IoT - examples of IoT solutions in MAHLE products

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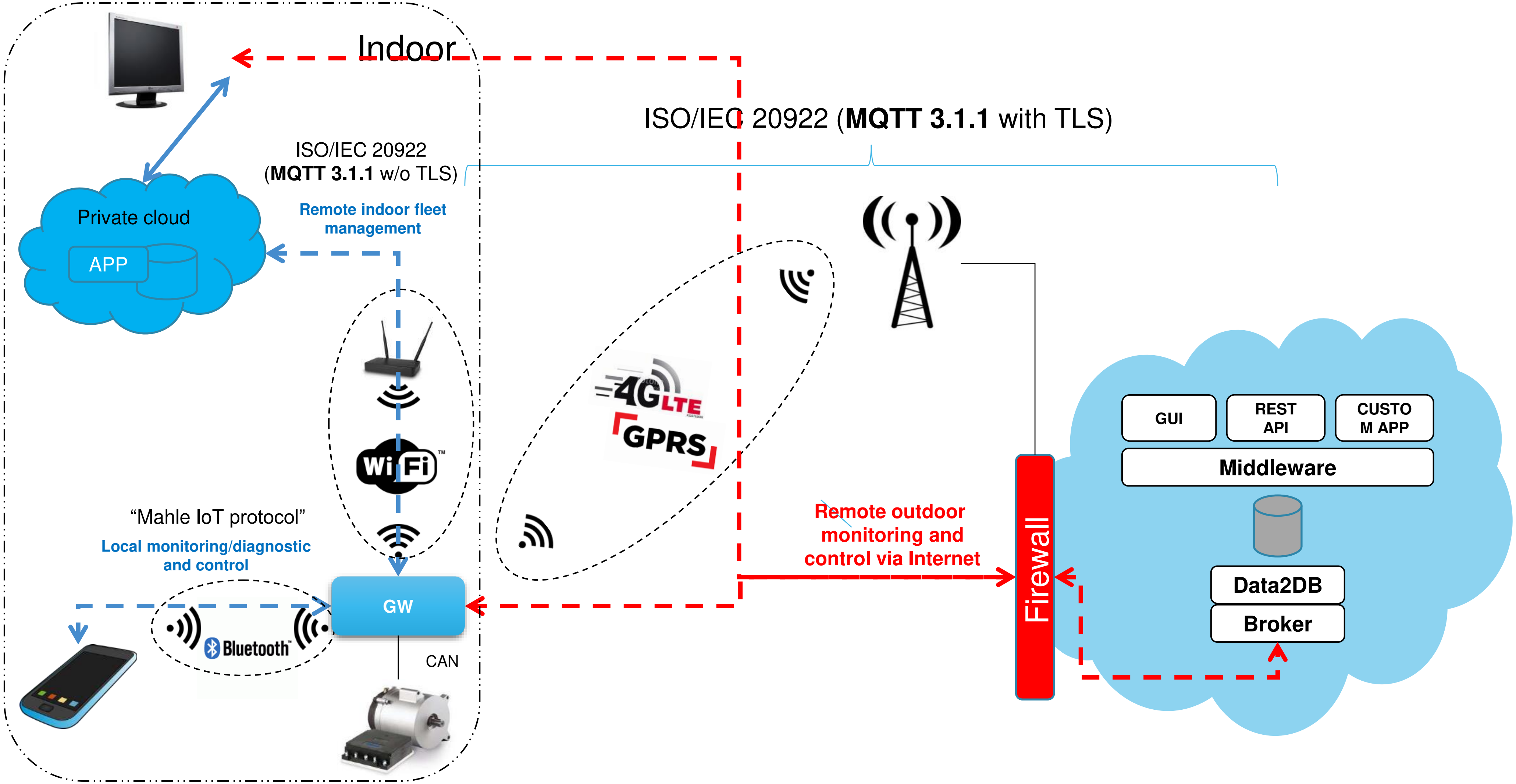
Why?

Business case and motivation

- MAHLE motivation
  - **Replacement of current LCD based console** with smart interface and laptop
    - Better on the field support (integration, testing)
  - **Offering after market services**
    - Machine status monitoring and reporting
  - **New added value products** (e-motor with connectivity option)
    - Research and development of IoT platform for remote access to the motor controller
- Customer motivation
  - Remote fleet management (monitoring equipment, usage and sharing)
    - Golf cart **geo-fencing**
    - Heavy-duty **working hour tracking**
    - **Security** (access control)
    - **Machine availability enhancement** (predictive maintenance - Failure prediction)

Final solution



MAHLE

Plan

Steps toward final solution

- 1. **Connectivity** enabling solution
  - Develop **Gateway prototype with remote access** via laptop, mobile or tablet **with browser**
  - **Wi-Fi** connectivity
  - **USB hub** with possibility to extend connectivity possibilities
  - **Offered as development system** and not as final product

- 2.**Extended GW** for customers wanted to integrate e-motor directly into existing monitoring system or developers
  - IoT GW **“bridge”**
  - WEB CAN **sniffer**
  - Firmware download (**OTA**)

- 3. **Cloud** enabled solution
  - **Mobile and LoWPAN** connectivity solutions (LoRa, NB-IoT, SigFox …)
  - Communication with **MQTT, AMQP** protocol
  - Support for **Private cloud**
  - Support for **Public or Hybrid cloud**
  - Improved security

