



# Adventures in Agricultural IoT

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

JARED BATER

# Jared Bater



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Linux & networking  
nerd for over 25 years

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IoT shenanigans for  
the last 4

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GSI/AGCO by way of  
151 Research

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



# Grain Storage: The Grain Bin

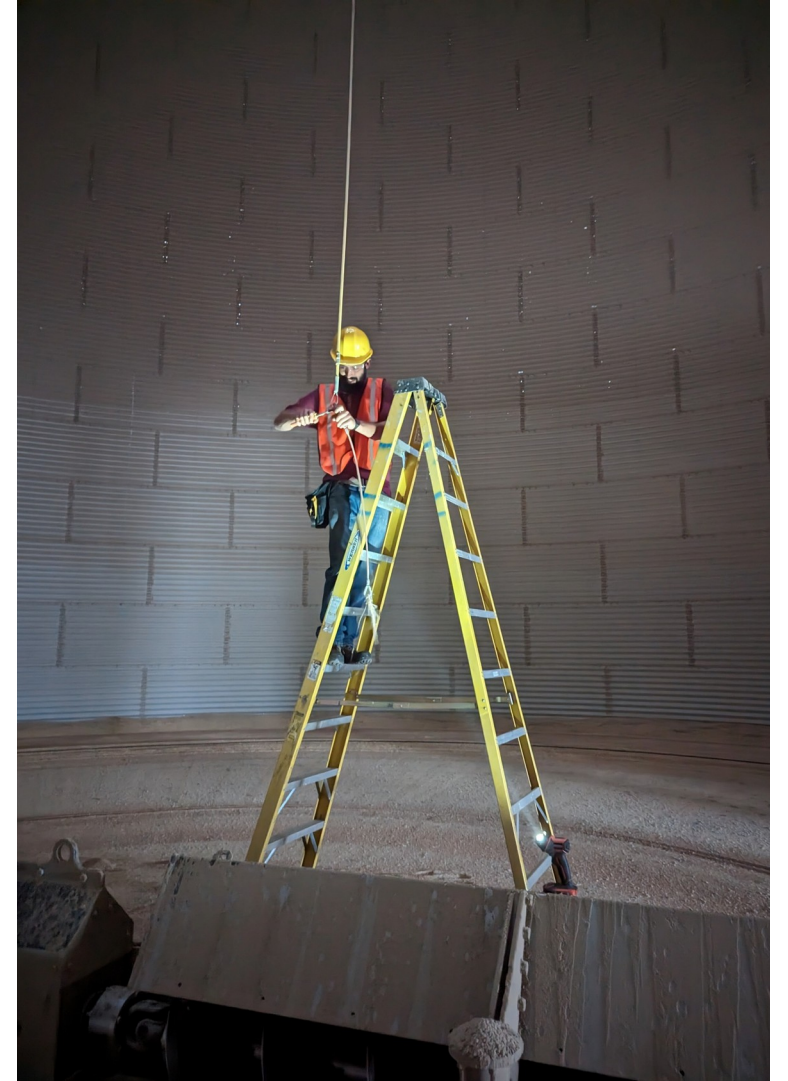
# Anatomy of a grain bin

- 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)

