Antenna Gain and Coverage Tradeoffs

Antenna Gain and Coverage Tradeoffs

Antenna gain is not free - it is always traded against something else. Understanding what gain costs you is essential before choosing an antenna for a mesh deployment. The fundamental law of antenna physics is conservation of energy: an antenna cannot create power, only redistribute it.

How Gain Concentrates Signal

Consider a theoretical isotropic antenna radiating 1 watt equally in all directions. At 1 km, that power is spread over a sphere of area $4\pi(1000)^2$ = 12.57 million square meters. A 5 dBi antenna (3.16× linear gain) compresses its radiation into a narrower cone, delivering up to 3.16× more power density in its peak direction (for a lossless antenna; real-antenna efficiency below 100% reduces the actual on-axis power density slightly below this figure). From the perspective of a receiver in the main beam, it is roughly equivalent to the transmitter having 3.16× the power.

This is the core of EIRP (Effective Isotropic Radiated Power):

```
EIRP (dBm) = Transmit Power (dBm) + Antenna Gain (dBi) − Feedline Loss (dB)
```

FCC Part 15.247 limits **conducted** output power to 1 watt (30 dBm) for digitally-modulated / spread-spectrum systems across the entire 902 - 928 MHz band, regardless of whether the link is point-to-point or point-to-multipoint. That conducted limit is referenced to an antenna of up to 6 dBi gain, which yields up to about 36 dBm (4 W) EIRP. If the antenna gain exceeds 6 dBi, conducted power must be reduced dB-for-dB for each dB above 6 dBi (15.247(b)(4)(i)), holding EIRP at roughly 36 dBm. There is no separate, lower point-to-multipoint limit, and there is no relaxed point-to-point antenna allowance at 915 MHz - that relaxation exists only at 2.4 and 5.8 GHz. See the directional antennas page for worked examples.

Most LoRa nodes run 17 - 20 dBm conducted transmit power. At those levels you may add an antenna of up to 6 dBi with no power reduction; beyond 6 dBi you must begin reducing conducted power dB-for-dB. Because the binding constraint above 6 dBi is conducted-power reduction (not a simple EIRP cap you spend "budget" against), high-gain antennas do not give you free EIRP headroom at 915 MHz.

Elevation Angle and Radiation Pattern Compression

As gain increases, the radiation pattern in the vertical plane becomes flatter - more like a pancake and less like a donut. This is measured as the vertical beamwidth (the angle between the −3 dB points above and below the horizon). The approximate beamwidths below are typical design figures, not exact datasheet values; consult a specific antenna's datasheet for its actual pattern.

Antenna Gain	Approx. Vertical Beamwidth	Radiation Elevation Angle
2 dBi (dipole)	~75°	Broad; works at steep angles
5 dBi collinear	~35 - 40°	Slightly elevated; works for nearby nodes
8 dBi collinear	~15 - 20°	Near-horizontal; close nodes may be in null
10 dBi collinear	~10 - 12°	Essentially horizontal; nodes must be far away to be in the beam

Dead Zones Below High-Gain Antennas

This is the most commonly overlooked problem with high-gain omnidirectional antennas in mesh networks. When you mount a 10 dBi collinear antenna on a rooftop, the signal goes predominantly outward - not down. Nodes directly beneath the tower, or on the same city block, may receive weaker signal than nodes kilometers away.

The reduced-coverage radius under a vertical omni antenna can be roughly estimated as the distance at which the main beam's lower −3 dB edge first reaches ground level, assuming the beam peak sits at the horizon:

```
Reduced-Coverage Radius ≈ h / tan(θ / 2)


Where:
 h = antenna height above nodes (meters)
 θ = full vertical beamwidth (degrees), so θ/2 is the
     angle from the horizon down to the lower −3 dB point
```

```
Example: 10 dBi antenna at 30 m height, 10° vertical beamwidth
(θ = 10°, so θ/2 = 5°):
Radius ≈ 30 / tan(5°) ≈ 30 / 0.0875 ≈ 343 meters
```

In this example, a node within roughly 343 meters of the tower base sits below the main beam's lower edge and may receive noticeably less signal - often 10 dB or more, depending on the antenna's side-lobe levels - than a node 2 km away. Treat 343 m as an order-of-magnitude reduced-coverage radius rather than a hard dead zone: signal inside it is attenuated but rarely a true null, since real coverage close in is governed by side-lobe levels, not a sharp cutoff. In a dense urban mesh, this reduced near-in coverage can still be a serious problem.

The 3 / 5 / 8 dBi Decision Guide

Use this framework when selecting omni antenna gain for a fixed node:

Gain Choice	Use When	Avoid When
2 - 3 dBi (whip, dipole, GP vertical)	Indoor node; node surrounded by other nodes at similar elevation; portable device; building where nodes are on every floor	Outdoor exposed relay where range to distant nodes is the primary goal
5 dBi (short collinear)	Outdoor rooftop node in urban/suburban area; nodes are within 2 - 5 km; mixed elevation terrain; best all-around choice for most mesh relay nodes	Indoor use; terrain with significant elevation variation around the node
8 dBi (medium collinear)	High hilltop or tower relay overlooking flat terrain; all served nodes are at roughly the same elevation and 5 - 20 km distant; rural backbone relay	Urban environment; any situation with nodes at varying elevations; anywhere nodes might be directly below the antenna

Rule of thumb: When in doubt, choose 5 dBi for any outdoor fixed node. It provides meaningful gain improvement over a whip without creating serious dead zone problems. Reserve 8+ dBi for well-planned backbone relay sites with known terrain profiles.

Directional antennas: When gain beyond 8 dBi is needed, switch to a directional antenna (panel or Yagi) aimed at the intended coverage direction. You gain range in the beam, and the dead zone problem is inherent to the design intent - it only covers one sector anyway. Remember that any antenna above 6 dBi requires reducing conducted power dB-for-dB at 902 - 928 MHz to stay within Part 15.247.

Revision #5
Created 2026-05-03 05:37:27 UTC by Mesh America Admin
Updated 2026-06-08 21:55:33 UTC by Mesh America Admin