The scope

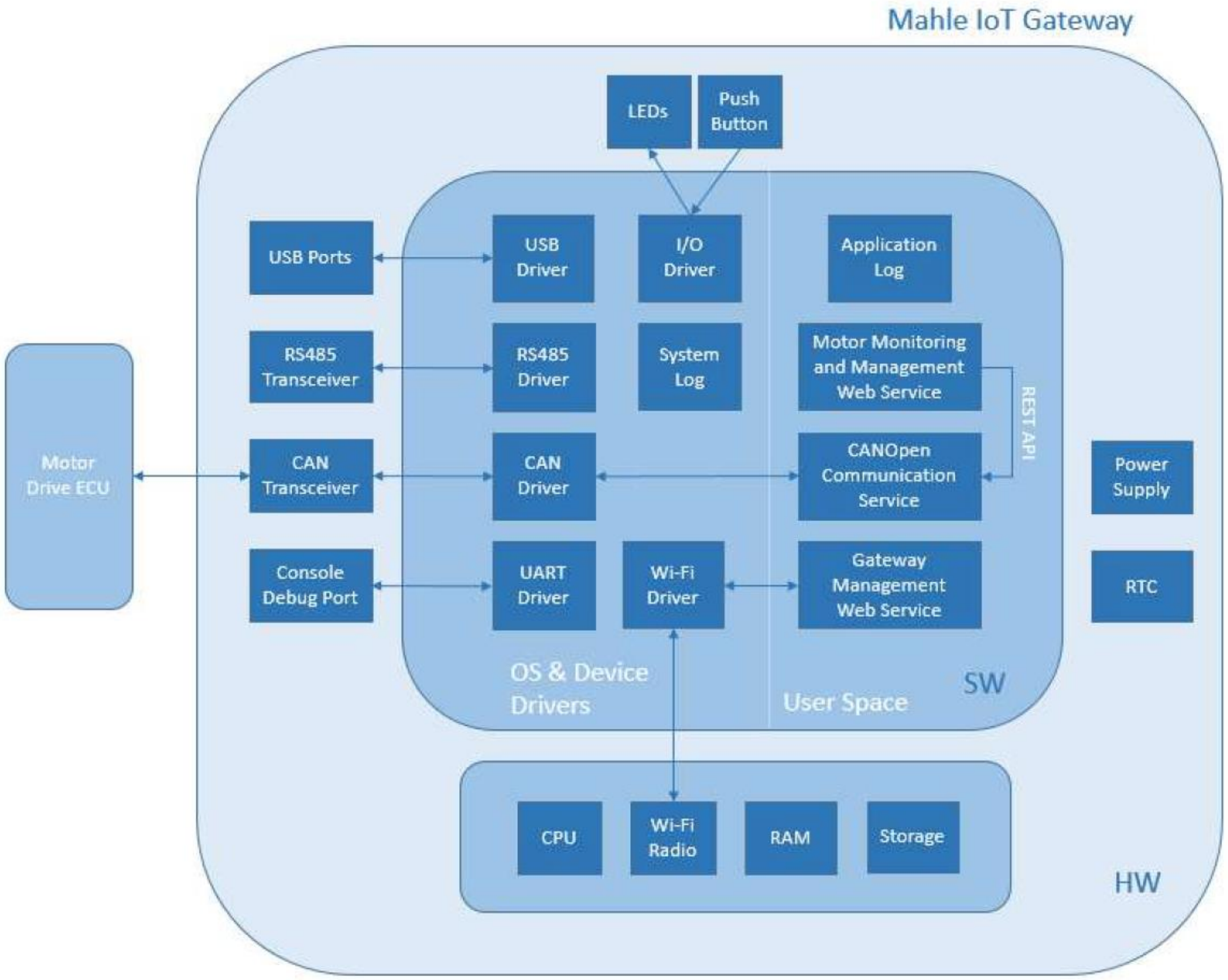
Basic requirements for 1.step

- Prototype was **developed as optional component** on e-motor
  - Separate **housing**
  - **Powered** from e-motor
  - Connected to existing **CAN interface**
  - Built-in **USB hub** for extending functions with off-the-shelf sensors/interfaces (GPS, additional storage)
- GW connectivity
  - Wireless interface via **Wi-Fi**
    - SSH access
    - Web client
  - **CAN** interface for e-motor connection
  - **RS-485** interface
  - Dedicated serial interface via on-board pins
- OS
  - **Standard Linux OS**
- HW
  - **Off-the-shelf uC** and custom periphery

Architecture

System architecture

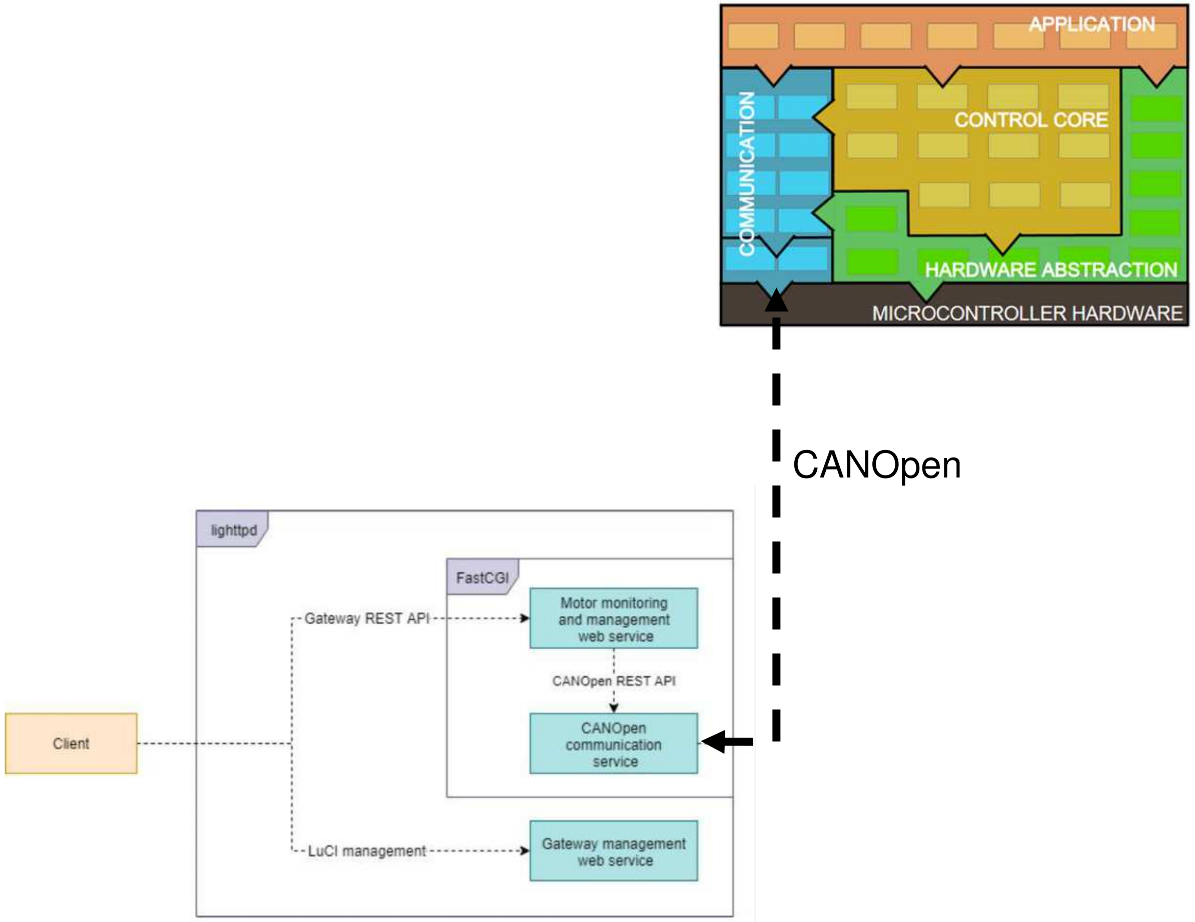
- GW is designed as development system design with all possible interfaces which can be later optimized for final product
  - Use of **SoC**
  - **Open source OS** is selected for SW platform
  - **Built-in WEB server** for presentation, configuration and control
  - Peripheral board with **USB hub with 4 ports**
  - **0.5 Mbps CAN interface**
  - **Wi-Fi in access or client mode**
  - **Battery supported RTC**
  - Separate **UART pins for direct console** access (115kbps)



