Planning long distance wireless links

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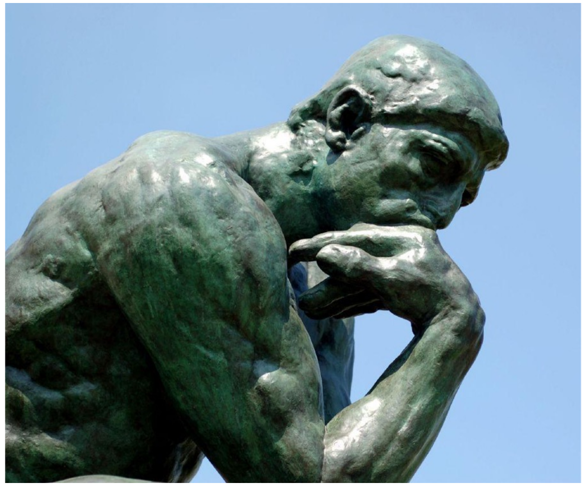
Agenda

- Wireless links planning considerations
- RF propagation scenarios
- RF link budget simulation tools
- Some examples of wireless networks deployments

Factors to consider in planning a network

- Availability of unlicensed frequencies and degree of occupancy
- Availability of service providers for different solutions
- Number of devices to be deployed
- Number and frequency of messages
- Minimum latency
- Maximum payload
- Battery duration
- In-house expertise



Define your goals

1) Define your goals and characterize the desired output of your project, with measurable figures like:

- Average usage (number of clients connected)
- Average/peak throughput (overall/per user)
- Latency and other network issues that can influence the services running on the network
- Reliability (percentage of downtime)
- Maintenance costs

Design and simulation

3) Feasibility check: **design** and **simulate** the architecture of your wireless network, considering aspects like:

- Location of nodes and their accessability (maps...)
- Equipment to be deployed in each node
- Availability of suitable antenna support structures
- RF power link budget and Line-of-Sight clearance for each hop (with the help of simulation tools)
- Source of powering for each equipment
- Selection of frequency of operation for each hop
- Co-location and interference issues in each node

Understand the constraints

2) Understand which are the constraints and limitations, like for example:

- Local availability of equipment
- Regulatory aspects (permits, fees, allowed frequencies and power, equipment homologation)
- Limitations of the ISP
- Access to sites and infrastructures
- Availability of power (and its quality/reliability)
- Human resources (for deployment/maintenance)
- Financial constraints (budget)

Design and simulation

3) Feasibility check: **design** and **simulate** the architecture of your wireless network, considering aspects like:

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- Co-location and interference issues in each node

Site survey

4) Site survey: **inspection** of every relevant site, evaluating its positive and negative aspects like:

- Accessibility to the site and inside the structure
- Electrical power provisioning, grounding
- Survey of the e.m. spectrum and its usage (to select the best operating channels to use)
- Line-of-Sight clearance towards other nodes
- Pre-existing structures for antenna mounting
- Arrange for practical considerations before the actual installation (required personnel, keys, ladders, etc)
- document everything with notes and pictures, take precise measurements where possible, take GPS coordinates and elevation data

Bring with you:

- Smart phone:
  - Compass, GPS
  - Digital camera
- Binoculars
- Measuring tape
  - Size of structures
  - Distances
- Harness and climbing gear

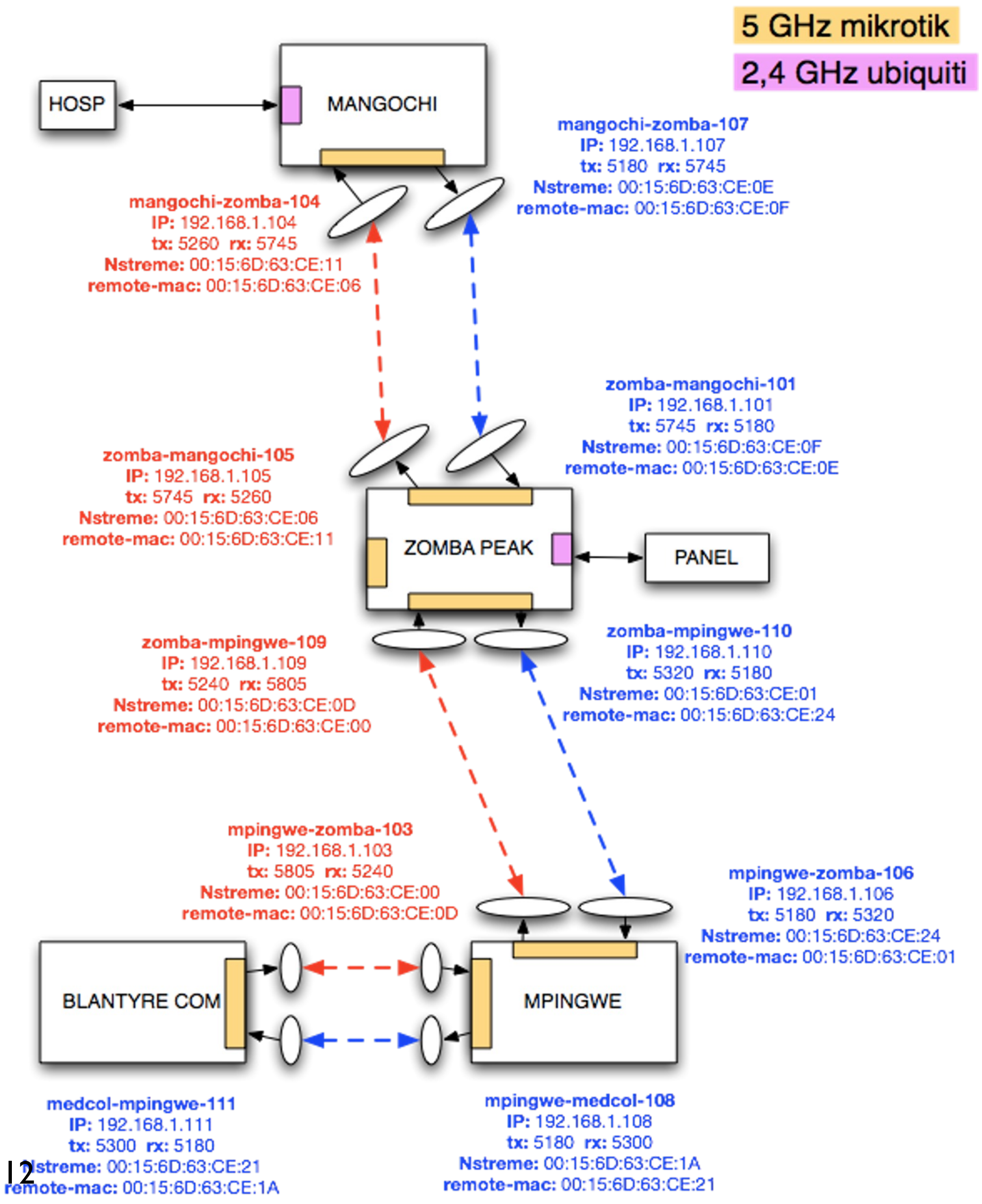
Often overlooked tips

- For very long distance links, it can be difficult to spot the remote end. In daytime, mirrors can be used to reflect light and make the other end easier to spot. At night, spot lights or strobe lights can help.
- A tethered balloon can also help locate the remote end of a link, as well as to estimate the necessary tower elevation needed to overcome any obstacles.
- Mobile phone coverage is not universal. Bring a pair of two way radios when working in remote places (especially for antenna alignment).
- Umbrellas can help shield glare on laptop screens on a sunny day.
- Safety first: wear gloves, helmet and harness when climbing towers.
- Don’t forget about the weather: wear a hat, sunglasses, and sun screen when appropriate.

Final design

5) Final design of your wireless network, using the relevant information acquired during the site survey:

- FInal choice of equipment for every node
- Recalculation of power budget for every hop
- Detailed plans for antenna mounting and the running of all RF/ethernet/power/grounding cables
- Frequency plan
- Network topology and architecture, IP addressing scheme



Here is an example of a network plan, with IP and MAC addresses, host names, locations, interconnections, operating bands, and frequency choices.

E. Pietrosemoli, M. Zennaro, and C. Fonda, "Low cost carrier independent telecommunications infrastructure" GIIS 2012, pp. 1–4.

Capacity of a digital channel

$$C = B \cdot \log_2(1 + S/(N_o \cdot B))$$

Noise power density, W/Hz

Signal power, W

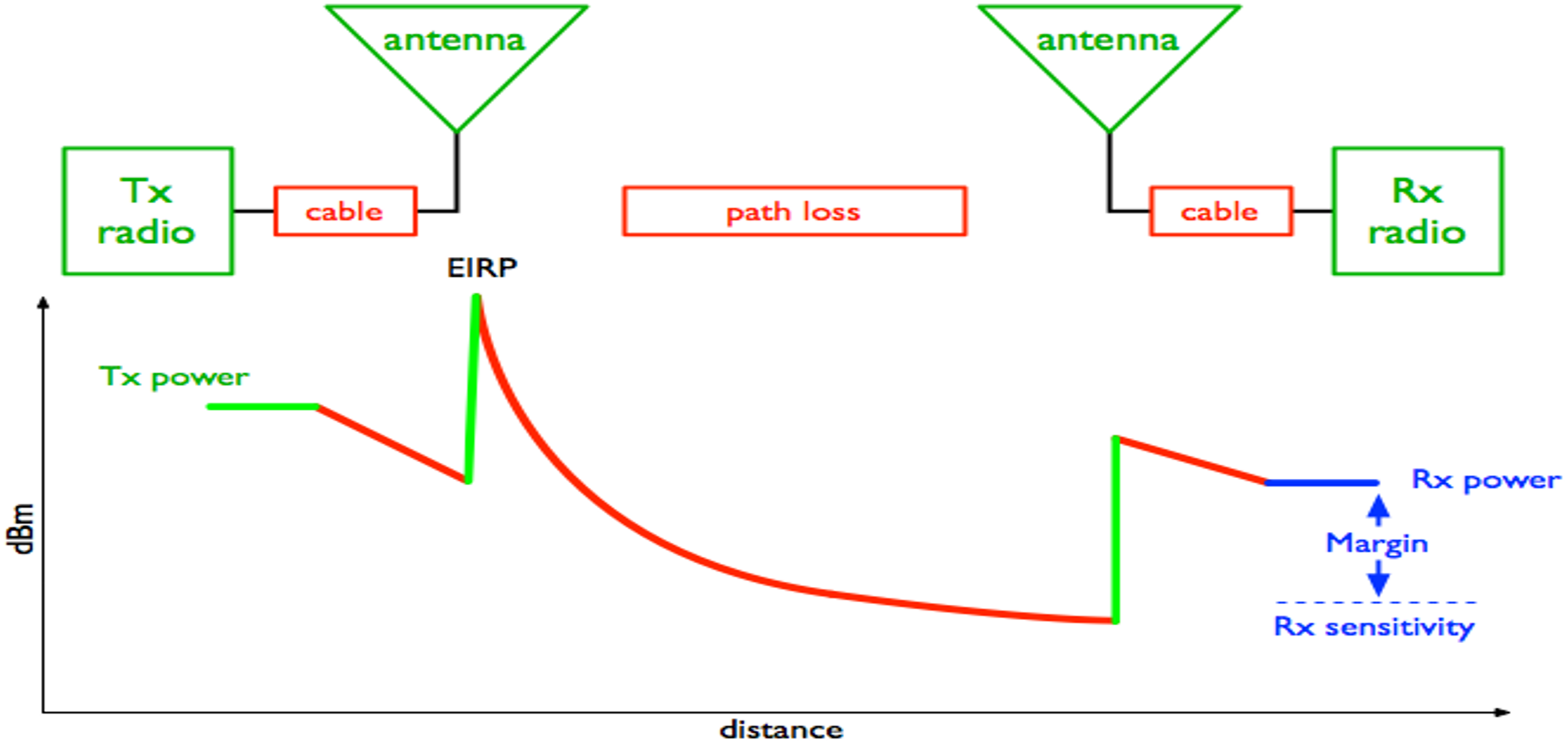
Bandwidth, Hz

Capacity, bits per second (maximum throughput)

The maximum range is determined by the energy per bit received (W·s), and depends on the effective transmitted power, receiver sensitivity, interference and data rate.

LoRa and Sigfox represent different strategies to achieve long range.

Power in a wireless system



Link budget

Link budget is a way of quantifying the link performance.

- The received power in an wireless link is determined by the following factors: transmitter power, loss of the cable between transmitter and antenna, transmitting antenna gain, *transmission path loss*, receiving antenna gain, and loss of the cable between the antenna and the receiver.
- If that power is greater than the ***sensitivity*** of the receiving radio, then the link is feasible.
- The sensitivity decreases with the bandwidth, transmission speed and the noise figure of the receiver.
- Transmission speed is determined by the modulation and coding (MCS) used.

Transmitted Power

- The transmitter power is limited by the regulations of each country, and depends on the type of service.
- In the 868 MHz unlicensed band the maximum allowed EIRP is 14 dBm in Africa and in Europe (ITU Region 1).
- The allowed transmit power can be higher in licensed bands, broadcasters can transmit at thousand of watts.
- When using a high gain transmitter antenna the conducted power of the transmitter might have to be reduced to comply with the allowed EIRP.
- In the 5.8 GHz unlicensed band the effective radiated power is much higher.