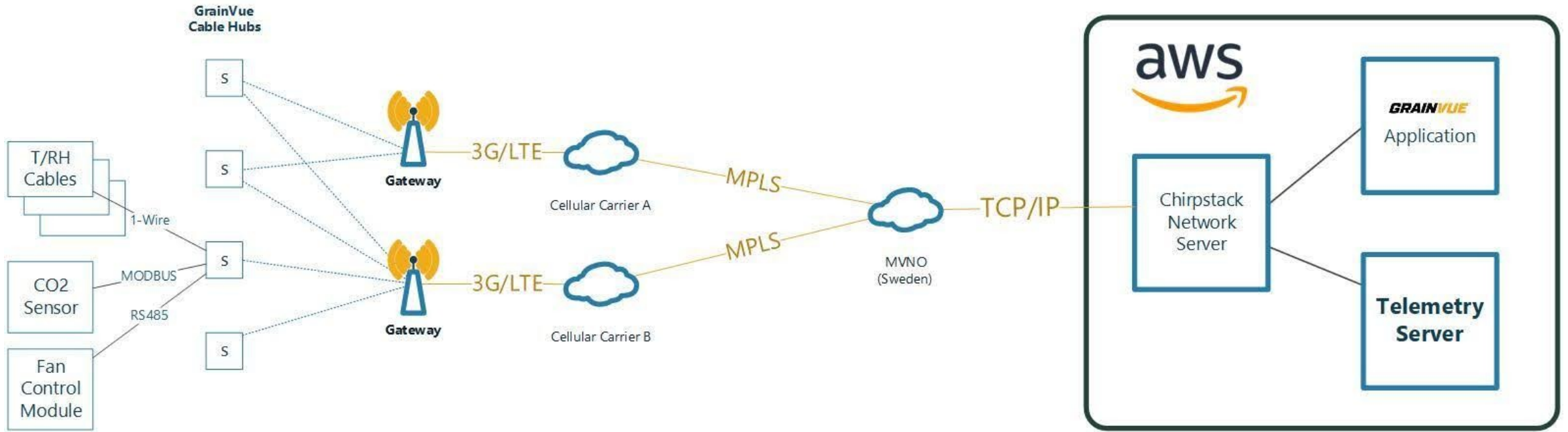




# GrainVue System

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

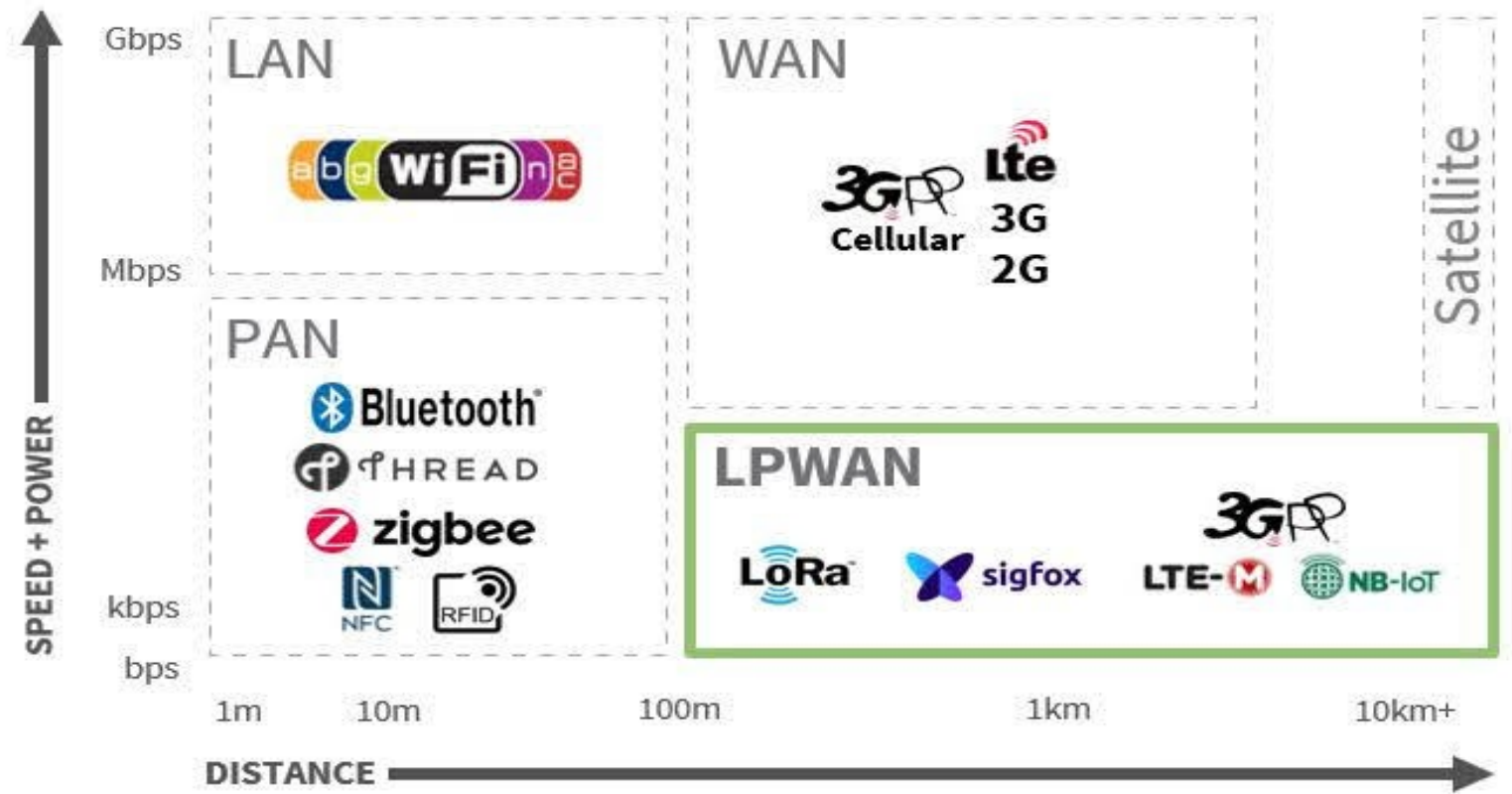
40

50

60

70

80



# LPWAN

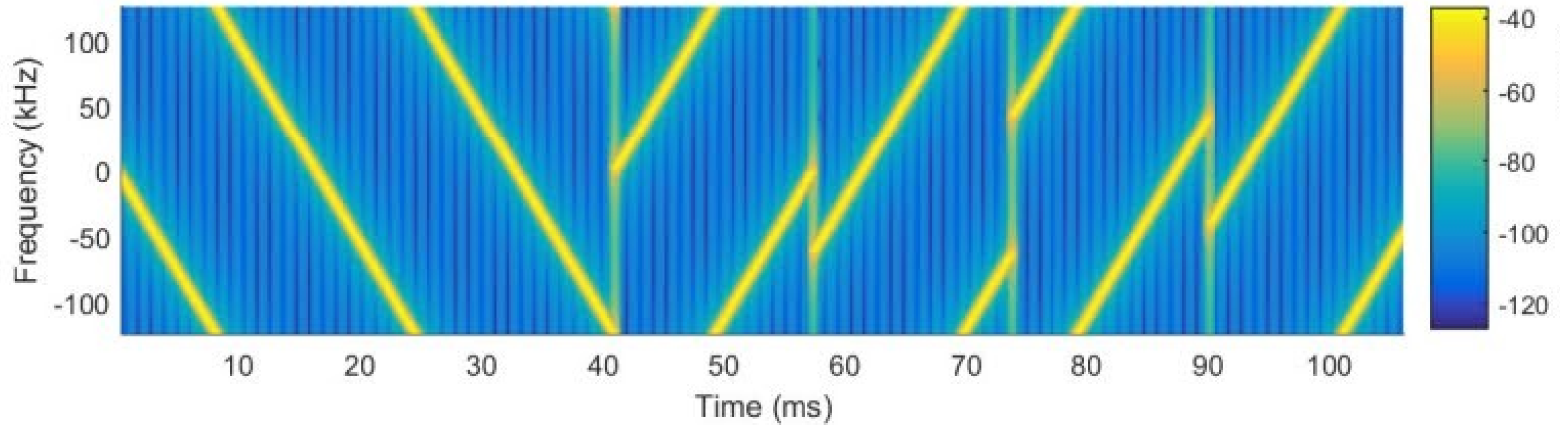
Low Power Wide Area Network

- 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<br>(For UL at 125 