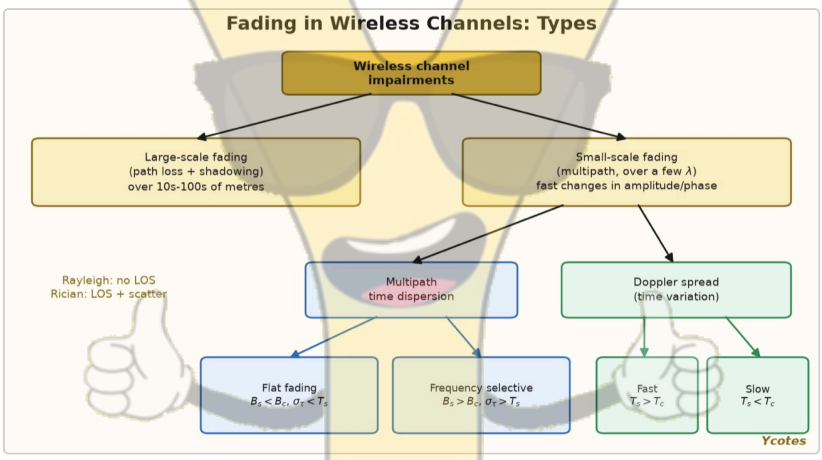
UNIT–1 : Wireless Channels: Path Loss and Fading (PYQ Solution)

PART–A Answers (≈70 Words Each)

Q1. What is fading in wireless channels and what are its types? (2019, Feb 2024)

Fading is the random variation of the received signal amplitude and phase with time, position or frequency, caused by multipath propagation, mobility and shadowing.

Types: large-scale fading (path loss and shadowing) and small-scale fading. Small-scale fading is further classified as flat or frequency selective (by delay spread) and fast or slow (by Doppler spread). The envelope is Rayleigh without line of sight and Rician with a line-of-sight path.



Q2. What is the scope and objective of wireless communication? (Feb 2024)

Wireless communication carries information between points without wires using electromagnetic waves.

Objective: to give mobile, anywhere and anytime access with reliable, high-rate links in spite of fading, noise and interference, while reusing the limited spectrum efficiently.

Scope: cellular systems (GSM, LTE, 5G), Wi-Fi, Bluetooth, satellite, IoT and sensor networks, broadcasting and navigation.

Q3. What is Doppler shift / Doppler spread? How does it affect signal transmission? (Feb 2024, 2025)

Doppler shift is the change in received frequency caused by relative motion: $f_d = \frac{v}{\lambda}\cos\theta$, with maximum value $f_m = v f_c / c$.

Doppler spread $B_D \approx 2f_m$ is the range of frequencies a single tone is spread over. It makes the channel time varying; if the coherence time $T_c \approx 0.423/f_m$ is shorter than the symbol time the channel shows fast fading, which causes spectral broadening and an irreducible error floor.

Q4. What is the difference between narrowband and wideband channels? (2025)

Narrowband channel	Wideband channel
Signal bandwidth $B_s < B_c$	Signal bandwidth $B_s > B_c$
Flat fading, single complex gain	Frequency selective fading
Multipath not resolvable, no ISI	Multipath resolvable, ISI present
Fixed by diversity or power control	Needs equaliser, RAKE or OFDM

Q5. Differentiate between fast fading and slow fading. (2025)

Fast fading	Slow fading
$T_c < T_s$ and $B_D > B_s$	$T_c > T_s$ and $B_D < B_s$
Channel changes within a symbol	Channel constant over many symbols
Caused by high speed or low data rate	Caused by low speed or high data rate
Distortion and burst errors	Channel can be tracked; long deep fades

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Q6. Define coherence bandwidth and its significance. (2025)

Coherence bandwidth B_c is the range of frequencies over which the channel frequency response is strongly correlated (roughly flat). It is inversely related to the RMS delay spread: $B_c \approx \frac{1}{5\sigma_\tau}$ for 0.5 correlation.

Significance: if the signal bandwidth is less than B_c the channel is flat fading, otherwise it is frequency selective and causes ISI. It guides the choice of equaliser, OFDM subcarrier spacing and symbol rate.