Receiver Sensitivity

The receiver sensitivity, frequently calculated at a 1% packet error rate (PER), is given by:

$$R_s = 10 \cdot \log_{10}(K \cdot T \cdot B) + S/N + NF$$

Where K is Boltzmann constant, 1.38E-38 J/K
T is absolute temperature in kelvins
B is bandwidth in hertzs
NF is the receiver noise factor in dB
S/N is signal to noise ratio required to detect the signal, which depends on the type of modulation and the data rate
At room temperature,

$$R_s = -174 \text{ dBm} + 10 \cdot \log_{10}(B) + S/N + NF$$

Example: 14 dBm Tx power at 868 MHz

- A LoRa signal with spreading factor 12 requires a S/N of -20 dB, assuming NF = 6 dB and using a 125 kHz channel we have:

  R_s = -174 dBm + $10 \cdot \log_{10}(125000)$+ (-20) + 6 = -137 dBm

  Maximum path loss = 14 dBm - (-137) = 151 dBm

- Sigfox uses a bandwidth of 100 Hz, assuming a NF = 6 dB, S/N= 10 dB, sensitivity at room temperature is

  R_s = -174 dBm + $10 \cdot \log_{10}(100)$+ 10 + 6 = -128 dBm

  Maximum path loss = 14 dBm - (-128) = 142 dBm

But Sigfox sends each message 3 times, so the effective Maximum path loss is greater

Path loss simulation tools

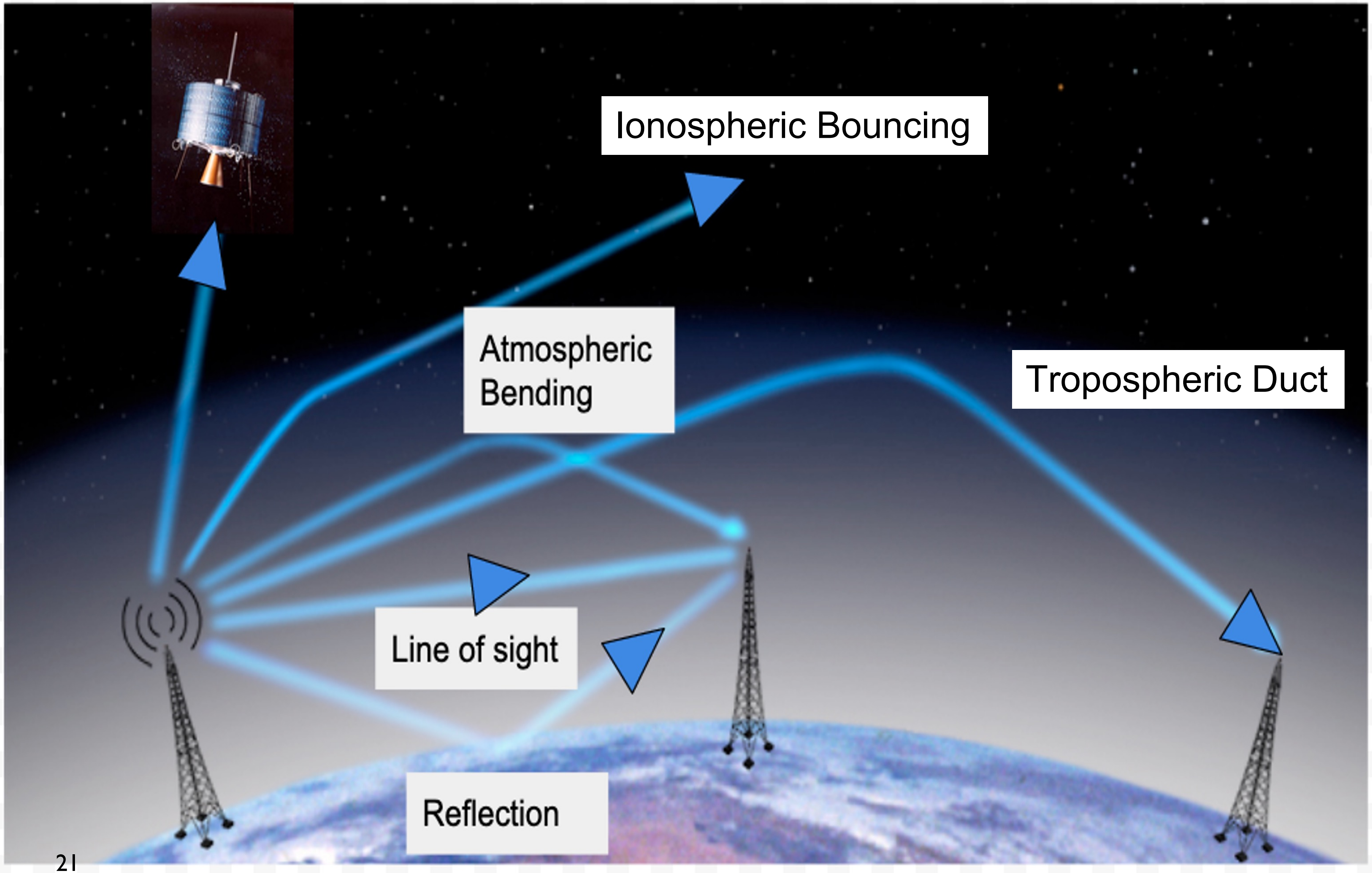
- There are many commercial software tools to simulate links, and a few are available for free.
- Radio Mobile is a free and powerful simulation tool for the Windows operating system. There is also an on-line version at: http://www.ve2dbe.com/rmonline.html
- BotRf is very simple to use app based on the *Telegram app*

M.Zennaro, E.Pietrosemoli M.Rainone "**Radio Link Planning made easy with a Telegram Bot**" GOODTECHS 2016, Venice, Italy, December 2016.

Wave propagation

Whenever a wave encounters a change of refractivity in the path it will undergo a change in the propagation speed and direction, as follows:

- Reflection, reversal of propagation direction
- Refraction, change of the propagation direction
- Diffraction, dispersion of the wave in many directions upon encountering a sizable sharp obstacle
- Scattering, dispersion of the wave in many directions when meeting irregularities (dust, rain or local inhomogeneities) in the propagation medium


Ionospheric Bouncing
Atmospheric Bending
Tropospheric Duct
Line of sight
Reflection

Atmospheric Refractivity

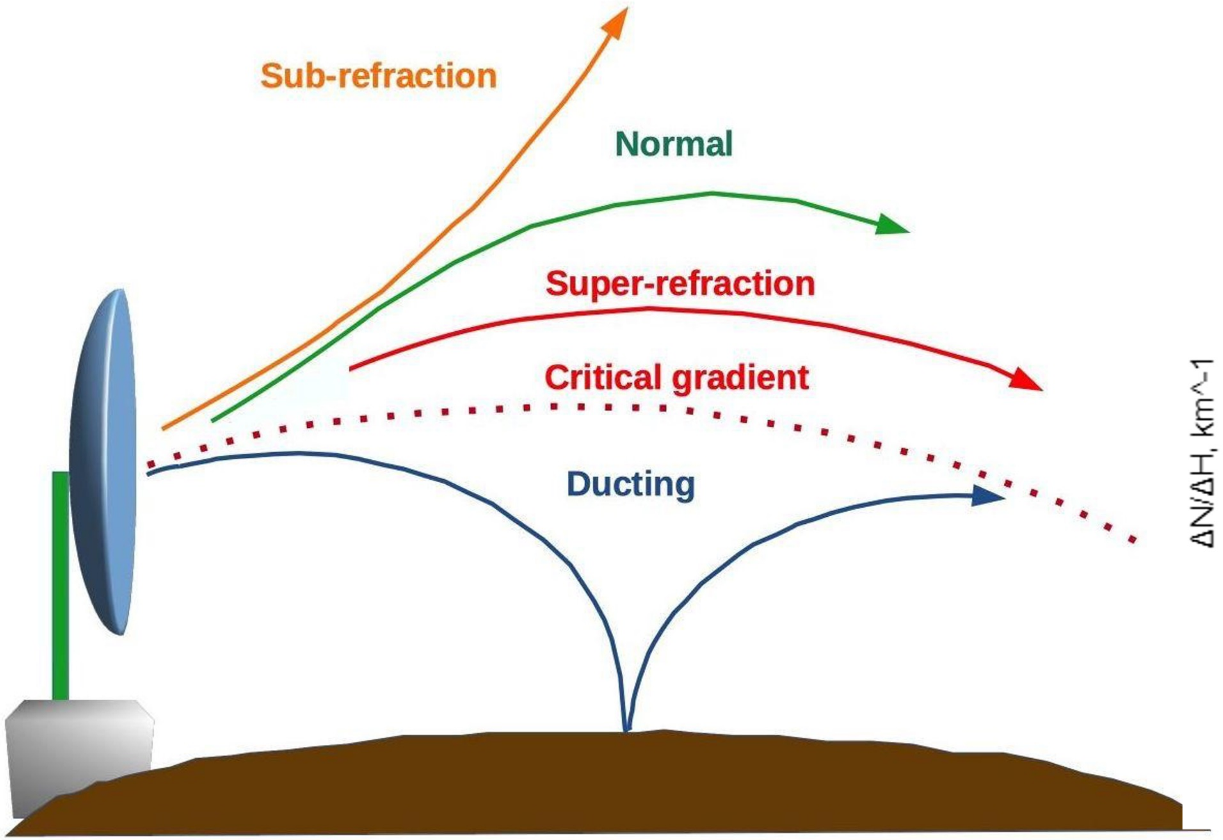
The atmospheric refractivity is given by:

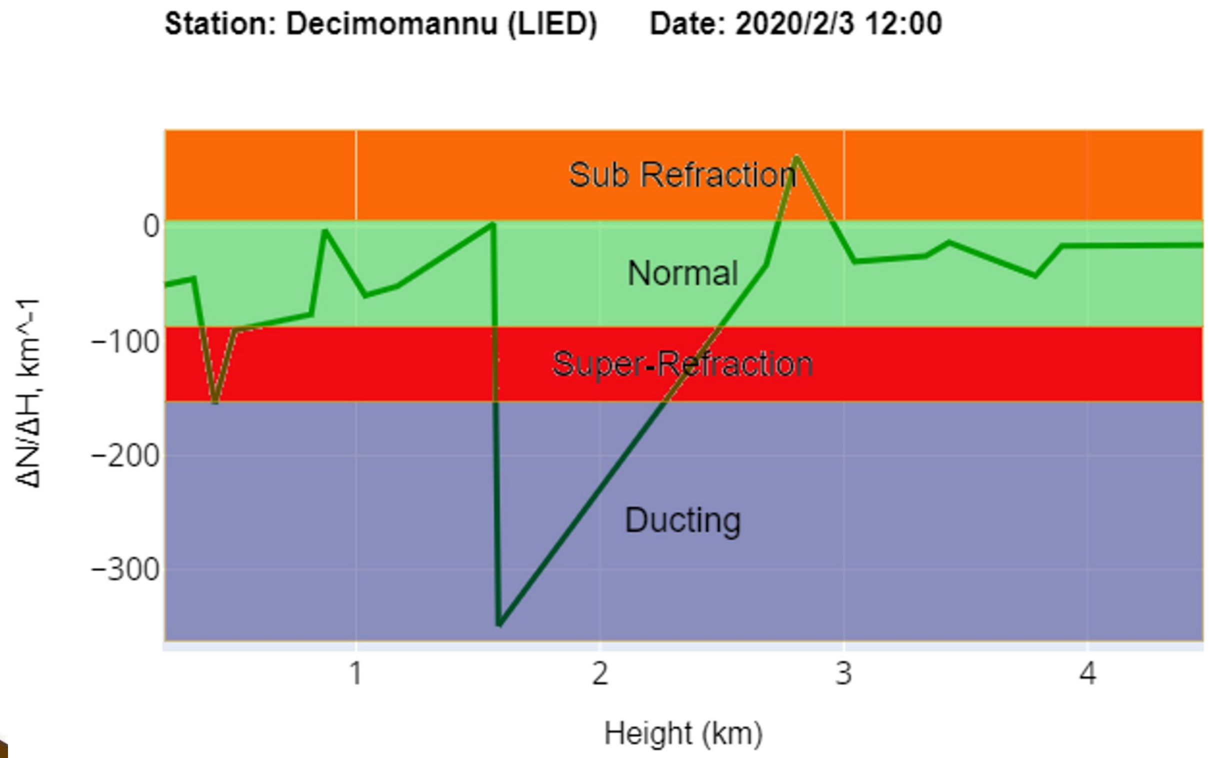
$$N = 77.6 * \frac{P}{T} + 3.73 * 10^5 \frac{r * P}{T^2 * (622 + r)}$$

Where P is the atmospheric pressure, T is the absolute temperature and r the relative humidity

