ECE6784 Semester Project:

“LoRa Performance Evaluation for Piedmont Region of Virginia”

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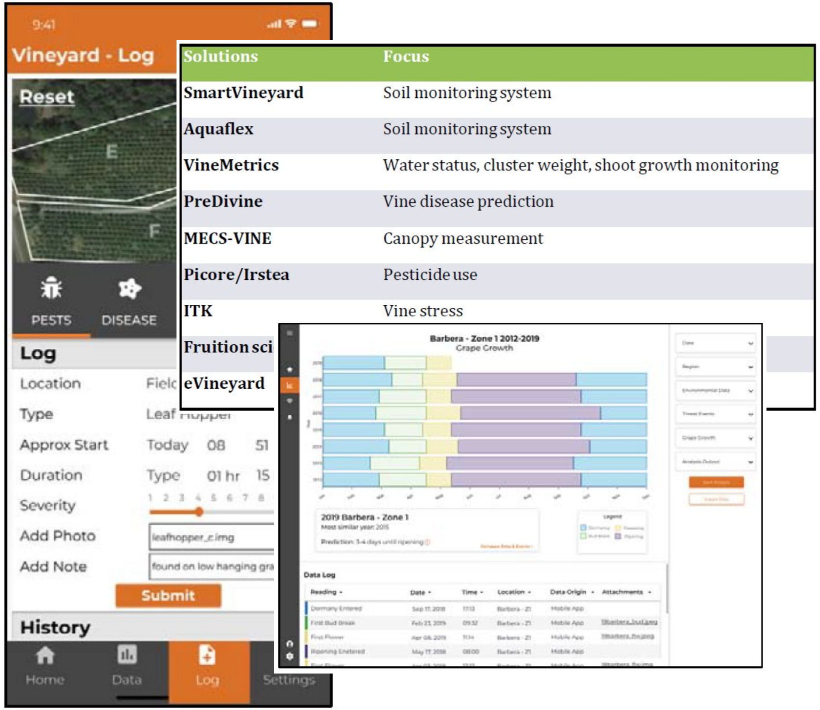
https://github.com/mjs161803/channel-modeling-project-public/

Background - Smart Agriculture

- Reduced costs enabling farmers to use low-power, wide-area sensor networks
- Soil moisture, humidity, pest detection
- Improve Profitability
  - Reduced water usage
  - Disease prediction
  - Reduced pesticide usage
  - Remote sensing vs human inspection
- Applicable for Virginia's Vineyards
  - 2017 Report to EU Commission
  - 2020 UVA Paper: "Low Power Wireless Networks in Vineyards"

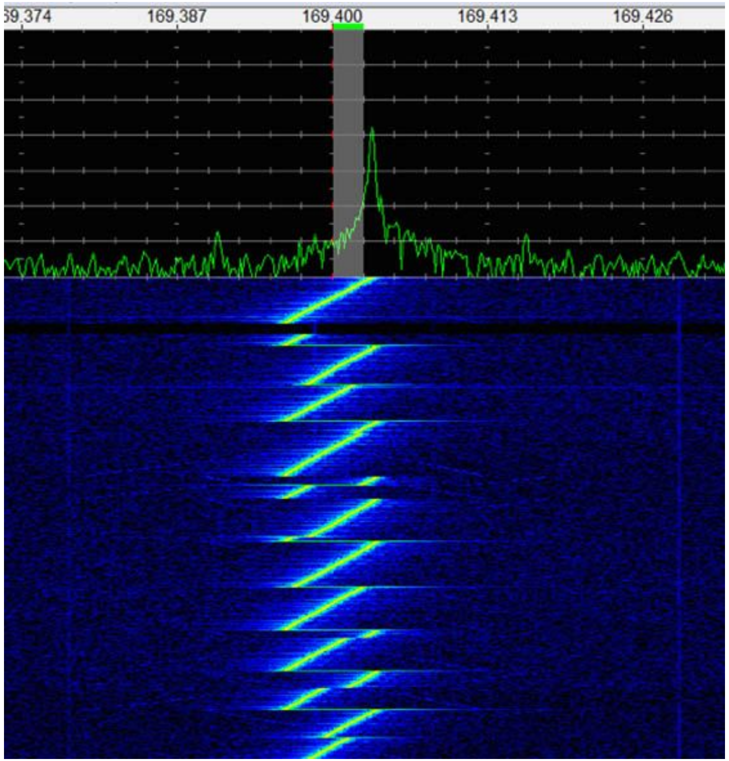


Solutions	Focus
SmartVineyard	Soil monitoring system
Aquaflex	Soil monitoring system
VineMetrics	Water status, cluster weight, shoot growth monitoring
PreDivine	Vine disease prediction
MECS-VINE	Canopy measurement
Picore/Irstea	Pesticide use
ITK	Vine stress
Fruition sci	
eVineyard	

Screenshots of Tools Developed in Renehan, et al '20

Background - LoRa

- LoRa: “Long Range”
- Chirped Spread Spectrum
- Proprietary Modulation
- Advertised ranges of 10+ km
- Low data rates



Spectrum and Waterfall Plot of LoRa Signal During Data Transmission (Source: [Link Labs]())

Project Goals

This project aimed to:

1. Characterize the Piedmont-specific wireless channel conditions for a specific LPWAN technology: LoRa ("LOng RAnge")
2. Develop a model for prediction of coverage area for LoRa-based LPWANs in the Piedmont area.

