

A photograph showing two workers on a metal roof. One worker is on the left, wearing a grey t-shirt and a grey cap, working on some yellow cables. The other worker is in the center, wearing a grey t-shirt with 'GSD' printed on it, blue jeans, and a tan bucket hat, working on a white rectangular device. They are both wearing safety harnesses and are positioned on a metal roof with a view of a field and trees in the background.

Adventures in Agricultural IoT

TALES OF SENSOR
NETWORKS,
INDUSTRIAL
CONTROL
SYSTEMS, AND
STORED GRAIN
MONITORING

JARED BATER

Jared Bater



Linux & networking
nerd for over 25 years

IoT shenanigans for
the last 4

GSI/AGCO by way of
151 Research

Conquered my fear of
heights (mostly) by
climbing sharp metal
structures on big
farms



Grain Storage: The Grain Bin

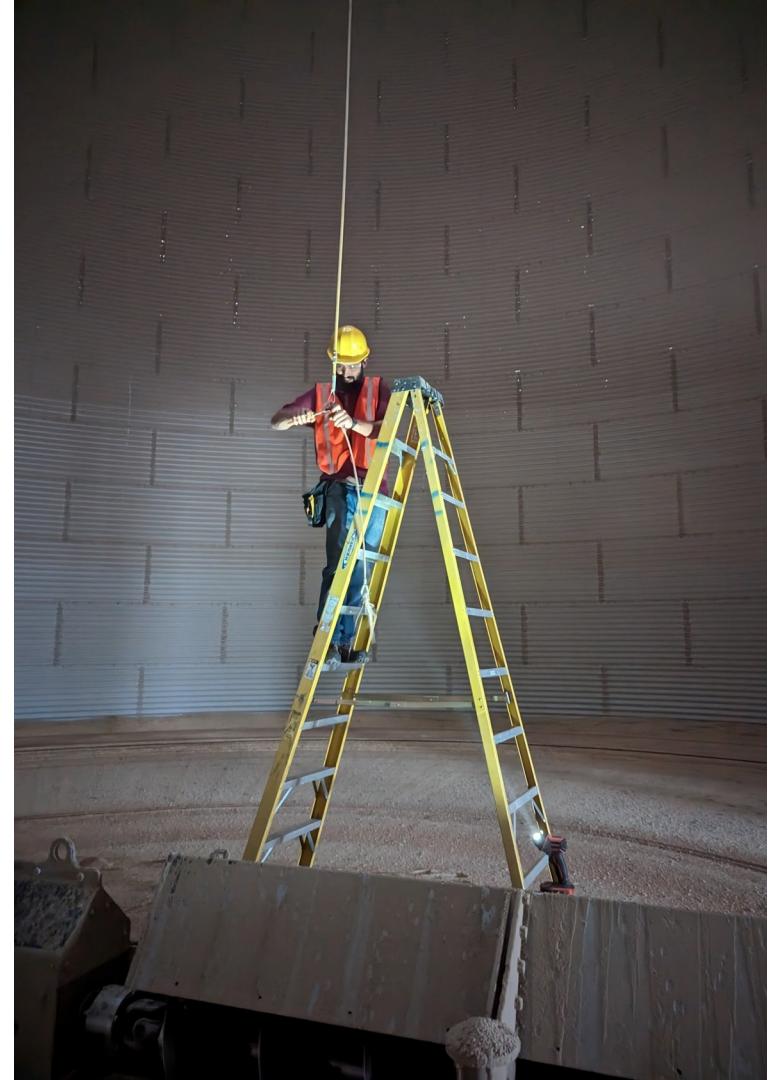
Anatomy of a grain bin

- Corrugated steel sheet walls
- Flat bottom
- Raised floor with perforated deck
- Plenum space between foundation and raised floor for air flow



Why monitor the grain?

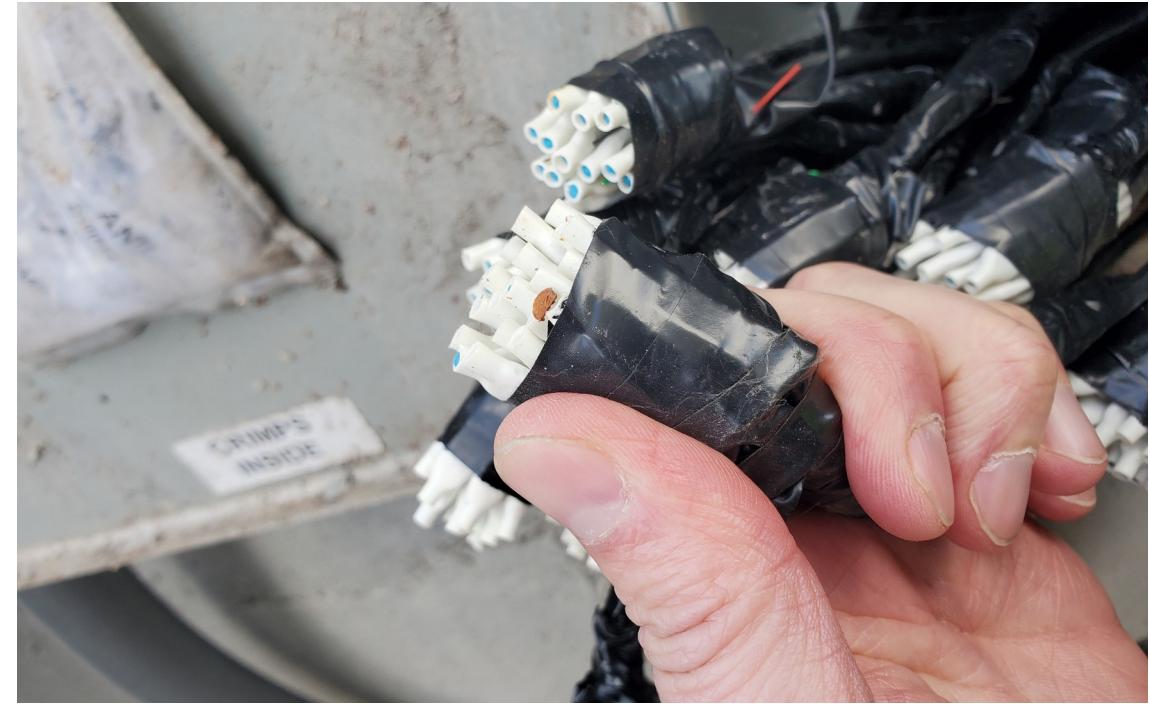
- Bins hold a **lot** of grain
- It's worth a **lot** of money
- We measure
 - Temperature
 - Moisture
 - CO2



Temperature / Moisture Cables

- We suspend temperature and/or humidity cables from the roof
- Grain fills the bin from the top and the cables become covered in grain
- Cables have sensor nodes evenly spaced (4' usually) along the cable
- Cable leads exit the roof





Analog Thermocouples

- Older cables use thermocouples
- Require large number of leads
- Manual reading
- Temperature only (no moisture)

Modern Digital Cables

Digital cables have two leads

1-wire based (Data + Power)

Temperature + Moisture



Grain Conditioning with Fans

- Optimize Temp / Moisture for storage
- Grain is sold by weight, not volume, so make it as wet as possible (kinda)

