PURDUE/ACRE TESTBED: MEASURING LORAWAN PERFORMANCE VIA A LARGE SCALE MEASUREMENT CAMPAIGN

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Project # 16

Sensor data is the cornerstone of decision-making in modern digital agriculture practices; however, transferring information from remote property and equipment remains a key prohibitor of adoption. Public network IoT solutions, primarily 3GGP's standards, are generally poorly supported in-field due to the lack of an existing robust market. On the other hand, typical private network solutions, e.g., Zigbee, Bluetooth, Z-Wave, and Wi-Fi, lack either sufficient communication range or require more power than feasibly available in a practical deployment. LoRaWAN has emerged as potential solution for small data IoT (e.g., soil sensors, weather station, fleet tracking). Its clever design achieves both extremely low power and long range communications, at the sacrifice of bandwidth. This work aims to measure LoRaWAN's performance in a large scale sensor deployment and seeks to better understand the impacts of an agricultural environment.

BACKGROUND & MOTIVATION

Data flow on the Farm

*Sensor **data** on the farm is as **important** as ever,*
*but collecting it **at scale** is still just as **hard**.*

IoT at the rural field

Public networks, e.g., LTE-M, NB-IoT, continue to mature in promising ways; however, the lack of an established and robust market in highly rural areas appears to have stifled deployment [1].

Private networks, e.g., Zigbee, Bluetooth, Z-Wave, and Wi-Fi, all utilize unlicensed spectrum, eliminating the market hurdle through self-installation. Unfourentaly, most existing technologies are too limited in range for a farmer managed deployment. In addition, most have too high of an energy demand for practical field use, where solar and battery dominate.

The x-factor: field data is (individually) small

The primary mismatch between the ubiquitous wireless options and field sensor demands is bandwidth. Much of the (low-hanging) sensor opportunity are small data in nature, e.g., soil sensors, weather station, fleet tracking. Where many individually powered sensors and radios transmits only a few bytes on an hourly or daily basis, resulting in a large dataset to be processed after arriving in an unconstrained computing environment.

LoRaWAN: LOng RAnge WAN

Energy

LoRa's clever physical layer design combines the low-computation Chirp Spread Spectrum (CSS) modulation and a rudimentary ALOHA based protocol, eschewing the need for high energy compute and accurate clocks.

Range

In the US there are five standard, orthogonal spreading codes, also known as data rates, for the 915MHz band. Each double the length of the prior, and each more capable of overcoming propagation loss at the receiver.
To be compliant with FCC regulation, the total transmission time is limited. Therefore, the longer the code, the fewer data that can be sent per message (worst case: 370 ms for 12 data bytes), but the further that data will travel. With this scheme, LoRaWAN is able to complete multi-mile links with inexpensive unlicensed transmitters.
Finally, LoRaWAN radios randomly select one of up to 64 individual channels for each transmission. Between the many channel options and spreading codes, the likelihood of packet collision is small, even with the ALOHA protocol.

