Connected Bus Monitor

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CONCEPT

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PROBLEM

- Air Quality on ground transport (Safety issues)
  - Elevated **CO2 concentration** leads to drowsiness, lethargy, fatigue, headaches, breathing problems
  - Higher **Relative Humidity** levels (> 60%) can encourage the growth of mold and mildew. Dust mites, bacteria and fungi all thrive under humid conditions
  - Lower RH levels (< 30%) can cause eye or nose irritation
  - Low RH levels (< 30%) can also lead to increased survival of some viruses, thereby increasing the spread of viral infections
  - Ambient temperature

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IDEA: BRIEF RECAP

- Monitor ground transport air quality
  - Temperature (°)
  - Relative Humidity (%)
  - CO2 concentrations (ppm)
- Provide aggregated indicators of air quality

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REQUIREMENTS SPECIFICATION

- The system shall ensure ground transport air quality monitoring as well as a normalized air quality indicator based on
  - Temperature
  - Humidity
  - CO2 concentrations
- The system shall enforce security policies
  - Data Integrity
  - End-device Authentication
  - Data Confidentiality
- The system shall provide updates in a near real-time offset
- The system shall be efficient in terms of energy consumption

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HARDWARE
AND
CLOUD BACK-END

24/05/2022

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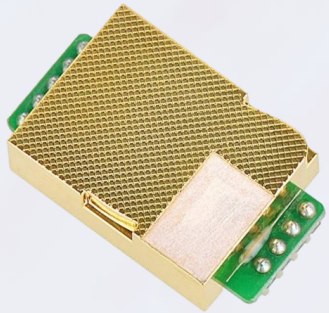
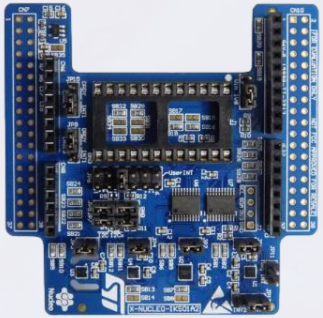
HARDWARE COMPONENTS



MH-Z19C:

- Non-Dispersive InfraRed (NDIR) CO2 sensor
- Detection range CO2 [200, 5000] ppm



X-NUCLEO-IKS01A2:

- Motion MEMS and environmental sensor
- HTS221: capacitive digital relative humidity and temperature

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HARDWARE COMPONENTS

B-L072Z-LRWAN1 Discovery kit:

- Embedded ultra-low-power STM32L072CZ MCU, based on Arm® Cortex®-M0
- LoRaWAN™ Class A certified
- LoRa® (+ Sigfox™ compatibility)
- Embedded SX1276 transceiver
- Frequency range: 860 MHz - 930 MHz

