Wireless communication systems. Wireless channel description

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Outline

- A short glance back.
  - Key technologies and major steps in wireless communication evolution
- Cellular concept.
- Wireless channel.
  - Large-Scale Fading : Path loss.
  - Small-Scale Fading : Multipath and Doppler shifts.
- A short summary.

A short glance back

Year of Introduction	Standard	Multiple access	Frequency band	Channel Bandwidth
1979	NTT (Japan)	FDMA	400/800 MHz	25 kHz
1981	NMT-450	FDMA	450-470 Mhz	25 kHz
1983	AMPS	FDMA	824-894 MHz	30 kHz
1990	GSM	TDMA	890-960 MHz	200 kHz
1991	USDC (DAMPS)	TDMA	824-894 MHz	30 kHz
1995	IS-95	CDMA	824-894 MHz	1.25 MHz

Common terminology

- *Mobile* - any radio terminal, that could be moved during the operation.
- *Subscriber* - a mobile user
- *Forward channel* - Radio channel used for transmission of information from the base station to the mobile.
- *Reverse channel* - Radio channel used for transmission of information from the base station to the mobile.
- *Base station* - A fixed station in a mobile system used for radio communication with mobile stations.
- *Handoff* - a process of transferring a mobile station from one channel or base station to another.

2G - second generation

	cdmaONE	GSM	PDC
Duplexing	FDD	FDD	FDD
Multiple access	CDMA	TDMA	TDMA
Channel data rate	1.23 Mchips/sec	270 kbps	42 kbps
Voice channels per carrier	64	8	3
Uplink frequencies	824-849MHz 1850-1910MHz	890-915MHz 1850-1910 MHz	1850-1910 MHz
Downlink frequencies	869-894MHz 1930-1990 MHz	935-960MHz 1930-1990 MHz	896-894MHz 1930-1990 MHz

2.5G - the current stage

Key improvements:

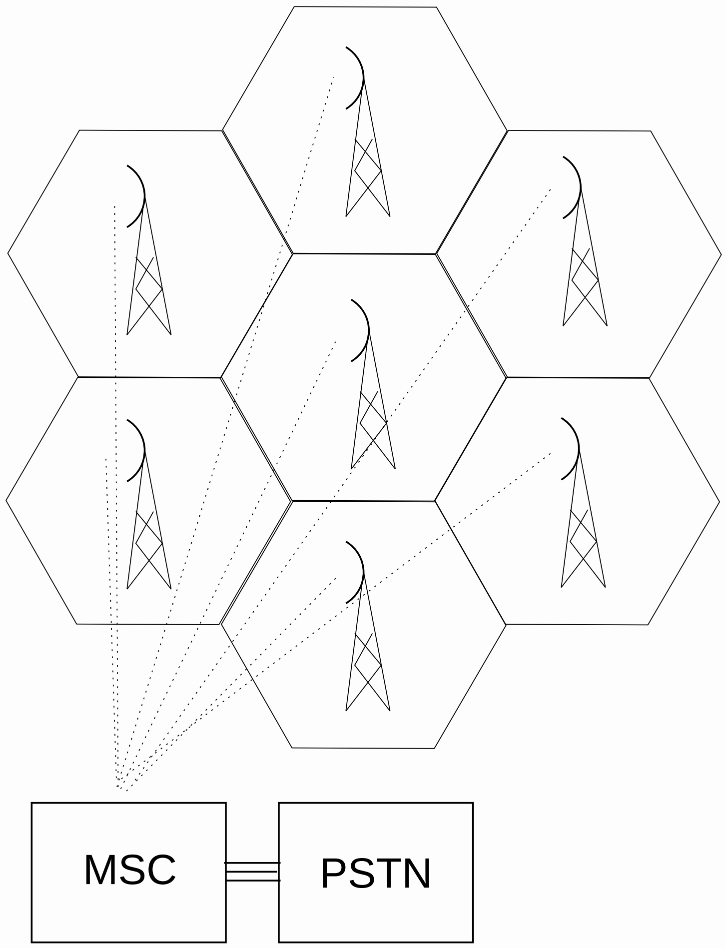
- Backward compatible
- More data-centric standards and protocols.
- *WAP* - Wireless Application Protocol
- *GPRS* - high rate data transmission
- redefined CAI (common air interface)

3G - A short overview

3G W-CDMA (UMTS)	Wideband DS-CDMA systems, backward compatibility with GSM1900, minimum forward channel bandwidth of 5MHz, FDD and TDD modes, variable chip rates at Nx0.960 Mcps with $N = 4, 8, 16$.
3G CDMA2000	Multicarrier DS-CDMA systems, backward compatibility with IS-95B(2.5G), asymmetric up/down-link channel bandwidth assignment, FDD and TDD modes, variable chip rates at Nx1.288 Mcps with $N = 1, 2, 6, 9, 12$s.