Network

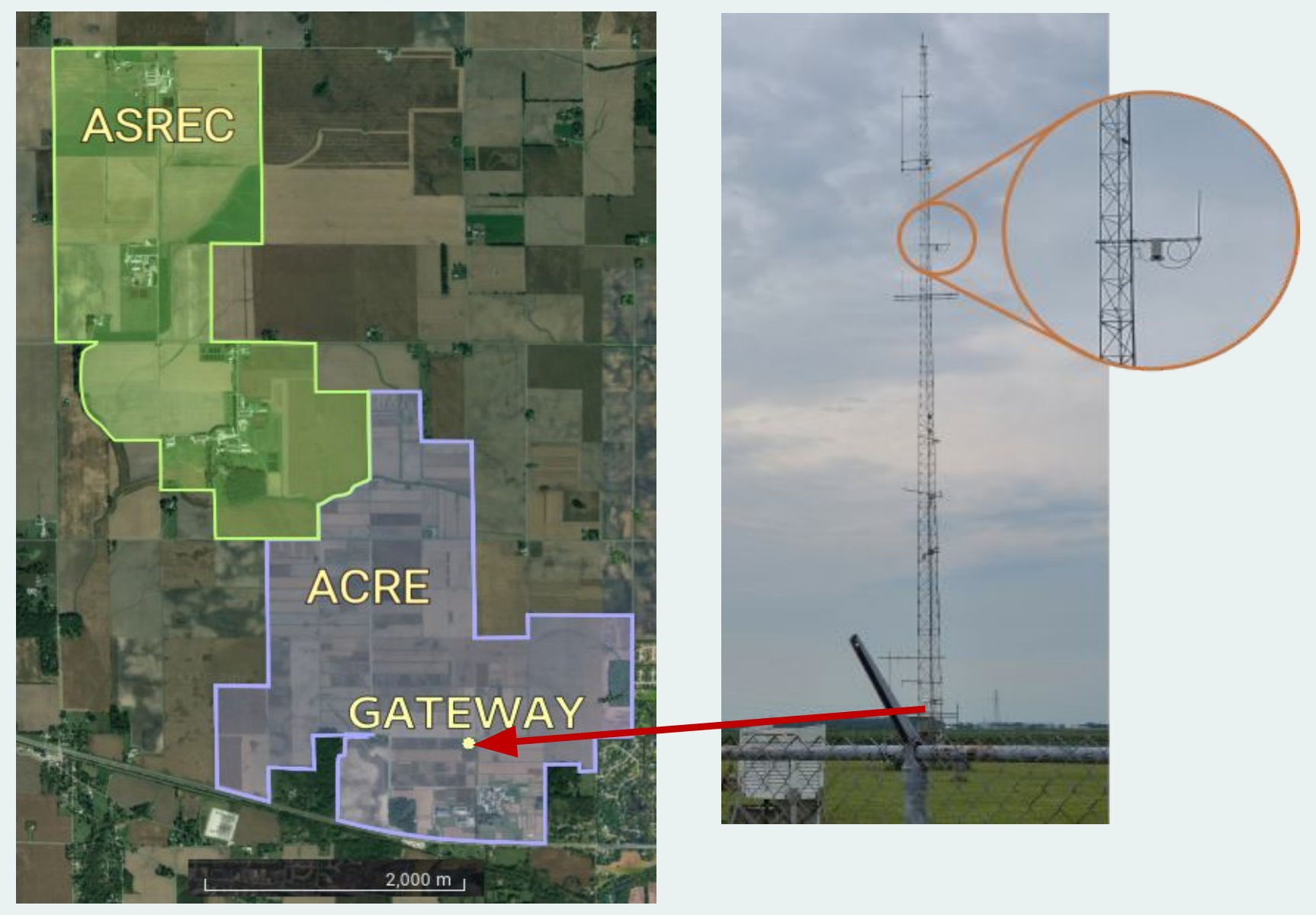
LoRaWAN itself is an open standard that encourages interoperability between LoRa based sensors and gateways. In LoRaWAN, an always listening (high-power) gateway is used to collect the transmissions of tens of thousands of sensors in a multi-mile range. One network may have many gateways, and those gateways may be geographically distributed.

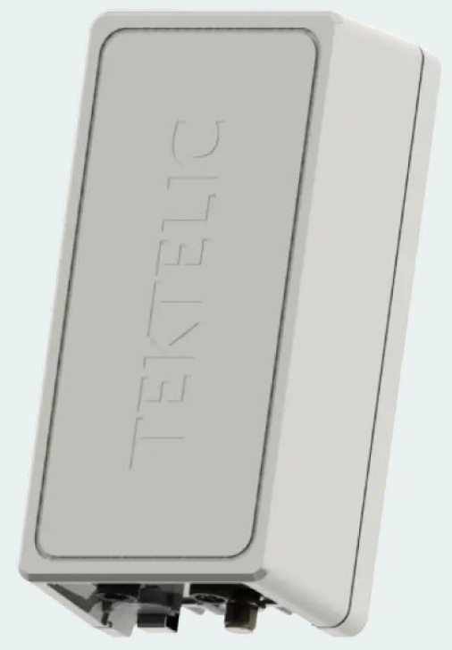
METHODS & MATERIALS

Measuring LoRaWAN Performance

Test site
- ACRE farm (1600ac)
- ASREC farm (1500ac)

The Agronomy (ACRE) and Animal Science (ASREC) farms together span about 4.4 miles by 2.75 miles.

