Multipath and Fading

Multipath and Fading of Signals

- Delay spread
- Rayleigh fading
- Flat/Frequency Selective fading
- Doppler Shift
- Log-Normal Shadowing

Multipath

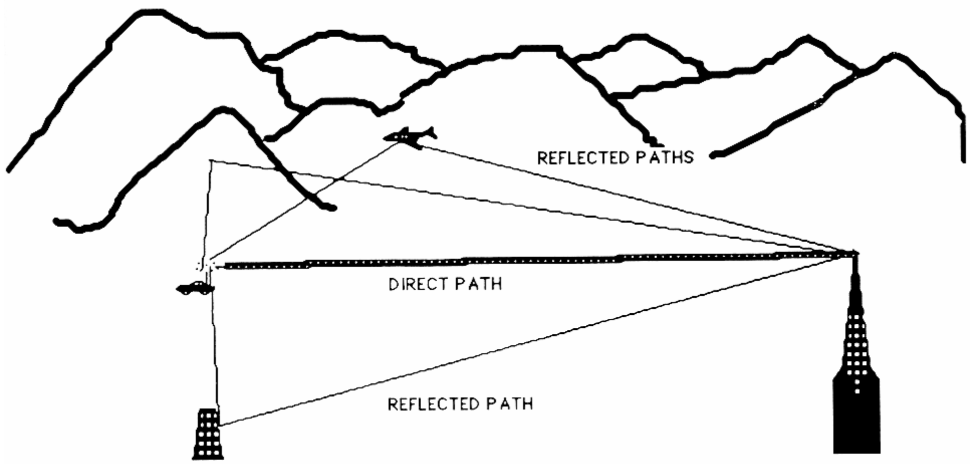


Figure 8.12 Multipath Propagation.

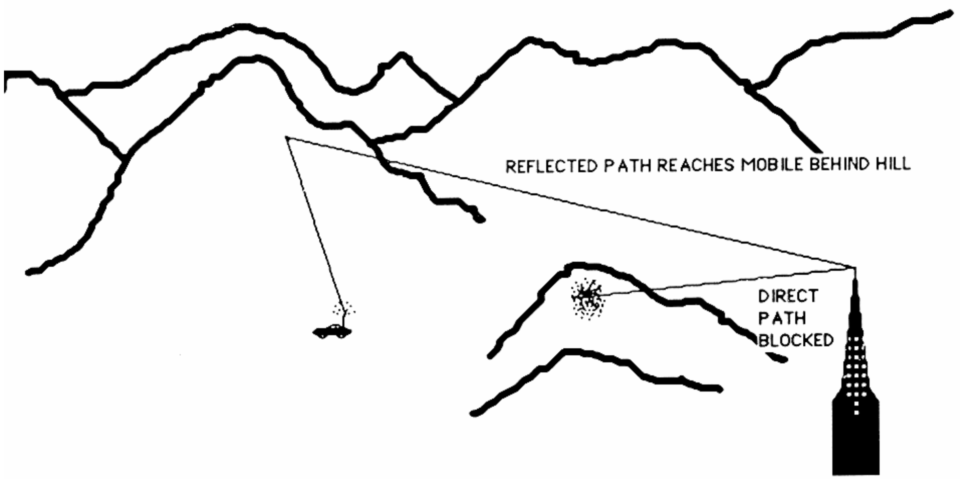


Figure 8.13 Multipath Allows Propagation around Obstacles.