The cellular concept

A cellular concept



MSC - Mobile Switching Center

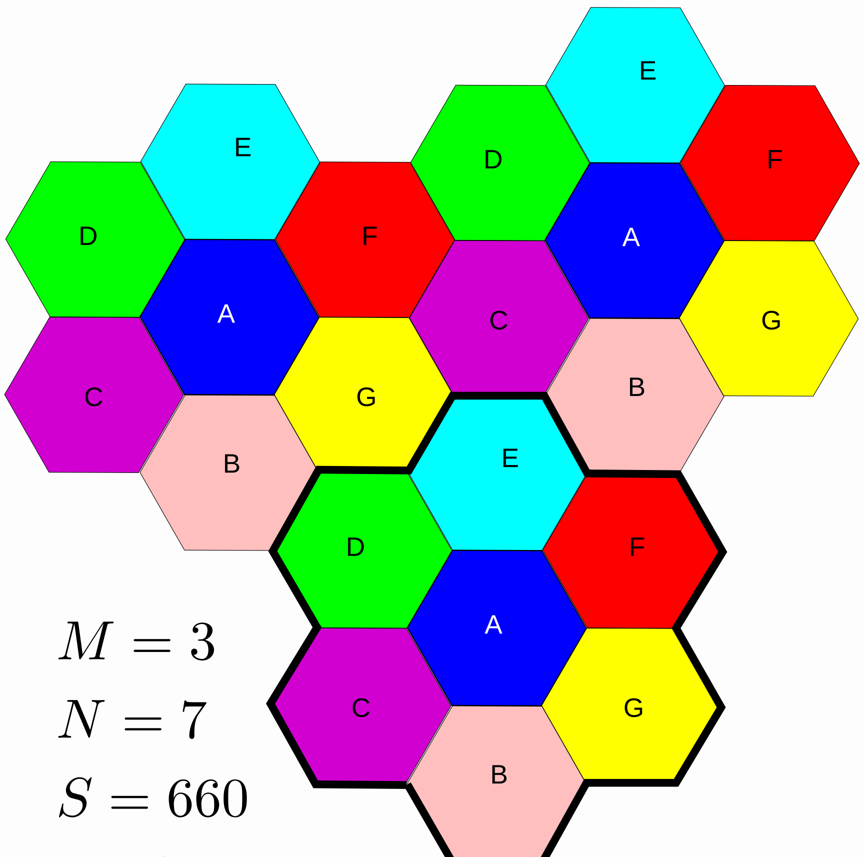
PSTN - Public Switched Telephone Network

CAI - common air interface

FVC/RVC - forward/reverse voice channel

FCC/RCC - forward/reverse control channel

Frequency reuse principle



$M = 3$

$N = 7$

$S = 660$

$i = 1$

$j = 2$

S - the total number of duplex channels

k - the number of channels per cell

N - the number of cells in a cluster(cluster size)

M - cluster replication factor

C - system capacity

$$C = MkN = MS$$

$1/N$ - frequency reuse factor.

$$N = i^2 + ij + j^2$$

Channel Assignment Strategies

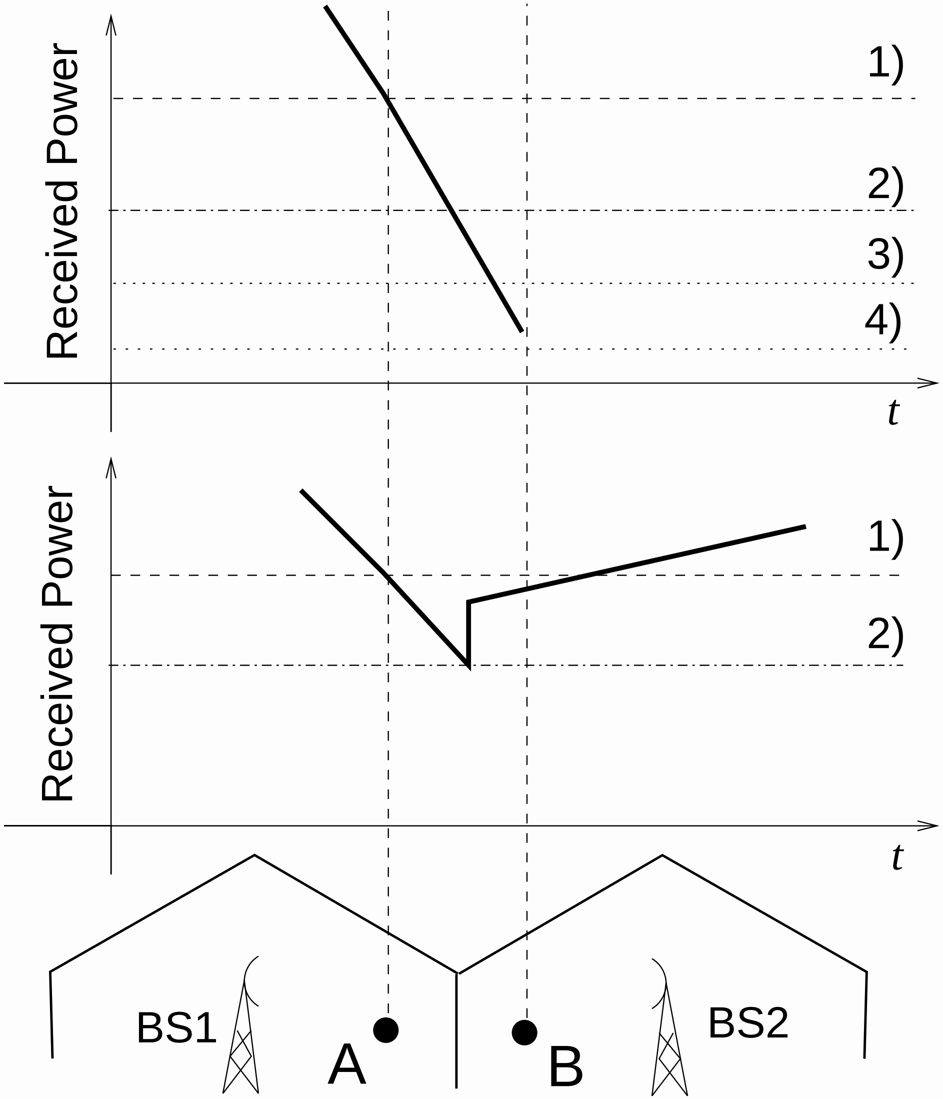
Fixed

- Number of voice channels/cell is fixed.
- Calls might be blocked
- The “borrowing” strategy to abate the call blockage.