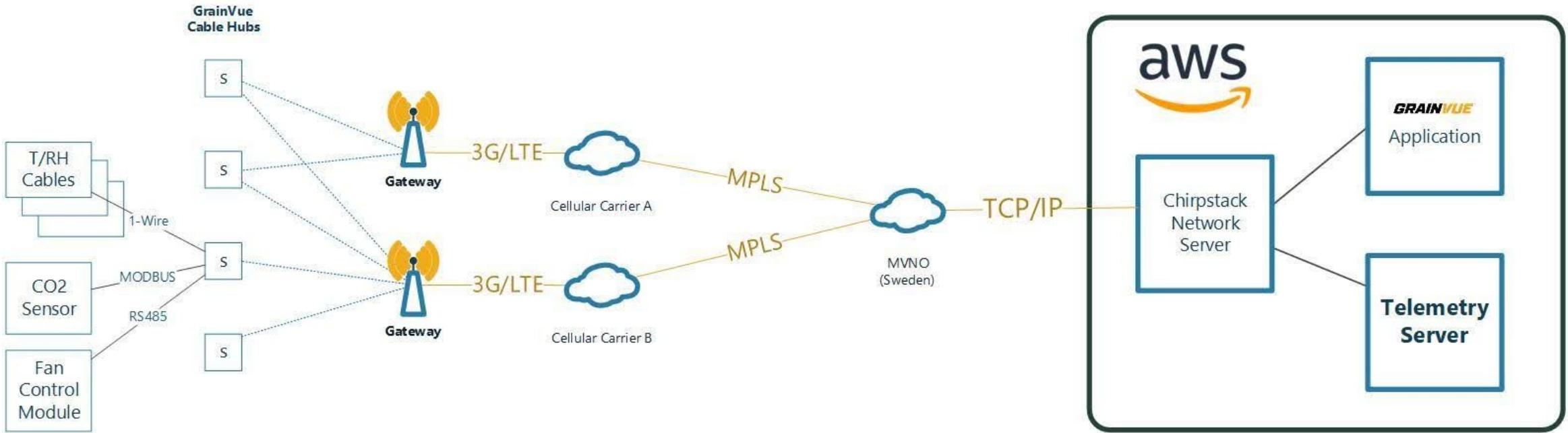




GrainVue System

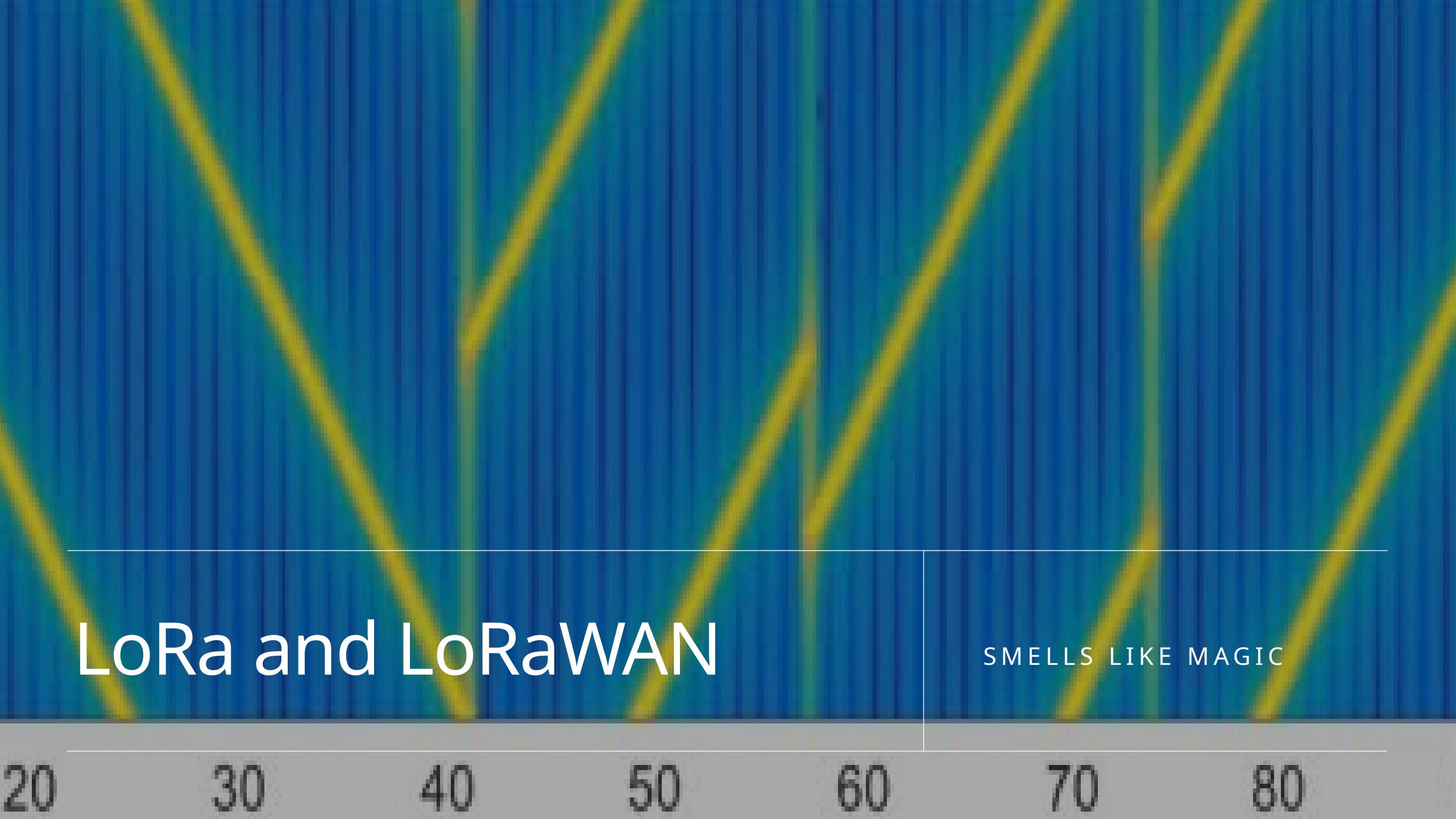
Marketing Says:

- Monitors temperature, moisture and inventory
- Automates fan operation to cool, dry, store or rehydrate
- Get alerts when potential signs of spoilage are detected



