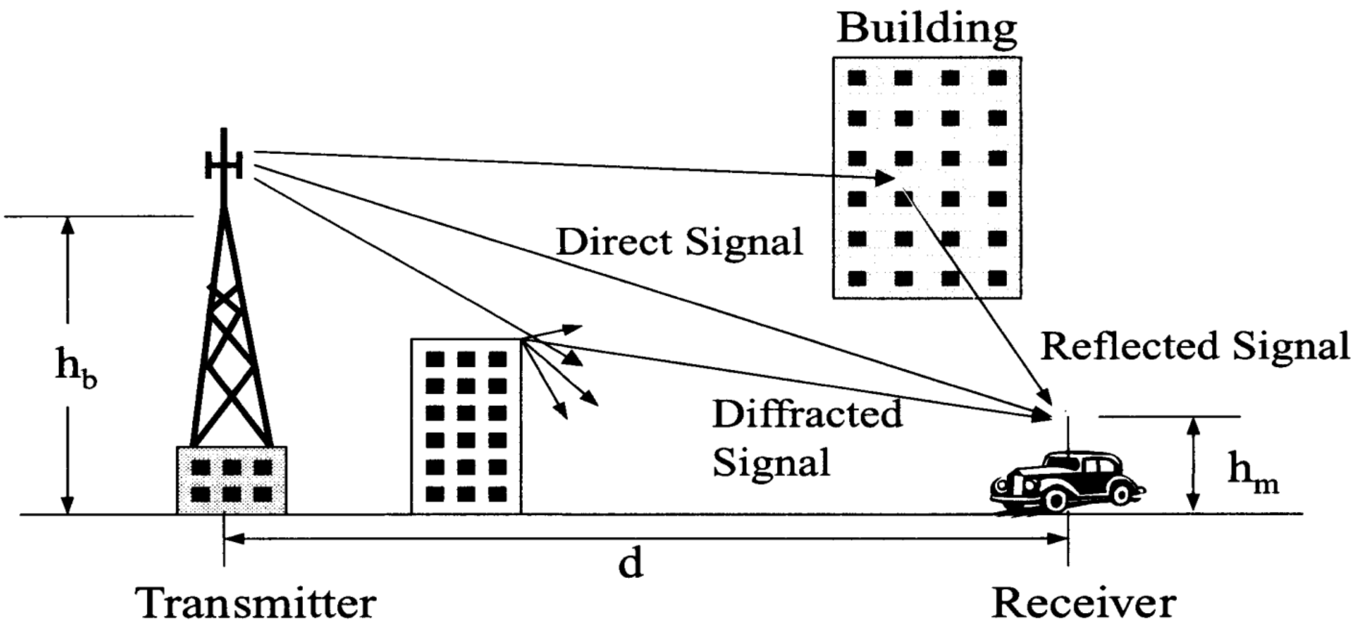
Fading. Propogation Loss

- **Multipath characteristics of radio waves**
- **Long and short-term fading**
- **Rayleigh and Rician fadings**
- **Long Term Fading**
- **Okumara –Hata model for median loss**
- **Delay spread. Intersymbol interferences**
- **Coherence Bandwidth**
- **Doppler spread**

Multipath characteristics of radio waves

- Multipath occurs when radio waves arrive at a mobile receiver from different direction with different magnitude and time delays. As mobile terminal moves from one location to another the phase relationship between the various incomming waves also change. Thus there are substantial amplitude and phase fluctations. This is known as fading.