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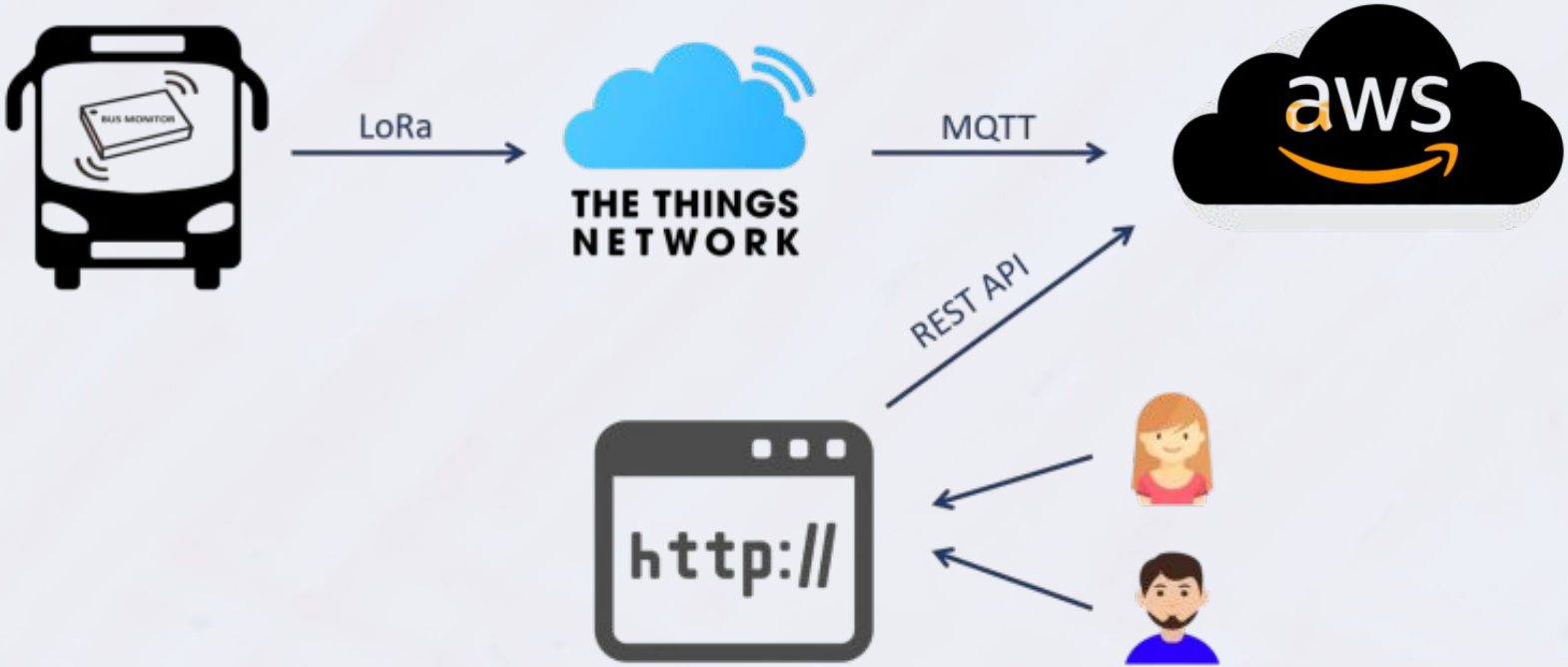
ARCHITECTURE



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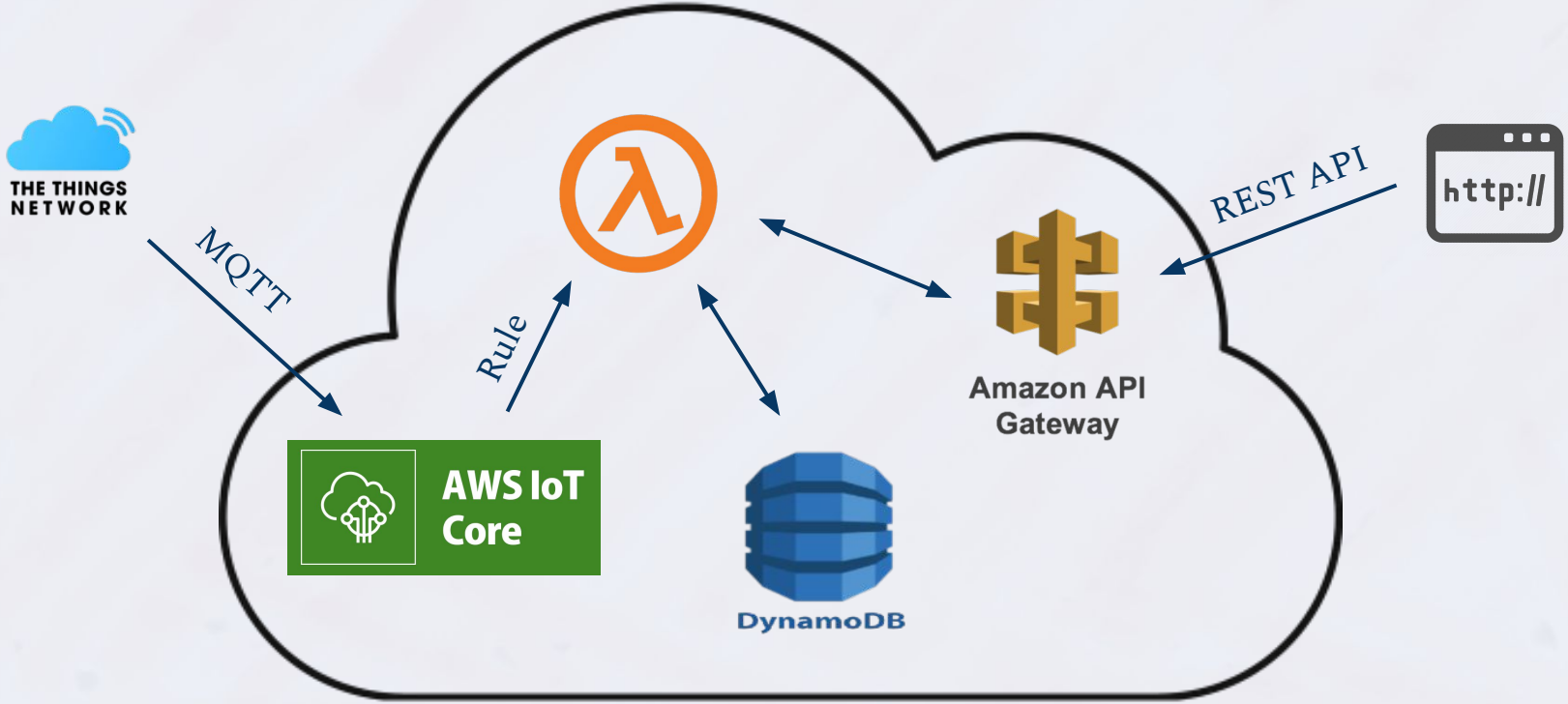
CLOUD BACK-END