KHz) | Bit Rate | Range<br>(Depends on Terrain) | Time on Air<br>for an 11-byte p |
|---|----------|-------------------------------|---------------------------------|
| 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:

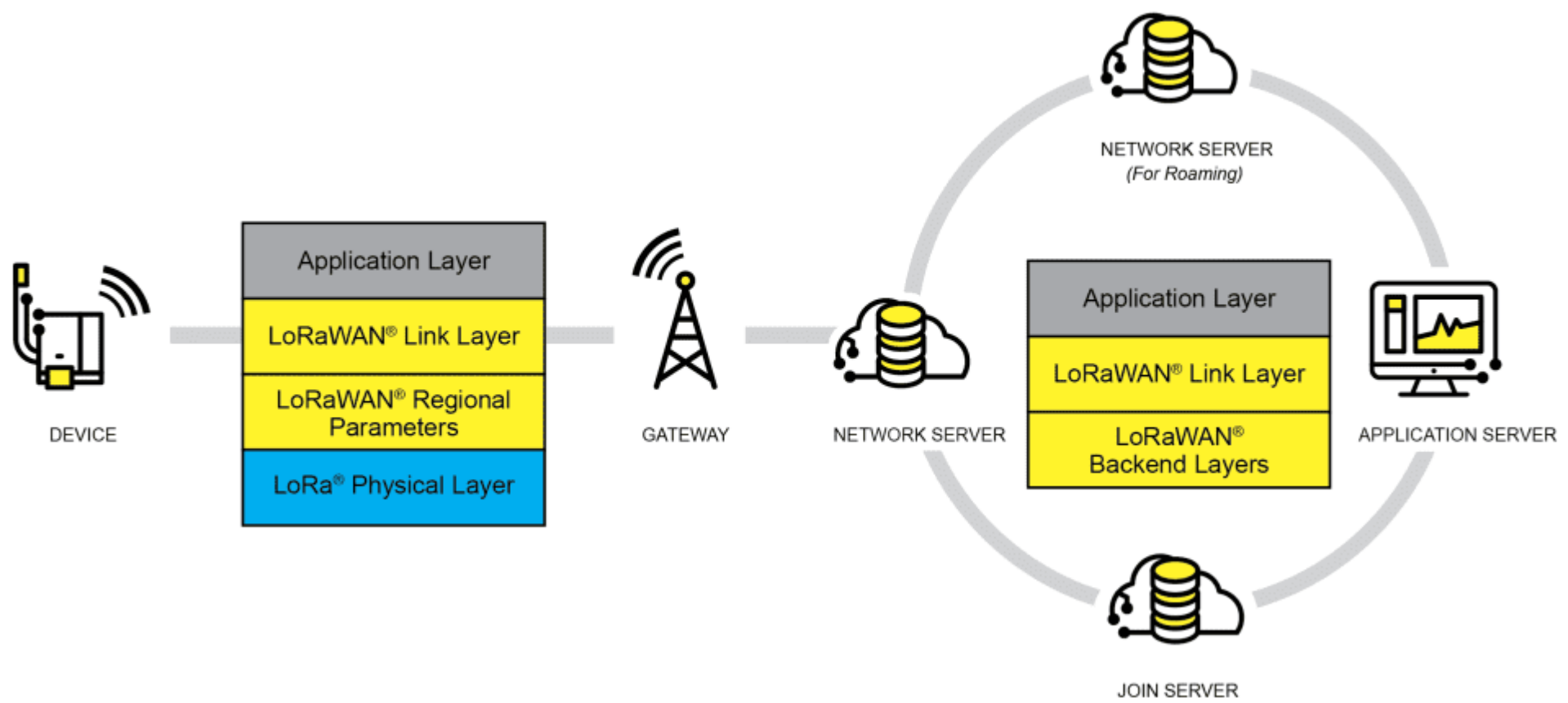
- Data rate
- Distance
- Time On Air
- Receiver Sensitivity
- Battery Life