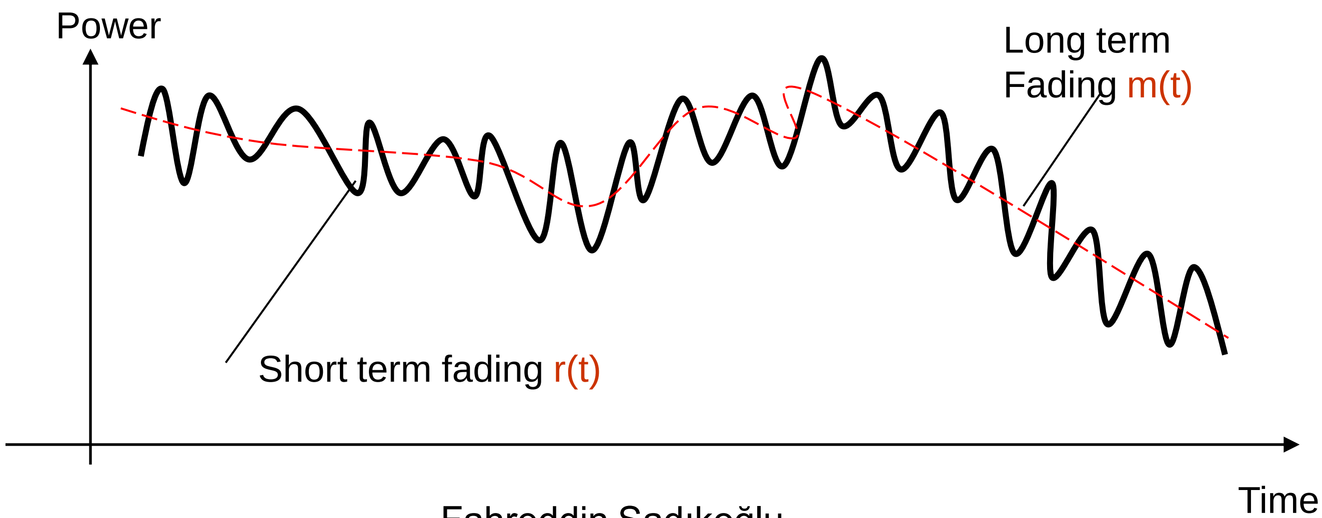


Fast fading- rapid fluctations of amplitude when mobile terminal moves short distance. FF is due to reflection of local objects and motion of user from this objects.

Slow fading arises when there are large reflected and difracted objects along the transmission path. The motion of the terminal to these distant objects is small and corresponding propogation change slowly.

Existing the motion yields a **Doppler shift** of the frequency in the received signal

