# Basics of Wireless Signal Propagation

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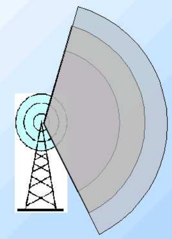

# RF Propagation

**Questions:**
How does RF propagate with distance?
Behaviour under different environments
How to quantify these?

**Goals:**
Estimate coverage area, link performance

**Use:**
Determine network design parameters
- Locations of transmitters
- Transmit power
- Type of antenna

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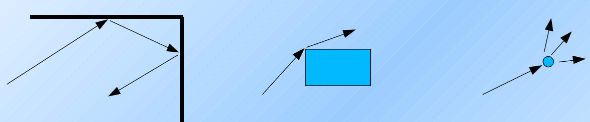
# Three Basic Propagation Phenomena



| Reflection | Diffraction | Scattering |
|---|---|---|
| $\lambda \ll D$ | $\lambda \simeq D$ | $\lambda \gg D$ |

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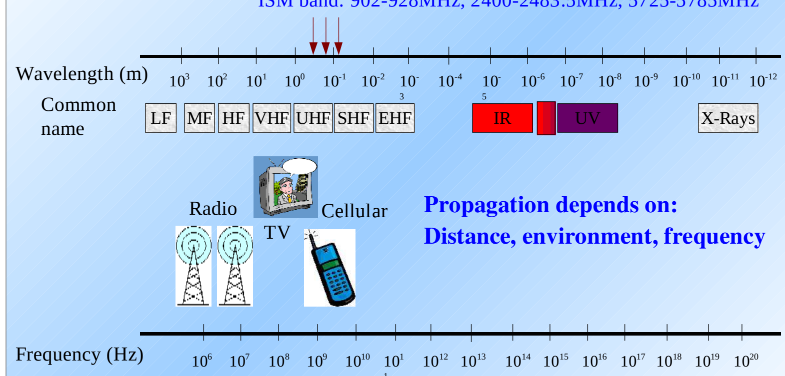
# Electro-Magnetic Spectrum

ISM band: 902-928MHz, 2400-2483.5MHz, 5725-5785MHz




**Propagation depends on:**
**Distance, environment, frequency**

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# dB: Relative Measure (to measure propapagtion)

Gravitational force on a mass *m* at distance *d/2* ← Gravitational force on a mass *m* at distance *d* → Gravitational force on a mass *m* at distance *10d*

**4 timers more**

**100 times less**

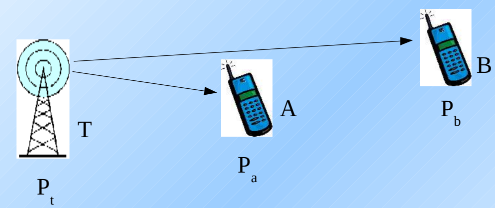
$$dB = 10 \times \log_{10}(\text{ratio})$$

**6dB more**

**20dB less**



# Measuring Path Loss in dB




$$\text{Path loss at A} = 10 \times \log_{10}\left(\frac{P_t}{P_a}\right)$$

$$\text{Path loss at B} = 10 \times \log_{10}\left(\frac{P_t}{P_b}\right)$$

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# Measuring Absolute Power in dBm

$$(\text{Absolute power P})\ \text{mW} \equiv (\text{Relative power of P w.r.t. 1mW})\ \text{dBm} \equiv 10 \times \log_{10}\left(\frac{P}{1\,\text{mW}}\right)$$

Examples:

$$1\,\text{mW} \equiv 0\,\text{dBm}$$
$$0.1\,\text{mW} \equiv -10\,\text{dBm}$$
$$10\,\text{mW} \equiv 10\,\text{dBm}$$
$$100\,\text{mW} \equiv 20\,\text{dBm}$$

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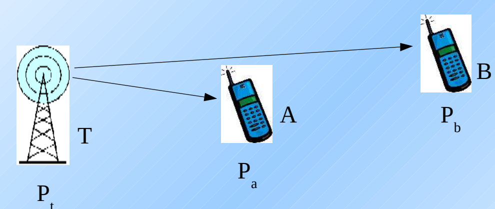
# Putting Together dB and dBm




$$P_t = 20\,\text{dBm}, \text{Path loss at A} = 30\,\text{dB}, P_a = ?$$

$$P_a = P_t - (\text{Path loss}) = -10\,\text{dBm}$$

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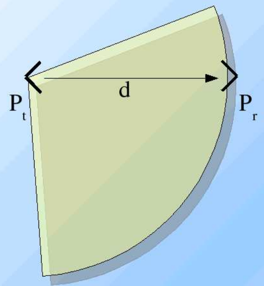
# How to Estimate Path Loss?




