LORA - LONG RANGE RADIO

- TECHNOLOGY OVERVIEW
- POTENTIAL APPLICATIONS FOR THE HAM

FEBRUARY 2023

COLIN BUCKUP – N5GG

LORA ???

LorRa is one of the many technologies used for IoT – Internet of Things

WHAT IS LORA?

LoRa is a technology that implements the Physical Layer (PHY) for IoT devices using the RF spectrum.

It allows the connection of IoT devices point-to-point or to a LoRaWan network.

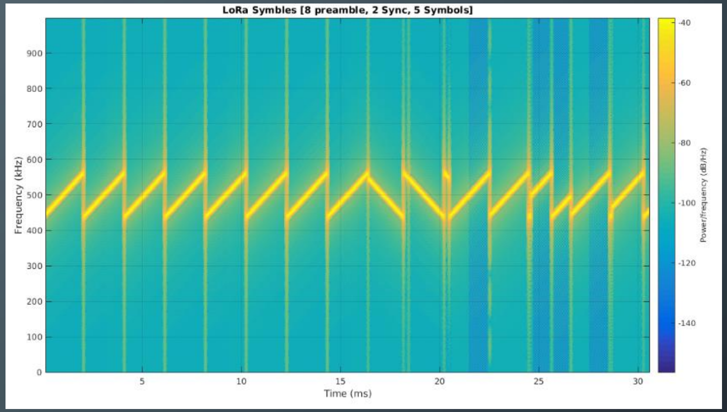
It is possible to achieve long range links (1-15mi) using low power (< 23dBm / 200 mW).

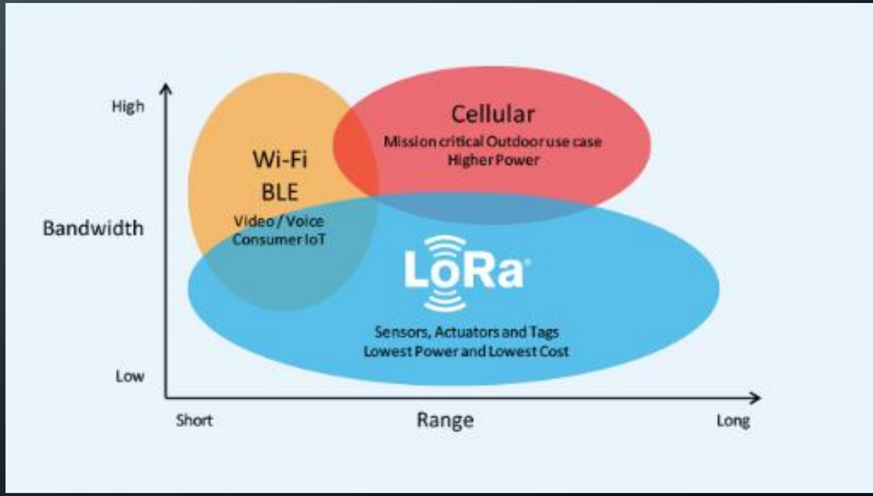
Typically occupies a 125 kHz bandwidth.

Offers a variable throughput range from 0.3 kbps to 50 kbps.

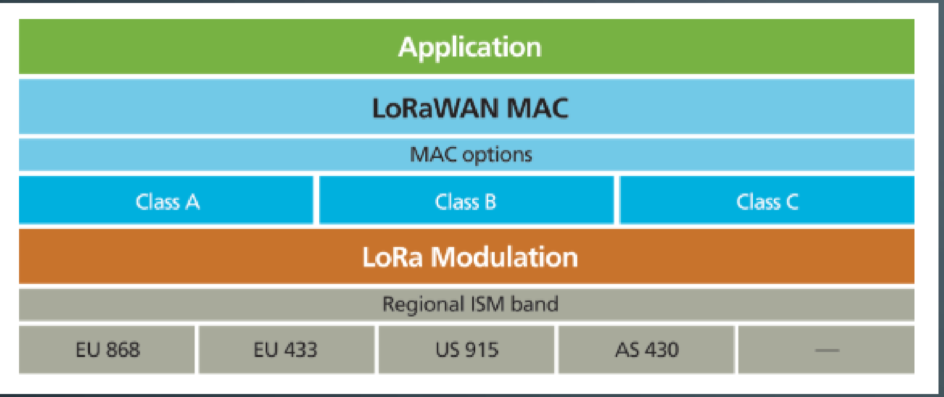
Operates on license-free frequency bands on 430 MHz, 858 MHz or 915 MHz depending on the country or geographic area.

Uses a frequency sweeping modulation technique, known as Chirp modulation.





WHAT IS LORAWAN?



LoRaWAN

- Specifies an open protocol for Wide Area Networks using as the physical layer a low power RF link operating on free-access frequency bands.

- The protocol aims to interconnect via RF battery powered IoT devices.

- The star-of-stars topology allows the interconnection of these LoRaWAN networks to regional and global internets

- The protocol addresses the IoT requirements for:
  - Bi-directional
  - Security end-to-end
  - Mobility

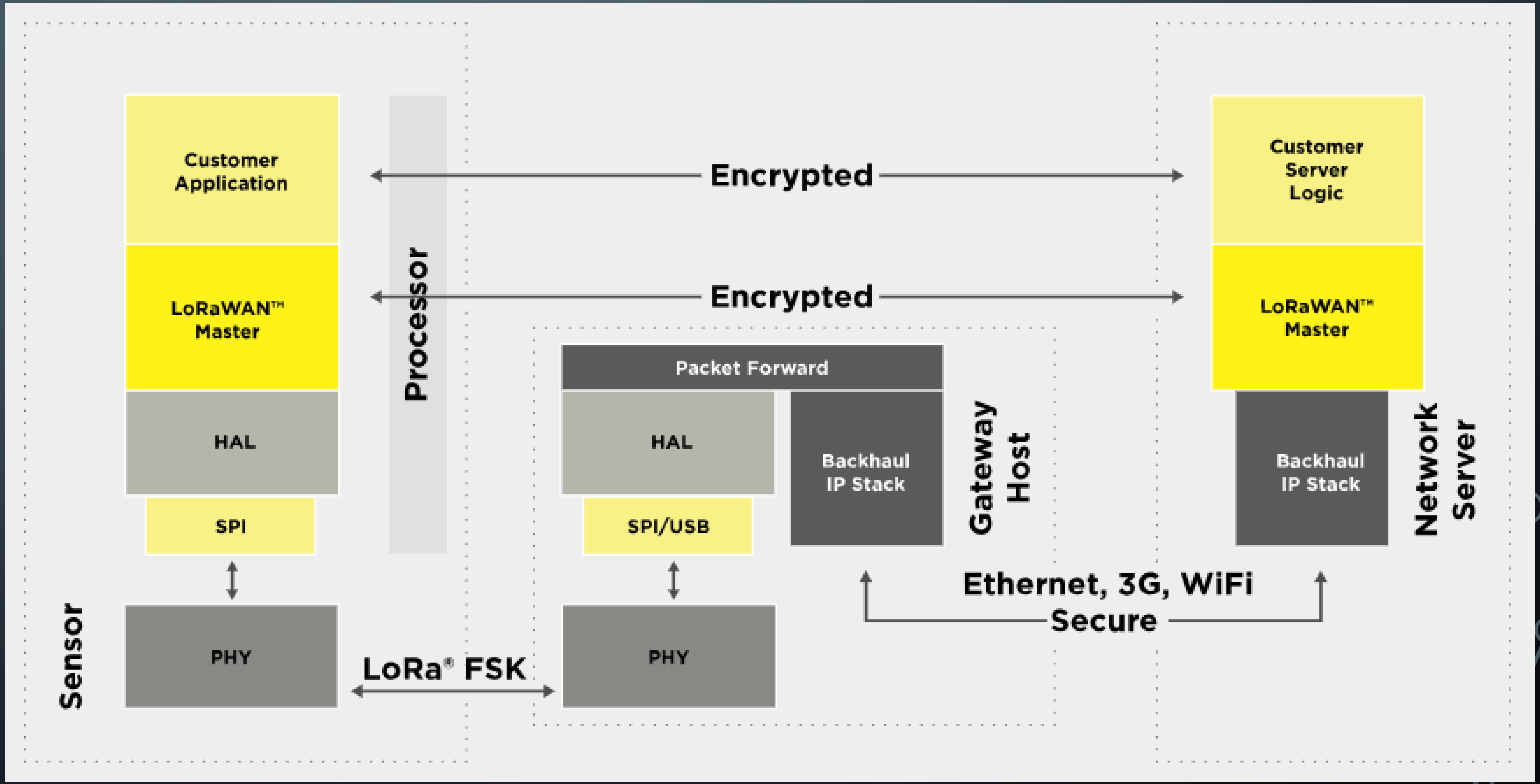
Link to the complete LoRaWAN specification :

https://lora-alliance.org/sites/default/files/2018-04/what-is-lorawan.pdf

LORAWAN - TOPOLOGY

The topology of a LoRaWAN network is based on 3 types of nodes:

- Sensor
- Gateway Host
- Network Server

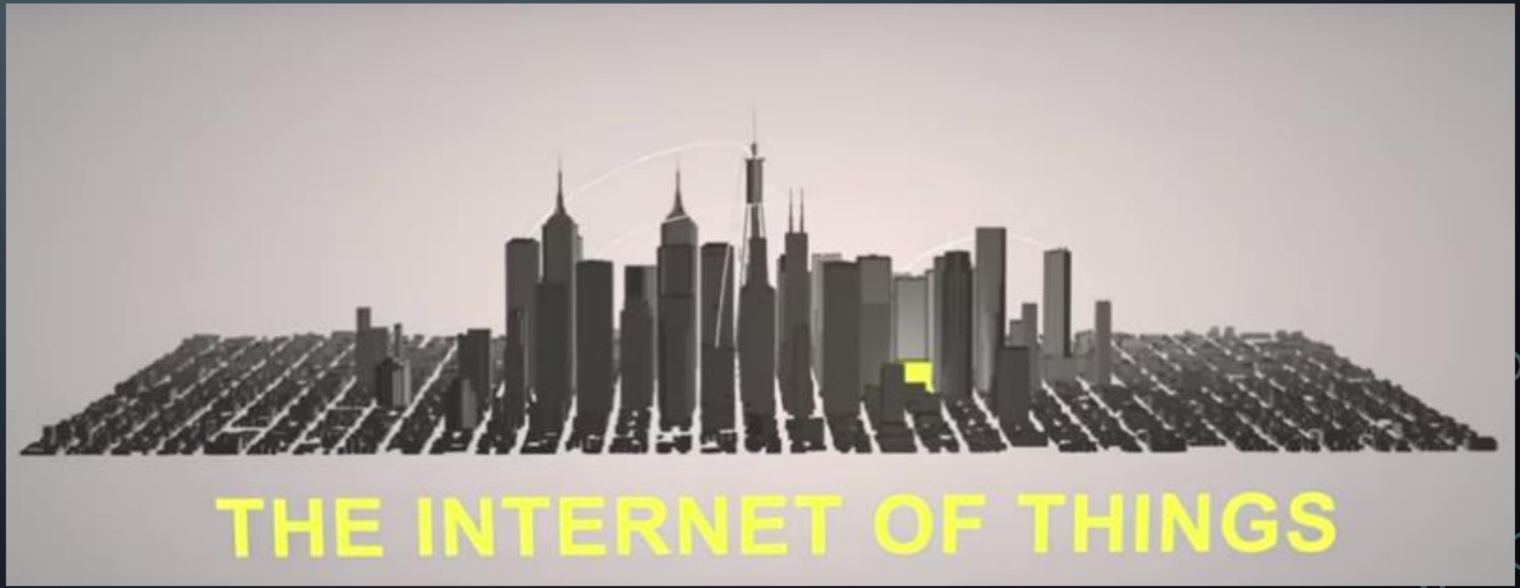


WHO IS BEHIND IT…

LoRa™ Alliance
www.lora-alliance.org

The LoRa Alliance® is an open, non-profit association with the mission to support and promote the global adoption of the LoRaWAN standard.

Members collaborate in a vibrant ecosystem of device makers, solution providers, system integrators and network operators, delivering interoperability needed to scale IoT across the globe, using public, private, and hybrid networks.



WHO PRODUCES THE LORA CHIP…

The physical layer used in the LoRa implementation is proprietary and belongs to SEMTECH, who authorized other vendors (i.e. HOPE RF) to manufacture the chips that are used in all devices that use the technology.

Since the physical layer is proprietary, we can't change it, but we can use it as is without any problems in our projects.

One of the most common and inexpensive chips is the SX1276 and its variants.