Conclusions Up Front

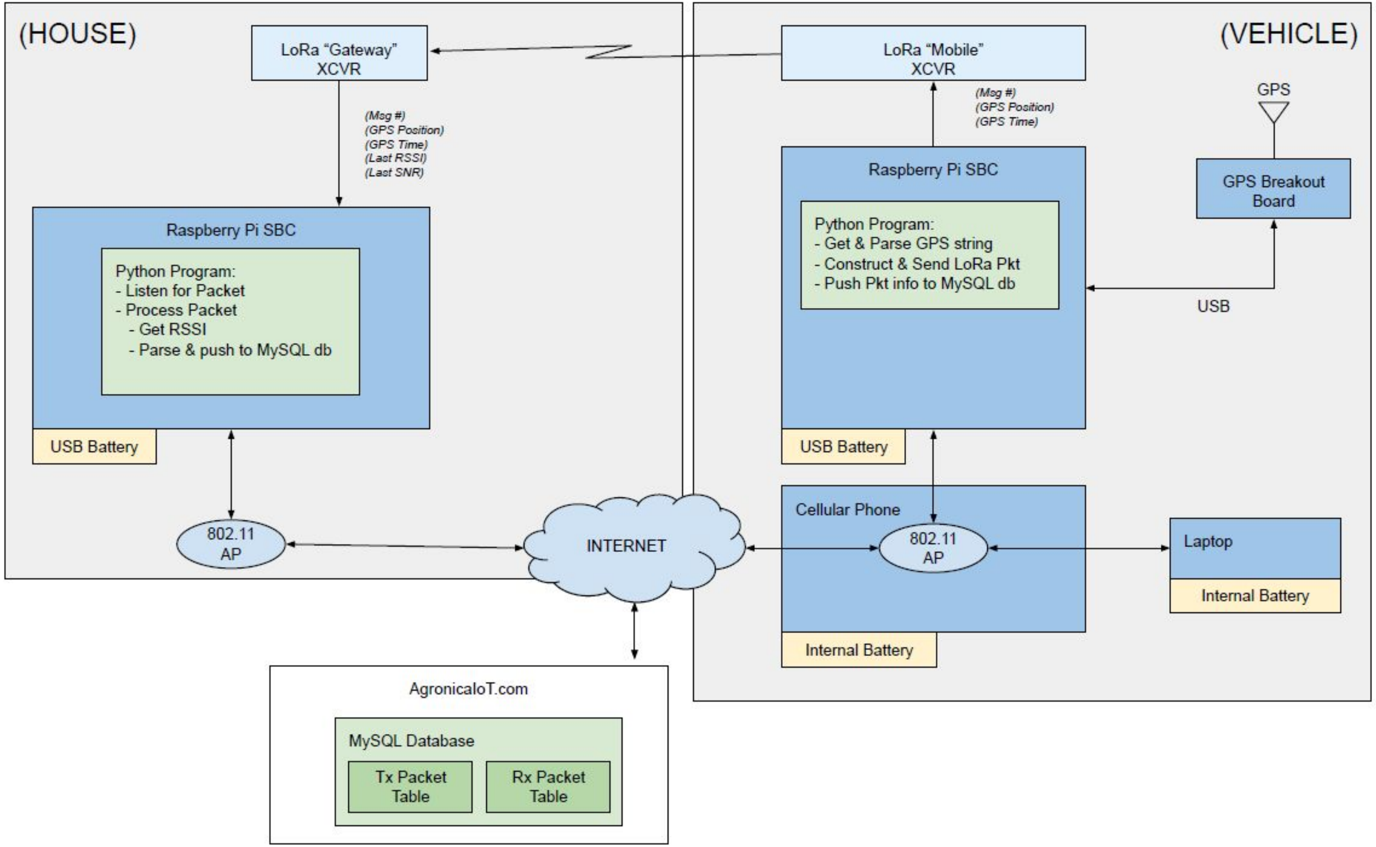
- LoRa-based wireless networks are a viable technology for enabling “smart” vineyards in the Piedmont Region.

