10th lesson

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Communication systems

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ELECTRONICS AND COMMUNICATIONS SYSTEMS
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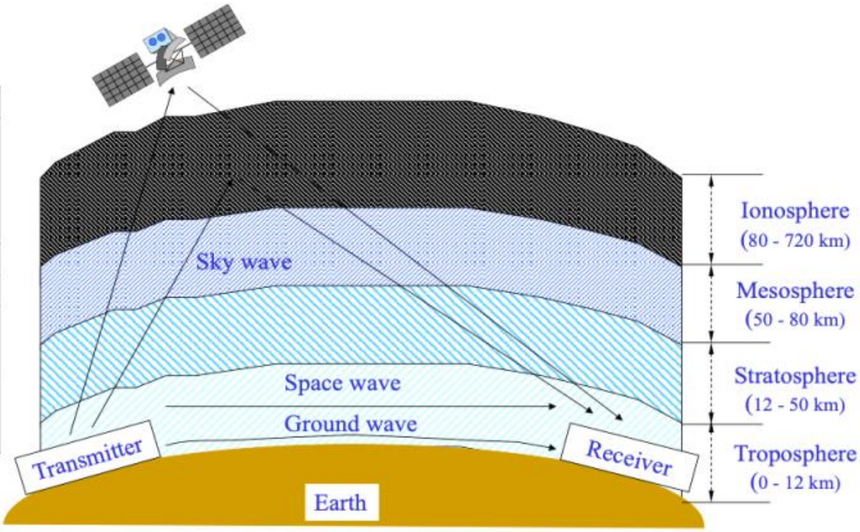
2. The wireless propagation channel

- Long-term fading: path-loss e shadowing
- Short-term fading: multipath fading
- Channel diversity: space, time and frequency diversity
- Multi-carrier modulations
- Channel coding. The Viterbi algorithm
- MIMO

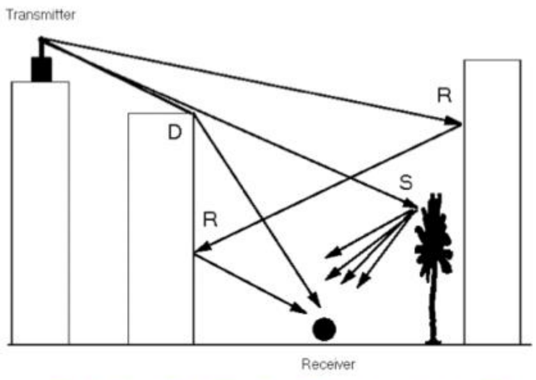
Signal propagation in the air

Classification Band	Initials	Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	Ground wave
Infra low	ILF	300 Hz - 3 kHz	
Very low	VLF	3 kHz - 30 kHz	
Low	LF	30 kHz - 300 kHz	
Medium	MF	300 kHz - 3 MHz	Ground/Sky wave
High	HF	3 MHz - 30 MHz	Sky wave
Very high	VHF	30 MHz - 300 MHz	Space wave
Ultra high	UHF	300 MHz - 3 GHz	
Super high	SHF	3 GHz - 30 GHz	



The wireless propagation channel (space wave)

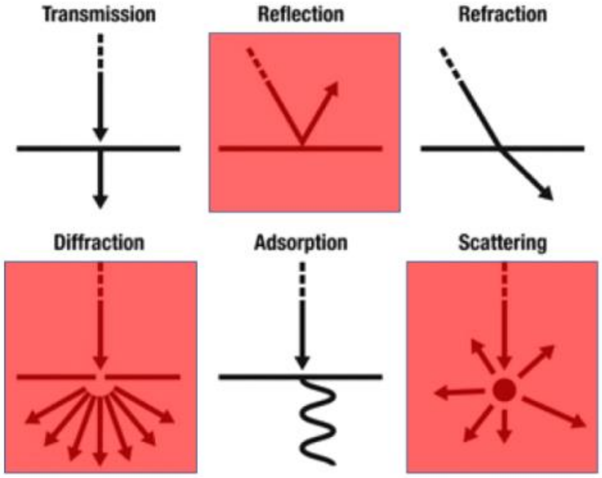
- Because, mobile services are mostly in the bandwidth 30MHz-30 GHz, *spacewave* is the most important wave propagation mechanism we need to consider.
- Most wireless radio systems operate in urban areas: No direct line-of-sight (los) between transmitter and receiver.
- The main physical phenomena are: reflection, diffraction, scattering.
- Can be categorized into two types:
  - Large-scale propagation models
  - Small-scale propagation models



Reflection (R), diffraction (D) and scattering (S).

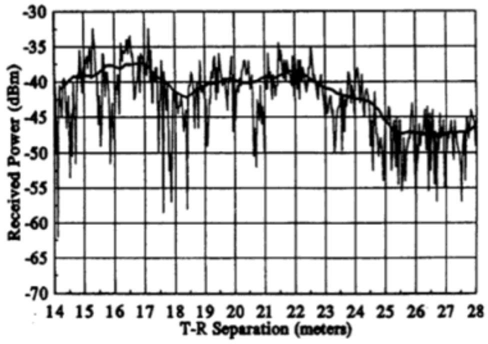
Propagation phenomena

- Three major propagation mechanisms:
  - **Reflection**
    Signal impinges on very large (w.r.t. to signal wavelength) objects. When a wave meets a boundary, it can be either reflected or transmitted.
  - **Diffraction**
    Signal is obstructed by objects that have sharp irregularities. Diffraction depends on the size of the object relative to the wavelength of the wave.
  - **Scattering**
    Propagation medium populated by small (wrt to signal wavelength) objects or rough surfaces (e.g. foliage, street signs).



