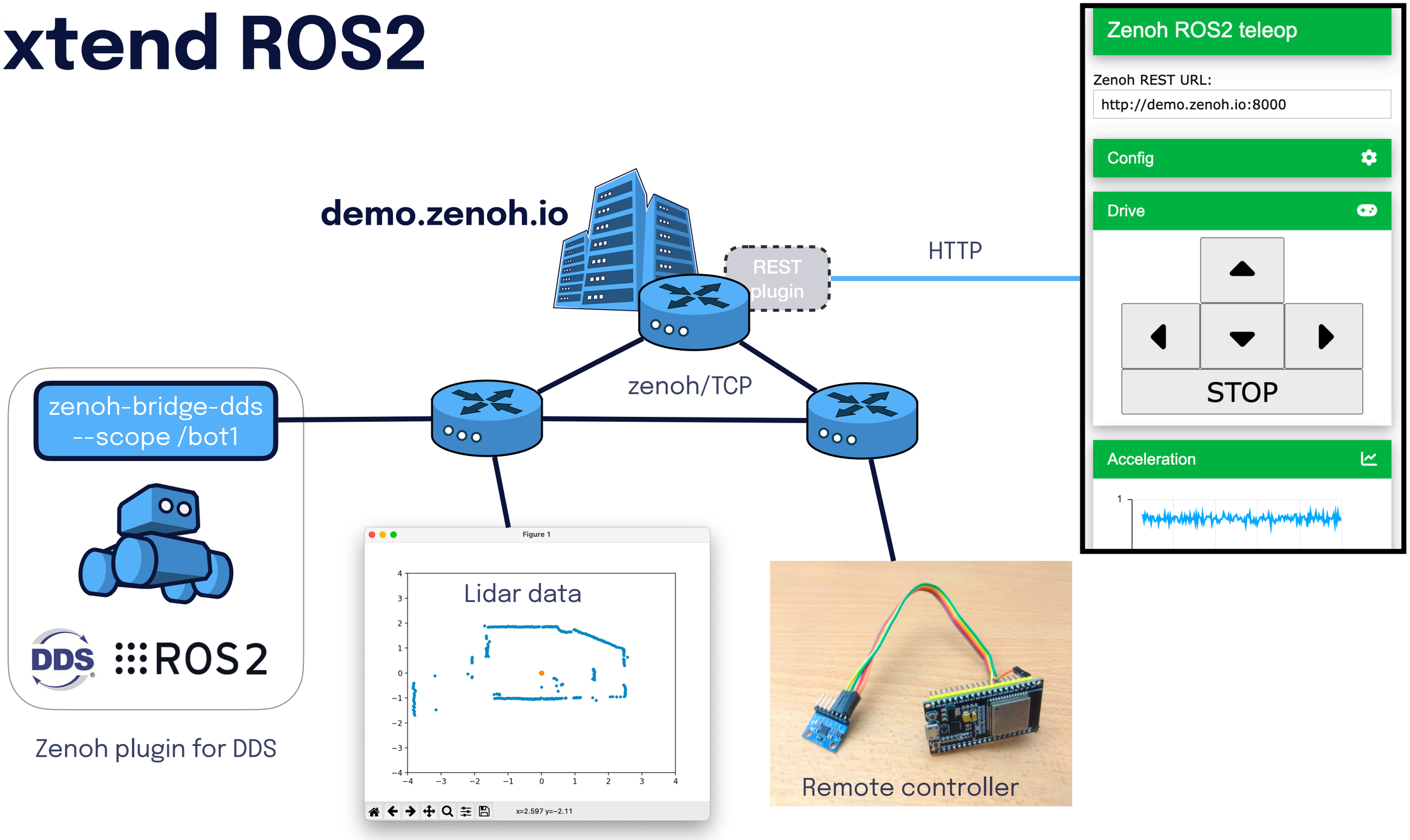