- A “conservative” model, based on empirical measurements, for a wireless channel at 915 MHz in the Piedmont area predicts a properly-located single LoRa base station should be capable of servicing a cell bigger than any vineyards in the state.
  - The average vineyard site in Virginia is approximately 15 acres, with a median size of approximately 7.5 acres[1]
  - The largest vineyard in the state is 227 acres (Trump Winery)[2]

Methodology

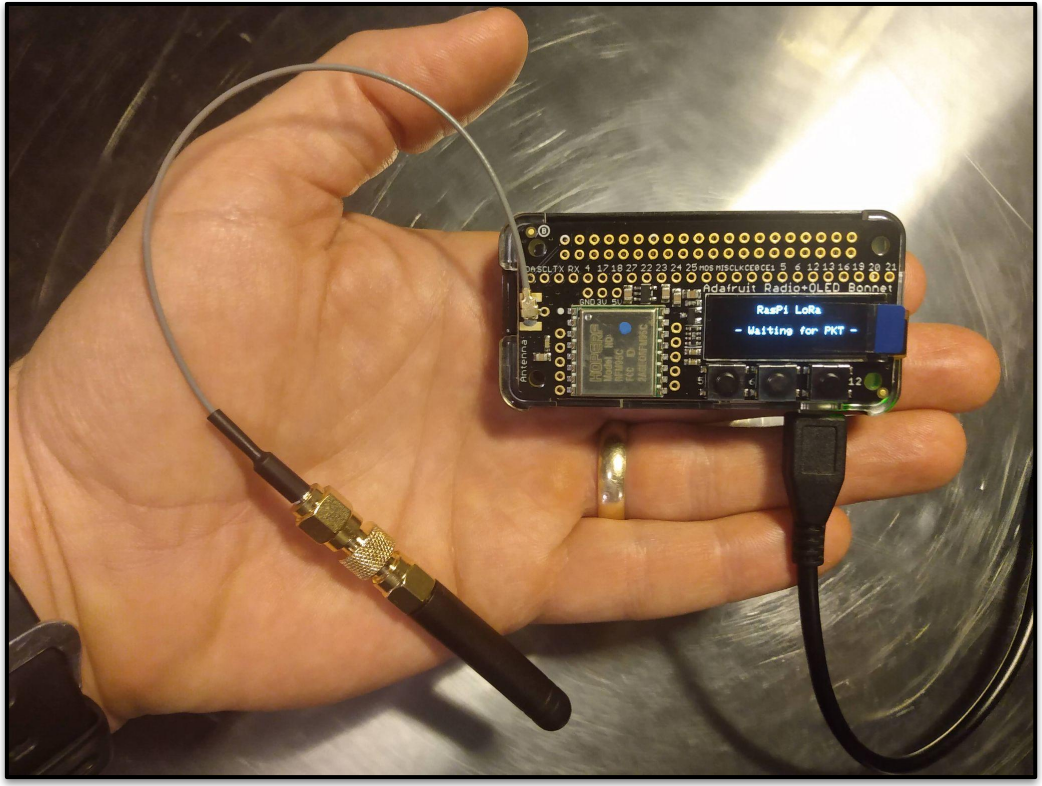
1. Transmit packets from various locations around Gateway. For each Tx Packet:
    a. Record position, date/time, message serial #, tx_power to ‘tx_packets’ table
    b. If received at gateway, record RSSI to ‘rx_packets’ table.
2. Analyze tx_packets and rx_packets:
    a. Calculate K and gamma for a Simplified Path Loss Model
    b. Use model to calculate standard deviation from model (i.e. - shadow fading)
    c. Calculate packet loss rates versus distance
3. Utilize model data to assess suitability for Virginia Piedmont-area vineyards

