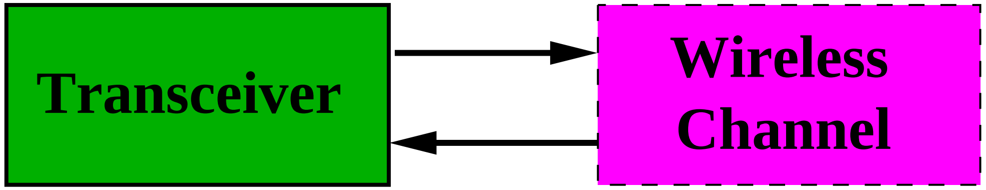
Revision of Lecture One

- **System block**



- **Signal / System**:

  Bandpass (Passband) ⇔ Baseband

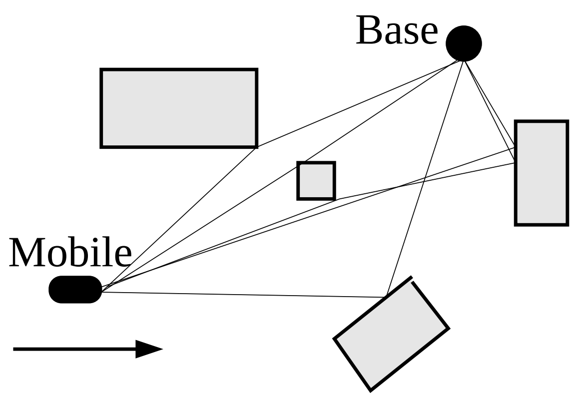
  Baseband complex envelope

- **Linear system**: complex (baseband) channel impulse response

- **Channel**: is medium for communication, understanding it is **key** to understand communication technology

  This will be our main focus in next three lectures

Mobile Radio Channel Characterisations



- Mobile radio links
  - MS → BS: *uplink*, also called *forward channel*
  - MS ← BS: *downlink*, also called *reverse channel*
- In UHF (900 - 1800 MHz), channels are inherent stochastic
- Why mobile channels are so hostile
  - **Doppler spread**: *Moving changes frequencies*, and this causes serious problem (Recall spectrum of a communication signal must be carefully specified)
  - **Multipath**: copies of signal arrive at receiver with different attenuation and delays, cause *dispersive* (ISI) and *fading* (power level fluctuates rapidly) effects
- Power budget: predict expected mean received signal power are crucial in determine cell size, frequency reuse, and other system design issues

Power Budget Factors

- **Propagation pathloss**: Distance effect – signal power is attenuated, as it travels in distance
  - One can simply use physical laws to derive theoretical formula for describing propagation pathloss, but more often, empirical models are sought
- **Slow (large-scale) fading**: Shadow variations that caused by large terrain features, such as small hills and tall buildings, between BS and MS
  - Power variation statistics due to large-scale fading can be well quantified, as the process is "slow"
- **Fast (small-scale) fading**: Multipath signals, having a range of delays, attenuations and frequency (Doppler) shifts, are summed at MS antenna, causing rapidly power level fluctuations
  - Small-scale fading is difficult to model accurately, as factors influencing fast fading characteristics are highly complex
  - When multipath signals cancel out each other because of different phase changes, signal level is in a deep fade
  - Deep fades typically occur every half-wavelength (180° phase), and for a carrier frequency of 1 GHz, wavelength is

$$\lambda = c/f = (3 \times 10^8 \text{ m/s})/(10^9 \text{ Hz}) = 30 \text{ cm}$$

Propagation Pathloss

We will consider one empirical model to illustrate how propagation pathloss can be characterised

