Chapter 5 :

Small scale multipath propagation

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Chapter 5

5.1 Small-scale fading

Small-scale fading: is used to describe the rapid fluctuations of the amplitude of a radio signal over a short period of time or travel distance.

- Fading is caused by interference between ***two or more versions of the transmitted signal*** which arrive at the receiver at slightly different times.
- These waves are called ***multipath waves***, combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase, depending on the distribution of the intensity and relative propagation time of waves and the bandwidth of the transmitted signal.

5.2 Small-scale fading effects:

1. Rapid changes in signal strength over a small travel distance or time interval.
2. Random frequency modulation due to varying Doppler shifts on different multipath signals.
3. Time dispersion caused by multipath propagation delays.

5.3 Factors influencing (causes of) small-scale fading:

- **Multipath propagation:** reflecting objects and scatters create a changing environment that affects the signal in amplitude, phase and time.
- **Speed of the mobile:** the relative motion between the mobile and the BS causes Doppler shifts, on each of the multipath components.
- **Speed of surrounding objects:** moving objects cause time-varying Doppler shifts.
- **Transmission bandwidth of the signal:** if the transmitted signal bandwidth is greater than the bandwidth of the channel, the signal will be distorted.

Coherent bandwidth of the channel is a measure of the frequency difference for which the signal is not distorted in amplitude (the channel does not distort the signal).

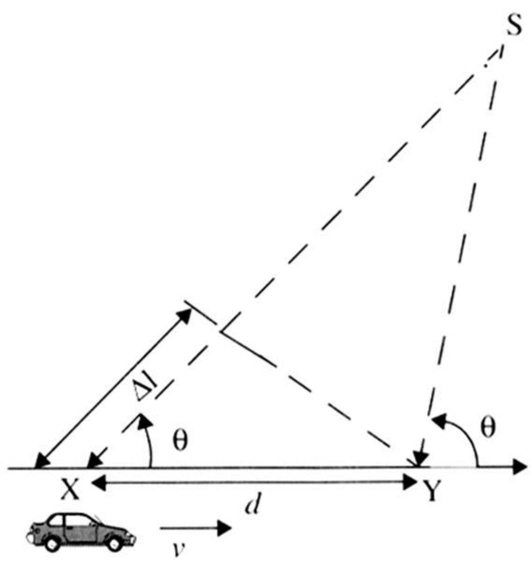
5.4 Doppler shift

- Consider a mobile terminal moving at a constant velocity *v*, along a path segment having length *d* between points *X* and *Y*, while it receives signal from a remote source *S*.

  The path length difference between S and points *X* and *Y*:

  $$\Delta l = d\cos\theta = v\Delta t\cos\theta$$

  where Δt is the time required for the mobile to travel from *X* to *Y*.



- The phase change in the received signal

$$\Delta\emptyset = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\theta$$

- The Doppler shift can be calculated using

$$f_D = \frac{1}{2\pi}\frac{\Delta\emptyset}{\Delta t} = \frac{v}{\lambda}\cos\theta$$

- **The Doppler shift depends on:**

1. Mobile velocity
2. Carrier frequency
3. Angle between the direction of motion and the direction of arrival of the wave

- Doppler shift is ***positive*** if the mobile is moving ***towards*** the source.
- Doppler shift is ***negative*** if the mobile is moving ***away*** from the source.

Example:

Consider a transmitter which radiates a sinusoidal carrier frequency of 1850 *MHz*. For a vehicle moving at 96.6 *km/h*, compute the received carrier frequency if the mobile is moving

a) Directly towards the transmitter,
b) Directly away from the transmitter,
c) In a direction which is perpendicular to the direction of arrival of the transmitted signal.

Solution:

Given:

$f = 1850\ MHz$,

$v = 96.6\ km/h = 96.6 \times (1000 / 3600) = 26.82\ m/s$

$\lambda = c / f = 3\times10^8 / 1850\times10^6 = 0.162m$

(a)

The vehicle is moving directly towards the transmitter, meaning that $\theta = 0^o$.