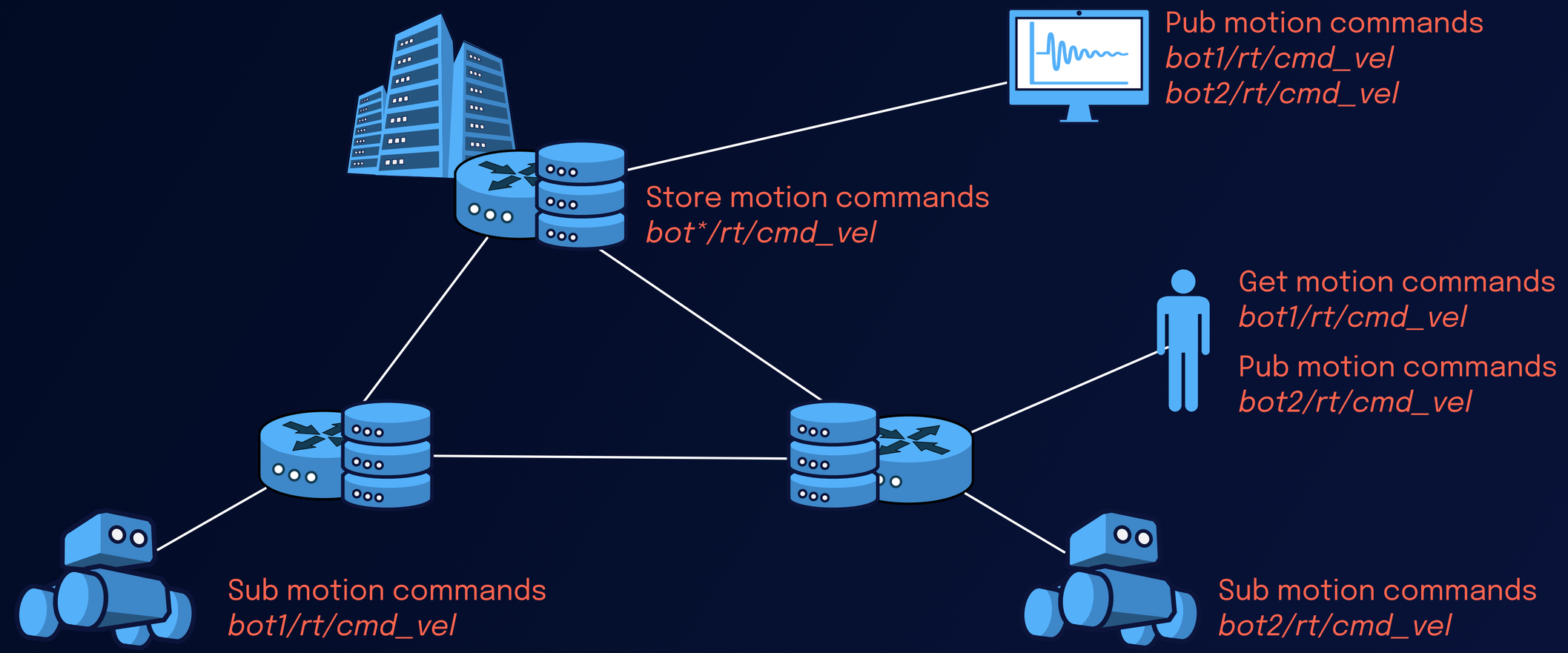
Robots are coming