Delay spread

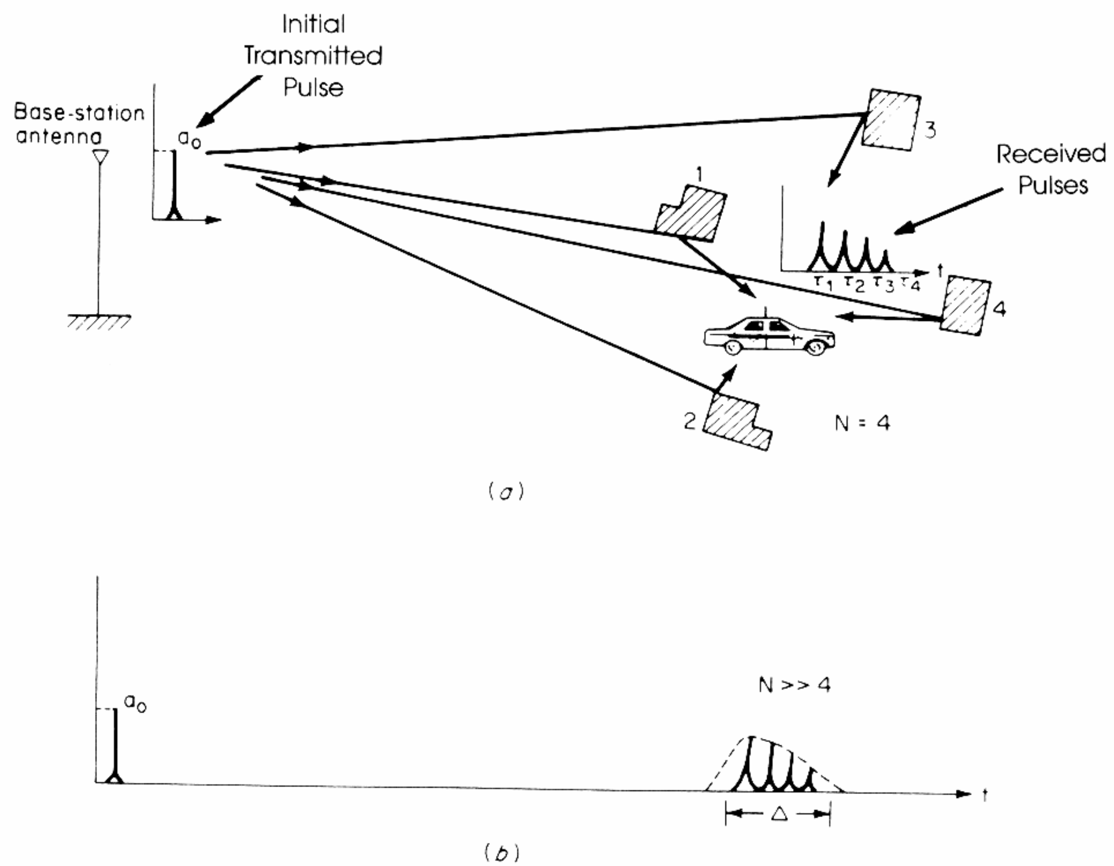


Figure 8.14 Illustration of Delay Spread.

Source: William C.Y. Lee, *Mobile Communications Engineering*, p.40.

Delay spread

- Due to multipath, several copies of signals are received
- Differences in arrival times caused by the multipath environment
  - Signals are spread out over time
  - It depends on the environment
    - Indoor < 1μsec
    - Rural environment: few μsec
    - Urban building: 10 μsec

Delay spread

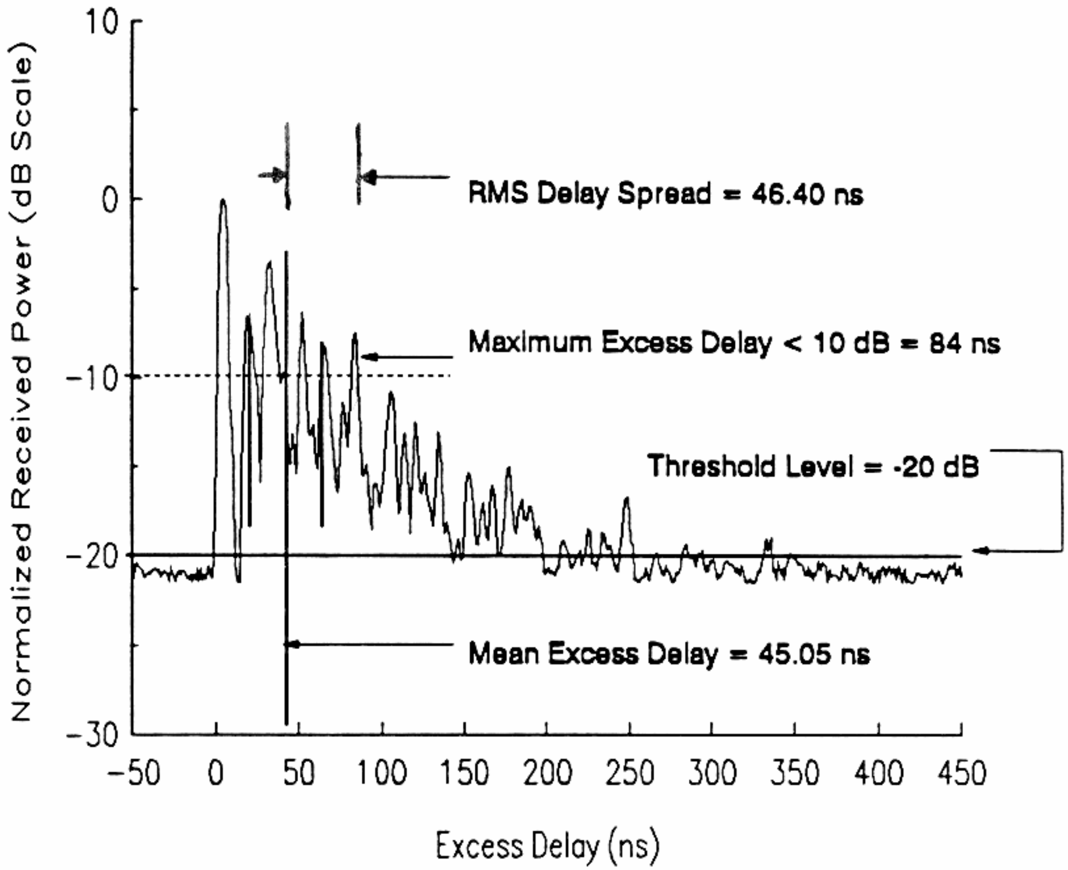


Figure 4.10
Example of an indoor power delay profile; rms delay spread, mean excess delay, maximum excess delay (10 dB), and threshold level are shown.

Delay spread

Each delay (t_i) is weighted with Power (P_i)

Mean excess delay: $$\frac{\sum P_i t_i}{\sum P_i}$$

Max excess delay (xdB): $t_x - t_0$

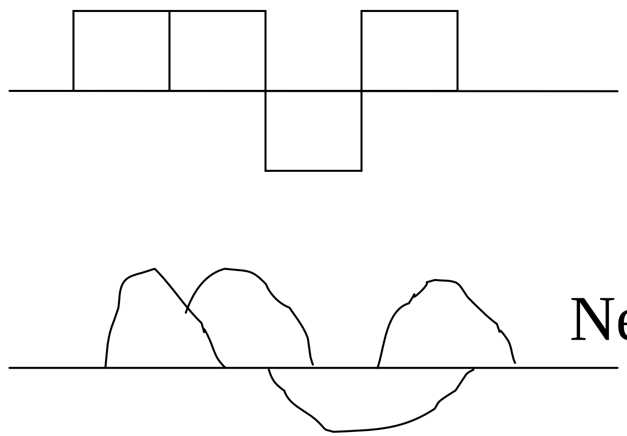
RMS delay: $$\delta_{RMS} = \sqrt{\frac{\sum P_i t_i^2}{\sum P_i} - \left(\frac{\sum P_i t_i}{\sum P_i}\right)^2}$$

Delay spread

Delay spread distorts the signal, increases error rate

Ideal — No delay spread

Practical — Need to reduce the delay spread



To reduce the delay spread

- Use longer bit time
- Reduce the data rate

Delay spread

Overlap = RMS delay spread/symbol period

$\leq$ 10 % overlap is acceptable in digital system

Delay of 1 msec is really bad

0.1 = 1 msec/10 msec, i.e., 100 bps

Coherence Bandwidth

Defined in relation with the RMS delay spread

- A statistical measure of bandwidth over which the channel can be considered “flat”
- Two frequency components have a strong amplitude correlation over the coherence bandwidth
- $BW_C = 1/50\delta_{RMS}$ (Frequency correlation function > 0.9)
- $BW_C = 1/5\delta_{RMS}$ (Frequency correlation function > 0.5)

Rayleigh Fading

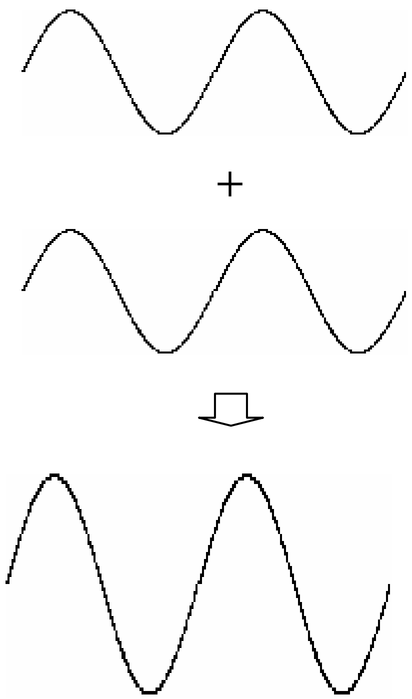
Under multipath environment, the reflected radio wave may undergo drastic alteration in phase and amplitude

