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 signal if obstacles intrude into the first Fresnel zone. A significant (near-grazing or deeper) intrusion can cost on the order of 10 - 20 dB; a light intrusion into the outer edge of the first zone costs only a few dB.

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 a grazing obstruction (obstacle tip exactly on the line of sight), diffraction loss is approximately 6 dB - the textbook knife-edge value. As the obstacle penetrates past the line of sight, loss continues to climb per the knife-edge model: an obstacle tip roughly one Fresnel radius or more above the line of sight gives 15 - 25 dB or more of loss.

The figures below use a single, consistent quantity: the **clearance ratio**, defined as the obstacle's position relative to the first Fresnel radius. A ratio of +1.0 means the obstacle is a full Fresnel

radius below the line of sight (first zone fully clear); 0 means the obstacle just touches the line of sight (grazing); a negative ratio means the obstacle has crossed above the line of sight and is blocking it. Intermediate values are interpolated from the knife-edge diffraction curve (ITU-R P.526) and are approximate:

```
Clearance ratio (obstacle relative to first Fresnel radius) → Diffraction Loss (approx.):
 +1.0 (first zone fully clear): ~0 dB loss
 +0.6 (standard 60% minimum): ~0.5 dB loss
 +0.4: ~3 dB loss
  0   (grazing, obstacle on line of sight): ~6 dB loss
 −0.2 (obstacle 20% of a Fresnel radius into the path): ~15 - 20 dB loss
```

Calculating the First Fresnel Zone Radius

The radius of the first Fresnel zone at any point along the path is calculated as (all distances in km, frequency in GHz, result in meters):

```
r₁ (meters) = 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) the constant 17.32 / √0.915 = 18.1, so:
 r₁ (meters) ≈ 18.1 × √(d₁ × d₂ / D)   (d₁, d₂, D in km)
```

The Fresnel zone is widest at the midpoint of the path. At the midpoint $d_1 = d_2 = D/2$, so $d_1 \times d_2 / D = D/4$ and the general formula above reduces to the midpoint form below (the constant 17.32 / 2 = 8.66 is the same constant, just specialized to the midpoint — not a new number to look up):

```
r₁_max at midpoint (meters) = 8.66 × √(D_km / f_GHz)

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

Examples:
 1 km path: r₁_max ≈ 9.05 m
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5 km path: r₁_max ≈ 20.2 m
10 km path: r₁_max ≈ 28.6 m
20 km path: r₁_max ≈ 40.5 m
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The 60% clearance requirement for the 5 km example means you need 0.6 × 20.2 ≈ 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:

```
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. The bulge at the **midpoint** of a path of total length D km, using the standard 4/3 Earth radius factor, is:

```
Earth bulge at midpoint (m) = D_km² / 68
 (4/3 Earth radius factor for standard atmosphere)

This comes from the general bulge formula h = d₁ × d₂ / 17 (d₁, d₂ in km),
evaluated at the midpoint where d₁ = d₂ = D/2, giving (D/2)² / 17 = D² / 68.

Example: a 20 km path → 20² / 68 = 400 / 68 ≈ 5.9 m of bulge at the midpoint.
```

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 typically need to be above the tree canopy (8 - 12 m AGL is a common guideline, depending on local canopy height); 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

Safety note: masts in the 30 - 50 ft range are not a casual install. They require professional-grade erection, guying, and grounding, and present serious fall and power-line hazards. Plan the lift so the full mast length plus at least 10 ft of margin stays clear of any overhead power line throughout the raise, and use qualified help.

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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