Large-scale fading

- Large-scale fading: propagation models that characterize signal strengths over Tx-Rx separation distance.
- Accounts for average received power, changes over distances > 1 m.
- Large-scale fading can be modelled as the combination of *path-loss* and *shadowing*.



Large-scale fading: path-loss

- Path-loss models simplify Maxwell's equations.
- Models vary in complexity and accuracy but, in general, mean power falloff w.r.t. the tx-rx distance d is proportional to d^2 in free space and to d^n in other environments.
- Considering only path-loss, the average received signal power is

$$P_{Rx} \propto P_{Tx}\Gamma(f_0, d_0)\left(\frac{d_0}{d}\right)^n \quad d > d_0$$

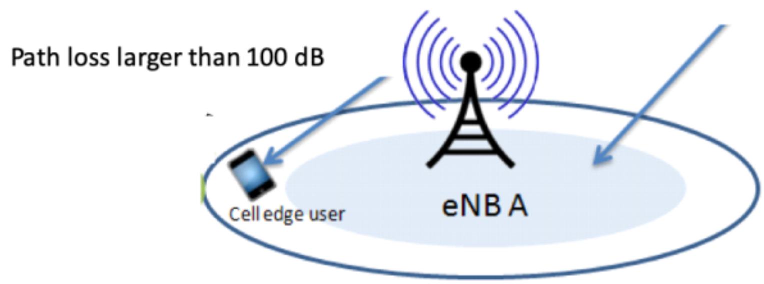
- *Near field term* $\Gamma(f_0, d_0) \approx \left(\frac{\lambda}{4\pi d_0}\right)^2$
- Path-loss A_{PL} is

$$A_{PL} = \frac{P_{Tx}}{P_{Rx}} = \Gamma(f_0, d_0)\left(\frac{d_0}{d}\right)^n$$

Environment	Path Loss Exponent, n
Free space	2
Urban area cellular radio	$2.7 - 3.5$
Urban area cellular (obstructed)	$3 - 5$
In-building line-of-sight	$1.6 - 1.8$
Obstructed in-building	$4 - 6$
Obstructed in-factories	$2 - 3$

Path-loss in cellular systems

- Path-loss: Signal attenuation defined as the ratio between the transmitted power and the average received power.
- The path-loss in a cellular system can be up to 100 dB for cell-edge users and represents the major impairment in any wireless cellular system



Large-scale fading: shadowing

- Two points with the same distance from the transmitter have theoretically the same path-loss, nevertheless their average attenuation may still greatly differ.
- *Shadowing* accounts for the random variations of the average channel attenuation.
- Shadowing fading A_S is a random variable log-normally distributed with parameters $\mu = 0$ and σ_S expressed in dB.
- The pdf in dB of A_S is

$$p(A_S) = \frac{1}{\sqrt{2\pi}\sigma_S} e^{-\frac{A_S^2}{2\sigma_S^2}}$$

where σ_S is the standard deviation in decibels (typical values 0-9 dB)

Large-scale fading: shadowing

$P_{Rx} = P_{Tx} \cdot A_{PL}$

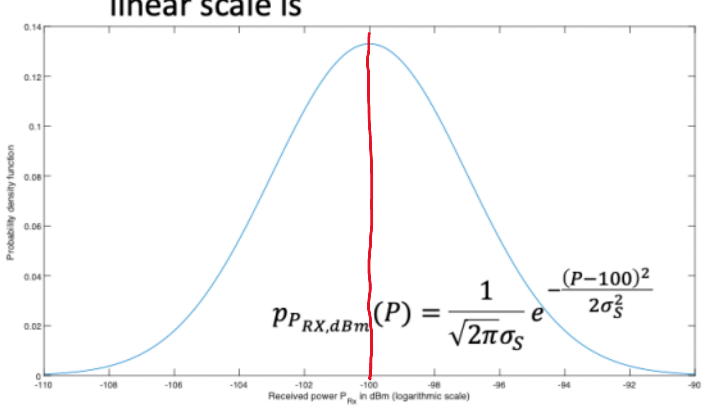
$P_{Rx} = P_{Tx} \cdot A_{PL} \cdot A_S .$

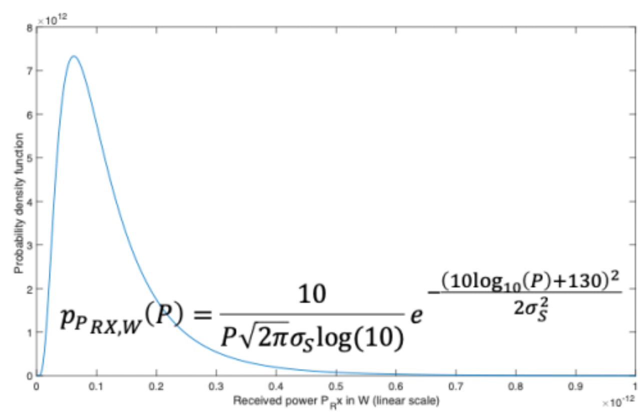
- Let's consider a channel with path-loss and shadowing ($\sigma_S = 3$ dB) only. The received power P_{RX} is

$$P_{RX} = P_{TX} A_{PL} A_S$$

dB and dBm

- Assume that $P_{TX}A_{PL} = -100\text{ dBm} = -130\text{ dBW} = 10^{-13}\text{ W}$.
- Because of shadowing, P_{RX} is a random variable and its distribution in dBm and linear scale is





$0\text{ dBm} \rightleftarrows 10^{-3}\text{ W}$

$0\ dBW \rightleftharpoons 1\ W$ $\quad 0\,dBW = 30\,dBm$

$-100\ dBm \Rightarrow 10^{-13}\ W$