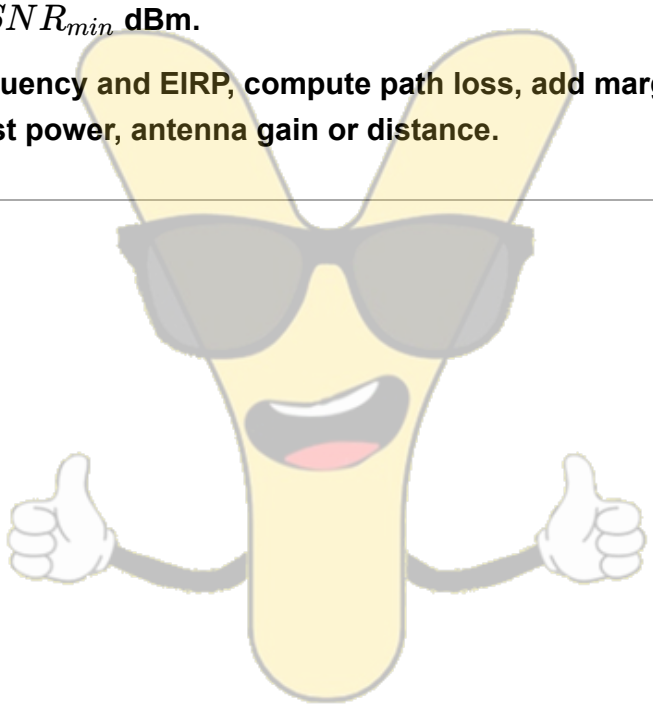
Q7. Explain link budget design. (Feb 2024)

A link budget accounts for all gains and losses from the transmitter to the receiver in dB:

$$P_r = P_t + G_t + G_r - PL - L_{other} - M_{fade}$$

The path loss comes from a propagation model, and the fade margin covers shadowing and fading. The link works if P_r is above the receiver sensitivity $-174 + 10\log B + NF + SNR_{min}$ dBm.

Design: choose frequency and EIRP, compute path loss, add margins, compare with sensitivity and adjust power, antenna gain or distance.



PART–B Answers (≈250 Words Each)

Q1. A mobile moves at 60 m/s in a cellular system at 930 MHz. Find the Doppler spread, coherence time and the appropriate sampling time and distance to predict small-scale fading. (2019)

Given: $v = 60$ m/s, $f_c = 930$ MHz.

Wavelength: $\lambda = c/f_c = 3 \times 10^8 / 930 \times 10^6 = 0.3226$ m.

Maximum Doppler shift: $f_m = v/\lambda = 60/0.3226 = 186$ Hz. The Doppler spread is $B_D = 2f_m = 372$ Hz, i.e. the band $f_c \pm 186$ Hz.

Coherence time:

$$T_c \approx \frac{0.423}{f_m} = \frac{0.423}{186} = 2.27 \text{ ms}$$

(The conservative formula $9/(16\pi f_m)$ gives 0.96 ms.)

Sampling: the channel must be sampled at least twice per coherence time:

$$T_s \leq \frac{T_c}{2} = 1.14 \text{ ms}$$

The distance travelled in this time is $d = vT_s = 60 \times 1.14 \times 10^{-3} = 0.068$ m = 6.8 cm. This is less than $\lambda/2 = 16.1$ cm, so the spatial spacing is also adequate.

Answer: Doppler spread 372 Hz ($f_m = 186$ Hz), $T_c = 2.27$ ms, sampling time about 1.1 ms, sampling distance about 6.8 cm.

Q2. Consider the free space propagation model. Calculate the received power in dBm at 100 m from a 50 W transmitter with a unity gain antenna and 900 MHz carrier. (2019)

Given: $P_t = 50$ W, $G_t = G_r = 1$, $f = 900$ MHz, $d = 100$ m.

Wavelength: $\lambda = 3 \times 10^8 / 900 \times 10^6 = 0.3333$ m.

Friis equation:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} = \frac{50 \times 0.1111}{(4\pi \times 100)^2} = \frac{5.556}{1.579 \times 10^6} = 3.518 \times 10^{-6} \text{ W}$$

In dBm: 3.518×10^{-6} W $= 3.518 \times 10^{-3}$ mW, so $P_r = 10\log_{10}(3.518 \times 10^{-3}) = -24.5$ dBm.