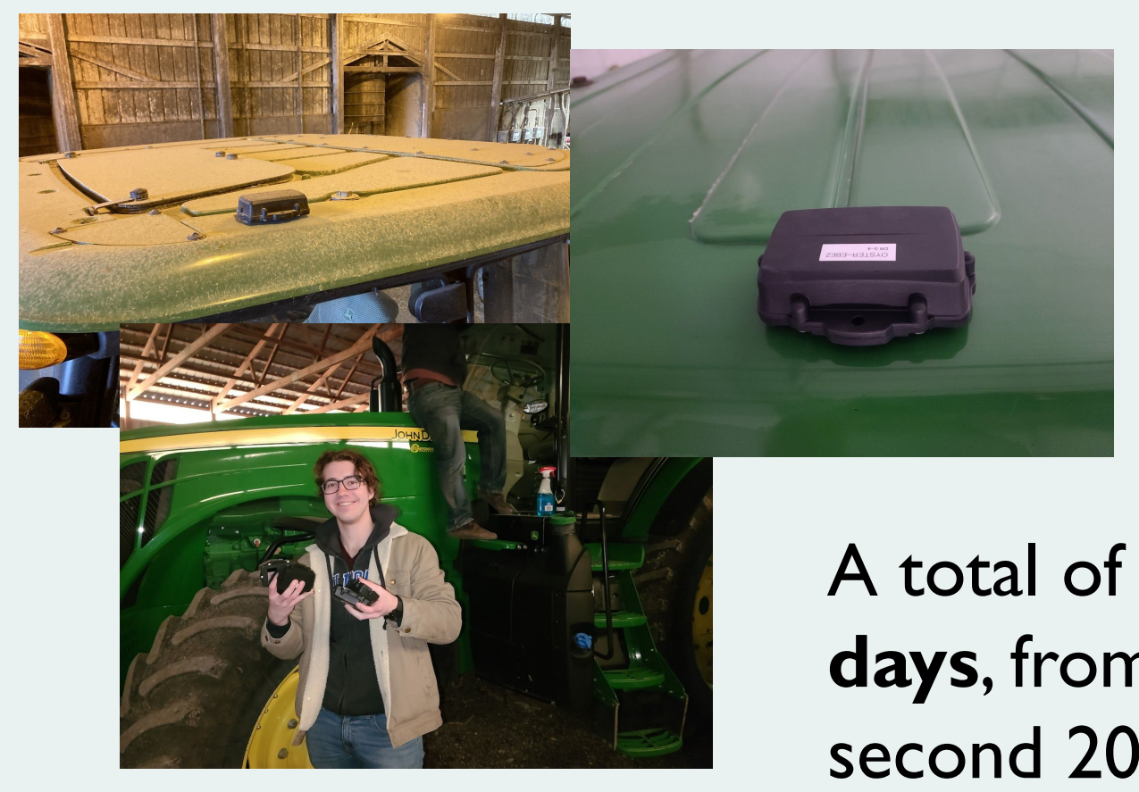




Gateway
A LoRaWAN gateway (Tektelic Kona Macro) was located on a tower on the southern side of the ACRE farm. The antenna is 60 ft (18.3m) high.

LoRaWAN GPS Tracker (Oyster)
The Digital Matter Oyster, a battery powered LoRaWAN GPS tracker, was used as the mobile transmitter.

The oyster makes **17 dBm** LoRa transmissions **once every 10 seconds** (when in motion) and switches between data rates 0-3 such that they all have equal air time. Each message contains the device's current GPS position.



Data
Over **60** trackers were installed; however, the bulk of the transmissions came from the 17 work tractors, combines, and grain carts.