# 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



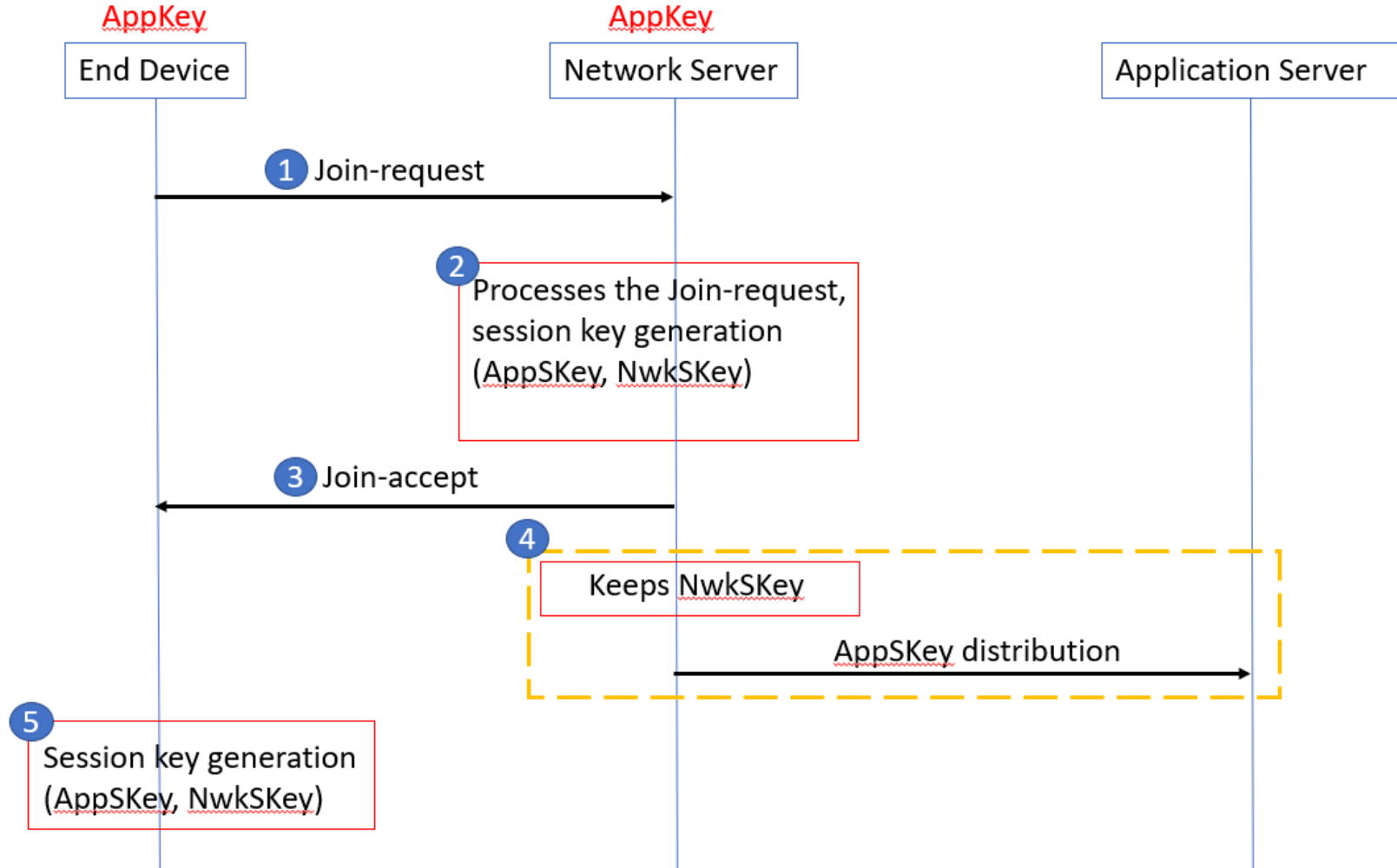


# LoRaWAN Architecture

- 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

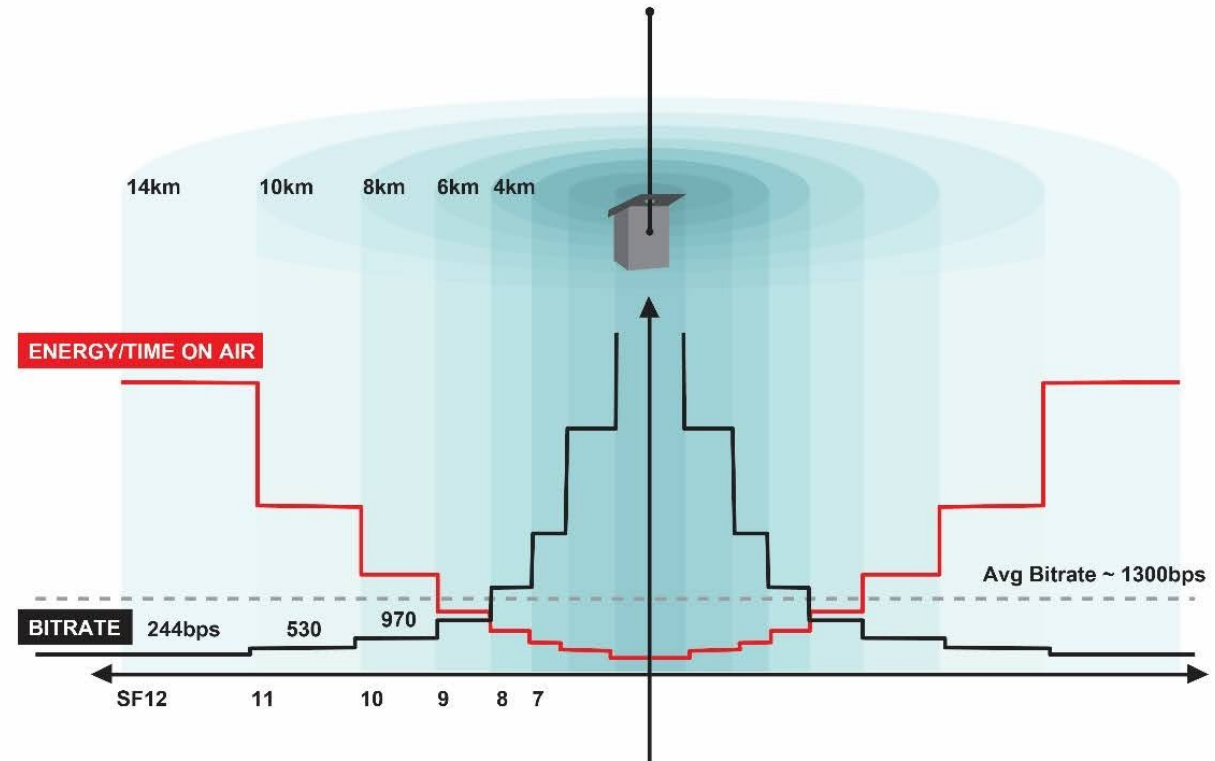
Sure it's "secure", but  
implementation matters

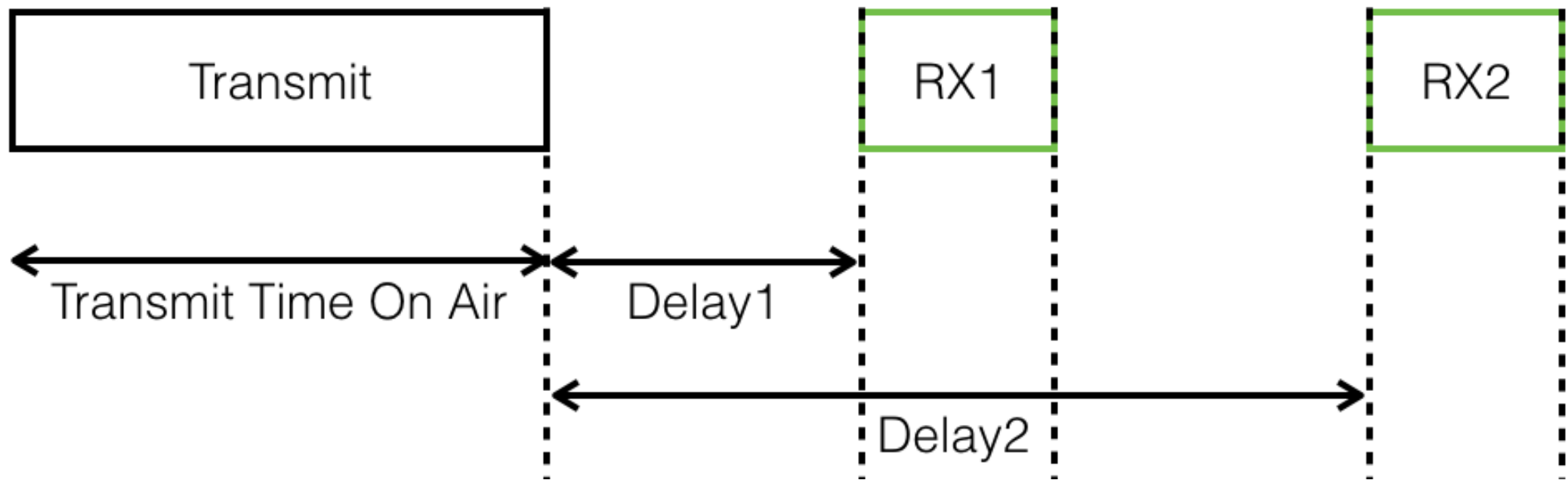
- Application Keys: Pre-Shared between Device and Join Server
- Dynamic Session Keys:
  - Network Session Key
  - Application Session Key
- Frame Counters for UL and DL
- Join Nonce
- MICs

# Adaptive Data Rate

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

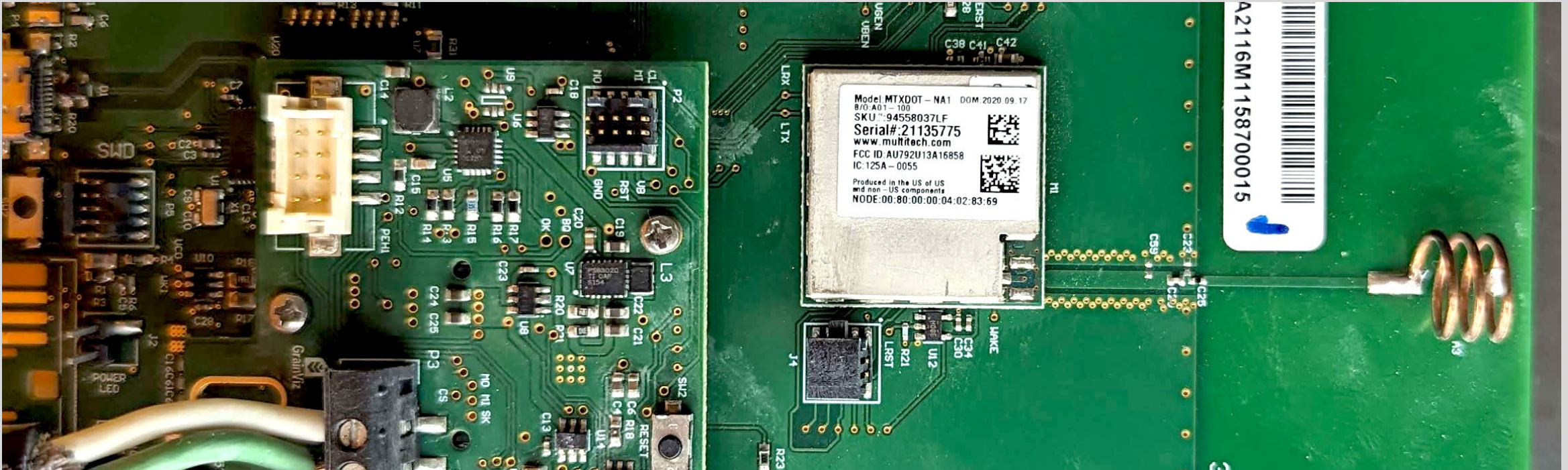
- Spreading Factor
- Bandwidth
- Transmission Power