Cross-check in dB: $P_t = 10\log(50 \times 1000) = 46.99$ dBm; path loss $= 20\log(4\pi d/\lambda) = 71.53$ dB; $P_r = 46.99 - 71.53 = -24.54$ dBm.

Answer: $P_r \approx -24.5$ dBm (about 3.5 microwatt).

Q3. Describe the Fraunhofer region and give its mathematical expression. (2025)

The space around an antenna is divided into the **reactive near field**, the **Fresnel (radiating near-field) region** and the **Fraunhofer (far-field) region**.

In the **Fraunhofer region** the radiated field is a spherical wave whose pattern shape is independent of distance, and the power density falls as $1/d^2$. Path loss models such as Friis are valid only here.

Fraunhofer distance:

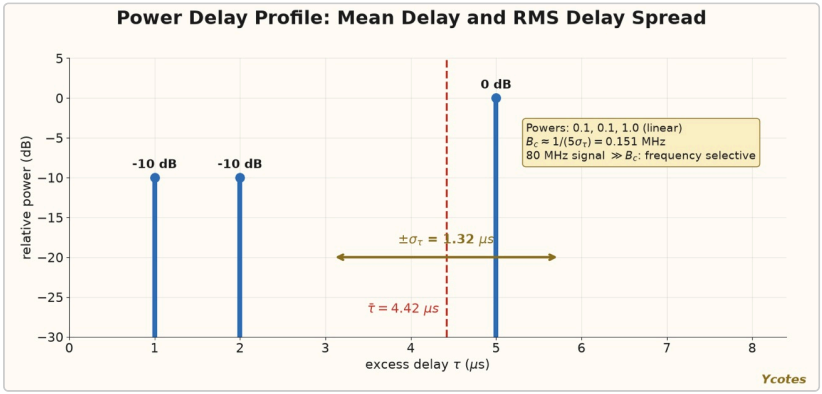
$$d_f = \frac{2D^2}{\lambda}, \qquad d_f \gg D, \quad d_f \gg \lambda$$

where D is the largest physical dimension of the antenna and λ the wavelength.

Example: $D = 1$ m at 900 MHz ($\lambda = 0.333$ m) gives $d_f = 2/0.333 = 6$ m. The reference distance d_0 in path loss models is chosen at least equal to d_f.

Q4. A complex baseband transmitter (80 MHz spectrum) has the receive power delay profile 0 dB at 5 us, -10 dB at 1 us and -10 dB at 2 us. Find (a) RMS delay spread (b) average weighted delay (c) coherence bandwidth. (2025)

From the figure: taps at 1 us (-10 dB), 2 us (-10 dB) and 5 us (0 dB). Linear powers: 0.1, 0.1, 1.0, total 1.2.



(b) Average (mean excess) delay:

$$\bar{\tau} = \frac{0.1(1) + 0.1(2) + 1.0(5)}{1.2} = \frac{5.3}{1.2} = 4.417\ \mu s$$

(a) RMS delay spread:

$$\overline{\tau^2} = \frac{0.1(1) + 0.1(4) + 1.0(25)}{1.2} = 21.25\ \mu s^2$$

$$\sigma_\tau = \sqrt{21.25 - 4.417^2} = \sqrt{1.743} = 1.32\ \mu s$$

(c) Coherence bandwidth:

$$B_c \approx \frac{1}{5\sigma_\tau} = \frac{1}{5 \times 1.32 \times 10^{-6}} = 151\ \text{kHz}$$

(For 0.9 correlation $1/50\sigma_\tau = 15$ kHz.)

Conclusion: the 80 MHz signal is far wider than B_c, so the channel is frequency selective.

Q5. Path loss exponent n = 4, 30 W transmitter, receiver 8 km away, 1.9 GHz, Gt = 2, Gr = 1. Find (a) the electric field at the receiver (b) the received power using the two-ray ground reflection model with ht = 40 m, hr = 2 m and ground reflection -1. (2025)

Given: $P_t = 30$ W, $G_t = 2$, $G_r = 1$, $d = 8000$ m, $f = 1.9$ GHz, $\lambda = 0.1579$ m.

