

# 無線網路多媒體系統

## Wireless Multimedia System

### Radio Propagation: Issues & Models

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<http://wmlab.csie.ncu.edu.tw/course/wms>

We  
provide  
無線網路多媒體實驗室  
Wireless  
Wireless Network & Multimedia Laboratory  
Solution

# Lecture II Agenda

- ◆ Radio Propagation
  - Physical of radio propagation
  - Two types of propagation models
  - Outdoor vs. Indoor Radio Propagation Model
  - How to do simple “link budget” calculation
  - Combating the radio channel impairment
  
- ◆ Wireless Modem Design
- ◆ Modern Application: 911 services



# Reading list for This Lecture

- ◆ Required Reading:

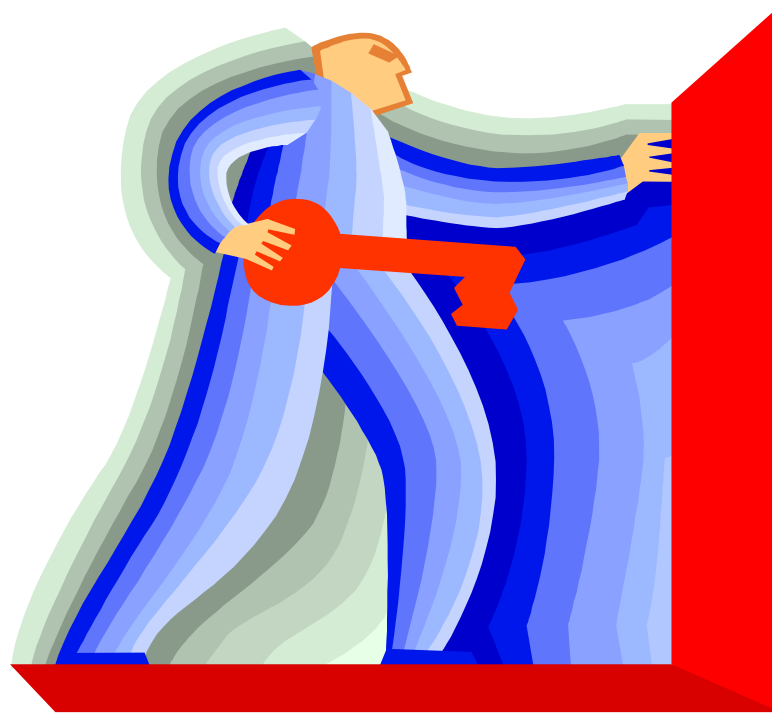
(Jorgen95) J. B. Andersen, T. S. Rappaport, “Propagation Measurements and Models for Wireless Communications channels”, (IEEE Communication Magazine), pp. 42~49

(Jeffrey H98) Jeffrey H. Reed, Kevin J. Krizman, Brian D. Woerner, and T. S. Rappaport, “An Overview of the Challenges and Progress in Meeting the E-911 Requirement for Location Service, (IEEE Communication Magazine), pp.30~37

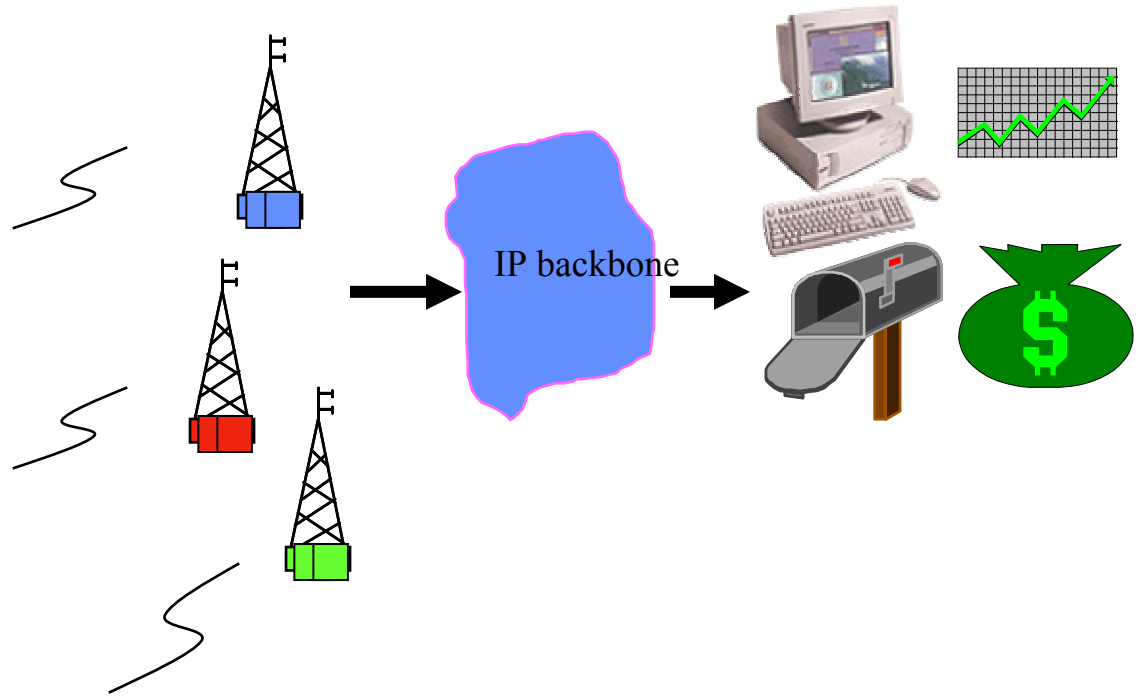
## Further Reading

(Rappaport97) T. S. Rappaport, K. Blankenship, H. Xu, “Propagation and Radio System Design Issues in Mobile Radio Systems for the GloMo Project