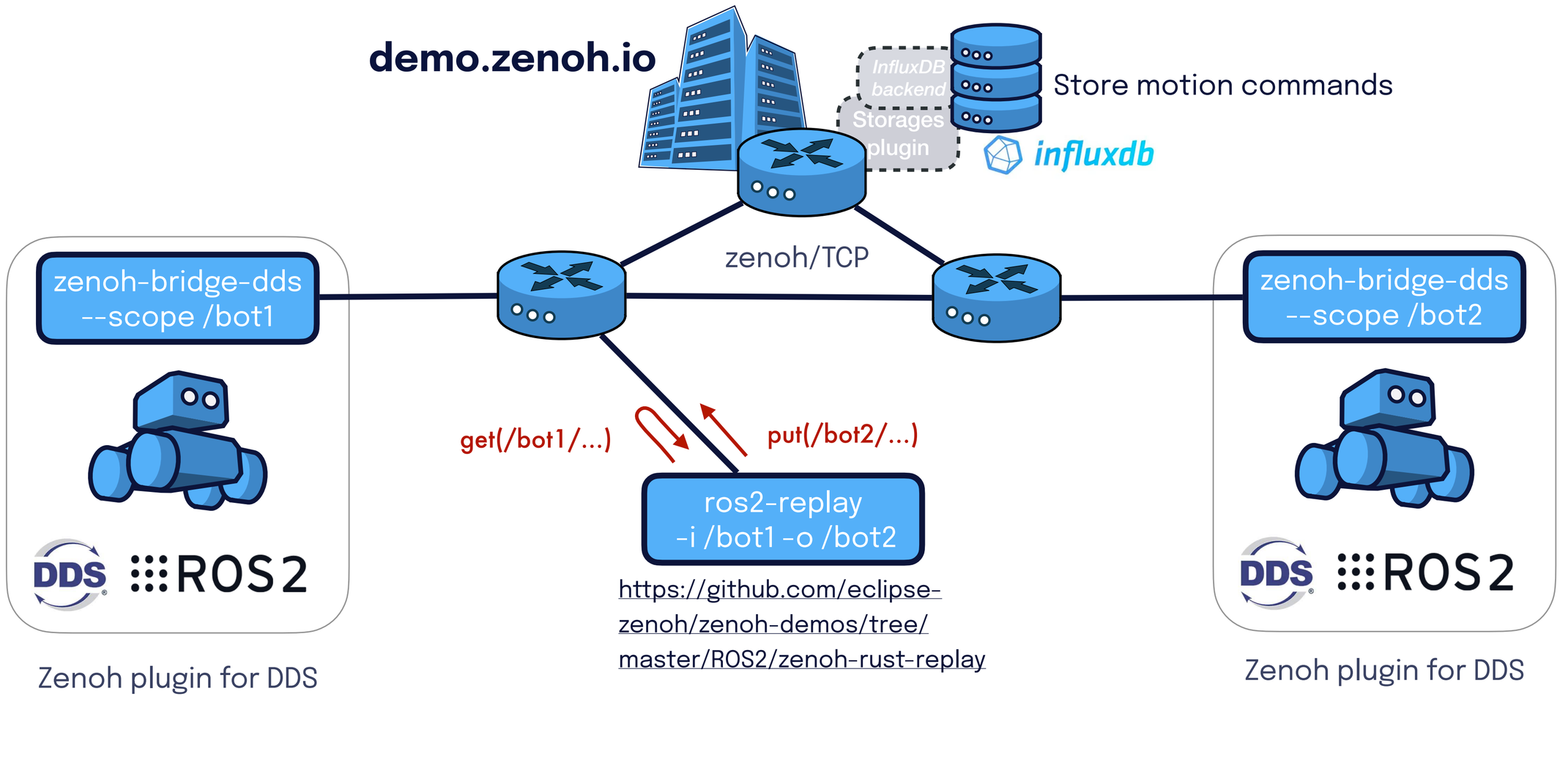
Extend ROS2


demo.zenoh.io
REST plugin
HTTP
zenoh/TCP
zenoh-bridge-dds --scope /bot1
DDS
ROS2
Zenoh plugin for DDS
Figure 1
Lidar data
x=2.597 y=−2.11
Remote controller
Zenoh ROS2 teleop
Zenoh REST URL:
http://demo.zenoh.io:8000
Config
Drive
STOP
Acceleration
1

Getting a twin



Record and replay ROS2



https://github.com/eclipse-zenoh/zenoh-demos/tree/master/ROS2/zenoh-rust-replay

Zenoh plugin for DDS

Zenoh plugin for DDS

Key takeaways

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Zenoh and the smart factory

Seamless mixing of **real time** and **stored** data

Different **devices** and **networks:** from **micro-controllers** to the **cloud**

Integration with third-party **technologies**

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Zenoh and robotics

Out-of-the box integration with **ROS2** robots

Intra-robot and **inter-robot** communication

High **throughput**, low **latency**, low **wire overhead**, and **simple API**

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Zenoh

Unifies data in **motion**, data **in-use**, data at **rest** and **computations**
from **embedded microcontrollers** up to powerful **data centres**

Provides a **location-transparent API** for high performance **pub/sub**
and **distributed queries** across **heterogeneous** systems

Facilitates data representation **transcoding**, **geo-distributed storage**
and **distributed computed values** in a plug-and-play fashion

“Some people want it to happen, some wish it would happen, others make it happen.” – Michael Jordan

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Zenoh-Flow: A data flow programming framework for the Cloud-to-Thing

Motivation

Zenoh holds a **promise**: becoming the *backbone of many (new) distributed applications*.