Dynamic

- MSC assignmes channels.
- Base stations have to collect a lot of real-time data.
- High computational load

Handoff



Improper Handoff situation

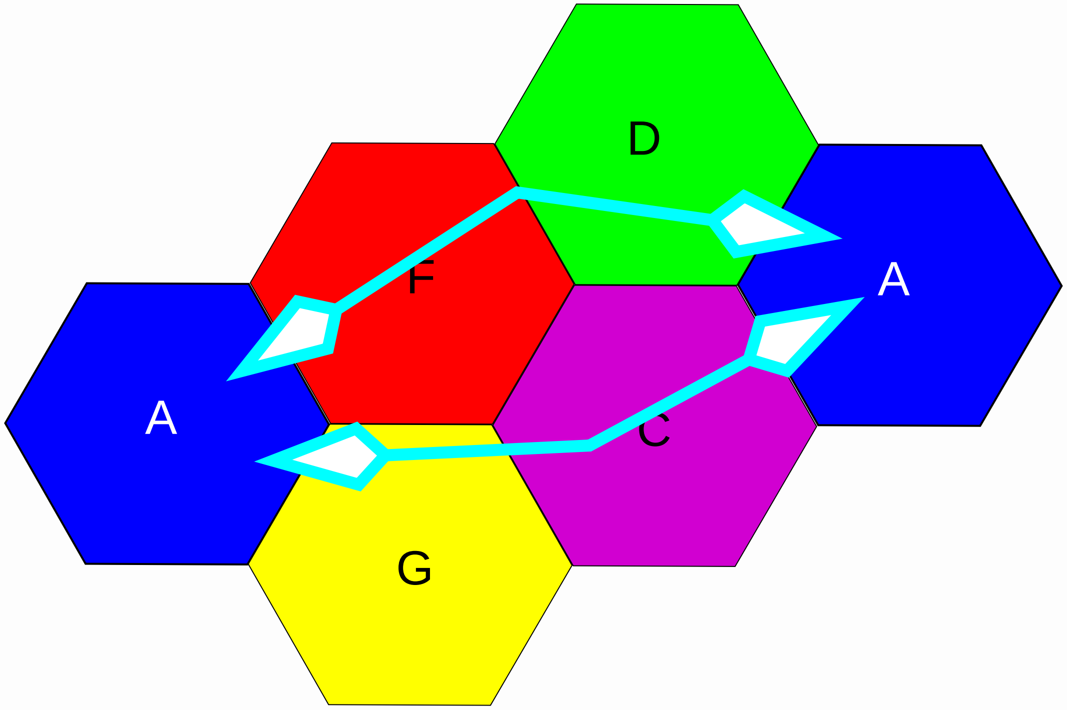
1) Level at point A.
2) Handoff threshold.
3) Minimum acceptable signal power.
4) Level at point B.

Proper Handoff

1) Level at point A.
2) Handoff level

Co-channel interference

Interference between cells that use the same set of frequencies is called *co-channel interference*

