EEE 6109 Wireless Communication.

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Today's Lecture

1. Noise and Interference Limited Systems

Noise and Interference Limited Systems

- In a noise limited system, performance is determined by received signal strength and noise power
- A WLAN with only one Base Station nearby operates in noise limited mode
- In unlicenced spectral bands and in systems with multiple users, intereference becomes important

Noise Limited Systems

- For proper operation, wireless systems require a certain minimum Signal-to-Noise Ratio (SNR)
- Assume received signal power decreases with d^2 where d is the distance between the Base Station (BS) and the Mobile Station (MS).
- We have

$$P_{RX} = P_{TX} G_{RX} G_{TX} \left(\frac{\lambda}{4\pi d} \right)^2 \quad (1)$$

  Where
  - G_{RX} and G_{TX} are the gains of the receive and transmit antennas respectively
  - λ is the wavelength
  - P_{TX} is the transmit power

Thermal Noise

- The noise power spectral density is

$$N_0 = k_B T_e \tag{2}$$

where $k_B = 1.38 \times 10^{-23} J/K$ is Boltzmann's constant
- The noise power is

$$P_n = N_0 B \tag{3}$$

- We express this in dBm as $10 \log_{10}(P/1mW)$
- Assuming an environmental temperature of $300K$ we have

$$N_0 = 10 \log_{10}(\frac{1.38 \times 10^{-23} \times 300}{1 \times 10^{-3}}) dBm/Hz \tag{4}$$

- Also the noise power in a bandwidth B is

$$P_n = -174 + 10 \log_{10}(B) dBm \tag{5}$$

Man-made Noise

- Spurious emissions from other electrical appliances
- Impulsive sources such as car ignitions are significant in outdoor environments
- In licenced bands, spurious emissions are the only source of man-made noise
- In unlicensed bands such as the ISM band, interference from other users is significant

Receiver Noise

- Amplifiers and mixers are noisy and increase total noise power
- The noise figure F is defined as the SNR at the RX input divided by the SNR at the RX output
- The total noise figure F_{eq} of a cascade of components is

$$F_{eq} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots \tag{6}$$

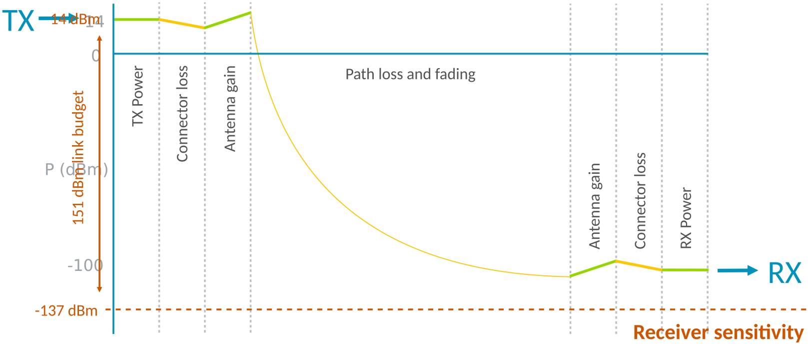
where F_i and G_i are the noise figures and noise gains of the individual stages in absolute units

Link Budget

- The link budget is useful in determining the required transmit power
- We use a simple model to account for signal attenuation due to propagation effects. We have

$$P_{RX}(d) = \begin{cases} P_{TX} G_{RX} G_{TX} \left(\frac{\lambda}{4\pi d}\right)^2 & d < d_{break} \\ P_{RX}(d_{break}) \left(\frac{d}{d_{break}}\right)^{-n} & d > d_{break} \end{cases} \quad (7)$$

- We include a fading margin



TX
14 dBm
14
0
P (dBm)
151 dBm link budget
-100
-137 dBm
TX Power
Connector loss
Antenna gain
Path loss and fading
Antenna gain
Connector loss
RX Power
RX
Receiver sensitivity

	TX Power	RX Sensitivity	Link budget
Wi-Fi	20 dBm	-75 dBm	**95 dBm**
Sub-GHz 6LoWPAN	11 dBm	-110 dBm	**121 dBm**
LoRa	14 dBm	-137 dBm	**151 dBm**

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r$$

Theoretical maximum in free space

2.4 GHz, with 95.5 dBm link budget:

550 meters

915 MHz, with 151 dBm link budget:

850,000 meters

Examples 3.1 and 3.2 in Molisch

Propagation

- The simplest propagation model assumes the TX and RX are in free space
- Assuming that the TX antenna radiates isotropically then

$$P_{RX}(d) = P_{TX} \frac{1}{4\pi d^2} A_{RX} \tag{8}$$

- If the TX antenna is not isotropic we have

$$P_{RX}(d) = P_{TX} G_{TX} \frac{1}{4\pi d^2} A_{RX} \tag{9}$$

- The relationship between the antenna gain and effective area is

$$G_{RX} = \frac{4\pi}{\lambda^2} A_{RX} \tag{10}$$

- Putting everything together we get

$$P_{RX} = P_{TX} G_{RX} G_{TX} \left(\frac{\lambda}{4\pi d} \right)^2 \tag{11}$$

Reflection and Transmission

- EM waves can be reflected at IOs in the propagation path
- In addition the EM waves can be transmitted through certain media
- Using EM theory we can obtain expression for the reflection and transmission coefficients for TE and TM waves
- The problem of transmission through dielectric layers is important for example when a BS is outdoors and the MS is within a building

The d^{-4} Power Law

- When we consider a direct LOS wave plus a ground reflected wave we can approximate

$$P_{RX}(d) = P_{TX} G_{RX} G_{TX} \left(\frac{h_{TX} h_{RX}}{d^2} \right)^2 \tag{12}$$

  where h_{TX} and h_{RX} are the height of the transmit and receive antenna.

- This is valid for

$$d_{break} \gtrapprox \frac{4 h_{TX} h_{RX}}{\lambda} \tag{13}$$

Diffraction

- So far we have ignored diffraction due to the wave nature of electromagnetic radiation
- We consider diffraction of a homogeneous plane wave and determine power received in the shadow region behind an obstacle

See Molisch Figure 4.4

Diffraction by a single screen

- We can determine the electric field at a point to the right of a screen
- If the incident wave is e^{-jk_0x} the field to the right of the screen is given by

$$E_{total} = e^{-jk_0x}\left(\frac{1}{2} - \frac{e^{j\pi/4}}{\sqrt{2}}F(\upsilon_F)\right) = e^{-jk_0x}\tilde{F}(\upsilon_F) \qquad (14)$$

where $\upsilon_F = -2y/\sqrt{\lambda x}$ and $F(\upsilon_F)$ is the Fresnel integral

$$F(\upsilon_F) = \int_0^{\upsilon_F} \exp\left(-\frac{j\pi t^2}{2}\right)dt \qquad (15)$$

Diffraction by a single screen

- It can be shown that

$$\upsilon_F = \theta_d \sqrt{\frac{2 d_{TX} d_{RX}}{\lambda (d_{TX} + d_{RX})}} \quad (16)$$

and

$$\theta_d = \arctan\left(\frac{h_s - h_{TX}}{d_{TX}}\right) + \arctan\left(\frac{h_s - h_{RX}}{d_{RX}}\right) \quad (17)$$

See Molisch Figure 4.6

Readings

- Molisch - Chapter 4 - 5