## 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



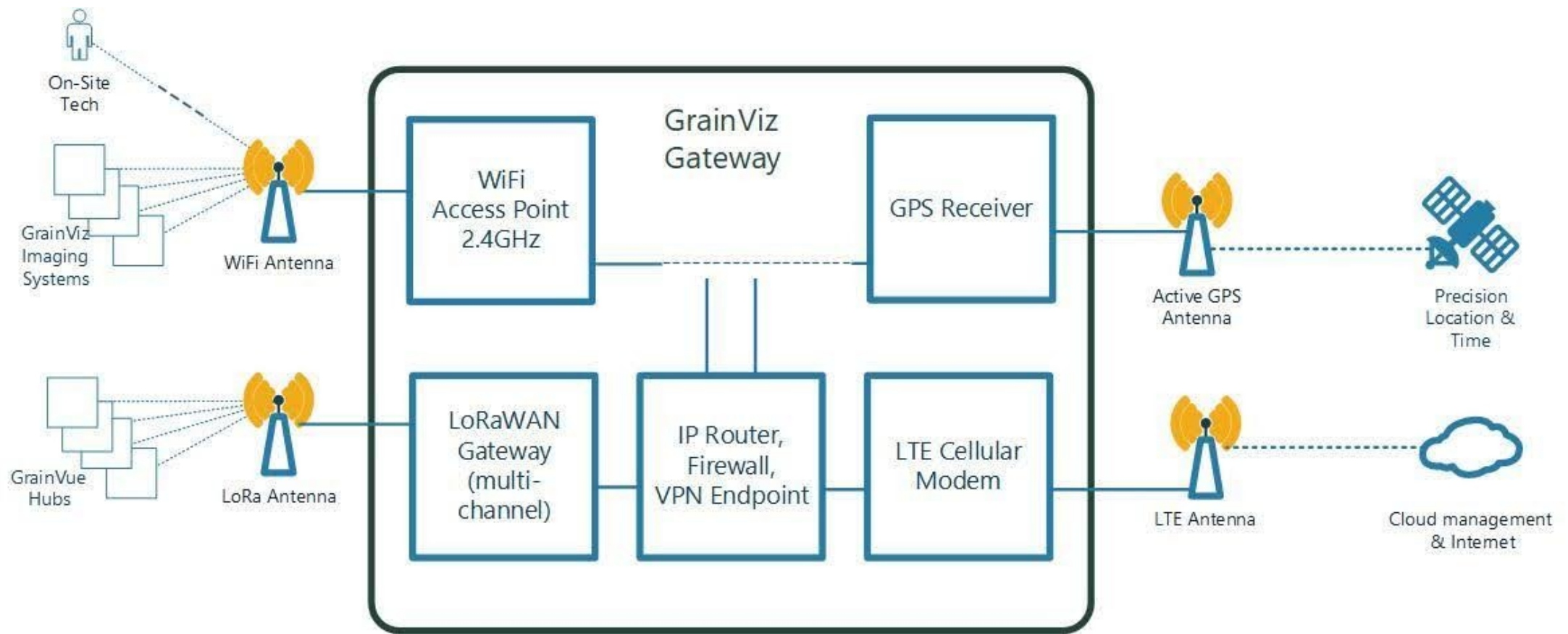
# LoRaWAN Device

- 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

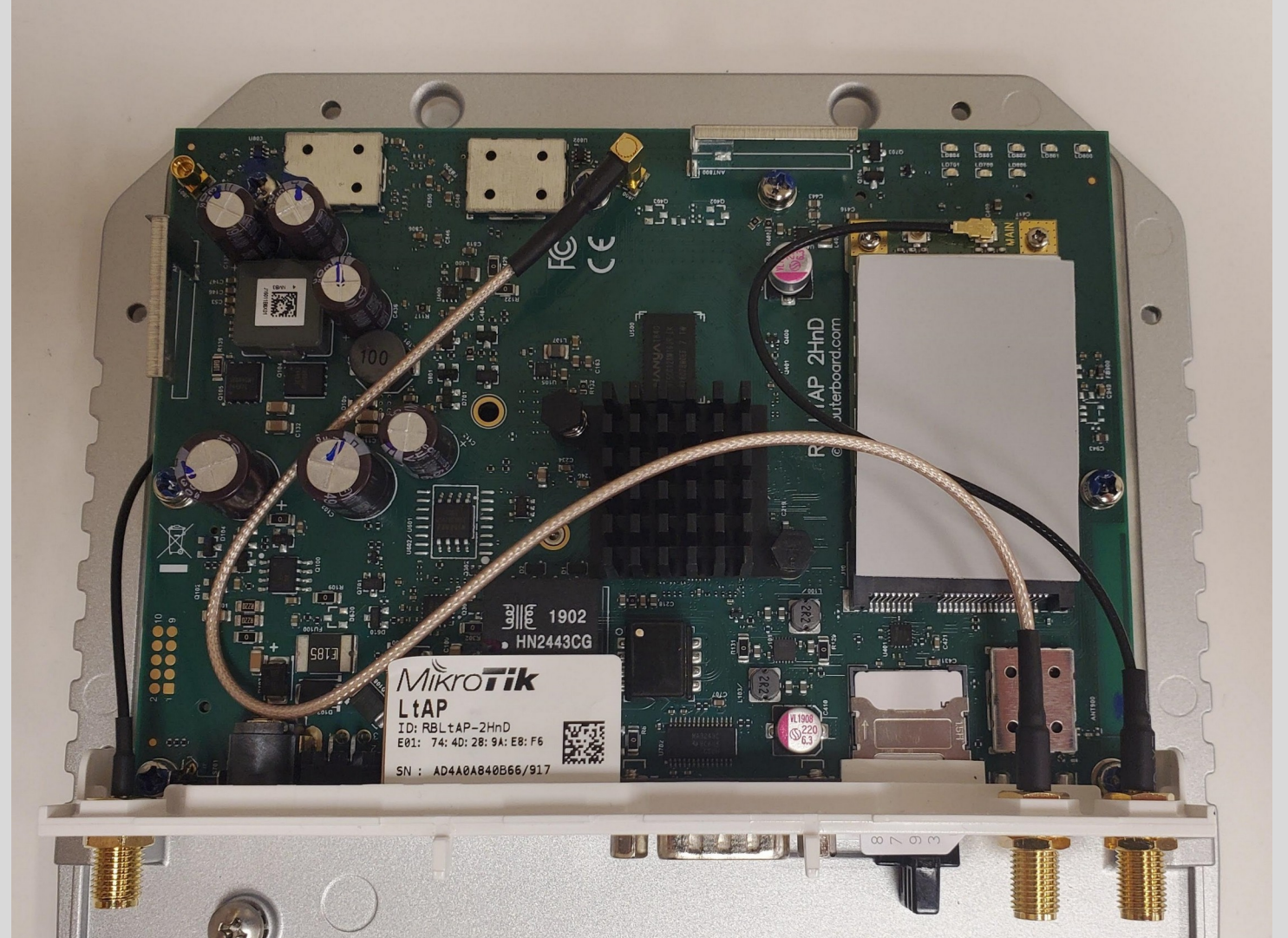
Wide DC power input options

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



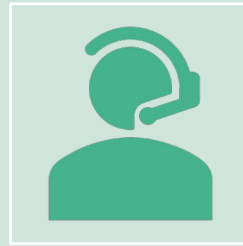
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# Gateway Configuration: Stage 1 (Preload)

