2.9 Outage Probability

dBm

Minimum requirement on received SNR: P_{min}

$P_{out}(P_{min}, d)$ Outage: $P_r < P_{min}$.

$$= P_r[P_r(d) \leq P_{min}]$$

$$= P_r[P_t + 10\log_{10}K - 10\gamma'\log_{10}\frac{d}{d_0} - \psi'_{dB} \leq P_{min}]$$

$$= P_r\left[\frac{\psi'_{dB}}{\sigma_{\psi_{dB}}} \geq -\frac{P_{min} - (P_t + 10\log_{10}K - 10\gamma'\log_{10}\frac{d}{d_0})}{\sigma_{\psi_{dB}}}\right]$$

$$= Q\left(-\frac{P_{min} - (P_t + 10\log_{10}K - 10\gamma'\log_{10}\frac{d}{d_0})}{\sigma_{\psi_{dB}}}\right)$$

$$= 1 - Q\left(\frac{P_{min} - (P_t + 10\log_{10}K - 10\gamma'\log_{10}\frac{d}{d_0})}{\sigma_{\psi_{dB}}}\right)$$

Cell Coverage ~~Area~~ Area: Percentage of locations where the received power is above a given minimum.

3. Statistical Multipath Model.

Wireless Channel Model.
(Multipath)

Deterministic — Statistical.

Ray-Tracing

3.1. Time-Varying Channel Impulse Response.

LTI

$$u(t) \longrightarrow \boxed{c(\tau)} \longrightarrow \int_{-\infty}^{+\infty} c(\tau)\, u(t-\tau)\, d\tau$$

$$u(t) \longrightarrow \boxed{c(\tau, t)} \longrightarrow \int_{-\infty}^{+\infty} c(\tau; t)\, u(t-\tau)\, d\tau$$

Time-Varying Linear System

$c(\tau, t)$

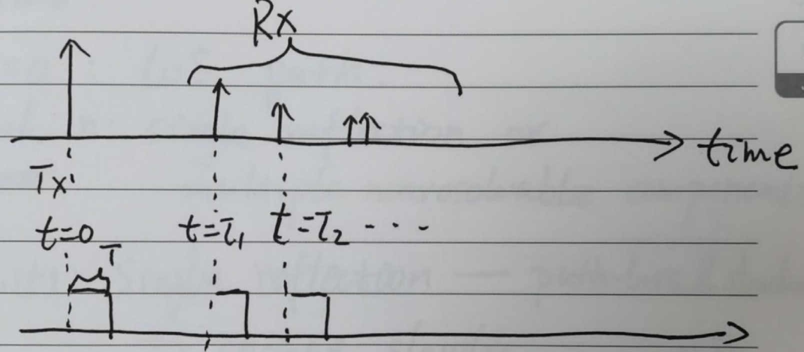
Delay time

Baseband Tx signal: $u(t)$

Bandpass form:

$$s(t) = Re\{u(t)\} \cdot \cos 2\pi f_c t - Im\{u(t)\} \sin 2\pi f_c t.$$

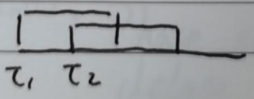
$$= Re\{u(t) e^{j2\pi f_c t}\}$$



$|\tau_1 - \tau_2| >> T \approx B_u^{-1}$: delay τ_1 and τ_2 sufficiently separated.

$\Rightarrow$ multipath components are resolvable.

Otherwise: nonresolvable.



$\Rightarrow$ combined as one multipath component.

Suppose there are $N(t)$ resolvable ~~多~~ multipath components.

The Rx signal (bandpass) $e^{j2\pi f_c t} \cdot e^{-j2\pi f_c \tau_n(t)} \cdot e^{j\phi_{Dn}}$

$$r(t) = \mathrm{Re}\left\{ \sum_{n=0}^{N(t)} \alpha_n(t) u(t-\tau_n(t)) e^{j(2\pi f_c(t-\tau_n(t)) + \phi_{Dn})} \right\}$$

$n=0$: LoS path.

Each n: single reflection or.
~~Each~~ multiple nonresolvable components.

$\alpha_n(t)$: Single reflection — path-loss & shadowing
⇒ change slowly

multiple components
— constructive or destructive addition
⇒ change quickly

$\tau_n(t)$: delay.

$e^{-j2\pi f_c \tau_n(t)}$: Phase shift ~~due~~ due to delay

$f_{D_n}(t)$: Doppler frequency.

$\phi_{Dn} = \int_0^t 2\pi f_{D_n}(t)\,dt$: Phase shift due to Doppler.

Let $\phi_n(t) = 2\pi f_c \tau_n(t) - \phi_{Dn}$.

$$r(t) = Re\left\{\left[\sum_{n=0}^{N(t)} \alpha_n(t) e^{-j\phi_n(t)} u(t-\tau_n(t))\right] e^{j2\pi f_c t}\right\}$$

Rx signal in baseband:

$$\sum_{n=0}^{N(t)} \alpha_n(t) \cdot e^{-j\phi_n(t)} \cdot u(t-\tau_n(t))$$

$$= \int_{-\infty}^{+\infty} c(\tau, t)\, u(t-\tau)\, d\tau$$

where $c(\tau, t) = \sum_{n=0}^{N(t)} \alpha_n(t) e^{-j\phi_n(t)} \delta(t-\tau_n(t))$

Observation: In baseband, wireless channel can be treated as a time-varying linear system with time-varying impulse response c