Architecture

SW architecture

- **OpenWRT**/**LEDE** Linux framework for embedded devices (other options are Yocto or Buildroot)
- For GUI we use **Flask**/**Bottle frameworks and SQLite** relational DB for persistence
- For direct communication **CANOpen** service is used, which is also supported on MAHLE industrial e-motors
- For CANOpen implementation **CANOpen for Python** is used
- Majority of implementation is implemented with Python, only some selected parts which where not available in **Python** or need performance where implemented in **C**



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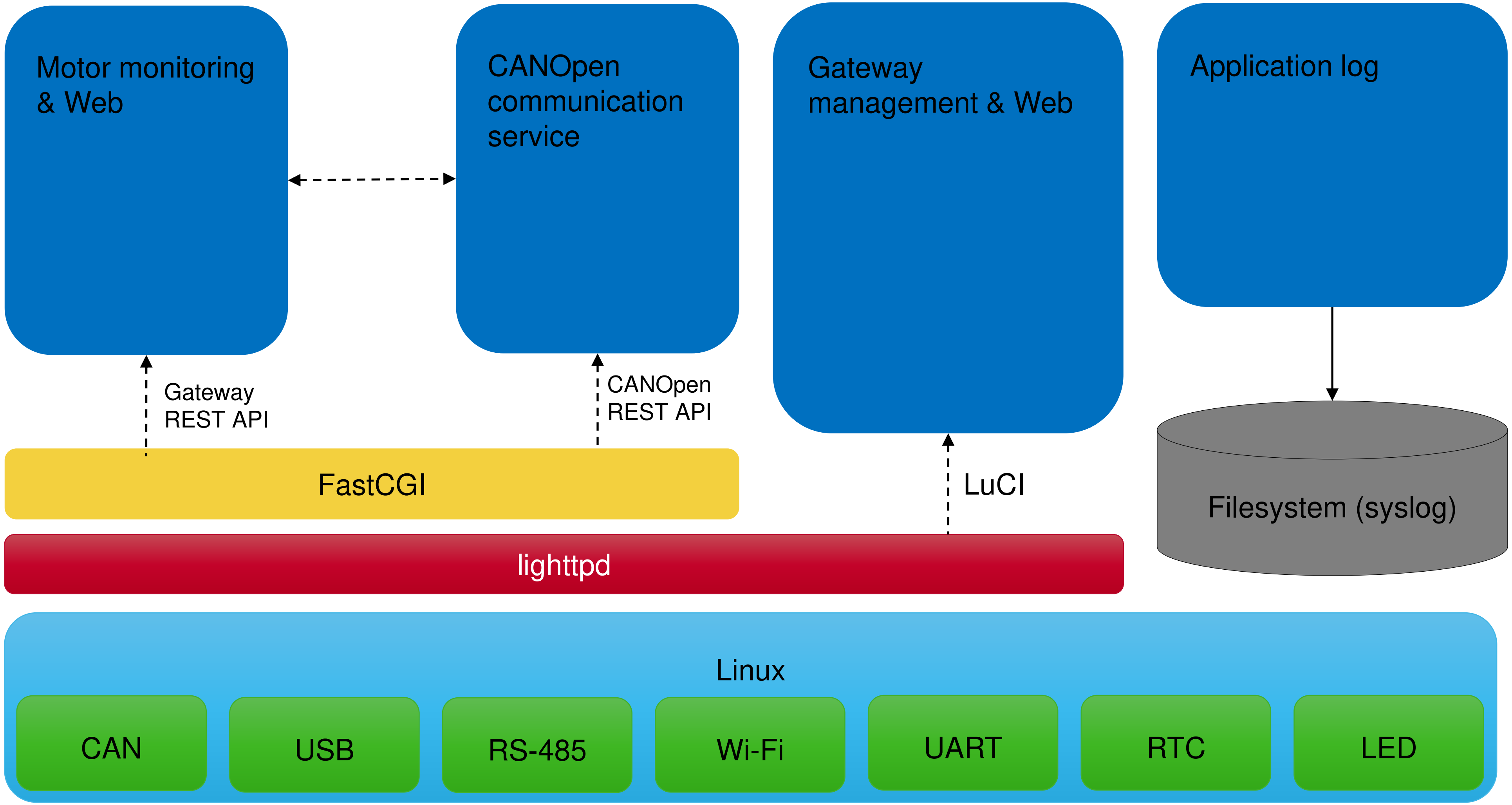
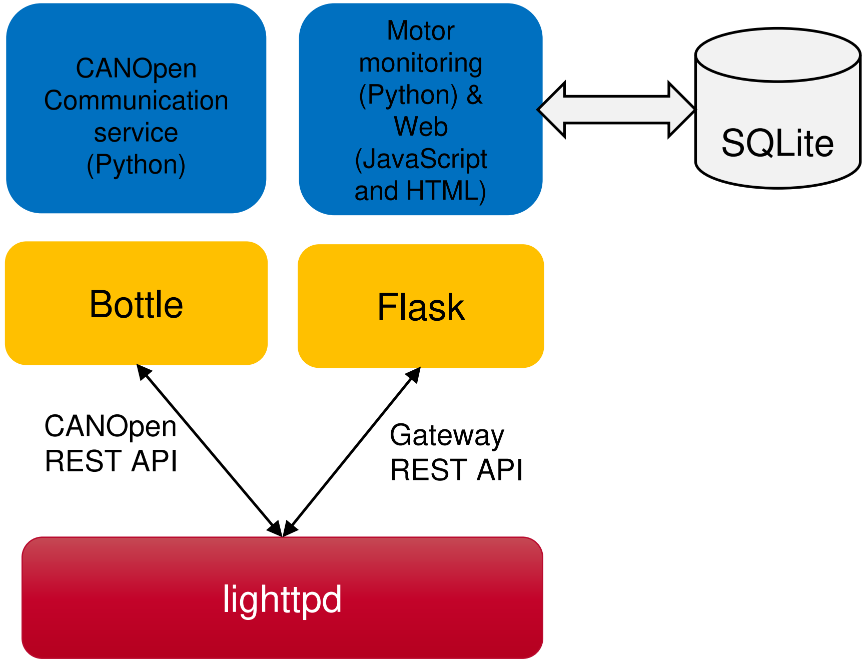
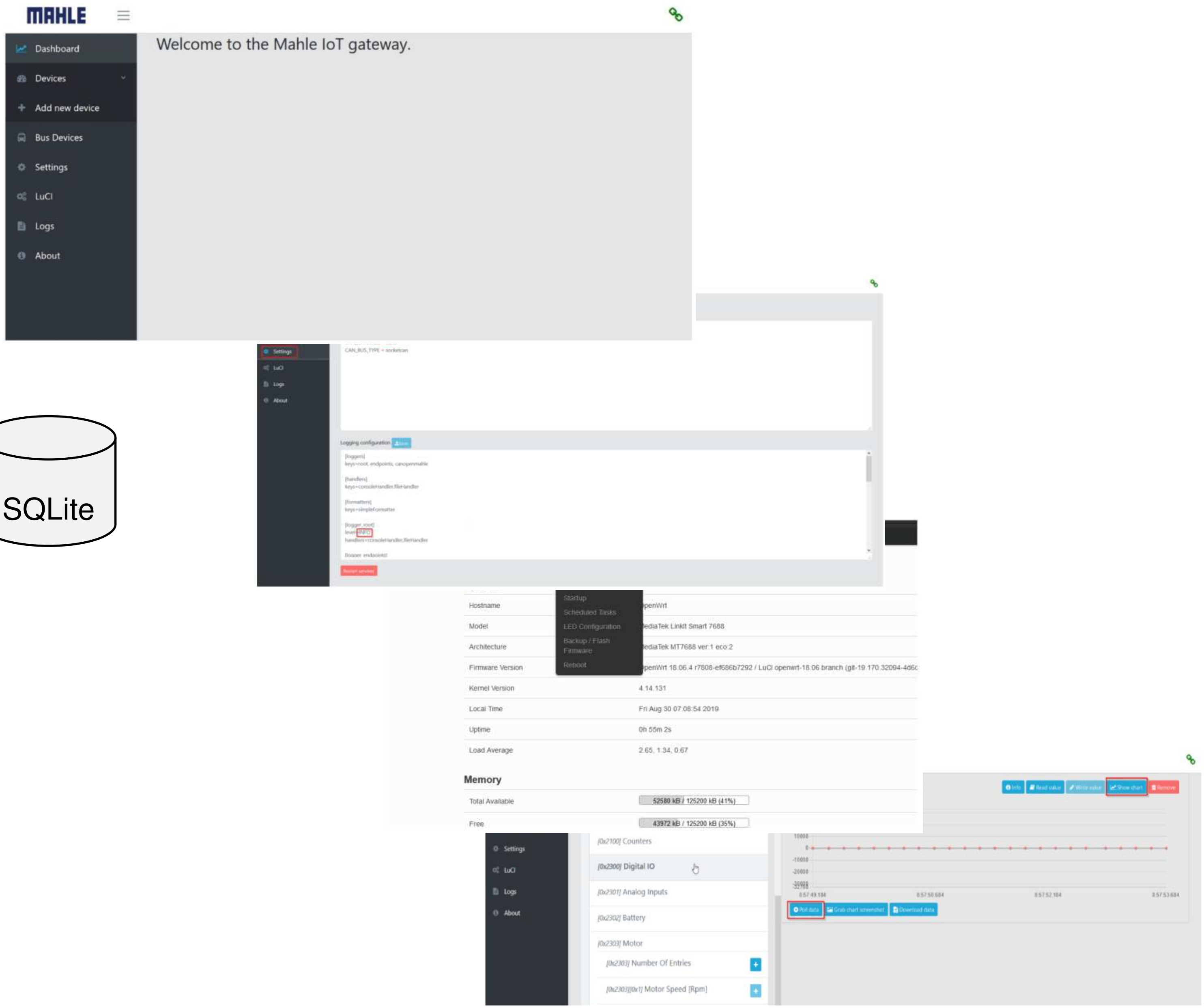
SW static view (components and interfaces)