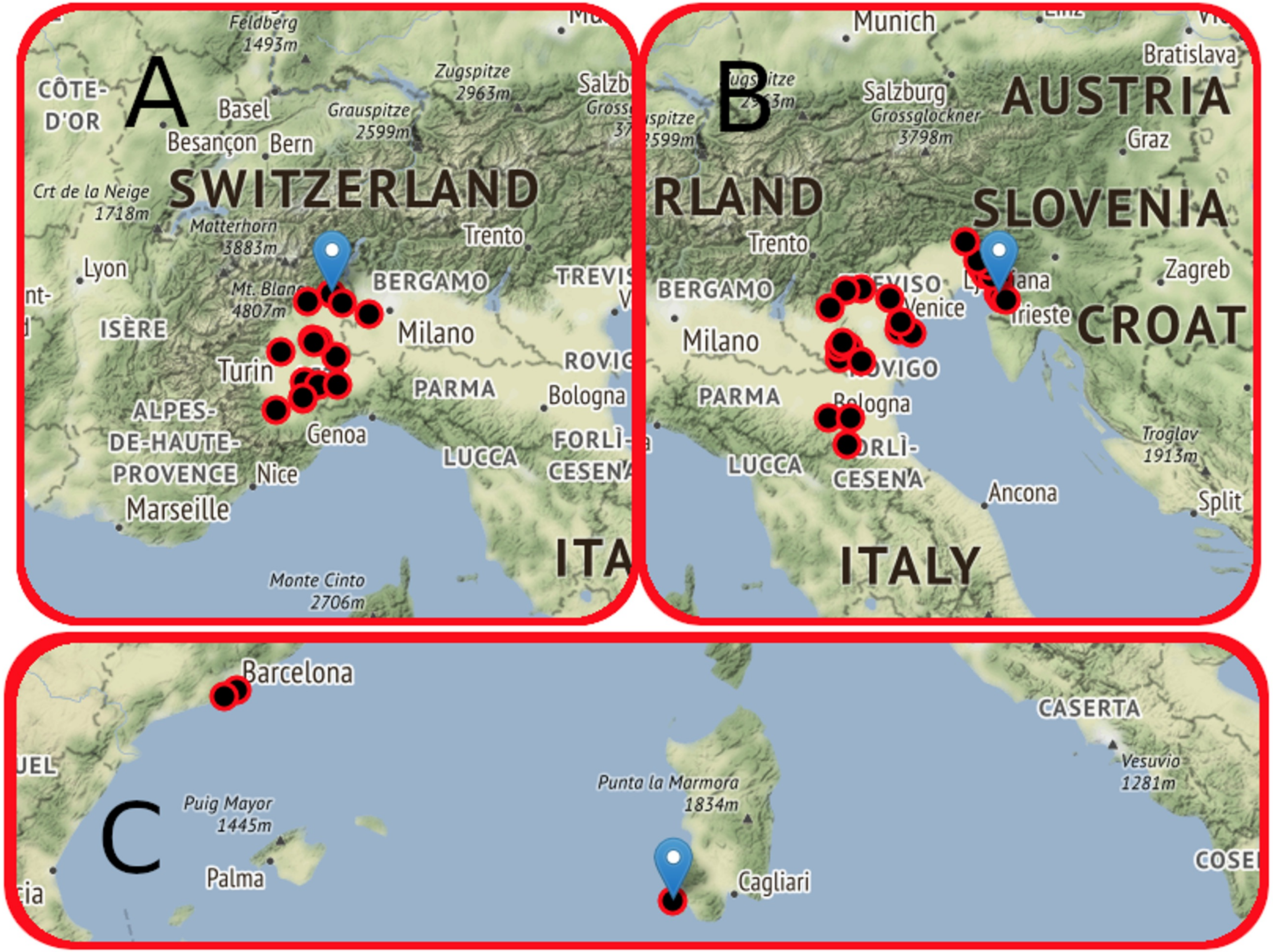
The refractivity gradient N' = ΔN/Δh determines the amount of the direction of propagation change, and can be obtained from the meteorological radiosondes launched worldwide

Tropospheric propagation variants





Location of TTN gateways that have received TROPPO Packets



BotRf: a telegram application for wireless links

To install the tool, first install the telegram application from the *play store* or the App store in your device.

You need to have a cell phone to receive an sms with the code that will grant you access. It does not need to be a smart phone.

With that code, you can run telegram in any web browser capable device, laptop, tablet or desktop, besides a smart phone phone.

Once telegram is running choose BotRf as a contact, and you are set.

BotRf was developed at ICTP with funding from the Internet Society.
The code was written by Marco Rainone and is freely available at:
https://github.com/tvws

BotRf: a telegram application for wireless links

To plan a point to point link you need:

- Coordinates and height above the terrain of the two antennas
- Frequency of operation in megahertz
- Transmission power and receiver sensitivity at the operating rate
- Transmitting and receiving antenna gains in the chosen direction
- Losses of the cables between the device and the antenna, if any
- BotRf calculates the power of the received signal by using the Longley-Rice Irregular Terrain Model, leveraging freely available digital elevation maps

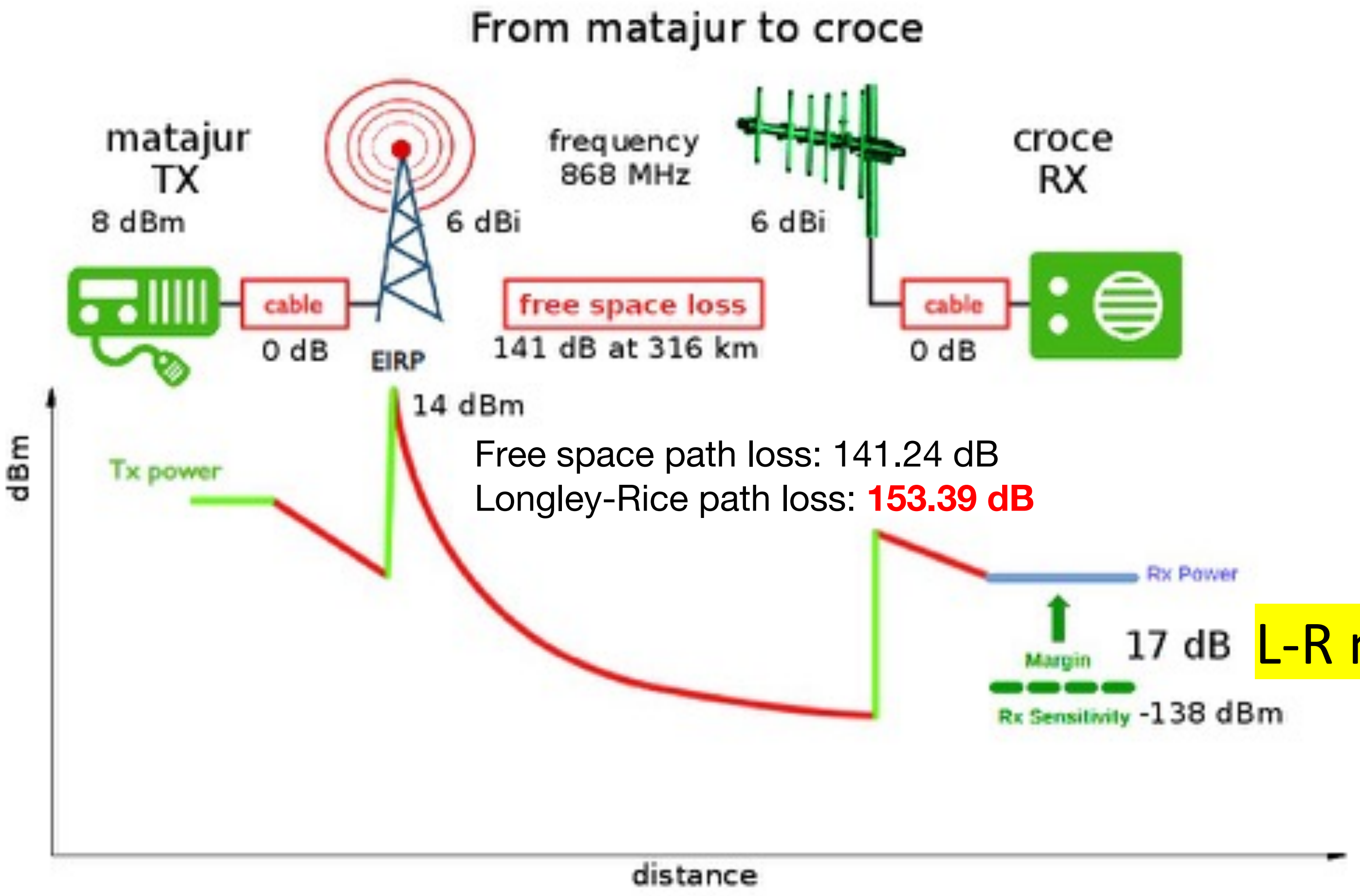
BotRf: a telegram application for wireless links

BotRf will automatically fetch the required digital elevation maps to:

- Draw the first Fresnel zone ellipsoid and optical line of sight
- Draw the apparent earth curvature for the specified refraction index
- Calculate the distance and the angles between both antennas
- Calculate the free space loss on the path and the estimated attenuation introduced by obstacles, if present
- Show a profile of the terrain between the antennas
- Draw a graph of power versus distance along the link
- Calculate the estimated received power and the link margin
- Additionally, BotRf will do many magnitude and units conversions to facilitate the planning of the link

BotRf

pow matajur croce 8 0 6 6 0 -138



Free space path loss: 141.24 dB

Longley-Rice path loss: **153.39 dB**

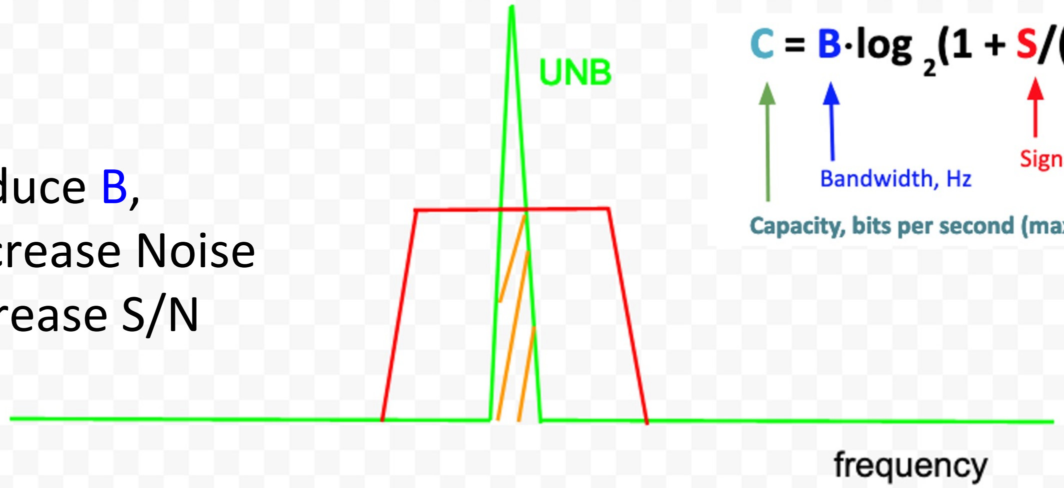
L-R margin is 5 dB

Link assessment with Google Earth

- Google earth can be used to determine LOS over short distance links.
- But it does not consider the curvature of the earth nor the bending of the radio waves because of the variation of the refractive index, so it is not a good simulation tool for radio links.

Two ways for increasing range

Reduce B,
decrease Noise
Increase S/N



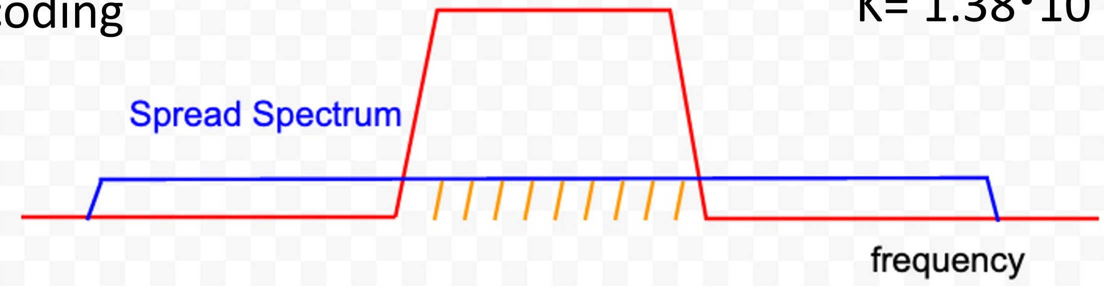
$C = B \cdot \log_2(1 + S/(N_o \cdot B))$

Noise power density, W/Hz
Signal power, W
Bandwidth, Hz
Capacity, bits per second (maximum throughput)

Increase B but reduce the required S/N for detection by means of coding

$N = (kT) \cdot B$

$K = 1.38 \cdot 10^{-23}$ J/K



Long Distance Link Requirements

For a successful long distance link one must:

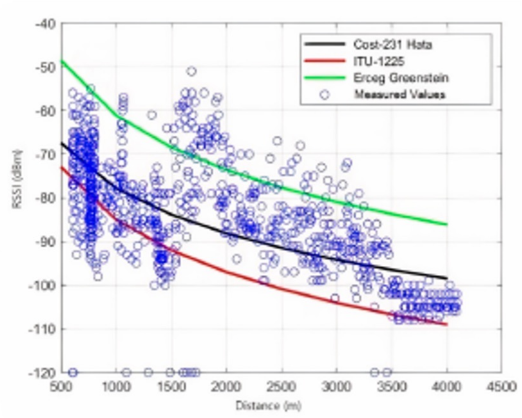
- Simulate the link and perform a site survey.
- Use suitable structures to hang antennas so that the Fresnel Zone and earth curvature can be cleared.
- Choose special purpose equipment, or modify short distance equipment, to allow for long distances.
- Use proper antenna alignment techniques.

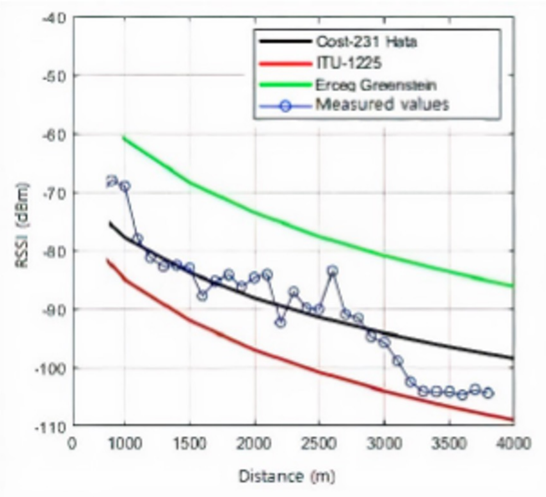
Examples of long distance LoRa Tests

Testbed	A-B	A-C	A-D	E-F
Mode of propagation	LOS over land	LOS over seawater	BLOS over seawater	LOS over land
Length	112 km	22 km	28 km	316 km
Longley-Rice path loss (868 MHz)	131.91 dB	118.26 dB	176.7 dB	152.82 dB
Longley-Rice path loss (434 MHz)	125.91 dB	112.25 dB	166.12 dB	145.96 dB
Free-space path loss (868 MHz)	132.18 dB	118.33 dB	–	141.24 dB
Free-space path loss (434 MHz)	126.16 dB	112.31 dB	–	135.22 dB
Terrain shielding att. (868 MHz)	−0.27 dB	−0.07 dB	56.47 dB	11.58 dB
Terrain shielding att. (434 MHz)	−0.26 dB	−0.06 dB	51.91 dB	10.74 dB

N. Jovalekic, V. Drndarevic, I. Darby, M. Zennaro, E. Pietrosemoli and F. Ricciato, "**LoRa Transceiver With Improved Characteristics**", IEEE Wireless Communications Letters, doi: 10.1109/LWC.2018.2855744, December 2018.