- Typical urban Hata model: $L_{Hu} = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_{BS} - a(h_{MS})$
$$+ (44.9 - 6.55 \log_{10} h_{BS}) \log_{10} d \quad \text{(dB)}$$
where f is frequency (MHz), h_{BS}/h_{MS} are BS/MS antenna heights (m), d is BS-MS distance (km) and $a(h_{MS})$ a correction factor. For small/medium city:
$$a(h_{MS}) = (1.1 \log_{10} f - 0.7)h_{MS} - (1.56 \log_{10} f - 0.8)$$
For large city:
$$a(h_{MS}) = \begin{cases} 8.29\,(\log_{10}(1.54 h_{MS}))^2 - 1.1 & f \leq 400 \text{ MHz} \\ 3.2\,(\log_{10}(11.75 h_{MS}))^2 - 4.97 & f \geq 400 \text{ MHz} \end{cases}$$
- Typical suburban Hata model: (L_{Hu} without $a(h_{MS})$ factor)
$$L_{Hsub} = L_{Hu} - 2\,(\log_{10}(f/28))^2 - 5.4 \text{ (dB)}$$
- Typical rural Hata model: (L_{Hu} without $a(h_{MS})$ factor)
$$L_{Hrur} = L_{Hu} - 4.78\,(\log_{10} f)^2 + 18.33 \log_{10} f - 40.94 \text{ (dB)}$$

Slow (Large Scale) Fading

- Shadow variations by large terrain features contribute to power variation about mean of propagation pathloss, and probability distribution of this power variation is **log-normal**, i.e. Gaussian in dB

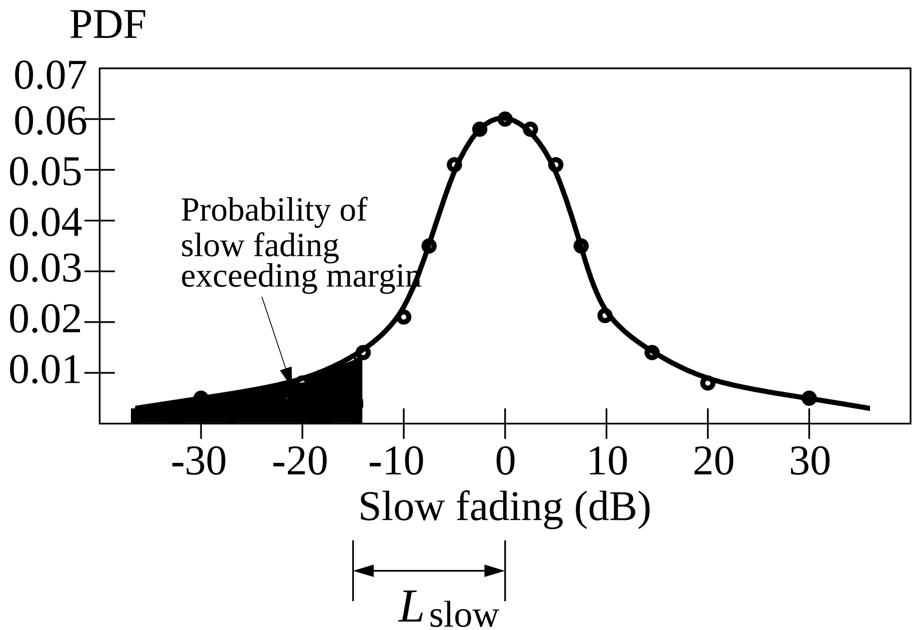
$$\mathrm{PDF}_{\mathrm{slow}}(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

where power variation x is measured in dB, and σ is standard deviation

- To guard against power loss due to slow fading, a margin L_{slow} must be allocated
  - From the definition of Q-function, 2% probability that loss due to slow fading exceeding margin gives $L_{\mathrm{slow}} = 2\sigma$:

$$Q(2.0) \approx 0.02 \rightarrow L_{\mathrm{slow}} = 2\sigma$$

  - In figure, $\sigma = 7$ and $L_{\mathrm{slow}} = 14$ dB



Fast (Small Scale) Fading

- Small scale fading contributes to fast power variations on top of mean of propagation pathloss and large scale fading, and factors influence this fast fading characteristics are highly complex

- In the case there exists a line-of-sight path, PDF of this power variation due to fast fading is Rice distribution

$$\mathrm{PDF}_{\mathrm{Rice}}(x) = \frac{x}{\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2} - K\right) I_0\left(\frac{x}{\sigma}\sqrt{2K}\right)$$

  where K is the ratio of LOS power to total power of all indirect paths, $I_0(\cdot)$ is the modified 0th order Bessel-function of 1st kind, σ is standard deviation, and x is not measured in dB

