RF Fundamentals

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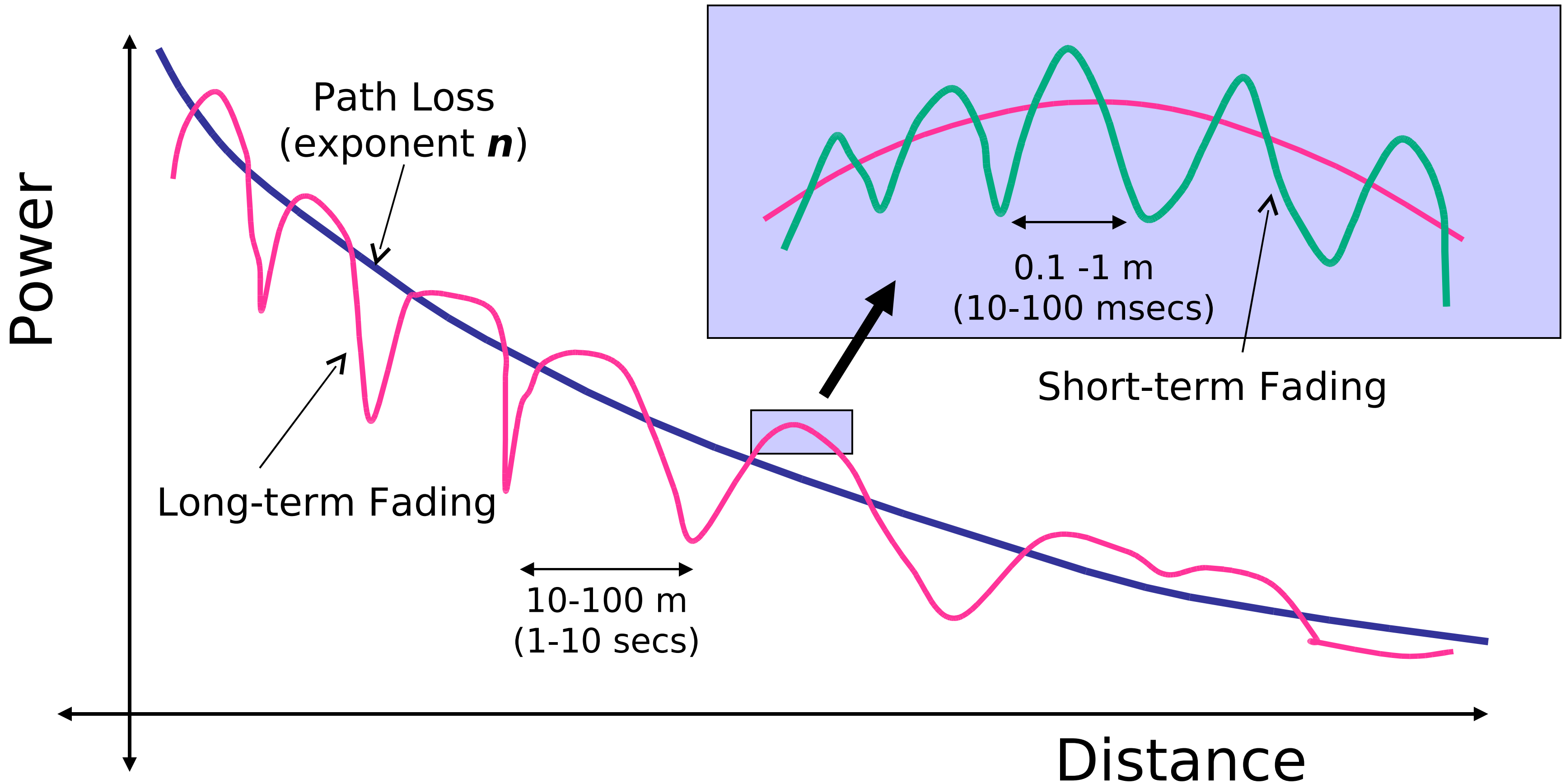
Contents

- 1. Terrestrial Wireless Propagation
- 2. Path Loss – Long Term, Short Term
- 3. Noise Figure of Receiver
- 4. Example: Communication Link Budget