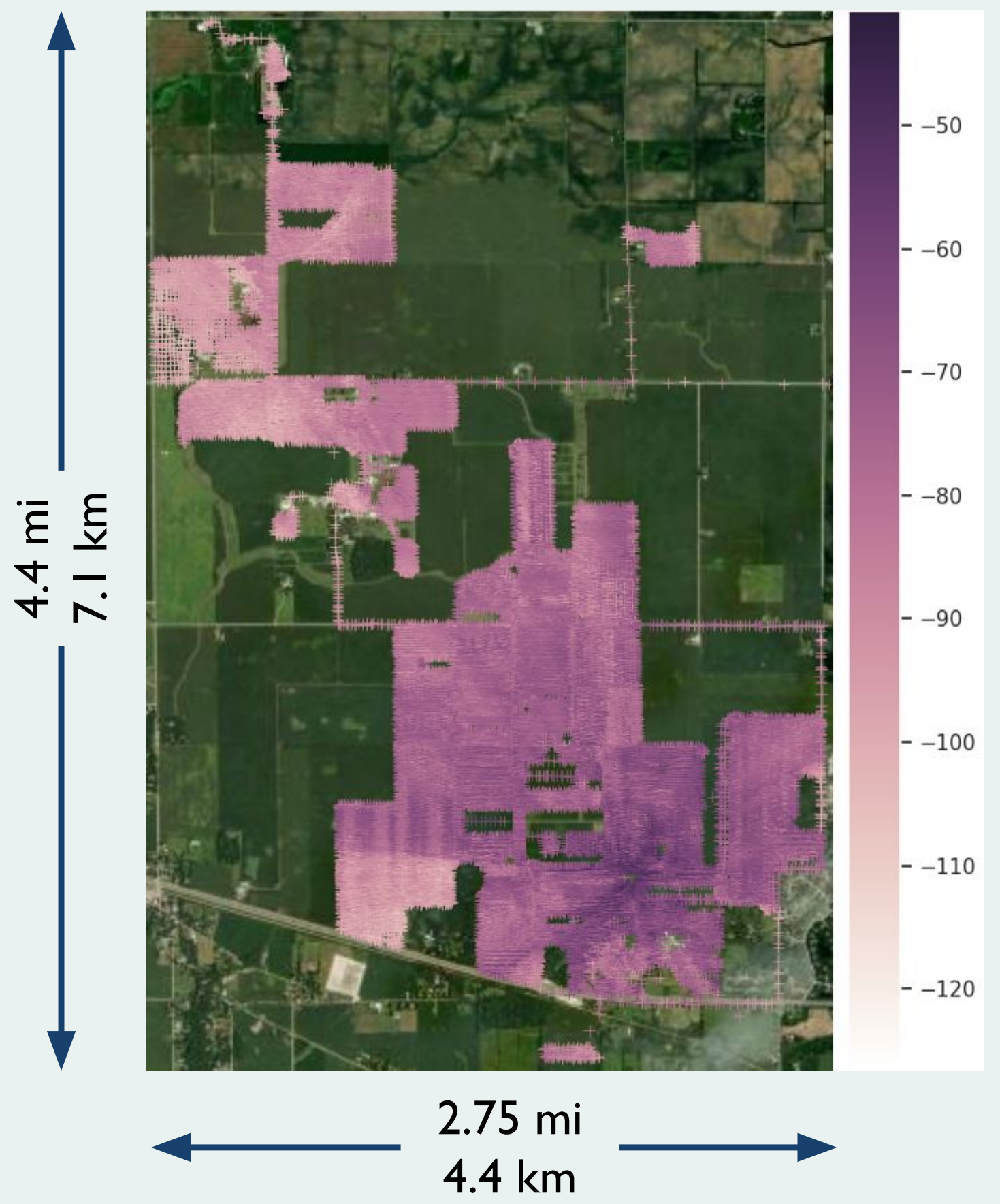
A total of **385,358** measurements were made in the **126 days**, from August 11th, 2021 to December 14th, 2021. A second 2022 collection was made, but not yet analyzed.

Receive Power (RSSI) and Signal to Noise Ratio (SNR)
The gateway's LoRa radio makes two independent measurements:
- RSSI (dBm) – Receive signal power at the antenna pre-demodulation
- SNR (dB) – Estimated as part of the demodulation

However, because LoRa routinely work under the noise floor, the RSSI values are limited by the radio's own noise power. We correct for with the estimated SNR

$$\widehat{\text{RSSI}} = \text{RSSI} - 10\log_{10}\left(1 + 10^{-\text{SNR}/10}\right)$$