(a) Electric field (free space): power density

$$P_d = \frac{P_t G_t}{4\pi d^2} = \frac{60}{4\pi (8000)^2} = 7.46 \times 10^{-8}\ \text{W/m}^2$$

$$|E| = \sqrt{120\pi P_d} = \sqrt{377 \times 7.46 \times 10^{-8}} = 5.3 \times 10^{-3}\ \text{V/m}$$

(b) Two-ray model: crossover $4h_t h_r/\lambda = 4 \times 40 \times 2/0.1579 = 2027$ m, less than 8 km, so the far-field form with ground reflection -1 applies:

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} = 30 \times 2 \times 1 \times \frac{1600 \times 4}{(8000)^4} = \frac{384000}{4.096 \times 10^{15}} = 9.375 \times 10^{-11}\ \text{W}$$

$$P_r = 10\log_{10}(9.375\times10^{-8}\ \text{mW}) = -70.3\ \text{dBm}$$

Answer: (a) $|E| = 5.3$ mV/m; (b) $P_r = 9.4\times10^{-11}$ W = -70.3 dBm.

Q6. Derive the pdf of y = x^2 where x is Rayleigh distributed with pdf f(x) = x e^(-x^2/2). (2025)

Given: $f_x(x) = x\,e^{-x^2/2}$ for $x \geq 0$, and $y = g(x) = x^2$.

Method of transformation: for $x \geq 0$ the mapping is one-to-one with inverse $x = \sqrt{y}$ and

$$\left|\frac{dx}{dy}\right| = \frac{1}{2\sqrt{y}}$$

Result:

$$f_y(y) = f_x(\sqrt{y})\left|\frac{dx}{dy}\right| = \sqrt{y}\,e^{-y/2}\cdot\frac{1}{2\sqrt{y}} = \frac{1}{2}e^{-y/2}, \quad y \geq 0$$

Check: $\int_0^\infty \frac{1}{2}e^{-y/2}dy = 1$.

Conclusion: y is exponentially distributed with mean 2. As x^2 is the instantaneous power of the Rayleigh envelope, the received power (and SNR) in Rayleigh fading is exponentially distributed.

Q7. Two-ray ground reflection model: ht = 30 m, hr = 1.5 m, Pt = 50 W, d = 2 km, f = 900 MHz. Compute the received signal strength in dBm. (2025)

Given: $h_t = 30$ m, $h_r = 1.5$ m, $P_t = 50$ W, $d = 2000$ m, $f = 900$ MHz; gains assumed $G_t = G_r = 1$.

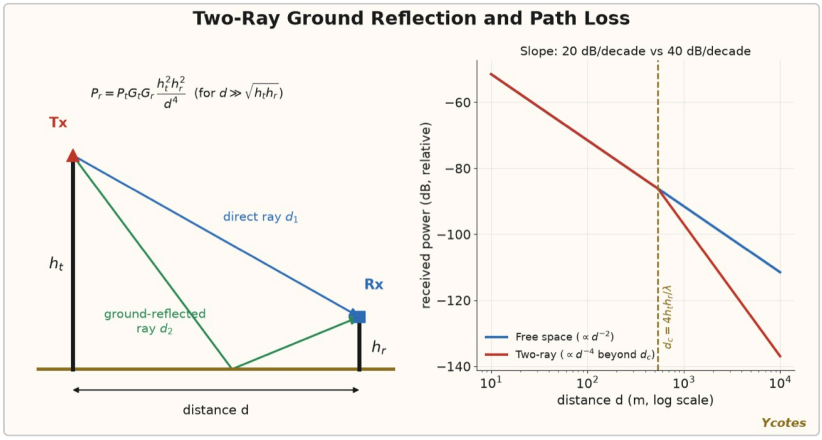
Check validity: $\lambda = 0.3333$ m; break point $d_c = 4h_th_r/\lambda = 4\times30\times1.5/0.3333 = 540$ m. Since $d = 2000 \gg 540$ m, use the fourth-power law.

Received power:

$$P_r = P_tG_tG_r\frac{h_t^2h_r^2}{d^4} = 50\times\frac{900\times2.25}{(2000)^4} = \frac{50\times2025}{1.6\times10^{13}} = 6.33\times10^{-9}\ \text{W}$$

$$P_r = 10\log_{10}(6.33\times10^{-6}\ \text{mW}) = -52.0\ \text{dBm}$$

Answer: $P_r \approx 6.3 \times 10^{-9}$ W = **-52.0 dBm**. (Free space at the same distance would give -50.6 dBm, so the two-ray loss is slightly higher.)



