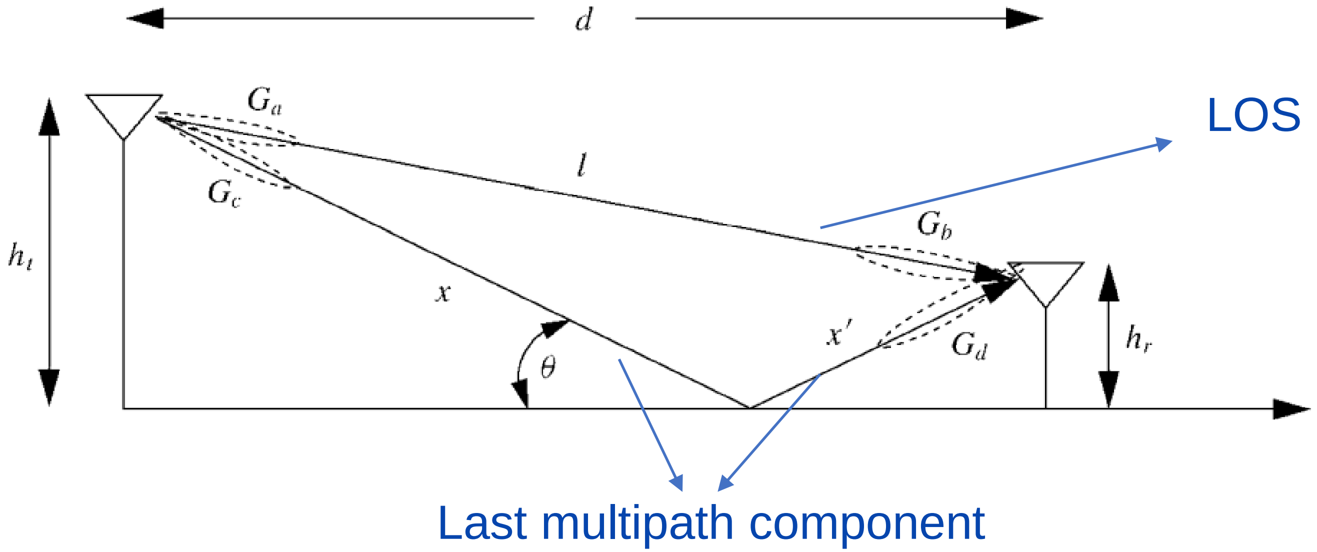
HW-1 习题课

2-2

- Delay spread:
  - Def: <u>difference</u> between the <u>time</u> of arrival of the **earliest** significant multipath component (typically the LOS) and the time of arrival of the **last** multipath components.

---- (from Wiki)



$$\tau = \frac{x + x' - l}{c}$$

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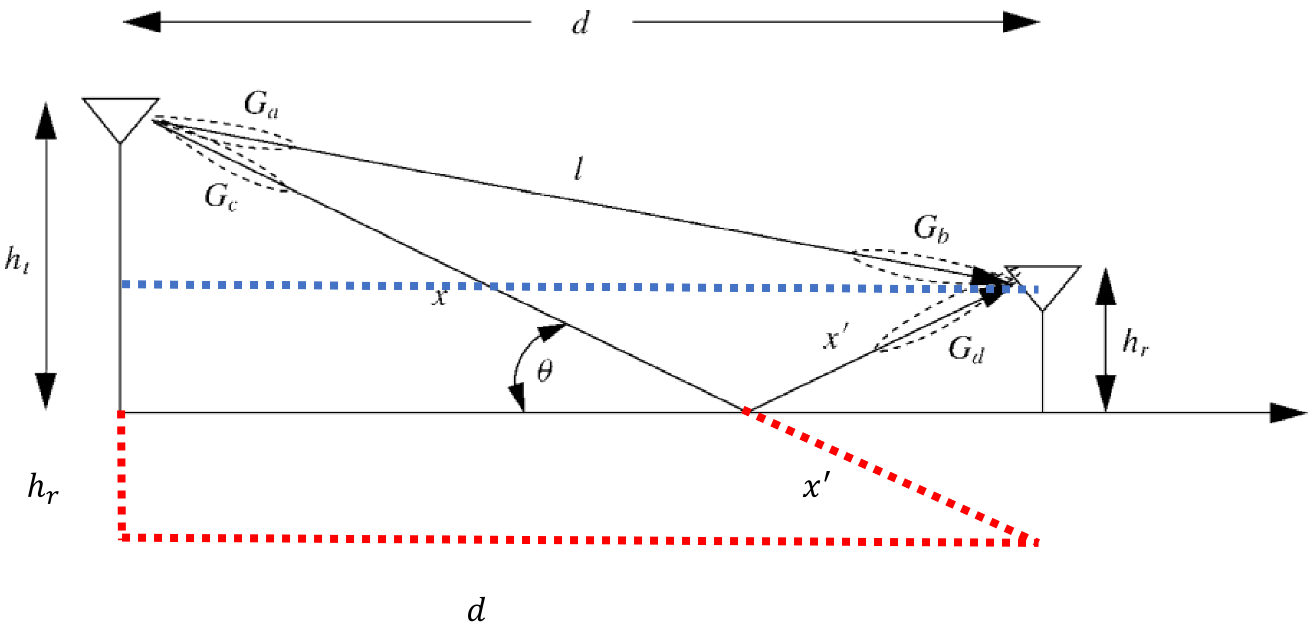

