Coverage Radius Estimation by Terrain Type

The Radio Horizon Formula

The theoretical radio horizon for a single antenna at height *h* metres above a smooth spherical earth, accounting for standard atmospheric refraction (the 4/3-earth model), is:

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d (km) = 4.12 × √h_m   (radio horizon, 4/3-earth refraction)
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For a link between two antennas at heights h_1 and h_2 the total radio horizon is:

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d_total (km) = 4.12 × (√h₁ + √h₂)
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Note: the purely geometric (optical) line-of-sight horizon uses the coefficient 3.57 × √h. The 4.12 coefficient adds the standard 4/3-earth refraction correction and is the value used for *radio* horizon throughout this book (consistent with the mountain-and-complex-terrain and repeater-placement pages). There is no latitude term in this formula.

This is the *maximum possible* range on a flat, unobstructed earth - a theoretical ceiling, not a usable-coverage promise. Real terrain, vegetation, and buildings reduce this significantly. The formula provides the ceiling; terrain obstruction factors bring it down to a realistic estimate.

Terrain Obstruction Factors

Apply these multipliers to the radio-horizon distance to get a realistic coverage radius. The factor bands below are *illustrative planning heuristics*, not measured constants - no Tier-1 standard assigns these exact multipliers to named terrain classes. The underlying propagation behaviour is described in ITU-R P.526 (diffraction), P.833 (vegetation), and P.1411 (urban/suburban short-range); use those for rigorous modelling.

Environment Type	Obstruction Factor	Effective Coverage (%)	Notes

Flat open (farmland, desert, water)	0.85 - 1.00	85 - 100%	Near-theoretical range; ground reflections can help at low angles
Gentle rolling terrain	0.65 - 0.80	65 - 80%	Moderate ridge shadowing; elevated repeaters mitigate well
Suburban (low-rise, gardens)	0.50 - 0.65	50 - 65%	Houses and trees add 5 - 15 dB of excess loss (ITU-R P.1411 range)
Dense forest / jungle	0.35 - 0.55	35 - 55%	Vegetation loss ~0.2 - 0.5 dB/m through canopy at 915 MHz (ITU-R P.833 / Weissberger); saturates beyond ~14 m depth
Urban (mid-rise, 3 - 8 floors)	0.30 - 0.50	30 - 50%	Building diffraction dominates; rooftop-to-rooftop paths much better
Dense urban (high-rise, canyons)	0.15 - 0.30	15 - 30%	Multipath + shadowing severe; per-block coverage planning needed
Mountainous / complex terrain	0.20 - 0.60	20 - 60%	Highly variable; valleys may have near-zero coverage from a single site

Worked Examples

The coverage *areas* below are theoretical maxima derived from the radio-horizon ceiling times an obstruction factor. They are **not** the usable coverage you should plan around. In practice a single well-placed repeater at ~30 m AGL delivers on the order of **300 - 800 km²** of reliable coverage in flat/rolling terrain, and far less in forest or urban settings - see the repeater-placement-principles and repeater-grid pages for realistic per-terrain planning densities. Treat the figures here as "maximum, not expected."

Example 1 - 30 m Tower on Flat Land

A community group installs a repeater at the top of a 30 m self-supporting tower in flat agricultural land. The mobile clients they serve have antennas at 1.5 m AGL.

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Radio horizon (tower): 4.12 × √30 = 4.12 × 5.48 = 22.6 km

Radio horizon (client): 4.12 × √1.5 = 4.12 × 1.22 = 5.0 km

Total radio horizon: 22.6 + 5.0 = 27.6 km
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Obstruction factor (flat open): 0.90

Theoretical coverage radius: 27.6 × 0.90 ≈ 24.8 km
Theoretical coverage area (ceiling): π × 24.8² ≈ 1,930 km²
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That ~1,930 km² is the radio-horizon ceiling, not a usable-coverage guarantee. Realistic usable coverage from a single well-sited rural tower is far lower - typically on the order of 300 - 800 km² once real-world fading, foliage, and link-margin requirements are accounted for. Plan around the usable figure, not the ceiling.

Example 2 - 10 m Mast in Suburbs

A volunteer mounts a repeater on a 10 m mast attached to their house in a typical American suburb (one-storey houses, trees). Mobile clients at 1.5 m.

