

ISOCS

IoT Technologies for Distributed Sensing

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ISOCS

International Society for
Olfaction and Chemical Sensing

Definition (Wikipedia):

„The Internet of Things (IoT) describes physical objects (or groups of such objects) with **sensors, processing ability**, software and other technologies that **connect and exchange data** with other devices and systems over the Internet or other communications networks.

Internet of things has been considered a misnomer because devices do not need to be connected to the public internet, they only need to be connected to a network and be individually addressable.”

Smart devices connected to a network

Basics: Communication technologies

Distributed sensing networks

- Wired Ethernet, Fieldbus, RS485, I2C, ...
- Wireless
 - Wifi / Bluetooth / GSM/UMTS/LTE/G5 / ZWave/Zigbee/Thread / 433MHz / LoRa / 6LowPAN / RFID/ IRDA / 802.15.4

Communication protocols

- TCP/IP / Zigbee / Thread / Matter
- The Things Network

Figures of Merit for networks

Throughput / bandwidth

Range (max cable range, coverage of wireless network)

Max devices adressable

Power demand (on device)

Real time / guaranteed delivery time

Security / Secrecy

Fault tolerance / redundancy

Topology (P2P / Bus / Star / Mesh)

Fieldbuses for Control systems

Broad range of fieldbuses is used!

Analog interfaces: 4-

20mA,

0..10V,

digital,

...

Fieldbus	Bus power	Cabling redundancy	Max devices	Synchronisation	Sub millisecond cycle
AFDX	No	Yes	Almost unlimited	No	Yes
AS-Interface	Yes	No	62	No	No
CANopen	No	No	127	Yes	No
CompoNet	Yes	No	384	No	Yes
ControlNet	No	Yes	99	No	No
CC-Link	No	No	64	No	No
DeviceNet	Yes	No	64	No	No
EtherCAT	Yes	Yes	65,536	Yes	Yes
Ethernet Powerlink	No	Optional	240	Yes	Yes
EtherNet/IP	No	Optional	Almost unlimited	Yes	Yes
Interbus	No	No	511	No	No
LonWorks	No	No	32,000	No	No
Modbus	No	No	246	No	No
PROFIBUS DP	No	Optional	126	Yes	No
PROFIBUS PA	Yes	No	126	No	No
PROFINET IO	No	Optional	Almost unlimited	No	No
PROFINET IRT	No	Optional	Almost unlimited	Yes	Yes
SERCOS III	No	Yes	511	Yes	Yes
SERCOS interface	No	No	254	Yes	Yes
Foundation Fieldbus H1	Yes	No	240	Yes	No
Foundation HSE	No	Yes	Almost unlimited	Yes	No
RAPIDnet	No	Yes	256	Under Development	Conditional
Fieldbus	Bus power	Cabling redundancy	Max devices	Synchronisation	Sub millisecond cycle

Fieldbus vs IoT

Fieldbus	IoT
Typical Applications	
Industrial automation Motor control / Automotive	Distributed sensing Monitoring Home automation
Typical Requirements	
Reliability Deterministic (fast) timing	Scalability Interoperability Low Cost

Communicaton: Wireless Networks

Type	Range	Power (on node)	Bandwidth	Topology	Cost
UMTS/LTE/5G	km / wide coverage	high	Very high	Star	high
Wifi	10-100m	high	Very high	Star (mesh)	low
Bluetooth LE	10-100m	Very low	Low	Star, p2p, mesh	low
LoraWAN	2km / wide coverage	Very low	Very low	Star	low
802.15.4 e.g. Zigbee	10-100m	Very low	Low	Mesh	low
RFID / NFC	1m	Very low / passive	Bytes on demand	p2p	Very low



matter



Bluetooth®



Communication Bluetooth BLE

Bluetooth LE Explorer













Discover

Start Enumeration finished

Continuous Enumeration

Filter:

Total Device Count: 19

 RSSI: -53 Name: BT Address: 7f:b5:bb:fe:23:63 Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: -64 Name: BT Address: 7d:a4:c5:c1:98:f6 Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: -71 Name: BT Address: 4e:cd:a7:24:4f:4a Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: Name: BT Address: 66:bc:37:22:10:3 Connected: False Last Seen: 1/17/2023 9 Pair
 RSSI: -81 Name: BT Address: 1c:1f:f1:9c:df:7f Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: -82 Name: BT Address: 5d:9a:1e:92:66:76 Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: -83 Name: BT Address: 6c:77:dd:8d:00:93 Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: Name: BT Address: 41:b3:6d:b0:b2: Connected: False Last Seen: 1/17/2023 9 Pair
 RSSI: -86 Name: BT Address: Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: -87 Name: BT Address: Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: -88 Name: BT Address: Connected: False Last Seen: 1/17/2023 9 Pair	 RSSI: Name: BT Address: Connected: False Last Seen: 1/17/2023 9 Pair