GrainVue Communications

- 1-Wire, MODBUS, RS485
- LoRaWAN
- Cellular 3G/4G w/ MVNO
- Commercial Internet



LoRa and LoRaWAN

SMELLS LIKE MAGIC

20

30

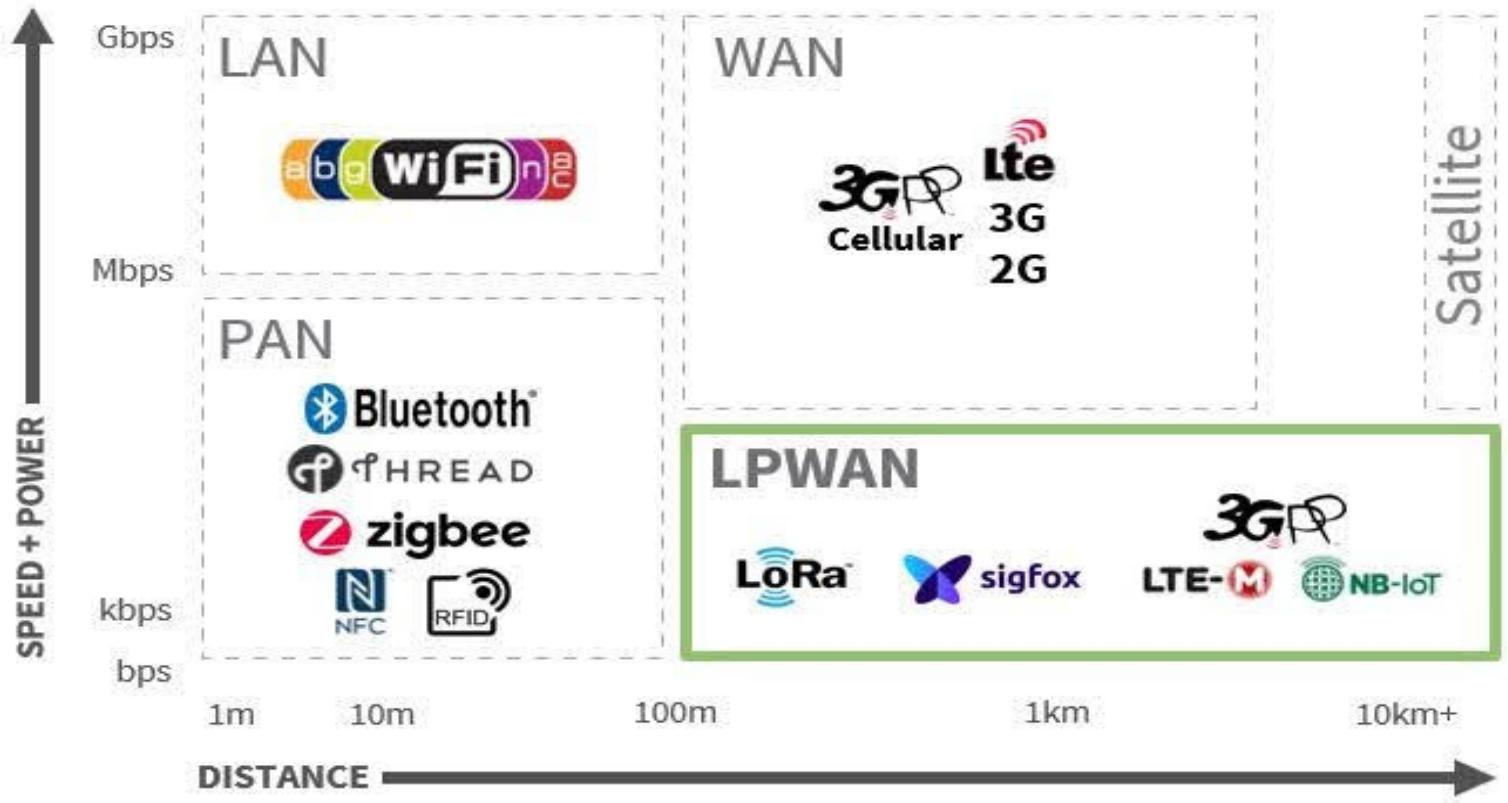
40

50

60

70

80



LPWAN

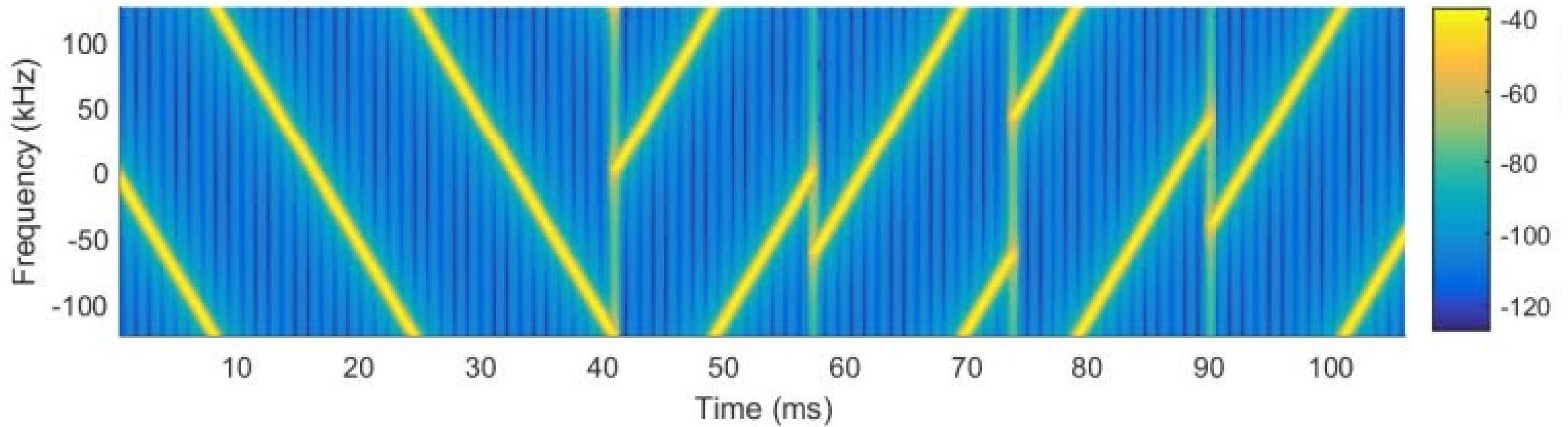
Low Power Wide Area Network

- Long Distance – Several KM
- Lower Power – Battery devices
- Low Bit Rate - < 100kbps
- High node density: many devices for few gateways

LoRa: The physical signaling



- Physical radio signaling technique, proprietary to Semtech
- Chirp Spread Spectrum
- Sub-gigahertz unlicensed spectrum
- 915 MHz (North America, AU, Others)
- 868 MHz (Europe)
- TX Power up to 20 dBm (100 mW), usually much lower
- Real-world link budget of ~ 135 dB



LoRa: The physical signaling

- Chirp Spread Spectrum (CSS)
- Good co-channel interference immunity
- Resistant to narrow and broadband disturbances
- Resistant to multipath fading
- Works well in noisy RF environments

Spreading Factor (For UL at 125 KHz)	Bit Rate	Range (Depends on Terrain)	Time on Air for an 11-byte payload
SF10	980 bps	8 km	371 ms
SF9	1760 bps	6 km	185 ms
SF8	3125 bps	4 km	103 ms
SF7	5470 bps	2 km	61 ms

LoRa Spreading Factors

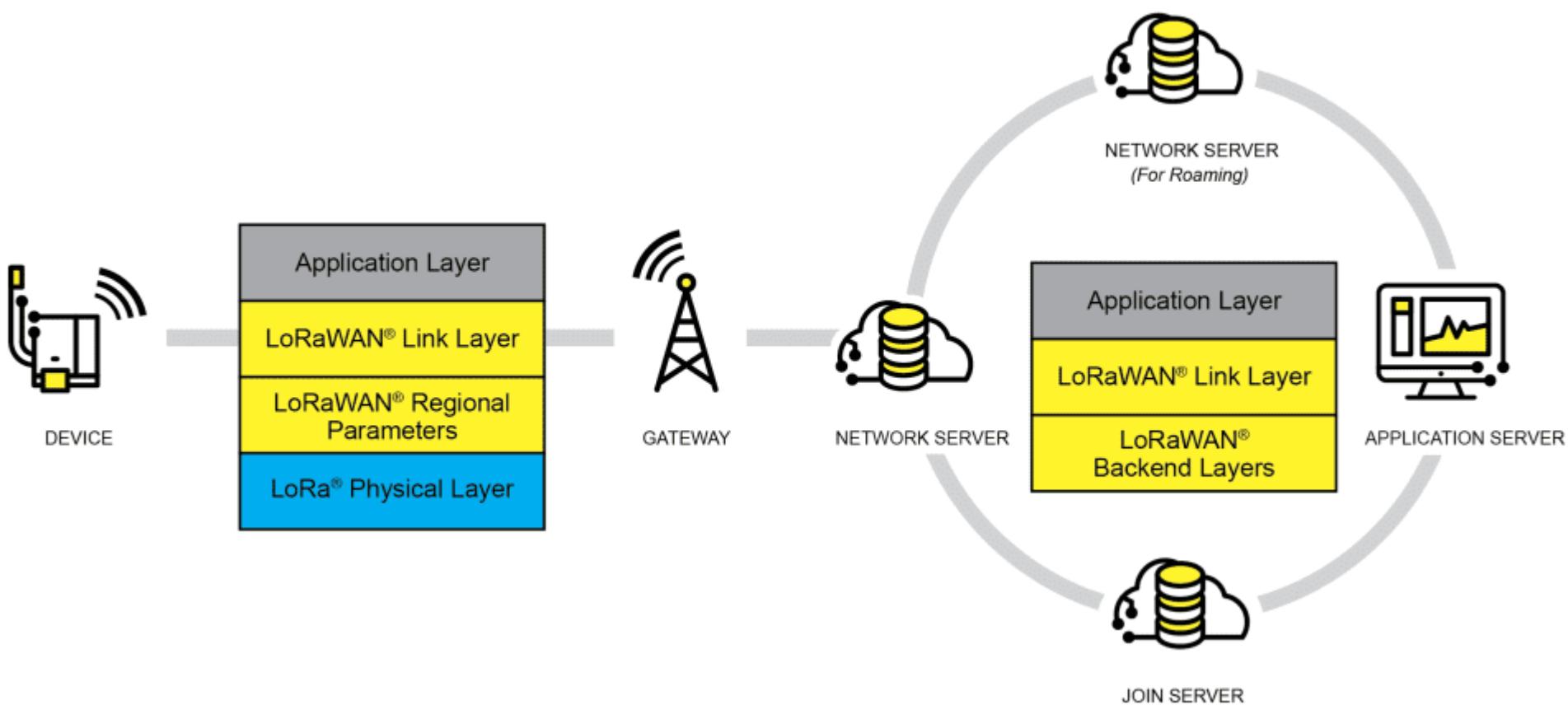
Influences:

- Data rate
- Distance
- Time On Air
- Receiver Sensitivity
- Battery Life

LoRaWAN: Networking protocol using the LoRa Phy

- ITU Standard
- LoRaWAN is developed by the LoRa Alliance
- Defines the MAC layer on top of LoRa Chirp Spread Spectrum physical layer
- Very region specific to adhere to regional RF use laws