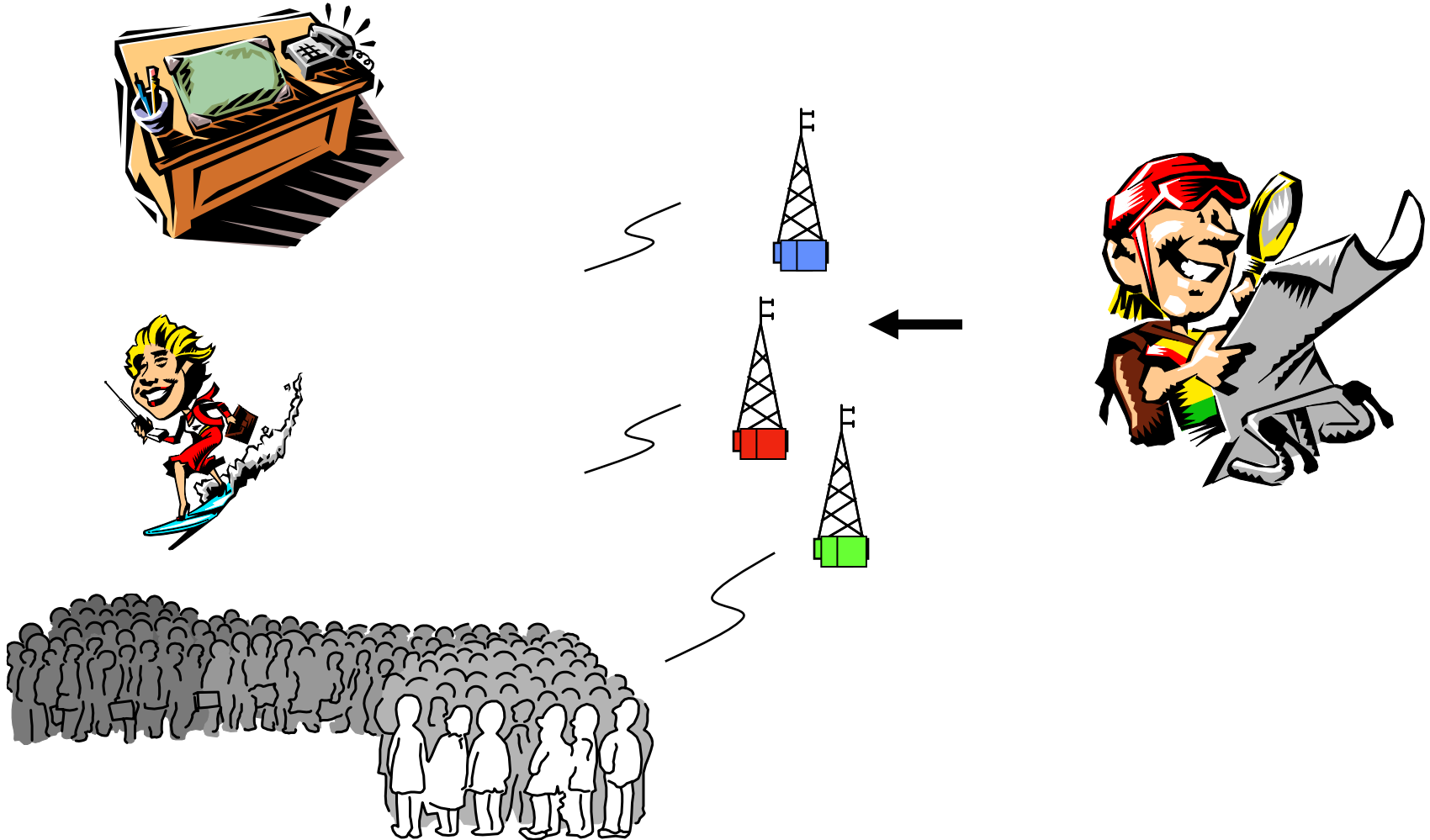
# The mystery of the Radio Propagation



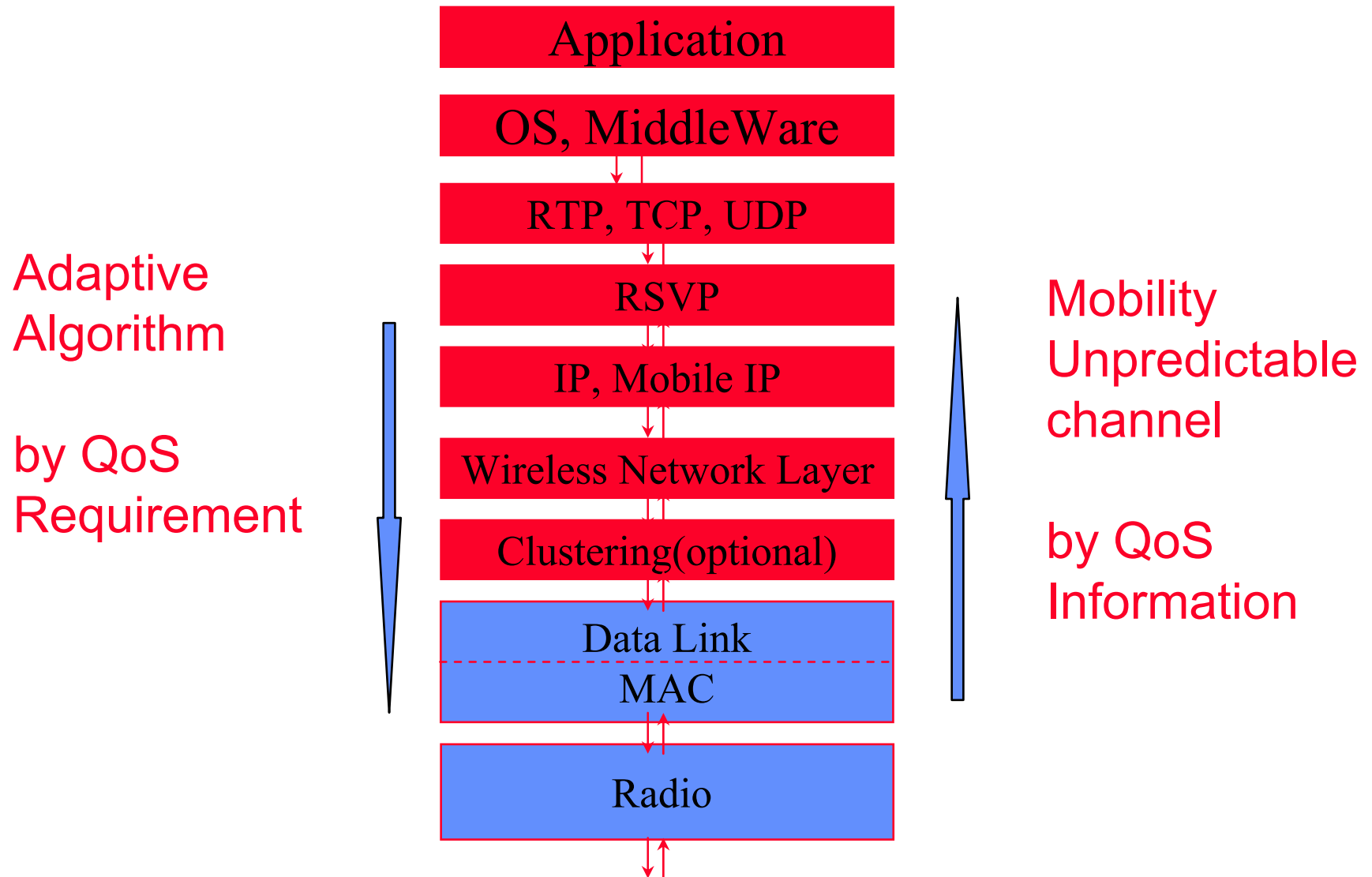