Test Setup



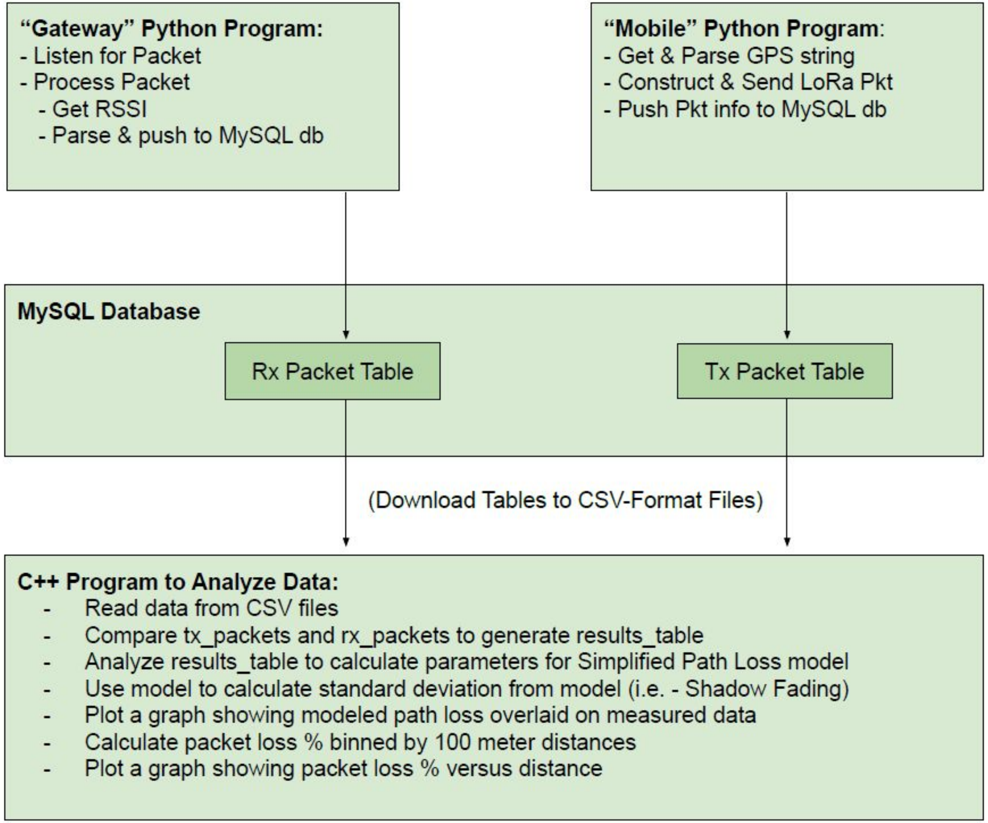
(HOUSE)
LoRa "Gateway"
XCVR
(Msg #)
(GPS Position)
(GPS Time)
(Last RSSI)
(Last SNR)
Raspberry Pi SBC
Python Program:
- Listen for Packet
- Process Packet
- Get RSSI
- Parse & push to MySQL db
USB Battery
802.11
AP
INTERNET
(VEHICLE)
LoRa "Mobile"
XCVR
(Msg #)
(GPS Position)
(GPS Time)
GPS
Raspberry Pi SBC
Python Program:
- Get & Parse GPS string
- Construct & Send LoRa Pkt
- Push Pkt info to MySQL db
GPS Breakout
Board
USB
USB Battery
Cellular Phone
802.11
AP
Internal Battery
Laptop
Internal Battery
AgronicaIoT.com
MySQL Database
Tx Packet
Table
Rx Packet
Table

Test Hardware



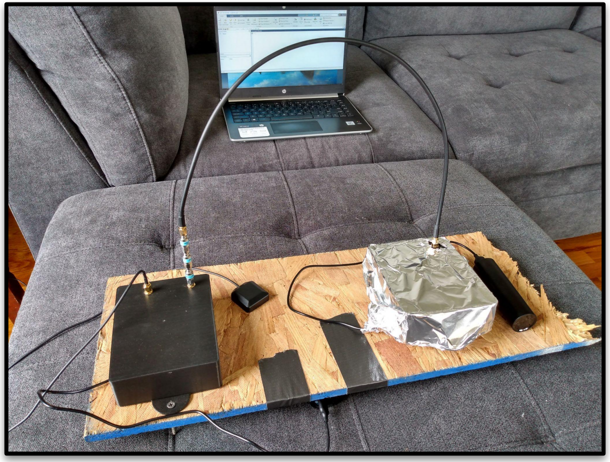
Test Hardware

Test Software



Analysis - Determining Tx Power

	30 dB ATTENUATION	60 dB ATTENUATION	90 dB ATTENUATION	120 dB ATTENUATION
Tx_Power = 20	RSSI = -52 dBm	RSSI = -70 dBm	RSSI = -82 dBm	RSSI = -83 dBm*
Tx_Power = 10	RSSI = -52 dBm	RSSI = -77 dBm	RSSI = -91 dBm	RSSI = -90 dBm
Tx_Power = 5	RSSI = -55 dBm	RSSI = -82 dBm	RSSI = -97 dBm	RSSI = -95 dBm



- RSSI = Tx_Power + $2L_{cables}$ - 60 dB
- L_{cables} = (Tx_power - RSSI - 60) / 2
  = (5 +82 - 60) / 2
  = 13.5 dB