The Doppler shift in this case is positive.

Doppler frequency $f_D = \frac{v}{\lambda}\cos\theta = \frac{26.82}{0.162}\cos(0) = 165\,Hz$

The received frequency $= f + f_D = 1850\times10^6 + 165 = 1850.000165\ MHz$

(b)

The vehicle is moving directly away from the transmitter, meaning that $\theta = 180^o$.

The Doppler shift in this case is negative.

Doppler frequency $f_D = \frac{v}{\lambda}\cos\theta = \frac{26.82}{0.162}\cos(180) = -165\,Hz$

The received frequency $= f + f_D = 1850\times10^6 - 165 = 1849.999834\ MHz$

(c)

The vehicle is moving perpendicular to the angle of arrival of the transmitted signal, meaning that θ = 90°.

Doppler frequency $f_D = \frac{v}{\lambda}\cos\theta = \frac{26.82}{0.162}\cos(90) = 0\,Hz$

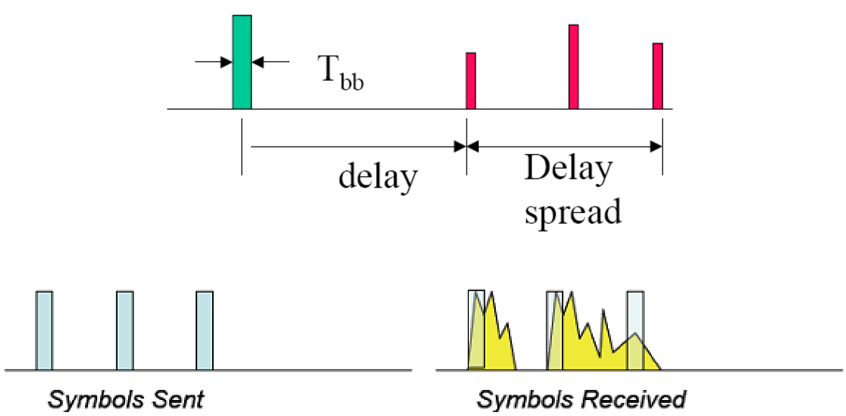
There is no Doppler shift.

The received signal frequency is the same as the transmitted frequency (f = 1850 MHz).

5.5 Determining the impulse response of a channel

- Transmit a narrowband pulse into the channel

- Measure replicas of the pulse that traverse different paths between transmitter and receiver



- A mobile radio channel may be modeled as a linear filter with a time-varying impulse response
- The time variation is due to receiver motion in space
- The filtering is caused by the summation of amplitudes and delays of multiple arriving waves, due to multipath

5.6 Power delay profile

- The power delay profile relates the received power of a signal through a multipath channel as a function of the time delay.
- The total received power is the sum of the powers in the individual multipath components.
- The power delay profile can be measured empirically.
- Time dispersion parameters are used to quantify the time-dispersive properties of multipath channels, and can be determined form the power-delay profile.

5.7 Coherence bandwidth

- The delay spread is a natural phenomenon caused by reflected and scattered propagation paths in the radio channel.
- The coherence bandwidth (B_c) is a statistical measure of the range of frequencies over which the channel can be considered "flat"
  - Spectral components within B_c pass with approximately equal gain & linear phase.
  - B_c is derived from the rms delay spread (σ_τ).
- Two sinusoids with frequency separation greater than B_c are affected quite differently by the channel, and their amplitudes would be considered uncorrelated.
  - If the coherent bandwidth (B_c) is defined as the bandwidth over which the frequency correlation function is above 0.9 (90%), then the coherence bandwidth is approximated by

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

- If the frequency correlation function is above 0.5 (50%) (relaxed definition), then the coherence bandwidth is approximately

$$B_c \approx \frac{1}{5\sigma_\tau}$$

5.8 Fading effects due to multipath time delay spread

- Time dispersion due to multipath causes the transmitted signal to undergo either one of the following:

  1. Flat fading
  2. Frequency selective fading

1- Flat fading

- The received signal undergoes ***flat fading*** if the channel has a constant gain and linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal.