# How to deal with Radio Propagation



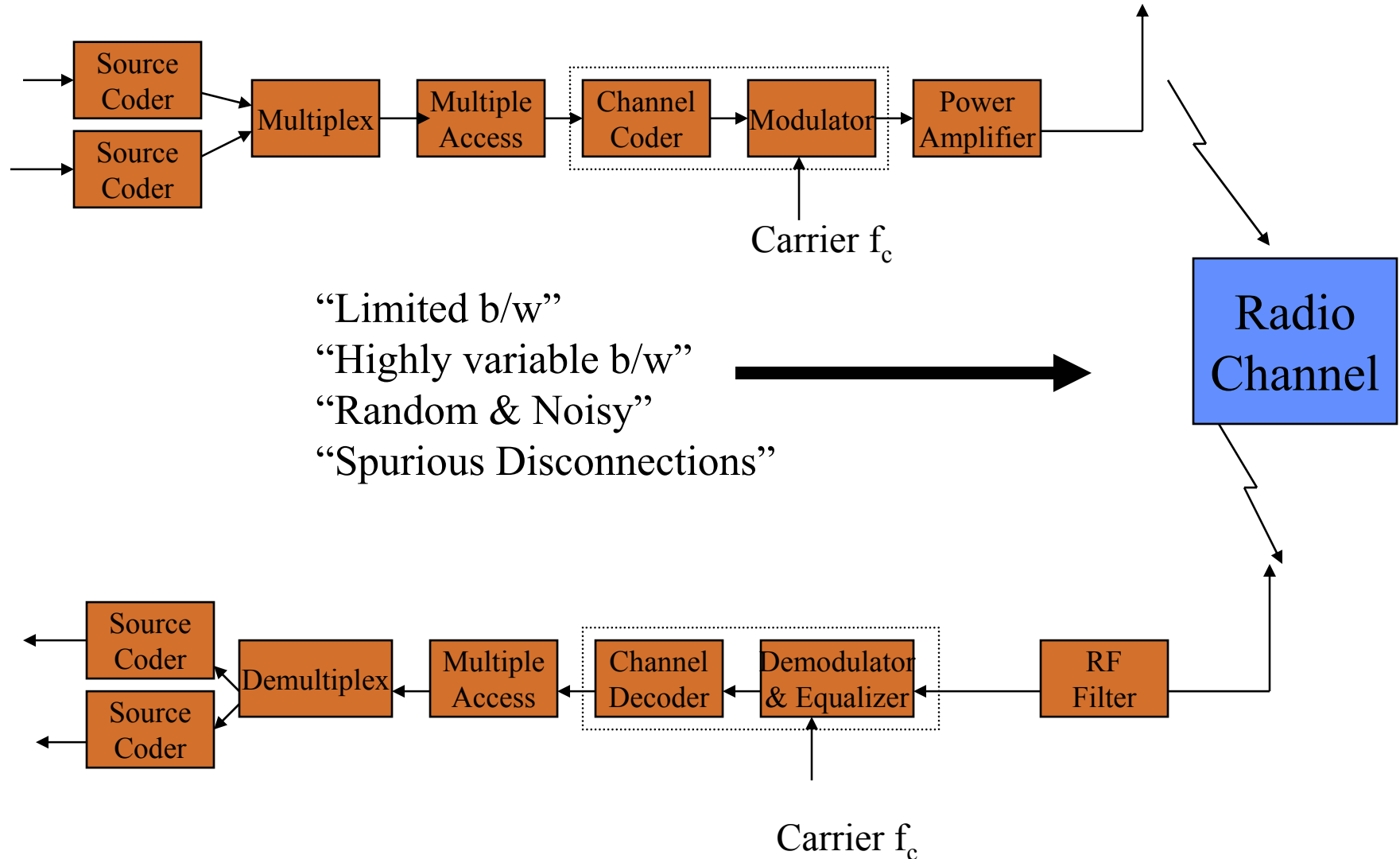
# Where are you from?