Q8. Explain Doppler spread and coherence time in detail. (Feb 2024)

Doppler shift: a mobile at speed v receiving a wave at angle θ sees $f_d = (v/\lambda)\cos\theta$. The maximum is $f_m = v f_c / c$.

Doppler spread B_D: because multipath components arrive at different angles, they have different shifts between $-f_m$ and $+f_m$. A pure tone at f_c is spread over $f_c \pm f_m$, so $B_D \approx 2f_m$. The Doppler spectrum is the classical Jakes (U-shaped) spectrum for isotropic scattering.

Coherence time T_c: the duration over which the channel impulse response is essentially constant (correlation above 0.5). It is inversely proportional to the Doppler spread:

$$T_c \approx \frac{0.423}{f_m} \quad \text{or} \quad \frac{9}{16\pi f_m}$$

Relation to signalling: if the symbol period $T_s \ll T_c$ the channel is slow fading; if $T_s > T_c$ it is fast fading. Example: $v = 100$ km/h at 2 GHz gives $f_m = 185$ Hz and $T_c = 2.3$ ms.

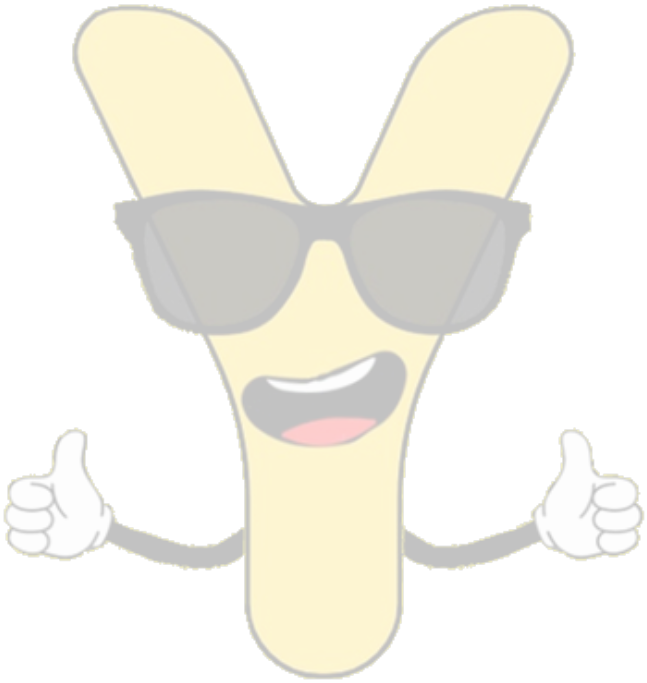
Effects: spectral broadening, time-varying channel, tracking difficulty, error floors for fast fading.

Q9. Describe fast fading and slow fading. (Feb 2024)

Fast fading: the channel impulse response changes within a symbol duration. This happens when the coherence time is smaller than the symbol period ($T_c < T_s$), or equivalently the Doppler spread is larger than the signal bandwidth ($B_D > B_s$). It is caused by high mobile speed or a low data rate. The result is signal distortion and a high, irreducible BER, because the receiver cannot estimate the channel.

Slow fading: the channel changes much more slowly than the symbol rate ($T_c > T_s$, $B_D < B_s$). A deep fade can last many symbols and cause burst errors, but the channel can be estimated and tracked, and interleaving with coding helps. (The term is also used for shadowing.)

Remember: fast or slow depends on the Doppler spread (time domain); flat or frequency selective depends on the delay spread (frequency domain). The two classifications are independent, so a channel can be for example flat and slow.



PART–C Answers (≈500 Words Each)

Q1. Explain the Hata model using a suitable example and diagram, and discuss its importance in wireless communication. (2025)

Hata model: an empirical closed-form version of Okumura's curves for predicting median path loss in macrocells.

Validity: $f_c = 150$ to 1500 MHz, base antenna height $h_b = 30$ to 200 m, mobile height $h_m = 1$ to 10 m, distance $d = 1$ to 20 km.