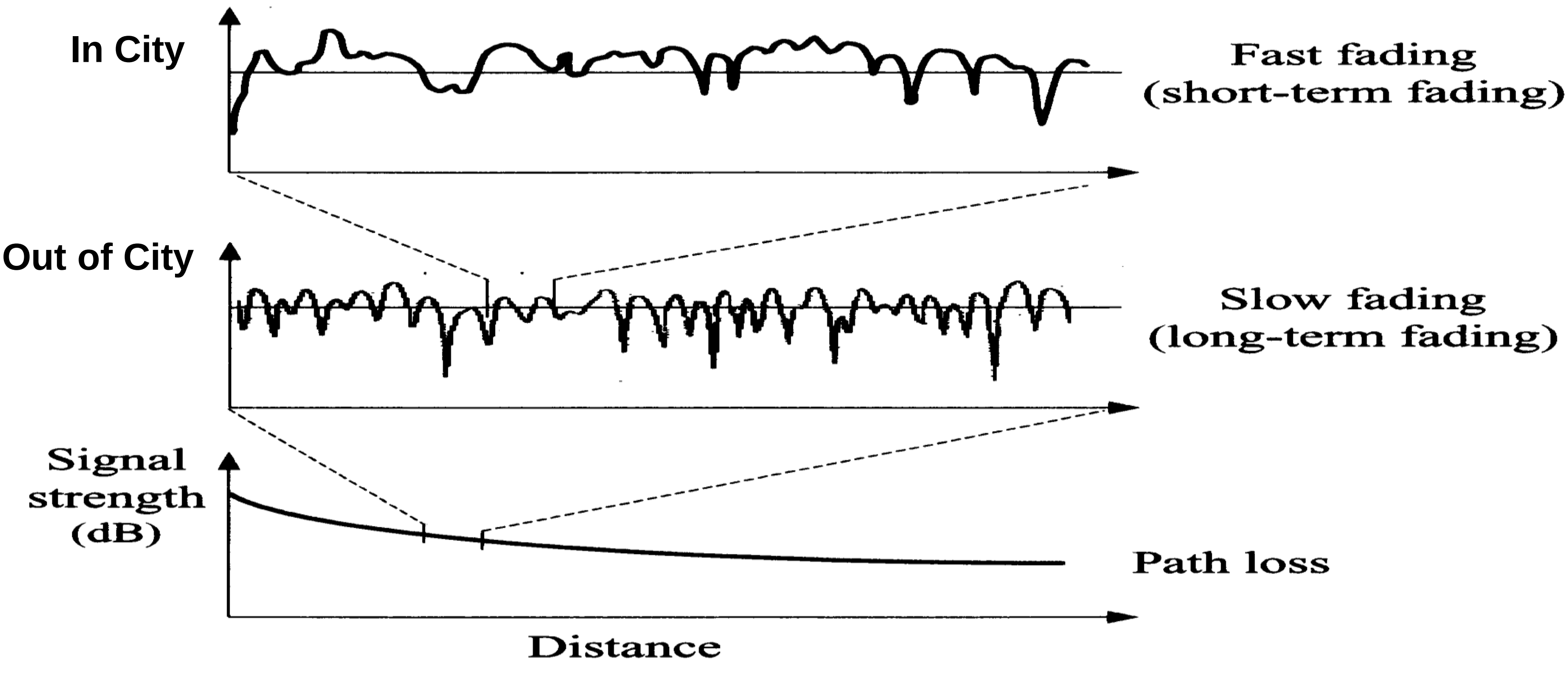
Reseived signal **s(t)=m(t).r(t)**



Long and short-term fading

fast fading (Short term fading): rapid fluctuation is observed over distances of about λ/2 . For VHF and UHF, a vehicle traveling at 30 mph can pass through several fast fades in a second.

slow fading (Long-term) : path loss "variation" caused by changes in lands cape, i.e., building. variation.



Short term fading

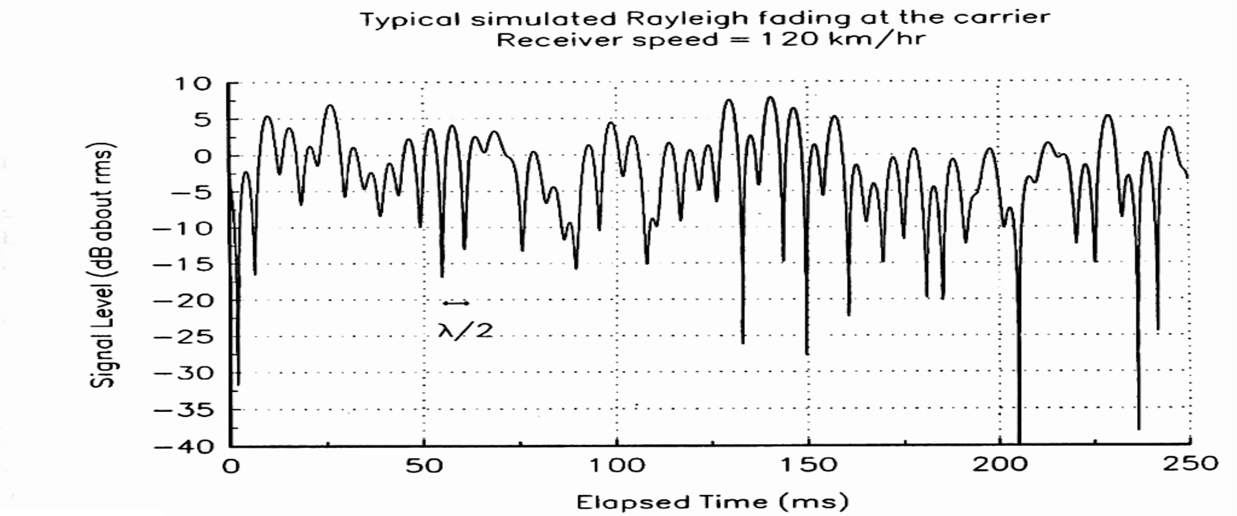
Probability density function of short term fading is given by **Rayleigh distributions.**

$$p(r) = \frac{r}{P_0} e^{(-r^2)/2P_0}$$

$2P_0 = 2\sigma^2$ is mean square power of the component subjected to STF; r^2 is instantenous power

$$P(r \le R) = P(R) = 1 - e^{-R^2/2P_0}$$

r_{mean}=1.25σ; Mean square $2P_0 = 2\sigma^2$; Variance σ_r^2=0.429 σ^2; Median value r_m=1.177 σ



A typical Rayleigh fading envelope at 900 MHz [from [Fun93] © IEEE].