LoRa

SEMTECH

HOPERF

APPLICATIONS IN HAM PROJECTS

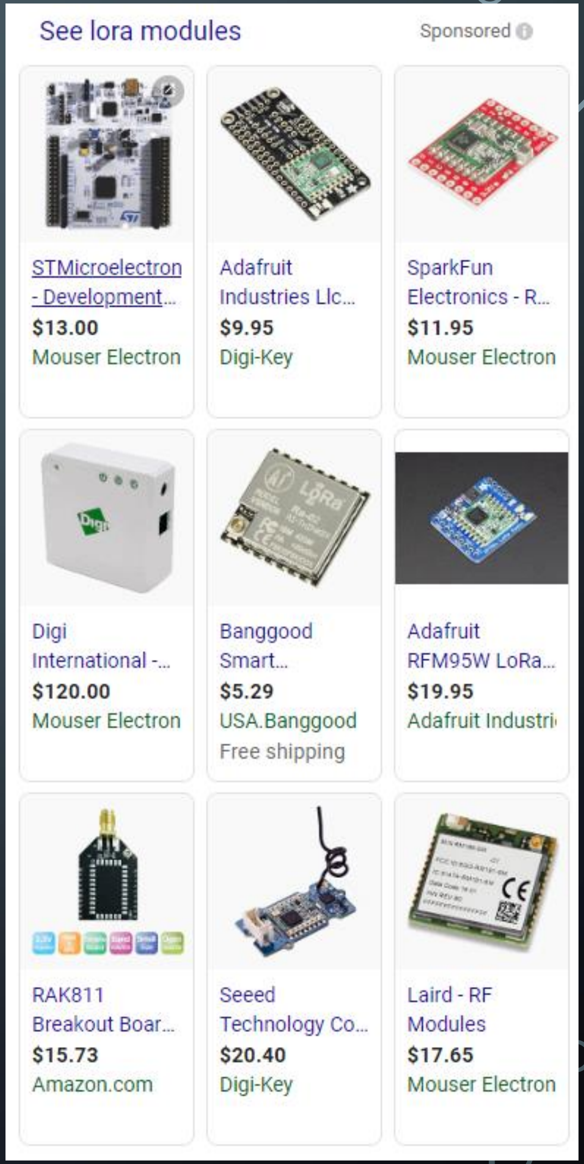
Opportunities for hams:

- Learn a new technology
- Use the new technology on 2 ham bands
  - 430 MHz
  - 902 MHz
- Implement remote sensing (telemetry)
- Implement trackers for geo-location
- Implement LoRa to APRS gateways
- Implement LoRa to internet gateways
- etc. etc. etc…

HARDWARE OPTIONS

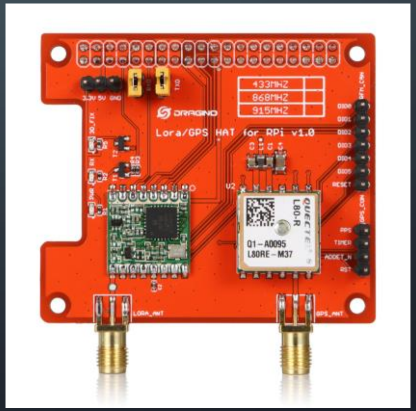
To begin experimenting with LoRa we could use one of these 3 platforms:
- Arduino and its variants
- Raspberry Pi family
- Own project

The most common and readily available LoRa sub-module is based on the SX1276 chip and is offered by several manufacturers of project modules: Adafruit, Dragino, Seeed, SparkFun, etc



RFM95W

LoRa Feather M0

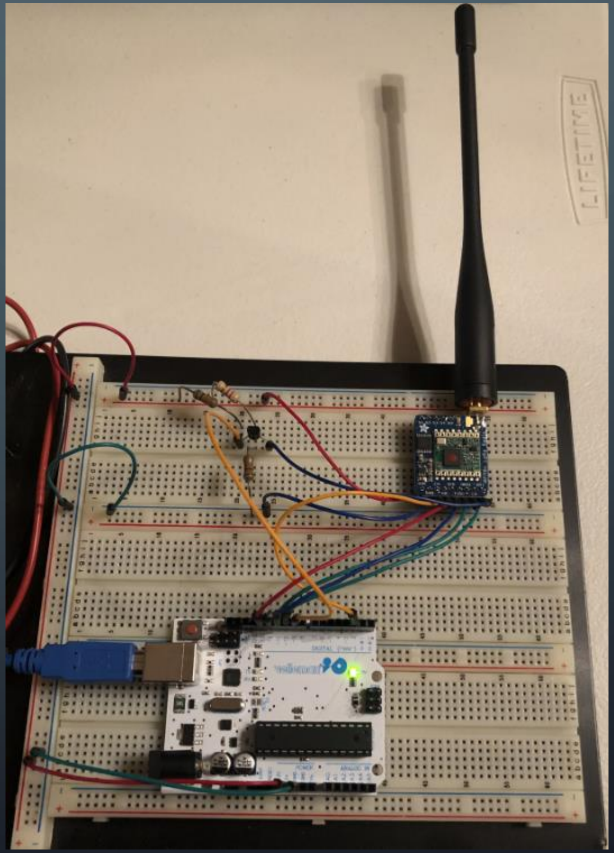


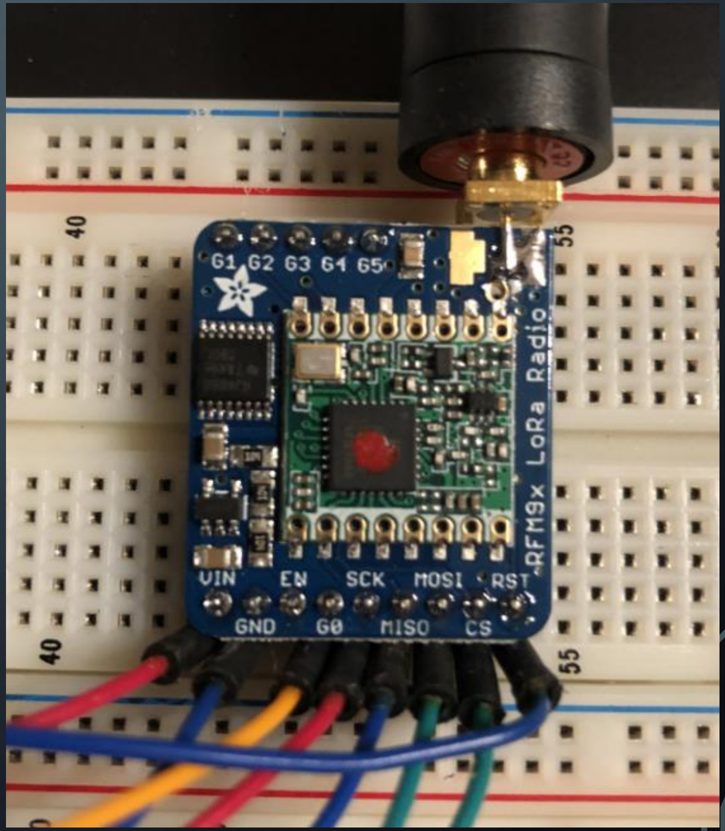
Dragino LoRa GPS HAT

PROJECT SUGGESTION:

TRANSMITTER / BEACON - LoRa 430 MHz

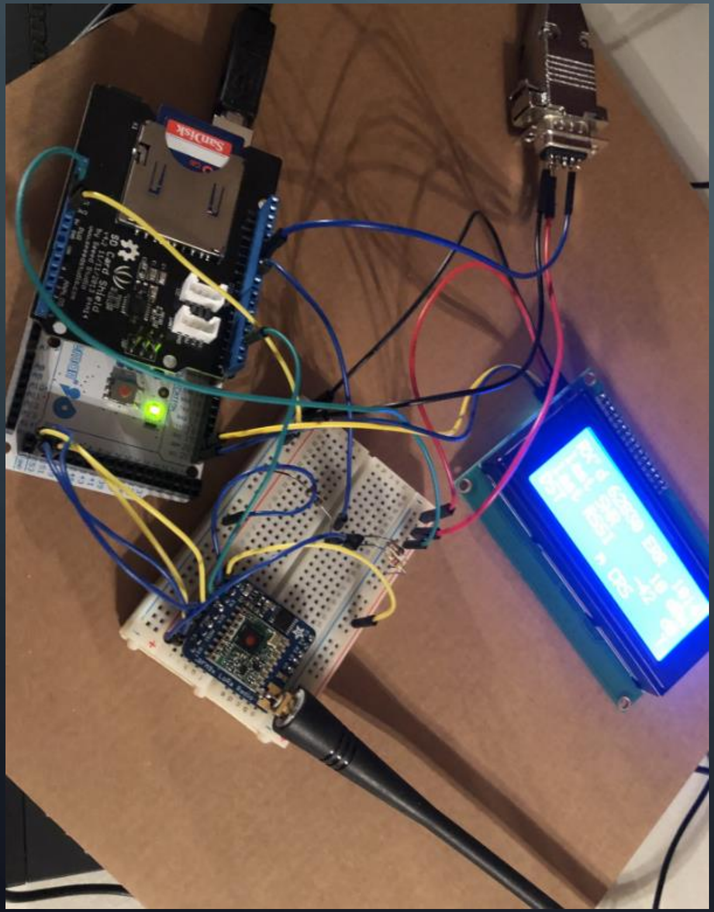
- LoRa RFM96W
- Arduino UNO
- 5V <-> 3.3V power converter





PROJECT SUGGESTION:

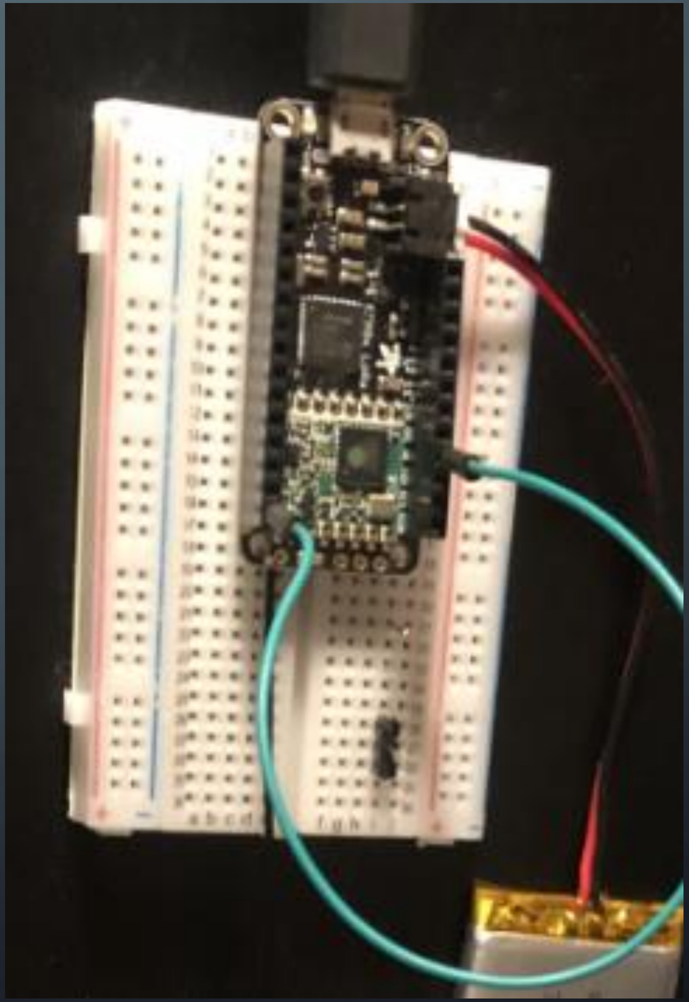
RECEIVER / LOGGER - LoRa 430 MHz

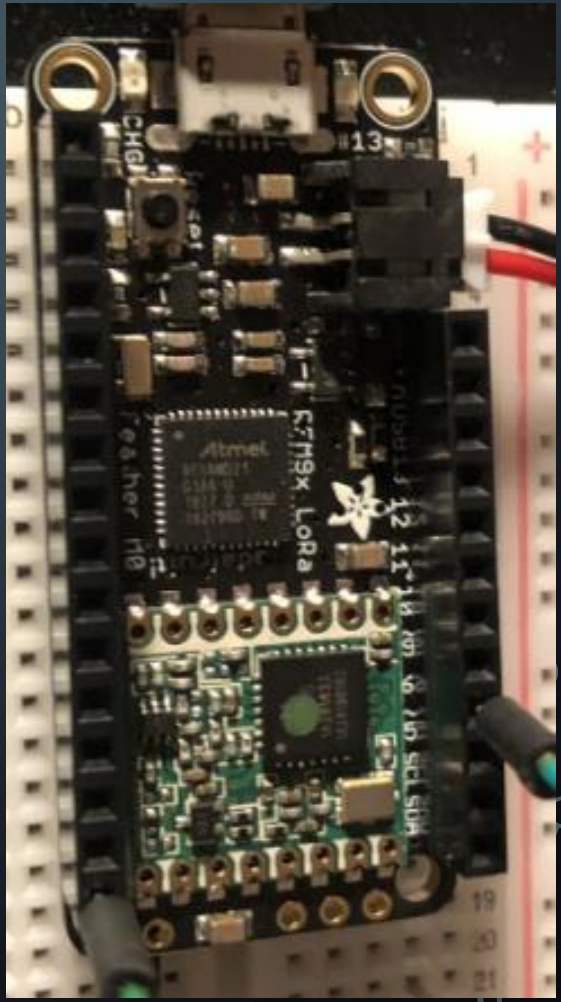


PROJECT SUGGESTION:

TRANSMITTER / BEACON - LoRa 915 MHz

- LoRa RFM95 - embedded
- Arduino M0 – Adafruit Feather
- 915 MHz Antenna

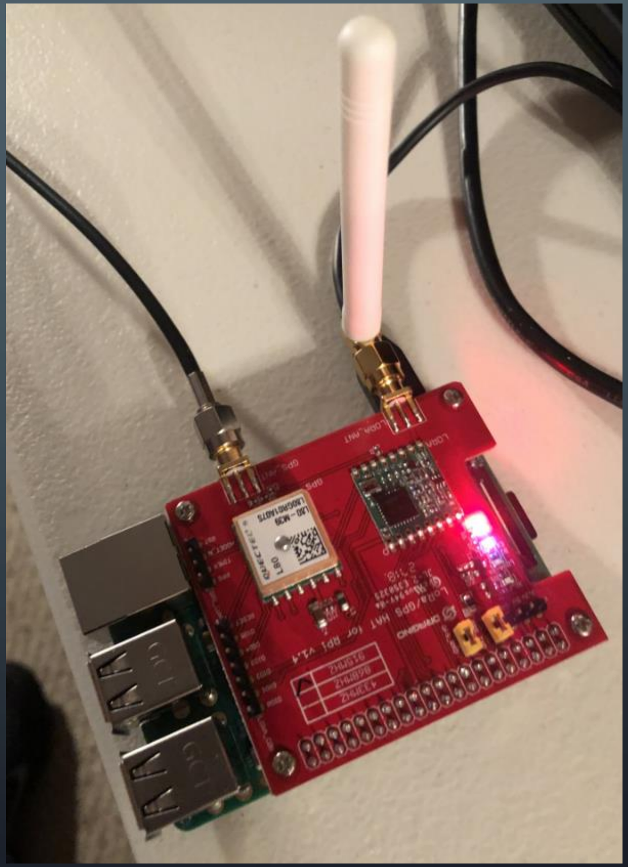




PROJECT SUGGESTION:

RECEIVER / GATEWAY LoRa to Internet / APRS

- Dragino LoRa GPS HAT
- Raspberry Pi 3B
- GPS antenna
- 915 MHz antenna

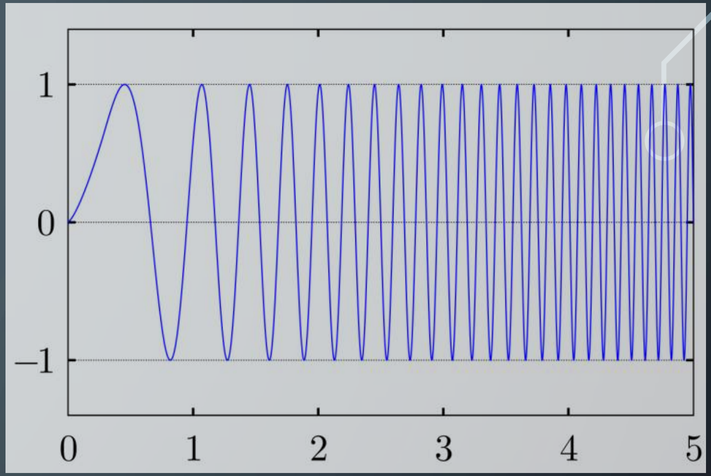


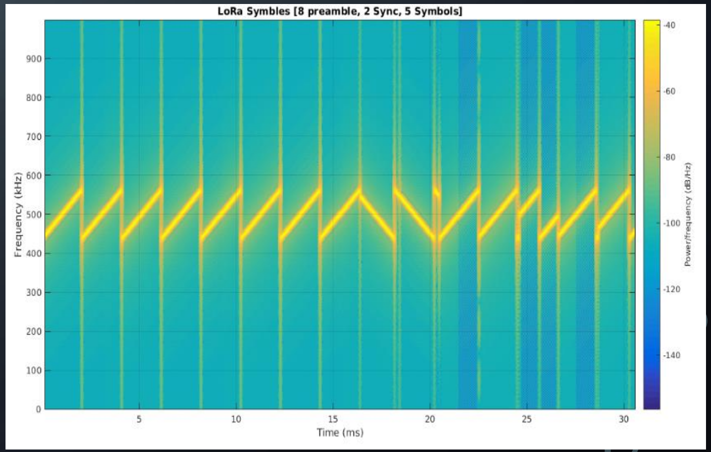
LORA – TECHNICAL ASPECTS

LoRa uses a proprietary spread spectrum modulation that is similar to and a derivative of chirp spread spectrum (CSS) modulation.

Each symbol is represented by a cyclic shifted chirp over the frequency interval f0-B/2, f0+B/2 where:
f0 is the center frequency
B the bandwidth of the signal (in Hertz).

The spreading factor (SF) is a selectable radio parameter from 6 to 12 and represents the number of bits sent per symbol and in addition determines how much the information is spread over time.





LORA – TECHNICAL ASPECTS

There are $M = 2^{SF}$ different initial frequencies of the cyclic shifted chirp.

The instantaneous frequency is linearly increased and wrapped to $f_0 - B/2$ when it reaches the maximum frequency $f_0 + B/2$.

The symbol rate is determined by $R_s = B / (2^{SF})$.

LoRa can trade off data rate for sensitivity (assuming a fixed channel bandwidth B) by selecting the SF, that is the amount of spread used.

A lower SF corresponds to a higher data rate but a worse sensitivity.

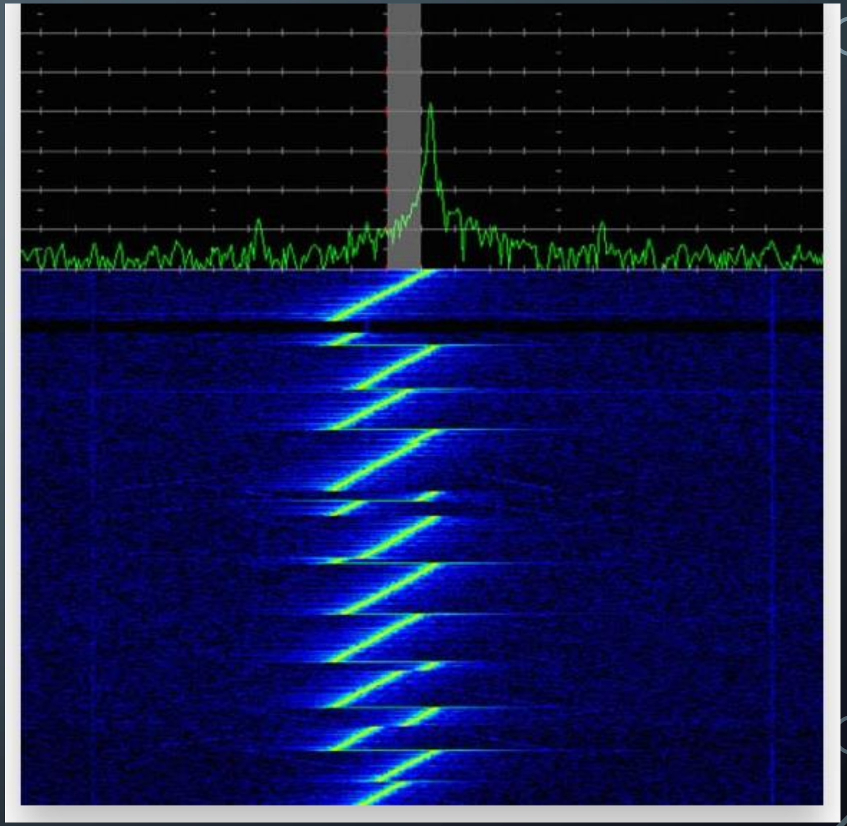
A higher SF implies a better sensitivity but a lower data rate.

LORA – TECHNICAL ASPECTS

Compared to lower SF, sending the same amount of data with higher SF needs more transmission time, known as time-on-air.

More time-on-air means that the modem is transmitting for a longer time and consuming more energy.

Typical LoRa modems support transmit powers up to +22 dBm.



CONFIGURATION PARAMETERS

What we USUALLY configure in ham radio links:

- Frequency
- Power

LoRa has SEVERAL MORE parameters to select from:

- Frequency – 2 bands (430, 902 MHz)
- Bandwidth – 5 bandwidths (31250, 62500, 125000, 250000, 500000 Hz)
- Spreading Factor – 7 SFs (64, 128, 256, 512, 1024, 2048, 4096 chips/s)
- Coding Rate – 4 CRs (4/5, 3/6, 4/7, 4/8)
- Power – several from -4 dBm to +23 dBm in 1dBm steps
- Packet Length – variable from 1 to 255 bytes

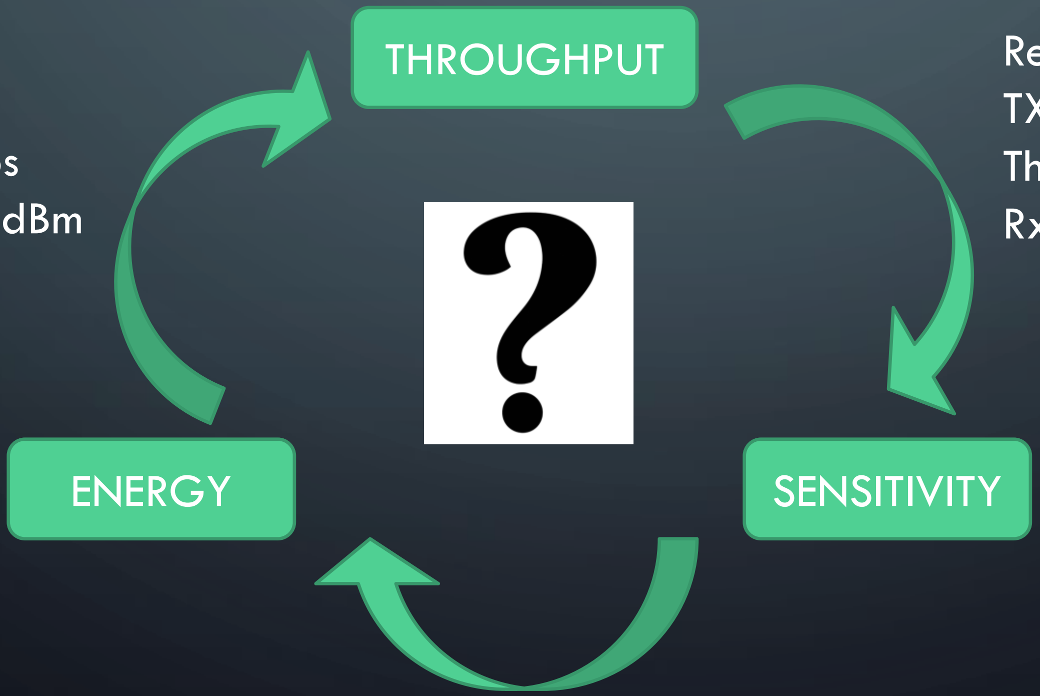
DECISIONS… DECISIONS…

Bandwidth = 125 kHz
Spreading Factor = 128chips/symbol (SF7)
Coding Rate = 4/5
Power = 5 dBm / 3.2 mW
Packet Length = 250 bytes

Results in:
TXoA = 389 ms
Throughput = 5.5 kbps
Rx Sensitivity = -125 dBm

Bandwidth = 125 kHz
Spreading Factor = 1024chips/symbol (SF10)
Coding Rate = 4/8
Power = 20 dBm / 100 mW
Packet Length = 61 bytes

Results in:
TXoA = 1017 ms
Throughput = 610 bps
Rx Sensitivity = -132.5 dBm



LORA – TECHNICAL ASPECTS

Free Space Loss (dB)

FSPL = (4*pi*dist*freq/c)^2

FSPL = 20log d + 20log f -147.55

	Distance (m)	100kHz	1MHz	10MHz	100MHz	1GHz	10GHz
		1.00E+05	1.00E+06	1.00E+07	1.00E+08	1.00E+09	1.00E+10
1m	1	-47.6	-27.6	-7.6	12.5	32.5	52.5
10m	10	-27.6	-7.6	12.5	32.5	52.5	72.5
100m	100	-7.6	12.5	32.5	52.5	72.5	92.5
1km	1000	12.5	32.5	52.5	72.5	92.5	112.5
10km	10000	32.5	52.5	72.5	92.5	112.5	132.5
100km	100000	52.5	72.5	92.5	112.5	132.5	152.5
1000km	1000000	72.5	92.5	112.5	132.5	152.5	172.5
10000km	10000000	92.5	112.5	132.5	152.5	172.5	192.5

Freq (Hz)

Frequency (Hz)	9.15E+08
Distance (m)	1.00E+06
FSPL	151.68

TX PWR: (dBm)	20	
FSPL: (dB)	151.68	
RX sensitivity: (dBm)	-132.531	
Headroom: (dB)	0.85	Can go Further if positive

Example:

LoRa operating on 915MHz @ 125kHz BW / SF12 and 23dBm power can GO UP TO 2500km in free space!!!

LoRa operating on 915MHz @ 125kHz BW / SF10 and 23dBm power can GO UP TO 1000km in free space!!!