Bluetooth LE Explorer

Device Services Page

BT Address: 7f:b5:bb:fe:23:63
Number of Services: 5
Number of service changed events: 5
Number of Advertisement Services: 0
BT 4.2 Secure Connection: False
Device Connected: True

Refresh

Start Transaction

Service Name: **GenericAttribute**
Service UUID: 00001801-0000-1000-8000-00805f9b34fb
Characteristic Name: **ServiceChanged** - Characteristic Short UUID: **0x2A05** - User Description: - Handle: **7** - **0x00000007** - Value: **Read Not Permitted**

Service Name: **d0611e78-bbb4-4591-a5f8-487910ae4366**
Service UUID: d0611e78-bbb4-4591-a5f8-487910ae4366
Characteristic Name: **8667556c-9a37-4c91-84ed-54ee27d90049** - Characteristic Short UUID: - User Description: - Handle: **11** - **0x0000000B** - Value: **Read Not Permitted**

Service Name: **9fa480e0-4967-4542-9390-d343dc5d04ae**
Service UUID: 9fa480e0-4967-4542-9390-d343dc5d04ae
Characteristic Name: **af0badb1-5b99-43cd-917a-a77bc549e3cc** - Characteristic Short UUID: - User Description: - Handle: **16** - **0x00000010** - Value: **Read Not Permitted**

Service Name: **DeviceInformation**
Service UUID: 0000180a-0000-1000-8000-00805f9b34fb
Characteristic Name: **ManufacturerNameString** - Characteristic Short UUID: **0x2A29** - User Description: - Handle: **21** - **0x00000015** - Value: **Apple Inc.**
Characteristic Name: **ModelNumberString** - Characteristic Short UUID: **0x2A24** - User Description: - Handle: **23** - **0x00000017** - Value: **Watch3,4**

Communication LoraWAN

The screenshot shows a web browser window with the URL <https://www.thethingsnetwork.org/map>. The page features a navigation menu with items like JLM, Home, News, Read, Projects, Shops, docker, Email, Travel, Music, and Medicconnect. A search bar contains 'things net'. A 'Login' button is visible in the top right. The main content is a map of the Alpine region with several blue dots representing gateways. A search bar at the top of the map says 'Enter address'. A tooltip for a specific gateway displays the ID: `neui-58a0cbffe80200a`. The map includes zoom controls and various geographical labels. At the bottom, it says 'LoRa Alliance Member' and 'LoRaWAN® is a mark used under license from the LoRa Alliance®'.

Overview - jlm-ttn-gateway - TTT X msftconnecttest.com/?tok=6894d3c X

https://eu1.cloud.thethings.network/cons

JLM Home News Read Projects Shops docker Email Travel Music Mediconnect Weitere Lesezeichen

THE THINGS NETWORK THE THINGS STACK Community Edition

Gateways > jlm-ttn-gateway

jlm-ttn-gateway
ID: jlm-ttn-gateway

Disconnected ⓘ 2 Collaborators 2 API keys

General information

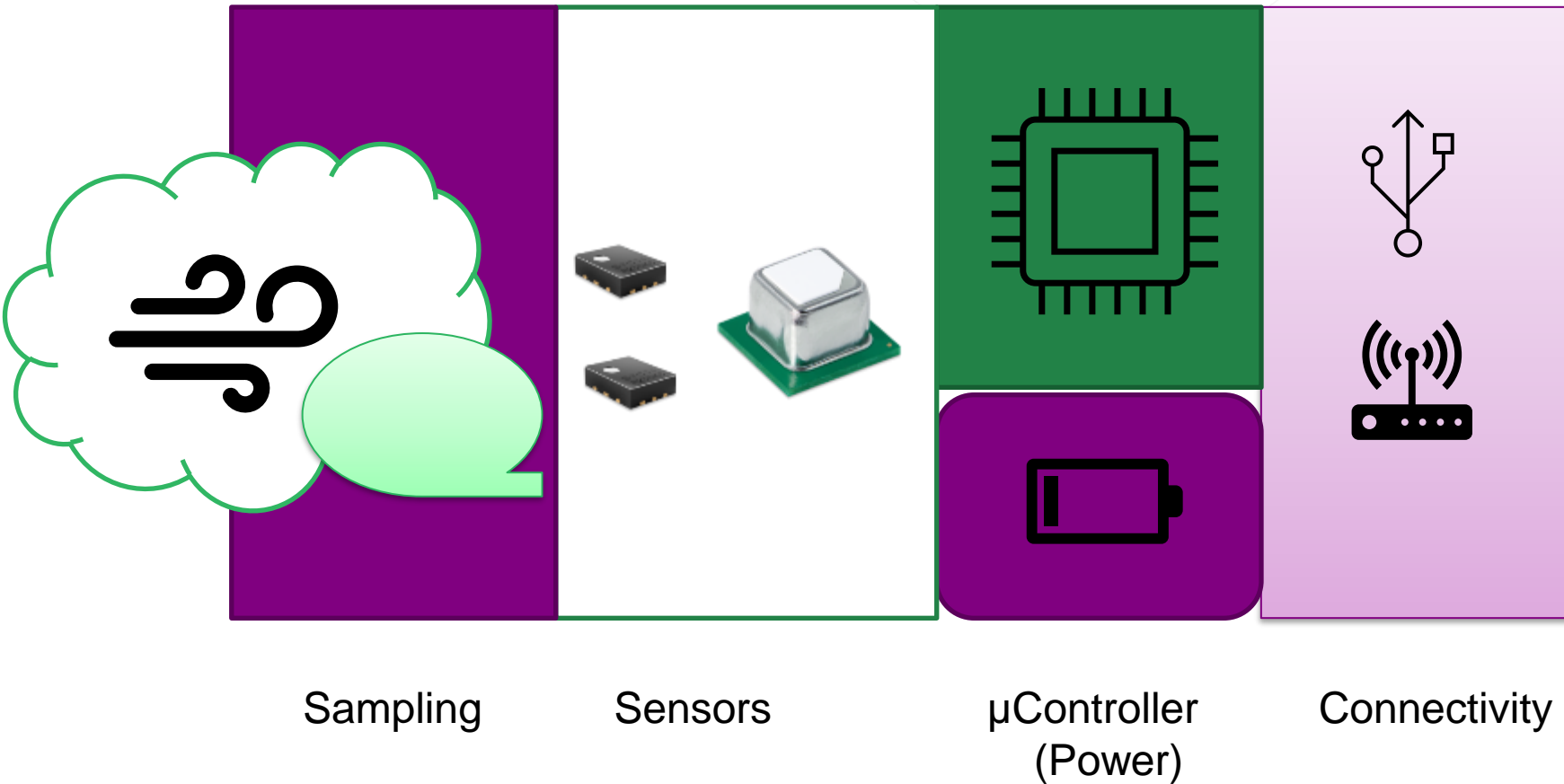
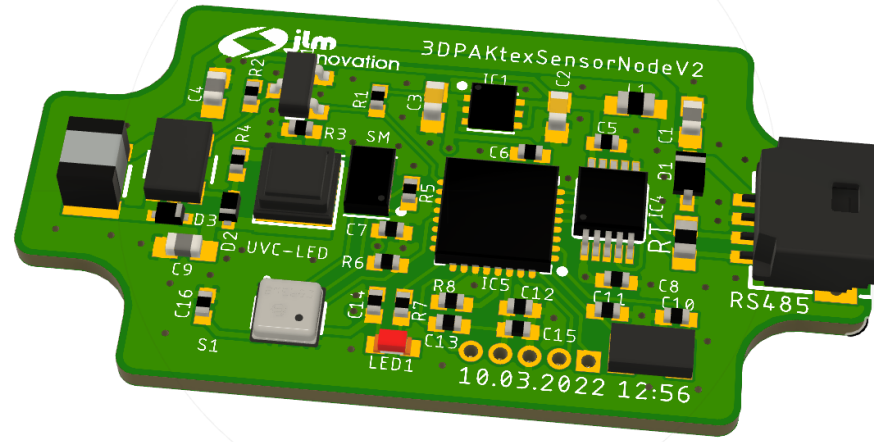
Gateway ID	jlm-ttn-gateway
Gateway EUI	58 A0 CB FF FE 80 11 70
Gateway description	None
Created at	Jan 12, 2022 14:21:22
Last updated at	Dec 29, 2022 12:56:21
Gateway Server address	eu1.cloud.thethings.network

Smart Sensor Trends



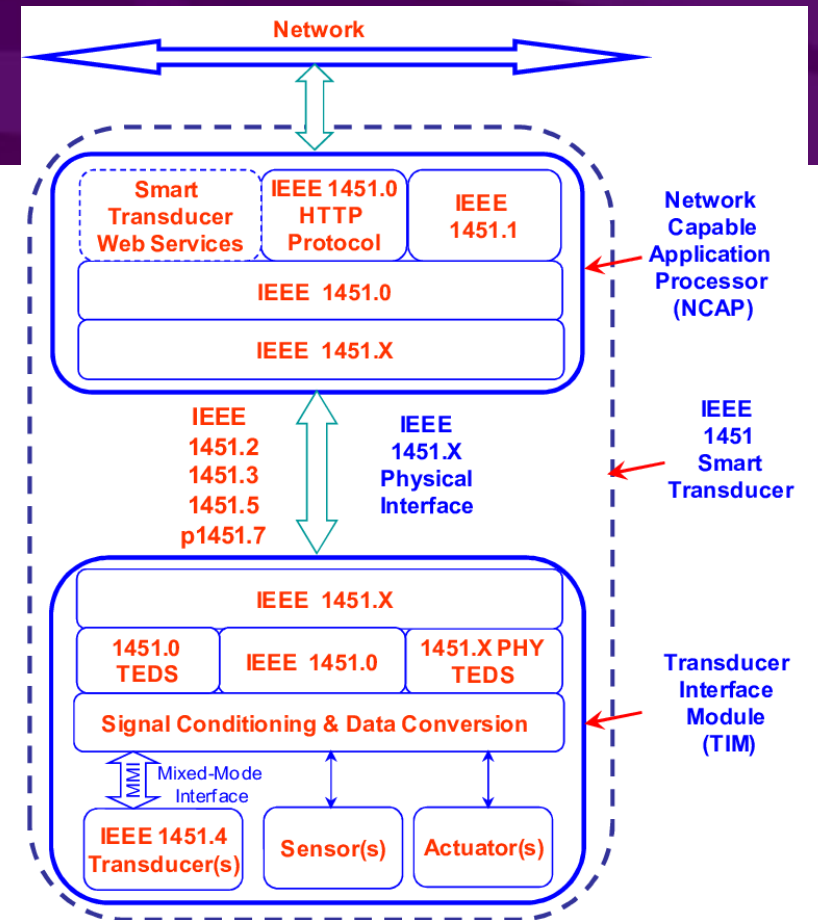
- Miniaturization
 - Lower Size, Lower Power Consumption, Lower Cost
- Integration
 - Combination of different sensors in one package (e.g. BME-680, SCD-41, SEN-5x)
 - New sensor types through combination of technologies (e.g. photoacoustic sensors with MEMS microphones)
- Software
 - More complex algorithms
 - Product diversification via firmware / operation modes

Sensor Nodes



IEEE 1451 smart transducers

- **1451.0–2007** Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats
- **1451.1–1999** Network Capable Application Processor Information Model
- **1451.2-1997** Transducer to Microprocessor Communication Protocols & TEDS Formats
- **1451.3-2003** Digital Communication & TEDS Formats for Distributed Multidrop Systems
- **1451.4-2004** Mixed-Mode Communication Protocols & TEDS Formats
- **1451.5-2007** Wireless Communication Protocols & Transducer Electronic Data Sheet (TEDS) Formats
- **1451.7-2010** Transducers to Radio Frequency Identification (RFID) Systems Communication Protocols and Transducer Electronic Data Sheet Formats



T. C. O'Reilly *et al.*, "Instrument interface standards for interoperable ocean sensor networks," *OCEANS 2009-EUROPE*, Bremen, Germany, 2009, pp. 1-10, doi: 10.1109/OCEANSE.2009.5278251. <https://ieeexplore.ieee.org/document/5278251/>

An IoT Environment



Distributed Nodes



Message communication

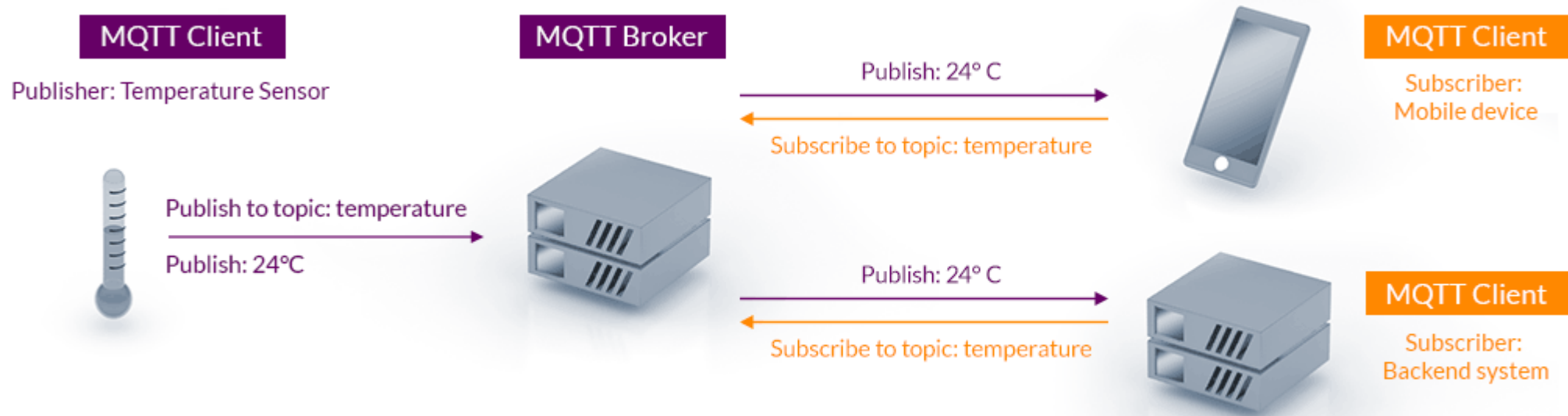


Application Layer / User Interface

MQTT is an **OASIS standard** messaging protocol for the Internet of Things (IoT). It is designed as an **extremely lightweight publish/subscribe** messaging transport that is ideal for connecting remote devices with a **small code footprint** and **minimal network bandwidth**. MQTT today is used in a wide variety of industries, such as automotive, manufacturing, telecommunications, oil and gas, etc.

Source: <https://mqtt.org/>

What is MQTT?



Main Properties:

Lightweight and Efficient

Scale to Millions of Things

Support for Unreliable Networks

Bi-directional Communications

Reliable Message Delivery

Security Enabled

MQTT Explorer

The screenshot displays the MQTT Explorer application window. The main interface includes a menu bar (Application, Edit, View), a search bar, and a 'DISCONNECT' button. A sidebar on the left lists several MQTT connections: 'iotserver' (selected), 'novis-redwine', 'HomeIoT', 'mqtt.eclipse.org', and 'test.mosquitto.org'. A modal window titled 'MQTT Connection' is open, showing configuration for the 'iotserver' connection. The modal includes fields for Name, Protocol, Host, and Port, as well as toggle switches for 'Validate certificate' and 'Encryption (tls)'. At the bottom of the modal are buttons for 'DELETE', 'ADVANCED', 'SAVE', and 'CONNECT'. A 'PUBLISH' button is visible in the bottom right corner of the application window.

MQTT Explorer

Application Edit View

MQTT Explorer Search...

DISCONNECT

Connections

- iotserver
mqtt://192.168.3.11:1883/
- novis-redwine
mqtt://novis-redwine.de:8883/
- HomeIoT
mqtt://homeIoT:1883/
- mqtt.eclipse.org
mqtt://mqtt.eclipse.org:1883/
- test.mosquitto.org
mqtt://test.mosquitto.org:1883/

MQTT Connection mqtt://192.168.3.11:1883/

Name iotserver

Validate certificate

Encryption (tls)

Protocol Host Port

mqtt:// 192.168.3.11 1883

Username Password

DELETE ADVANCED SAVE CONNECT

PUBLISH

MQTT Topics

The screenshot shows the MQTT Explorer application window. The title bar reads "MQTT Explorer". The menu bar includes "Application", "Edit", and "View". The main interface has a dark teal header with a hamburger menu icon, the text "MQTT Explorer", a search bar with "Search...", a "DISCONNECT" button with a power icon, and a share icon.

The left pane shows a tree view of topics under the IP address "192.168.3.11". The tree is expanded to show the following structure:

- 192.168.3.11
 - homeassistant (20 topics, 20 messages)
 - awesome (4 topics, 4 messages)
 - ds18b20 (11 topics, 11 messages)
 - ws23_demo
 - debug = [0;36m[D][sensor:127]: 'MH-Z19 Temperature': Sending state ...
 - status = offline
 - sensor
 - workshop_co2 (1 topic, 1 message)
 - workshop_temperature (1 topic, 1 message)
 - workshop_humidity (1 topic, 1 message)
 - scd41_co2
 - state = 894
 - scd41_temperature (1 topic, 1 message)
 - scd41_humidity (1 topic, 1 message)
 - mh-z19_co2 (1 topic, 1 message)
 - mh-z19_temperature (1 topic, 1 message)
 - SSYS (38 topics, 320 messages)

The right pane shows the details for the selected topic "ws23_demo/sensor/scd41_co2/state". It includes a breadcrumb trail with buttons for each part of the path. Below this, there is a "Value" field with a document icon and an upward arrow. The value is "894". To the right of the value, it says "QoS: 0", "16.01.2023", and "12:05:48". A yellow "RETAINED X" button is visible. At the bottom of the right pane, there is a small input field with a checkmark icon and the value "894".

Topic: ws23_demo/sensor/scd41_co2/state

MQTT services / topics



Topics are hierarchically ordered



MQTT has 3 defined quality of service levels:

0 - at most once,
1 - at least once,
2 - exactly once



MQTT publish messages contain a flag to retain the data



Clients can subscribe to topics using wildcards

A range of ready to use services exists to connect various sources into MQTT

- Zigbee2MQTT
- ESP32-ble2mqtt

MQTT is supported by many automation systems
e.g. FHEM, OpenHab, Homeassistant

MQTT is easily integrated in Arduino, Python, C#, Java, ...

MQTT often directly supported by IOT devices (e.g. Tasmota, Shelly, ESPHome, ...)

IoT Tools Node Red

The screenshot displays the Node-RED web interface in a browser window. The address bar shows the URL `192.168.1.144:1880/#flow/add9f1628970bf16`. The interface includes a top navigation bar with a 'Übernahme (deploy)' button. On the left, there is a 'Nodes filtern' sidebar with categories like 'Allgemein' and 'Funktion'. The main workspace contains a flow for 'Paho Python Demo' with the following nodes: 'Sensor in' (purple), 'TestValues' (blue), 'debug input' (green), 'Extract SensorID' (yellow), 'Format Sensor ID' (orange), 'Influx Database' (brown), and 'debug output' (green). The flow is connected as follows: 'Sensor in' and 'TestValues' connect to 'debug input'. 'Sensor in' also connects to 'Extract SensorID'. 'TestValues' connects to 'Format Sensor ID'. 'Extract SensorID' connects to 'Format Sensor ID'. 'Format Sensor ID' connects to 'Influx Database'. 'Influx Database' connects to 'debug output'. The right sidebar shows an 'Info' panel with a search bar and a list of flows, including 'Paho Python Demo' and 'esphome Demo'. Below the list, the 'Paho Python Demo' flow is selected, showing its ID as 'add9f1628970bf16'.

Node-Red Dashboard

The dashboard is divided into two main sections: 'Aquarium' and 'Envy'.

Aquarium Section:

- Temperature 1:** A gauge showing a value of 21.19.
- Temperature 2:** A gauge showing a value of 14.56.
- pH:** A gauge showing a value of 15.11.
- Shelly:** A section with a 'RAINBOW' indicator and three toggle switches labeled 'switch', 'switch', and 'Jani LEDs On'.
- DS18B20:** A bar chart titled 'Temperature' showing data for 'ds18b20/sensor/temperature_8/state'.

Envy Section:

- Temperature:** No Data.
- Humidity:** No Data.
- MQ2:** No Data.
- Hue:** A toggle switch labeled 'Esszimmer'.

The dashboard is titled 'Multisensor' and contains four main visualizations:

- Temperature:** A line graph showing temperature fluctuations over a 24-hour period (22:00:00 to 23:00:00). The y-axis ranges from 16.5 to 18.
- Battery:** A gauge showing a battery level of 100.
- Humidity:** A line graph showing humidity fluctuations over a 24-hour period. The y-axis ranges from 62 to 68.
- Pressure:** A line graph showing pressure fluctuations over a 24-hour period. The y-axis ranges from 950 to 970.

IoT Tools: Time Series Databases InfluxDB2



Influx-DB is optimized to store data (typically JSON) with TimeTags



InfluxDB2 adds an optimized query language and integrates various services (e.g. Telegraph to automatically pull data from other sources).



Data can be separated by Organizations and Buckets



Buckets may contain different types of measurements



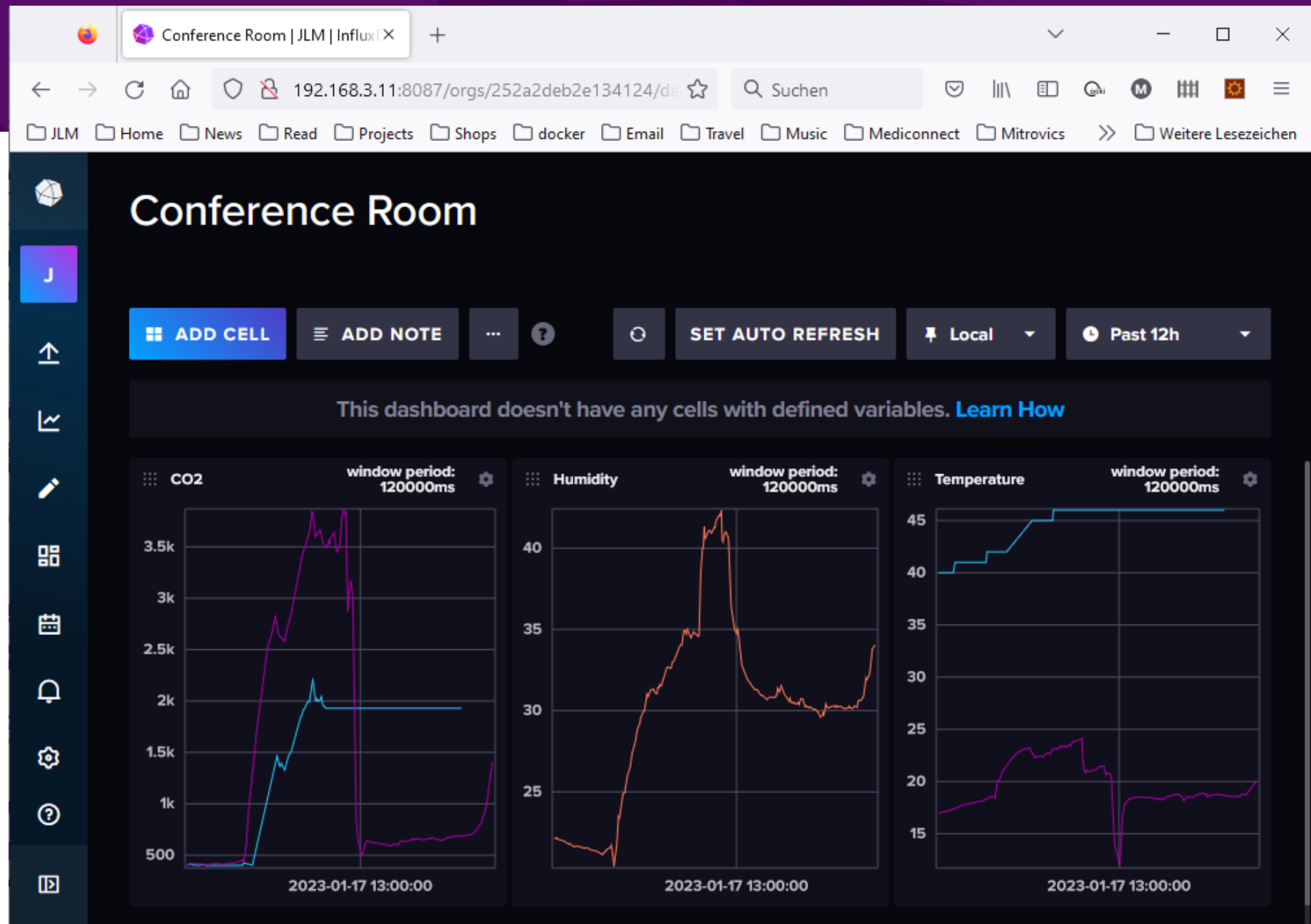
Data can be deleted automatically after a defined period of time



Annotations can be added to describe events at certain point of time

InfluxDB 2

Integrated Grafana to create dashboards with graphs of data from different sources



Server

- Cloud Server / Web Services: AWS / Azure / ...
- Root Server running Linux
- Single Board Computers: Raspberry Pi

Services Infrastructure

- Virtual Machines (HyperV, Proxmox, VirtualBox, ...)
- Containers (e.g. Docker)

Virtualization with Proxmox

The screenshot shows the Proxmox Virtual Environment 7.3-3 web interface. The browser address bar shows the URL `https://192.168.2.154:8006/#v1:0:18:4:.....`. The interface includes a navigation menu on the left with options like Datacenter, Summary, Notes, Cluster, Ceph, Options, Storage, Backup, Replication, and Permissions. The main content area displays a table of resources with columns for Type, Description, Disk usage, Memory usage, CPU usage, Uptime, and Host CPU usage.