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



CALLS HOME TO AN OPENVPN  
PROVISIONING SERVER



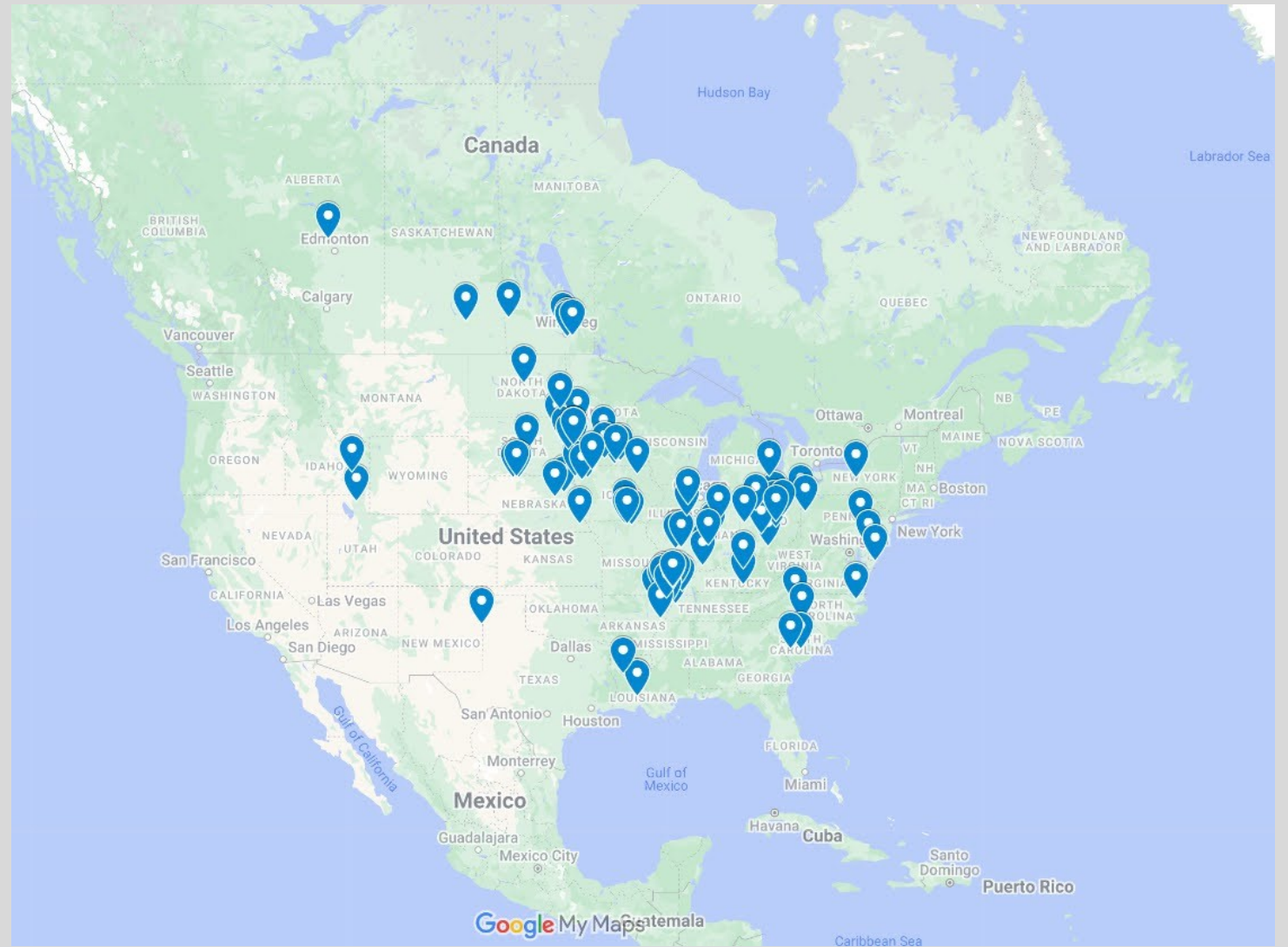
BASIC WIFI ACCESS POINT FOR ON-SITE  
TECHNICAL SUPPORT TO CONNECT (IF  
REQUIRED) FROM THEIR PHONE

