Fresnel Zones and Clearance

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One of the most common causes of unexpectedly poor radio links is obstruction of the Fresnel zone - not just the line of sight. Even when two antennas have a clear geometric line of sight to each other, a rooftop, hilltop, or dense tree canopy can severely degrade the link if it intrudes into the Fresnel zone. Understanding Fresnel zones allows you to choose correct antenna heights and predict real-world link performance.

What Is a Fresnel Zone?

When RF energy travels from a transmitter to a receiver, it does not travel solely as a thin ray. The energy spreads into an ellipsoidal region of space around the direct path. This is because of the wave nature of radio: energy arriving at the receiver via slightly longer indirect paths can either add to or subtract from the direct signal, depending on the path length difference.

The Fresnel zones are concentric ellipsoids centered on the direct path. The first Fresnel zone contains the paths where indirect waves arrive with less than 180° of phase difference from the direct path - these waves reinforce the direct signal. Obstructions within the first Fresnel zone scatter energy and cause diffraction loss.

Key insight: you can have "clear line of sight" while still losing 10 - 20 dB of signal if obstacles intrude into the first Fresnel zone.

Why 60% Clearance Matters

Radio engineering rules of thumb require 60% of the first Fresnel zone radius to be clear of all obstacles for a link to experience negligible diffraction loss (less than about 0.5 dB). If clearance drops to 0% (grazing obstruction), diffraction loss is approximately 6 dB. Full obstruction (tip of obstacle at center of path) results in 15 - 25 dB or more of loss.

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Fresnel Zone Clearance → Diffraction Loss (approximate):
 100% (full first zone clear): ~0 dB loss
 60% (standard minimum): ~0.5 dB loss
 40%: ~3 dB loss
 0% (line-of-sight only): ~6 dB loss
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−20% (LOS blocked by 20%): ~15 - 20 dB loss
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Calculating the First Fresnel Zone Radius

The radius of the first Fresnel zone at any point along the path is calculated as:

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r₁ = 17.32 × √(d₁ × d₂ / (f × D))

Where:
 r₁ = first Fresnel zone radius (meters)
 d₁ = distance from transmitter to the obstacle (km)
 d₂ = distance from receiver to the obstacle (km)
 f = frequency (GHz)
 D = total path length d₁ + d₂ (km)

At 915 MHz (f = 0.915 GHz), simplified:
 r₁ = 17.32 × √(d₁ × d₂ / (0.915 × D))
 ≈ 18.1 × √(d₁ × d₂ / D)
```

The Fresnel zone is widest at the midpoint of the path. For the midpoint ($d_1 = d_2 = D/2$):

```
r₁_max (midpoint) = 8.66 × √(D / f)

At 915 MHz:
 r₁_max = 8.66 × √(D_km / 0.915)
 ≈ 9.05 × √(D_km)

Examples:
 1 km path: r₁_max ≈ 9.05 m
 5 km path: r₁_max ≈ 20.2 m
 10 km path: r₁_max ≈ 28.6 m
 20 km path: r₁_max ≈ 40.5 m
```

The 60% clearance requirement for the 5 km example means you need 12.1 m of clearance at the midpoint of the path. If there is a tree canopy at 8 m height at the midpoint, your link will experience significant diffraction loss even if you can see over it.

Practical Antenna Height Selection

To determine required antenna height, you need to know:

1. The height profile of the terrain and vegetation along the path (from topographic data or observation)
2. The point of maximum obstruction (worst-case obstacle)
3. The Fresnel zone radius at that point

Required antenna height to achieve 60% Fresnel clearance over an obstacle:

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Needed clearance above obstacle = 0.6 × r₁ at obstacle location


Height of antenna above ground ≥
 (Obstacle height − Earth's bulge correction)
 + 0.6 × r₁_at_obstacle
 + mast height needed to achieve this elevation
```

For long paths over curved earth, Earth bulge must also be added. Earth bulge at the midpoint of a path of length D km:

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Earth bulge (m) = D_km² / 17 (assuming 4/3 Earth radius factor for standard atmosphere)
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Practical Implications for Mesh Deployments

Scenario	Recommendation
Urban node-to-node, 0.5 - 2 km through buildings	Fresnel zone mostly in buildings anyway; gain antenna height to maximize chance of LOS paths between building gaps
Suburban, 2 - 5 km, trees and houses	Antennas must be above tree canopy (8 - 12 m AGL typical); verify at least 60% Fresnel clearance to intended relay nodes
Rural, 5 - 20 km, rolling terrain	Use topographic analysis; hilltop sites preferred; 30 - 50 ft antenna heights often needed to clear ridge midpoints
Long-range backbone, 20+ km	Strict Fresnel analysis required; professional path planning tools recommended; Earth bulge significant

Free tools for Fresnel zone and path analysis include HeyWhatsThat.com, Radio Mobile Online, and the SPLAT! propagation analysis tool. For critical links, use at least two independent analysis methods.

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