2.2. Signal Model.

~~Base~~ Bandpass signal: carrier frequen

$s(t) = s_I(t)\cdot\cos 2\pi f_c t - s_Q(t)\cdot\sin 2\pi f_c t$

Equivalent baseband / Lowpass signal:
complex envelope

$u(t) = s_I(t) + j s_Q(t)$

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

$= \mathrm{Re}\{s_I(t)\cdot e^{j2\pi f_c t} + j s_Q(t)\cdot e^{j2\pi f_c t}\}$

$= s_I(t)\cdot\cos 2\pi f_c t - s_Q(t)\cdot\sin 2\pi f_c t$

Let $h(t)$ be the channel impulse respon

$r(t) = s(t) * h(t)$

Let $R(f)$, $S(f)$, $H(f)$ be F.T. of
~~st~~ $r(t)$, $s(t)$, $h(t)$, respective.

$R(f) = S(f)\cdot H(f)$

Remark:

Let P_t, P_u be the power of $s(t)$, $u(t)$,

$$P_t = \frac{1}{T}\int_0^T s^2(t)\,dt, \quad P_u = \frac{1}{T}\int_0^T |u(t)|^2\,dt.$$

$$\Rightarrow P_t = P_u/2$$

Actual signal power = Baseband power /2.

Equivalent LP Channel Impulse Response : $h_l(t)$

$$\begin{array}{lcccc}
\text{Bandpass:} & r(t) = & s(t) & * & h(t) \\
 & \Updownarrow & \Updownarrow & & \Updownarrow \\
\text{Baseband:} & v(t) = & u(t) & * & h_l(t)
\end{array}$$

$$r(t) = \mathrm{Re}\{v(t)\, e^{j2\pi f_c t}\}$$

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

$$* \; h(t) = 2\mathrm{Re}\{h_l(t)\cdot e^{j2\pi f_c t}\}$$

A factor of 2 for channel.

If $h_l(t) = h_{l,I}(t) + j h_{l,Q}(t)$

Then $h(t) = 2h_{l,I}(t)\cos 2\pi f_c t - 2h_{l,Q}(t)\sin 2\pi f_c t$

Let $V(f)$, $U(f)$, $H_L(f)$ be the F.T. of $v(t)$, $u(t)$, $h_L(t)$,

$$V(f) = U(f) \cdot H_L(f)$$

Moreover,

$$S(f) = \frac{1}{2}\left[U(f-f_c) + U^*(-f-f_c)\right]$$

$$H(f) = H_L(f-f_c) + H_L^*(-f-f_c)$$

$$R(f) = \frac{1}{2}\left[V(f-f_c) + V^*(-f-f_c)\right]$$

$Tx: P_t \xrightarrow{\text{Path Loss}} Rx: P_r$

Linear Path Loss $P_L = P_t / P_r$.

Path loss (in decibel)

$$P_L \, \cancel{dB} = 10 \log_{10} \frac{P_t}{P_r} \text{ dB}$$

Path gain (in decibel)

$$P_G = -P_L$$

2.3 Free-Space Path Loss

$$v(t) = \frac{\lambda\sqrt{G_L}}{4\pi d}\underbrace{e^{-j2\pi d/\lambda}}_{\text{phase shift}}\cdot u(t)$$

$$\frac{P_r}{P_t} = \frac{\frac{1}{T}\int_0^T |v(t)|^2 dt}{\frac{1}{T}\int_0^T |u(t)|^2 dt} = \left[\frac{\lambda\sqrt{G_L}}{4\pi d}\right]^2$$

P_r dBm

$= 10\cdot\log_{10} P_r - 30$

$= 10\log_{10}\left[\frac{\lambda\sqrt{G_L}}{4\pi d}\right]^2 + 10\log_{10} P_t - 30$

$= P_t \text{ dBm} + 20\log_{10}\lambda + 10\log_{10} G_L$

$\quad - 20\log_{10}(4\pi) - 20\log_{10} d$

$P_G \text{ dB} = 10\log_{10}\frac{P_r}{P_t} = P_r \text{ dBm} - P_t \text{ dBm}$

$= 20\log_{10}\lambda + 10\log_{10} G_L - 20\log_{10}(4\pi) - 20\log_{10} d$

2.4 Ray Tracing

Use finite # of rays to approximate the signal propagation from T_x to R_x

$\Rightarrow$ The received signal is the summation of the signals along the rays

$\Rightarrow$ Scenario-dependent.

2.4.1 Two-Ray Model.

Open space : LoS + Single reflection off the ground.