Type	Description	Disk usag...	Memory u...	CPU usage	Uptime	Host CPU ...
node	smartbox	4.2 %	67.8 %	1.9% of 8 ...	21 days 05:...	
qemu	100 (HomeAssistant)	0.0 %	91.3 %	3.7% of 2 ...	21 days 05:...	0.9% of 8C...
qemu	101 (HomeIoT)	0.0 %	55.9 %	1.6% of 2 ...	21 days 05:...	0.4% of 8C...
storage	local (smartbox)	4.2 %			-	
storage	local-lvm (smartbox)	5.6 %			-	

At the bottom of the interface, there are buttons for 'Tasks' and 'Cluster log', and a table header with columns: Start Time, End Time, Node, User name, Description, and Status.



docker

Advantages over Virtual Machines:

- Lightweight (share a common kernel)
- Easy to configure complete stack (via docker-compose)
- One container per service
 - Dependencies can be met per container!
- Virtual networks connecting containers
- Configurable network bridge to the outside
- Easy to move containers (e.g. from Docker on Windows to Linux)
- Huge repository of ready to use containers
<https://hub.docker.com/>
- Easy to separate (and access) data via volumes

Creating a stack of services

A stack with all required services can be defined in one simple configuration file

All service can be started with one command
docker-compose up -d

Containers can expose ports to the outside. Traffic between containers can be kept within the host

Images are automatically pulled from the hub.docker.com.

Data can be stored persistent in volumes that are also accessible on the host.

```
services:
  node-red:
    image: nodered/node-red:latest
    restart: unless-stopped
    networks:
      - node-red-net
    ports:
      - "1880:1880"
    volumes:
      - node-red-data:/data

  MQTTbroker:
    image: eclipse-mosquitto:1.6.13
    restart: unless-stopped
    networks:
      - node-red-net

volumes:
  node-red-data:

networks:
  node-red-net:
```

IOTstack a simple configuration tool to create a docker-compose.yamp file for IOT

<https://sensorsiot.github.io/IOTstack/>

Optimized for Rapberry PI

Simply select different services from a menu to build a complete stack

Can run on other Linux platforms, but requires small changes to remove Raspberry Pi specific parts

Management of Docker Containers via Portainer

The screenshot displays the Portainer web interface in a browser window. The browser's address bar shows the URL `homeiot:9000/#!2/docker/containers`. The interface features a dark blue sidebar on the left with the Portainer logo and navigation options: Home, local (selected), Dashboard, App Templates, Stacks, Containers, Images, Networks, Volumes, Events, and Host. The main content area is titled "Containers" and "Container list". At the top of this area, there are control buttons: Start, Stop, Kill, Restart, Pause, Resume, Remove, and Add container. Below these buttons is a table listing the containers. The table has columns for Name, State, Quick Actions, Stack, Image, Created, IP Address, GPUs, and Published Ports. The containers listed are grafana (healthy), influxdb2 (healthy), mosquito (healthy), nodered (healthy), portainer-ce (running), telegraf (running), zigbee2mqtt (running), and zigbee2mqtt_assistant (running). Each row includes a checkbox, a state indicator (healthy or running), a set of quick action icons, the stack name (iotstack), the image name, the creation timestamp (2022-12-08 01:55:16), the IP address, and the published ports.

<input type="checkbox"/>	Name ↓↑	State ↓↑ Filter	Quick Actions	Stack ↓↑	Image ↓↑	Created ↓↑	IP Address ↓↑	GPUs	Published Ports
<input type="checkbox"/>	grafana	healthy		iotstack	grafana/grafana	2022-12-08 01:55:16	172.21.0.3	none	3000:3000
<input type="checkbox"/>	influxdb2	healthy		iotstack	influxdb:latest	2022-12-08 01:55:16	172.21.0.4	none	8087:8086
<input type="checkbox"/>	mosquitto	healthy		iotstack	iotstack-mosquitto	2022-12-08 01:55:16	172.21.0.5	none	1883:1883
<input type="checkbox"/>	nodered	healthy		iotstack	iotstack-nodered	2022-12-08 01:55:16	172.21.0.6	none	1880:1880
<input type="checkbox"/>	portainer-ce	running		iotstack	portainer/portainer-ce	2022-12-08 01:55:16	172.21.0.2	none	8000:8000 9000:9000
<input type="checkbox"/>	telegraf	running		iotstack	iotstack-telegraf	2022-12-08 01:55:16	172.21.0.7	none	8092:8092 8094:8094 8125:8125
<input type="checkbox"/>	zigbee2mqtt	running		iotstack	koenkk/zigbee2mqtt:latest	2022-12-08 01:55:16	172.21.0.8	none	8080:8080
<input type="checkbox"/>	zigbee2mqtt_assistant	running		iotstack	carldebilly/zigbee2mqttassistant	2022-12-08 01:55:16	172.21.0.9	none	8880:80