Comparison of propagation models





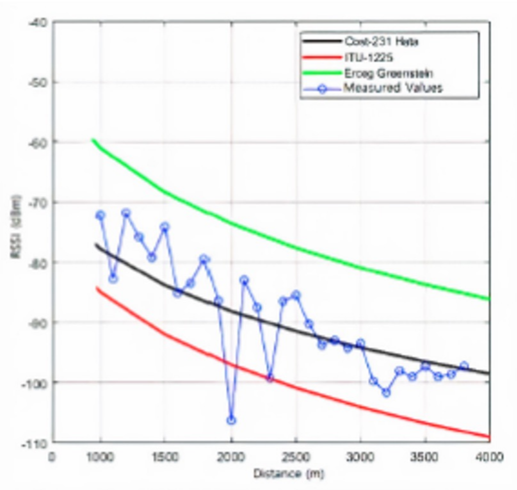


Figure 6. RSSI on the urban route 4.

Received power comparison: Measured Vs 3 different models at 1800 MHz

From: Francine Cassia and Jose Marcos Camara, ICN 2021, INATEL,Brazil, ISBN: 978-1-61208-837-2

"A Comparative Study of Performance Analysis of Empirical Propagation Models for NB-IoT Protocol in Suburban Scenarios"

Propagation measurements

Matajur-Crocearcana

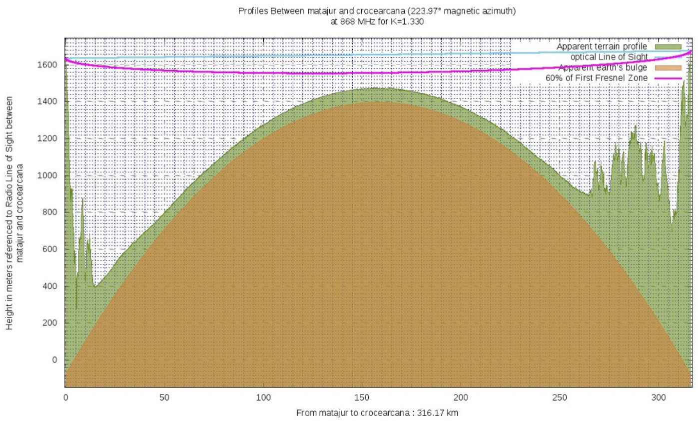
316 km, clear LoS

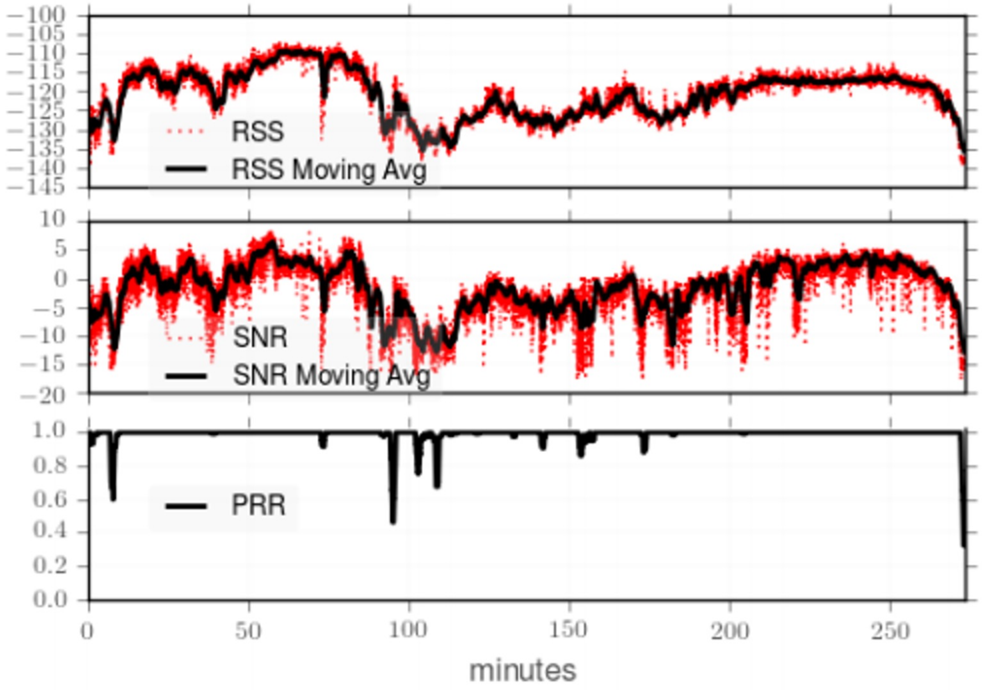
LoRa at 434 MHz

Omnidirectional antennas

PRR: Packet Reception Rate

RSS: Received Signal





Marco Zenneraro et al, "**TROPPO LoRa: TROPospheric Personal Observatory using LoRa signals**"
FRUGALTHINGS'20:, September 2020, pp 24–29
https://doi.org/10.1145/3410670.3410856