- In the case of no LOS, $K = 0$ and this leads to the worst case Rayleigh distribution

$$\mathrm{PDF}_{\mathrm{Rayleigh}}(x) = \frac{x}{\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

Small Scale Fading (continue)

- There is more general fast fading distribution model, which includes Rice and Rayleigh as special cases, but Rayleigh model is widely used

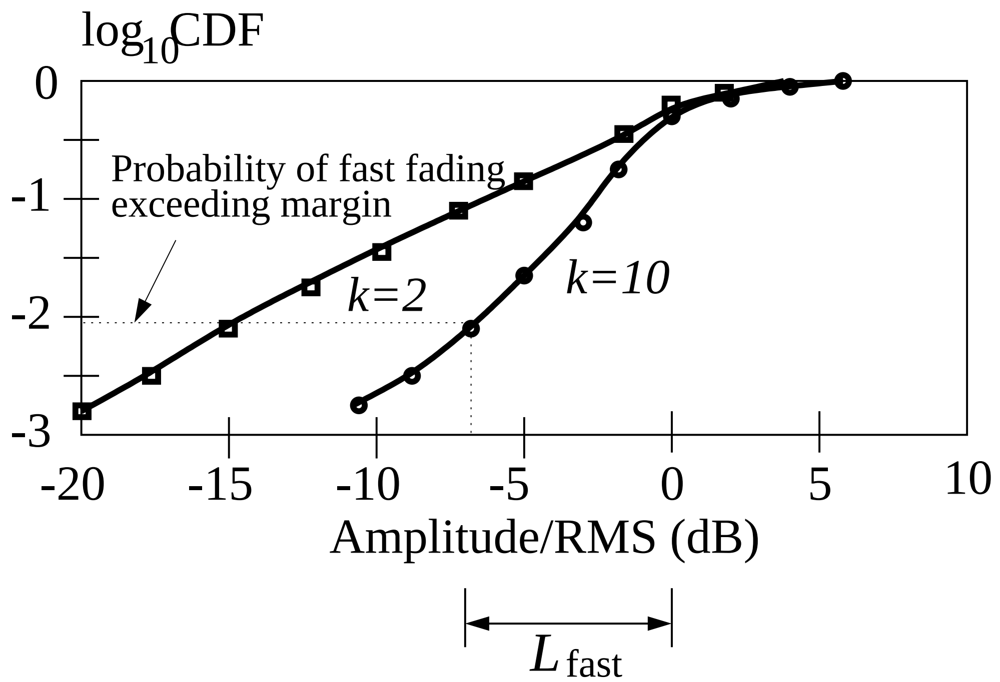
- To guard against power loss due to this fast fading, a margin L_{fast} must be allocated

  – For convenience, let power x be measured in dB

  – Value of cumulative distribution function is:

$$\text{Prob}(x \leq -L_{\text{fast}}) = \int_{-L_{\text{fast}}}^{\infty} \text{PDF}(y) d\, y$$

  – In figure, for 1% (0.01) probability of exceeding margin with $K = 10$, $L_{\text{fast}} = 7$ dB