Constructive/Destructive interference by fixed set of signals with multipath

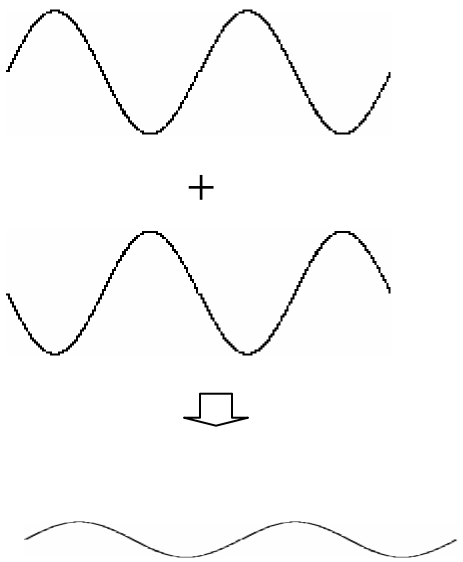
Destructive interference (Rayleigh fading): signal cancellation as a summation of several phasors

Rayleigh Fading

Constructive interference



Destructive interference



Phase cancellation of multipath reflections

Rayleigh Fading

Multipath fading due to the waves reflected from building and other structures

Fast fading: short time

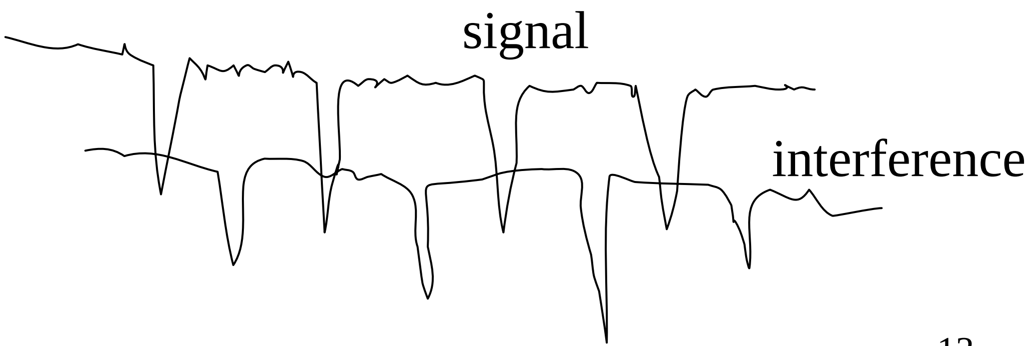
Small scale fading: short distance

every $\lambda/2$ (= 15cm, f = 900MHz)

120km/h ≈30m/sec

30m/15cm = 200 fadings/sec

Picket fence effect



Rayleigh Fading

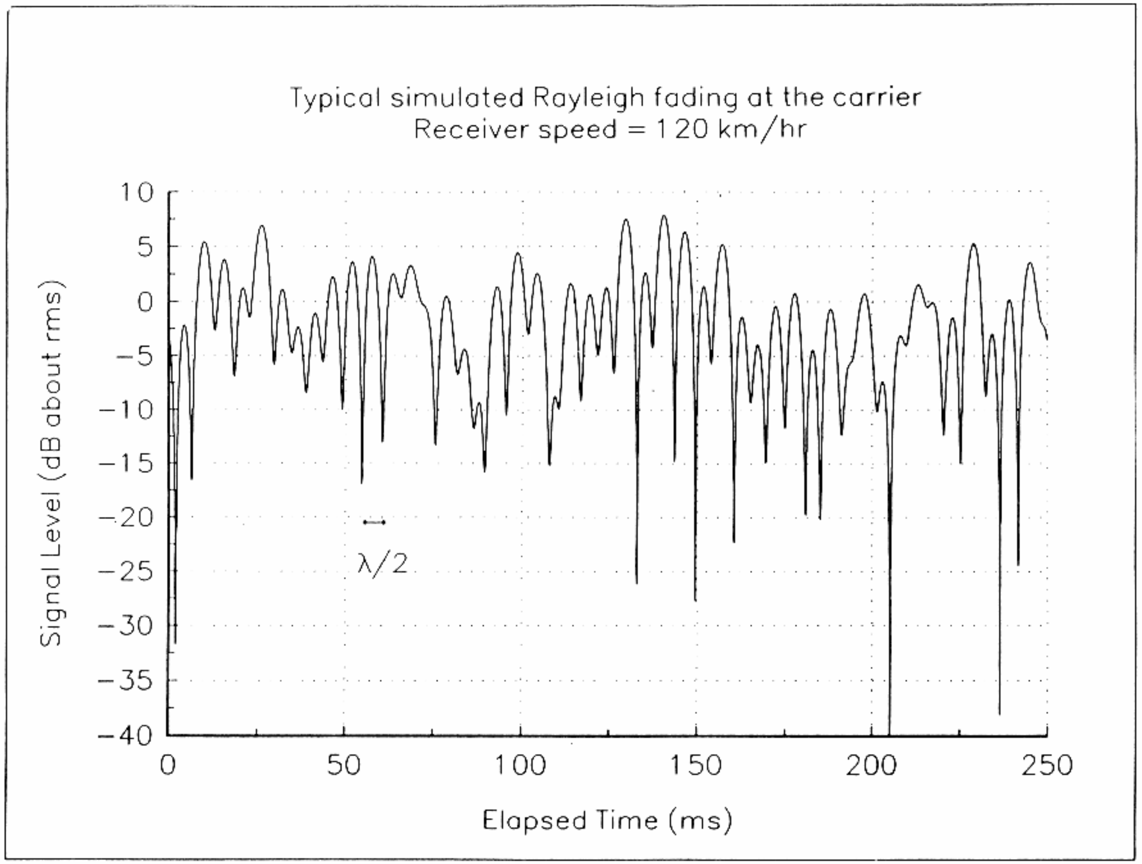


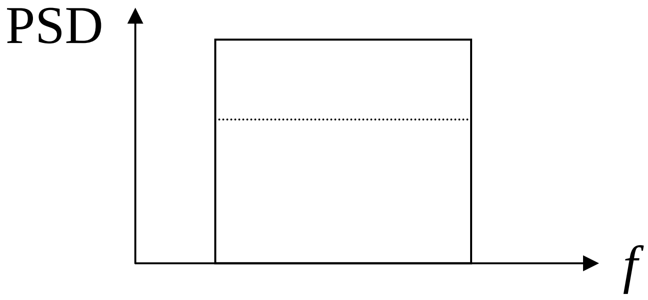
Figure 4.15
A typical Rayleigh fading envelope at 900 MHz [From [Fun93] © IEEE].

Interplay between fast fading and delay spread

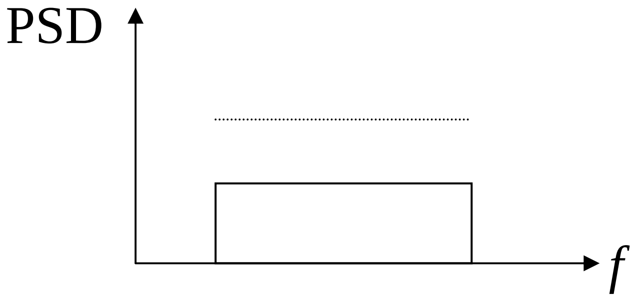
Flat fading

It occurs BW of signal < BW of channel (Coherence BW)

Delay spread < Symbol period



Constructive interference



Destructive interference

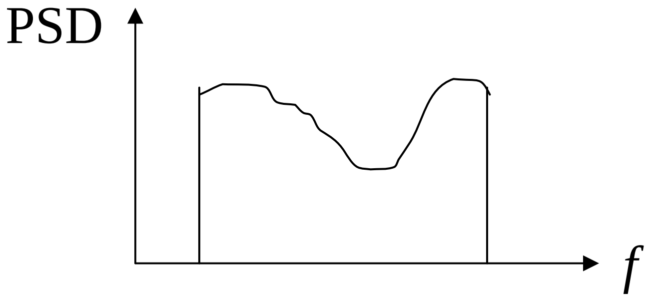
Interplay between fast fading and delay spread

