Link Budget & Propagation

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Link Budget Calculations

A link budget calculation estimates whether a radio path between two nodes will work reliably before you deploy hardware. It's the single most useful tool for avoiding wasted installation trips and surprised failures.

The link budget equation

```
Received Power (dBm) = TX Power (dBm)
  + TX Antenna Gain (dBi)
  − TX Cable Loss (dB)
  − Free Space Path Loss (dB)
  − Obstruction Loss (dB)
  + RX Antenna Gain (dBi)
  − RX Cable Loss (dB)

Link Margin (dB) = Received Power (dBm) − Receiver Sensitivity (dBm)
```

A positive link margin means the link should work. A margin of 10 dB or more is considered reliable. Below 3 dB is borderline and not recommended for permanent infrastructure.

Key values for LoRa at 915 MHz

Receiver sensitivity by MeshCore preset

Preset equivalent (SF / BW)	Receiver sensitivity
USA/Canada (SF7 / 62.5 kHz)	~−125 dBm
Long Fast (SF11 / 250 kHz)	~−137 dBm
Long Slow (SF12 / 125 kHz)	~−141 dBm
Medium Slow (SF10 / 250 kHz)	~−134 dBm

Lower sensitivity number = can receive weaker signals = more range potential. Long Slow gives the best sensitivity but at the cost of extremely low data rate.

Free Space Path Loss at 915 MHz

FSPL (dB) = 20×log10(d) + 20×log10(f) + 20log10(4π/c)

In practical terms for 915 MHz:

Distance	Free Space Path Loss
1 km (0.62 mi)	91.6 dB
5 km (3.1 mi)	105.6 dB
10 km (6.2 mi)	111.6 dB
20 km (12.4 mi)	117.6 dB
50 km (31 mi)	125.6 dB

Note: Free space path loss assumes clear line of sight with no obstructions. Real-world losses are always higher.

Worked example: Rooftop repeater to ground-level node

Scenario: 5 km path, rooftop repeater at 30m height, portable node at 2m height.

Parameter	Value
TX Power (repeater)	27 dBm
TX Antenna Gain	+5 dBi
TX Cable Loss (1m LMR-200)	−0.1 dB
Free Space Path Loss (5 km, 915 MHz)	−105.6 dB
Obstruction/Fresnel loss estimate	−10 dB (mixed urban)
RX Antenna Gain (portable node, 2 dBi)	+2 dBi
RX Cable Loss (none for portable)	0 dB
Received Power	**27 + 5 − 0.1 − 105.6 − 10 + 2 = −81.7 dBm**
Receiver Sensitivity (USA/Canada SF7)	−125 dBm
Link Margin	**−81.7 − (−125) = +43.3 dB**

A 43 dB margin is very comfortable - this link will work reliably even with additional obstruction losses not captured in the estimate.

Fresnel zone clearance

Even in "clear" line-of-sight paths, the Fresnel zone must be 60% clear of obstructions for reliable communication. The first Fresnel zone radius at the midpoint of a path:

```
r = 8.66 × sqrt(d / f_GHz) meters

Where d = path length in km, f = frequency in GHz

For 915 MHz, 10 km path:
r = 8.66 × sqrt(10 / 0.915) = 8.66 × 3.30 = 28.6 meters

Any obstruction within 28.6m of the direct path midpoint will partially block the signal.
```

This is why hilltop-to-hilltop links work so well: the terrain clears the Fresnel zone naturally. For rooftop-to-rooftop links in cities, trees and building facades at path midpoints can add 10 - 20 dB of loss even when the antennas themselves have direct line of sight.

When to use a link budget

- Before installing a repeater at a new site, calculate whether it can reach your intended coverage area
- When planning a point-to-point relay link between two specific nodes
- When a deployed link is underperforming - work backwards from measured RSSI to identify where the losses are
- When comparing two candidate repeater sites - small differences in height can produce large differences in link budget

RF Propagation Planning Tools

Several free tools can help you model coverage and plan repeater placement before deploying hardware. Using these tools can save wasted trips and help you choose between candidate sites.