Level crossing rate and Average fade duration

LCR N(R), at the specified signal level R is defined as average number of times per second that the signal envelope crocess the level in positive going directions (r>0).

$$\mathbf{N(R) \approx \sqrt{2\pi}\,\frac{v}{\lambda}\,\rho}$$

Or $\mathbf{N(R) = n_0 n_R}$

$\rho = \frac{R}{\sqrt{2}\sigma} = \frac{R}{R_{rms}}$; R_{rms}- rms amplitude of the fading envelope; V-speed; λ-carrier wavelength

$n_R = \rho e^{-\rho 2}$ - is called normalized level-crossing rate. $n_0 = \sqrt{2\pi} f_m; f_m = \upsilon/\lambda$

Average fade duration:

$$\boldsymbol{\tau(R) = \frac{e\rho^2 - 1}{n_0\rho} = \frac{\lambda}{\upsilon}\,\frac{\rho}{\sqrt{2\pi}}}$$

Rician Fading

When there is dominanr signal component (ex. LOS), the SCF envelope distribution is Rician distribution:

$$p(r) = \frac{r}{\sigma^2} e^{-[\frac{r^2+A^2}{2\sigma^2}]} . I_0[Ar/\sigma^2]; \quad \text{for } A \geq 0 \text{ and } r \geq 0$$

Rician factor

$$K = 10\log\frac{A^2}{2\sigma^2} \text{ [dB]}$$

as A ⟶ 0 Rician distribution degenerates to Rayleigh distribution

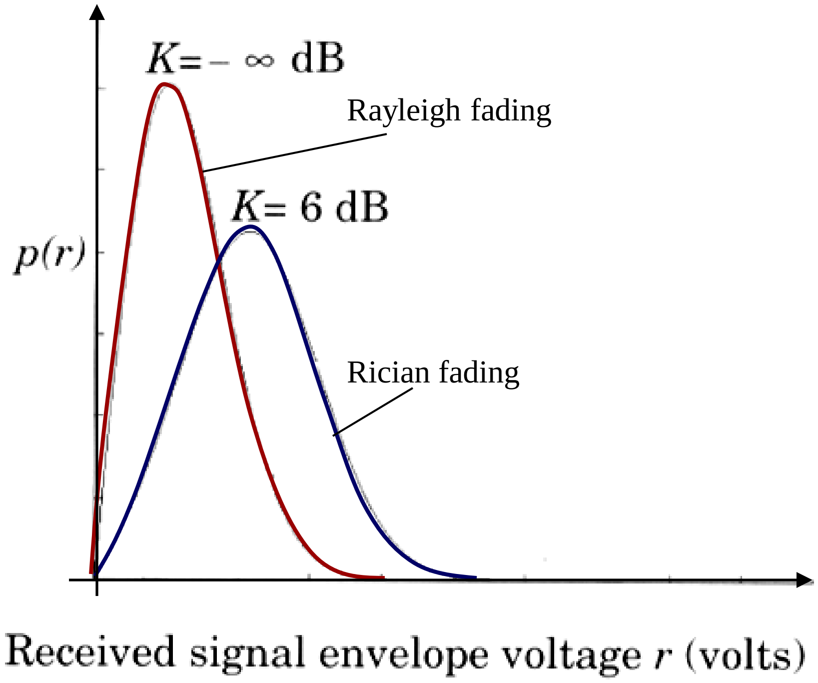
Long Term Fading

Probability density function is given by log-Normal distribution

$$\mathbf{p(m) = \frac{1}{m\sigma_m\sqrt{2\pi}} e[-(Logm - m_0)/2\sigma_m{}^2]}$$