GUI


CANOpen Communication service (Python)
Motor monitoring (Python) & Web (JavaScript and HTML)
SQLite
Bottle
Flask
CANOpen REST API
Gateway REST API
lighttpd



Welcome to the Mahle IoT gateway.

```
CAN_BUS_TYPE = socketcan
```

```
[loggers]
keys=root, endpoints, canopenmahle

[handlers]
keys=consoleHandler,fileHandler

[formatters]
keys=simpleFormatter

[logger_root]
level=INFO
handlers=consoleHandler,fileHandler

[logger_endpoints]
```

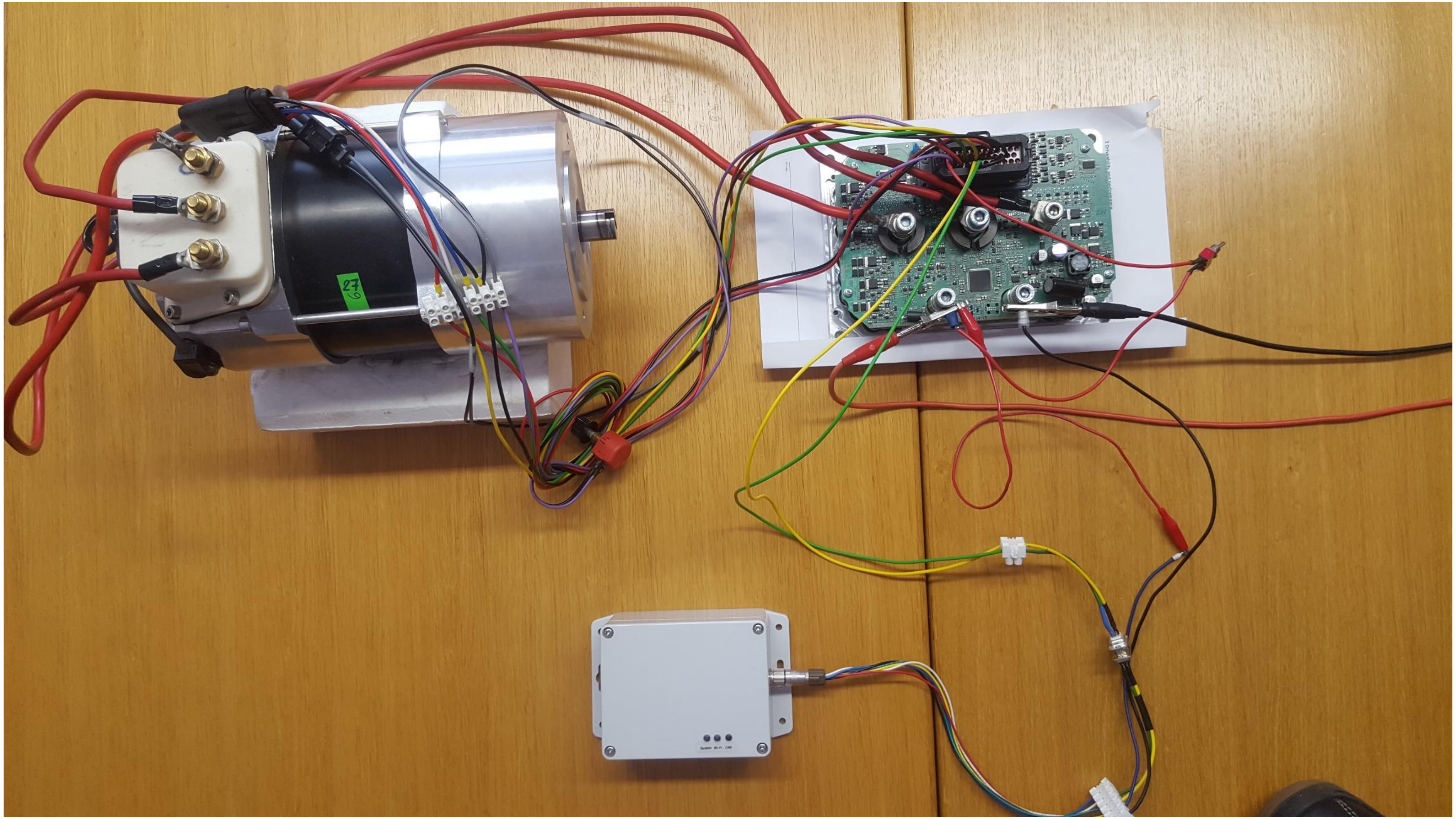
Hostname	OpenWrt
Model	MediaTek LinkIt Smart 7688
Architecture	MediaTek MT7688 ver:1 eco:2
Firmware Version	OpenWrt 18.06.4 r7808-ef686b7292 / LuCI openwrt-18.06 branch (git-19.170.32094-4d6c
Kernel Version	4.14.131
Local Time	Fri Aug 30 07:08:54 2019
Uptime	0h 55m 2s
Load Average	2.65, 1.34, 0.67