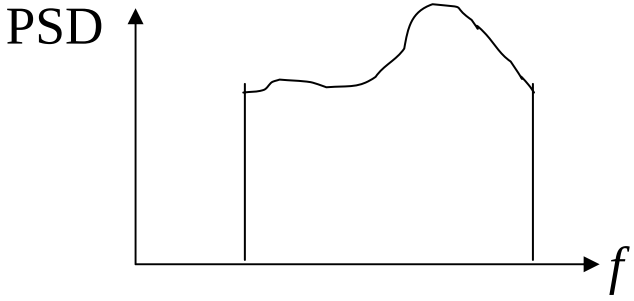
Frequency Selective fading

- BW signal > BW of channel (Coherence BW)
- Delay spread > Symbol period

Example in WCDMA

- 3.84Mcps with chip duration 0.26μsec





Doppler shift

Frequency shifts caused by relative motion

When two movers communicate each other, frequency is shifted

move forward: higher frequency

move away: lower frequency

$(f \times v)/c$

ex) (900MHz × 30m/sec)/(3×10^8m) = 90Hz shift

Doppler shift

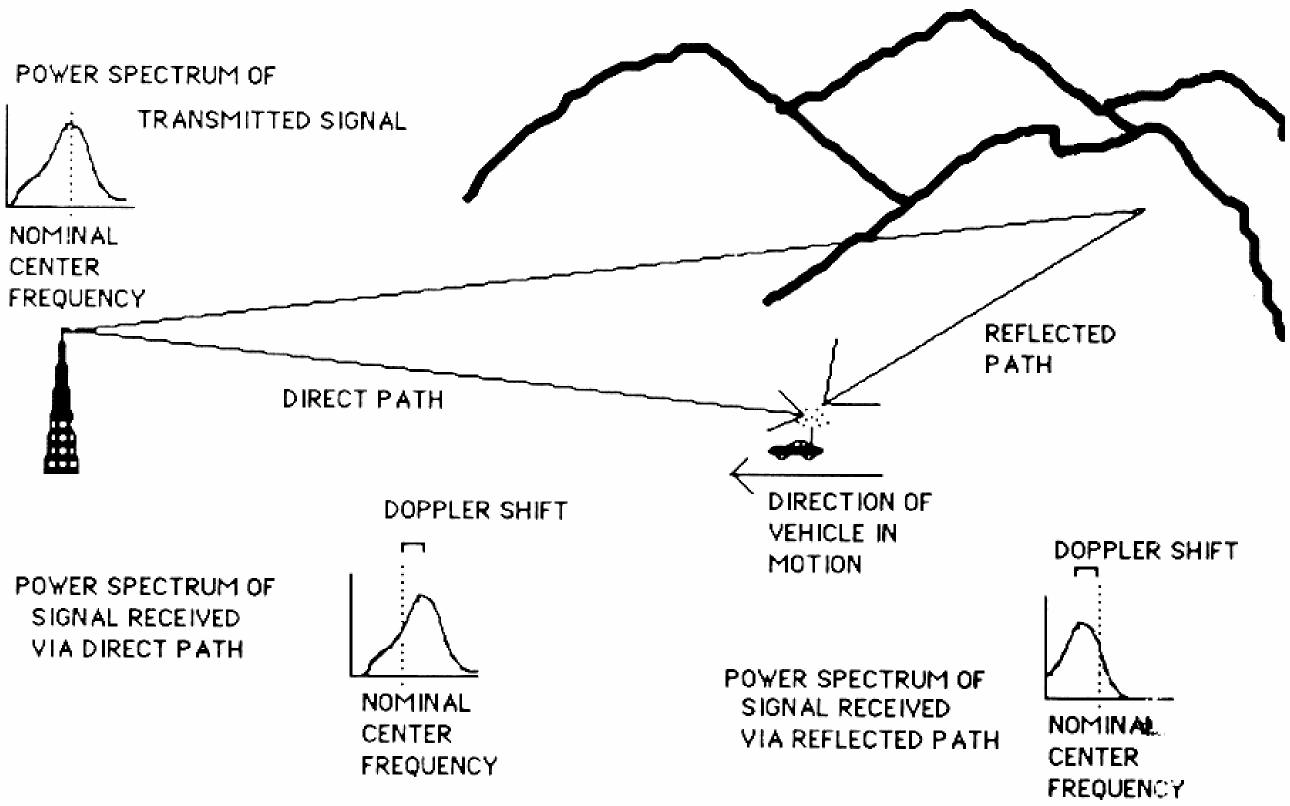


Figure 8.20 Idealization of the Doppler Effect on Received Signals in a Mobile Multipath Environment.