Zenoh-Flow builds on that promise: providing a **Cloud-to-Thing framework** that **eases** the “making” of complex applications.

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Ambition

Simpler & Resilient foundations

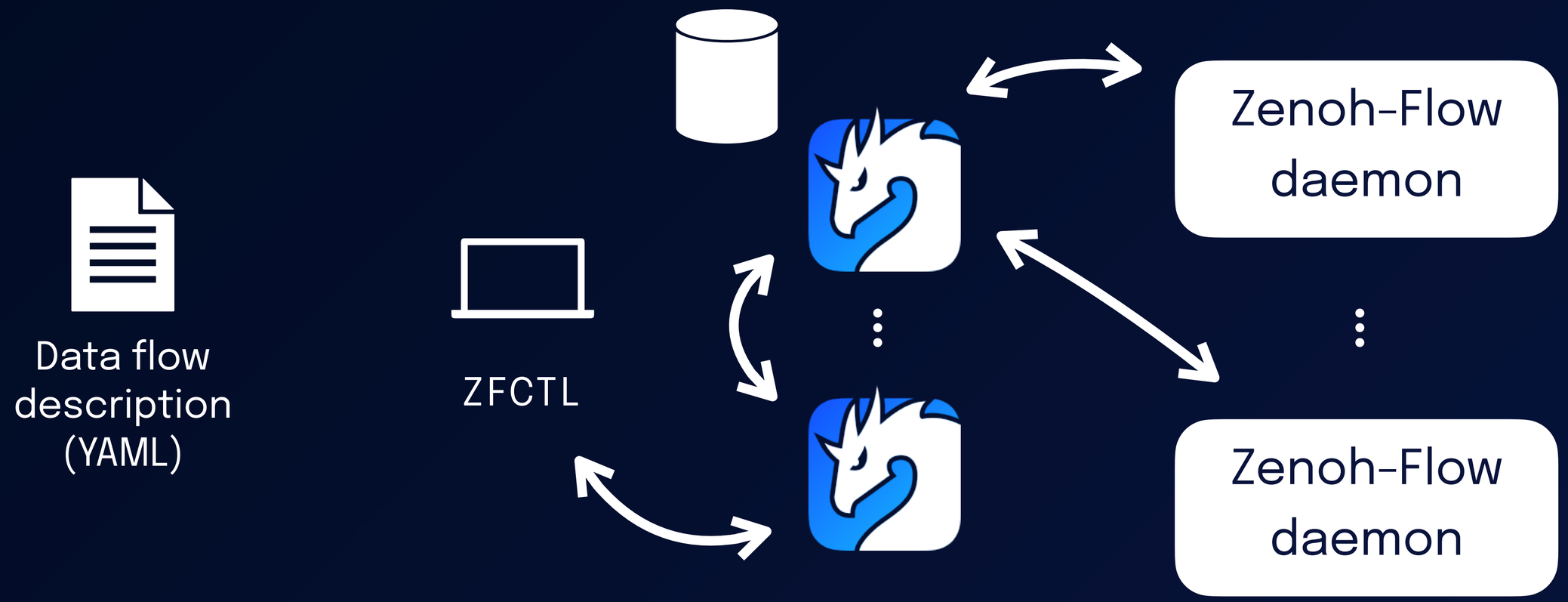
Declarative

Unified abstraction

Automatic deployment

Rust-based

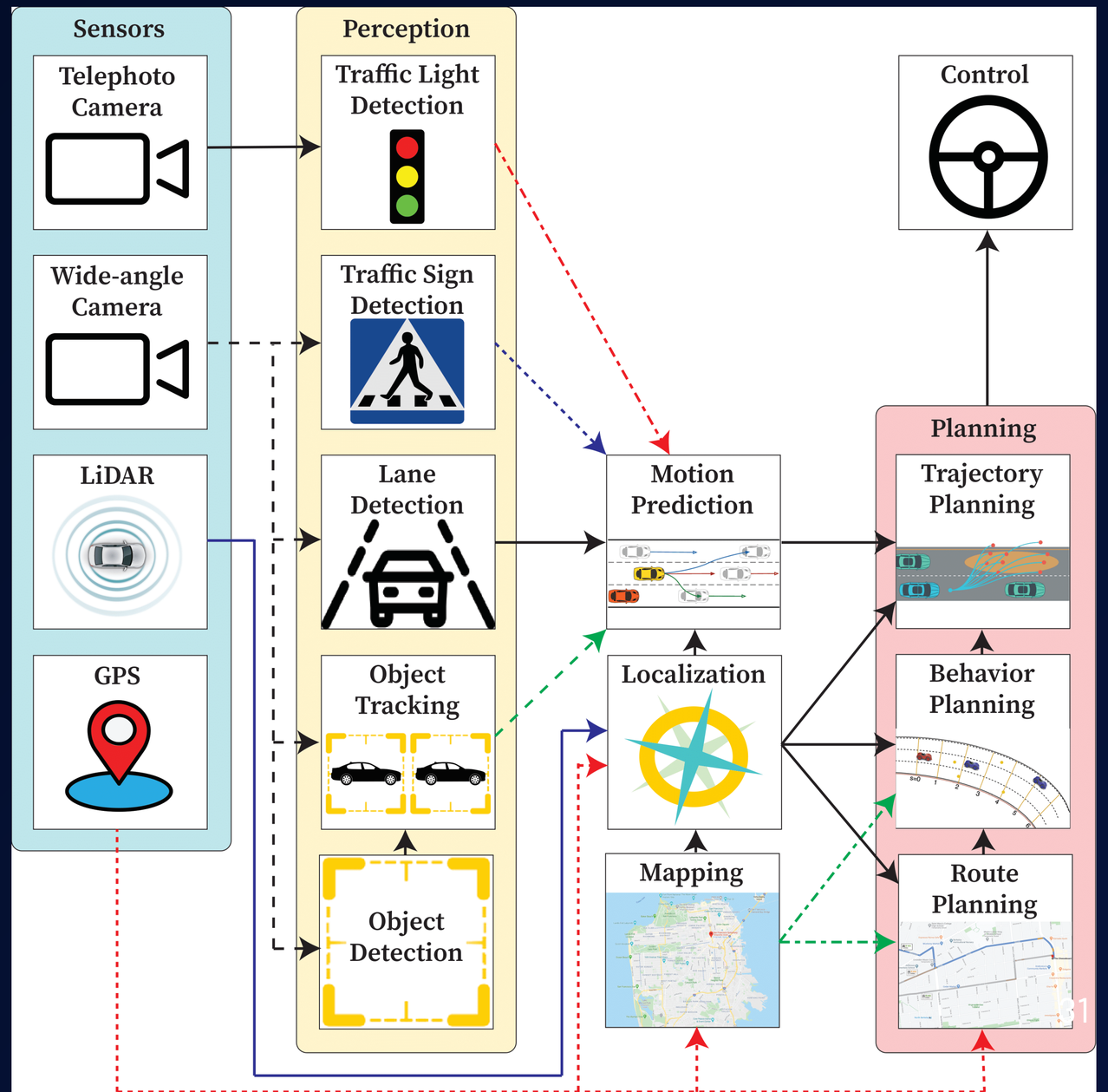
What it looks like



Example?

“**Pylot** is an autonomous vehicle platform for **developing** and **testing autonomous vehicle components** (e.g., perception, prediction, planning) on the **CARLA simulator** and real-world cars.”

https://github.com/erdos-project/pylot



Activities Terminator Apr 22 16:21 fr

abderahmane@goku: ~/work/ZF_pylot/dependencies/scenario_runner-0.9.11

abderahmane@goku: ~/work/ZF_pylot/dependencies/scenario_runner-0.9.11 65x43

```
│ Duration (Game Time)         │ 11.96s       │
│ Ratio (System Time / Game Time) │ 0.999s    │

 > Criteria Information

│ Actor                  │ Criterion                │ Result
│ Actual Value           │ Expected Value │
│ lincoln.mkz2017 (id=259) │ CheckMaximumVelocity (Opt.) │ SUCCES
S │ 0.012203460226641363 │ 20 │
│ lincoln.mkz2017 (id=259) │ CollisionTest (Req.) │ SUCCES
S │ 0 │ 0 │
│ lincoln.mkz2017 (id=259) │ CheckDrivenDistance (Req.) │ FAILUR
E │ 1.15 │ 150 │
│ tesla.model3 (id=260) │ CollisionTest (Req.) │ SUCCES
S │ 0 │ 0 │
│ │ Timeout (Req.) │ SUCCES
S │ 11.96 │ 180 │
│ │ GLOBAL RESULT │ FAILUR
E │ │ │

 ================================================================
================

Not all scenario tests were successful
No more scenarios .... Exiting
abderahmane@goku:~/work/ZF_pylot/dependencies/scenario_runner-0.9
.11$
```