Receiver Sensitivity (dBm)

Sens = -174 + 10log BW + NF + SNRlimit

Spreading Factor	chips/symbol	SNR limit (dB) [2]
7	128	-7.5
8	256	-10
9	512	-12.5
10	1024	-15
11	2048	-17.5
12	4096	-20

Note: If the SF increases by 1, the SNR_{limit} changes by -2.5 dB

SX1276 NF is 5.5 dB

SF	7	8	9	10	11	12
SNR limit	-7.5	-10	-12.5	-15	-17.5	-20
BW (Hz)	Receiver Sensitivity (dBm) at SNR_limit					
31250	-131.1	-133.6	-136.1	-138.6	-141.1	-143.6
62500	-128.0	-130.5	-133.0	-135.5	-138.0	-140.5
125000	-125.0	-127.5	-130.0	-132.5	-135.0	-137.5
250000	-122.0	-124.5	-127.0	-129.5	-132.0	-134.5
500000	-119.0	-121.5	-124.0	-126.5	-129.0	-131.5

Bandwidth (Hz)	125000	
Noise Figure (dB)	5.5	for SX1276
SNR (dB)	-15	
Sensitivity	-132.531	

HOPERF LORA CHIPS

Values taken from corresponding data sheets (Oct 10, 2018), see: http://www.hoperf.com/rf_transceiver/lora/

Chip	Freq. range MHz	RF output power dBm	Max Link Budget dBm	Max Rx Sensitivity dBm	Compatible With	Chip Marking	Available in Freq. MHz
RFM95(W)	868-915	20	168	-148	SX1276	RF96	868, 915
RFM96(W)	433-470	20	168	-148	SX1276	RF96	433
RFM98(W)	433-470	20	168	-148	SX1278	RF98	433

LORA – TECHNICAL ASPECTS

LoRa Calculations
1/19/2023
N5GG

Rs = Symbol Rate = BW / 2^SF

Ts = Symbol Time = 1 / Rs

SF = Spreading Factor (bits per Symbol)

2^SF	128	256	512	1024	2048	4096
SF	7	8	9	10	11	12
BW (Hz)	Symbol Time (ms) = (2^SF)/BW = 1/Rs					
31250	4.1	8.2	16.4	32.8	65.5	131.1
62500	2.0	4.1	8.2	16.4	32.8	65.5
125000	1.0	2.0	4.1	8.2	16.4	32.8
250000	0.5	1.0	2.0	4.1	8.2	16.4
500000	0.3	0.5	1.0	2.0	4.1	8.2

CR = Coding Rate = 4 / (4+cr)   cr= 1 to 4

Rb = Bit Rate = SF * Rs * CR = SF * [BW / 2^SF] * CR

CR = 4/5, 0.8

2^SF	128	256	512	1024	2048	4096
SF	7	8	9	10	11	12
BW (Hz)	Bit Rate (bit/s)					
31250	1,367	781	439	244	134	73
62500	2,734	1,563	879	488	269	146
125000	5,469	3,125	1,758	977	537	293
250000	10,938	6,250	3,516	1,953	1,074	586
500000	21,875	12,500	7,031	3,906	2,148	1,172

-125 dBm
-132.5 dBm
-137.5 dBm

CR = 4/8, 0.5

2^SF	128	256	512	1024	2048	4096
SF	7	8	9	10	11	12
BW (Hz)	Bit Rate (bit/s)					
31250	854	488	275	153	84	46
62500	1,709	977	549	305	168	92
125000	3,418	1,953	1,099	610	336	183
250000	6,836	3,906	2,197	1,221	671	366
500000	13,672	7,813	4,395	2,441	1,343	732

ToA = Tpacket = Tpreamble + Tpayload

Tpreamble = (Npreamble + 4.25) * Ts

Npreamble is typically 8

Example of TXoA for 125kHz BW in USA

SF	7	8	9	10	11	12
Ts (s)	0.001024	0.002048	0.004096	0.008192	0.016384	0.032768
Payload	ToA (s) [Tpre + Tpay]					
1	0.025856	0.051712	0.103424	0.206848	0.413696	0.827392
2	0.030976	0.051712	0.103424	0.206848	0.413696	0.827392
5	0.030976	0.061952	0.123904	0.247808	0.413696	0.827392
10	0.041216	0.072192	0.144384	0.288768	0.495616	0.991232
19	0.051456	0.102912	0.185344	0.329728	0.659456	1.318912
61	0.112896	0.205312	0.369664	0.698368	1.314816	2.465792
133	0.220416	0.389632	0.697344	1.271808	2.379776	4.431872
250	0.389376	0.686592	1.229824	2.254848	4.100096	7.544832
(bytes)	Red Area not allowed in USA					

Npreamble	8	default
CRC	1	on
Header	0	explicit
LowRate	0	on > 16ms
cr	1	4/5

note: make autocalc for LowRate for 11 and 12

$$n_{payload} = 8 + max\left(ceil\left[\frac{(8PL - 4SF + 28 + 16CRC - 20IH)}{4(SF - 2DE)}\right](CR + 4), 0\right)$$

LORA – TECHNICAL ASPECTS

PRACTICAL NOTE:
Common configuration used for close proximity networks (less than 1000 ft):

BW = 125 kHz
SF = 128chips/symbol (SF7)
PWR = 5 dBm / 3.2 mW

Mode	Equivalent bit rate (kb/s)	Sensitivity (dBm)	Δ (dB)
FSK	1.2	-122	-
LoRa SF = 12	0.293	-137	+15
LoRa SF = 11	0.537	-134.5	+12.5
LoRa SF = 10	0.976	-132	+10
LoRa SF = 9	1757	-129	+7
LoRa SF = 8	3125	-126	+4
LoRa SF = 7	5468	-123	+1
LoRa SF = 6	9375	-118	-3

Table 1: Link Budget Comparison for Narrowband FSK

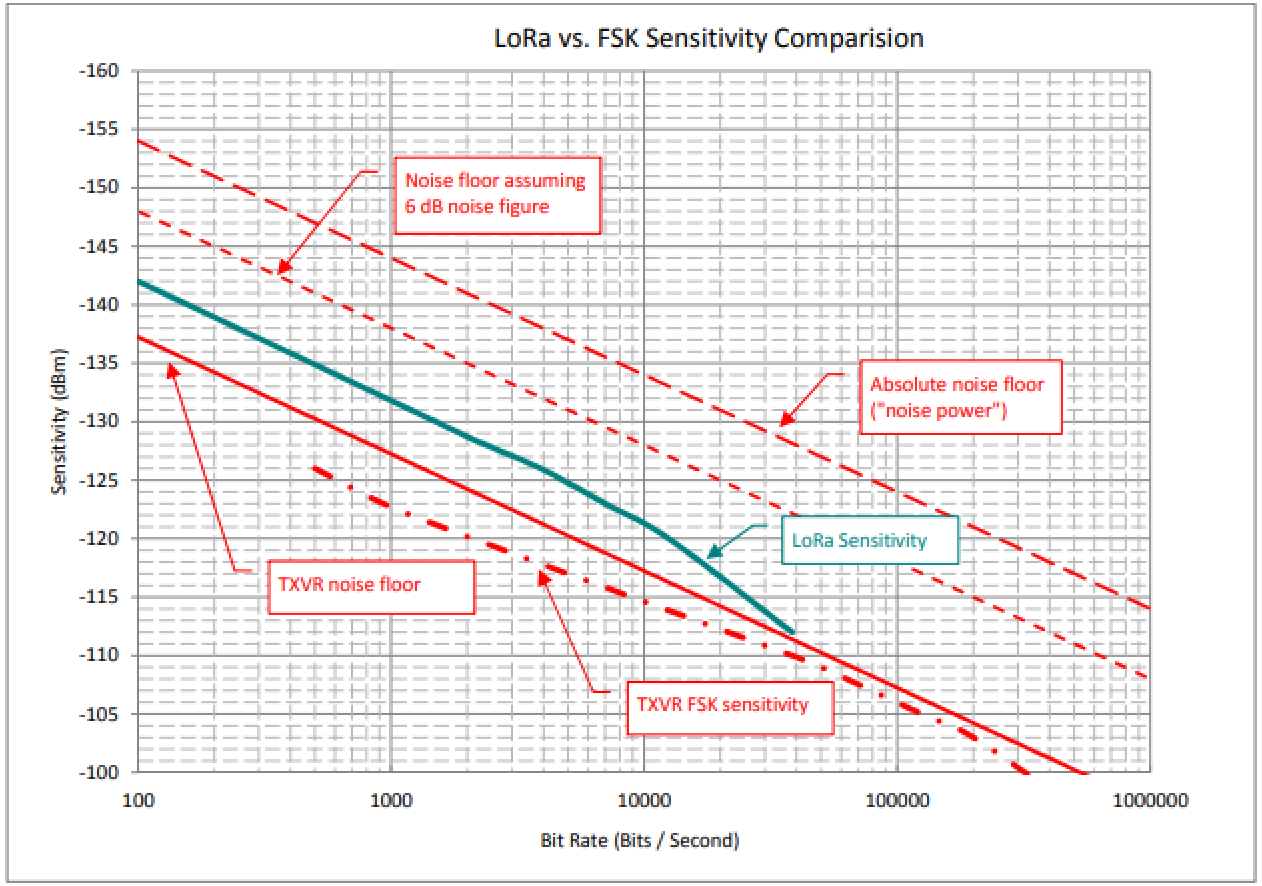
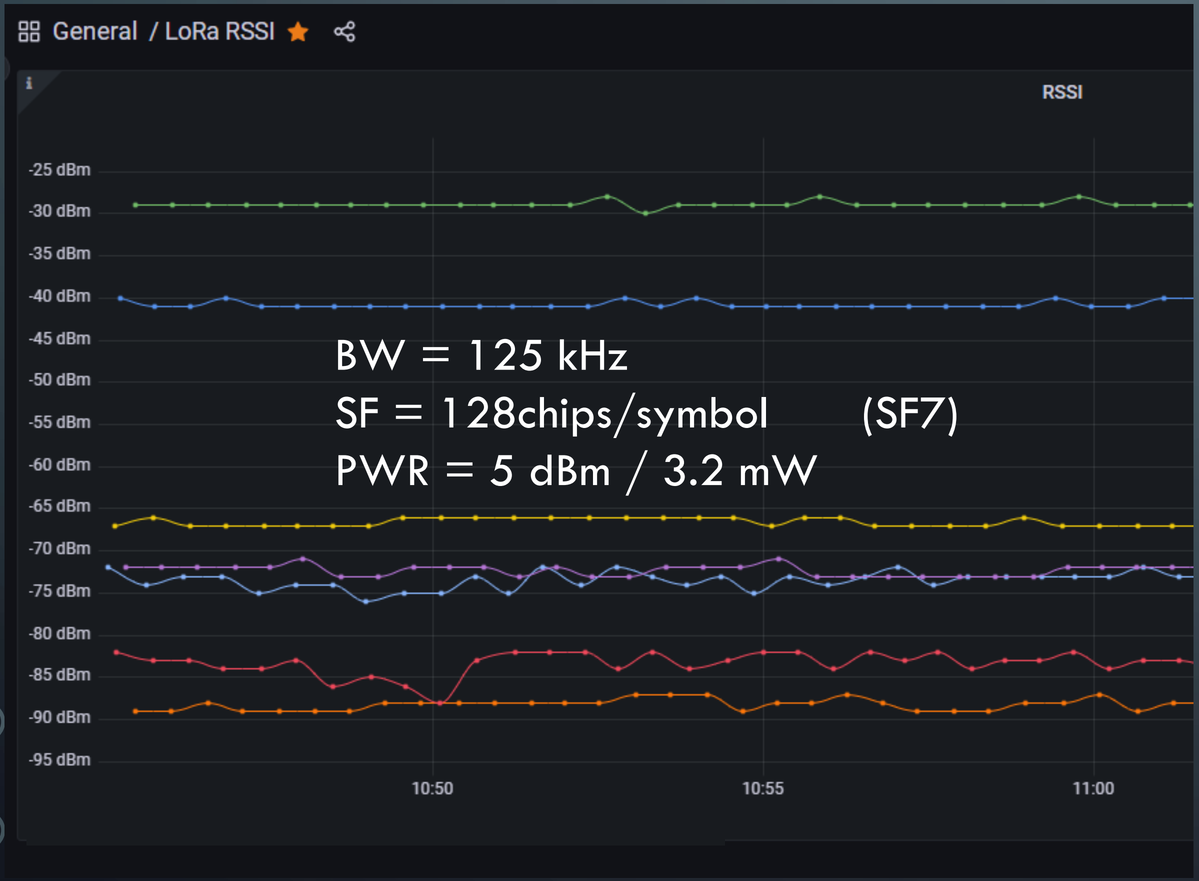