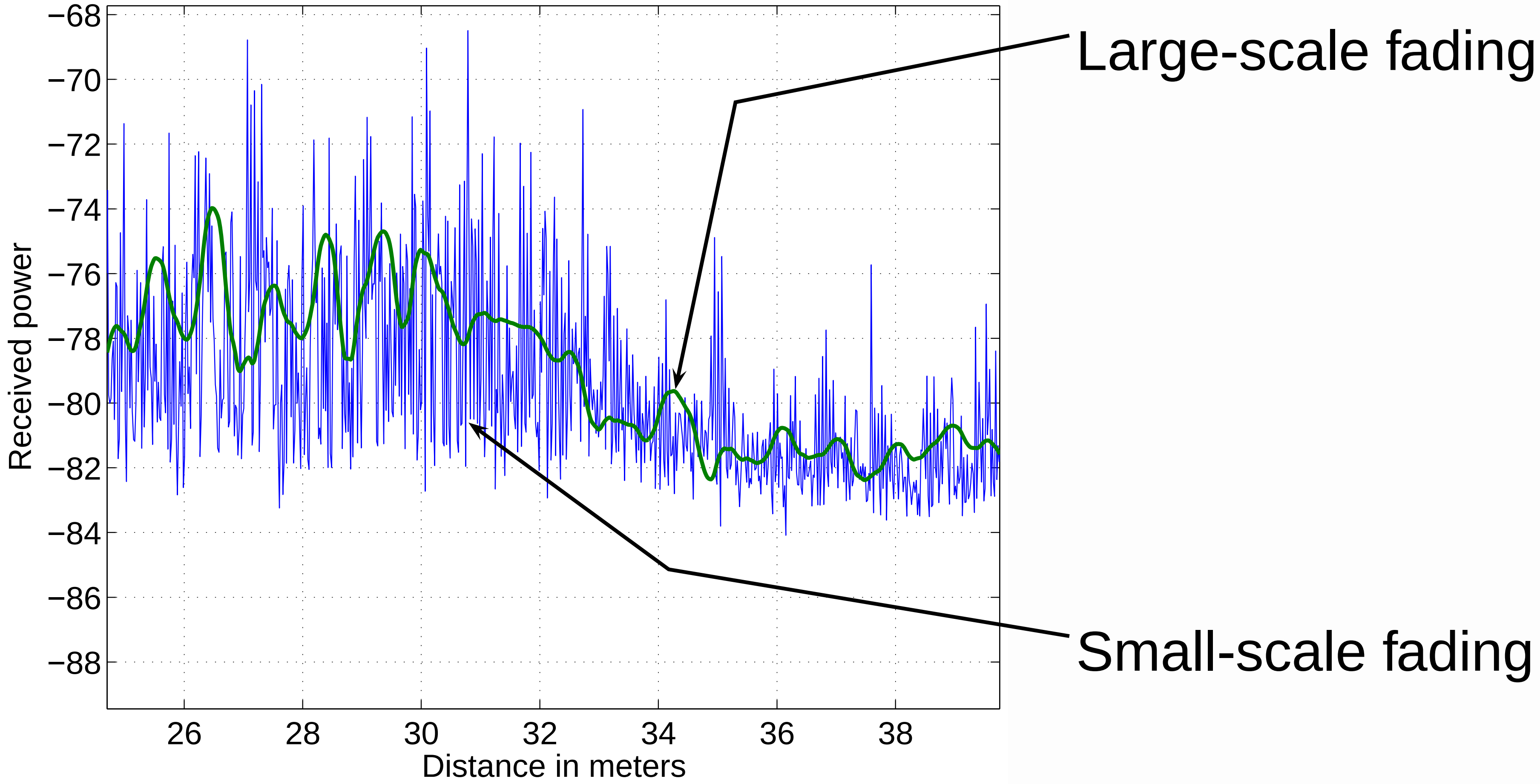


Summary

- Cellular structure allows us to increase the coverage area.
- The co-channel interference is the major limiting factor in increasing system capacity, and the the SNR.

Wireless Channel

Small/Large-scale fading



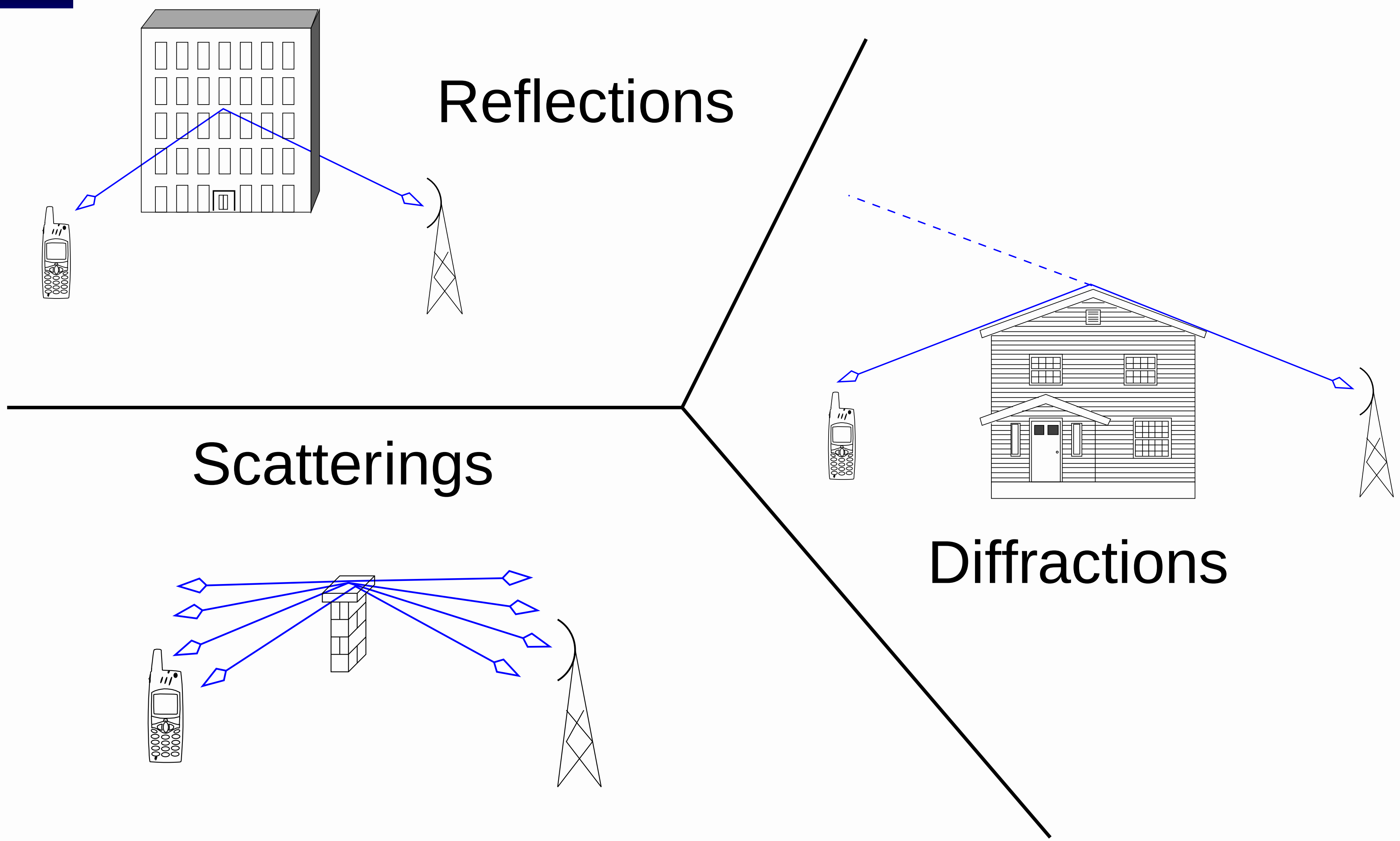
Free Space Propagation Model

The received unobstructed line-of-sight power could be expressed as:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