abderahmane@goku: ~/work/zenoh/zenoh-flow/zenoh-flow-python 55x43


```
ss":null,"interface":null,"autoconnect":null},"gossip":
{"autoconnect":null,"peers_autoconnect":null},"add_tim
estamp":true,"local_routing":null,"queries_default_time
out":null,"transport":{"unicast":{"accept_timeout":1000
0,"accept_pending":100,"max_sessions":1000,"max_links":
1},"multicast":{"join_interval":2500,"max_sessions":100
0},"qos":{"enabled":true},"link":{"tx":{"sequence_numbe
r_resolution":268435456,"lease":10000,"keep_alive":2500
,"batch_size":65535,"queue":{"size":{"control":1,"real_
time":1,"interactive_high":1,"interactive_low":1,"data_
high":2,"data":4,"data_low":4,"background":4},"backoff"
:100},"threads":4},"rx":{"buffer_size":65535,"max_messa
ge_size":1073741824},"tls":{"root_ca_certificate":null,
"server_private_key":null,"server_certificate":null,"cl
ient_auth":null,"client_private_key":null,"client_certi
ficate":null}},"shared_memory":{"enabled":true},"auth":
{"usrpwd":{"user":null,"password":null,"dictionary_file
":null},"pubkey":{"public_key_pem":null,"private_key_pe
m":null,"public_key_file":null,"private_key_file":null,
"key_size":null,"known_keys_file":null}}},"plugins_sear
ch_dirs":["/usr/lib/"],"plugins":{"storage_manager":{"s
torages":{"zf":{"key_expr":"/zenoh-flow/**","volume":"m
emory"},"zfrpc":{"key_expr":"/zf/runtime/**","volume":"
memory"}}}}}
```


```
[2022-04-22T14:20:41Z INFO  zenoh::net::runtime] Using
PID: 91017AB0999648E7BC74147910B460EA
[2022-04-22T14:20:41Z INFO  zenoh::net::runtime::orches
trator] zenohd can be reached on tcp/192.168.16.147:788
7
[2022-04-22T14:20:41Z INFO  zenoh::net::runtime::orches
trator] zenohd can be reached on tcp/192.168.21.247:788
7
[2022-04-22T14:20:41Z INFO  zenoh::net::runtime::orches
trator] zenohd can be reached on tcp/172.17.0.1:7887
[2022-04-22T14:20:41Z INFO  zenoh::net::runtime::orches
trator] zenohd listening scout messages on 224.0.0.224:
7447
[2022-04-22T14:20:41Z INFO  zenohd] Successfully starte
d plugin storage_manager from "/usr/lib/libzplugin_stor
age_manager.so"
[2022-04-22T14:20:41Z INFO  zenohd] Finished loading pl
ugins
```

abderahmane@goku: ~/work/ZF_pylot 80x22

```
[2022-04-22T14:20:19Z INFO  zenoh_flow::runtime::dataflow::instance::runners] No
deRunner controller received stop trigger
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ RUST_LOG=zenoh_flow=info zenoh-flow-daemon -c
/etc/zenoh-flow/runtime.yaml
[2022-04-22T14:20:44Z INFO  zenoh_flow_daemon::daemon] Loaded extension /etc/zen
oh-flow/extensions.d/01-python.zfext
[2022-04-22T14:20:44Z WARN  zenoh_flow_daemon::daemon] Skipping /etc/zenoh-flow/
extensions.d/placeholder as it as no extension
[2022-04-22T14:20:45Z INFO  zenoh_flow_daemon::daemon] Runtime main loop startin
g
[2022-04-22T14:20:47Z INFO  zenoh_flow_daemon::daemon] Instantiating: ZF_AV
[2022-04-22T14:20:47Z INFO  zenoh_flow_daemon::daemon] Creating Flow ZF_AV - Ins
tance UUID: 50f9f6e8-a6b3-4cf1-a9e3-1a533afab8aa
[2022-04-22T14:20:47Z INFO  zenoh_flow_daemon::daemon] Preparing for Instance UU
ID: 50f9f6e8-a6b3-4cf1-a9e3-1a533afab8aa
[2022-04-22T14:21:14Z INFO  zenoh_flow_daemon::daemon] Instantiating: ZF_AV
[2022-04-22T14:21:14Z INFO  zenoh_flow_daemon::daemon] Creating Flow ZF_AV - Ins
tance UUID: 90076972-7c36-4866-bf0a-bc26a0918d84
[2022-04-22T14:21:14Z INFO  zenoh_flow_daemon::daemon] Preparing for Instance UU
ID: 90076972-7c36-4866-bf0a-bc26a0918d84
```