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STORE THE DATA

- AWS IoT Core receives the data with topic lorawan/devID/uplink
- A rule sends the incoming message to a lambda function
- Lambda function:
  - get the arrival time of the form Y-m-dTH:M:S
  - computes the timestamp
  - get the payload
    - decodes the payload (base64)
    - decrypts the payload
    - get busID
    - get air parameters

timestamp	bus	date	payload
1653132476	11	2022-05-21T11:27:56	{"humidity": 29.5, "temperature": 31.5, "co2": 400}

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API GATEWAY

Two APIs are supported: /bus and /bus/id

1. The web page invokes the api and sends a request to the cloud
2. The API Gateway forwards the request to a lambda function
3. The lambda computes and sends back a response
4. The API Gateway forwards the response to the web page

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SECURITY

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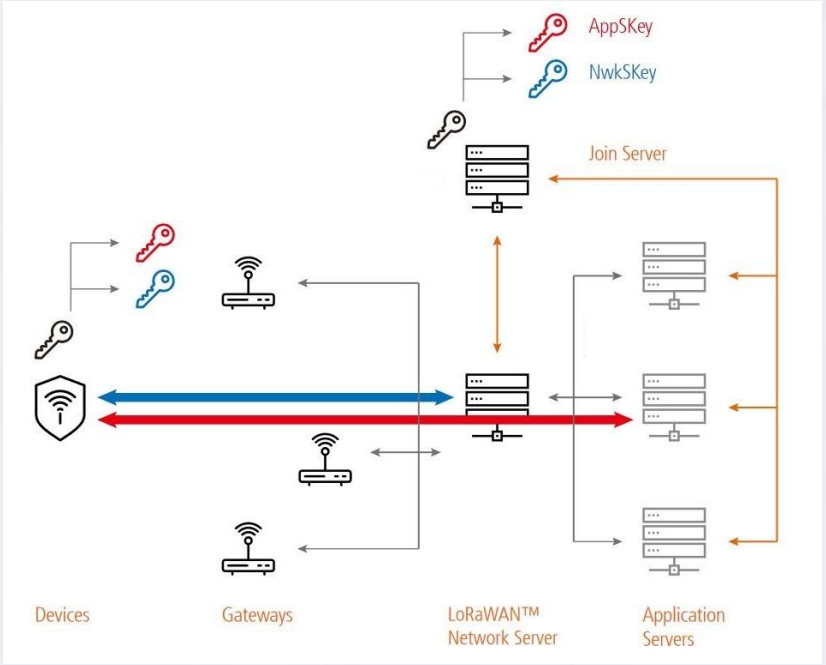
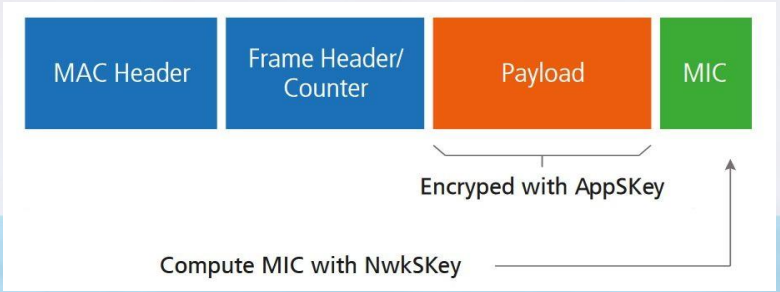
LoRaWAN ENCRYPTION