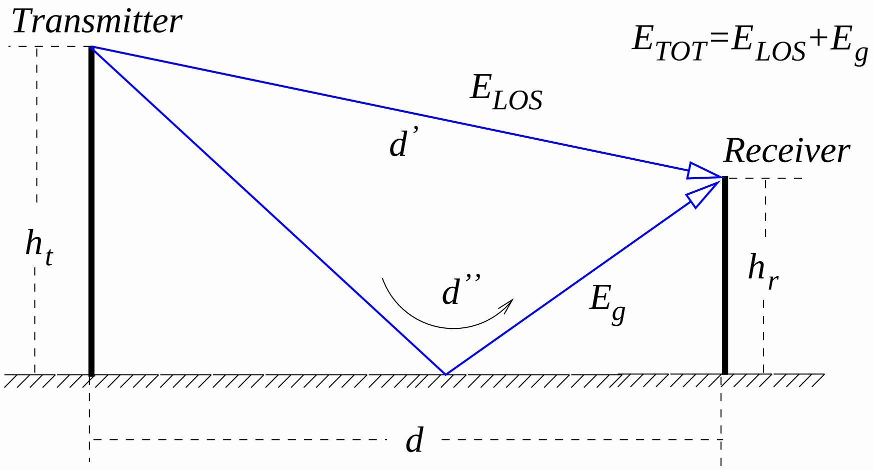
P_t is the transmitted power
G_t, G_r are transmitter and receiver gains
λ is a wavelength
d is a T–R separation in meters
and L is a loss factor not related to propagation.

Basic Propagation Mechanisms



Reflections

Under some mild conditions, the total received power could be expressed as



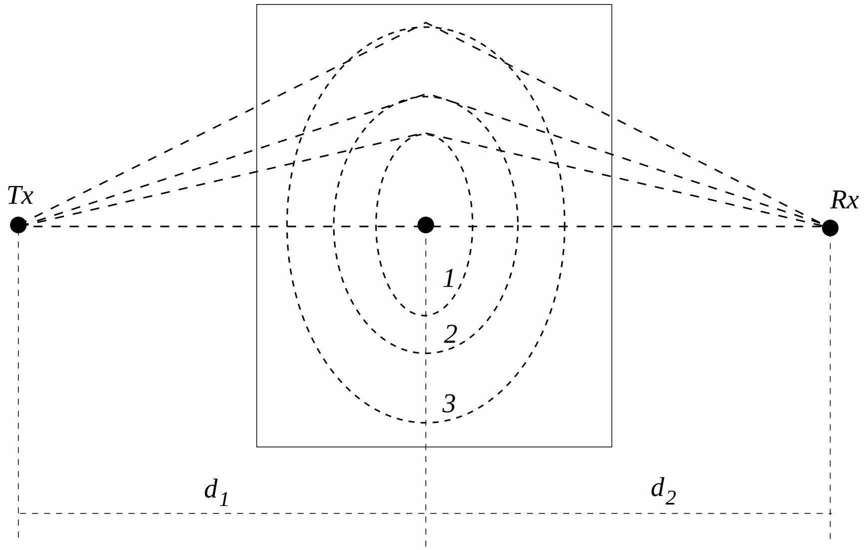
$$|E_{TOT}(d,t)| = 2\frac{E_0 d_0}{d}\sin\left(\frac{\theta_\Delta}{2}\right)$$

where E_0 is a free space E-field at a reference point d_0 and $\theta_\Delta = \frac{2\pi(d''-d')}{\lambda}$. This approximation is valid for only large distances d, and could be used to obtain the expression in dB's.

$$PL(dB) = 40\log d - (10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r)$$

Diffraction - Fresnel zones

The principle of diffraction is understood in the context of Fresnel zones and ray optics.



The Fresnel zones represent successive regions, where the total path length is $n\lambda/2$ greater then the length of the LOS path. *Fresnel-Kirchoff* diffraction parameter ν, expressed as

$$\nu = h\sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}}$$

where h is the effective height of the obstacle and λ is the wave length.

Path gain due to diffraction

The diffraction gain, compared to the free space E-field, is given by following equation

$$G_d(dB) = 20\log(|F(\nu)|)$$

where $F(\nu)$ is a complex Fresnel integral

$$F(\nu) = \frac{1+j}{2}\int_{\nu}^{\infty} \exp\left(\frac{j\pi t^2}{2}\right) dt$$

In practice, the graphical or numerical solutions are relied upon to compute the diffraction gain.

Scattering

The rough surfaces tend to diffuse the energy in space, thereby providing some extra energy for the receiver. For rough surfaces, a flat surface reflection coefficient needs to be multiplied by a scattering loss factor, ρ_S, to account for the diminished reflected field

$$\rho_S = \exp\left[-8\left(\frac{\pi\sigma_h \sin(\theta_i)}{\lambda}\right)^2\right]$$

where θ_i is an angle of incidence. The more practical approach uses *Radar Cross Section* methods, when the power loss due to the scattering could be approximated as

$$P_r(dBm) = P_t(dBm) + G_t(dBi) + 20\log(\lambda) + RCS[dB \cdot m^2] \\ -30\log(4\pi) - 20\log(d_t) - 20\log(d_r)$$

Empirical Path Loss Models

- Log-distance Path Loss Model

$$\overline{PL}(d)[dB] = \overline{PL}(d_0) + 10n\log(\frac{d}{d_0})$$

where d_0 is a reference point, and bars over $PL(\cdot)$ denote ensemble averages.