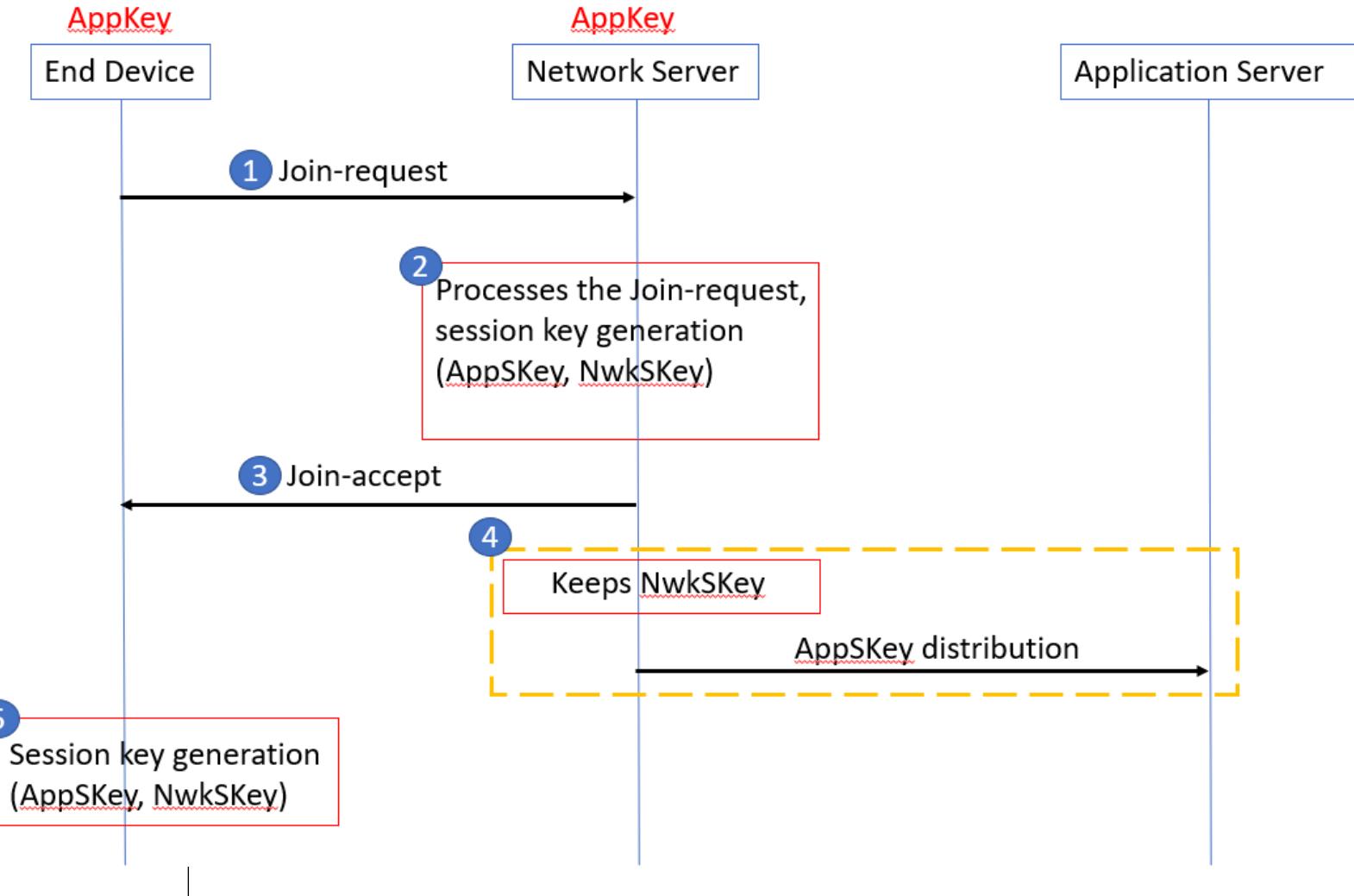
LoRaWAN Architecture

- Device
- Gateway
- Join Server
- Network Server
- Application Server

Join Process

1. Device sends **Join Request**:
DevEUI, nonce
2. Network Server derives
NwkSKey and AppSkey
3. NS sends **Join Accept** to
Device
4. NS distributes AppSKey to AS
5. Device derives same NwkSKey
and AppSkey

Device may now send uplink



LoRaWAN Security Features

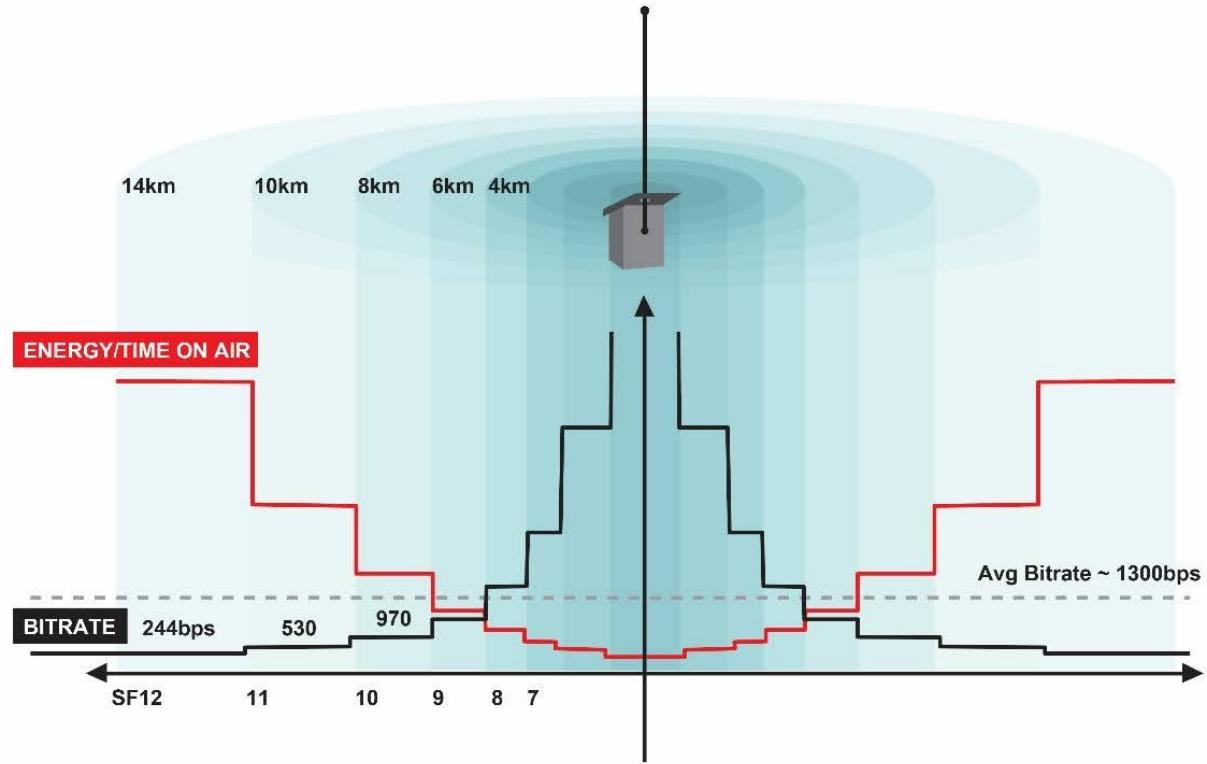
Sure it's "secure", but implementation matters

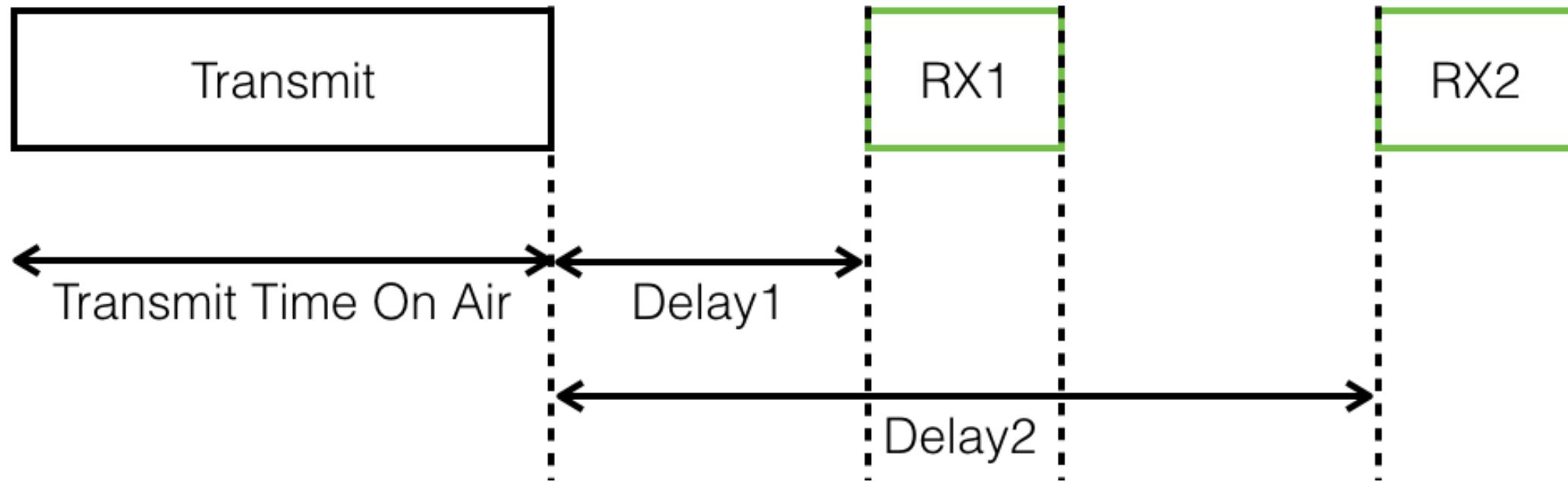
- Application Keys: Pre-Shared between Device and Join Server
- Dynamic Session Keys:
 - Network Session Key
 - Application Session Key
- Frame Counters for UL and DL
- Join Nonce
- MICs