$$\tau = \frac{x + x' - l}{c}$$

$$= \frac{\left(\sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}\right)}{c}$$

The answer is $\frac{\sqrt{(12)^2 + 100^2} - \sqrt{(8)^2 + 100^2}}{c} \approx \frac{100.7174 - 100.3195}{3 \cdot 10^8} = 1.3265 \cdot 10^{-9} s$

2-13

2-13. Consider a receiver with noise power -160 dBm within the signal bandwidth of interest. Assume a simplified path-loss model with $d_0 = 1$ m, K obtained from the free-space path-loss formula with omnidirectional antennas and $f_c = 1$ GHz, and $\gamma = 4$. For a transmit power of $P_t = 10$ mW, find the maximum distance between the transmitter and receiver such that the received signal-to-noise power ratio is 20 dB.

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma}.$$

K: a unitless constant depends on antenna characteristic and the average channel attenuation

d_0: reference distance for the antenna **far field**

γ: pathloss exponents

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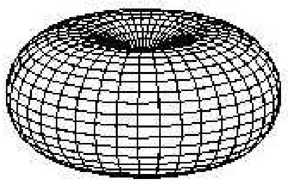
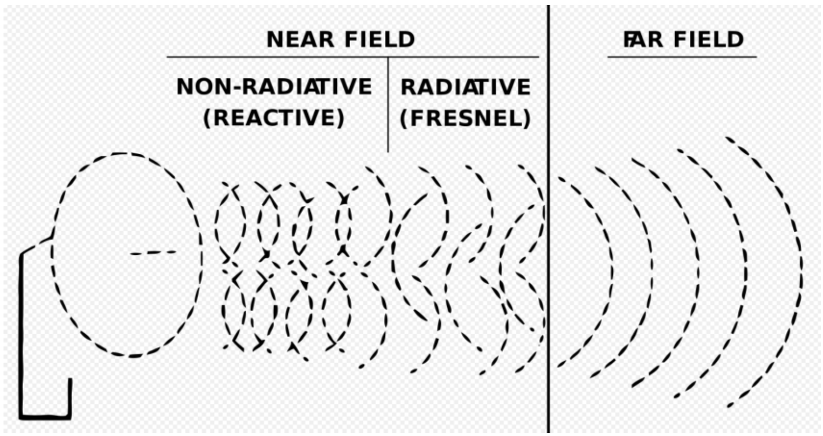
$$\frac{P_r}{P_t} = \left[\frac{\sqrt{G_l}\lambda}{4\pi d}\right]^2.$$

In free-space formula, this factor K is the **free space antenna gain** at d_0 assuming omnidirectional antenna.



$$K = \left(\frac{\lambda}{4\pi d_0}\right)^2 \rightarrow K\ dB = 20\log_{10}\lambda/4\pi d_0$$



d_0

d_0: reference distance for the antenna **far field**

2-13

$$K = \left(\frac{\lambda}{4\pi d_0}\right)^2 = \left(\frac{c}{4\pi d_0 f_c}\right)^2 = \left(\frac{0.3}{4\pi}\right)^2 \approx 5.699 \cdot 10^{-4}$$

$$P_r = P_t K \left[\frac{d_0}{d}\right]^\gamma = 10^{-2} \cdot 5.699 \cdot 10^{-4} \cdot \left(\frac{1}{d}\right)^4 W$$

$$d = \left(\frac{5.699 \cdot 10^{-6}}{P_r}\right)^{1/4} \rightarrow \max d = \min_{P_r} \left(\frac{5.699 \cdot 10^{-6}}{P_r}\right)^{\frac{1}{4}}$$

Knowing $SNR = 20dB, P_N = -160\ dBm$

$$P_r = P_N \cdot SNR \rightarrow P_r\ dBm = P_N\ dBm + SNR = -140\ dBm$$

$$P_r = 10^{-14} mW = 10^{-17} W \rightarrow d_{max} = (5.699 \times 10^{11})^{0.25} \approx 868.8597\ m$$

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Another approach:

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma}$$

$$\rightarrow P_r\ dBm = P_t\ dBm + K\ dB + \gamma\ d_0\ dB\ - \gamma\ d\ dB$$

NOTE: this notation is actually not “correct” !!!