- Log-normal shadowing

$$PL(d)[dB] = \overline{PL}(d) + X_\sigma$$

where X_σ is a zero-mean Gaussian random variable (in dB's) with the standard deviation σ (also in dB's). The log-normal distribution describes the random *shadowing* effect which occur over a large number of measurement locations.

Empirical Path Loss Models, cont'd

The Hata-Okumura model is best suited for large cell coverage (distances up to 100 km) and it can extrapolate predictions up to the 2GHz band.

$$PL(d)[dB] = 69.55 + 26.16\log(f) - 13.82\log(h_t)$$
$$-a(h_m) + [44.9 - 6.55\log(h_t)]\log(d),$$
$$a(h_m) = [1.1\log(f) - 0.7]h_m - [1.56\log(f) - 0.8] \text{ for midsize city}$$

h_t and h_m are the effective transmitter and receiver(mobile) antenna height, in meters.
$a(h_m)$ is the correction factor for the mobile height.
There are several modifications to this model to account for smaller cell sizes, suburban and metropolitan areas.

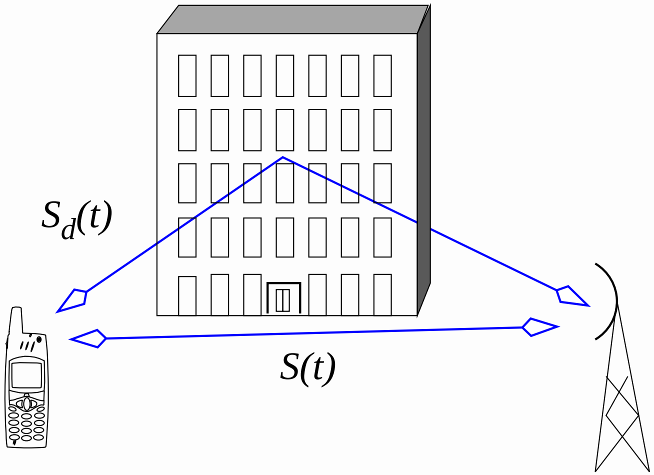
Small-Scale Multipath Propagation

Rapid fluctuations of the receiving conditions as the mobile moves even a fraction of the wavelength are called *Small-scale fading*.

- Rapid changes in the signal strength over a small traveled distance
- Random frequency modulation due to the mobile movement
- Time dispersion (echoes) caused by the multipath propagation delays.

Multipath propagation

Multipath component cause the transmitted signal to spread in time.



Here $S_d(t) = S(t-\tau)$ and the received signal $R(t)$ is then expressed as

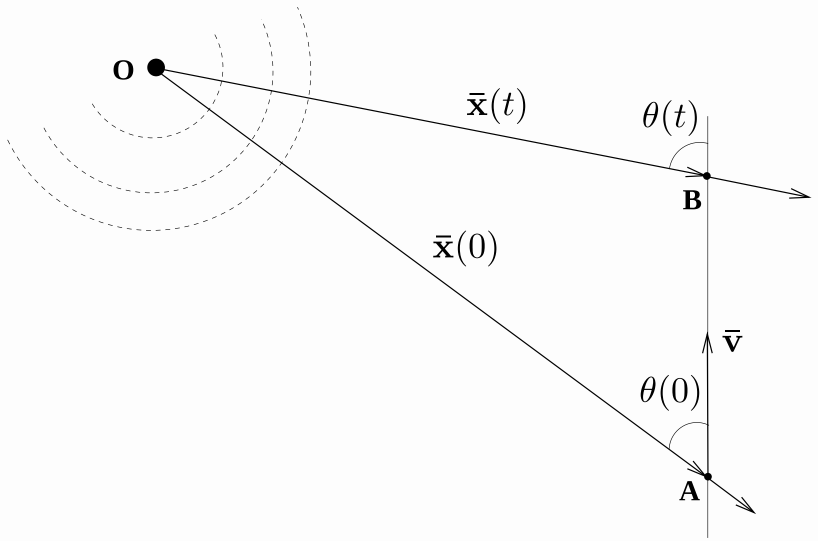
$$R(t) = S_d(t) + S(t) = S(t-\tau) + S(t)$$

The random addition of complex waves arriving at the mobile cause the significant fluctuations of the received power, thereby inducing the small-scale fading.

Doppler shifts

The movement of the mobile results in a random frequency modulation of the frequency content of a transmitted signal.

These variations are called Doppler shifts. If the mobile moves with the constant velocity $\bar{\mathbf{v}}$, the Doppler frequency f_d is expressed as



$$f_d = \frac{2\pi}{\lambda} \|v\| \cos\Big(\theta(t)\Big)$$

The Doppler shift results in variations of the received signal bandwidth.