# QoS and Multimedia Traffic Support

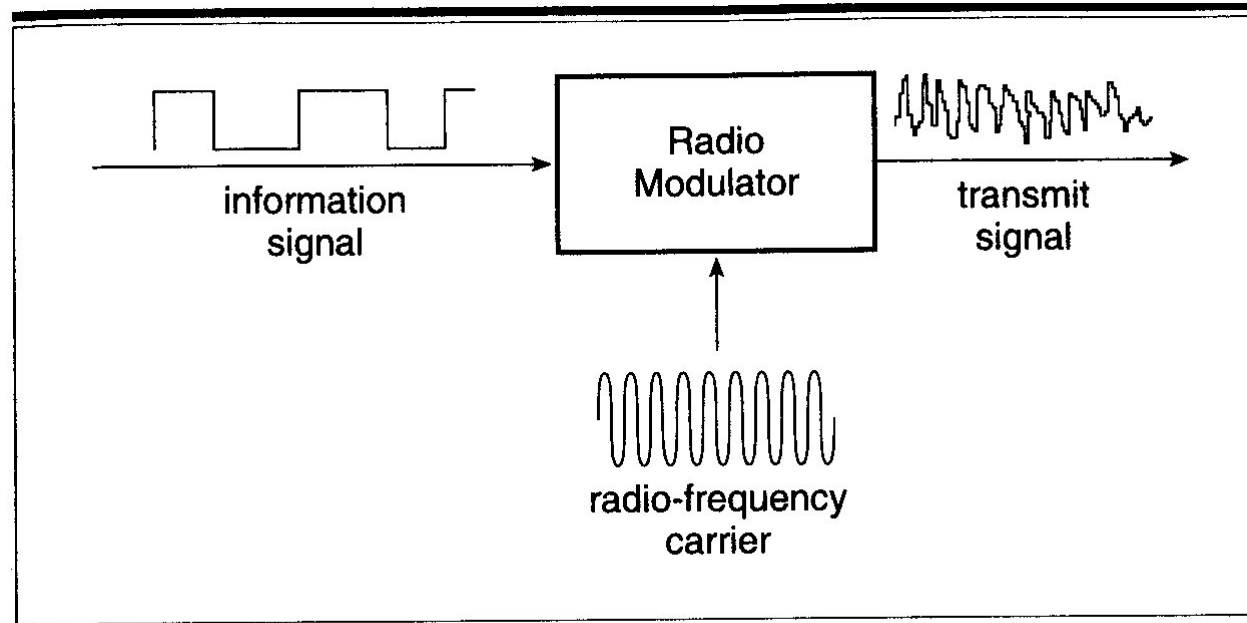


# Simplified View of a Digital Radio Link



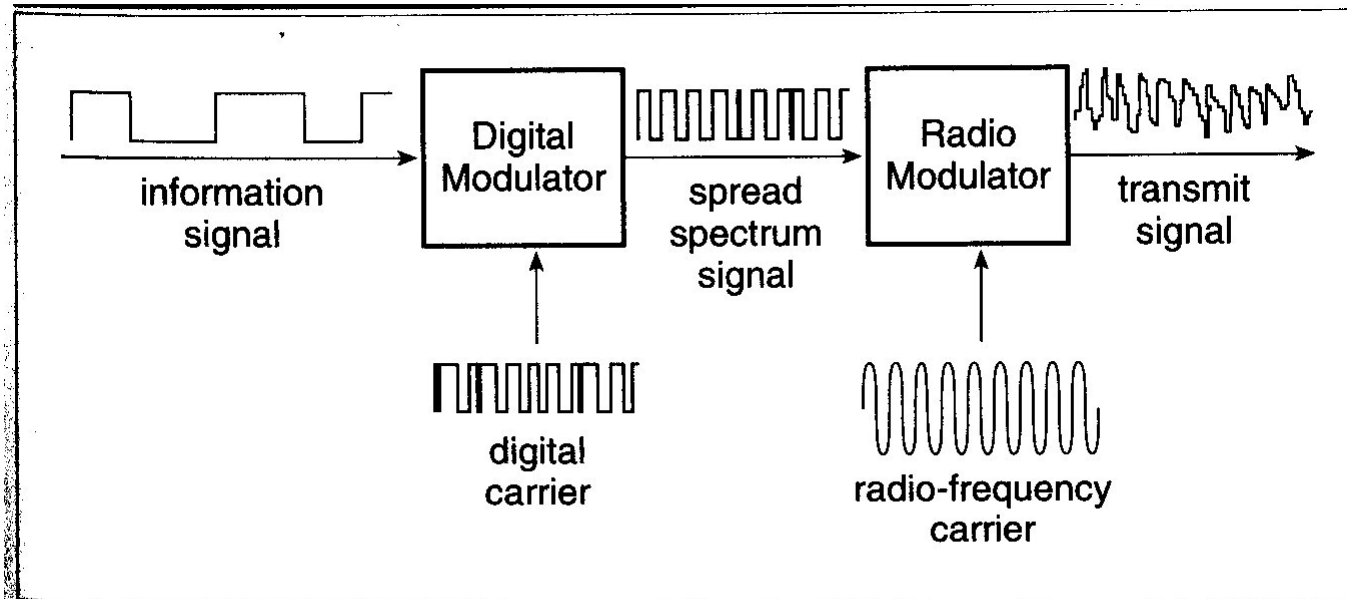


# Digital to Analog Modulation



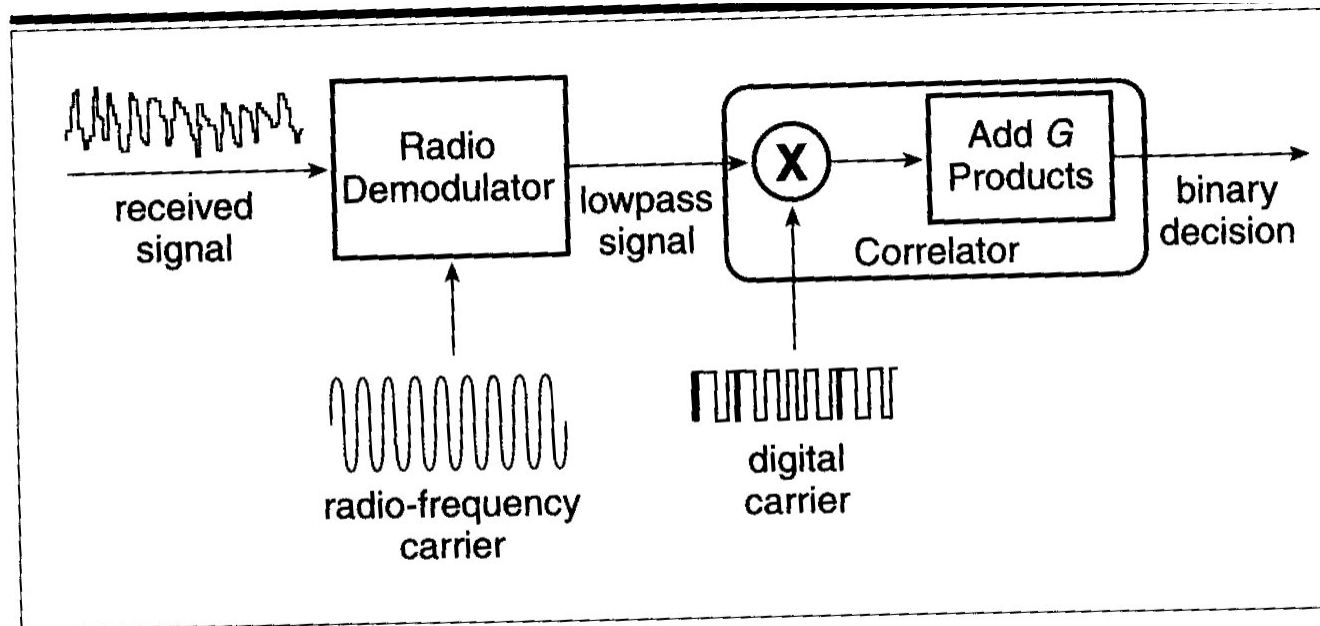
**Figure 6.2** Single-stage digital modulation (TDMA and FDMA).