Propagation measurements

Matajur-Crocearcana

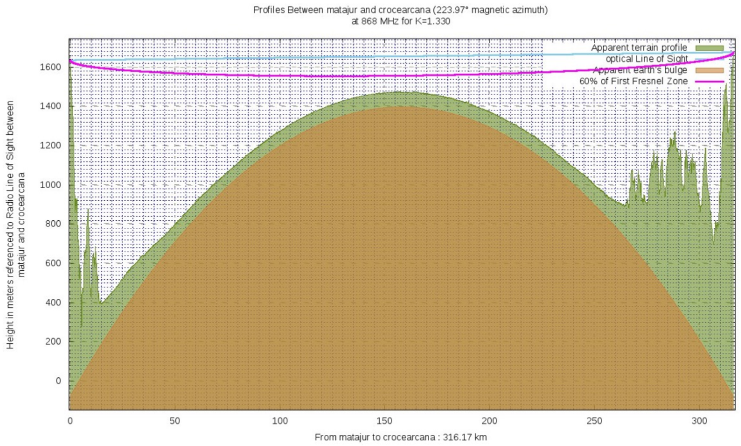
316 km, clear LoS

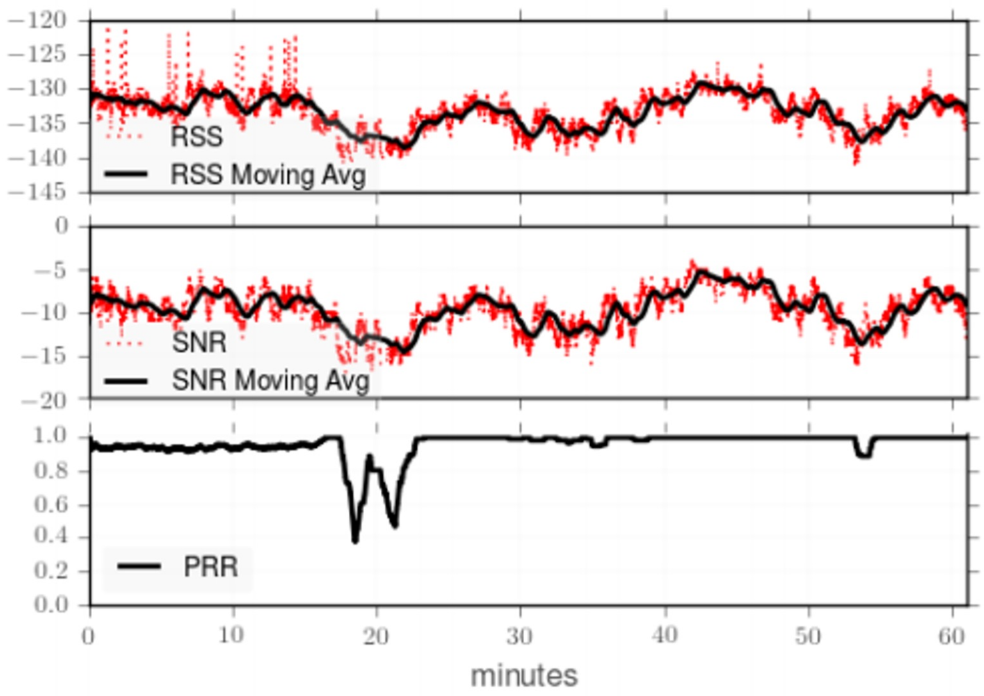
LoRa at 868 MHz

Omnidirectional antennas

PRR: Packet Reception Rate

RSS: Received Signal

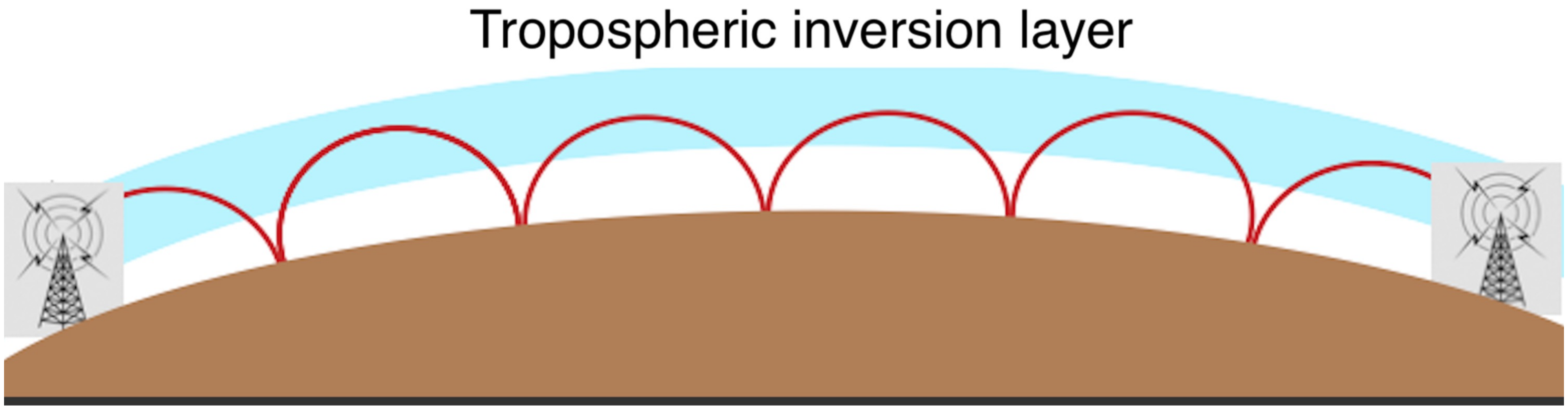




Propagation measurements

Tropospheric ducts

LoRa at 868 MHz



Propagation measurements

Trieste-Cesena

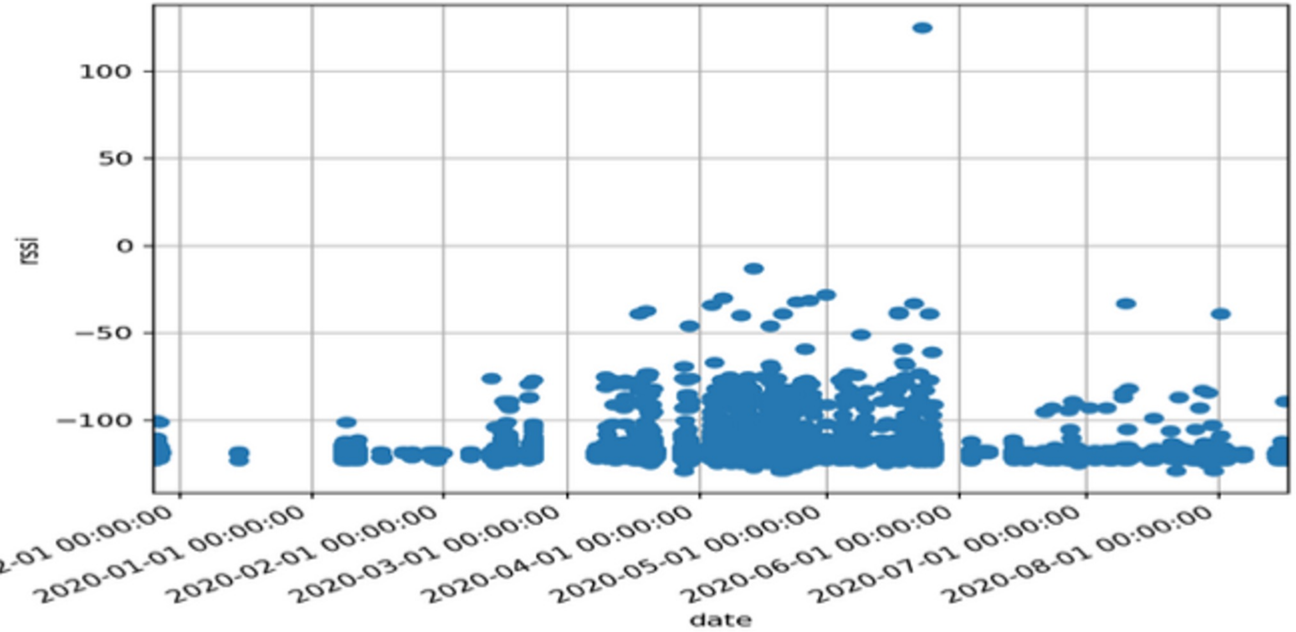
234 km,

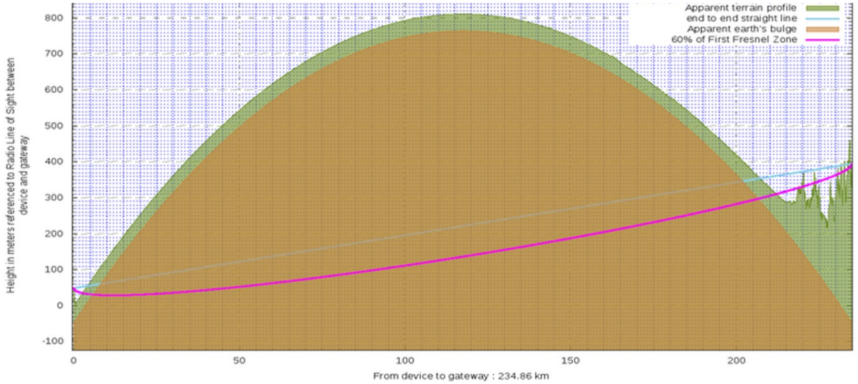
Obstructed LoS

LoRa at 868 MHz

PRR = 14%

Anomalous tropospheric propagation





Propagation measurements

Trieste-Bologna

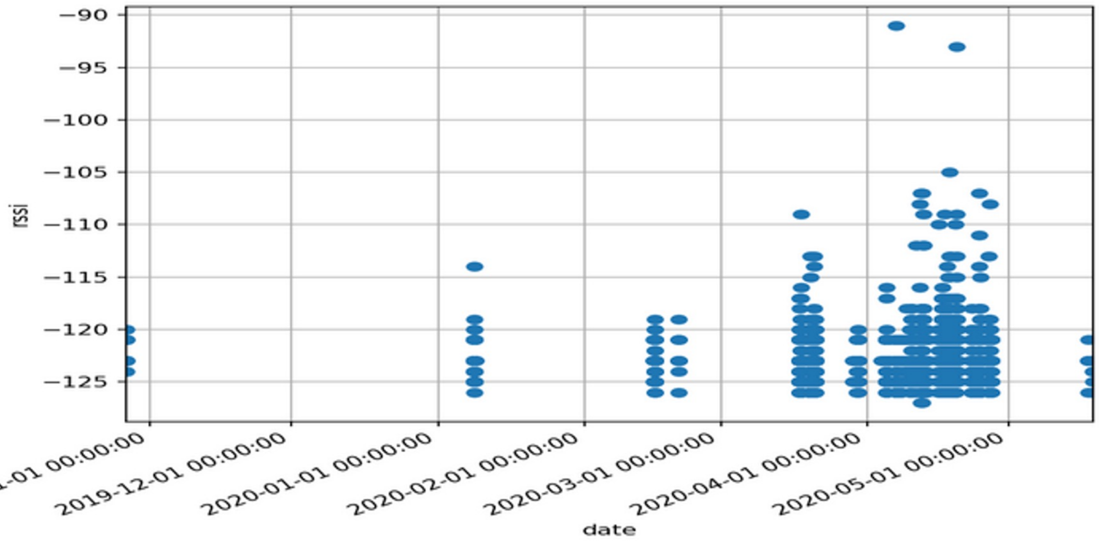
213 km,

Obstructed LoS

LoRa at 868 MHz

Anomalous propagation

by Tropospheric Duct



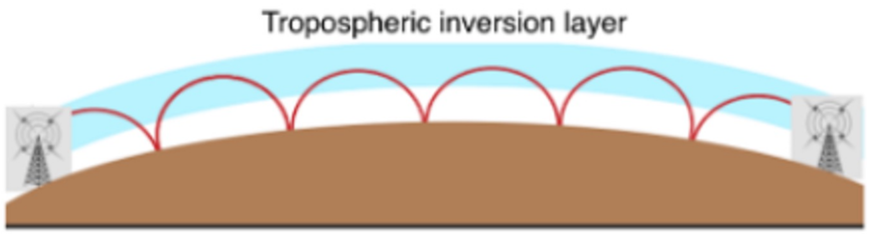
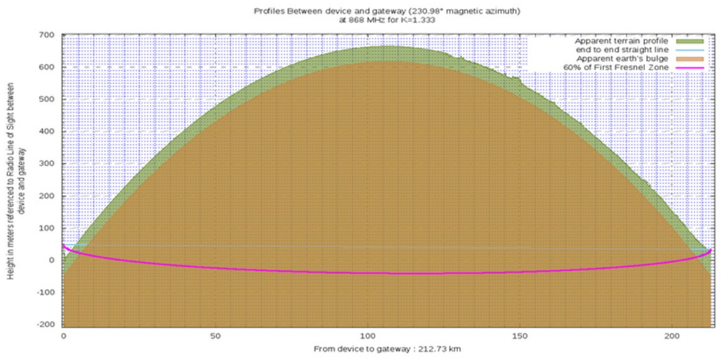
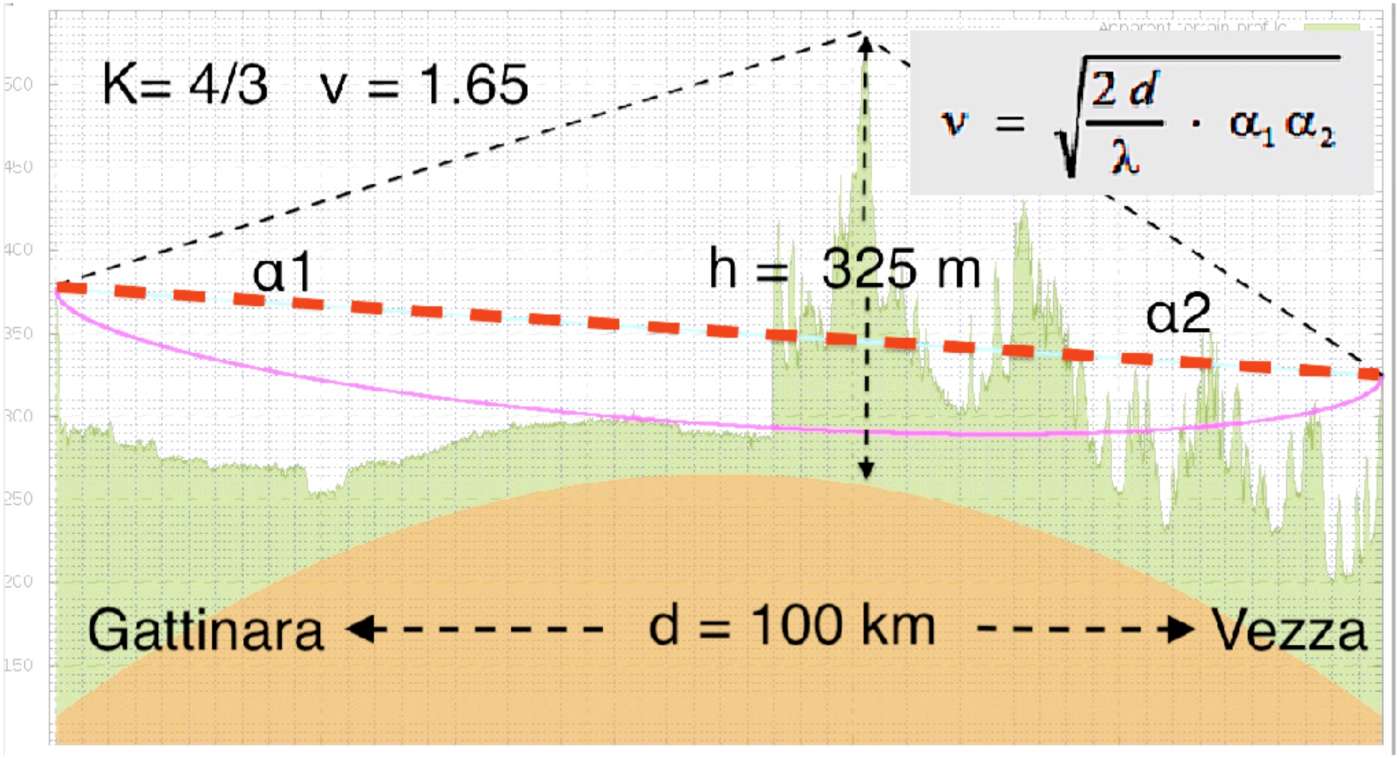


Fig. 1. Tropspheric duct propagation: Wave reflection on the surafce (water or ground) is sharp, while in the tropospheric layer a succession of gradual bends emulates a softer reflection. Happens more frequently in paths over water, which is a better reflector than ground, while its evaporation favors the formation of inversion layers,



Propagation by diffraction

The sharp edge introduces an additional loss of 17 dB, but reception is still possible due to the ample margin offered by the LoRa modulation



$$J(v) = 6.9 + 20 * log[\sqrt{(v-1)^2 + 1} + v - 0.1]$$

Propagation measurements

Trieste-Ronchi

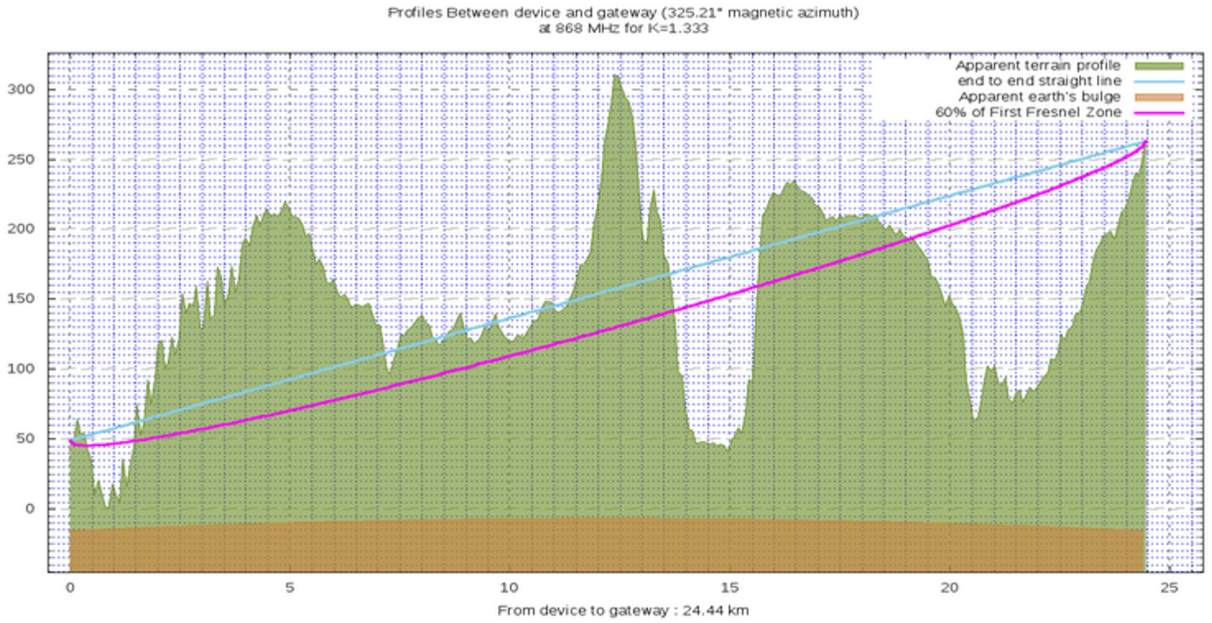
24 km,

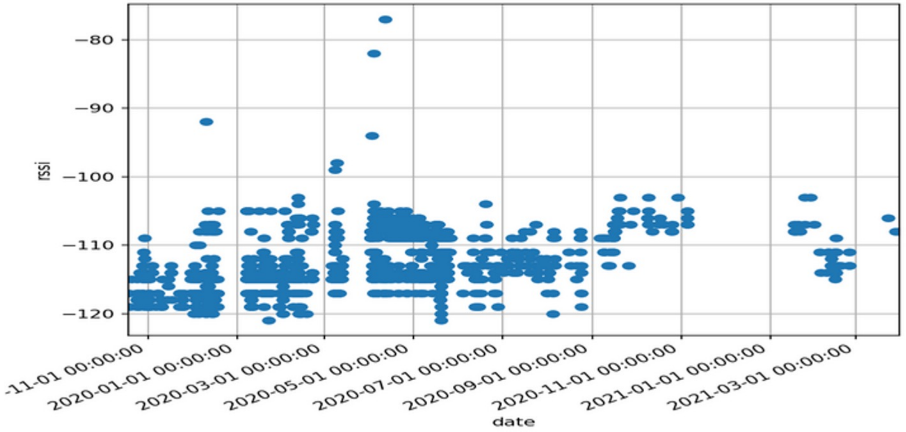
Obstructed LoS,

sharp edges

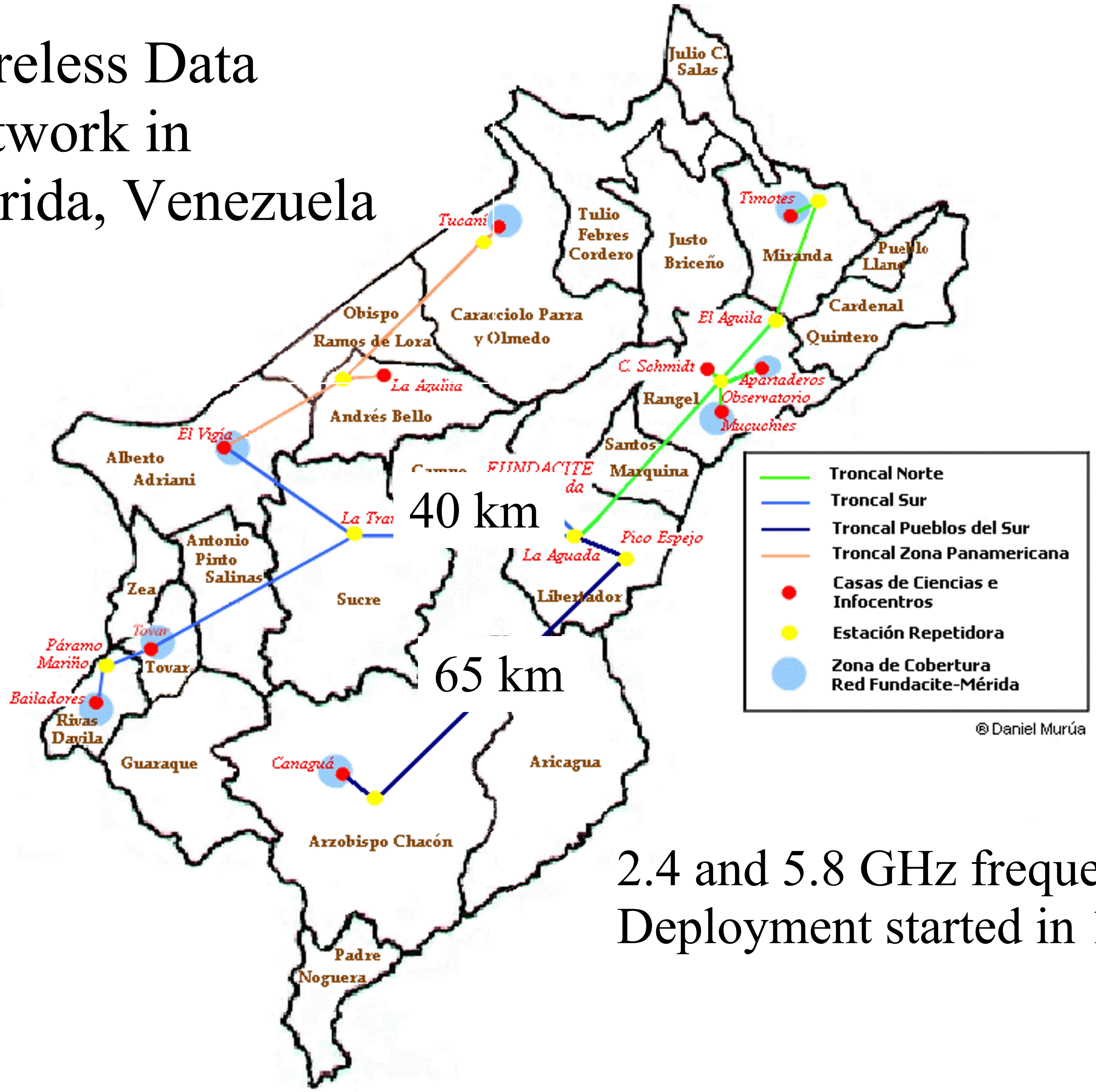
LoRa at 868 MHz

Diffraction propagation





Wireless Data Network in Mérida, Venezuela



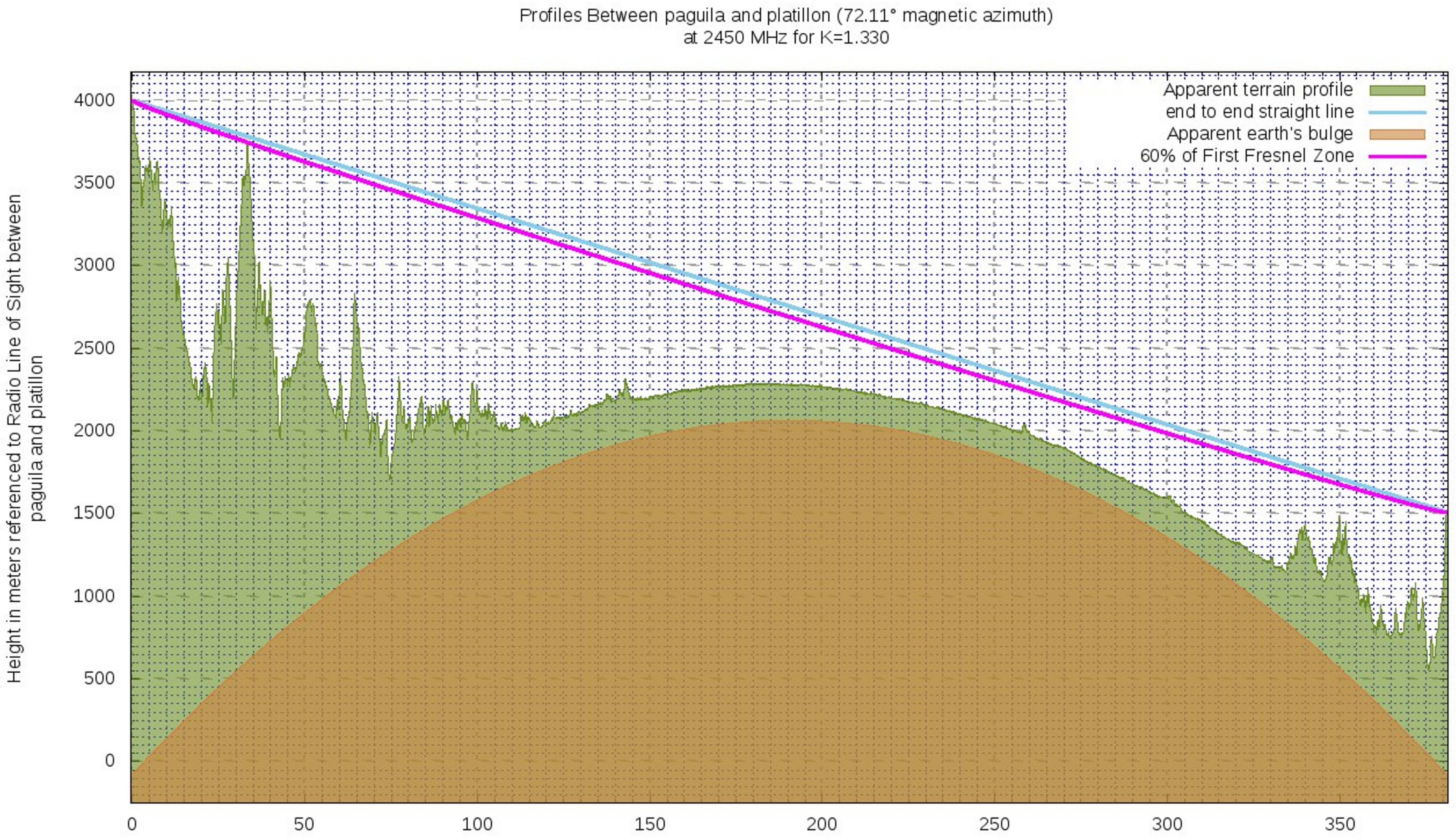
2.4 and 5.8 GHz frequencies
Deployment started in 1995

Longest distance modified WiFi link (382 km)

High end points can overcome the blockage of the earth's curvature over long distance wireless links.

Pico Aguila to Platillón, Venezuela, 2007.

30 dBi antennas at 2.42 MHz.



382 km

https://guinnessworldrecords.com/world-records/longest-broadband-wireless-connection

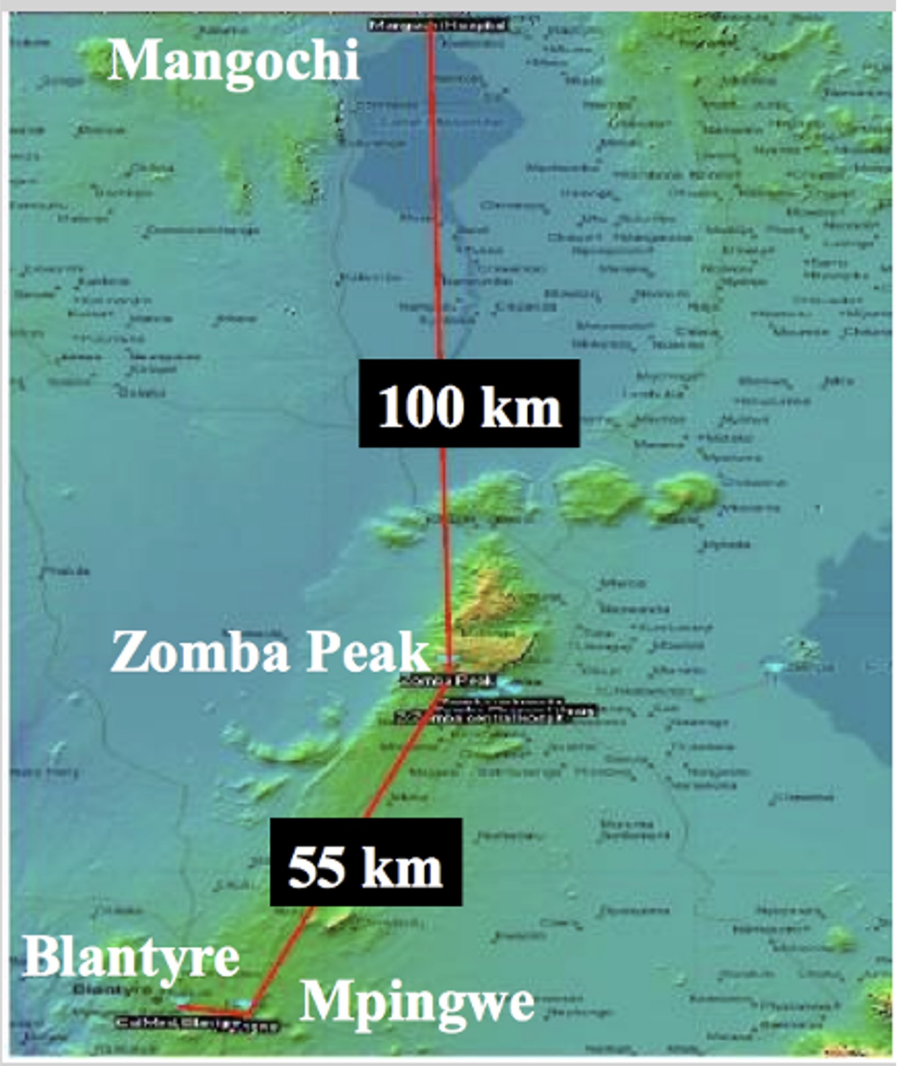
The antenna alignment was performed using a signal generator at one end and a spectrum analyzer at the other end.

Wireless long distance link in Malawi

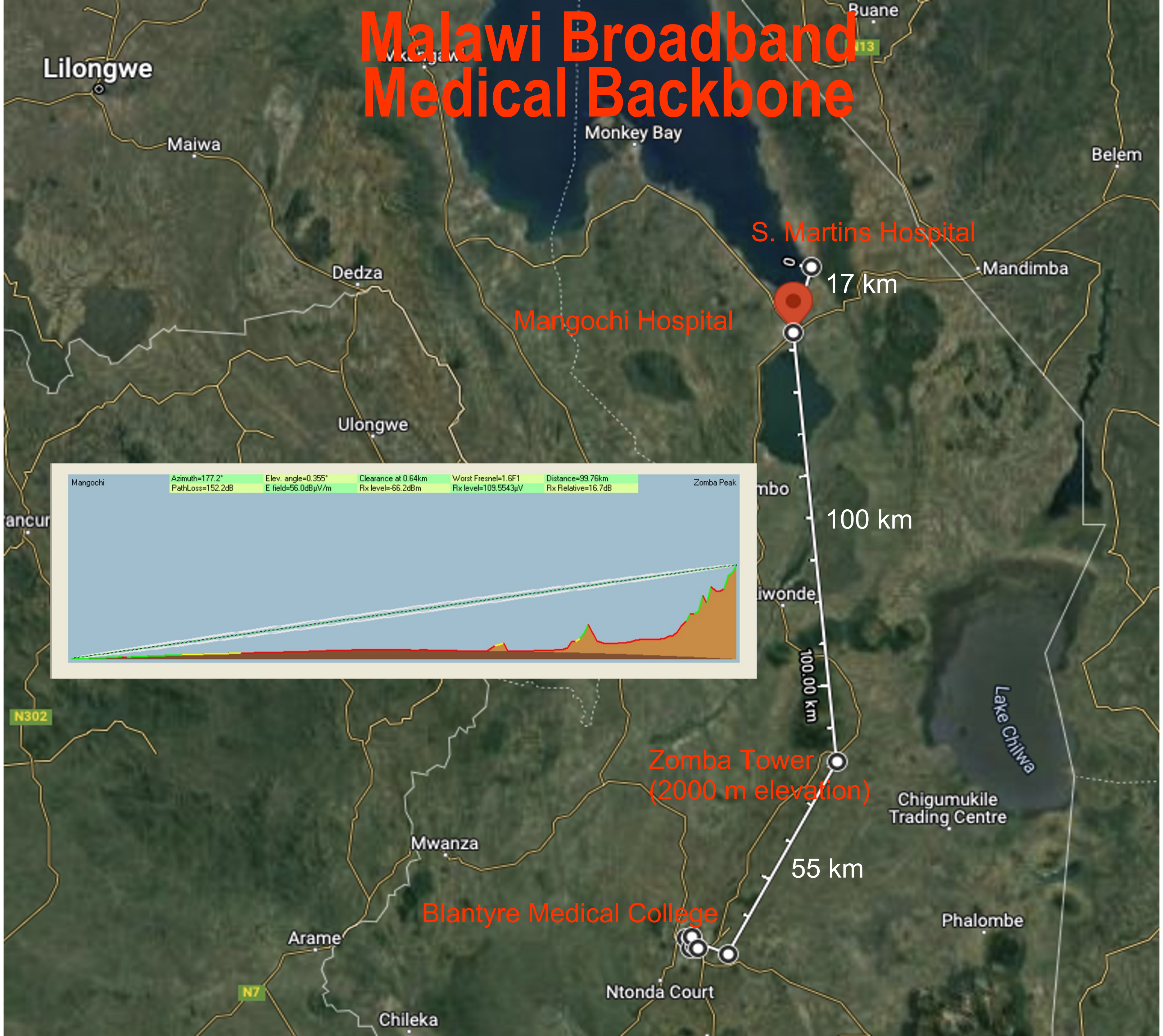
Communication network for health provisioning in hospitals and universities

