Mobile Communications
Problem Set 2

Dr.-Ing. Ralf Lübben
M.Sc. Felix Langenbruch

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1. Name and explain the attributes of radio wave propagation. How does the transition from a light to a denser medium impact the wave propagation? How does the radio wave frequency impact its propagation? Name three general classes of waves classified through the frequency range.

   Solution:

   Unimpeded radio waves propagate in a straight line. However, irregularities of the propagation medium such as obstacles and different materials impact the radio wave propagation. This impact depends often on the wavelength/ frequency. Mainly, the following effects arise: Reflection, Diffraction, Scattering and Refraction.

   Refraction describes the transition of a wave from one medium to another. The velocity of the electromagnetic wave depends on the density of the medium. A wave traveling from a light medium to a denser one is bent towards the medium (Snell's law).

   The frequency of the radio wave is important for its propagation properties. A higher frequency, that is a shorter wavelength, means that the wave is impaired more often. Effects such as reflection, diffraction, scattering and refraction occur more often as the wave behaves similar to visible light.

   In the lecture we distinguished the following wave classes depending the frequency range:

   - Ground waves: for frequencies below 2 MHz. (wave follows earth curvature).
   - Sky waves: for frequencies between 2 and 30 MHz (short waves that are reflected from the ionosphere).
   - line of sight wave: for frequencies above 30 MHz (nearly optical propagation that follows a line of sight).

2. Explain the problems occurring with multipath propagation. How can these problems be approached?

   Solution:

   Radio waves that propagate along different paths and are superposed at the receiver cause a distortion of the received signal. Since the propagation speed is finite and the paths have different lengths the signal is received more than once with a certain time delay. This delay spread causes a smeared received signal where the different signal copies interfere with each other. This is called inter symbol interference (ISI). This problem is addressed using training sequences that are known at the sender and receiver to tune an equalizer at the receiver that compensates the arising distortion.

3. In which communication scenarios is the doppler shift considered harmful?

   Solution:

   The doppler shift is a change of frequency f_D that is given by

   $$f_D = \frac{v}{c} f$$

   where v is the relative speed of a transceiver, c is the speed of light and f is the carrier frequency. It is obvious that the doppler shift is only relevant for very fast moving transceivers such as satellites.

4. Explain the Shannon limit for AWGN channels. Next, consider an AWGN channel with 4 kHz bandwidth, a signal-to-noise ratio (SNR) of 20 dB and calculate the channel capacity.

   Solution:

   The Shannon limit expresses how bandwidth and noise affect the transmission rate over an AWGN channel. It states that the theoretical limit for the data rate is given by

   $$C = B \log_2 \left(1 + \frac{S}{N}\right)$$

   with channel bandwidth B and signal-to-noise ratio $\frac{S}{N}$.

   For the given example we convert the SNR of 20 dB as

   $$\begin{aligned} 10 \log_{10} \left(\frac{S}{N}\right) &= 20 \\ \Leftrightarrow \log_{10} \left(\frac{S}{N}\right) &= 2 \\ \Leftrightarrow \frac{S}{N} &= 10^2 \end{aligned}$$

   The capacity of the AWGN channel is then given as

   $$\begin{aligned} C &= B \log_2 \left(1 + \frac{S}{N}\right) \\ &= 4000 \log_2 (101) \\ &= 26.6 \text{ kbit/s} \end{aligned}$$