Urban path loss:

$$L_{50}(\text{dB}) = 69.55 + 26.16 \log f_c - 13.82 \log h_b - a(h_m) + (44.9 - 6.55 \log h_b) \log d$$

with f_c in MHz, h_b in m and d in km. For a small or medium city $a(h_m) = (1.1 \log f_c - 0.7)h_m - (1.56 \log f_c - 0.8)$; for a large city $a(h_m) = 3.2(\log 11.75 h_m)^2 - 4.97$ at 300 MHz and above.

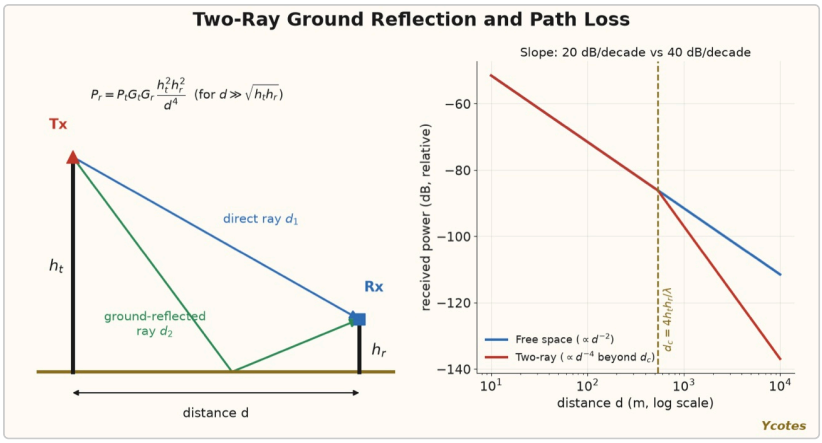
Suburban: $L_{sub} = L_{urban} - 2[\log(f_c/28)]^2 - 5.4$.
Open area: $L_{open} = L_{urban} - 4.78(\log f_c)^2 + 18.33 \log f_c - 40.94$.

Example: $f_c = 900$ MHz, $h_b = 50$ m, $h_m = 1.5$ m, $d = 5$ km, medium city.
$a(h_m) = (1.1 \times 2.954 - 0.7) \times 1.5 - (1.56 \times 2.954 - 0.8) = 3.82 - 3.81 \approx 0.01$ dB.
$L = 69.55 + 77.28 - 23.48 - 0.01 + (44.9 - 11.13) \times 0.699 = 123.3 + 23.6 = 146.9$ dB.
So the path loss is about **147 dB**; with $P_t = 43$ dBm and 0 dB antennas the received power is about -104 dBm.

Importance:

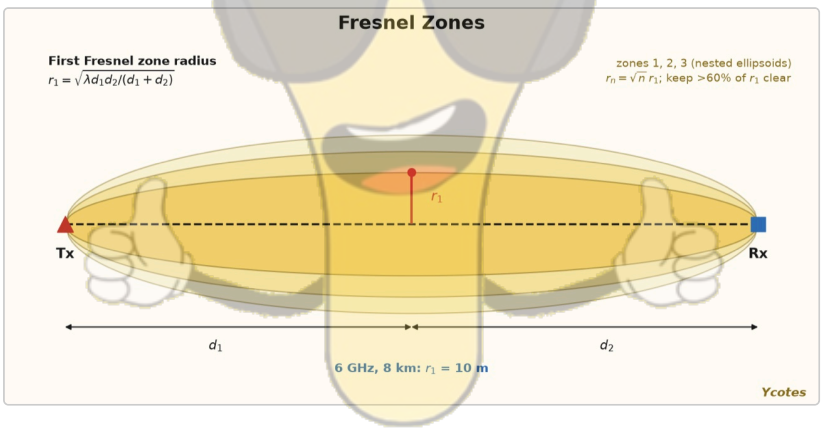
- Gives quick, computer-friendly coverage prediction with no field survey
- Used to set cell radius, transmit power and link budget margins
- Basis of COST-231 Hata for 1.5 to 2 GHz
- Limitations: not valid for micro-cells, indoors or below 30 m base height

Path loss exponent from Hata: slope $(44.9 - 6.55 \log h_b)$ dB per decade, i.e. $n \approx 3.5$ to 4 in urban areas.