# Digital-Digital-Analog Modulation



**Figure 6.3** Two stages of modulation in a spread spectrum system.

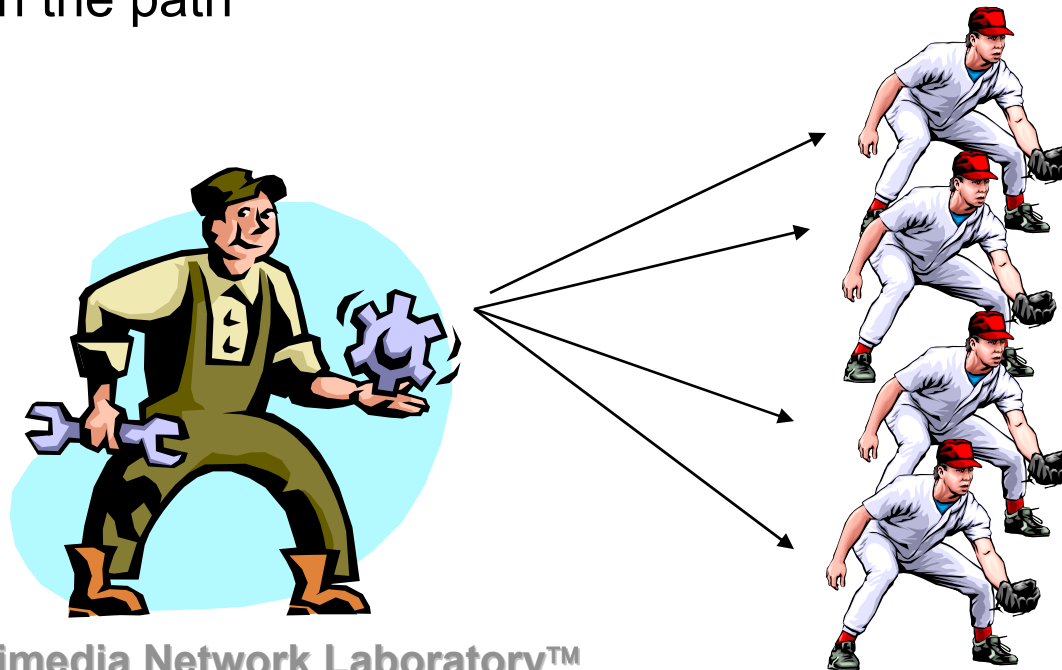
# Digital Correlator



**Figure 6.4** Two stages of demodulation in a spread spectrum receiver.

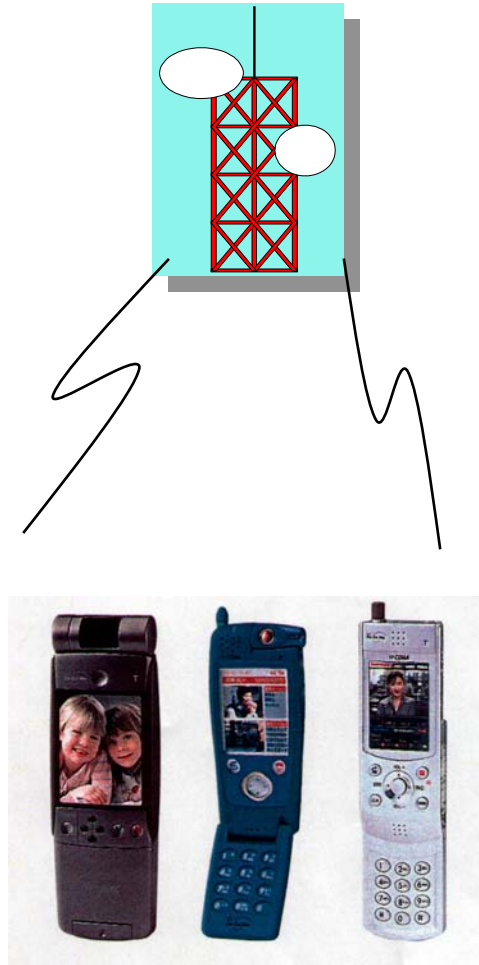
# Multiple correlators

- ◆ Multiple correlators in each receiver
- ◆ At any instant of time, the signal carriers in the different correlators are synchronize to signal paths with different propagation times
- ◆ A search circuit examines the arriving signal in order to detect the appearance of a new path, then assign a correlator to synchronize the signal on the path



# Key role for the radio propagation

- ◆ Radio Propagation determines
  - the area which could be covered
  - The maximum data rate in a system
  - Battery power requirement for mobile transceivers