Wireless long distance link in Malawi (Modified WiFi)

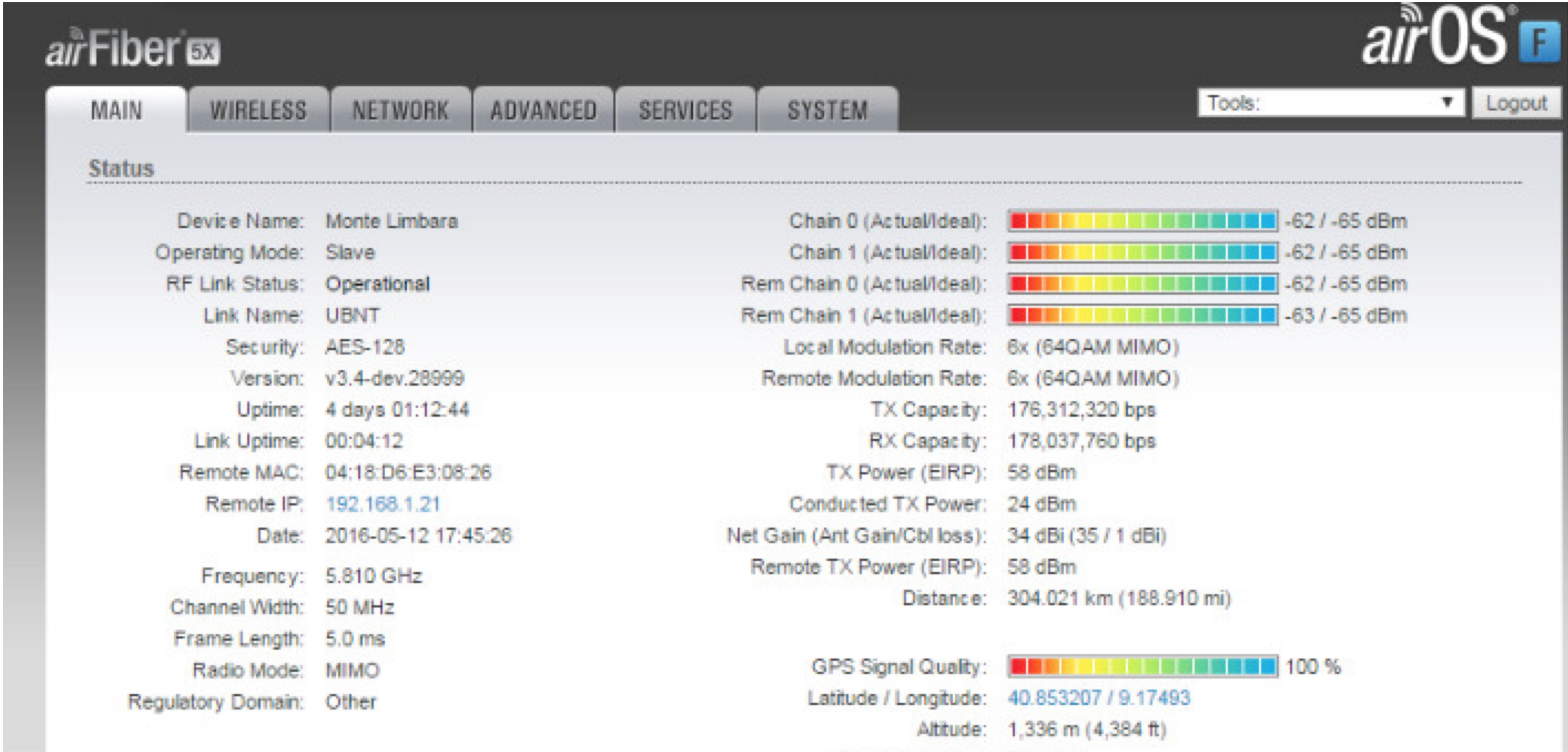
From the College of Medicine in Blantyre to Mangochi Hospital via Mpingwe and Zomba Peak.



Malawi Broadband Medical Backbone



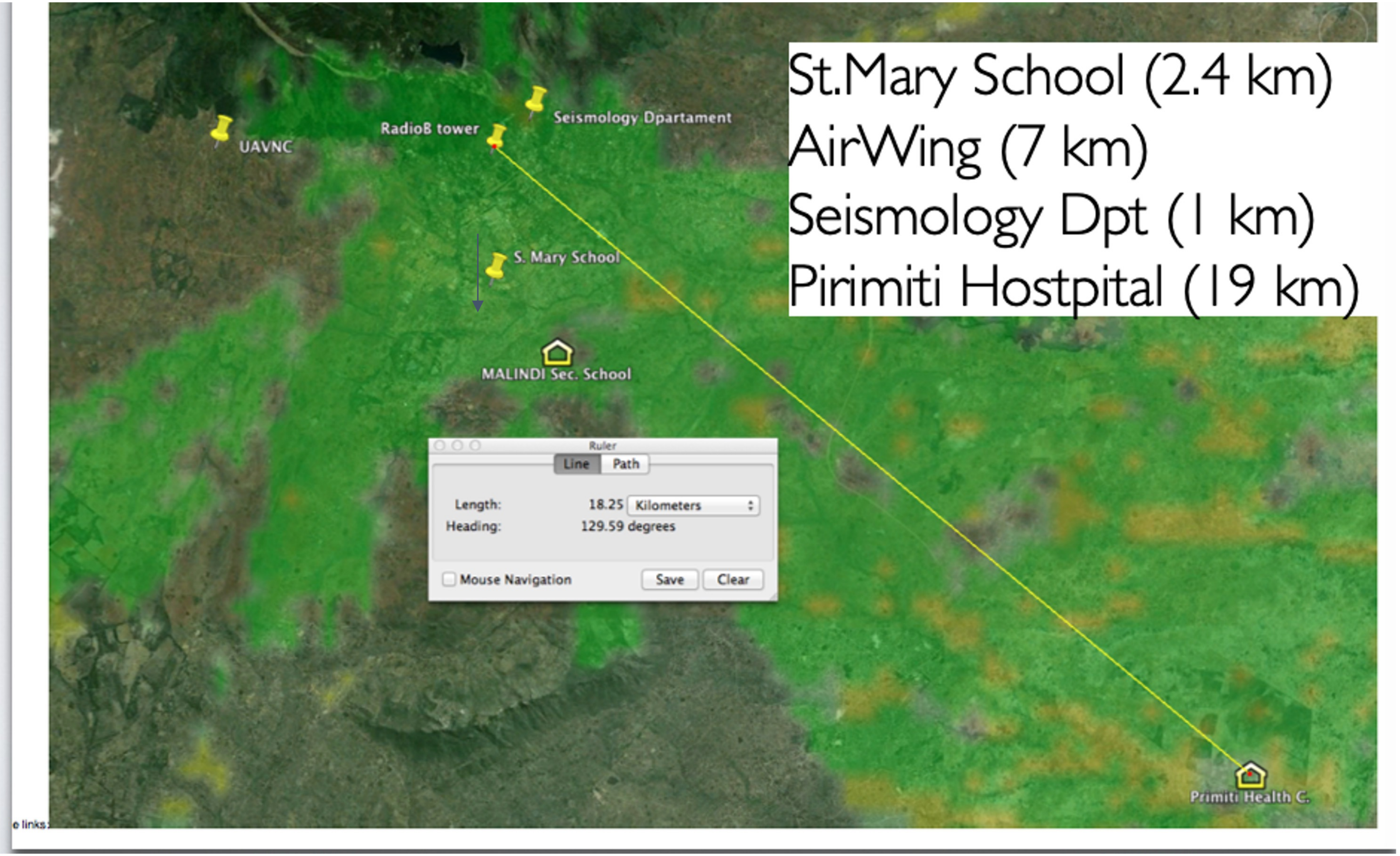
High speed long distance wireless link in Italy, in collaboration with the CISAR radio amateur club.


airFiber 5X
airOS F
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Status
Device Name: Monte Limbara
Operating Mode: Slave
RF Link Status: Operational
Link Name: UBNT
Security: AES-128
Version: v3.4-dev.28999
Uptime: 4 days 01:12:44
Link Uptime: 00:04:12
Remote MAC: 04:18:D6:E3:08:26
Remote IP: 192.168.1.21
Date: 2016-05-12 17:45:26
Frequency: 5.810 GHz
Channel Width: 50 MHz
Frame Length: 5.0 ms
Radio Mode: MIMO
Regulatory Domain: Other
Chain 0 (Actual/Ideal): -62 / -65 dBm
Chain 1 (Actual/Ideal): -62 / -65 dBm
Rem Chain 0 (Actual/Ideal): -62 / -65 dBm
Rem Chain 1 (Actual/Ideal): -63 / -65 dBm
Local Modulation Rate: 6x (64QAM MIMO)
Remote Modulation Rate: 6x (64QAM MIMO)
TX Capacity: 176,312,320 bps
RX Capacity: 178,037,760 bps
TX Power (EIRP): 58 dBm
Conducted TX Power: 24 dBm
Net Gain (Ant Gain/Cbl loss): 34 dBi (35 / 1 dBi)
Remote TX Power (EIRP): 58 dBm
Distance: 304.021 km (188.910 mi)
GPS Signal Quality: 100 %
Latitude / Longitude: 40.853207 / 9.17493
Altitude: 1,336 m (4,384 ft)

304 km long link on a 50 MHz channel with a total throughput of 356 Mbps using 64 QAM MIMO with 1.2m parabolic dishes

E. Pietrosemoli, M. Zennaro, G. Misuri, M. Calderini, R. Rossi, M. Brunozzi, G. Chiuppesi, N. Sardo, G. Scinti, G. Corona, P. Piredda, M. Mellis, and G. Usai, “High capacity long distance wireless link.” https://www.academia.edu/es/69258642/%20High%20Capacity%20long%20distance%20wireless%20link

TV White Spaces in Malawi




CARLSON
COS'
CRUSADERS

TV White Spaces in Malawi

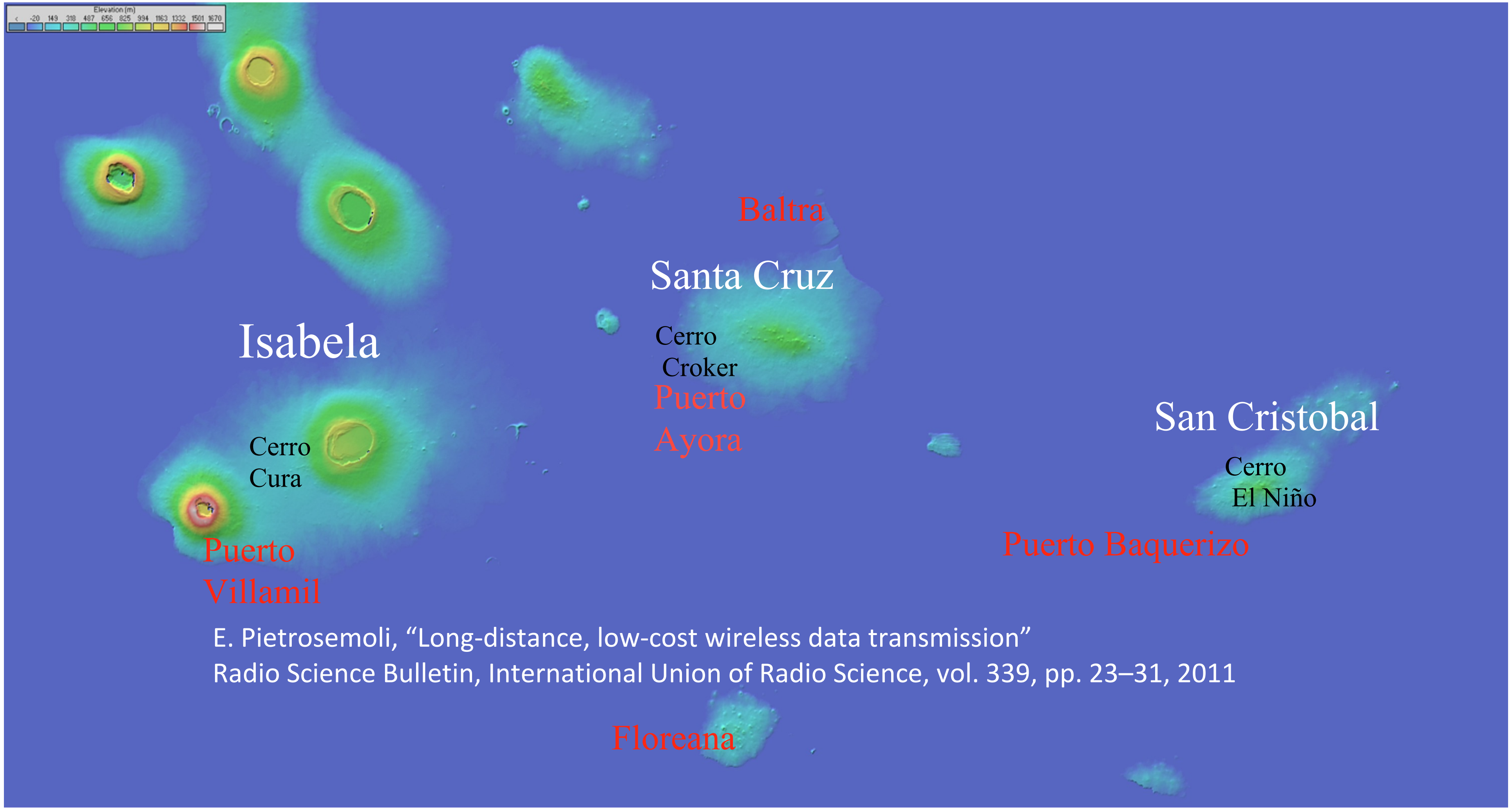
This project paved the way for the Malawian regulator to authorize the use of Television frequencies for two way broadband communications