Memory

Total Available	52580 kB / 125200 kB (41%)
Free	43972 kB / 125200 kB (35%)

- [0x2100] Counters
- [0x2300] Digital IO
- [0x2301] Analog Inputs
- [0x2302] Battery
- [0x2303] Motor
  - [0x2303] Number Of Entries
  - [0x2303][0x1] Motor Speed [Rpm]

Setup with e-motor



2nd step: “CAN bridge” extension

Feature set

- **CAN bridge**
  - GW acting like transparent bridge for CAN protocol over TCP/IP network (CANOpen over TCP)
  - Adaptation of existing System Monitor connectivity to GW

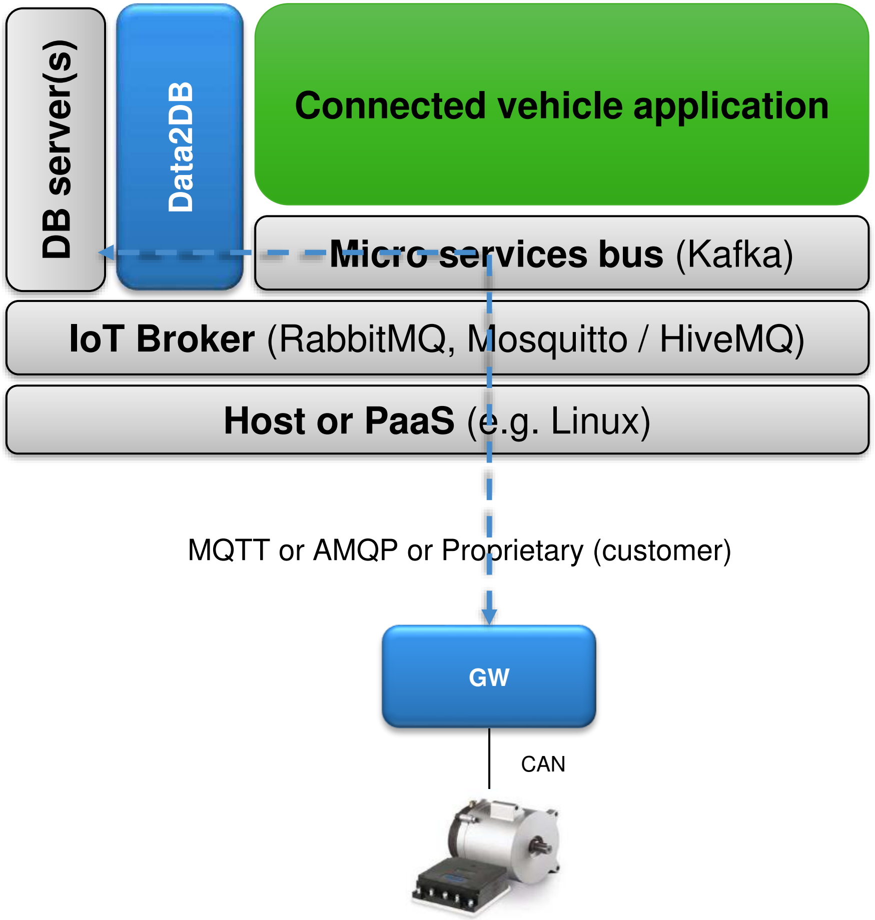
- **Web CAN sniffer**
  - Implementation of the backend service software around the “candump utils” toolset
  - Implementation of the frontend web interface (sniffer settings, limited live web view, dumping to file)
  - Use of existing SD card for short time storage (dump files)

- **Firmware downloader**
  - OTA firmware update feature for upgrading e-motor via GUI or REST API

3rd step: Cloud edition

Features

- **Cloud solution shall be agnostic to location or platform**
  - It can be completely at customer premises or by PaaS provider (AWS, Azure, …)
- **IoT Broker** shall be well established communication protocol **based on widely accepted standard**
  - MQTT 3.1.1. (ISO/IEC 20922) compatible broker for clients with low internal resources (power, CPU, memory, storage)
  - AMQP broker for high end clients
- **Message bus for easy service provisioning** (large support in community)
  - Kafka for high-speed and high reliable communication
  - RabbitMQ (AMQP) for large scale deployments (high scalability options)
  - Mosquitto/HiveMQ (MQTT) for starting deployments
- **Storage**
  - Relational DB for managing business part of solution
  - NoSQL DB for series data delivered by IoT node (data periodically delivered equipped with timestamp)
- **Presentation & Integrability**
  - REST based cloud application easily upgraded for graphical presentation requested for mobile terminals (phone, tablet), computers (PC, laptop) or translation for exporting the data to other form (integration into other clouds).