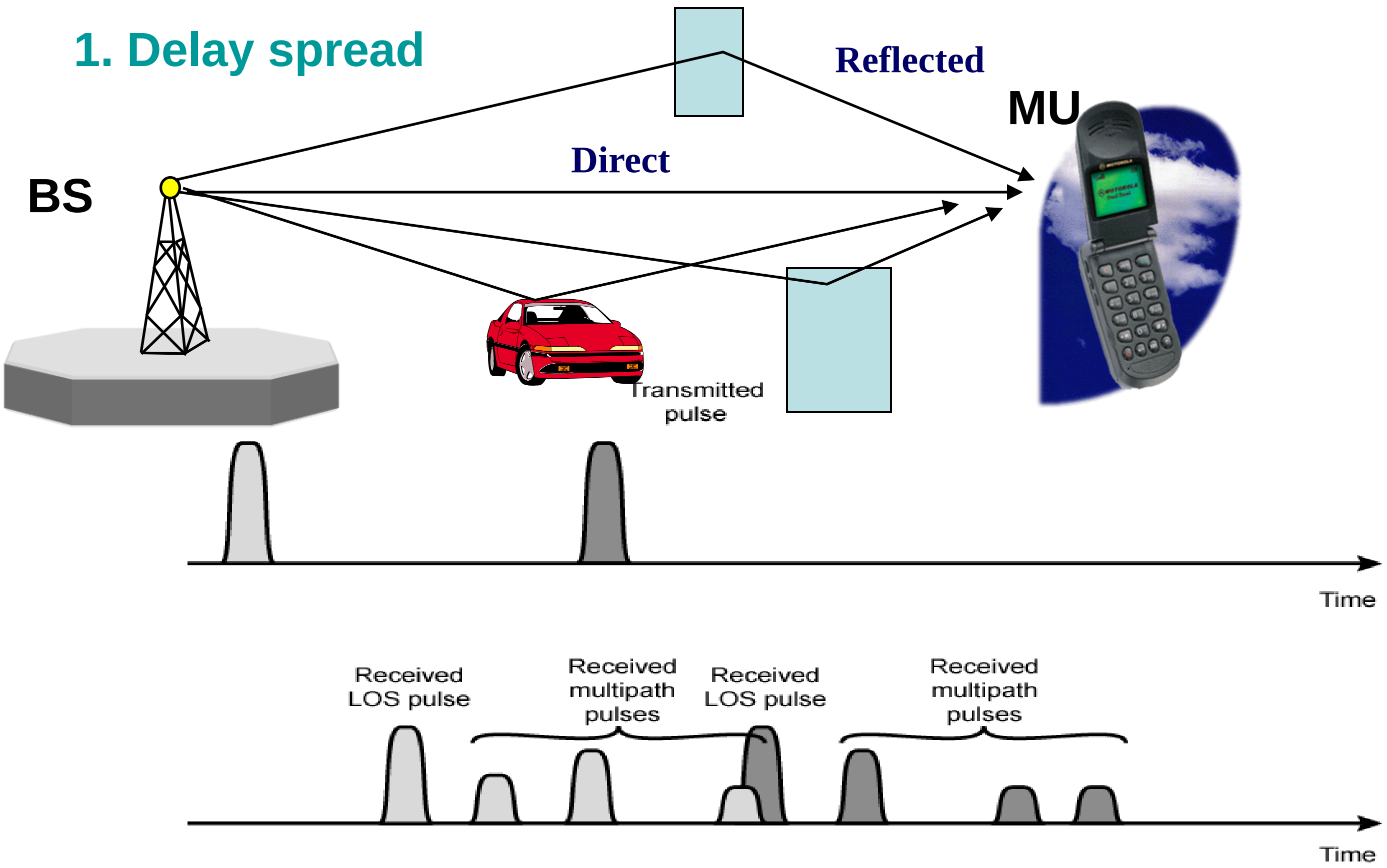
m_0 is the mean of log m.