1. Basics of Terrestrial Radio Propagation



2. Path Loss -- Long Term Losses

- **Free-space Propagation** $(n=2)$ → Received Power

P_T – Power at Tx port of Isotropic Antenna in Watts

Power density at distance $d = P_T / 4\pi d^2$ Watts/m^2

G_T – Directivity or Gain in a particular direction

Effective Isotropically Radiated Power (EIRP) $= P_T G_T$

Received power extracted by Rx is proportional to the effective area A_R of the Rx antenna

$$P_R = \frac{P_T G_T}{4\pi d^2} A_R \text{ Watts}$$

Aside: Effective Area of Rx Antenna

From EM Theory, the effective area A_R of the Rx antenna is related to the Rx antenna directivity G_R as follows

$$A_R = \frac{G_R}{(4\pi/\lambda^2)} \text{ m}^2$$

where λ is the wavelength of carrier

Example 1: For parabolic dish antenna of diameter D

$$A_R = \frac{\pi D^2}{4}\eta, \text{ where illumination efficiency } 0.5 \le \eta \le 0.6$$

Therefore, the directivity (gain) for the antenna is

$$G_R = \eta \left(\frac{\pi D}{\lambda} \right)^2$$

Received Power

- **Received power** (for $n=2$)

$$\text{Substitution of } A_R = \left(\frac{\lambda^2}{4\pi}\right) G_R \text{ gives Rx power}$$

$$P_R = \frac{P_T G_T G_R}{(4\pi d/\lambda)^2} \text{ Watts}$$

Taking 1milliwatt = 0dBm, this can be expressed in a convenient Log (dBm) scale as

$$P_R(\text{dBm}) = P_T(\text{dBm}) + G_T(\text{dBi}) + G_R(\text{dBi}) - L_d(\text{dB})$$

where

$$L_d = 10\log_{10}((4\pi d/\lambda)^n) \text{ dB} \quad \text{-- in free space, } n=2$$

Factors affecting Rx Power

In the presence of large-scale scatterers (buildings, usually) a random variation is expected (also called long-term fading)

$$P_R(\text{dBm}) = P_T(\text{dBm}) + G_T + G_R - L_d - L_{shadow} - L_{cable}$$

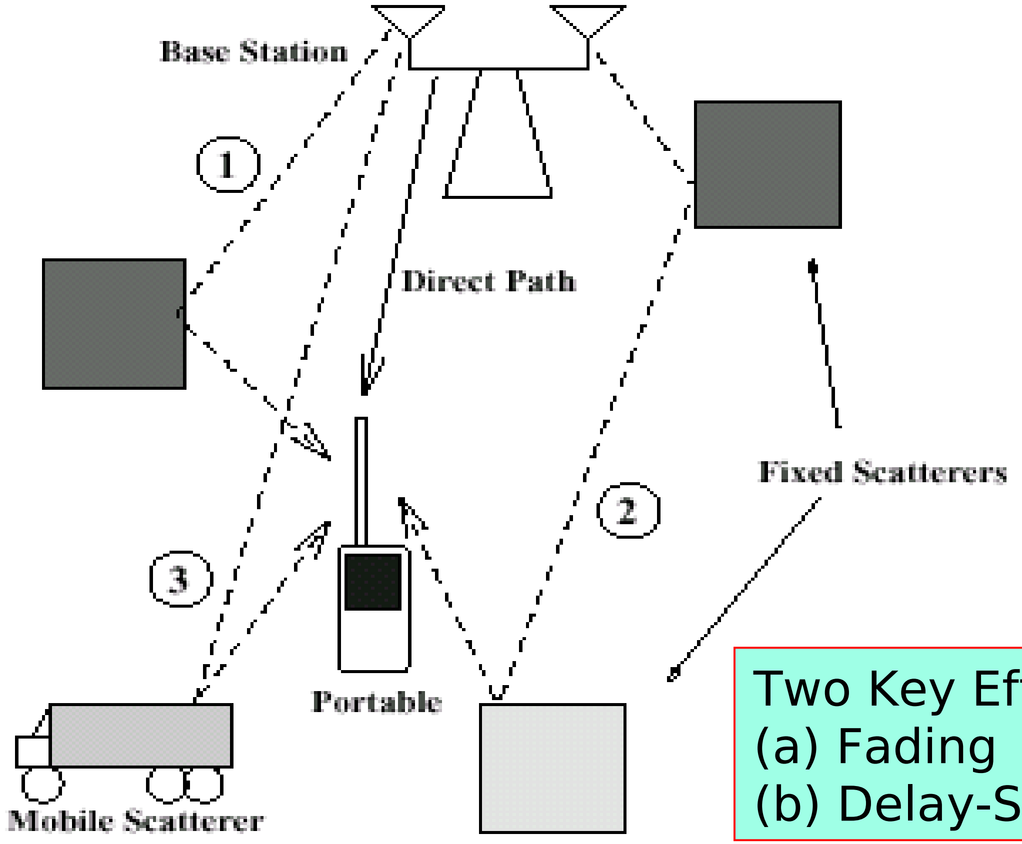
where L_{shadow} (in dB) is an random-variable with pdf $\mathrm{N}(0,\sigma)$, and standard-deviation σ is in dB scale -- log-normal distribution; L_{cable} (in dB) is the RF cable loss (specified in dB/meter).