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Radio horizon (mast): 4.12 × √10 = 4.12 × 3.16 = 13.0 km
Radio horizon (client): 4.12 × √1.5 = 4.12 × 1.22 = 5.0 km
Total radio horizon: 13.0 + 5.0 = 18.0 km

Obstruction factor (suburban): 0.55

Theoretical coverage radius: 18.0 × 0.55 ≈ 9.9 km
Theoretical coverage area (ceiling): π × 9.9² ≈ 308 km²
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This is a solid community repeater covering roughly the footprint of a small city, though the 308 km² figure is again a ceiling - expect meaningfully less usable coverage. Pockets of shadow behind larger buildings will exist. A wardriving survey is recommended after installation to confirm actual coverage.

Example 3 - Rooftop in Dense Urban

A repeater is placed on the flat roof of a 7-storey (21 m) apartment building in a dense city. Surrounding buildings average 6 storeys (18 m). Mobile clients at street level (1.5 m).

```
Radio horizon (roof): 4.12 × √21 = 4.12 × 4.58 = 18.9 km
Radio horizon (client): 4.12 × √1.5 = 4.12 × 1.22 = 5.0 km
Total radio horizon: 18.9 + 5.0 = 23.9 km

Obstruction factor (dense urban): 0.25
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Theoretical coverage radius: 23.9 × 0.25 ≈ 6.0 km

Theoretical coverage area (ceiling): π × 6.0² ≈ 113 km²
```

Only 25% of the theoretical range is realised because the repeater barely clears the surrounding roofline. Raising the antenna by 3 additional storeys (to 30 m) lifts the horizon to ~27.6 km and, at an improved ~0.35 obstruction factor, the ceiling rises to a radius of ~9.7 km - roughly $\pi \times 9.7^2 \approx 295$ km² (still a theoretical maximum, with usable coverage well below that). In dense urban networks, rooftop height relative to surroundings matters enormously.

Coverage Overlap: The 20 - 30% Rule

When planning adjacent repeaters, their coverage footprints should overlap by 20 - 30% of the coverage radius. This is a rule of thumb borrowed from cellular and WLAN cell-planning practice (which commonly calls for 15 - 30% overlap). It ensures:

- No gap corridor between repeaters where nodes lose connectivity
- Sufficient signal margin at the cell edge for reliable forwarding (not just barely detectable signals)
- Redundancy: a node in the overlap zone can reach two repeaters

If repeater A has a coverage radius of 8 km and repeater B also has 8 km, place the two sites about 12 - 13 km apart to keep ~20 - 30% overlap (a single shared lens-shaped zone roughly 3 - 4 km wide in the middle - not "on each side"). At exactly 16 km the two cells are tangent: they just touch, with zero overlap margin and zero gap. Only beyond ~16 - 18 km does a real gap corridor open up where nodes may lose both repeaters.

Link Budget Margin: Target >10 dB

Coverage radius estimates are not hard boundaries - they define the distance at which the link margin drops to zero. In practice, a link operating at exactly the sensitivity floor is unreliable. Fading, multipath, vegetation sway, and atmospheric changes will cause it to fail intermittently.

Target at least 10 dB of margin at the cell edge for reliable operation. This means planning for a coverage radius at which the received signal is 10 dB above the receiver sensitivity floor. The 10 dB figure is a standard engineering convention (see any link-budget reference); the margin you actually need scales with the environment - budget more in heavy-fading or foliage-dense paths.

For Meshtastic on SF12 / BW125 (the Long Slow preset), receiver sensitivity is approximately −137 dBm with the SX1262's *Rx Boosted* gain enabled (standard gain is ~3 - 4 dB worse). Note that LongFast (SF11 / BW250) has a sensitivity closer to −131 dBm, not −137. A link budget target of −127 dBm at the coverage boundary gives 10 dB of margin relative to the SF12/BW125 floor. Links measured below −127 dBm at normal operating distances should be treated as marginal and either reinforced with a relay node or deprioritised until a better repeater site is available.

Quick field check: If a node reports RSSI < −125 dBm or SNR < −10 dB when communicating with its nearest repeater, that link is at or below the 10 dB margin boundary. Plan to add a relay or move the repeater closer.

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