Ricean and Rayleigh fading distributions

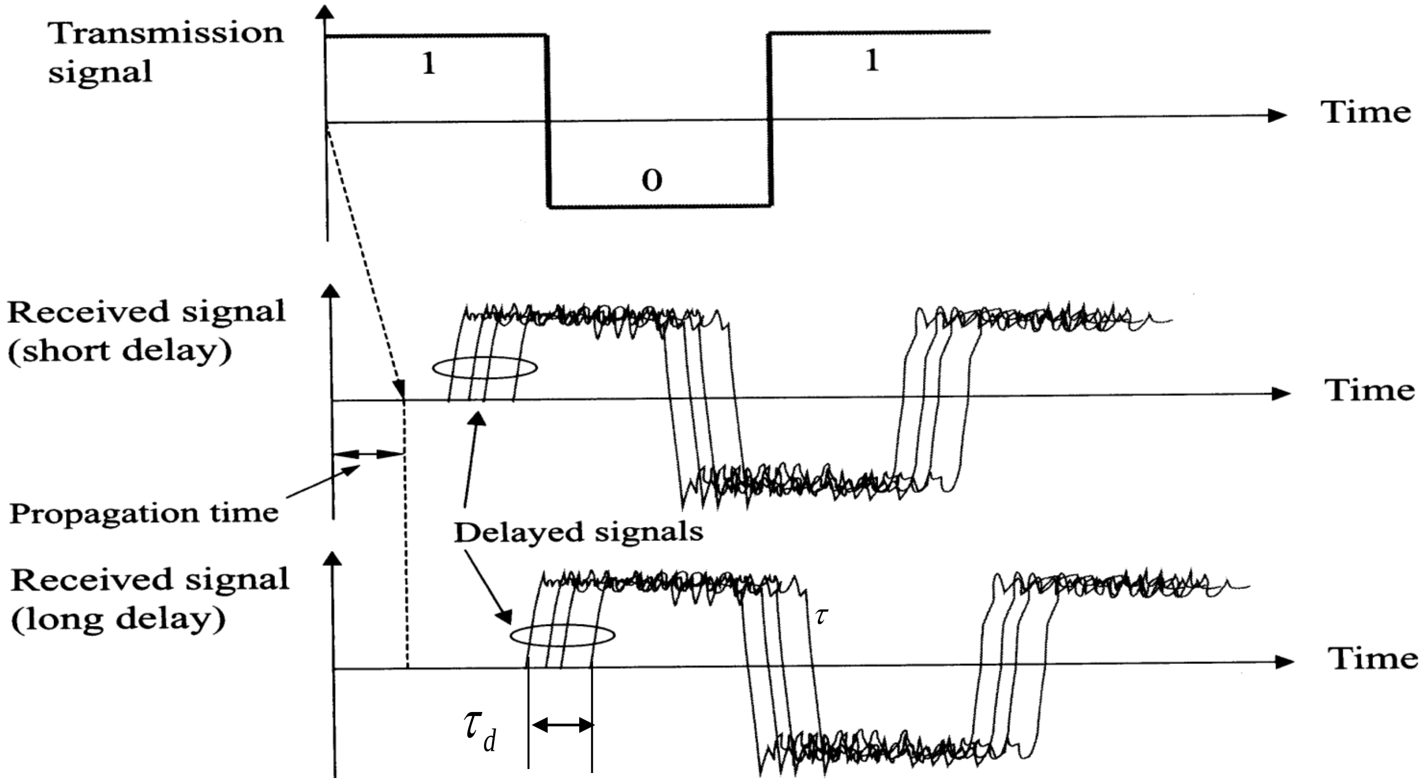


Delay spread. Coherence Bandwidth. Doppler Shift

1. Delay spread



- **Intersymbol interference (ISI) occurs if the delay spread of the channel exceeds the symbol time (or the sampling interval)**
- **Cancellation of ISI is done via an equalizer at the receiver**



In a Time diversity medium transmission rate R is limited by delay spread.

$$R < \frac{1}{2\tau_d}$$

Environment	Delay spread (μs)
Open area	<0.2
Suburban area	0.5
Urban area	3

Coherence Bandwidth

The coherence B_c is the bandwidth for which either amplitudes or phases of two receiver signals have a high degree of similarity. Bc is a statistical measure of range of frequencies over which yhe channel passes all spectral components with approximately equal gain and linear phase.

$$B_c = \frac{1}{\tau_{d\max}}$$

More useful measurement is often expressed in terms of " rms" delay spread τ_{drms}.

Two fading signal with frequencies f_1 and f_2, where $\Delta f = |f_1 - f_2|$, if correlation function nbetween two faded signal R(Δf)=0.5, then

$$\Delta f > B_c = \frac{1}{2\pi\tau_{drms}} \qquad (2)$$

More popular approximation is

$$\Delta f > B_c = \frac{1}{5\pi\tau_{drms}} \qquad (3)$$

$Bc<1/T_s=B_w$ corresponds to frequency-selective (all freq. components are not affected by channel a similar manner)channel

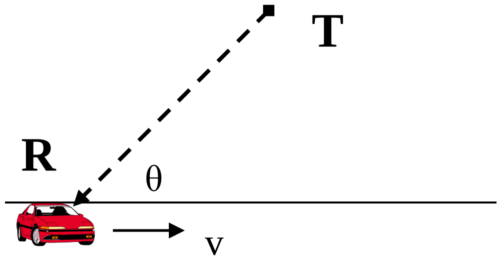
Bc>1/Ts=Bw corresponds to flat fading (all freq. components are affected by channel a similar manner)channel channel

For GSM **Bw =200 kHz**, an urban environment $\boldsymbol{\tau_{drms}}$**=2 µ**s .and from (3) **Bc=100 kHz <Bw. And there are frequency-selective distortions. For ovecome this problem is used Viterbi equalizer**

Doppler spread

Doppler shift. If receiver is moving toward the source, then zero crossing of the signal appear faster, and receiver frequency becomes higher. The opposite effect occurs if the receiver moving away from the source.The resulting change Known as the Doppler shift.

$$\mathbf{f_d = f_0 \frac{v}{c} \cos\theta}$$



f_0- carrier transmitted frequency; v-speed of moving; θ- angle between terminal motion and signal radiation directions.