RESULTS & CONCLUSIONS

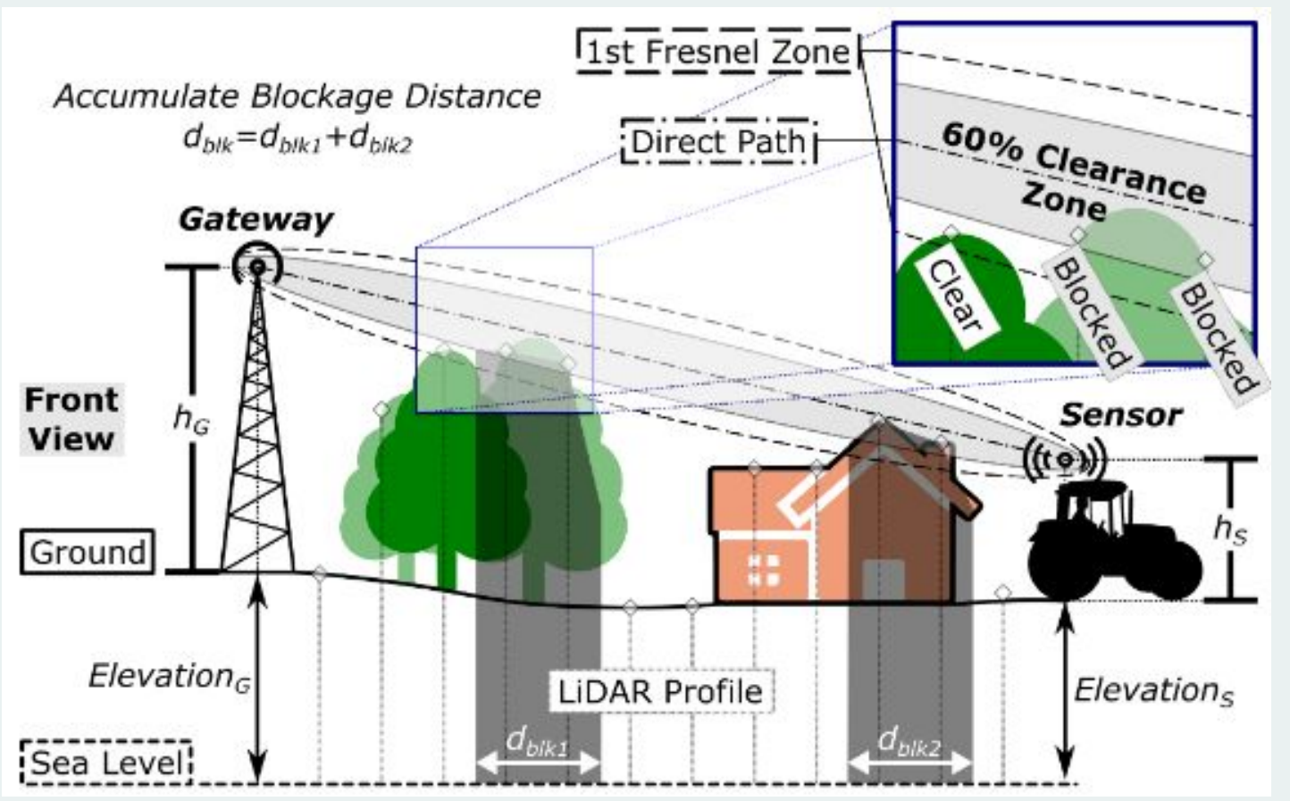


The **measured propagation map** in corrected RSSI, quantized to 20m x 20m grid via a median filter. Median was selected due to the outlier prone dataset.

One gateway is sufficient to cover both farm areas. The fastest rate did not work reliably in the northern fields.

Blockage matters

Notice the anomalously RSSI values in the southwest corner of the ACRE farm. This is apparently caused by a small wooded area.



To account for these issues, we utilized a LIDAR based blockage tool [2] to label each reception's **blockage distance**. Blockage distance is the accumulated distance in which the link's 1st Fresnel zone is more than 60% blocked.