Figure 3: Comparison of LoRa and FSK Sensitivity

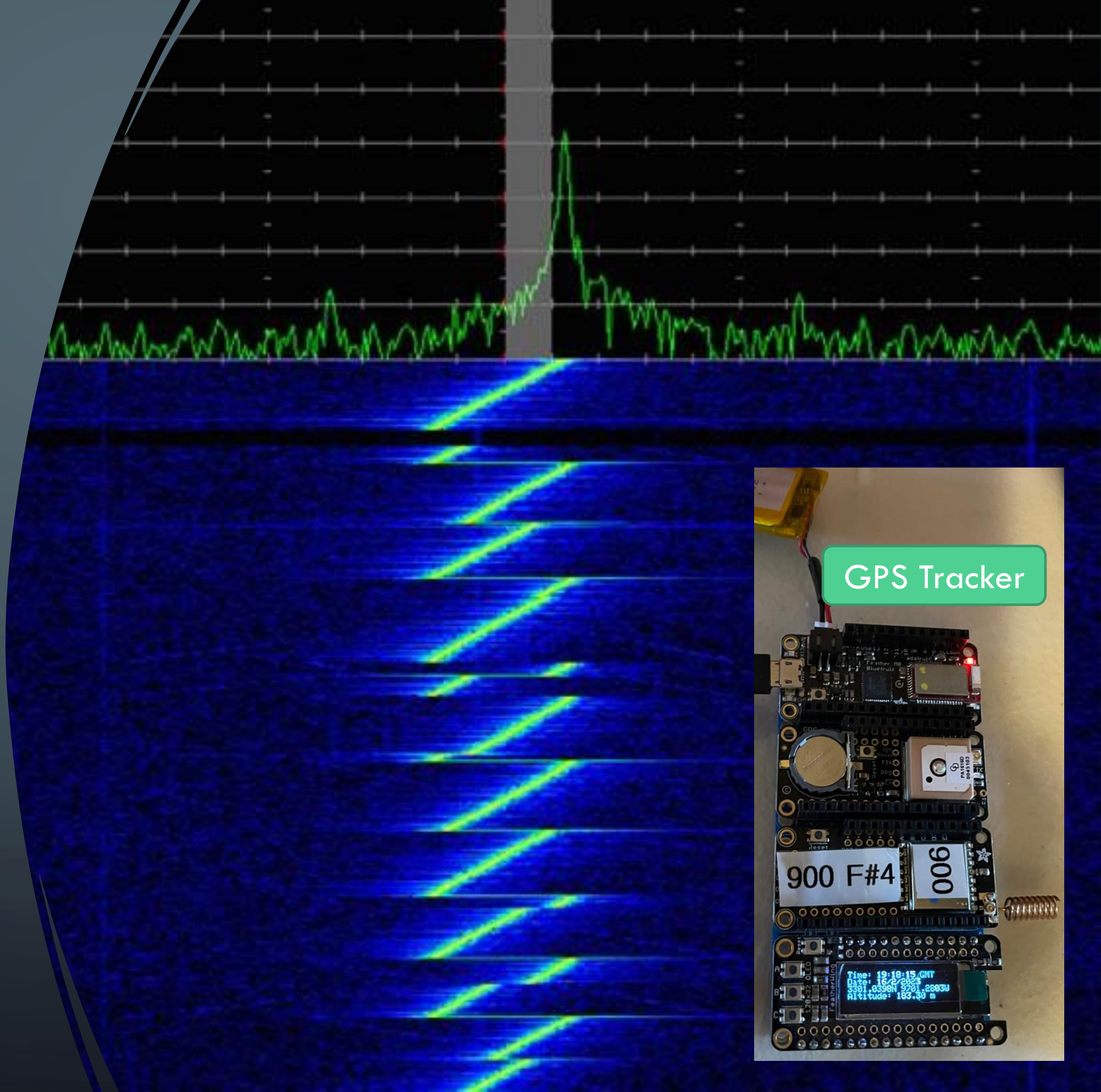
LORA – TECHNICAL ASPECTS



N5GG
433/900 MHZ LORA + WIFI MESH NETWORK

AN IMPLEMENTATION EXAMPLE

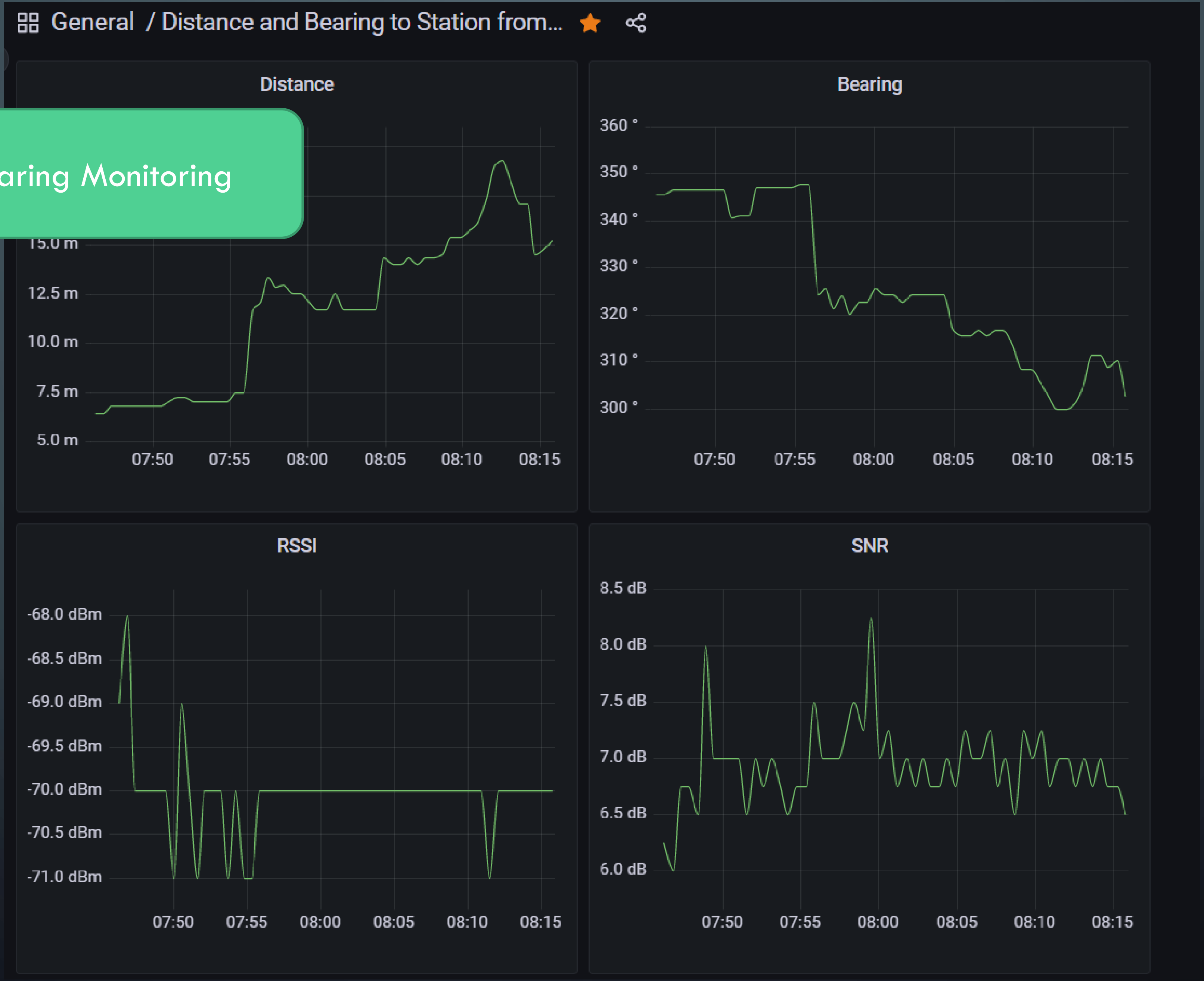
COLIN - N5GG



THE FINAL RESULT

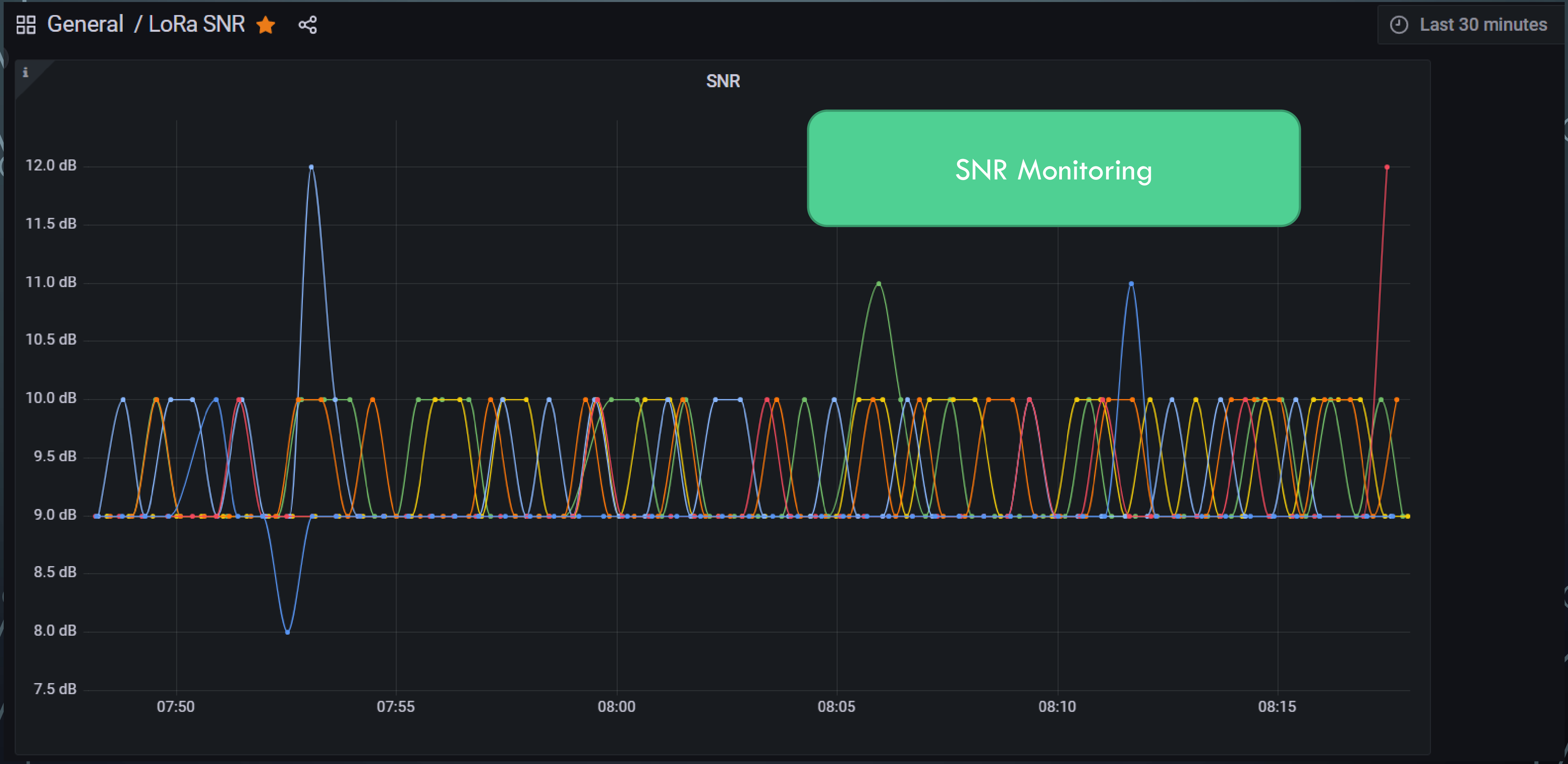
GPS Tracking

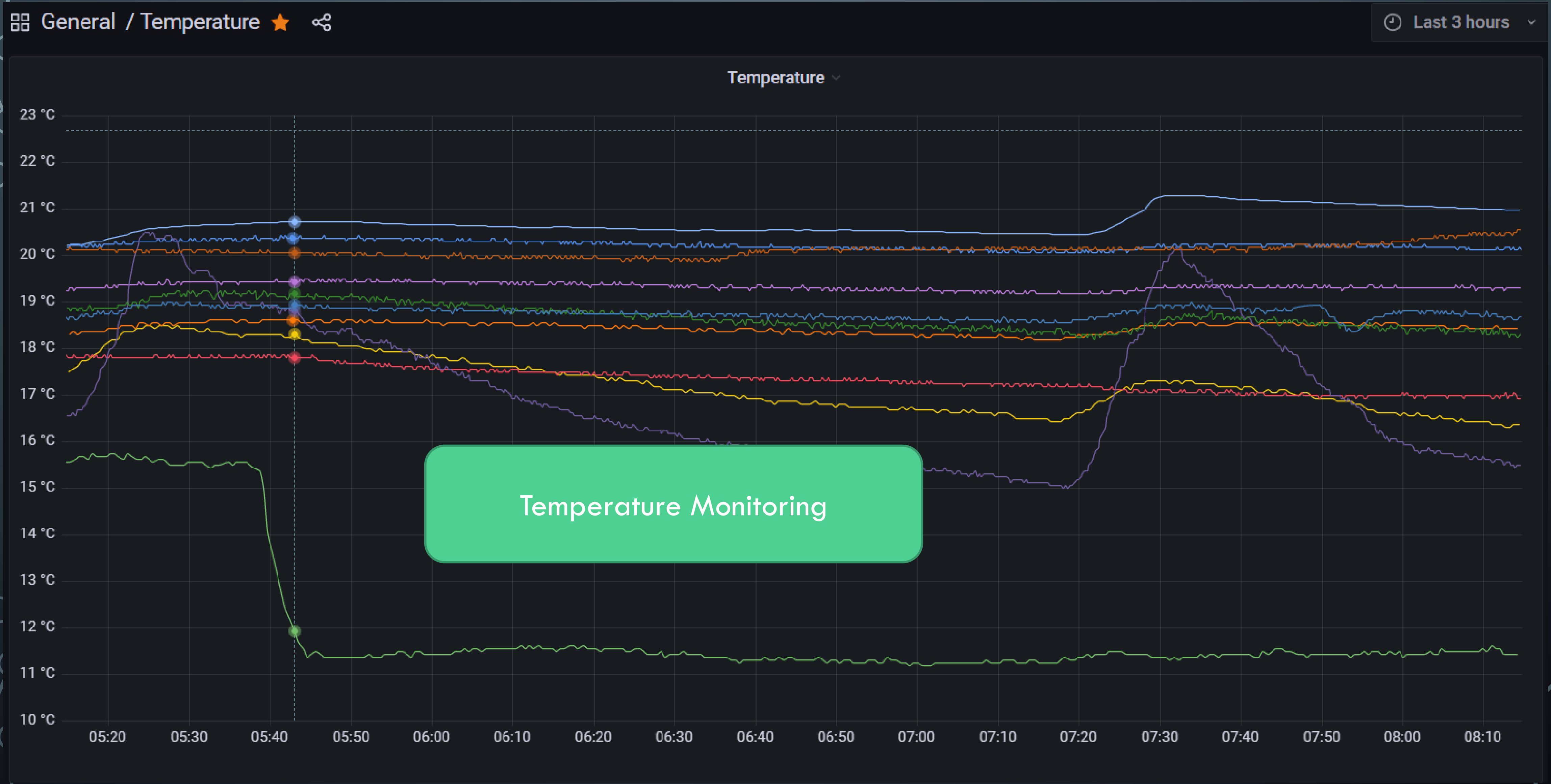
Distance/Bearing Monitoring

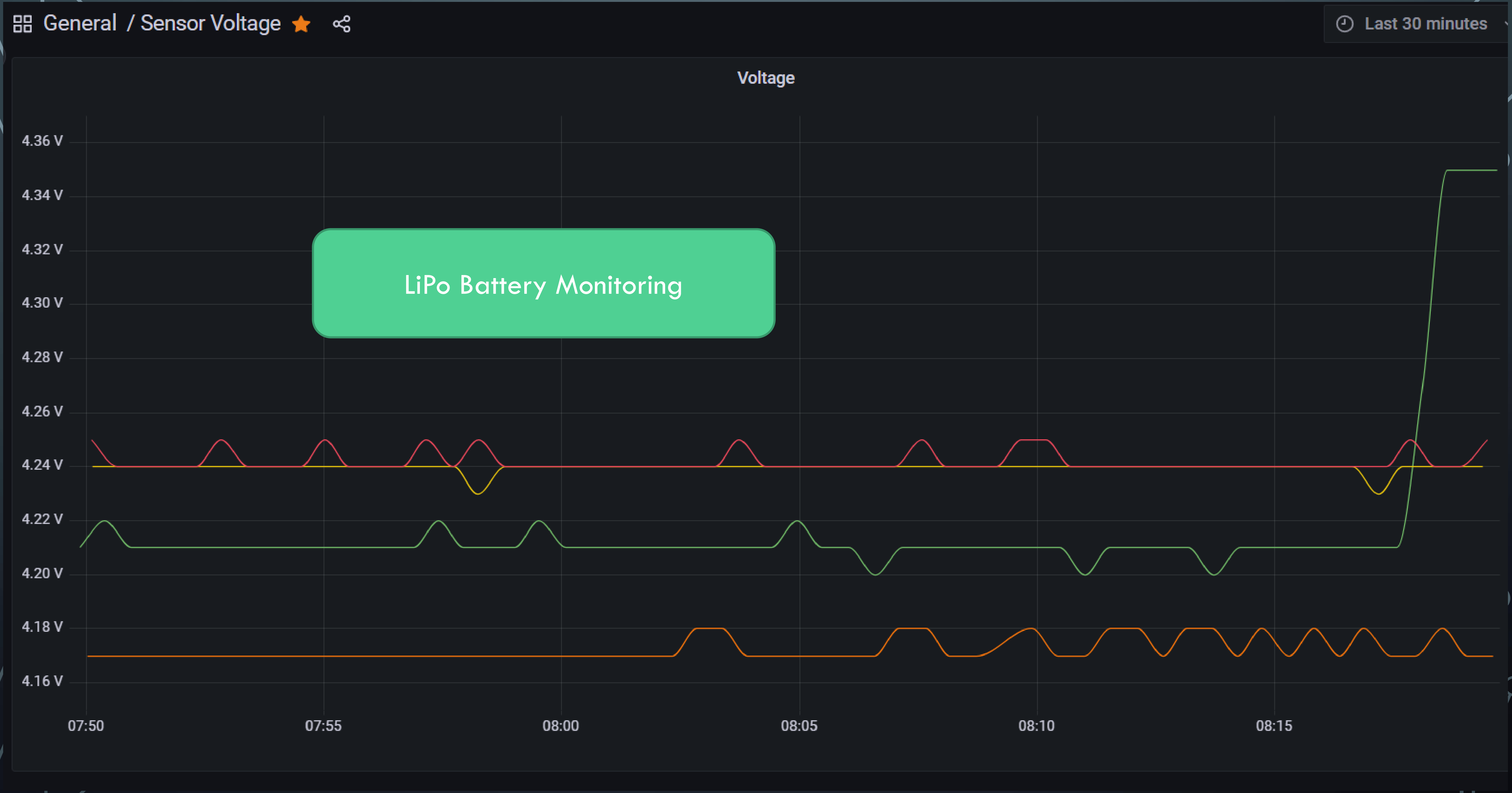


Signal Strength Monitoring

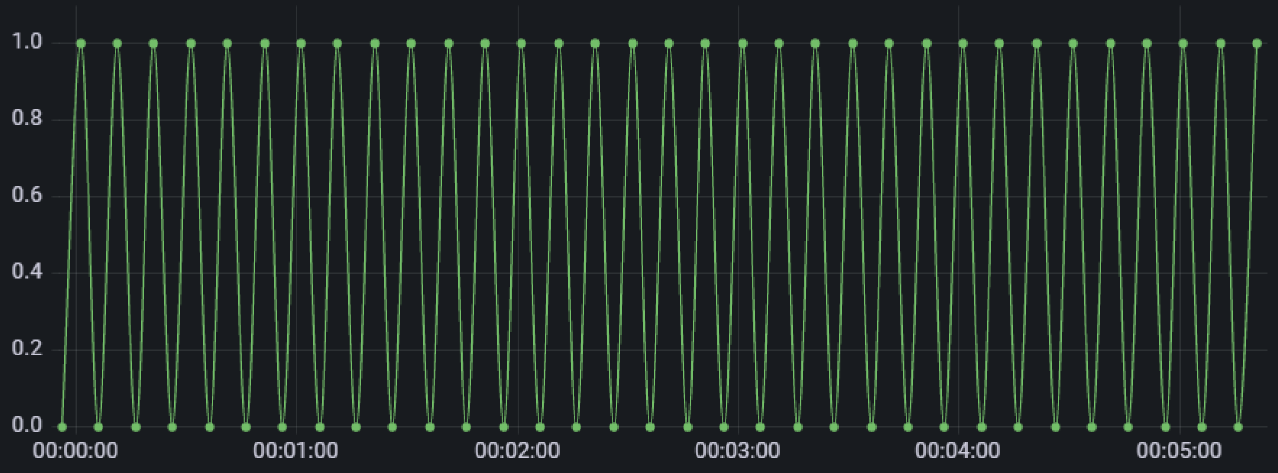
SNR Monitoring




General / Temperature
Last 3 hours
Temperature
23 °C
22 °C
21 °C
20 °C
19 °C
18 °C
17 °C
16 °C
15 °C
14 °C
13 °C
12 °C
11 °C
10 °C
05:20
05:30
05:40
05:50
06:00
06:10
06:20
06:30
06:40
06:50
07:00
07:10
07:20
07:30
07:40
07:50
08:00
08:10
Temperature Monitoring

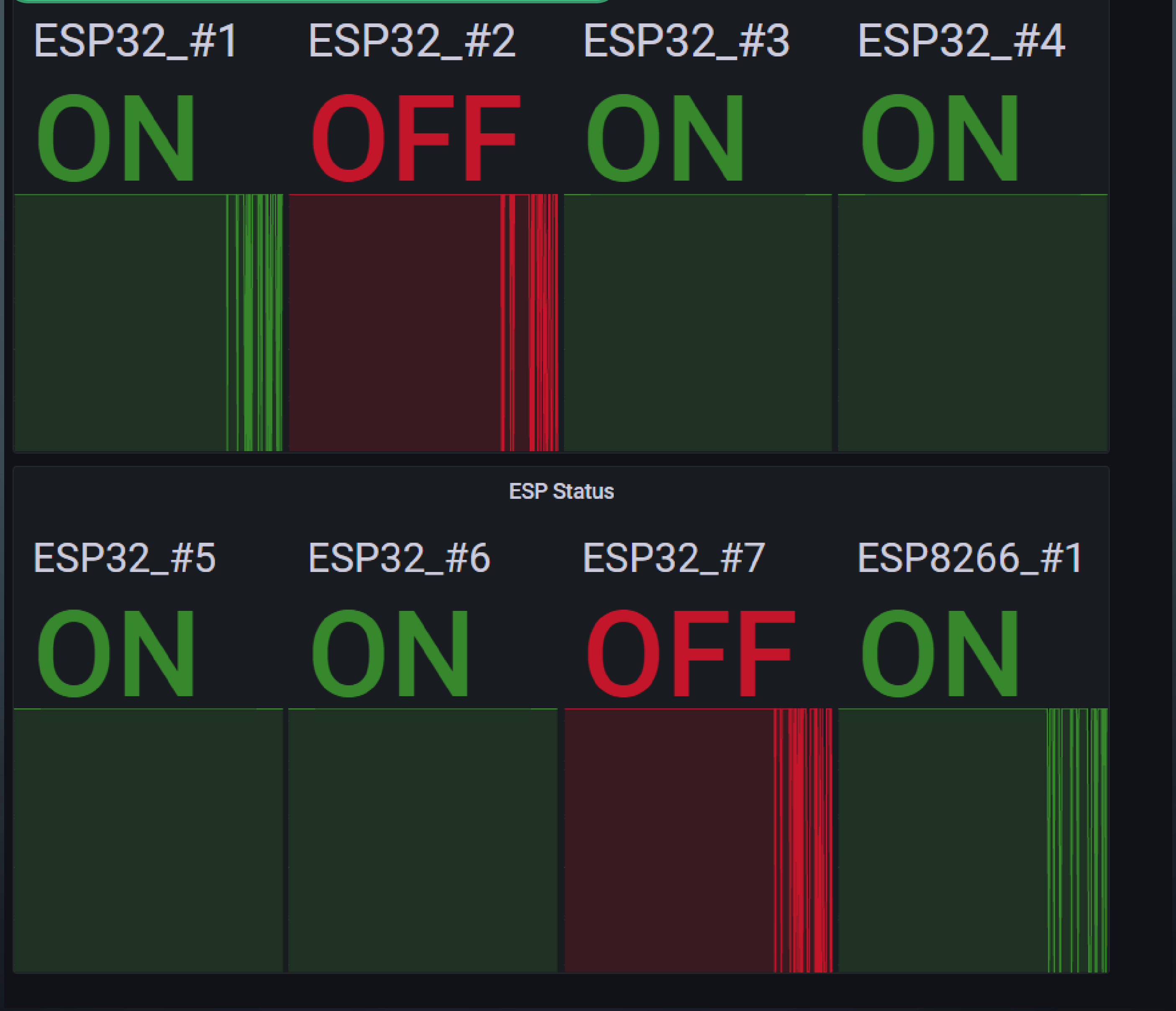

General / Sensor Voltage
Last 30 minutes
Voltage
4.36 V
4.34 V
4.32 V
4.30 V
4.28 V
4.26 V
4.24 V
4.22 V
4.20 V
4.18 V
4.16 V
07:50
07:55
08:00
08:05
08:10
08:15
LiPo Battery Monitoring

Generic Signal Monitoring



Tank Pressure

Sensor Status Monitoring



FIRST THINGS FIRST:

ENCODE THE INFORMATION TO BE SENT OVER LORA…

LoRa Payload Structure

Challenge:

1- Make Payload as compact as possible

2- Make Payload as flexible as possible

3- Allow for Payload to carry multiple measurements

4- Allow for several (hundreds) of different stations using same CALLSIGN but preserve unique identification

5- Detect error in Payload data

$	START of PAYLOAD
W5LVC	CALLSIGN
23	STATION ID
MEASUREMENTS…	
*	END of PAYLOAD
CHECKSUM	[XOR from $ to *]

Types of Measurements

```
TYPE of defined MEASUREMENTS:
empty - NO MEASUEMENTS (HEARTBEAT PACKET) payload has no measurement blocks (TLdddd)
0     - COUNTER
1     - TEMPERATURE
2     - PRESSURE
3     - HUMIDITY
4     - GPS_LAT
5     - GPS_LONG
6     - GPS_ALT