- In frequency domain: $B_S < B_C$

  B_s: signal bandwidth

  B_c: coherence bandwidth

- In time domain: $T_S > \sigma_\tau$

  $\boldsymbol{T_s}$**:** symbol period (reciprocal bandwidth)

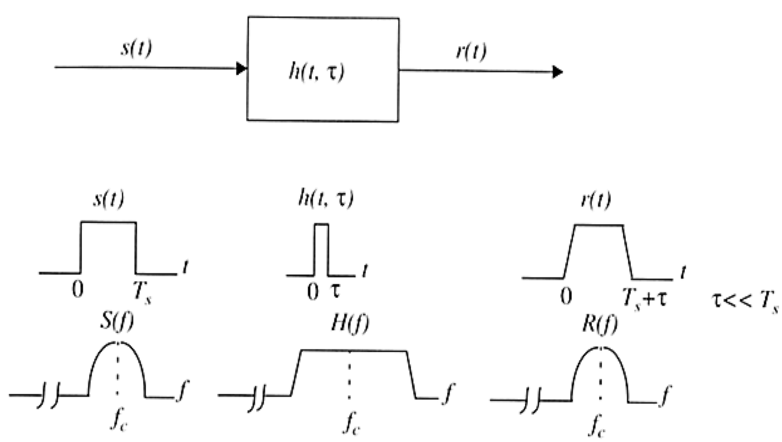
  $\boldsymbol{\sigma_\tau}$**:** rms delay spread of channel

  In general $\sigma\tau \leq 0.1\, T_S$

- ***Inter-symbol interference (ISI) is low (negligible)***

- The received signal strength changes with time, due to fluctuations in the gain of the channel caused by multipath.
- The spectral characteristics of the transmitted signal are preserved.
- Flat fading channel is also called:
  - Amplitude varying channel.
  - Narrow band channel: bandwidth

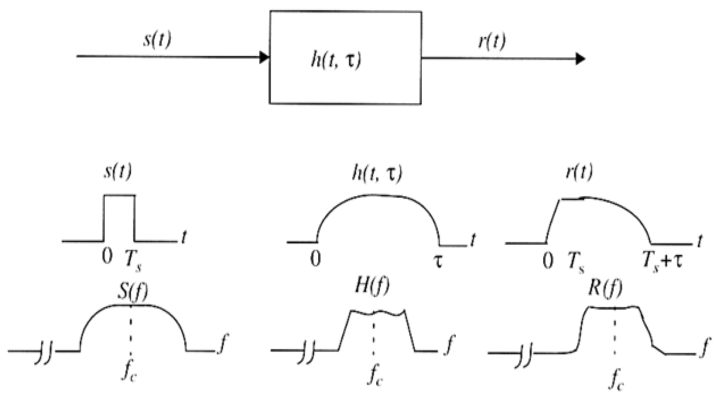
  of the applied signal is narrow as compared to the channel bandwidth.
- Channel modeling:
  - Rayleigh flat fading channel model.



Flat fading channel characteristics

2- Frequency selective fading

- The channel creates ***frequency selective fading*** if the channel possesses a constant gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal.
- **In frequency domain:** $B_S > B_C$
  - B_s**:** signal bandwidth
  - B_c**:** coherence bandwidth
- **In time domain:** $T_S > \sigma_\tau$
  - T_s**:** symbol period (reciprocal bandwidth)
  - σ_τ**:** rms delay spread
- ***Inter-symbol interference (ISI) is high (significant).***
- Frequency selective fading is due to time dispersion of the transmitted symbols within the channel, and causes inter-symbol interference (ISI).
- Frequency selective fading channels are much more difficult to model than flat fading channels.
- Statistic impulse response models:
  - 2-ray Rayleigh fading model
  - Computer generated models
  - Measured impulse response



Frequency selective fading channel characteristics