Adaptive Data Rate

The Network can dynamically control device behavior based on signal strength of previous frames

- Spreading Factor
- Bandwidth
- Transmission Power





LoRa Uplink and Downlink Timing

- Class-A (Battery Powered) Wakes up and sends Uplink
- RX1: Waits for `Delay1` then listens for Downlink
- RX2: Waits for `Delay2` then listens for Downlink
- Sleepy Time

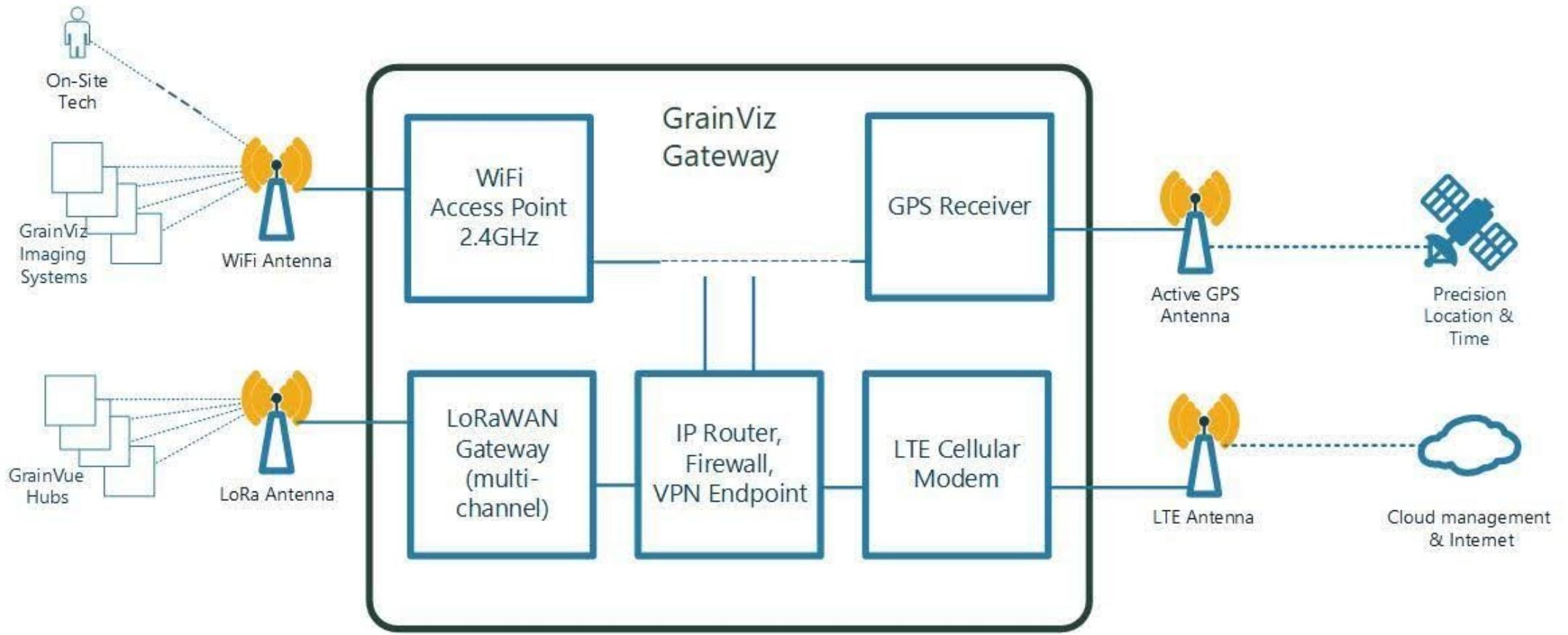


LoRaWAN Device

- Multitech xDot
- Implements the whole end-device stack
- Interface with a UART
- Driven by a microcontroller



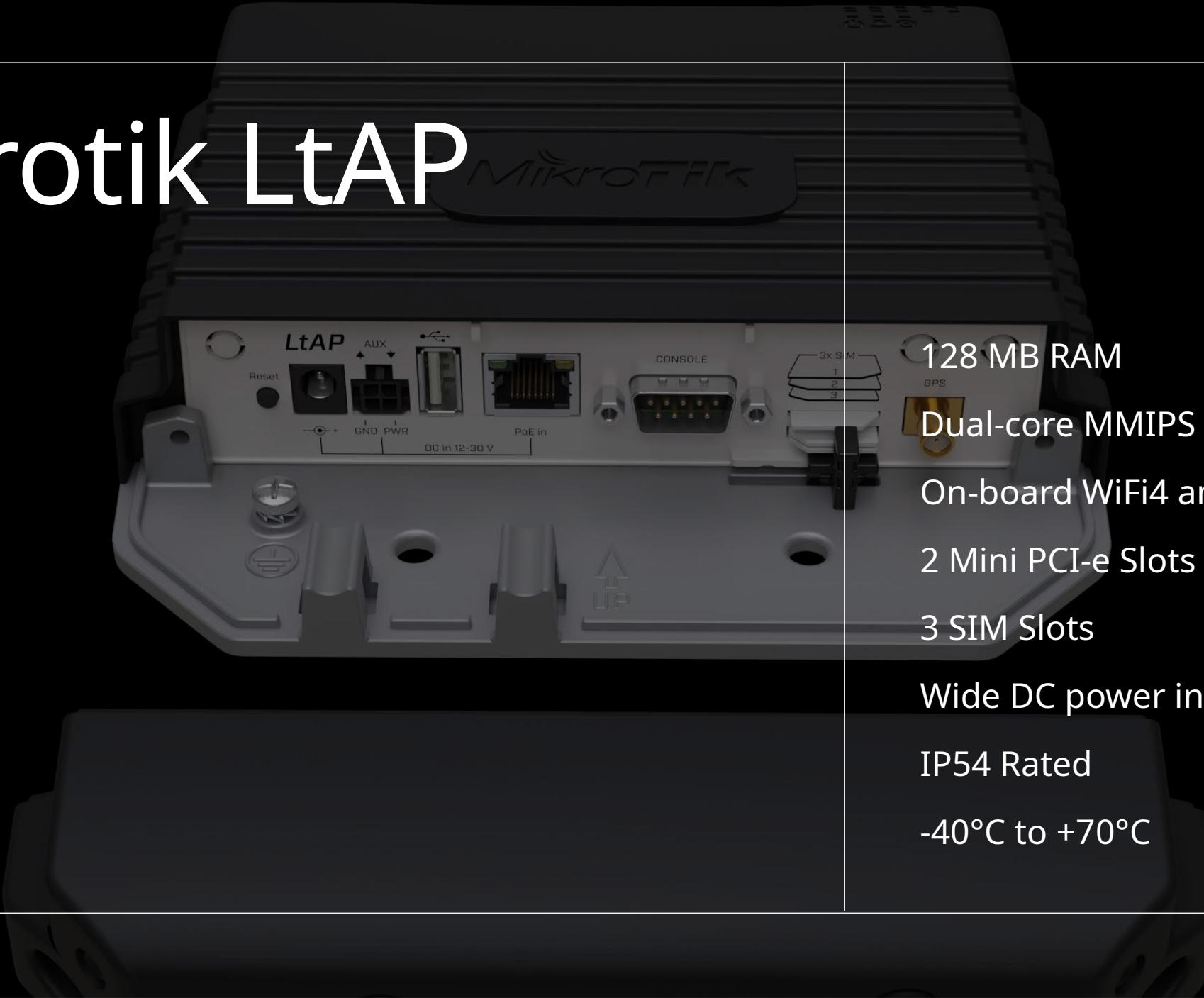
LoRaWAN & Cell Gateway



Gateway Functions

- LoRaWAN multi-channel gateway
- WiFi AP
- GPS Receiver
- LTE/3G modem
- Regular “router stuff”

Mikrotik LtAP



128 MB RAM

Dual-core MMIPS CPU

On-board WiFi4 and GPS

2 Mini PCI-e Slots

3 SIM Slots

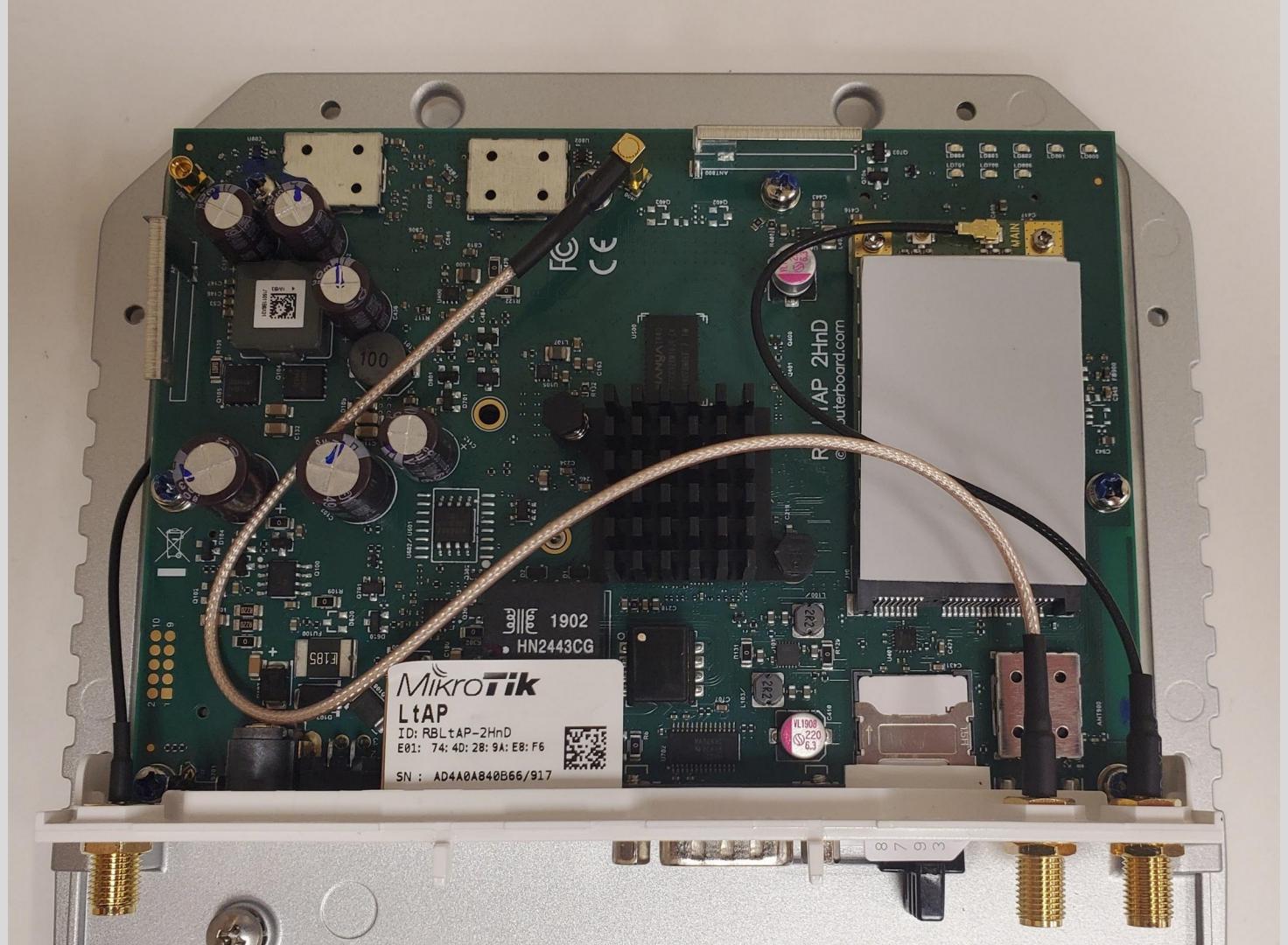
Wide DC power input options

IP54 Rated

-40°C to +70°C

Additional Boards

- LTE category 6
(International)
 - R11e-LTE6
- LoRaWAN Concentrator
Card for 915MHz (868
MHz EU)
 - R11e-LR9



External Antennas

- LoRa: Mikrotik 6.5 dBi omni
- WiFi: Digikey something 2.3 dBi omni rubber duck
- LTE: mANT LTE 5o: 5dBi omni
- GPS: flush mount patch active antenna



Gateway Configuration: Stage 1 (Preload)



BASIC LTE CONFIG, SUPPORTING > 100 COUNTRIES AND > 400 CARRIERS



CALLS HOME TO AN OPENVPN PROVISIONING SERVER

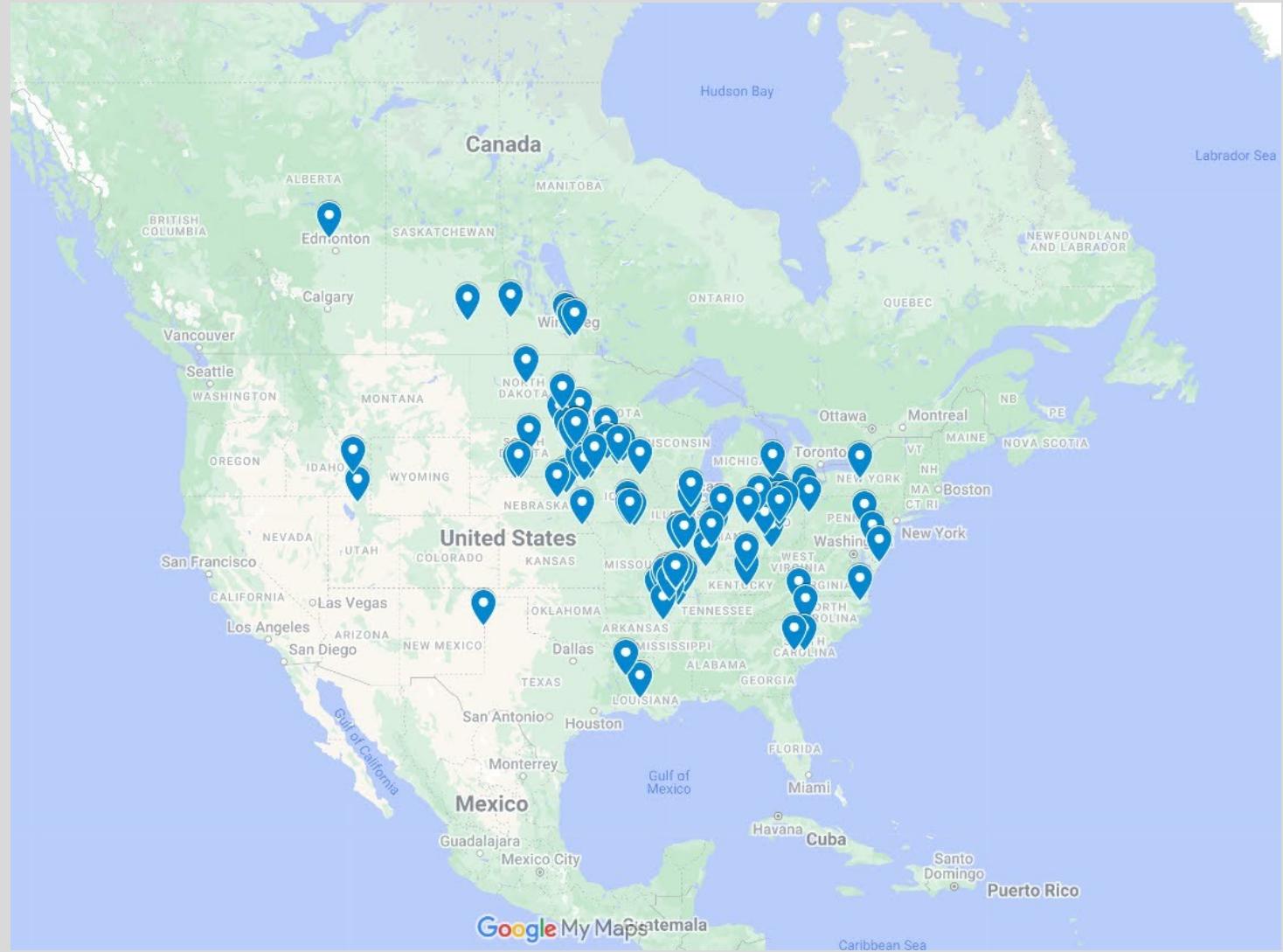


BASIC WIFI ACCESS POINT FOR ON-SITE TECHNICAL SUPPORT TO CONNECT (IF REQUIRED) FROM THEIR PHONE

Gateway Configuration: Stage 2 (Customization)

Once the gateway is on the client site

- Customized OpenVPN client certificate for management VPN
- LibreNMS / Prometheus monitoring
- Chirpstack LoRaWAN configuration
- GPS
- Lock to a specific LTE operator or cell (optional)



Why the WiFi?