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# 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>
```



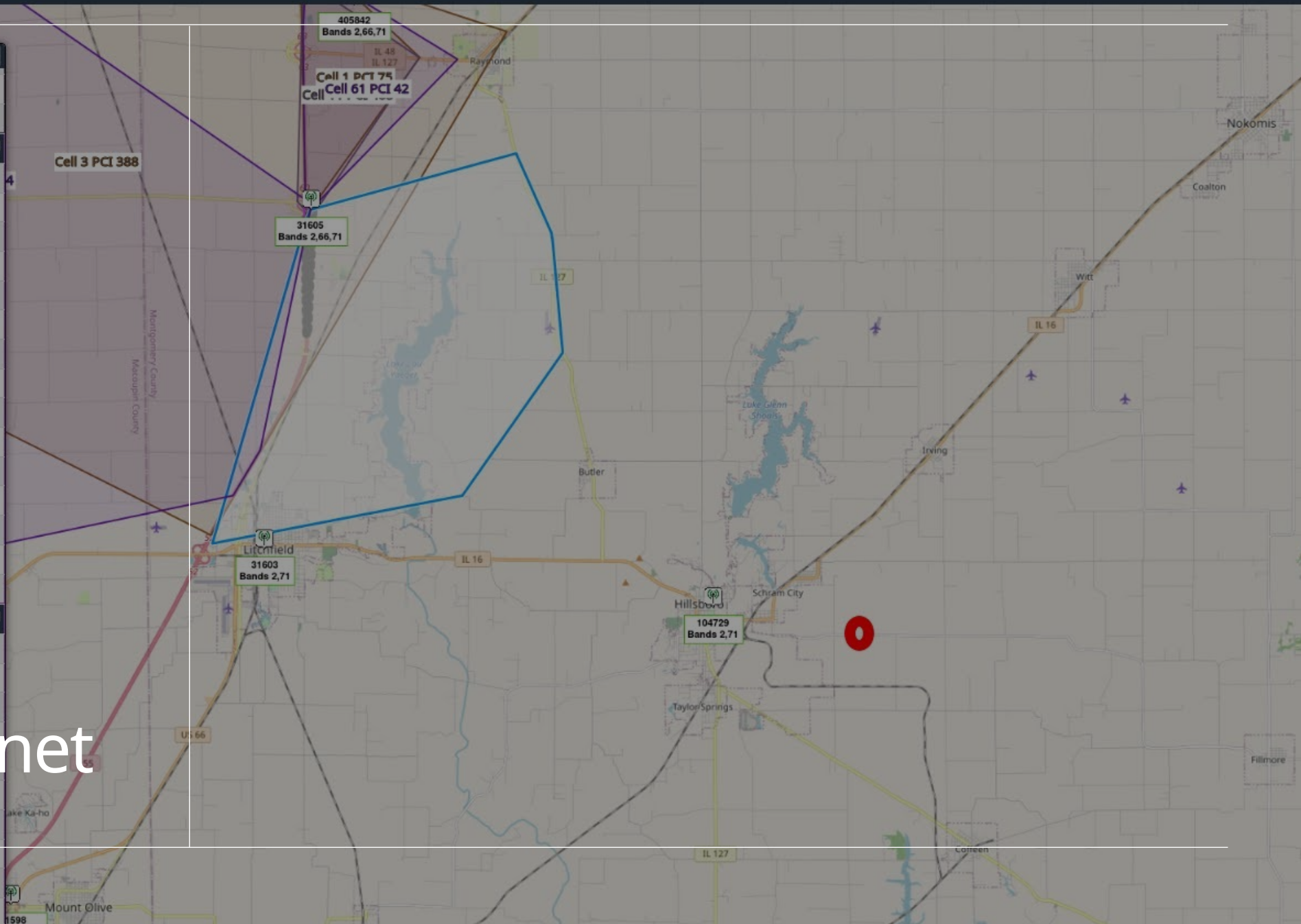
Hide Menu

### Tower Info

|                       |                            |
|-----------------------|----------------------------|
| Downlink Frequency    | 1952.6 MHz                 |
| Frequency Band        | PCS blocks A-F (B2 FDD)    |
| <b>Cell 12</b>        |                            |
| 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               | <a href="#">Go to Cell</a> |
| 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

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# Swedish Traffic Trombone

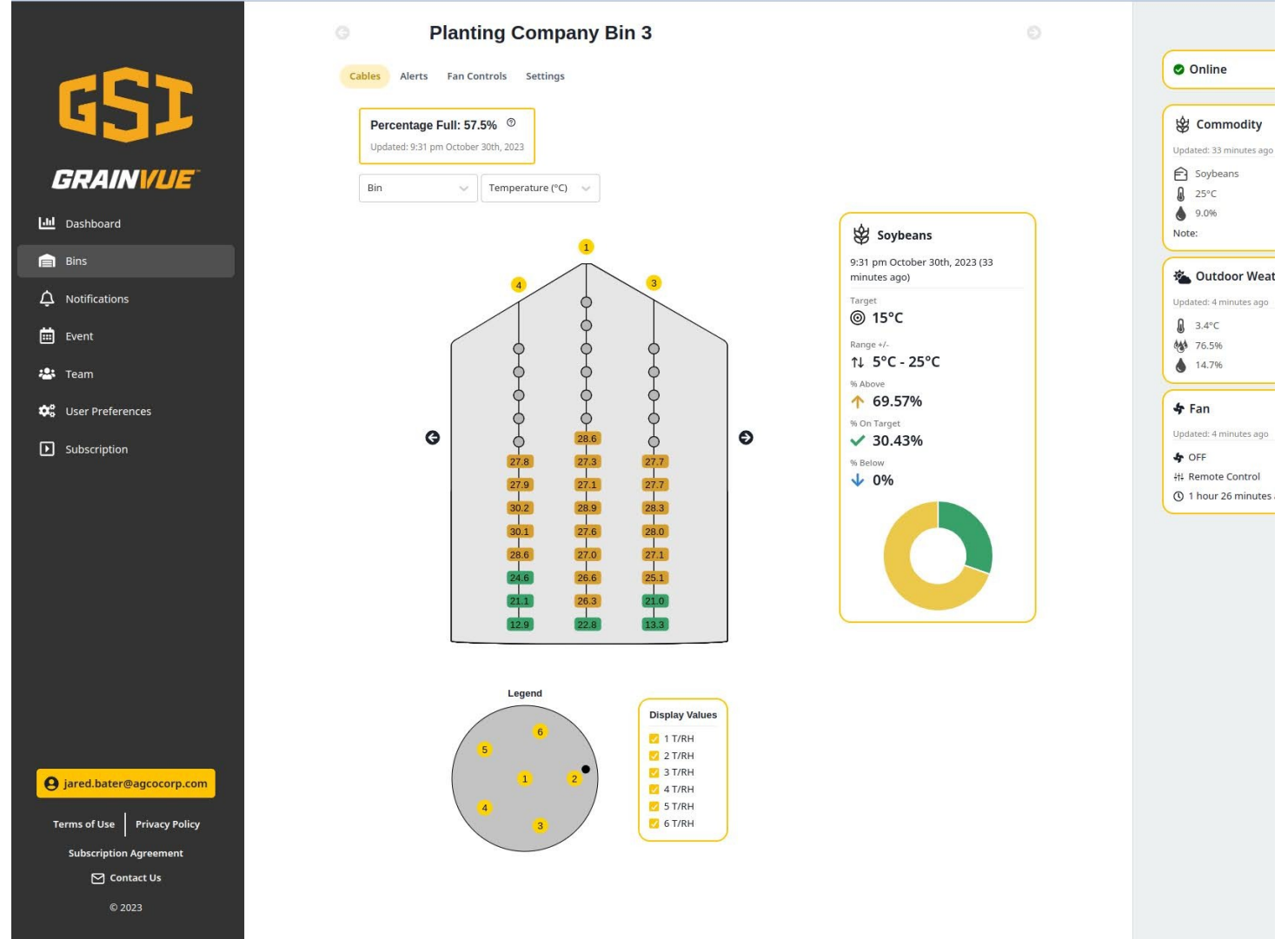
Q: HUH?!! Traffic goes from North America, to Europe, and Back?! Isn't this a problem?

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)

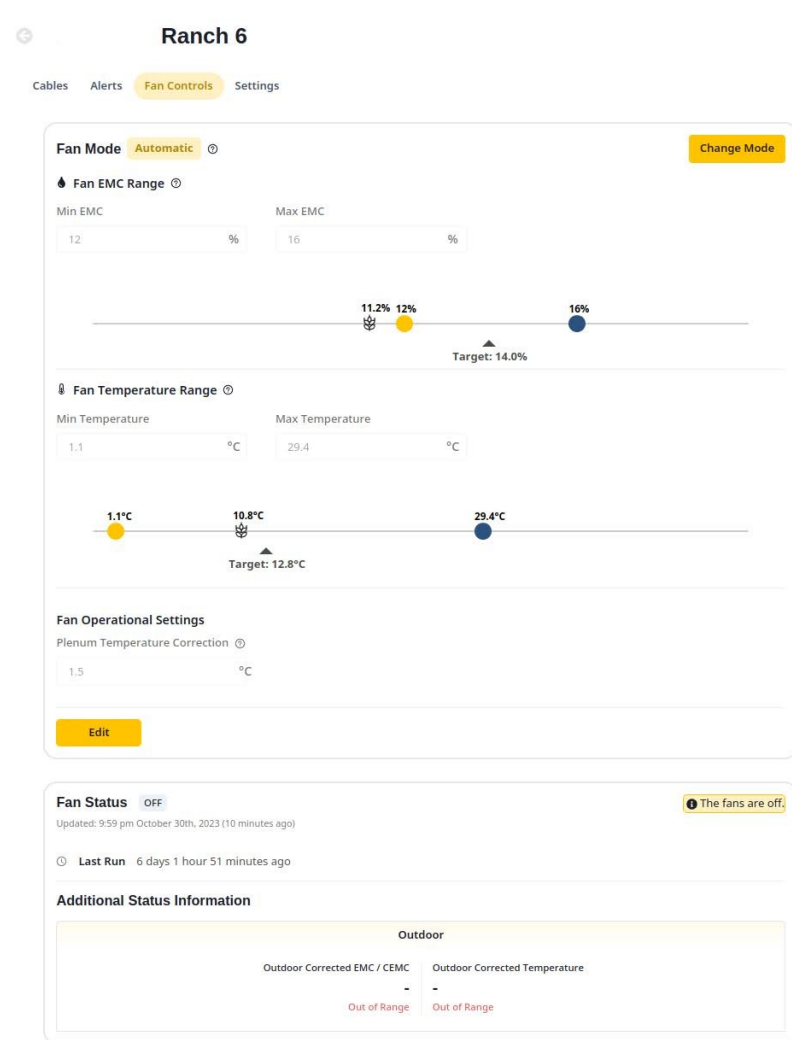
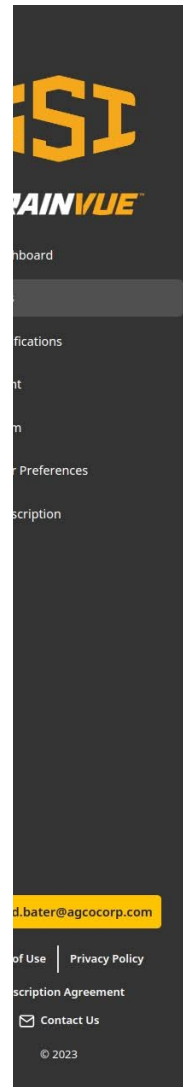
- Temp/Moisture
- CO2
- Outdoor Weather
- Plenum Conditions
- Inventory (Bin fill level)



# User Portal: Fan Control

Set Fan and heater modes


- Remote Control
- Automatic
- Smart Drying
- Smart Storage



The right-hand sidebar contains the following widgets:

- Online:** Status indicator (green checkmark).
- Commodity:** Updated: 14 minutes ago. Soybeans. 10.8°C, 11.2%. Note: (empty).