7     - GPS_GMT_TIME
8     - GPS_GMT_DATE
9     - GPS_SATS
10    - GPS_HDOP
11    - GPS_SPEED
12    - GPS_COURSE
13    - SNR
14    - RSSI
15    - POWER
16    - CURRENT
17    - VOLTAGE
18    - LOGIC
19    - tbd
...
44    - NO MEASUEMENTS (HEARTBEAT PACKET) payload has no measurement blocks (TLdddd) - note: this is the ASCII for '*' which is the END of data delimiter
...
253   - tbd
254   - tbd
255   - tbd
```

LoRa Payload Structure

```
==============================
LoRa Packet Payload Structure:
==============================
Payload up to 128 bytes (absolute max per LoRa standards is 255 bytes, code limits to 64 due to memory constaints)
0000000000111111111122222222223333333333444444444455555555556666
0123456789012345678901234567890123456789012345678901234567890123
$CCCCCCI<meas-1><meas-2>...<meas-n>*S
where:
$ - start of LoRa payload
CCCCCC - call sign - up to 6 ASCII characters
I - station ID 0-255 - 1 byte

<meas-1> measurement 1 composed of:
00000000001111111
01234567890123456
TLdddd...
where:
T - type of measurement (see table)
L - length of datastream - 1 byte
dddd - data set - up to 15 bytes

<meas-2> measurement 2 composed of:
00000000001111111
01234567890123456
TLdddd...
where:
T - type of measurement (see table)
L - length of datastream - 1 byte
dddd - data set - up to 15 bytes

<other measurements> (follows same sequence)

* - end of LoRa payload
S - simple xor checksum of all bytes from start to end, including start and end markers
```

LoRa Payload - Example

1 2 3 4 5 6 7 8 9 10 11

data":[36,78,53,71,71,0,0,33,17,2,1,163,4,4,1,247,205,200,5,4,250,55,146,152,6,3,0,6,125,11,2,0,2,12,2,104,7,42,196],

Block 1	36
Block 2	78,53,71,71,0,0
Block 3	33
Block 4	17,2,1,163
Block 5	4,4,1,247,205,200
Block 6	5,4,250,55,146,152
Block 7	6,3,0,6,125
Block 8	11,2,0,2
Block 9	12,2,104,7
Block 10	42
Block 11	196