A similar TVWS project was later implemented in Mozambique

C. Mikeka, J. Mlatho, M. Thodi, J. Pinifolo, D. Kondwani, L. Momba, M. Zennaro, A. Arcia-Moret, C. Fonda and E. Pietrosemoli,
"Preliminary performance assessment of TV White Spaces technology for broadband communication in Malawi"
Procedia Engineering, vol. 78, p. 149–154, 2014

Galapagos Islands Network

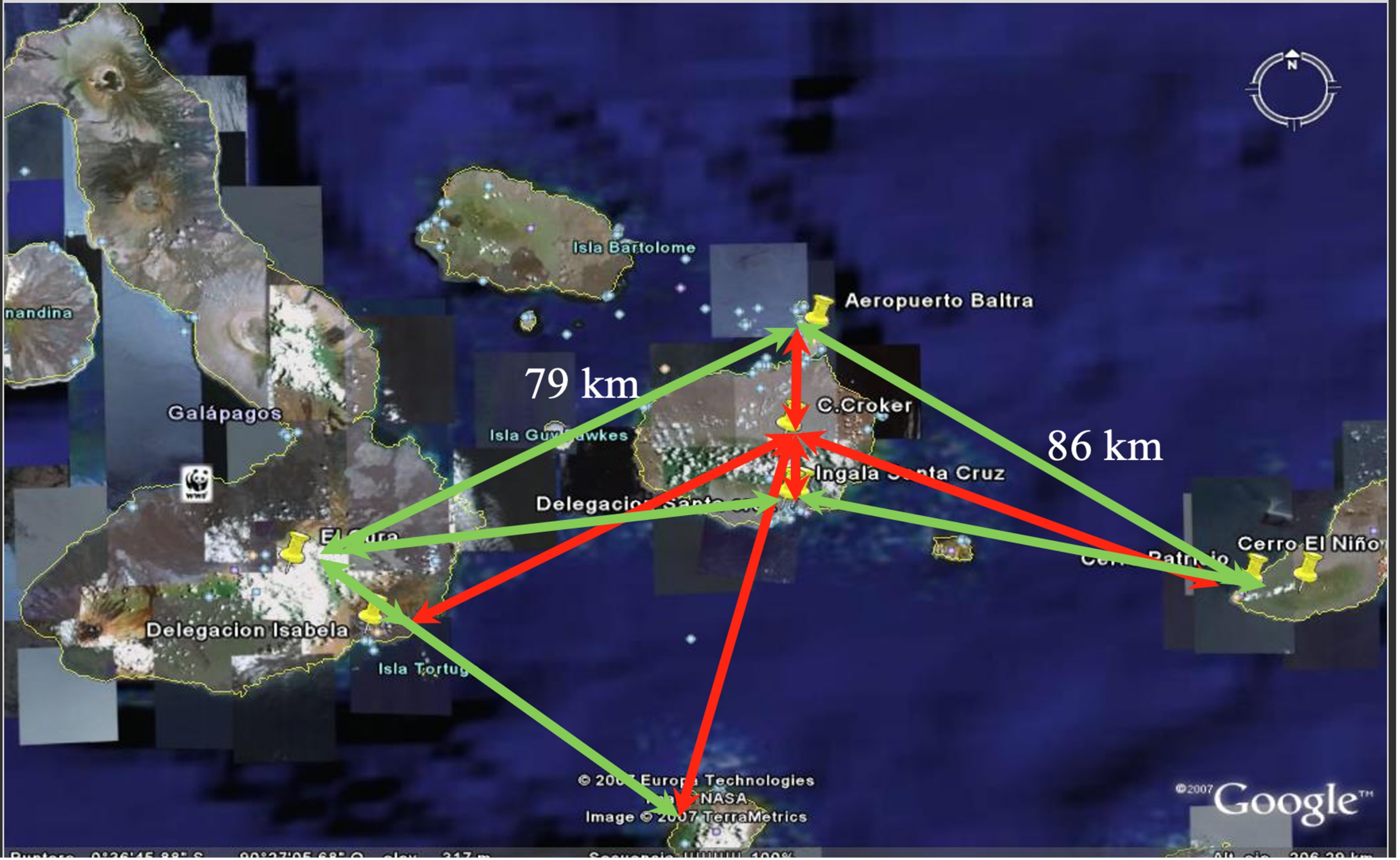
Settlements to be served   Repeater Sites



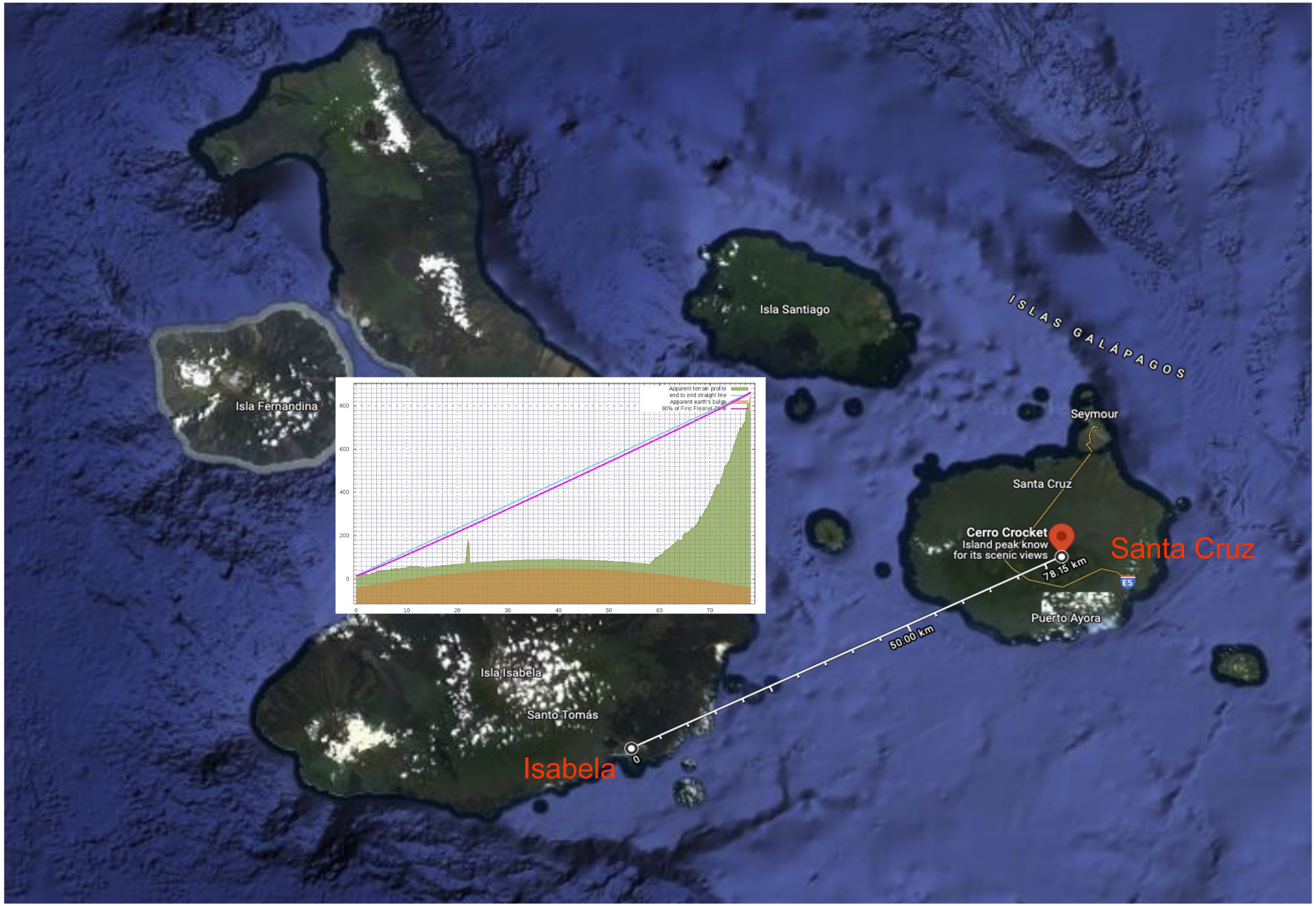
E. Pietrosemoli, "Long-distance, low-cost wireless data transmission"
Radio Science Bulletin, International Union of Radio Science, vol. 339, pp. 23–31, 2011

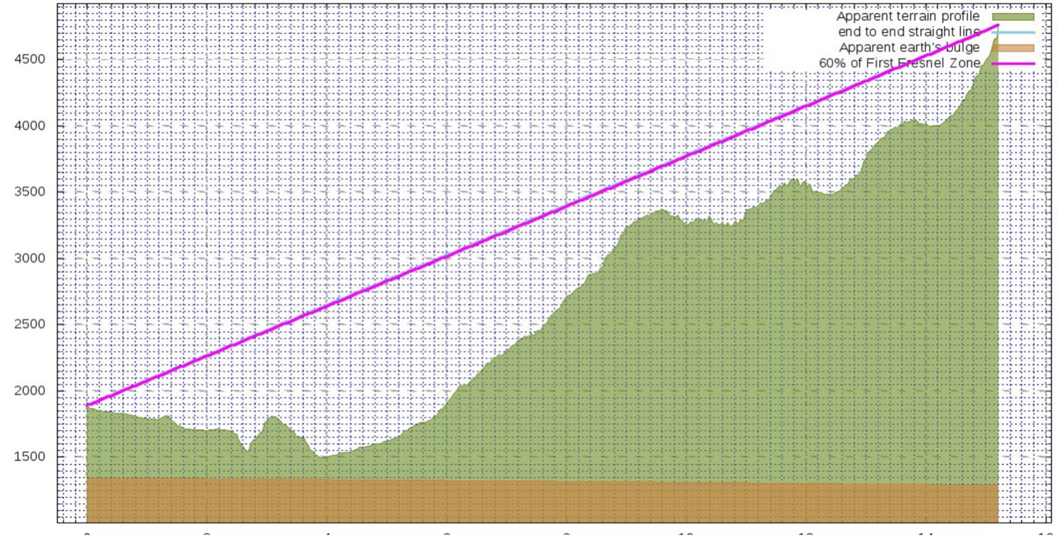
Galapagos Islands Broadband Network

Central links and Peripheral links



Isabela to Santa Cruz 79 km link, Galapagos

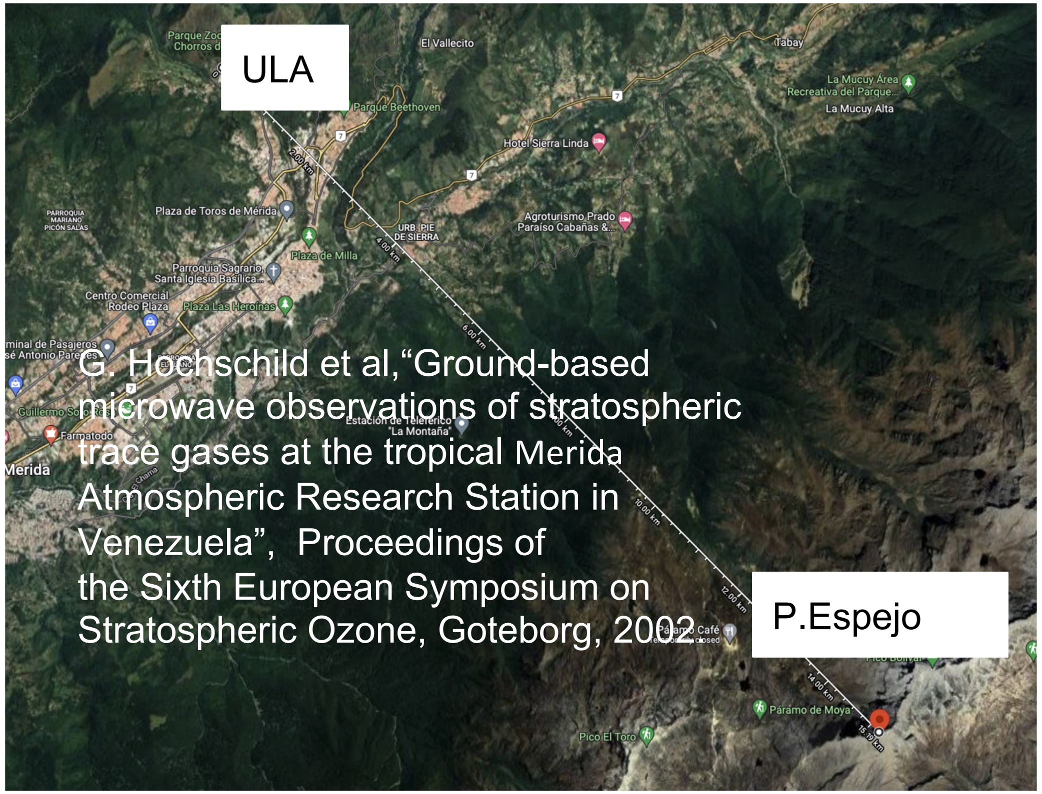




Mérida Atmospheric Research Station (MARS)

Joint Venezuelan-German project:

5.8 GHz, 16 km link: ULA at 1800 m to P. Espejo at 4765 m



Conclusions

- Effort spent in planning will save ten times the effort in installation and maintenance.
- Configure and test all equipment “in the lab” before deploying it in the field.
- Keep good documentation of all configuration settings for all devices to assist in troubleshooting and expanding the network later.
- Don’t forget to account for maintenance in your planning (both financial and logistical)!
- Proper planning takes time.

Conclusions

- Planning is a very creative undertaking and different perspectives might lead to different results.
- Simulation tools can automate many parts of the network planning process, but must be used with caution, since they provide statistical results, which might significantly deviate from actual measurements.

- Some examples of installations leveraging wireless technologies in unlicensed frequency bands in a variety of scenarios and for different applications were presented.
- The underlying theme is the possibility of meeting the communication needs of underserved communities with affordable technologies.

Thanks for your attention

Questions?