Here just for simplification.

2-17

2-17. Using the $\boxed{\text{indoor attentuation model,}}$ determine the required transmit power for a desired received power of -110 dBm for a signal transmitted over 100 m that goes through three floors with attenuation 15 dB, 10 dB, and 6 dB (respectively) as well as two double plasterboard walls. Assume a reference distance $d_0 = 1$, exponent $\gamma = 4$, and constant $K = 0$ dB.

$$P_r \text{ dBm} = P_t \text{ dBm} - P_L(d) - \sum_{i=1}^{N_f} \text{FAF}_i - \sum_{i=1}^{N_p} \text{PAF}_i, \qquad (2.38)$$

- FAF_i: floor attenuation factor --- attenuation across floor
- PAF_i: partition attenuation factor --- attenuation between floor

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Note: 900–1300 MHz

Table 2.1: Typical partition losses

Partition type	Partition loss (dB)
Cloth partition	1.4
Double plasterboard wall	3.4
Foil insulation	3.9
Concrete wall	13
Aluminum siding	20.4
All metal	26

$$P_r\ dBm = P_t\ dBm - P_L(d) - \sum^{N_f} \mathrm{FAF}_i - \sum^{N_p} \mathrm{PAF}_i$$

$$\begin{aligned} P_t\ dBm &= -110\ dBm + 31\ dB + 6.8\ dB + P_L(d) \\ &= -72.2\ dBm + P_L(d) \\ P_L(d) &= P_t'\ dBm - P_r'\ dBm \\ &= -(\ K\ dB + \gamma\ d_0\ dB - \gamma\ d\ dB) = 80dB \\ P_t\ dBm &= 7.8dBm \end{aligned}$$

2-19

2-19. Consider a cellular system operating at 900 MHz where propagation follows free-space path loss with variations about this path loss due to log-normal shadowing with $\sigma = 6$ dB.

Suppose that for acceptable voice quality a signal-to-noise power ratio of 15 dB is required at the mobile. Assume the base station transmits at 1 W and that its antenna has a 3-dB gain. There is no antenna gain at the mobile, and the receiver noise in the bandwidth of interest is -40 dBm. Find the maximum cell size such that a mobile on the cell boundary will have acceptable voice quality 90% of the time.

$$\frac{P_r}{P_t} = \left[\frac{\sqrt{G_l}\,\lambda}{4\pi d}\right]^2, P_r = \frac{P_t}{\psi} \longrightarrow P_r\ dBm = P_t\ dBm - \psi\ dB + \boxed{G_l}\,dB + 2\left(\frac{\lambda}{4\pi}\right) dB - 2d\ dB$$

$$p(\psi_{\mathrm{dB}}) = \frac{1}{\sqrt{2\pi}\,\sigma_{\psi_{\mathrm{dB}}}} \exp\left[-\frac{(\psi_{\mathrm{dB}} - \mu_{\psi_{\mathrm{dB}}})^2}{2\sigma^2_{\psi_{\mathrm{dB}}}}\right]$$

Product of antenna gain

(here l means LOS, not loss)

2-19

$$P_r\ dBm = 30\ dBm + 3\ dB - 31.53\ dB - 20\log_{10} d\ dB - \psi_{dB}\ dB$$
$$= 1.47\ dBm\ - 20\log_{10} d\ dB - \psi_{dB}\ dB$$

$$\Pr[P_r\ dBm \leq P_{\min}\ dBm] = \Pr[1.47\ dBm\ - 20\log_{10} d - \psi_{dB}\ \leq P_{\min}\ dBm]$$
$$= \Pr[1.47\ dBm\ - 20\log_{10} d - P_{\min} dBm \leq \psi_{dB}\ ]$$
$$= \Pr\left[\frac{\psi_{dB}}{\sigma_{\psi_{dB}}} \geq \frac{(1.47\ dBm\ - 20\log_{10} d - P_{\min}\ dBm)}{\sigma_{\psi_{dB}}}\right]$$
$$= Q\left(\frac{26.47 - 20\log_{10} d}{6}\right) \leq 0.1$$

$$P_{\min}\ dBm = -40\ dBm + 15 = -25\ dBm$$

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$$Q\left(\frac{26.47 - 20\log_{10} d}{6}\right) \leq 0.1 \;\rightarrow \frac{26.47 - 20\log_{10} d}{6} \geq 1.282$$

$$\rightarrow 20\log_{10} d \leq 26.47 \; - 6 \cdot 1.282$$

$$\rightarrow d \leq 8.6876\, m$$