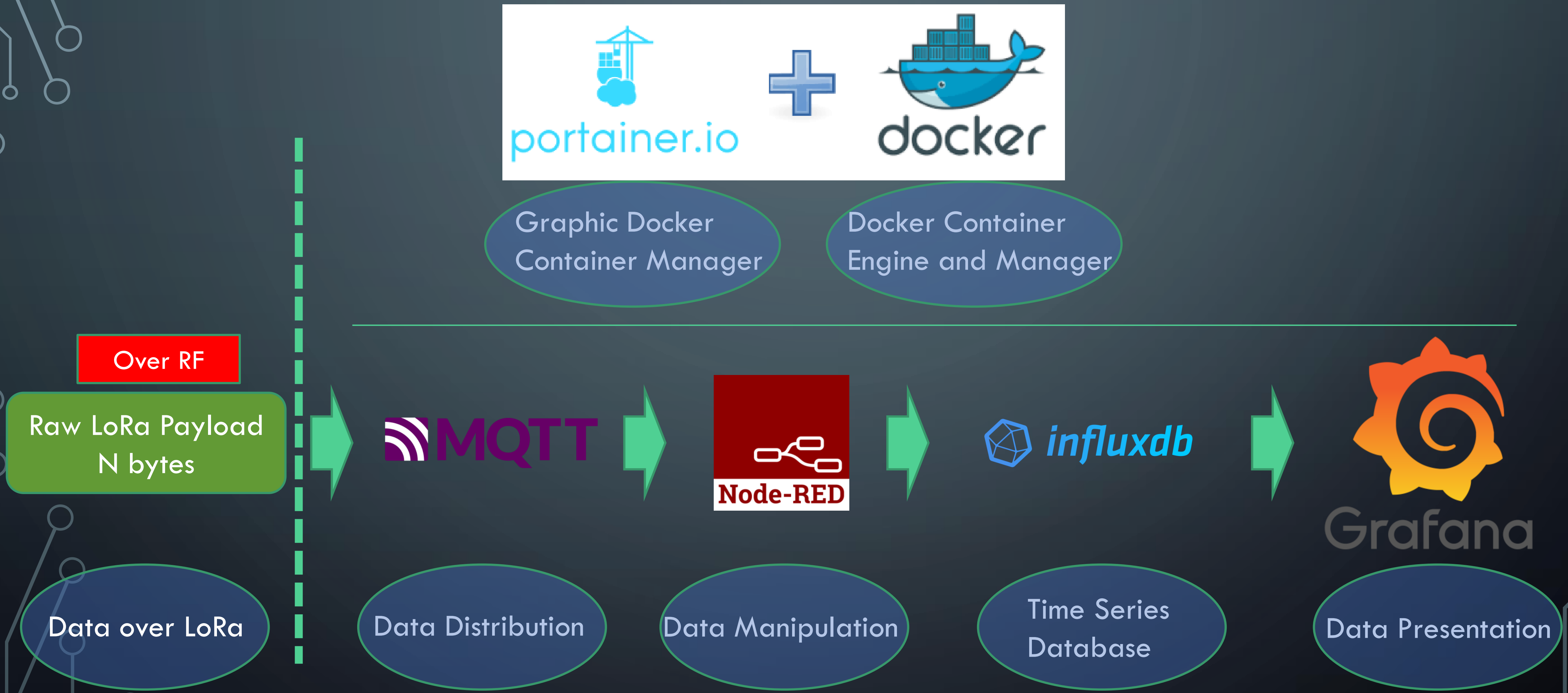
total of 39 bytes

$	START of PAYLOAD
N5GG	CALLSIGN
33	STATION ID
VOLTAGE	2 data bytes
GPS LATITUDE	4 data bytes
GPS LONGITUDE	4 data bytes
GPS ALTITUDE	3 data bytes
GPS SPEED	2 data bytes
GPS COURSE	2 data bytes
*	END of PAYLOAD
CHECKSUM	[XOR from $ to *]

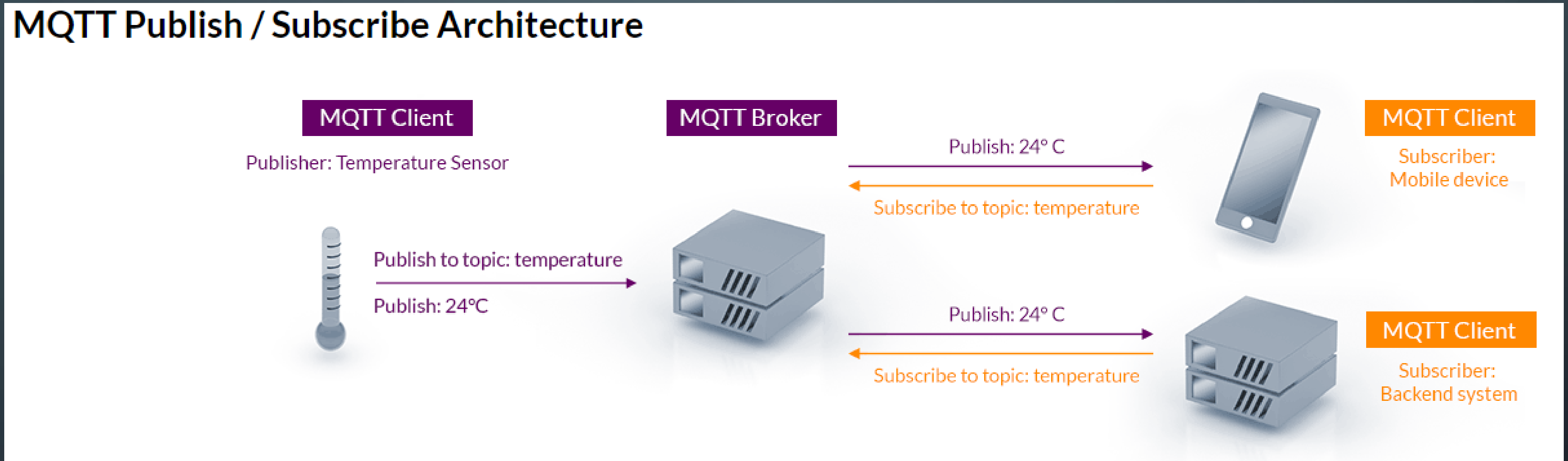
DATA PROCESSING AND PRESENTATION

MQTT / NODERED / INFLUXDB / GRAFANA

Data Workflow



MQTT stands for Message Queuing Telemetry Transport

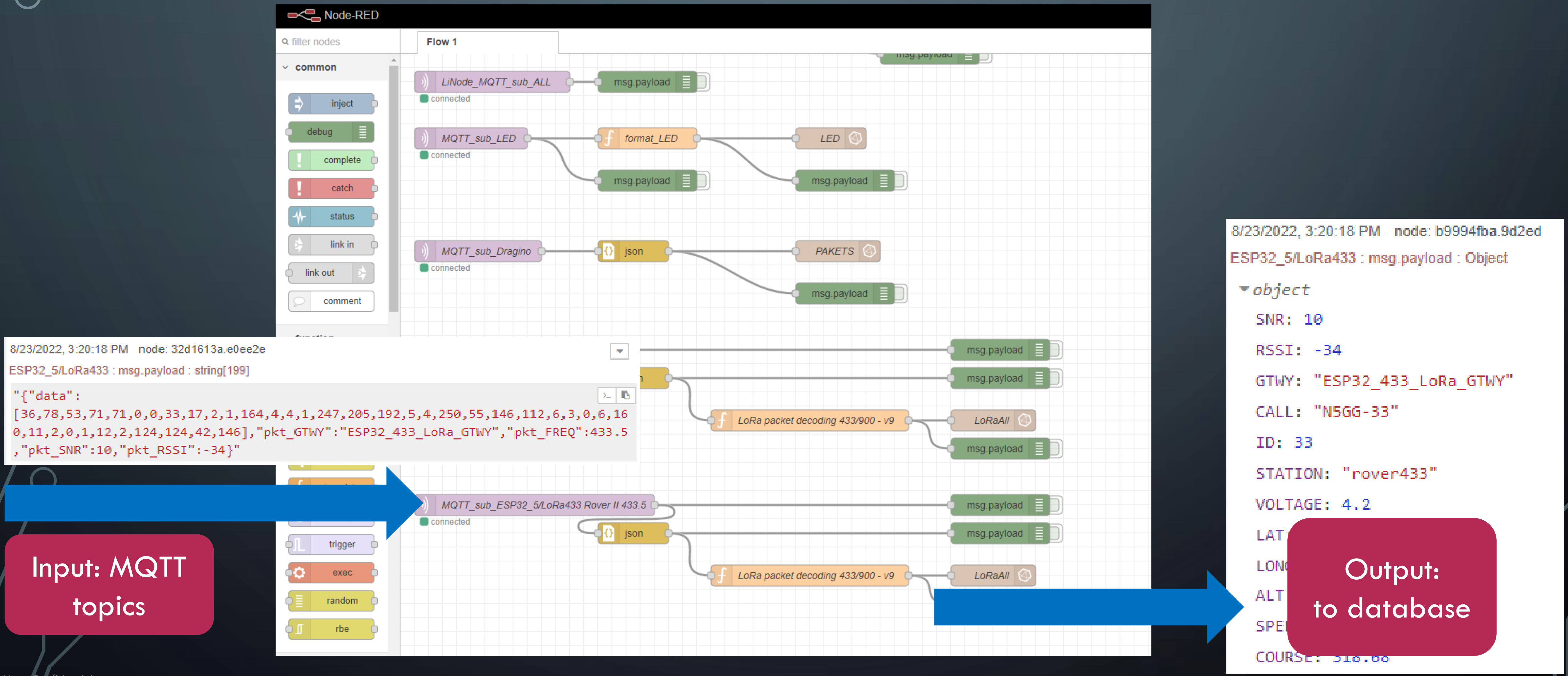


8/23/2022, 3:20:18 PM node: 32d1613a.e0ee2e

ESP32_5/LoRa433 : msg.payload : string[199]

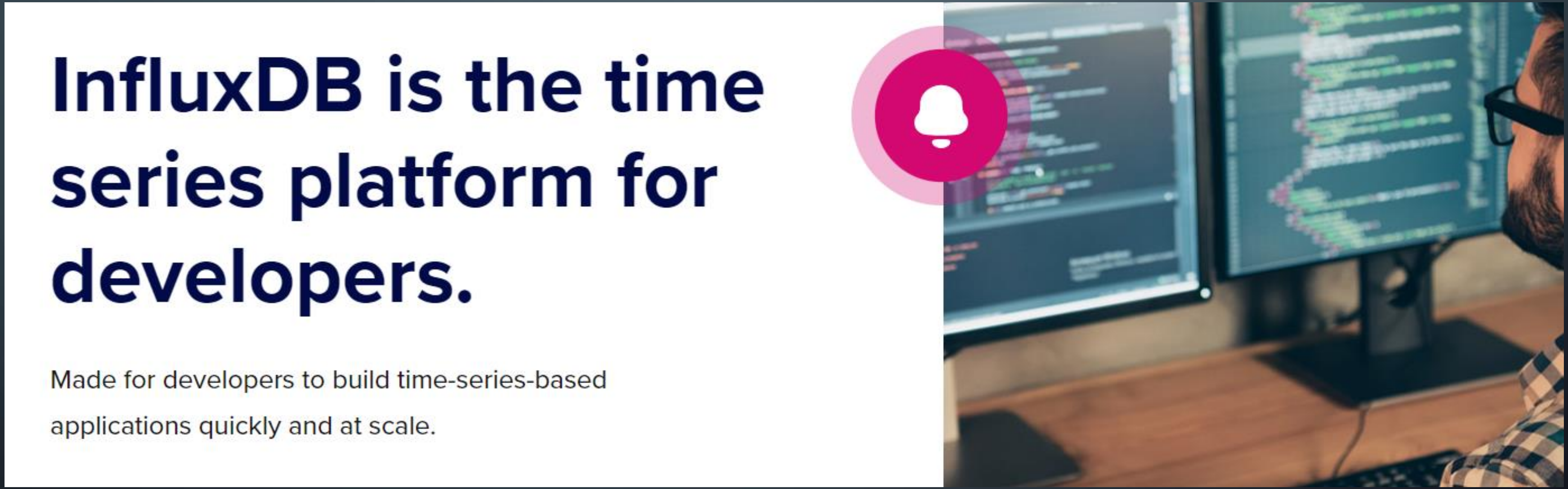
"{"data":[36,78,53,71,71,0,0,33,17,2,1,164,4,4,1,247,205,192,5,4,250,55,146,112,6,3,0,6,160,11,2,0,1,12,2,124,124,42,146],"pkt_GTWY":"ESP32_433_LoRa_GTWY","pkt_FREQ":433.5,"pkt_SNR":10,"pkt_RSSI":-34}"

Node-RED is a programming tool for **wiring together hardware devices, APIs and online service**