Modeling loss

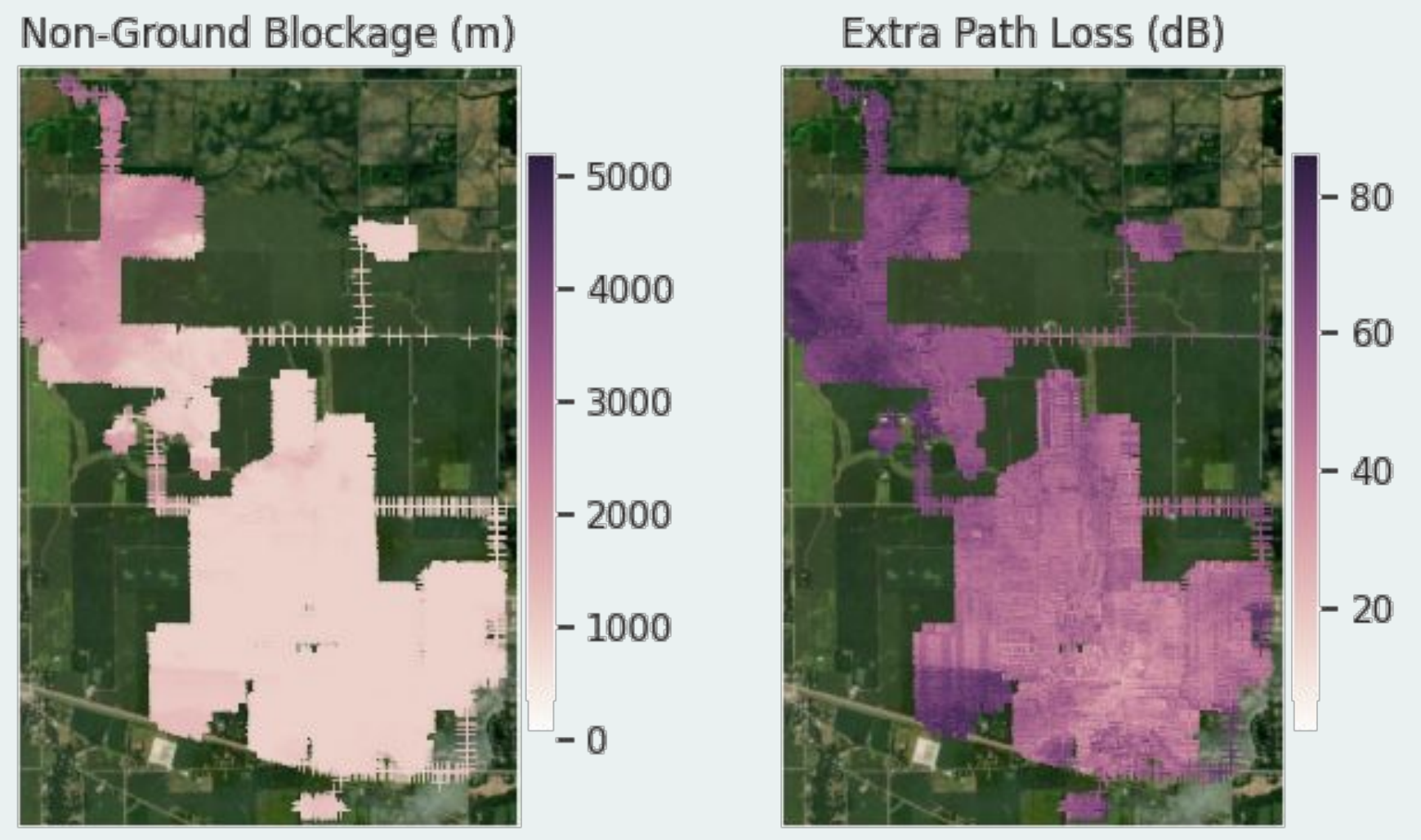
Considering free space path loss, with a non-ideal loss term $\text{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^{\alpha}$

We write our expected loss function as (in db): $L_{\text{path}} = 10\alpha\log_{10} d + \kappa$

Using the blockage labels, the data was reduced to line of sight measurements, quantized to 20 m bins of path length, and median filtered. A least squares fit reveals the **loss parameters** as:

$$\alpha = 1.52 \qquad \kappa = 51.64$$

Note: The loss term is less than the ideal case, which is not physical realizable. The gateway's meter may not be sufficiently calibrated, but the relative trends are still indicative of performance.



Shown above, the left diagram visualizes the LiDAR derived blockage distances. To the right, the excess path loss, unexplained by the line-of-sight loss model. There appears to be considerable correlation between blockage distance and excess path loss. This is the current focus of the ongoing work.

[1] Zhang, Y.; Love, D.J.; Krogmeier, J.V.; Anderson, C.R.; Heath, R.W.; Buckmaster, D.R. Challenges and Opportunities of Future Rural Wireless Communications. 59, 16–22. https://doi.org/10.1109/mcom.001.2100280.

[2] Zhang, T. Arakawa, J.V. Krogmeier, C. R. Anderson, D. J. Love and D. R. Buckmaster, "Large-Scale Cellular Coverage Analyses for UAV Data Relay via Channel Modeling," ICC 2020 - 2020 IEEE International Conference on Communications (ICC), Dublin, Ireland, 2020, pp. 1-6, doi: 10.1109/ICC40277.2020.9149403.

LoRaWAN @ IoT4Ag Testbeds

Interested in a unified IoT4Ag LoRaWAN network for seamless data collection and easy experiment movement between campuses?
Please talk with us about your use case.
See poster "Scaling up Battery Testing to ERC Testbeds with LoRaWAN" for an example.