'cause it comes with the LtAP

It's handy for on-site
troubleshooting if the LTE is down

We can support other
experiments and products at test
sites



LTE Operators an our MVNO

> 450 Cell Providers

> 200 Countries

1 SIM Card

1 APN

```
[admin@LTaP-08-55-31-C1-89-51] /interface lte> info 0 once
    pin-status: ok
registration-status: roaming
    functionality: full
    manufacturer: "MikroTik"
        model: "R11e-LTE6"
            revision: R11e-LTE6_V029
current-operator: T-Mobile
    roaming: yes
        lac: 45053
current-cellid: 8090892
    enb-id: 31605
    sector-id: 12
    phy-cellid: 398
access-technology: Evolved 3G (LTE)
session-uptime: 1d20h29m20s
    imei: 356662100091443
    imsi: 240422605872875
    uicc: 89464283526058728753
subscriber-number: "", "+467191015872875", 145
    primary-band: B2@15Mhz earfcn: 825 phy-cellid: 398
        rssi: -87dBm
        rsrp: -121dBm
        rsrq: -13.5dB
        sinr: 0dB
        cqi: 6
        ri: 2
[admin@LTaP-08-55-31-C1-89-51] /interface lte>
```



Hide Menu

Tower Info

Downlink Frequency 1952.6 MHz

Frequency Band PCS blocks A-F (B2 FDD)

Cell 12

Cell Identifier 8090892

System Subtype LTE

PCI 398 (132/2)

Bandwidth 15 MHz

EARFCN 825

Maximum Signal (RSRP) -68 dBm

Direction N (358°)

Max / Avg DL Speed 8 Mbps / 7 Mbps

First Seen Sat, Oct 31, 2015

Last Seen Thu, Oct 19, 2023

5G ENDC Available Yes

Actions • Go to Cell

Uplink Frequency 1872.5 MHz

Downlink Frequency 1952.5 MHz

Frequency Band PCS blocks A-F (B2 FDD)

Cell 13

Cell Identifier 8090893

System Subtype LTE

PCI 250 (83/1)

Bandwidth 15 MHz

EARFCN 825

Maximum Signal (RSRP) -73 dBm

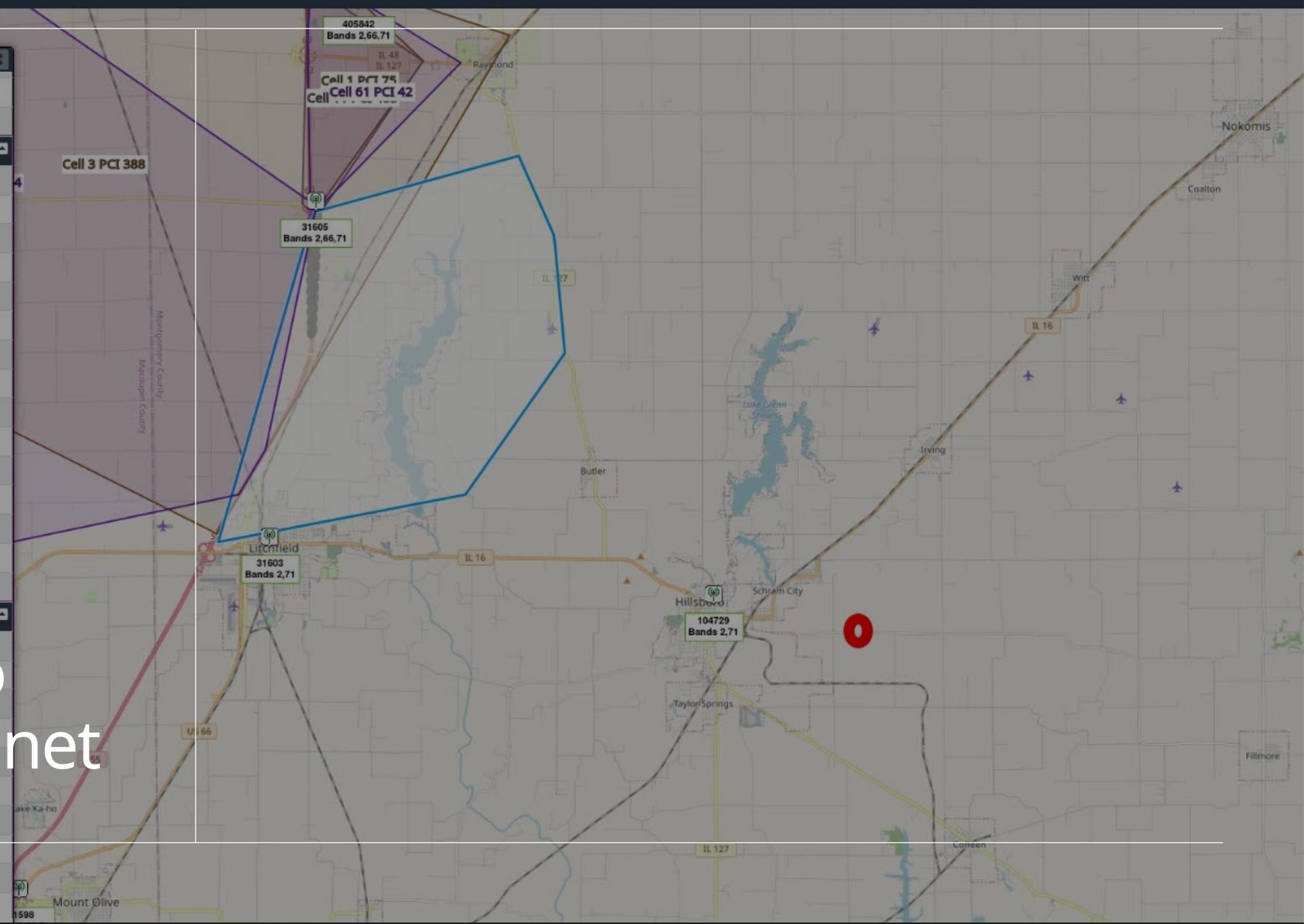
Direction S (180°)

Max / Avg DL Speed 450 Mbps / 283 Mbps

First Seen Sat, Nov 25, 2017

Last Seen Thu, Oct 19, 2023

Shoutout to CellMapper.net



Swedish Traffic Trombone

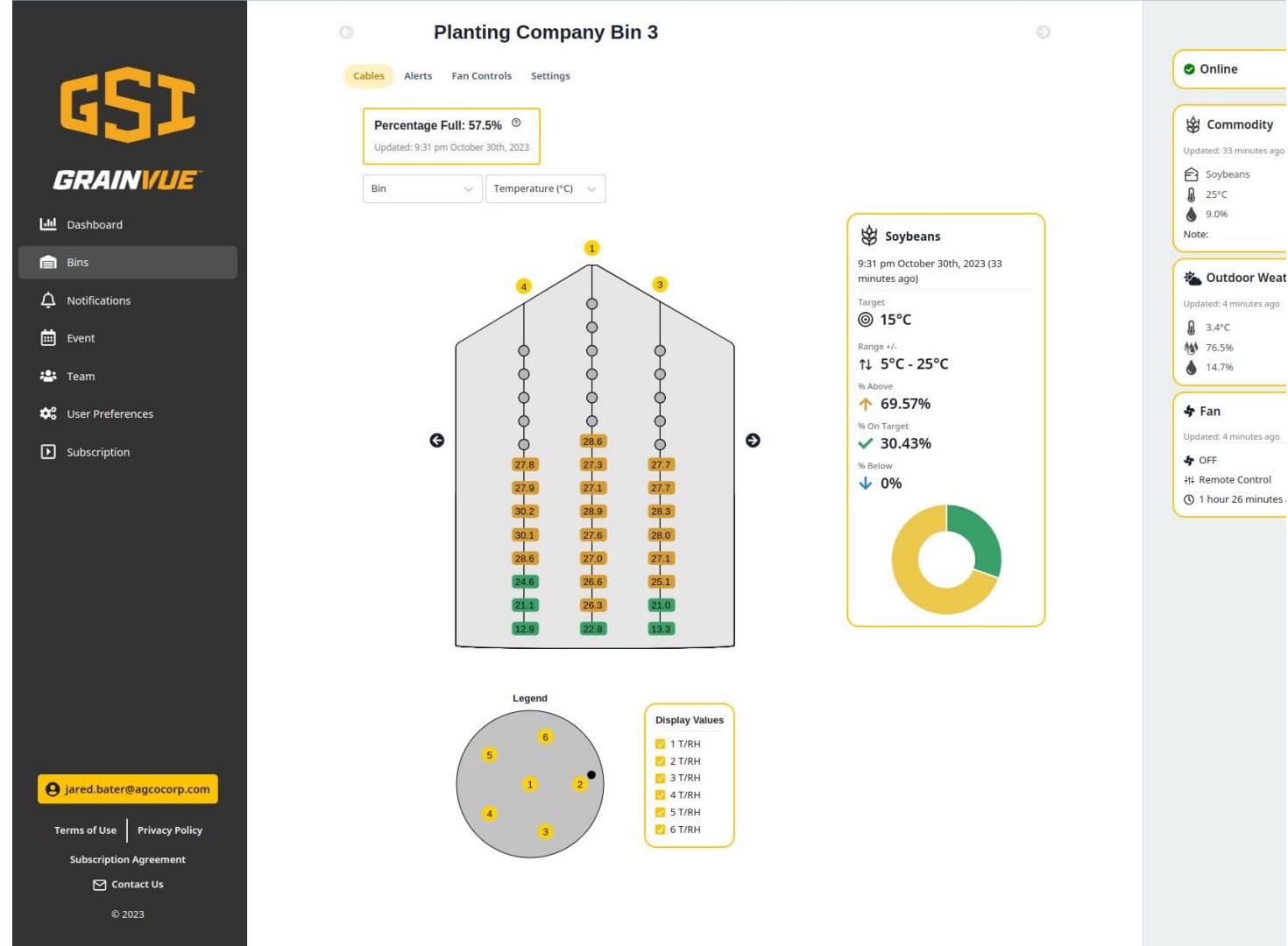
Q: HUH?!! Traffic goes from North America, to Europe, and Back?! Isn't this a problem?