Shadow-loss, Cable-loss, and antenna mis-alignment is sometimes clubbed into a single "Installation margin" term (in dB)

- What about short-term fading?

$$P_R(\text{dBm}) = P_T(\text{dBm}) + G_T + G_R - L_d - L_{shadow} - L_{cable} - L_{fading}(\text{dB})$$

Short-term Fading – Multipath Propagation



Two Key Effects --
(a) Fading
(b) Delay-Spread

$$r(t) = \alpha_0\, s(t-\tau_0) + \alpha_1\, s(t-\tau_1) + \alpha_2\, s(t-\tau_2) + \alpha_3\, s(t-\tau_3)$$

How much Rx Power is required?

Minimum P_R (dBm) required depends on SNR needed for a target BER!

This required SNR (specified in dB) is a function of:

(a) Receiver Sensitivity ? f(bandwidth, RF design, Baseband algorithms, architechture, implementation)

(b) Digital Modulation and Coding used for getting the target BER

- Key Question: How to relate P_R and SNR?
- Answer: Understand receiver noise power!

3. Rx Noise Figure

Thermal noise (passives) dominates over shot noise (actives);

at temperature T Kelvins, for bandwidth Δf Hz,

Noise Power $= N_o \Delta f = kT\Delta f \quad k = 1.38?10^{-23}$ (Boltzmann const.)

Example 1: Room temp $T = 300^{\circ}$K and $\Delta f = 1$MHz

Noise spectral density $N_o = kT = -174$ dBm;

Noise power $kT\Delta f = -174 + 60 = -114$ dBm;

If signal power $P_T = -90$ dBm (say), then SNR $= 24$ dB

Rx Sensitivity –
Impact of Noise Figure and Modulation used

Example 1 (contd.): Room temp $T = 300^{o}$K and $\Delta f = 1$MHz

Noise power $kT\Delta f = -174 + 60 = -114$ dBm;

a) If Rx noise figure $F = 6$ dB ? noise floor rises to -108 dBm

(for RF-BB combo chip, F could reflect base-band accuracy as well!)

b) Let the digital modulation technique used be Quadrature Phase Shift Keying (QPSK). For BER=10^{-3}, QPSK requires in AWGN channels (and in the absence of any FEC), a SNR=6.7dB

? minimum signal strength required is -108+6.7 = -101.3 dBm

? sensitivity of the receiver is = -101.3 dBm

- With diversity reception, turbo-coding, etc., required SNR for QPSK to (get same BER) would further reduce

4. Link Budget Example

Example 2: Communication link budget for GSM uplink

Given $P_T = 100$milliwatts, G_T =2dBi, G_R =15dBi, cable loss of 2dB, and no (zero) allowance for shadow loss or fading loss, compute the maximum link distance possible (in meters) for a GSM phone with a 5dB noise figure operating in the 800MHz band.

GSM uses 200KHz channelisation (bandwidth), and requires a SNR=7dB to achieve the target BER=10^{-3}. Assume free-space propagation on the uplink (i.e., exponent n=2), & T=300°K.

Recall: $P_R(\text{dBm}) = P_T(\text{dBm}) + G_T + G_R - L_d^{'} - L_{cable}$

which conveniently $= P_T + G_T + G_R - L_{1\text{m}} - L_d - L_{cable}$

where at 1m, $L_{1\text{m}} = 10\log_{10}\left(\frac{4\pi}{\lambda}\right)^2$, and $L_d = 10\log_{10} d^n$