$$\text{Power density at receiver} = PD = \frac{P_t}{4 \times \pi \times d^2}$$

$P_r = PD \times A_{eff}$, $A_{eff}$ is the Antenna Efficiency

$$A_{eff} = \frac{\lambda^2}{4 \times \pi} \qquad P_r = P_t \times \left(\frac{\lambda}{4 \times \pi \times d}\right)^2$$

$$\text{Path loss} = \frac{P_r}{P_t} = \left(\frac{\lambda}{4 \times \pi \times d}\right)^2$$

The above calculations assume the use of **isotropic antennae**



# Frii's Free-Space Formula

**Antenna Gain G:** ratio of transmit/receive power in a particular direction, to that of an isotropic antenna

Transmit gain == Receive gain

$$P_r = P_t \times G_t \times G_r \times \left(\frac{\lambda}{4 \times \pi \times d}\right)^2$$

Some more useful forms of the Frii's formula:

$$P_r = P_t \times G_t \times G_r \times \left(\frac{c}{4 \times \pi \times f \times d}\right)^2$$

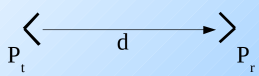
Free-space path-loss

$$(P_r)_{dBm} = (P_t)_{dBm} + (G_t)_{dB} + (G_r)_{dB} - [32.5 + 20\log_{10}(f) + 20\log_{10}(d)]$$

where f is in MHz and d is in km



# Path Loss Example




$P_t = 50\,mW$, $2.4\,GHz$ transmission, $d = 2\,km$, $P_r = ?$

$PathLoss = 32.5 + 20\log_{10}(2400) + 20\log_{10}(2) \simeq 106\,dB$

$P_r = P_t - PathLoss = 17\,dBm - 106\,dB = -89\,dBm$

$G_t = 24\,dBi$, $G_r = 24\,dBi$, $P_r = ?$

$-89\,dBm + 24\,dB + 24\,dB = -41\,dBm$



# Path Loss Remarks

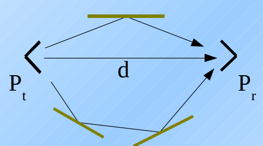
- Free space path loss is idealistic
- In reality, there is more path loss
  - Proportional to d^3 or higher
- Several path loss models are available
  - For indoor environments, outdoor metropolitan, etc.
- Now: more on RF propagation

# Fading and Multipath

**Fading:** the rapid variation of received signal strength over a small period of time

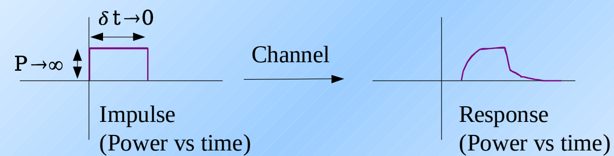
Due to multi-path

Due to mobility



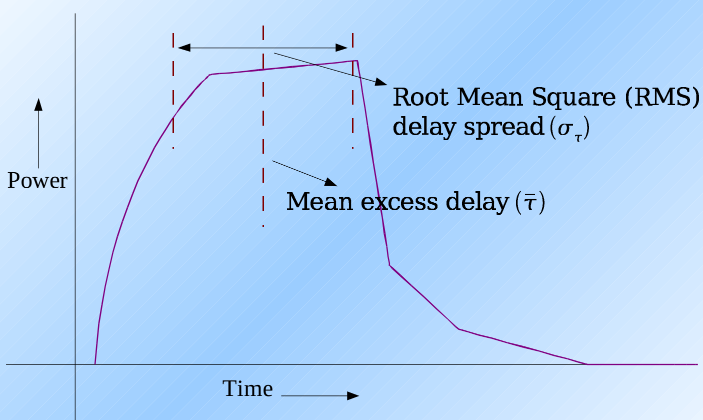



# Channel Impulse Response



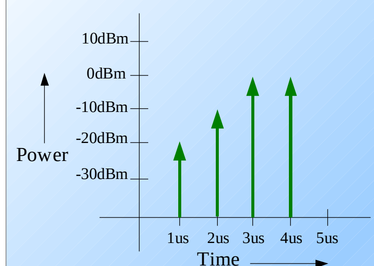



# Power Delay Profile






# An Example




$\bar{\tau}=?$ $\sigma_\tau=?$

$$\bar{\tau}=\frac{(0.01\times1+0.1\times2+1\times3+1\times4)}{(0.01+0.1+1+1)}$$

$\bar{\tau}=3.42\,\mu s$

$$\bar{\tau^2}=\frac{(0.01\times1^2+0.1\times2^2+1\times3^2+1\times4^2)}{(0.01+0.1+1+1)}$$

$\bar{\tau^2}=12.04\,\mu s^2$

$$\sigma_\tau=\sqrt{12.04-3.42^2}=0.59\,\mu s$$

## Some Remarks

- RMS delay spread is a good measure of multi-path
  - Urban environments: 2-10 us
  - Indoors: 10-500 ns
- Symbol time: time to transmit a bit (0/1)
- Symbol time ~ RMS delay spread ==> Inter-Symbol Interference (ISI)
  - Equalization required
  - Generally, ISI results when
    - symbol time < 10 x RMS-delay-spread