Dopler spread. Dopler shift of each arriving path is generally different. Dopler spread is estimated by coherence time **T_0=1/fd .**

A popular rule to define T_0

$$\mathbf{T_0 = \sqrt{\frac{9}{16\pi f_d^2}} = \frac{0.423}{f_d}}$$

Fast fading channel: $Bw<f_d$ or $T_s>T_0$

Slow fading channel: $Bw>f_d$ or $T_s<T_0$

Emprical models

1. Hata –Okumara Model

1. Urban area

L_{50}= 69.55+26.16log f_c-13.82log h_b-a(hm)+(44.9-6.55log h_b)log R

L_{50} – median path loss with dB; fc=100-1500 MHz-frequency range;
h_b=30-200m-BS antenna height; R=1-20km distance from BS
Correction factor for mobile antenna height - a(hm)

For asmall or medium-sized city:

a(hm)=(1.1fc-0.7)h_m-(1.56 log fc-0.8) dB; h_m=*1-10 m-mobile* antenna height

2. Suburban area

L_{50}= L_{50}(urban)-2[log $(fc/28)^2$-5.4] dB

2. Open area

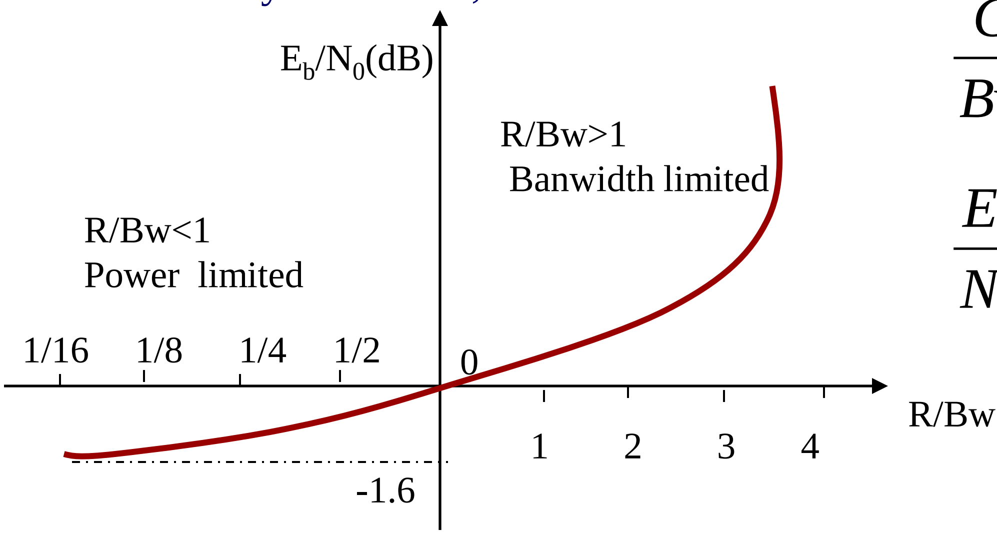
L_{50}= L_{50}(urban)-4.78log (fc)2+18.33log fc-40.94] dB

Capacity of Communication Channel

$$C = B_w \log_2\left[1+\frac{S}{N_0 B_w}\right] = B_w \log_2\left[1+\frac{E_b}{N_0}\left(\frac{R}{Bw}\right)\right]$$

C-channel capacity (bits/s); Bw-one-way transmission bandwidth(Hz); Eb-energy per bit; R-inforemation rate (bits/s); S=E_bR-signal power; N_0 noise power spectral dencity.

An ideal systems R=C, and



$$\frac{C}{Bw} = \log_2\left[1+\frac{E_b}{N_0}\left(\frac{C}{Bw}\right)\right]$$

$$\frac{E_b}{N_0} = \frac{2^{\alpha}-1}{\alpha}; \qquad \alpha = \frac{C}{B_w}$$