- RSSI = $P_T + 2G_{Ant} - 2L_{cables}$ - Pathloss

Pathloss = P_T - RSSI + $2G_{Ant} - 2L_{cables}$

Analysis - Determining K and d_o

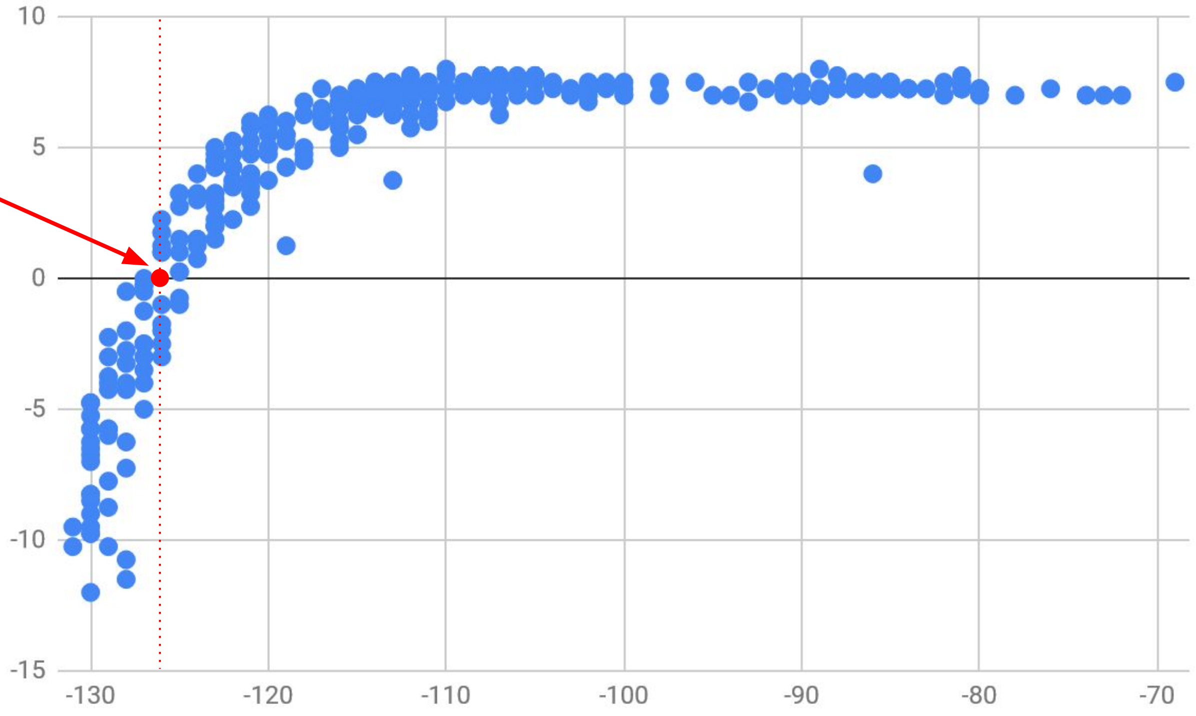
- How to pick reference distance and K values?
- Textbook indicates simply using FSPL
- Or… just brute force it! Pseudocode:
  - Iterate over all distances between minimum and maximum tx locations
    - Iterate over all possible path losses from 0 to -160 dB
      - For each combination of d_o and K…
      - Calculate gamma
      - Calculate standard deviation from model
      - Keep track of which values give the lowest standard deviation
- ~ (3000 d_o iterations) * (160 K-value iterations) = 480,000 iterations

Analysis - Noise Floor

SCATTERPLOT OF (RSSI, SNR)

Noise Power =

~ 126 dBm



Analysis - Determining Gamma

1) Simplified Path Loss Model:

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma}$$

2) Re-arranged using dB:

$$P_r \text{ dBm} = P_t \text{ dBm} + K \text{ dB} - 10\gamma \log_{10}\left[\frac{d}{d_0}\right]$$

3) Iterate over every result and determine MSE as a function of gamma:

$$F(\gamma) = \sum_{i=1}^{N} [M_{\text{measured}}(d_i) - \underbrace{M_{\text{model}}(d_i)}_{K \text{ dB} - 10\gamma \log_{10}\left[\frac{d}{d_0}\right]}]^2$$