- All LoRaWAN traffic is protected using two session keys.
- The payload is encrypted by AES-CTR and carries a frame counter (to avoid packet replay)
- Message Integrity Code (MIC) computed with AES-CMAC (to avoid packet tampering).





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LoRaWAN ENCRYPTION

- Over-The-Air Activation

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OVERALL SEC

- Bus-TTN is secured by LoRaWAN
- What about TTN-AWS?

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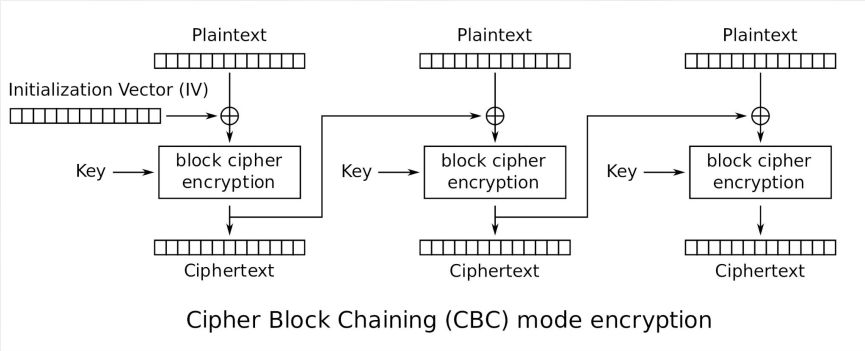
DATA ENCRYPTION

- To assure confidentiality in all the path bus-aws we encrypt the data using AES-CBC



Cipher Block Chaining (CBC) mode encryption

- We need:
  - 16 bytes key
  - 16 bytes IV

- On RIOT:
  - module random to generate random key and IV
  - module crypto to perform AES-128

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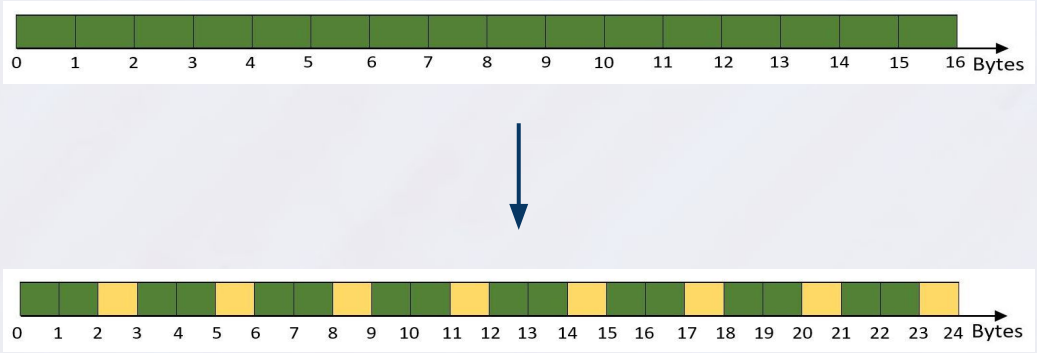
HIDDEN KEY