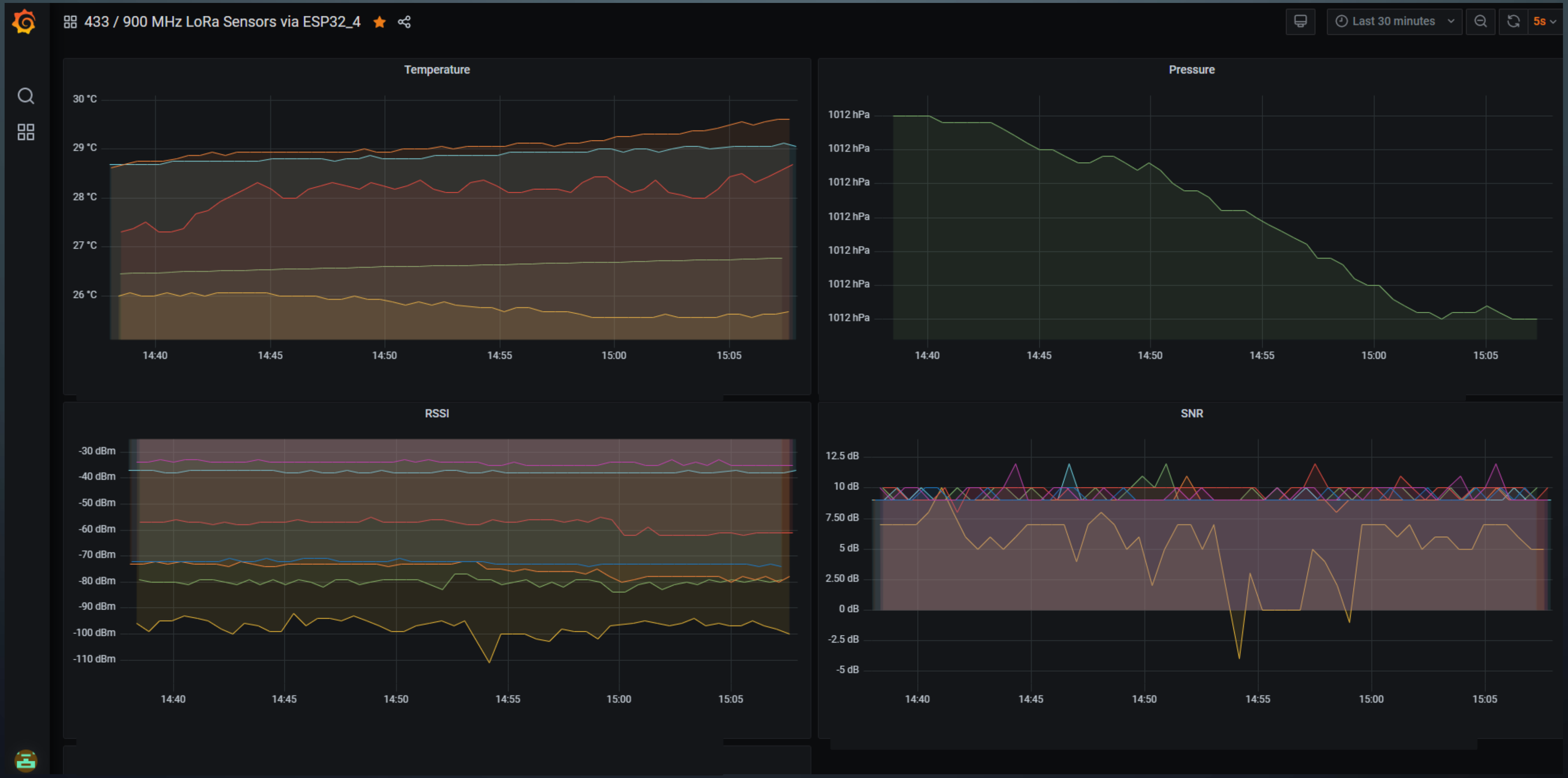
influxdb

InfluxDB is an open-source time series database (TSDB)



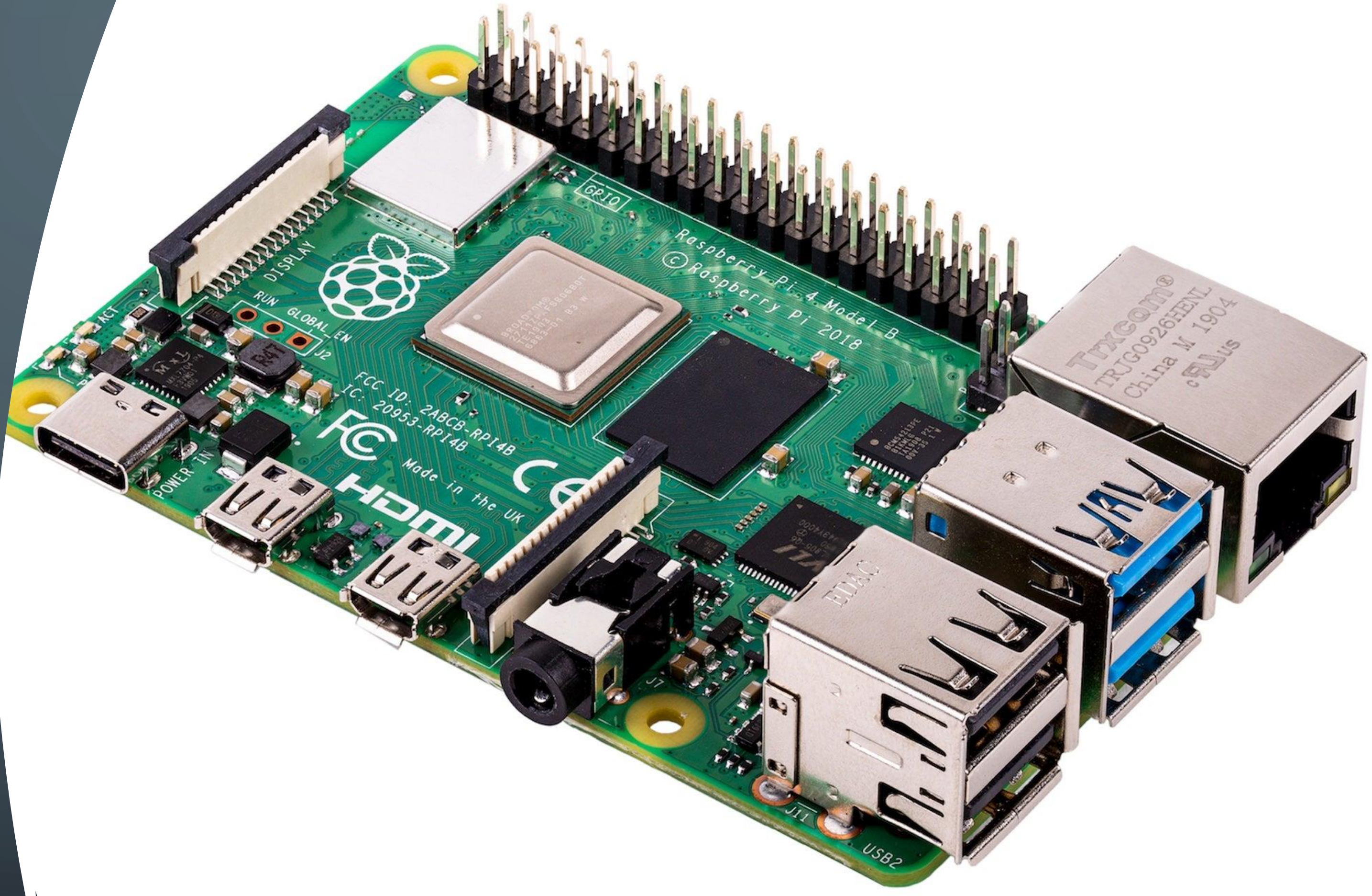
Grafana

Grafana used to query, visualize, alert on, and understand metrics no matter where they are stored



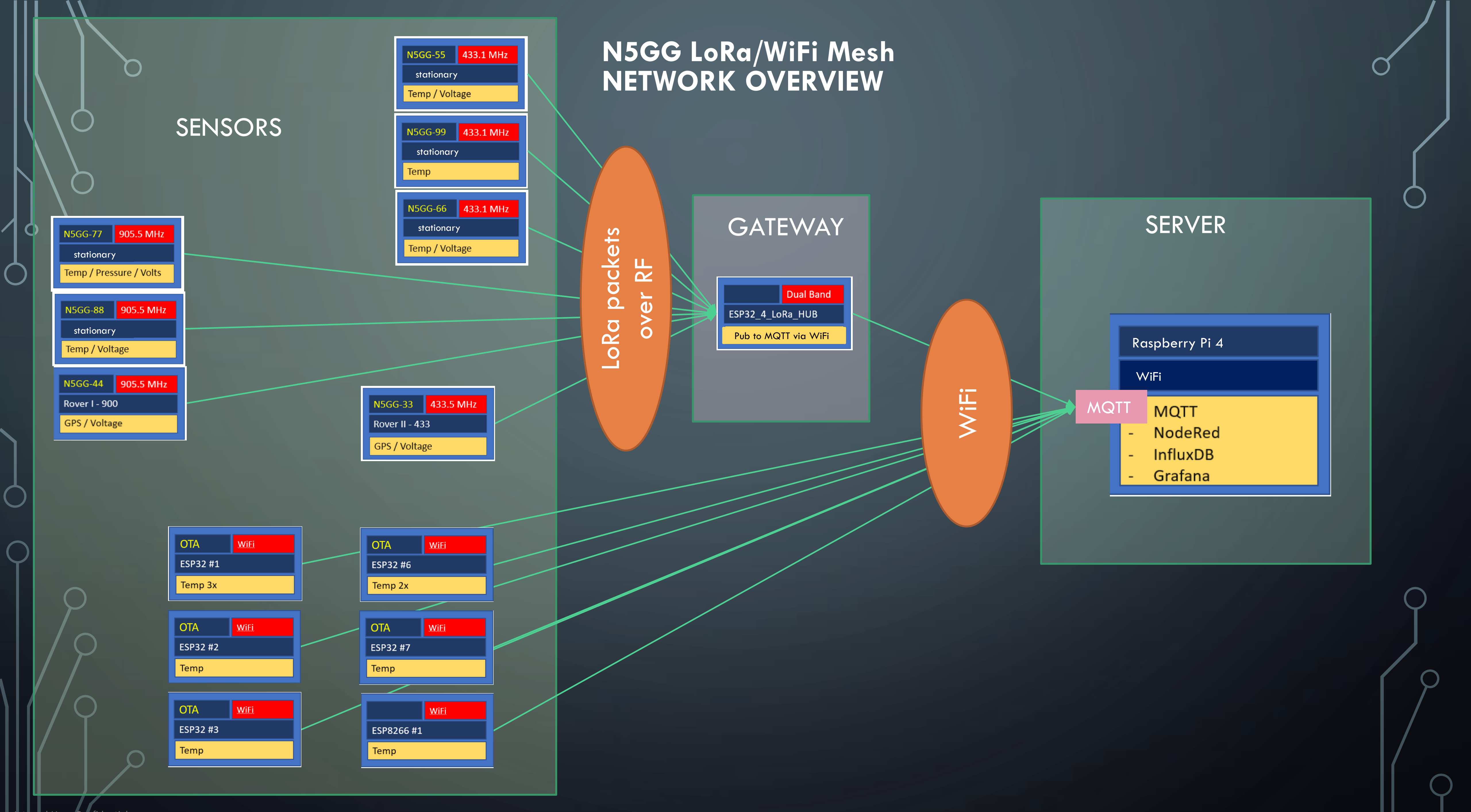
EVERYTHING RUNS ON RASPBERRY PI HARDWARE

THE PI IS THE SERVER



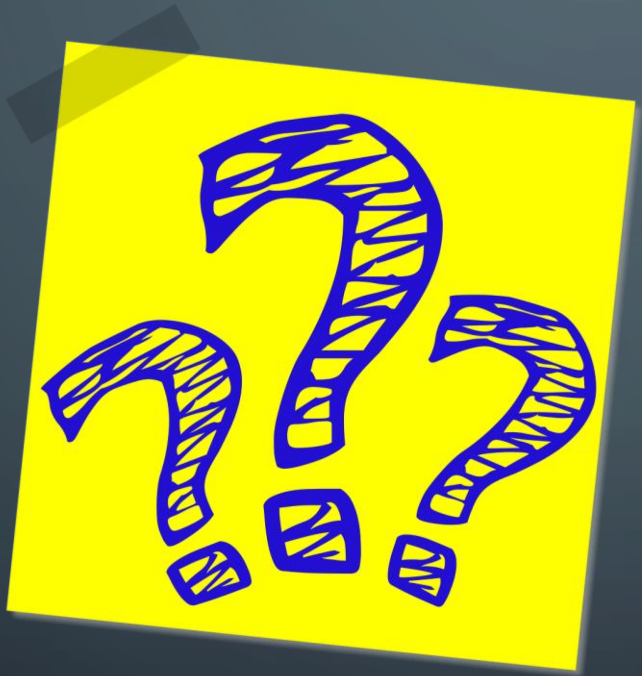
NETWORK OVERVIEW

SENSORS / GATEWAY / SERVER



N5GG LoRa/WiFi Mesh
NETWORK OVERVIEW
SENSORS
N5GG-55
433.1 MHz
stationary
Temp / Voltage
N5GG-99
433.1 MHz
stationary
Temp
N5GG-66
433.1 MHz
stationary
Temp / Voltage
N5GG-77
905.5 MHz
stationary
Temp / Pressure / Volts
N5GG-88
905.5 MHz
stationary
Temp / Voltage
N5GG-44
905.5 MHz
Rover I - 900
GPS / Voltage
N5GG-33
433.5 MHz
Rover II - 433
GPS / Voltage
OTA
WiFi
ESP32 #1
Temp 3x
OTA
WiFi
ESP32 #6
Temp 2x
OTA
WiFi
ESP32 #2
Temp
OTA
WiFi
ESP32 #7
Temp
OTA
WiFi
ESP32 #3
Temp
WiFi
ESP8266 #1
Temp
LoRa packets over RF
GATEWAY
Dual Band
ESP32_4_LoRa_HUB
Pub to MQTT via WiFi
WiFi
SERVER
Raspberry Pi 4
WiFi
MQTT
MQTT
- NodeRed
- InfluxDB
- Grafana

QUESTIONS? COMMENTS?



73 de N5GG

dah dah dit dit dit
dit dit dit dah dah!


感謝你
Danke
Gracias
Grazie
Merci
Thanks!
THANK
YOU!