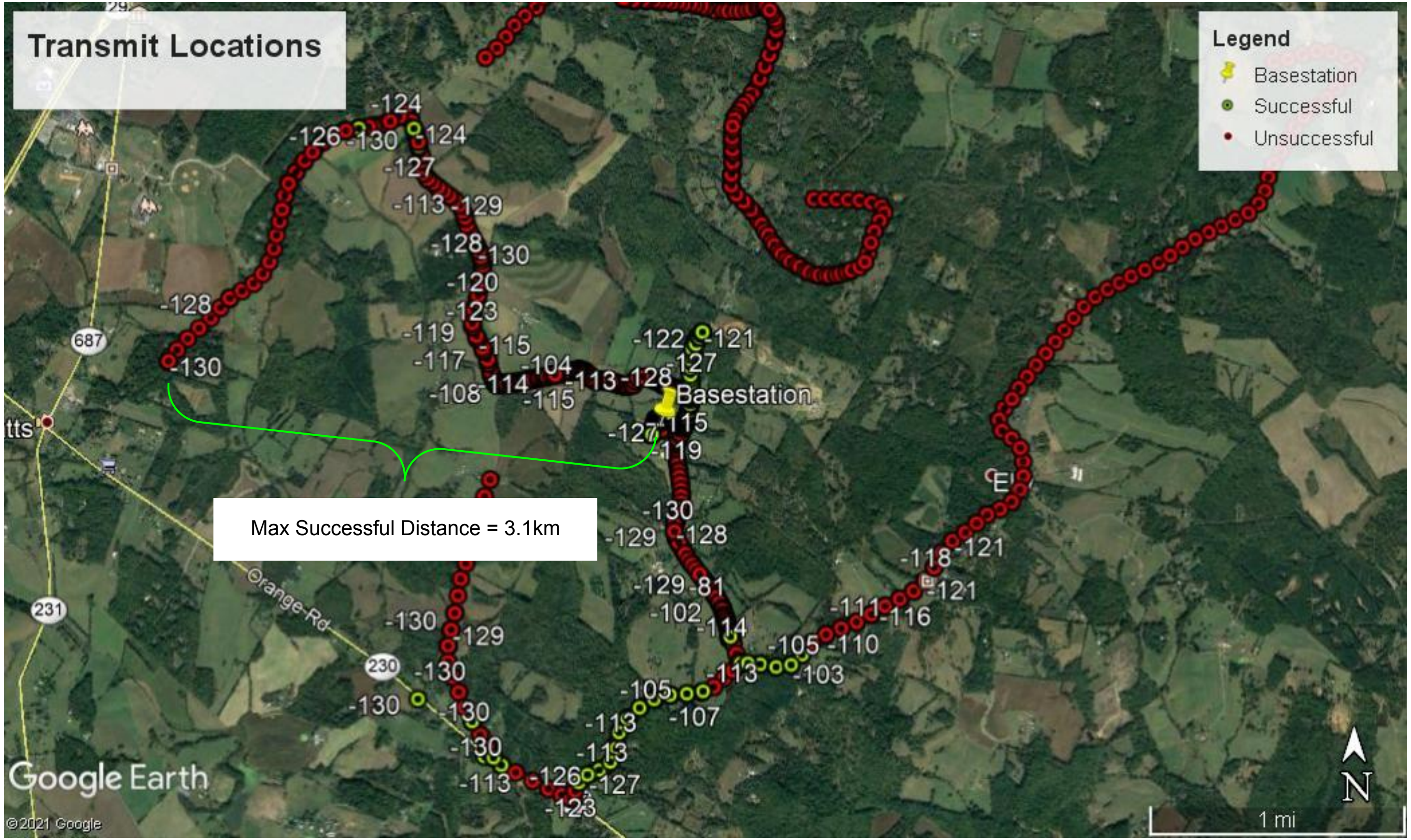
4) Differentiate, set equal to zero, and solve for gamma.

Environment	γ range
Urban macrocells	3.7-6.5
Urban microcells	2.7-3.5
Office Building (same floor)	1.6-3.5
Office Building (multiple floors)	2-6
Store	1.8-2.2
Factory	1.6-3.3
Home	3