DB server(s)
Data2DB
Connected vehicle application
Micro services bus (Kafka)
IoT Broker (RabbitMQ, Mosquitto / HiveMQ)
Host or PaaS (e.g. Linux)
MQTT or AMQP or Proprietary (customer)
GW
CAN

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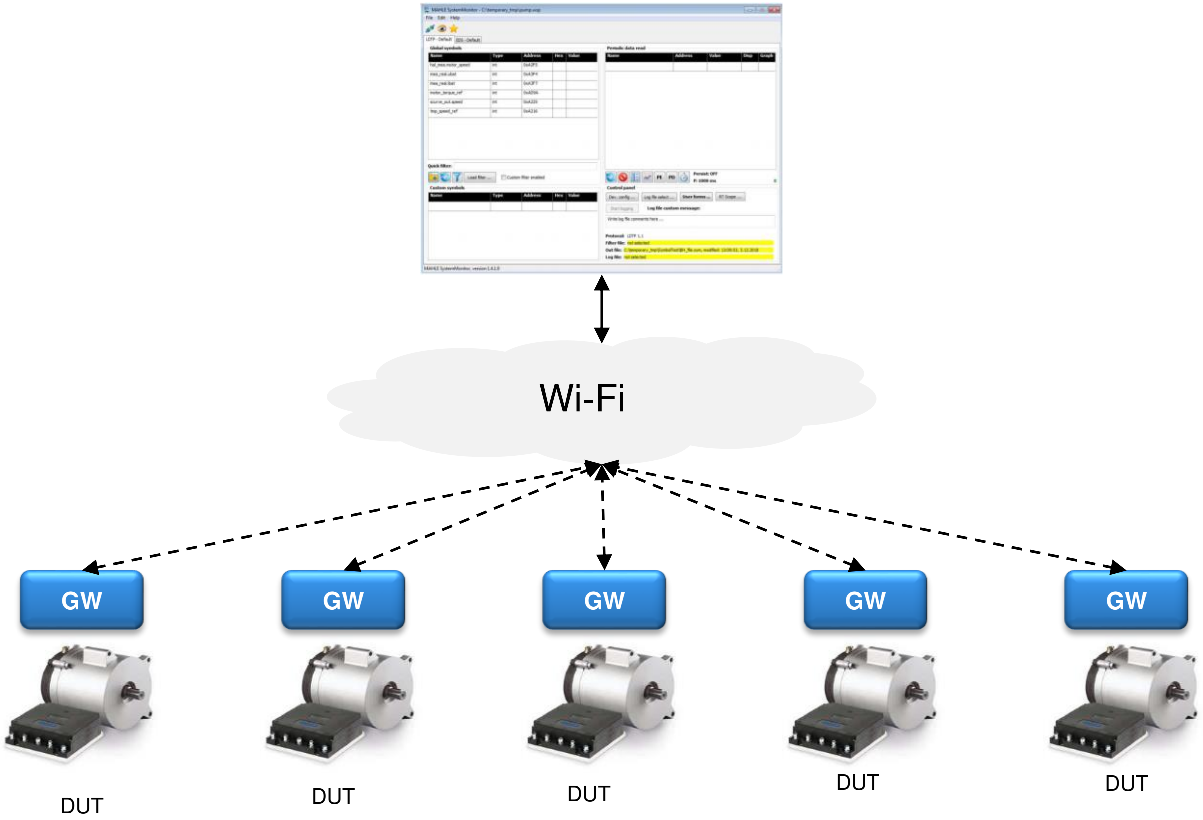
Support for testing

Use cases

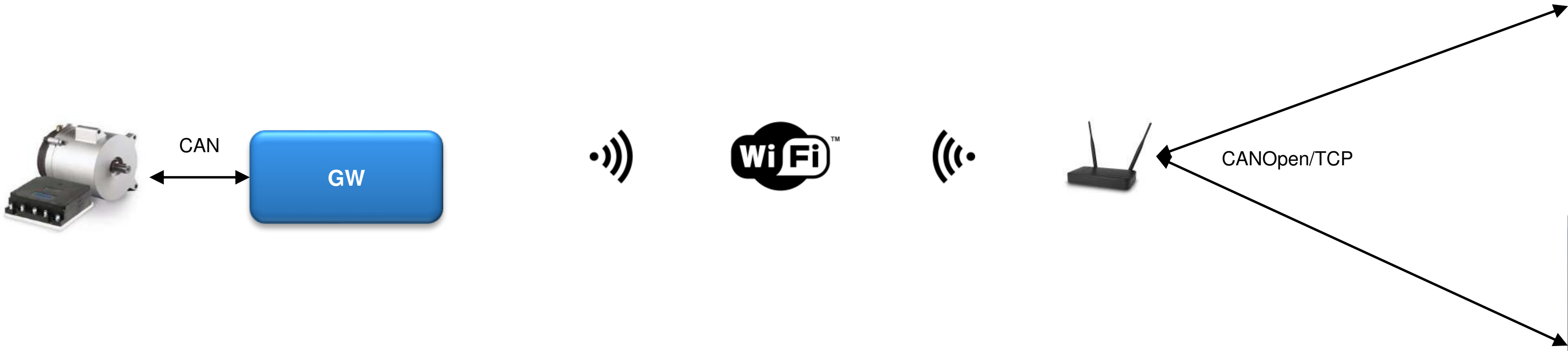
- Help for developers (CAN bridge)
  - Thermal cycling where we connect several e-motors and execute repeatable tests for several months

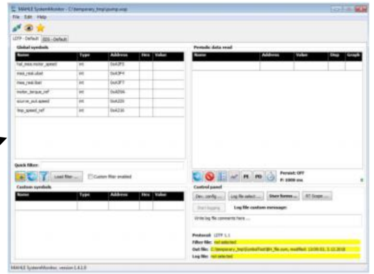


Support for developers

CAN Bridge

- Developing and monitoring test setup in area covered by Wi-Fi network
  - Equipped fork-lifters in real applications and collecting data via internal Wi-Fi network
  - Replacement for more expensive tools (E.g. Vector VN devices) and support for local tools due to open API
  - Remote monitoring via internal network





Global symbols

Name	Type	Address	Hex	Value
hal_meas.motor_speed	int	0x42F5		
meas_real.ubat	int	0x42F4		
meas_real.ibat	int	0x42F7		
motor_torque_ref	int	0x4204		
source_out.speed	int	0x4220		
trip_speed_ref	int	0x4216		

Periodic data read

Name	Address	Value	Disp	Graph

Quick filter:

□ Custom filter enabled

Custom symbols

Name	Type	Address	Hex	Value

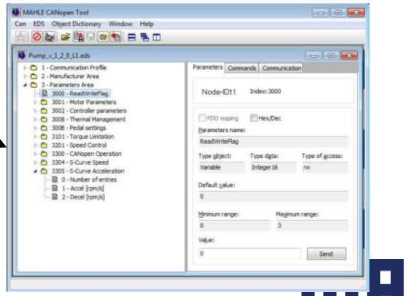
Persist: OFF
P: 1000 ms

Control panel

Log file custom message:
Write log file comments here ...