- In order to let AWS be able to decrypt the message we need to sends the key and the IV
- We can send the IV in clear but protecting the key



AES-128 key

fake AES-192 key

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ENC PAYLOAD

- The clear payload has dimension between 54 and 60 bytes
- To be encrypted with AES-128 it is padded to 64 bytes
- The encrypted payload to send is 94 bytes long

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FRONT-END

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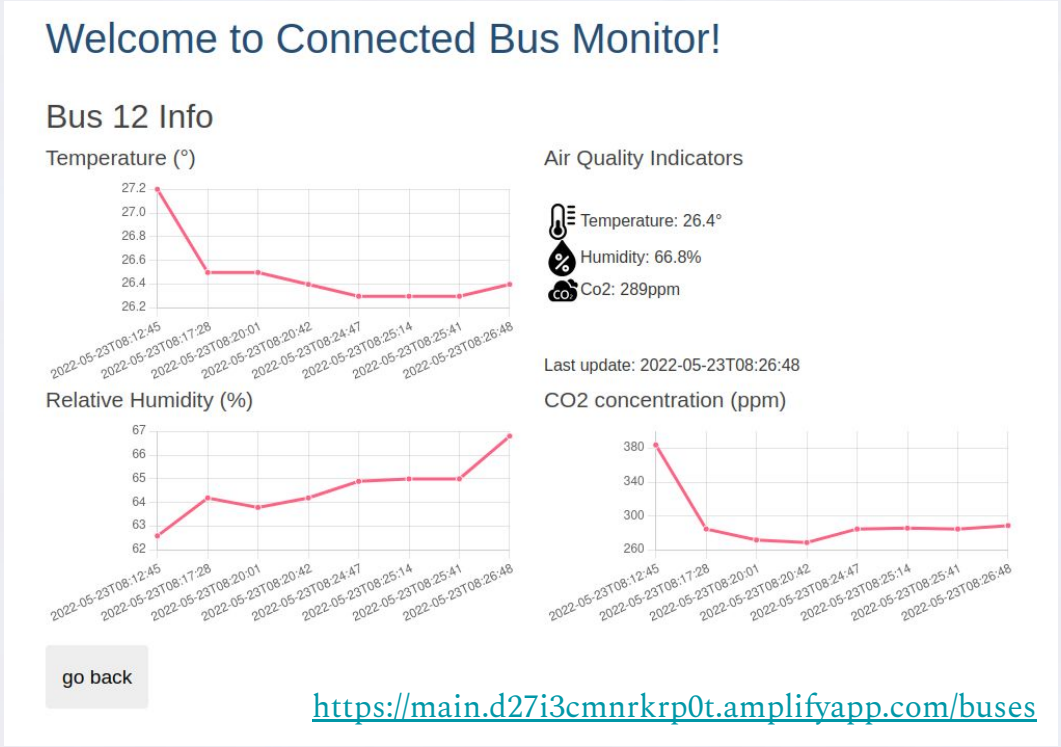
WEB DASHBOARD

Angular application

- ng2-charts

Get bus IDs

Get bus air quality data



https://main.d27i3cmnrkrp0t.amplifyapp.com/buses

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EVALUATION

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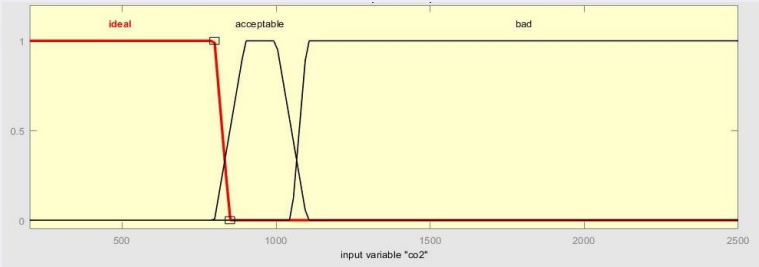
AIR QUALITY INDEX (AQI)

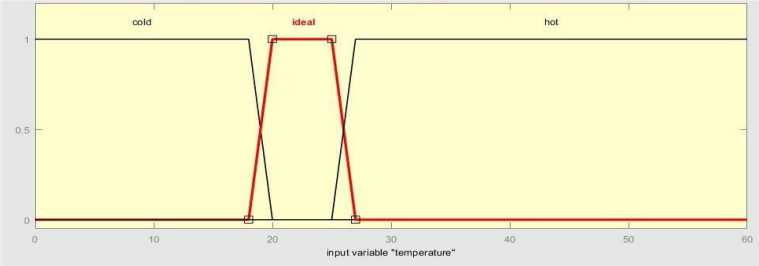
CO2 concentration thresholds [ppm]:

- Ideal: < 800
- acceptable: [800, 1110]
- bad: > 1100



Temperature thresholds [°C]:

- cold: < 20
- ideal: [20, 25]
- hot: > 25



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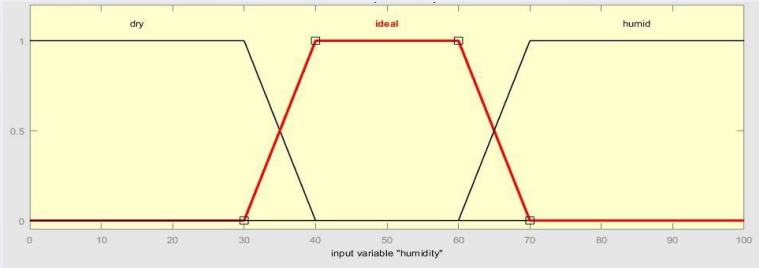
AIR QUALITY INDEX (AQI)

Humidity thresholds [%]:

- Dry: < 40
- Ideal: [40, 60]
- Too humid: > 60



First strategy to compute AQI:

- AQI $\in [0, 3]$
- equivalent to the number of parameter in the ideal range

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AIR QUALITY INDEX (AQI)

Second strategy to compute AQI:

- AQI $\in [0, 3]$
- Normalized contribution of temp and hum

$$hum_{cont} = \begin{cases} 1 & \text{if } hum \in [40, 60] \\ \frac{hum}{40} & \text{if } hum < 40\% \\ \frac{100 - hum}{100 - 60} & \text{if } hum > 60\% \end{cases}$$

$$temp_{cont} = \begin{cases} 1 & \text{if } temp \in [20, 25] \\ \frac{temp - 5}{20 - 5} & \text{if } temp < 20°C \\ \frac{40 - temp}{40 - 25} & \text{if } temp > 25°C \end{cases}$$

$$co2_{cont} = \begin{cases} 0 & \text{if } co2 > 1100ppm \\ 1 & \text{if } co2 \in [200, 1100] \end{cases}$$

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AIR QUALITY INDEX (AQI)

Lets see the different outcomes of the two methods taking as examples the parameters:

- temp = 34°C
- hum = 21%
- co2 = 227 ppm

AQI with first method = 1
AQI with second method = 1.9

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SAMPLING FREQUENCY

The sampling frequency is strictly related to the transmission time bus-TTN since we need to respect the 1% duty-cycle.

Reminder: The payload is 94 bytes long

Data rate	Spreading factor	Channel bandwidth	Bit rate	Maximum payload size
0	SF12	125 kHz	250 bps	51 bytes
1	SF11	125 kHz	440 bps	51 bytes
2	SF10	125 kHz	980 bps	51 bytes
3	SF9	125 kHz	1.76 kbps	115 bytes
4	SF8	125 kHz	3.13 kbps	242 bytes
5	SF7	125 kHz	5.47 kbps	242 bytes
6	SF7	250 kHz	11 kbps	242 bytes

$$t_{trans} = \frac{PayloadSize_{bit}}{BitRate}$$

$$= \frac{PayloadSize_{byte} * 8}{BitRate}$$

$$= \frac{94\ bit * 8}{5470\ bit/s} = 0.137\ s$$

Transmission time bus-TTN: t_{trans} = 0.137 seconds

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SAMPLING FREQUENCY

Respecting the 1% duty-cycle, we can transmit each 14 seconds

Is SF=7 the best to use in our case?

SF	BitRate [Kbit/s]	T_{trans} [s]	Transmission Period [s]	Range[km]
7	5,47	0,137	14	2
8	3,13	0,240	24	4
9	1,76	0,427	43	6

For our purposes it is better to use SF=9:

- The range is tripled
- We can sample each 43 seconds

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ENERGY CONSUMPTION

All major bus manufacturers foresee the presence of USB ports in the new buses

→ The CBM can be plugged to the bus through USB

We wanted to maintain the device on also while the bus is powered off (terminus) to do not re-calibrate the co2 sensor

→ We have experienced that the CO2 sensor takes around 10 minutes to give stable values, that is acceptable for our purposes

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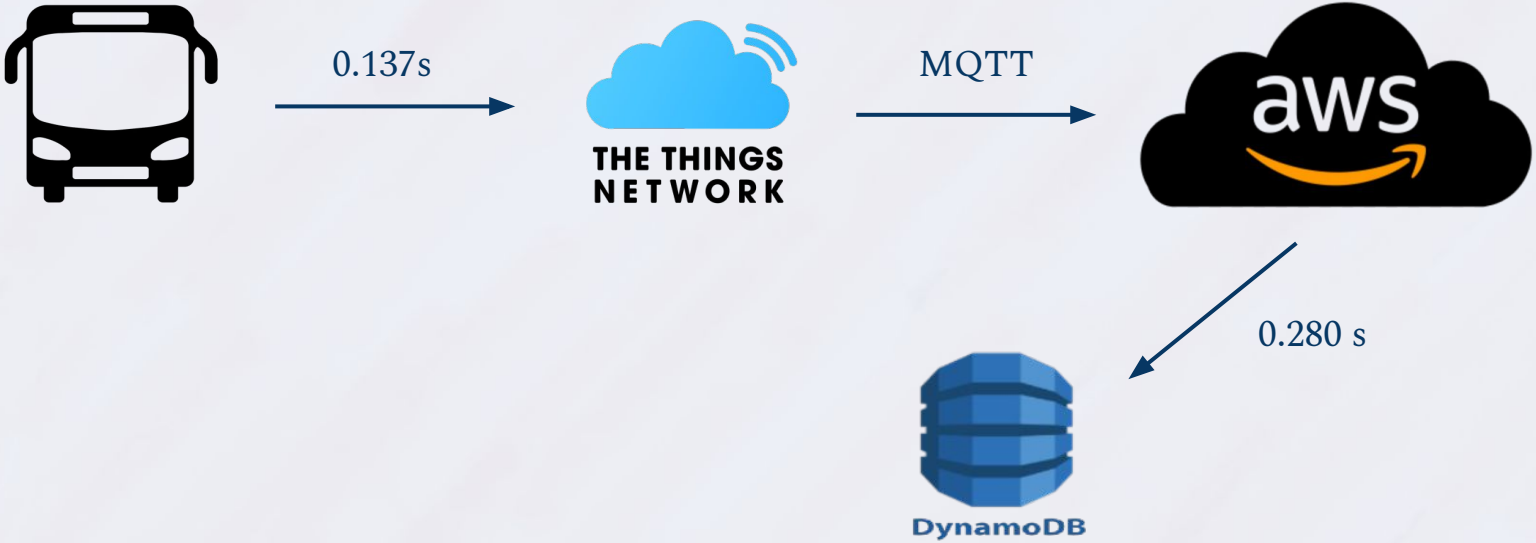
STORE DELAY



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FUTURE PLANS

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POTENTIAL ADDITIONAL HARDWARE

- Exploit the MEMS sensor for supplying data (acceleration and inclination) in order to assess city traffic conditions
- Include a Volatile Organic Compounds (VOC) sensor
- Noise sensor for additional pollution metrics
- Supplement an already existent GPS system combining heterogeneous information

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POTENTIAL SOFTWARE DEVELOPMENTS

- Analytics
  - Provide an approximation of the number of people onboard
  - Ground transport statistics (conditions, degree of usage)

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THANKS FOR YOUR ATTENTION

github.com/FrancescoCrino/ConnectedBusMonitor

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