abderahmane@goku: ~/work/ZF_pylot 80x19

```
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ zfctl launch ZF_AV.yml
92450e8c-52db-465c-9709-076a74926dfd
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ zfctl launch ZF_AV.yml
thread 'main' panicked at 'called `Result::unwrap()` on an `Err` value: Empty',
zfctl/src/main.rs:550:64
note: run with `RUST_BACKTRACE=1` environment variable to display a backtrace
Aborted (core dumped)
abderahmane@goku:~/work/ZF_pylot$ zfctl launch ZF_AV.yml
```

abderahmane@goku: ~/work/ZF_pylot 100x17

```
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ sc
4.24.3-0+++UE4+Release-4.24 518 0
Disabling core dumps.
^CFUnixPlatformMisc::RequestExitWithStatus
FUnixPlatformMisc::RequestExit
Exiting abnormally (error code: 130)

abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ ^C
abderahmane@goku:~/work/ZF_pylot$ sc
4.24.3-0+++UE4+Release-4.24 518 0
Disabling core dumps.
```

abderahmane@goku: ~/work/pylot 101x17

```
abderahmane@goku:~/work/ZF_pylot$ cd ..
abderahmane@goku:~/work$ cd pylot/
abderahmane@goku:~/work/pylot$ code .
abderahmane@goku:~/work/pylot$ ^C
abderahmane@goku:~/work/pylot$ ^C
abderahmane@goku:~/work/pylot$ ^C
abderahmane@goku:~/work/pylot$ ^C
abderahmane@goku:~/work/pylot$ ^C
abderahmane@goku:~/work/pylot$ ^C
abderahmane@goku:~/work/pylot$ ^C
abderahmane@goku:~/work/pylot$
```

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...and the blog

zenoh.io

Home Documentation Community Adopters Media Blog

Zenoh

Zero Overhead Pub/sub, Store/Query and Compute.

zenoh /zeno/ unifies data in motion, data at rest and computations. It elegantly blends traditional pub/sub with geo distributed storage, queries and computations, while retaining a level of time and space efficiency that is well beyond any of the mainstream stacks.

Get started

Don't forget to visit Zenoh's website...

https://zenoh.io/

zenoh.io

Documentation Community Adopters Media **Blog**

...ve and

...valuation ...onous

... and ...

DragonBotOne Egg Hatching with Zenoh and Zenoh-Pico

ROS 2 and microcontrollers integration via Zenoh-pico

Zenoh goes embedded with zenoh-pico

Indy Autonomous Challenge (IAC): Experiences from the

Zenoh-Pico: Above and Beyond

09 June 2022 -- Paris.

In a previous blog post, we introduced Zenoh-Pico, an implementation of Zenoh for microcontrollers and embedded devices, along with a preliminary performance results and its integration on off-the-shelf robots (by bridging both legacy ROS2+DDS and Zenoh systems or by making it a full-fledged Zenoh system).

In this post, we will dive deeper on Zenoh-Pico, show, how Zenoh-Pico is capable of:

- exchanging close to **2.5M msg/s** for small payloads, and over **25 Gbps** for larger messages,
- achieving end-to-end latency (i.e., one way delay) as small as **45 µsec** and **15 µsec** for unicast and multicast transports, respectively,
- minimizing the overhead in the wire down to **5 bytes** per data transmission,
- fitting all its capabilities in less than **50KB** footprint, which can be quickly reduced to **~15KB** in tailored compilation setups, and
- provides **simple** to use and yet **powerful APIs**.