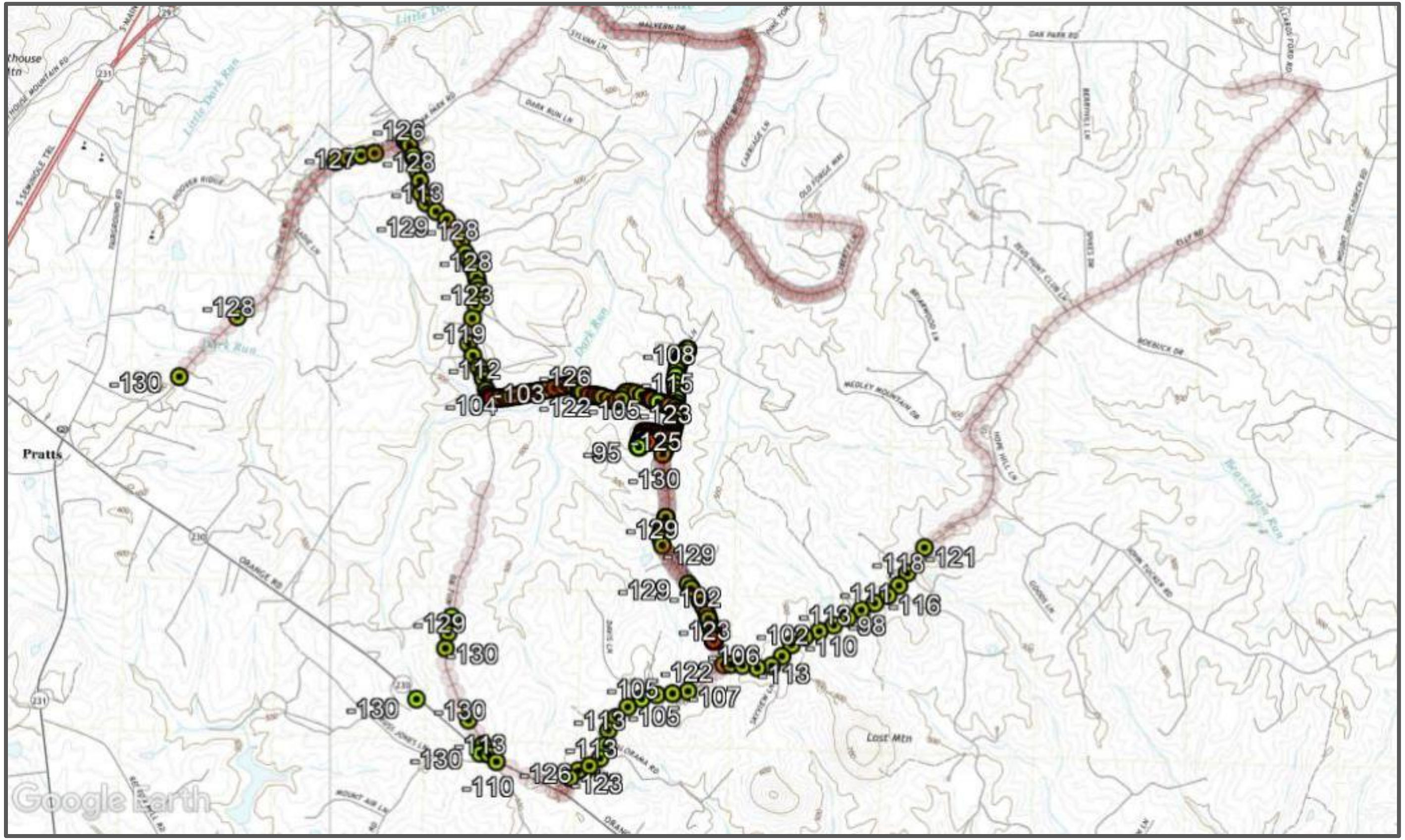
Table 2.2: Typical Path Loss Exponents

Results - Google Earth

- 809 Packets transmitted
- 330 Packets received
- More data needed
- Limited to collecting along roadways, which are not identically-distributed testing points.