HeyWhatsThat (heywhatsthat.com)

The fastest tool for estimating radio horizon from a specific point.

- Enter a location (address, coordinates, or click on map)
- Set the antenna height
- Get a visualization of the radio horizon: which areas have line-of-sight from that point

How to use for repeater site selection:

1. Go to heywhatsthat.com
2. Click on your candidate repeater site on the map
3. Set height to your intended antenna mounting height
4. Click "Submit" and examine the color-coded visibility map
5. Compare multiple candidate sites by opening each in a new tab

Limitations: HeyWhatsThat uses terrain elevation data (SRTM) but does not include buildings or vegetation. Actual coverage will be lower than predicted in areas with tall buildings or forest.

Radio Mobile Online (radiomobile.ca)

More sophisticated link analysis tool with full path profile and link budget integration.

- Enter transmitter and receiver coordinates, heights, antenna gain, TX power, and frequency
- Generates a path profile showing terrain elevation along the path
- Calculates predicted received signal level
- Shows Fresnel zone clearance along the path

Radio Mobile is best for detailed analysis of specific point-to-point paths, not area coverage visualization.

CloudRF (cloudrf.com)

Professional-grade coverage prediction with a free tier. Features:

- SRTM + LIDAR terrain data (more accurate than basic tools)
- Can include clutter data (buildings, vegetation) for urban environments
- Overlay predicted coverage on Google Maps or OpenStreetMap
- Free tier: limited calculations per month; paid plans for heavy use

Best for: precise coverage maps for presentations, permitting, or professional deployments. Overkill for casual site selection.

Splat! (free, offline)

Open-source RF propagation tool that runs locally on Linux/Mac. Uses SRTM terrain data.

```
# Install on Debian/Ubuntu
sudo apt install splat


# Download SRTM data for your region from usgs.gov
# Generate coverage map
splat -t transmitter.qth -r receiver.qth -f 915 -erp 0.5 -d /path/to/srtm/data
```

Splat! is overkill for most community mesh deployments but valuable when building professional-grade coverage documentation or integrating with GIS workflows.

Practical planning workflow

For most community mesh network planning, this workflow is sufficient:

1. **Identify candidate sites**
   Use topographic maps (USGS topo viewer, CalTopo) to identify hilltops, ridgelines, water towers, and tall buildings in your coverage area.
2. **Quick horizon check**
   For each candidate site, run HeyWhatsThat at the proposed antenna height. Immediately discard sites with poor visibility to your target coverage area.
3. **Link budget for remaining candidates**
   For the 2 - 3 best candidates, calculate link budgets to your target coverage area edges (farthest points). Compare margin values.
4. **On-site test before permanent install**
   Set up a temporary antenna and node at the candidate site. Walk/drive your coverage area while monitoring RSSI/SNR. Real-world testing always beats prediction tools.

5. **Document the result**
   Record the actual coverage performance after deployment. This data helps plan future expansion nodes.

Interpreting RSSI and SNR from field tests

RSSI	SNR	Link quality assessment
>−90 dBm	>+10 dB	Excellent - reliable at all data rates
−90 to −105 dBm	+5 to +10 dB	Good - reliable for all normal use
−105 to −115 dBm	0 to +5 dB	Marginal - may see occasional packet loss
−115 to −120 dBm	−5 to 0 dB	Weak - intermittent; not suitable for infrastructure
<−120 dBm	<−5 dB	Very weak - expect frequent failure

Key insight: SNR matters more than RSSI for LoRa. A signal at −125 dBm with +5 dB SNR is more reliable than one at −100 dBm with −5 dB SNR (which is being swamped by noise). When diagnosing a marginal link, prioritize improving SNR over increasing RSSI.