Distortion

Amplitude distortion: Rayleigh fading (-few dB ~ -40dB)

Phase distortion: when the mutipath signal is reflected

Frequency distortion: Doppler Shift

Log-normal Shadowing

Large scale path loss

For arbitrary T-R separation d,

Average Path Loss $\propto (d/d_0)^n$

d_0: reference distance

d: T-R separation

n: path loss exponent

Vastly different environmental effect depending on the measurement locations even with the same T-R separation

Log-normal Shadowing

The measured signal levels at a specific T-R separation have a normal distribution in dB about the average path loss

Slow fading, Large scale propagation loss (10m~100m)

Log-normal Shadowing

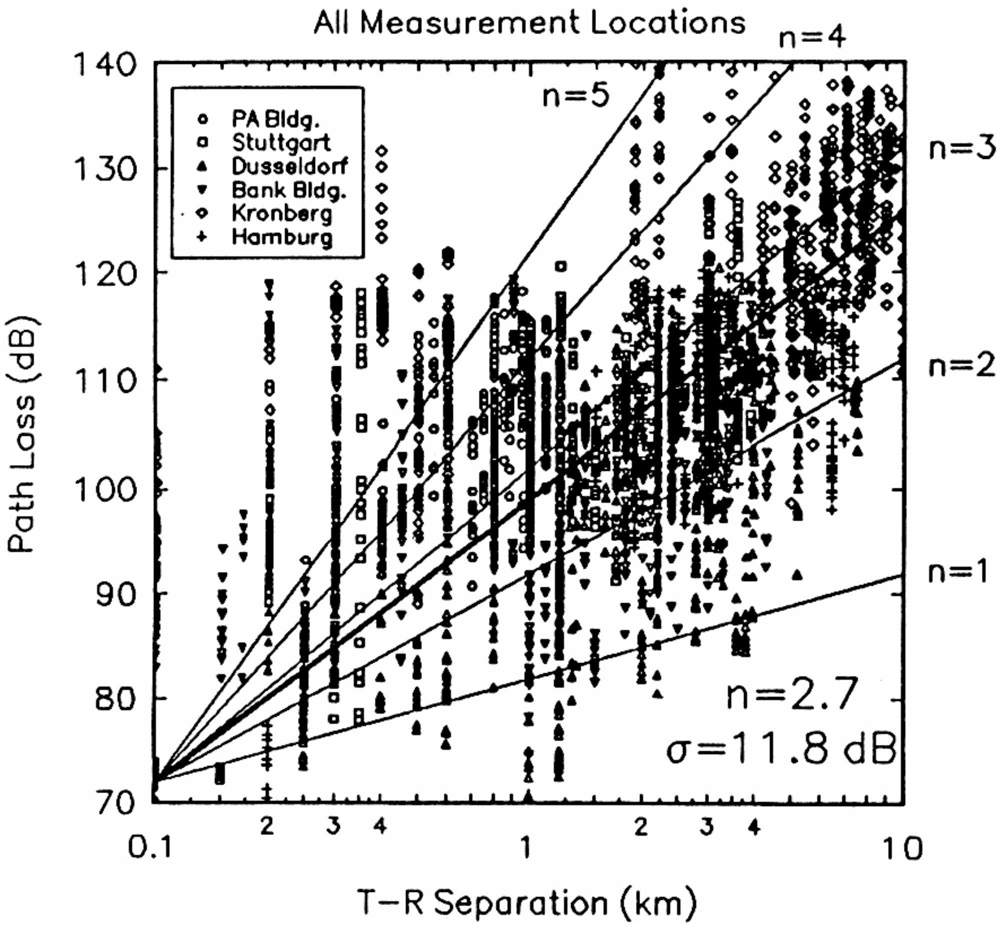


Figure 3.17
Scatter plot of measured data and corresponding MMSE path loss model for six cities in Germany. For this data, $n = 2.7$ and $\sigma = 11.8$ dB [From [Sei91] © IEEE].