Q2. Explain the Fresnel zone with a diagram. A 6 GHz signal is sent over 8 km and an obstacle of height 10 m sits at the midpoint. Does it interfere with the first Fresnel zone? (2025)

Fresnel zones: consider an ellipsoid around the line of sight between Tx and Rx. The n-th Fresnel zone contains all points where the indirect path is longer than the direct path by between $(n-1)\lambda/2$ and $n\lambda/2$. Energy in odd zones adds, in even zones it cancels, so obstacles in the first zone cause fading and diffraction loss.



Radius:

$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

Clearance rule: for near free-space propagation at least **60% of** r_1 must be free of obstacles.

Numerical: $f = 6$ GHz gives $\lambda = 3 \times 10^8 / 6 \times 10^9 = 0.05$ m. With the obstacle at the midpoint $d_1 = d_2 = 4000$ m:

$$r_1 = \sqrt{\frac{0.05 \times 4000 \times 4000}{8000}} = \sqrt{100} = 10 \text{ m}$$

The obstacle height is 10 m (measured above the line of sight, assumed).

Fresnel-Kirchhoff parameter:

$$v = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)} = 10\sqrt{\frac{2}{0.05}\times\frac{2}{4000}} = 10\sqrt{0.02} = 1.41$$

The approximate knife-edge loss is $6.9 + 20\log(\sqrt{(v-0.1)^2+1}+v-0.1) = 16.3$ dB.

Conclusion: the obstacle height equals r_1 (10 m), so the obstacle just reaches the outer edge of the first Fresnel zone and the line of sight is fully blocked; it **does interfere**. The required clearance is $0.6r_1 = 6$ m of free space, which is not met. The remedy is to raise the antennas or move the path.

Q3. Describe large scale path loss and define the path loss models. (Feb 2024)

Large-scale path loss is the average decrease of received power with distance between Tx and Rx (over tens to hundreds of metres), plus slow variation due to shadowing by buildings and terrain. It determines coverage and cell size.

1. Free space (Friis) model:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2 L}, \quad PL = 20\log\frac{4\pi d}{\lambda}$$

Exponent $n = 2$.

2. Two-ray ground reflection model: direct plus reflected ray gives $P_r = P_t G_t G_r h_t^2 h_r^2 / d^4$ for $d > 4h_t h_r/\lambda$, exponent $n = 4$.

3. Log-distance model:

$$PL(d) = PL(d_0) + 10n\log\frac{d}{d_0}$$

with $n = 2$ (free space), 2.7 to 3.5 (urban cellular), 3 to 5 (shadowed urban), 1.6 to 1.8 (in-building LOS), 4 to 6 (obstructed in-building).

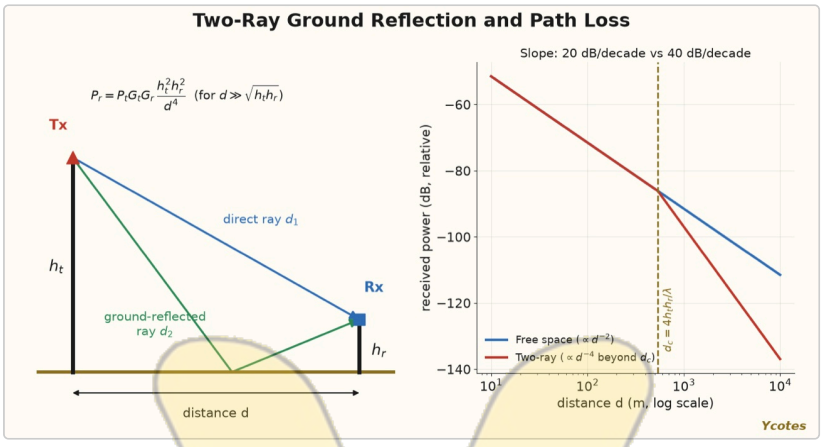
4. Log-normal shadowing:

$$PL(d) = PL(d_0) + 10n\log\frac{d}{d_0} + X_\sigma$$

where X_σ is a zero-mean Gaussian random variable (in dB) with standard deviation σ = 4 to 12 dB.

5. Empirical models: Okumura (curves, 150 to 1920 MHz), **Hata** (formula for Okumura), COST-231 Hata, Walfisch-Ikegami, and indoor models with partition and floor losses.

6. Knife-edge diffraction for obstructed paths using the Fresnel parameter v.



Use: link budget, cell planning and handoff design.