IR Model of a Multipath Channel

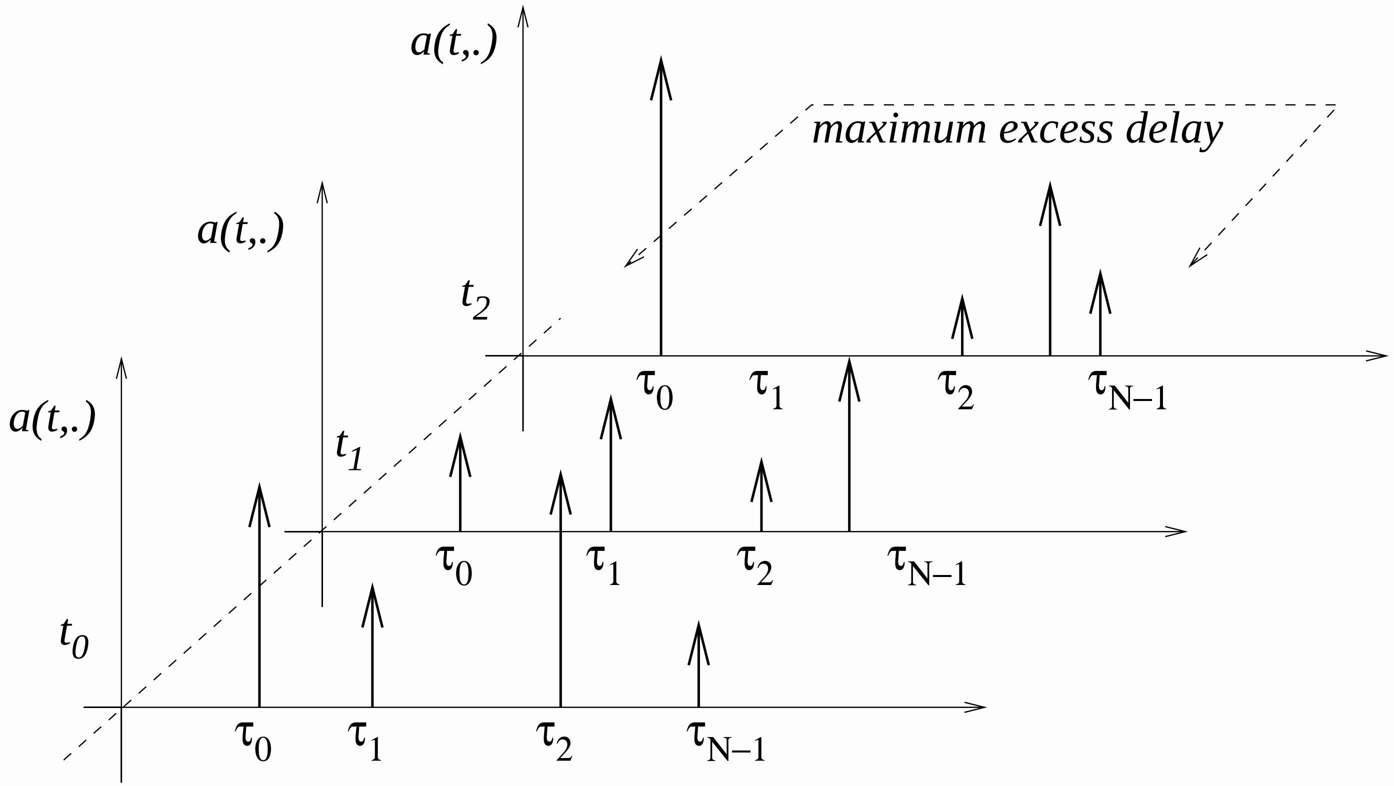
The channel impulse response could be expressed as a sum of individual multipath components:

$$h_b(t,\tau) = \sum_{i=0}^{N-1} a_i(t,\tau)\delta(\tau - \tau_i(t))\mathrm{e}^{j(2\pi f_c \tau_i(t) + \phi_i(t,\tau))}$$

$a_i(t,\tau)$ - time-varying complex amplitude of $i-$th multipath component.
The multipath delay axis τ is quantized into *excess delay bins* with the duration $\tau_i(t)$ each.
The phase term $2\pi f_c \tau_i(t) + \phi_i(t,\tau)$ accounts for the phase shift due to the free space propagation and antenna pattern.
$N\tau_i(t)$ is the *maximum excess delay*.