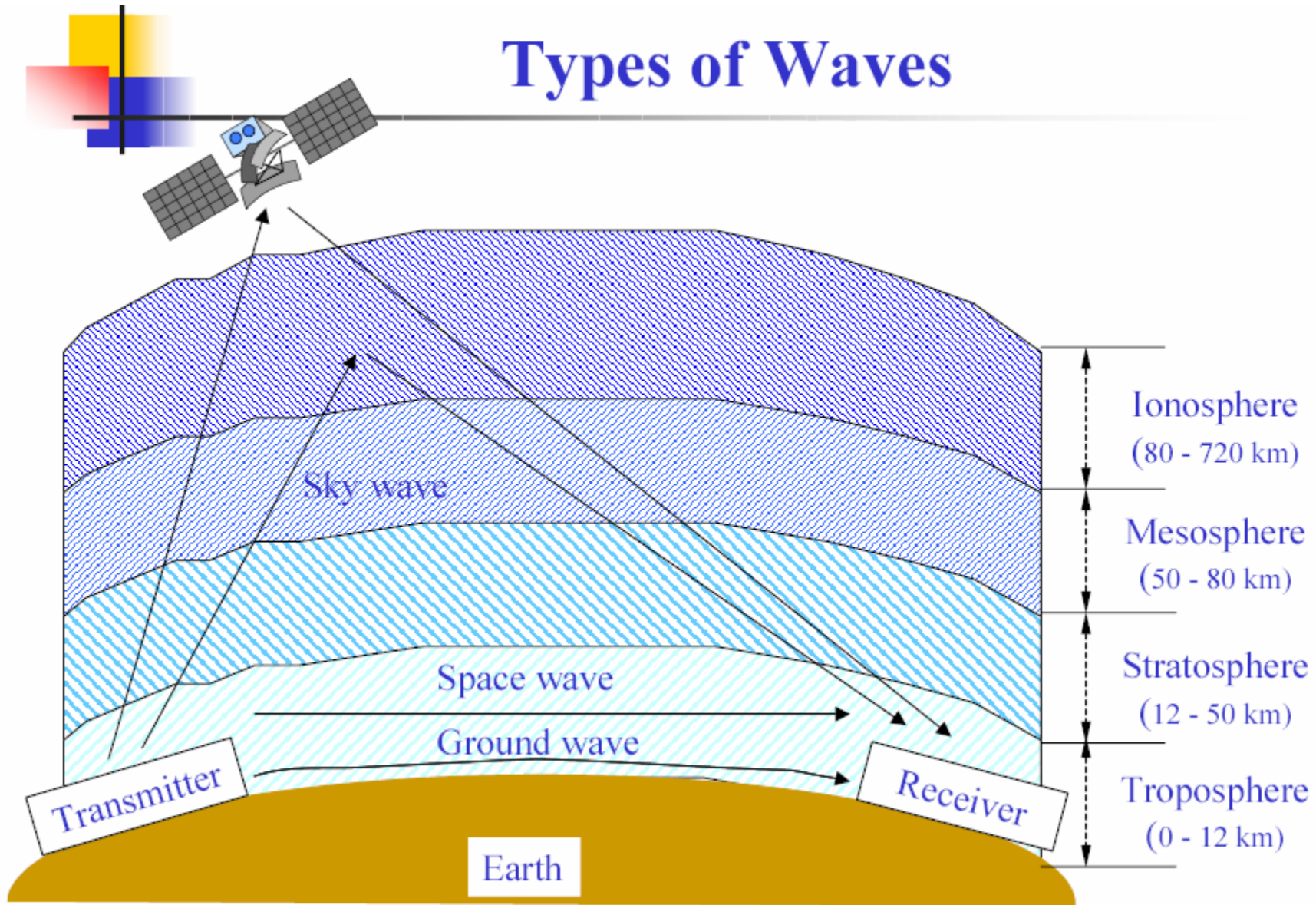
# Speed, Wavelength, Frequency

Light speed = Wavelength x Frequency

=  $3 \times 10^8$  m/s = 300,000 km/s

System	Frequency	Wavelength
AC current	60 Hz	5,000 km
FM radio	100 MHz	3 m
Cellular	800 MHz	37.5 cm
Ka band satellite	20 GHz	15 mm
Ultraviolet light	$10^{15}$ Hz	$10^{-7}$ m

# Types of Waves



# Radio Frequency Bands

Classification Band	Initials	Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	
Infra low	ILF	300 Hz • •3 kHz	
Very low	VLF	3 kHz • •30 kHz	