- Outdoor Weather:** Updated: 10 minutes ago. Humidity, Wind, Rain, and Temperature icons, all showing dashes.
- Fan:** Updated: 10 minutes ago. OFF. Automatic. 6 days 1 hour 51 minutes ago.

# User Portal: Historical Data



**RAINVUE**

- Dashboard
- Sensors
- Configurations
- Alerts
- Fan Controls
- Settings
- Preferences
- Subscription

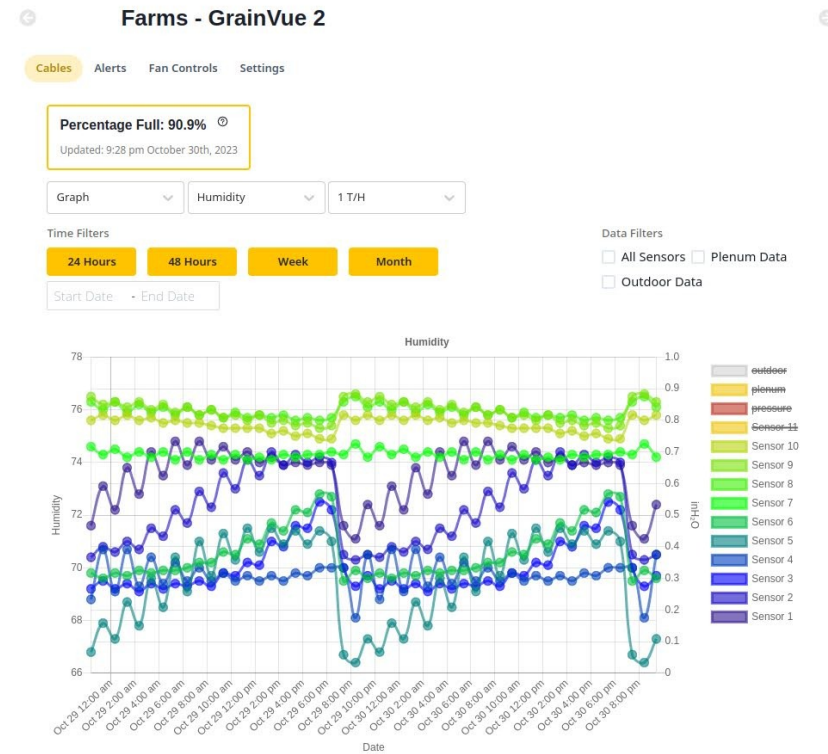
[d.bater@agcocorp.com](mailto:d.bater@agcocorp.com)


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 Online


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 **Commodity**  
Updated: an hour ago

 Rice  
8.7°C  
15.3%


Note: Fill this bin next


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 **Outdoor Weather**  
Updated: an hour ago

 20.5°C  
 65.3%  
 13.4%

---

 **Fan**  
Updated: a few seconds ago

 ON  
Automatic  
2 days 3 hours 59 minutes

# Stuff Going Sideways

A photograph of a laptop computer sitting on a dark metal surface, likely a piece of industrial equipment. The laptop screen is open and displays a complex network monitoring or data analysis interface with various graphs and text. A small blue USB dongle is plugged into the laptop's port. To the left of the laptop, a black USB dongle with the brand name 'nobelec' is visible. The background shows a dark, industrial environment with metal structures and a concrete floor.

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



Fin