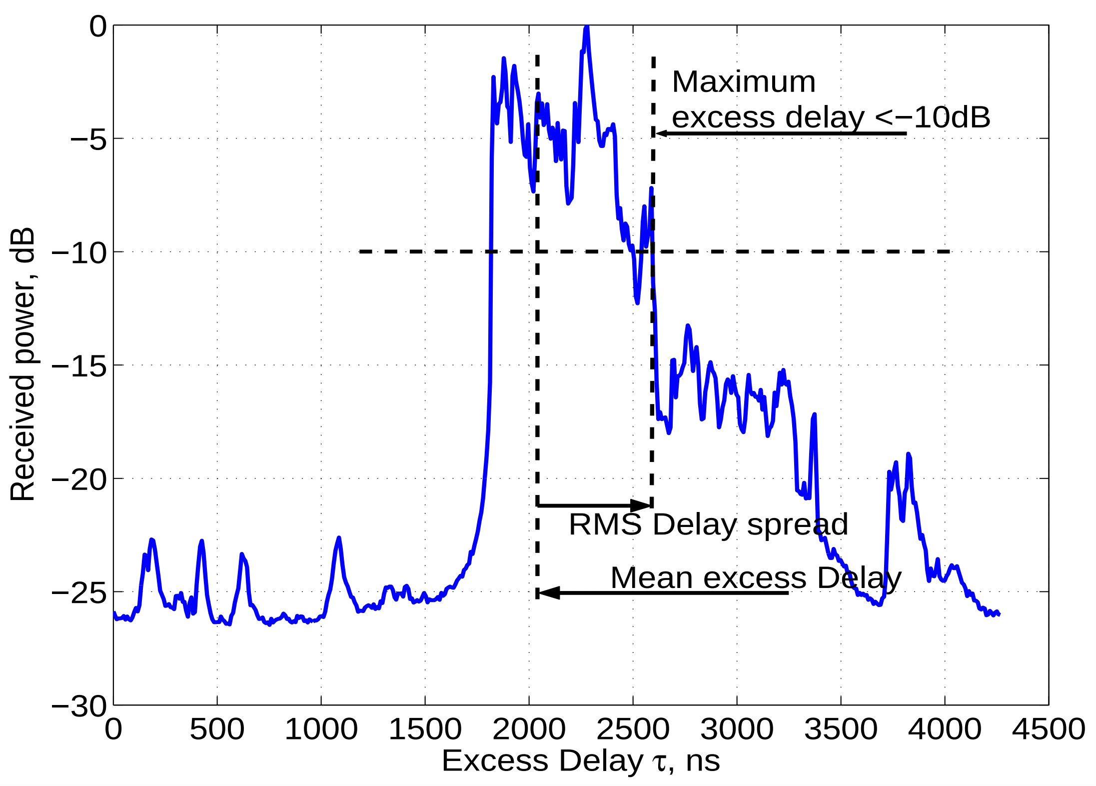
Channel impulse response

$$h_b(t,\tau) = \sum_{i=0}^{N-1} a_i(t,\tau)\delta(\tau - \tau_i(t))\mathrm{e}^{j(2\pi f_c \tau_i(t) + \phi_i(t,\tau))}$$



Time Dispersion parameters

The most important parameters are *mean excess delay*, $\bar{\tau}$, *RMS delay spread*, $\bar{\tau^2}$, and *excess delay spread*, σ_τ



$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2}$$

$$\bar{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2}$$

$$\sigma_\tau = \sqrt{\bar{\tau^2} - \bar{\tau}^2}$$

Frequency dispersion parameters

- Coherence bandwidth B_C: bandwidth over which different frequency are affected similarly.

$$B_c \approx \frac{1}{50\sigma_\tau}$$

- Doppler spread, B_D is a measure of spectral broadening caused by the mobile movement. The amount of broadening depends on the Doppler shift f_d
- The coherence time T_c is the the reciprocal of Doppler spread B_D. It quantifies the time over which the channel IR is essentially time-invariant.

Flat/Non-flat fading

- If the mobile channel has a constant gain and linear phase over a band of frequencies which is greater than the bandwidth of the signal, than the signal undergoes *flat fading*, i.e.

$$B_{Symbol} \ll B_C, \text{ and } T_{Symbol} \gg \sigma_\tau$$

- *Non-flat* (or frequency-selective) fading occurs when $B_{Symbol} \geq B_C$ and as the result the effect of inter-symbol interference become substantial.

Fast/Slow fading

- In case of *slow fading* the channel IR varies at a rate much slower than the transmitted baseband signal, i.e.

$$T_S \ll T_C, \text{ and } B_S \gg B_D$$

- When the channel coherence time T_C is smaller than the symbol duration time, i.e.

$$T_S > T_C, \text{ and } B_S < B_D$$

the signal undergoes *fast fading*. This causes frequency distortion of the received signal.

Bringing all together

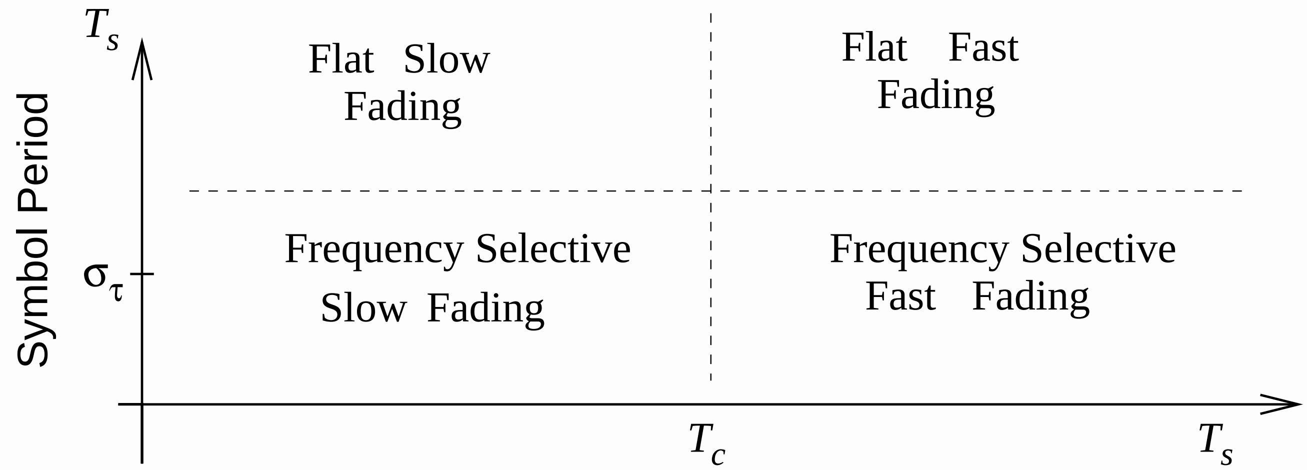
Small−Scale Fading
(based on multipath time delay spread)

Flat Fading

BW of signal < BW of channel
Delay Spread < Symbol period

Frequency Selective Fading

BW of signal > BW of channel
Delay Spread > Symbol period



Summary

- There are large- and small-scale fading effects.
- Flat/Non-flat fading is determined by the multipath environment
- Slow/fast fading is governed by the Doppler effects