Low	LF	30 kHz • •300 kHz	Surface/ground wave
Medium	MF	300 kHz • •3 MHz	
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	
Extremely high	EHF	30 GHz • •300 GHz	Satellite wave
Tremendously high	THF	300 GHz • •3000 GHz	



# Radio Channel

- ◆ Free Space
- ◆ Land Mobile
- ◆ Multi-path Propagation
- ◆ Shadow



# Some Distributions

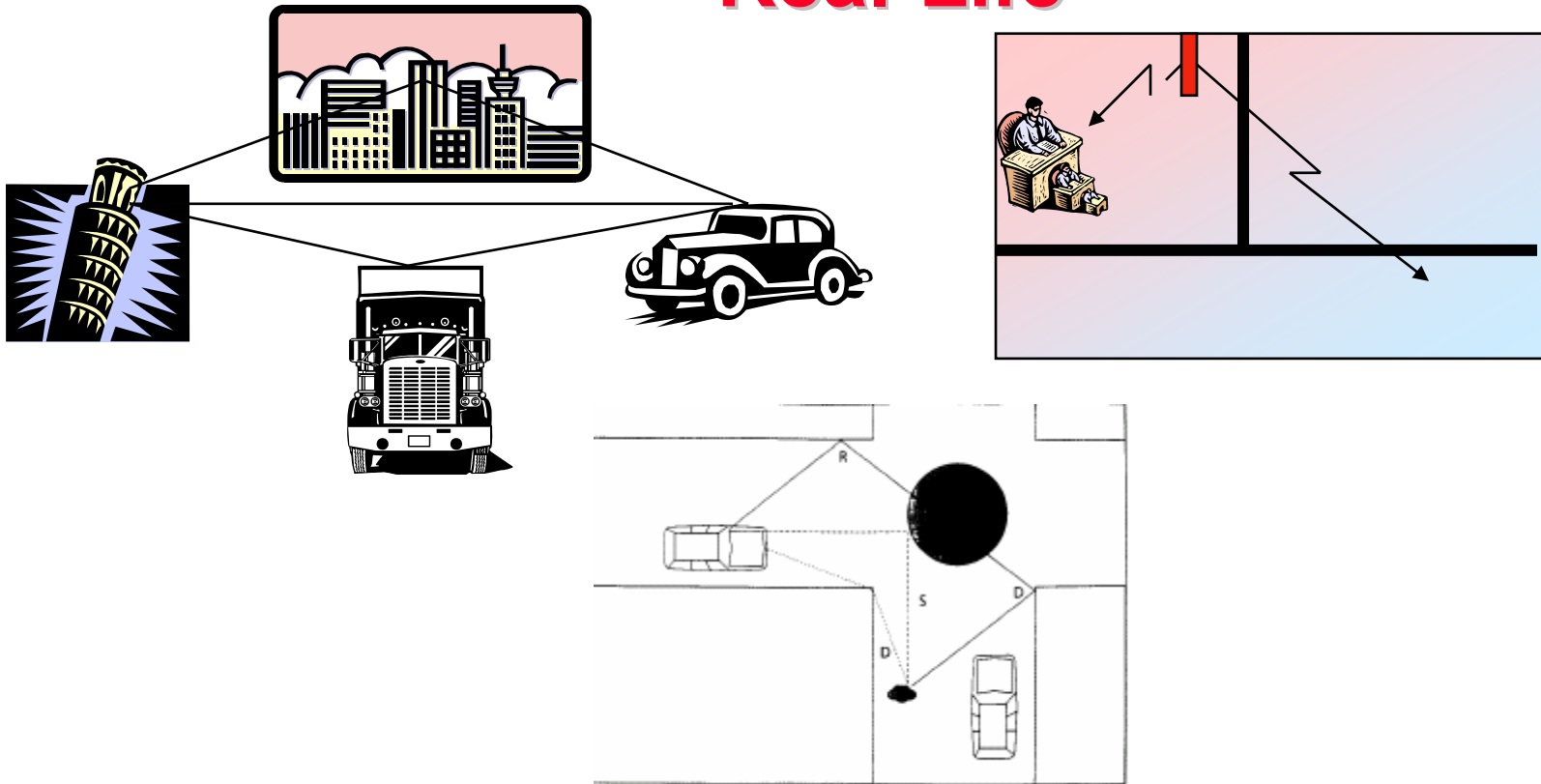
- ◆ Normal (Gaussian)
- ◆ Log-normal Distribution
- ◆ Rayleigh Distribution
- ◆ Rician Distribution
  - Dominant path
- ◆ Impulse Response



# Propagation Mechanisms in Space with Objects

- ◆ Reflection (with Transmittance and Absorption)
  - Radio wave impinges on an object
  - Surface of earth, walls, buildings, atmospheric layers
  - If perfect (lossless) dielectric object, then zero absorption
  - If perfect conductor, then 100% reflection
- ◆ Diffraction
  - Radio path is obstructed by an impenetrable surface with sharp irregularities (edges)
  - Secondary waves “bend” around the obstacle (Huygen’s principle)
  - Explain how RF energy can travel without LOS
  - “shadowing
- ◆ Scattering (diffusion)
  - Similar principles as diffraction, energy reradiated in many directions

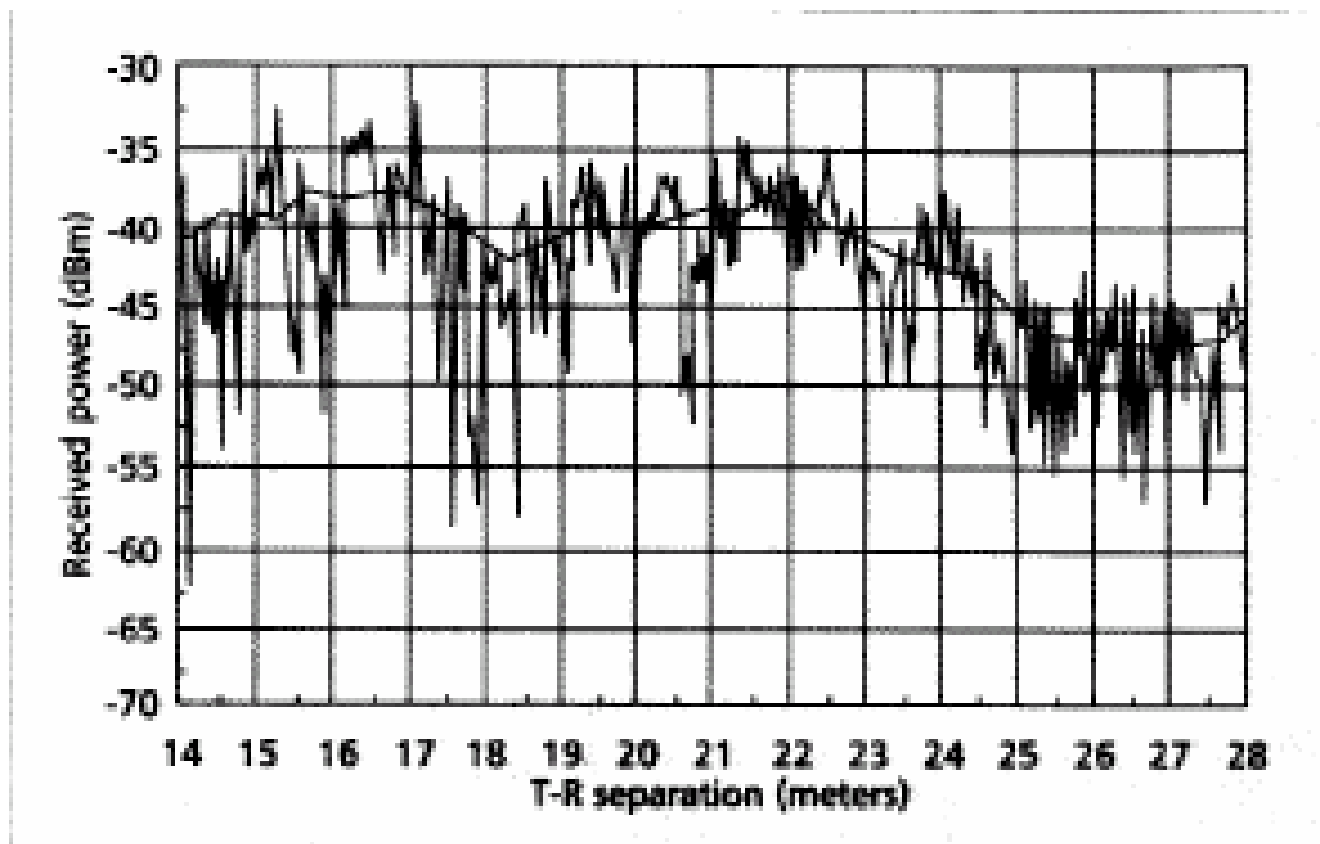
# Reflection, Diffraction, and Scattering in Real-Life



- ◆ Received signal often a sum of contributions from different directions
- ◆ Random phases make the sum behave as noise (Rayleigh Fading)

# Small-scale and Large-scale Fading

- ