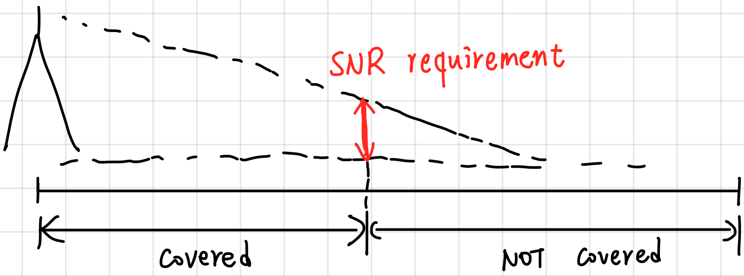
Wireless Communication Ch3

2024 Fall

Link Budget

- Wireless system are required to provide certain minimum transmission quality at Rx
- This is usually measured by signal-to-noise ratio (SNR)
- When users move away from the BS/Tx, the SNR change and might NOT achieve the requirement
- If the case is that the interference is NOT an issue, the performance is limited by the noise power level.
  → called noise-limited system



- Link budget is a way to do a quick approximation of <u>link quality</u> and <u>system capacity</u>

- Key factor

Tx

- Transmission power (P_{Tx})
- Transmit antenna gain (G_{Tx})
- Radio frequency loss at Tx (L)

→ called equivalant isotropically radiated power (EIRP)

- Path loss ($PL(d)$)

Rx

- Fading margin
- Receive antenna gain (G_{Rx})
- Noise power level
  - Thermal noise
  - Receive noise

Definition of dBm and dBW

- Suppose we have P <u>mW</u>

⇒ equivalent to $\boxed{10\log_{10}\left(\frac{P}{1mW}\right)\ \underline{dBm}}$

Ex.

1 mW ⟷ 0dBm

10 mW ⟷ 10dBm

10^3 mW ⟷ 30dBm

- Suppose we have P <u>W</u>

⇒ equivalent to $\boxed{10\log_{10}\left(\frac{P}{1W}\right)\ \underline{dBW}}$

Ex.

20W ⟷ 13dBW ⟷ 43dBm

40 W ⟷ 16dBW ⟷ 46 dBm

Pathloss model

$$\begin{cases} P_{Rx} = P_{Rx}(d_{break}) \cdot \left(\dfrac{d}{d_{break}}\right)^{-n} \\ P_{Rx,dB} = P_{Rx,dB}(d_{break}) - 10n\log_{10}\left(\dfrac{d}{d_{break}}\right) \end{cases}$$

$$\begin{cases} P_{Rx}(d_{break}) = P_{Tx} \cdot G_{Tx} \cdot G_{Rx} \left(\dfrac{\lambda_c}{4\pi d_{break}}\right)^2 \\ P_{Rx,dB}(d_{break}) = P_{Tx,dB} + G_{Tx,dB} + G_{Rx,dB} + 20\log_{10}\left(\dfrac{\lambda_c}{4\pi d_{break}}\right) \end{cases}$$

$$\rightarrow P_{Rx,dB}(d) = P_{Tx,dB} + G_{Tx,dB} + G_{Rx,dB} - 20\log_{10}\frac{4\pi}{\lambda_c} - 20\log_{10}(d_{break}) - 10n\log_{10}\left(\frac{d}{d_{break}}\right)$$

Pathloss model: $\boxed{PL(d) = 20\log_{10}\frac{4\pi}{\lambda_c} + 20\log_{10} d_{break} + 10n\log_{10}\frac{d}{d_{break}}}$

NOTE:

If $d_{break} = 1\text{m}$ and let $f_c = 1\,\text{GHz}$, then

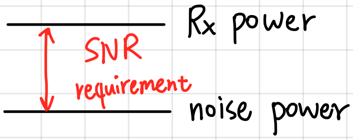
$20\log_{10}\left(\frac{4\pi}{\lambda_c}\right) \approx 32\,\text{dB}$

Fading margin

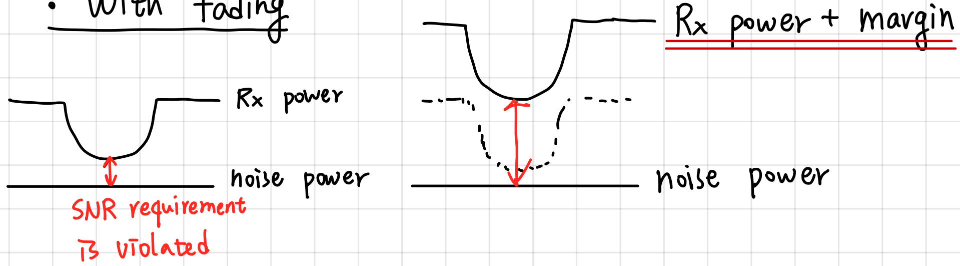
- 在傳播時可能受到fading影響，為了確保在fading下仍可接收信號

→會在 RX 處加上 fading margin

- No fading



- With fading



Thermal Noise

$$\boxed{P_n = K_B T_e \cdot B}$$

- B : Bandwidth at Rx (in Hz)
- K_B : 1.38×10^{-23} J/K (Boltzmainn's constant)
- T_e : environment temperature (in K)

$\rightarrow$ $N_0 = K_B T_e$: noise power density (W/Hz)

Ex.