A: Nah. LoRaWAN RX1 window is 1000 ms after uplink, which is an eternity in “internet time”.

User Portal: Cable Readings

Displays real-time-(ish)

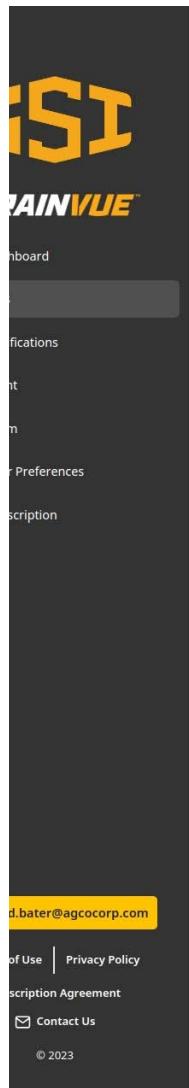
- Temp/Moisture
- CO₂
- Outdoor Weather
- Plenum Conditions
- Inventory (Bin fill level)



User Portal: Fan Control

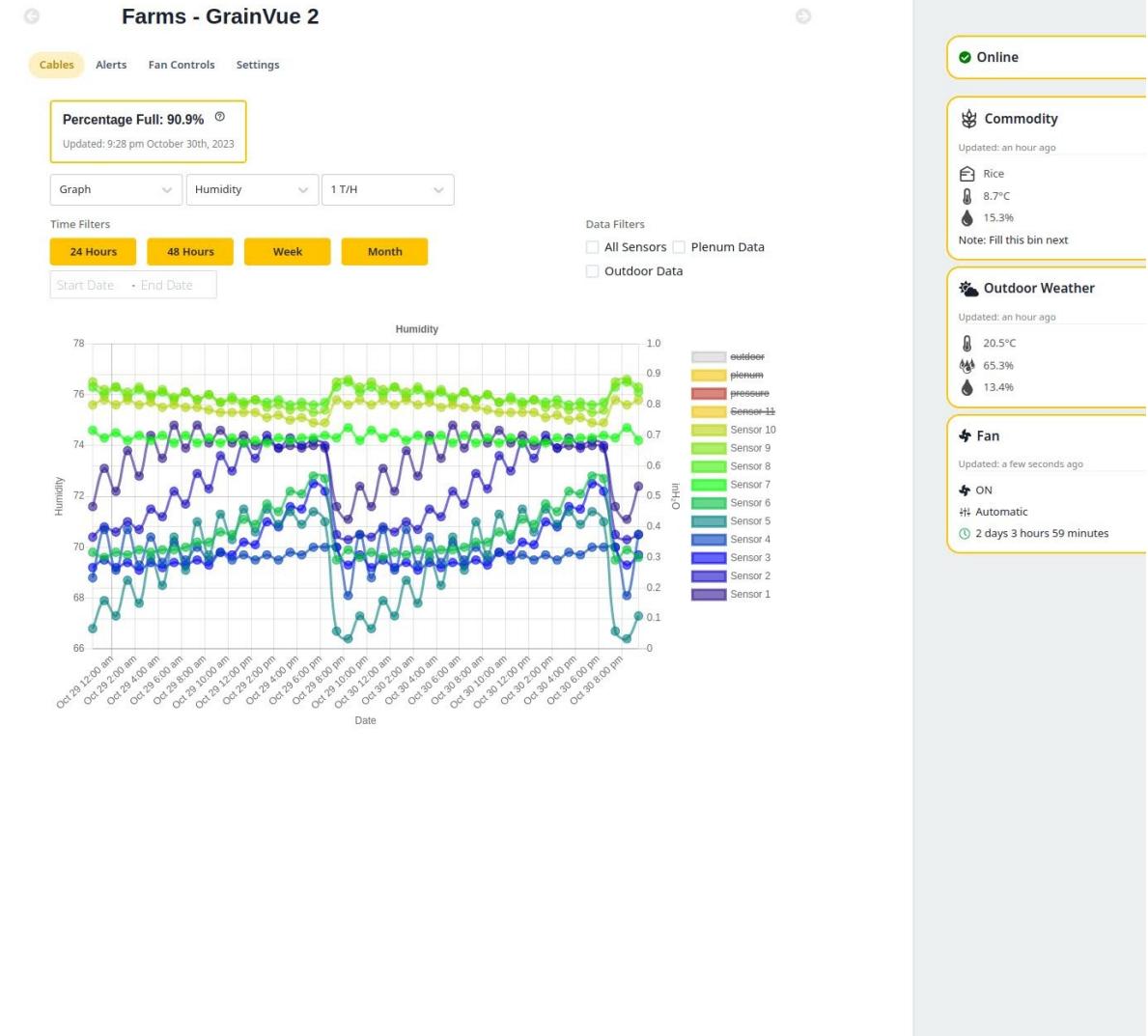
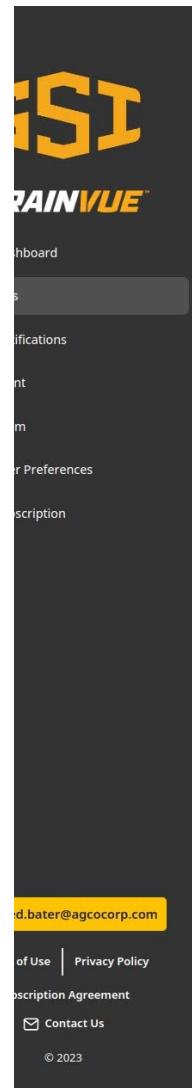
Set Fan and heater modes

- Remote Control
- Automatic
- Smart Drying
- Smart Storage



The screenshot displays the Ranch 6 fan control interface. At the top, there are tabs for Cables, Alerts, Fan Controls (highlighted in yellow), and Settings. The main area is divided into sections:
1. **Fan Mode:** Set to Automatic. A "Change Mode" button is available.
2. **Fan EMC Range:** Shows a slider from 12% to 16%. The current setting is at 12%, labeled "11.2%". The target is set to 14.0%.
3. **Fan Temperature Range:** Shows a slider from 1.1°C to 29.4°C. The current setting is at 1.1°C, labeled "1.1°C". The target is set to 12.8°C.
4. **Fan Operational Settings:** Plenum Temperature Correction is set to 1.5°C. An "Edit" button is present.
5. **Fan Status:** OFF. Last run was 6 days 1 hour 51 minutes ago. A note says "The fans are off."
6. **Additional Status Information:** Shows "Outdoor" status with "Outdoor Corrected EMC / CEMC" and "Outdoor Corrected Temperature" both listed as "Out of Range".
On the right side of the dashboard, there are three vertical cards:
1. **Commodity:** Updated 14 minutes ago. Shows Soybeans at 10.8°C and 11.2%.
2. **Outdoor Weather:** Updated 10 minutes ago. Shows temperature and humidity data.
3. **Fan:** Updated 10 minutes ago. Shows the fan is OFF, mode is Automatic, and last run was 6 days 1 hour 51 minutes ago.

User Portal: Historical Data



Stuff Going Sideways

- LoRa RF Environment Troubles
- Power Problems
- Internet go ByeBye
- Stuff goes missing
- Things get COLD

Fin