Protocol: LDTP 1.1
Filter file: not selected
Out file: C:\temporary_tmp\ComboTest\[illegible] file.csm, modified: 13:09:01, 3.12.2018
Log file: not selected

MAHLE SystemMonitor, version 1.4.1.0



Node-ID11 Index: 3000

□ PDO maping □ Hex/Dec

Parameters name: ReadWriteFlag

Type object: Variable
Type data: Integer16
Type of access: rw

Default value: 0

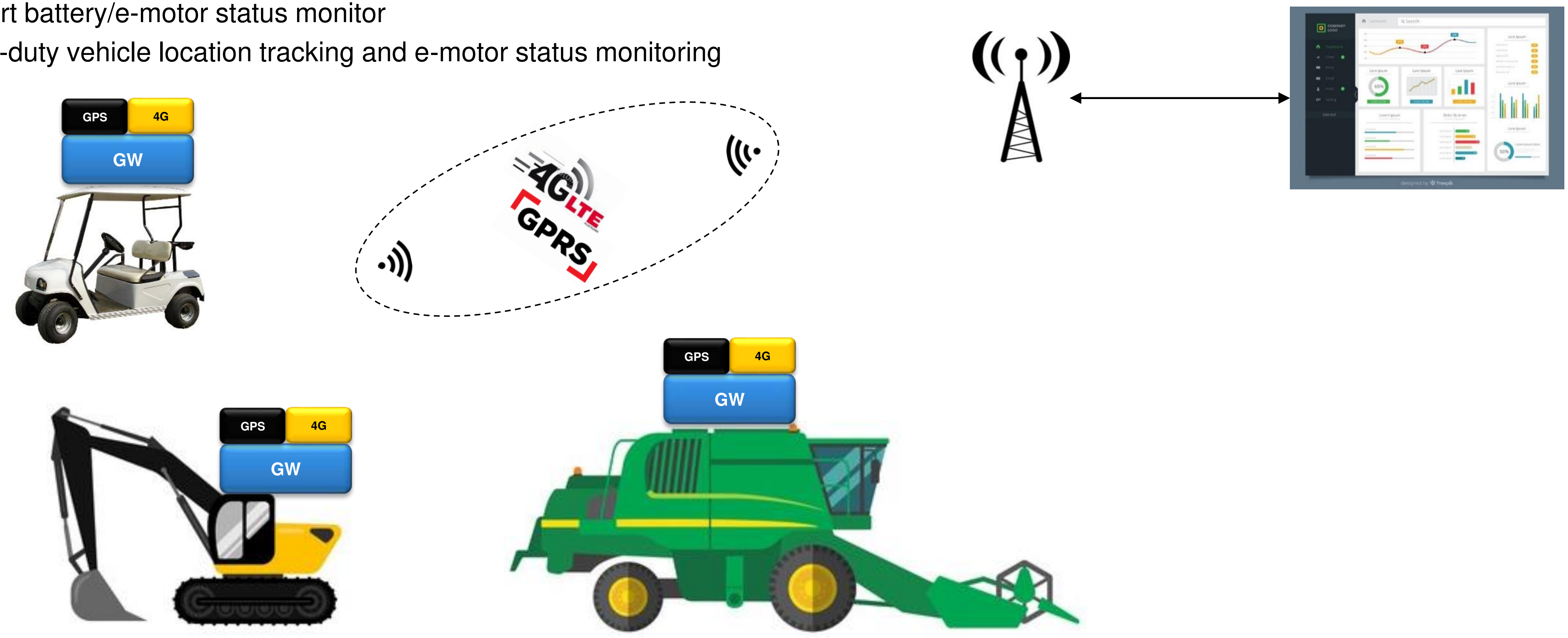
Minimum range: 0
Maximum range: 3

Value: 0

Customer support

Geofencing

- Remote vehicle monitoring for defects
  - Golfcart battery/e-motor status monitor
  - Heavy-duty vehicle location tracking and e-motor status monitoring



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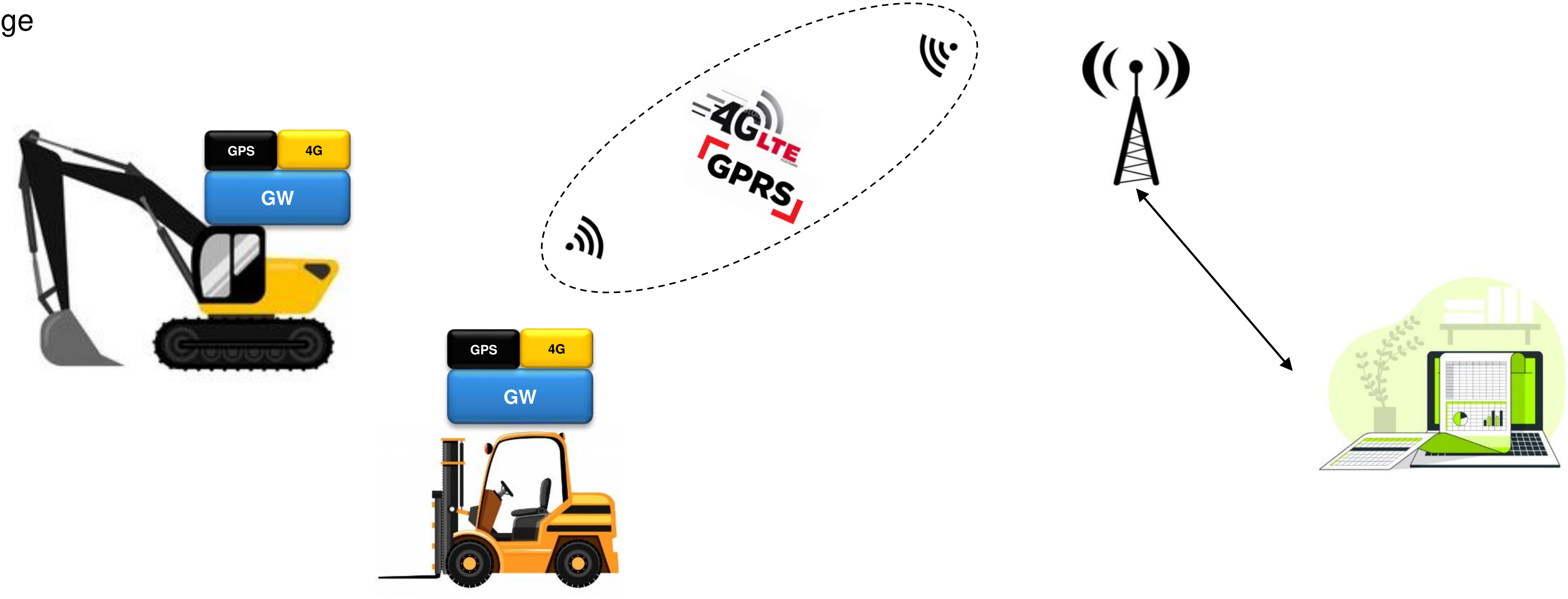
Customer support