If $T_e = 300K$, then

$N_0 = -174$ dBm/Hz

$\Rightarrow P_{n,dB} = -174 + 10\log_{10}(B)$

Receive noise

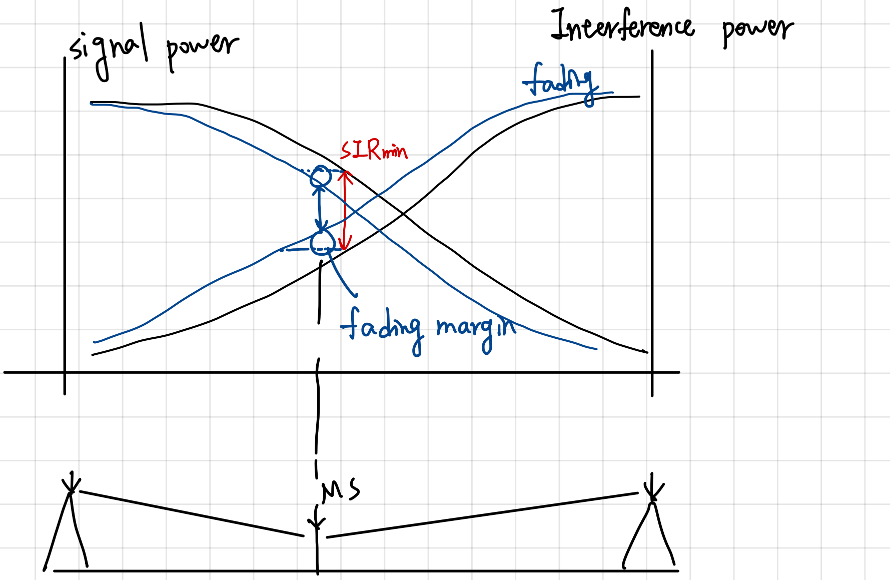
$$\boxed{F = \frac{\text{SNR at Rx input}}{\text{SNR at Rx output}}}$$

→會放大雜訊,因此須要先把 input SNR乘F倍

- The amplifier and mixer at Rx are noisy
- This increase the noise power. such effect is in general described by noise figure F

Interference - limited system

- The major issue is the interference
- We look at the signal-to-interference ratio (SIR)
- We can do the SIR link budget caculation based on our previous approach.
- If we consider fading effect on both signal and interference, we need to increase fading margin
- In this case, fading margin can be set to be twice of the margin of the noise-limited system



Example 3.1 *Link budget*

Consider the downlink of a GSM system (see also Chapter 24). The carrier frequency is 950 MHz and the RX sensitivity is (according to GSM specifications) −102 dBm. The output power of the TX amplifier is 30 W. The antenna gain of the TX antenna is 10 dB and the aggregate attenuation of connectors, combiners, etc. is 5 dB. The fading margin is 12 dB and the breakpoint d_{break} is at a distance of 100 m. What distance can be covered?

Tx
- $P_{TX} = 30W = 45dBm$
- $G_{TX} = 10dB$
- Losses = 5dB (非 PL)

$\Rightarrow EIRP = 45+10-5 = 50dB$

Rx
- Rx sensing = −102dB
- Fading margin = 12dB

$\Rightarrow$ minimum RX power = −90dB

考慮 Pathloss suppose $n=3.5$

$50 - PL(d) \geq -90$

$$PL(d) = 20\log_{10}\left(\frac{4\pi}{\lambda_c}\right) + 20\log_{10}(d_{break}) + 10n\log_{10}\left(\frac{d}{d_{break}}\right) \leq 140dB$$

$$= 32 + 20\log_{10}(100) + 3.5 \cdot 10\log_{10}\left(\frac{d}{100}\right) \leq 140$$

則 $d \approx 8.8km$ ＃

Example 3.2 *Link budget*

Consider a mobile radio system at 900-MHz f_c carrier frequency, and with 25-kHz B bandwidth, that is affected only by thermal noise (temperature of the environment $T_e = 300$ K). Antenna gains at the TX and RX sides are 8 dB G_{TX} and 2 dB G_{RX},[4] respectively. Losses in cables, combiners, etc. at the TX are 2 dB. The noise figure of the RX is 7 dB F and the 3-dB bandwidth of the signal is 25 kHz. The required operating SNR is 18 dB and the desired range of coverage is 2 km. The breakpoint is at 10-m distance; beyond that point, the path loss exponent is 3.8, n and the fading margin is 10 dB. What is the minimum TX power?

The way this problem is formulated makes working our way backward from the RX to the TX advantageous.

① Noise:
- $N_0 = -174dBm/Hz$
- $B = 25kHz = 44dBHz$

$\Rightarrow P_n = -174+44 = -130dBm$

RX noise $= P_n + F$

$= -130+7 = -123dBm$

② SNR:
- require SNR = 18dB

$\rightarrow$ require $P_{RX} = -123+18 = -105dBm$

$P_{RX} = -105dB$

SNR requirement 18dB

noise = −123dBm

③ 考慮 Pathloss
- $P_{TX} - PL(d) \geq P_{RX}$
- $PL(d) = 20\log_{10}\left(\frac{4\pi}{\lambda_c}\right) + 20\log_{10}(d_{break}) + 10n\log_{10}\left(\frac{d}{d_{break}}\right)$

$$= 32 + 2 \cdot 10\log_{10}10 + 3.8 \cdot 10\log_{10}\left(\frac{2000}{10}\right)$$

$$= 32+20+87 = 139dB$$

故 $P_{TX} + G_{TX} + G_{RX} - PL(d) - Loss \geq P_{RX} +$ fading margin

$\Rightarrow P_{TX} + 8 - 2 - 139 - 2 \geq -105 + 10$

$P_{TX} \geq 40dBm = 10W$ ＃

$\rightarrow 10^4 mW = 10W$