Results - Google Earth



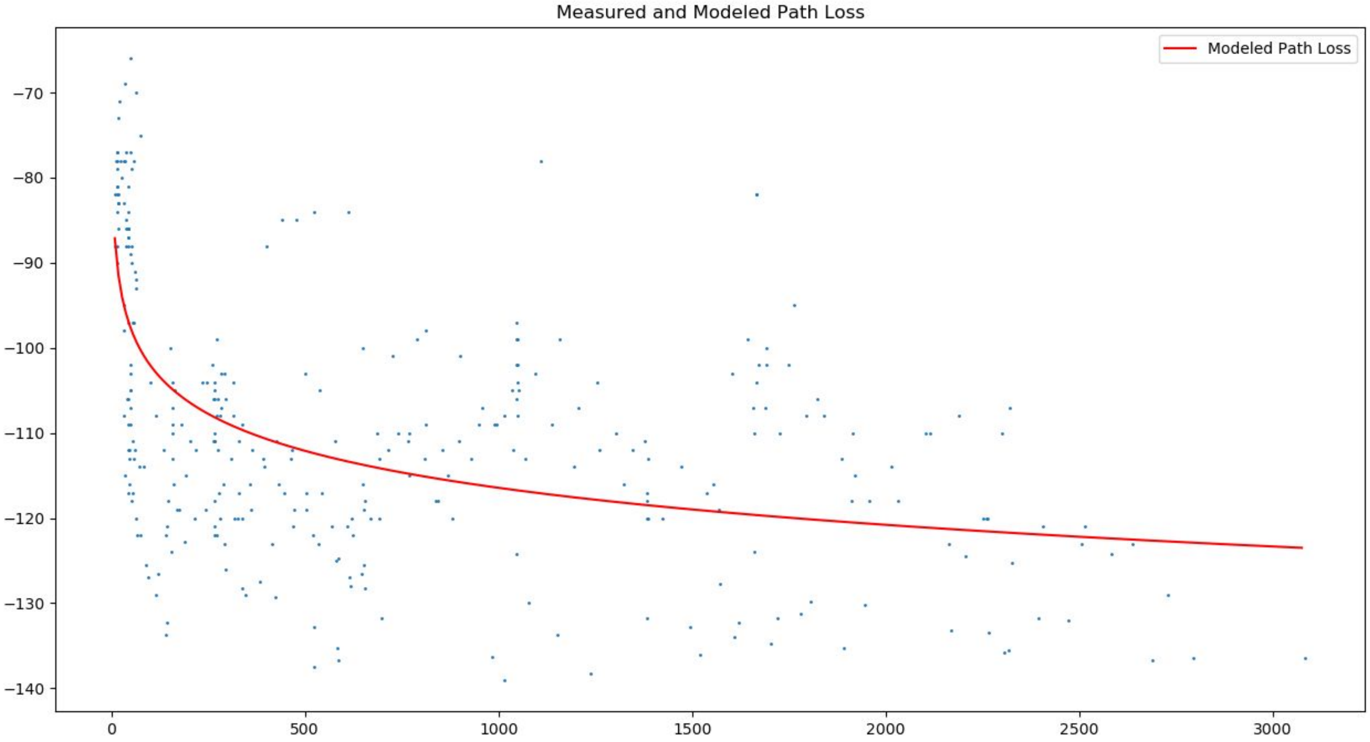
Results - Path Loss

- Reference distance d_o = 2844 meters
- K = -123 dB using measured data
  - K = -100.7 dB using FSPL
- Gamma = 1.45
- std = 12.8 dB

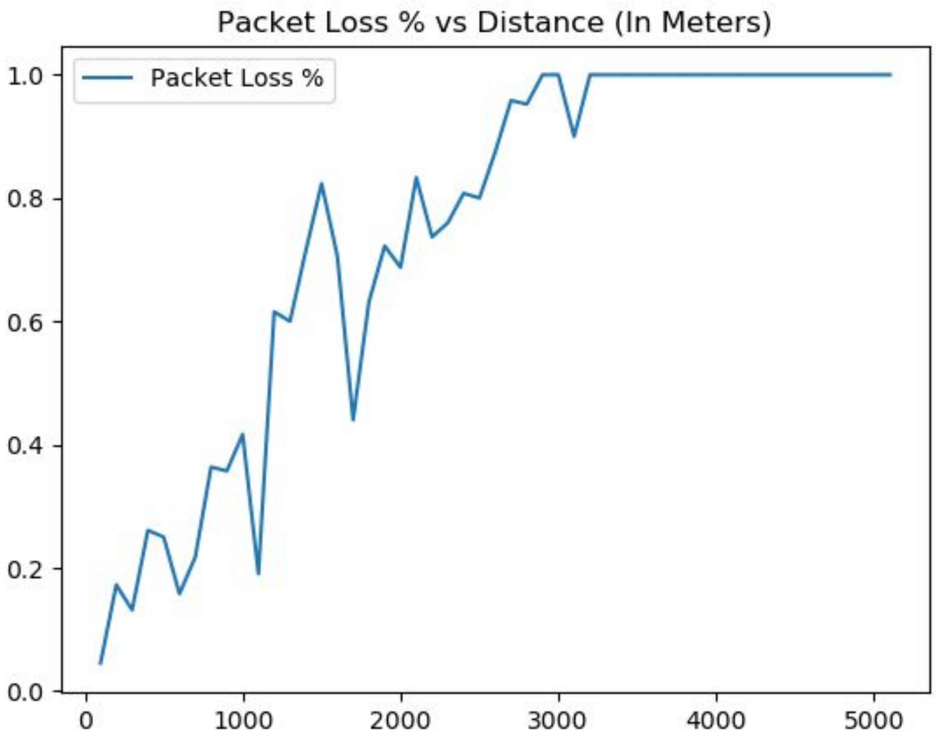
```
mjs161803@apollos: ~/ECE6784/Project/channel-modeling-proj...
mjs161803@apollos:~$ cd ECE6784/Project/channel-modeling-project/
mjs161803@apollos:~/ECE6784/Project/channel-modeling-project$ ./runprogram
Optimized model reference distance (d_o): 2844.59
Optimized model path loss @ d_o (K): -123
Optimized model gamma value: 1.44505
Optimized model standard deviation from model: 12.7991
mjs161803@apollos:~/ECE6784/Project/channel-modeling-project$
```

$$P_r \text{ dBm} = P_t \text{ dBm} \;\; \text{-123} \;\; \text{dB} \;\; \text{-14.5*} \;\; \log_{10}\left[\frac{d}{2844}\right]$$

Results - Path Loss



Results - Packet Loss



Conclusions - Vineyard Suitability

- Different ways of calculating maximum cell size…
  - Ignore fading: d_max = 629 km
  - Packet Loss < 1.0: ~3.1 km
  - 50% availability: 93 km
  - 90% availability: 6.9 km
  - 99% availability: 0.83 km

Method:	Max Range (km):	Equivalent Circular Acreage:
Ignore Fading	629	3.07 * 10^8
Packet Loss	3.1	7,460
99% Availability	0.83	535

- Median Virginia Vineyard size = 15 acres
- Maximum Virginia Vineyard Size = 227 acres

ASSUMPTIONS:

- +20 dBm Tx Power
- -148 dBm min Rx Power
- +2 dBi Antenna Gains at both Tx and Rx
- -27 dB Total Cable Losses
- Both antennas approximately 2 meters above ground

QUESTIONS?