Usage monitoring

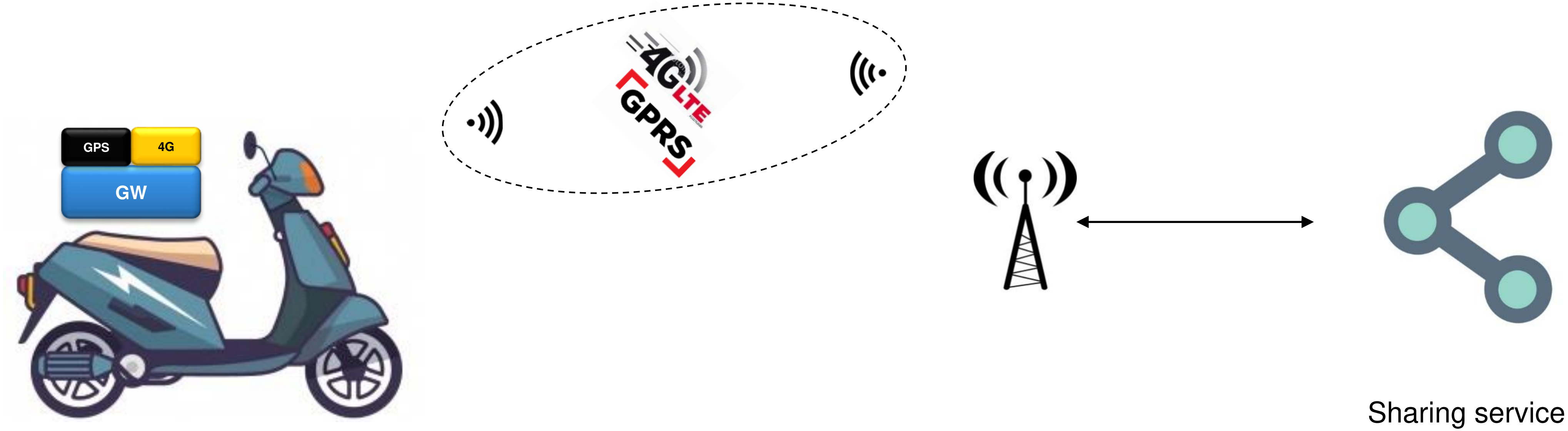
- Renting heavy-duty vehicle tracking and logging
- Renting forklift usage



Customer support

Sharing

- Locking/Unlocking (inhibition) access after registration on service portal
- Geofencing to prevent steal
- E-motor status control (battery, vehicle health)



Sharing service portal

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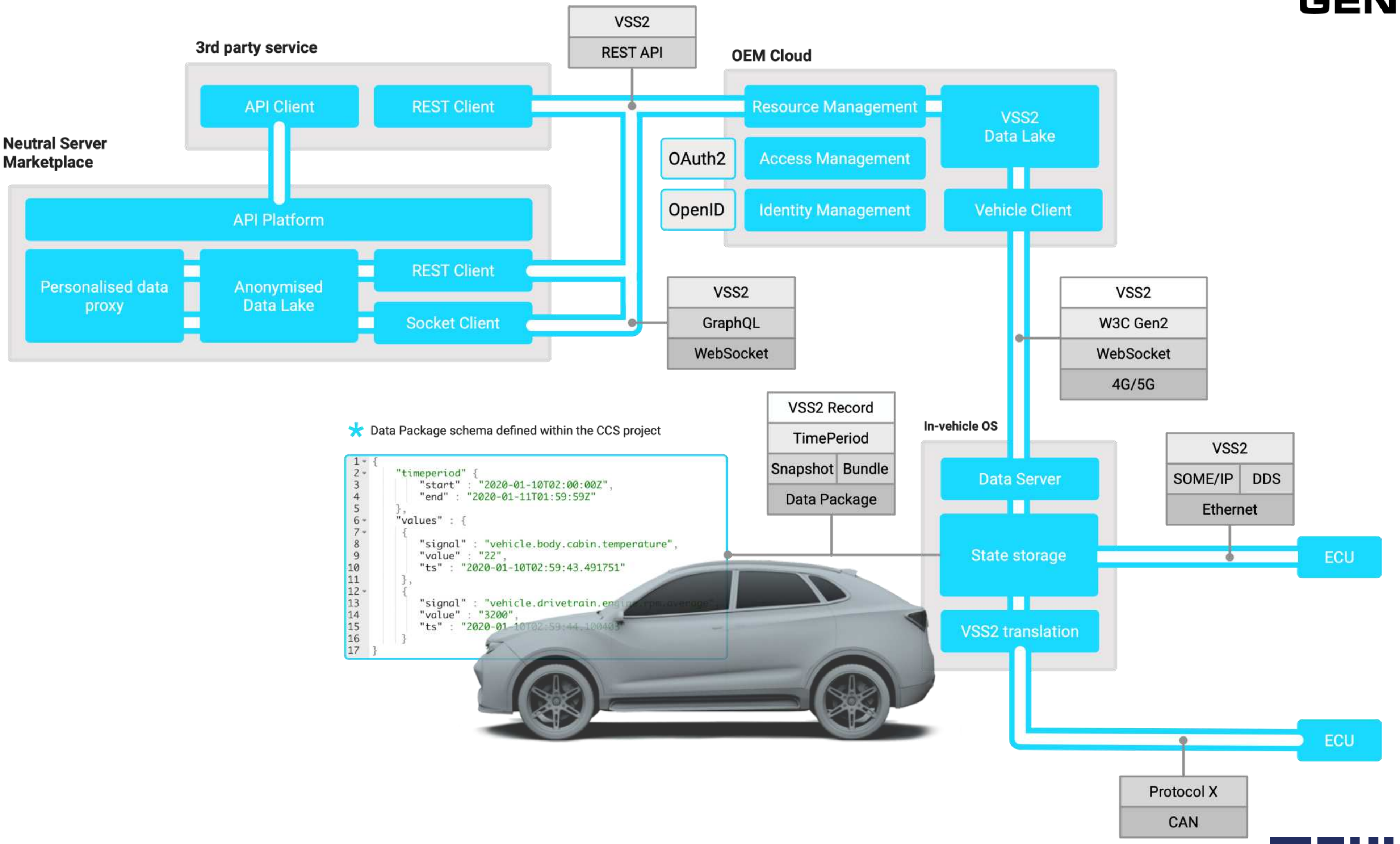
Aftermarket support

Connected vehicles



* Data Package schema defined within the CCS project

```
{
    "timeperiod" {
        "start" : "2020-01-10T02:00:00Z",
        "end" : "2020-01-11T01:59:59Z"
    },
    "values" : {
     {
        "signal" : "vehicle.body.cabin.temperature",
        "value" : "22",
        "ts" : "2020-01-10T02:59:43.491751"
     },
     {
        "signal" : "vehicle.drivetrain.engine.rpm.average",
        "value" : "3200",
        "ts" : "2020-01-10T02:59:44.100403"
     }
}
```

Aftermarket support

Predictive maintenance

- Predictive maintenance based on history data
  - Filtering huge amounts of data
  - Defining what we want to achieve
  - Prevent the failures before they occur
  - Build knowledge based on actions from history
  - Build competence by helping customers solving their problems