Power Budget Rule

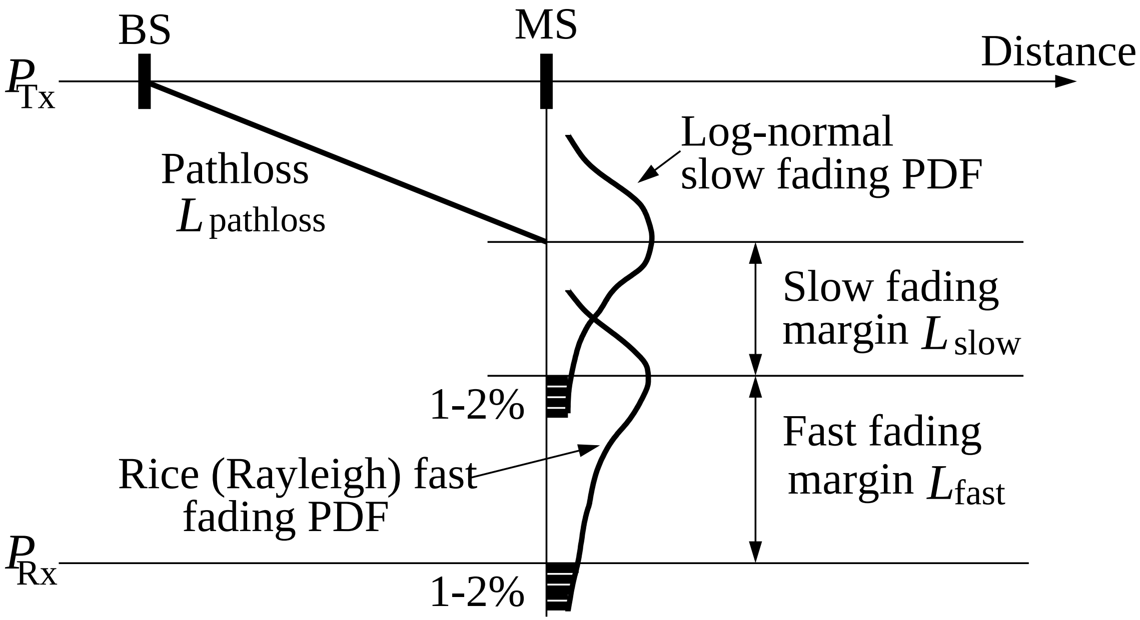
Let P_{Rx} be the required power level at MS receiver, then what the designed level of power P_{Tx} at BS transmitter should be?

- The calculation rule:

$$P_{\mathrm{Tx}} = P_{\mathrm{Rx}} + L_{\mathrm{total}}$$

with

$$L_{\mathrm{total}} = L_{\mathrm{pathloss}} + L_{\mathrm{slow}} + L_{\mathrm{fast}}$$



- Provisions are made for the worst case pathloss, slow fading overload margin and fast fading overload margin

- Probability of exceeding fading margin is typically set at 1 to 2%

Power Budget Example

Question: Assume that the propagation pathloss can be calculated using the typical urban Hata model L_{Hu} with a small/medium city correction factor $a(h_{MS})$. The mobile antenna height $h_{MS} = 1$ m, the base antenna height $h_{BS} = 100$ m, the carrier frequency is $f = 1$ GHz, and the cell radius is $d = 300$ m. Further assume that 2% slow fading overload margin is $L_{\text{slow}} = 14$ dB, and 2% fast fading overload margin is $L_{\text{fast}} = 7$ dB. The receiver sensitivity is -104 dBm (dBm: dB with respect to a 1 mW reference). Calculate the transmitter power.

Solution:

$$L_{\text{pathloss}} = 69.55 + 26.16 \log_{10} 10^3 - 13.82 \log_{10} 10^2 + (44.9 - 6.55 \log_{10} 10^2) \log_{10} 0.3$$

$$-(1.1 \log_{10} 10^3 - 0.7) \times 1 + (1.56 \log_{10} 10^3 - 0.8)$$

$$= 69.55 + 78.48 - 27.64 - 16.63 - 2.6 + 3.88 = 105.04 \text{ (dB)}$$

$$L_{\text{total}} = L_{\text{pathloss}} + L_{\text{slow}} + L_{\text{fast}} = 105.04 + 14 + 7 = 126.04 \text{ (dB)}$$

$$P_{\text{Tx}} = L_{\text{total}} + P_{\text{Rx}} = 126.04 - 104 = 22.04 \text{ (dBm)} = 0.16 \text{ (W)}$$

Summary

- Mobile radio channels are hostile, due to Doppler spread and multipath, and we will see that
  - Doppler spread $\longrightarrow$ causing frequency dispersion
  - Multipath $\longrightarrow$ causing time dispersion
- Power budget design is important for deciding cell size, frequency reuse, other system design parameters
- Design has to take into account propagation loss, slow (large scale) fading and fast (small scale) fading
- Power budget Rule:

$$P_{\text{Tx}} = P_{\text{Rx}} + L_{\text{total}}$$
$$L_{\text{total}} = L_{\text{pathloss}} + L_{\text{slow}} + L_{\text{fast}}$$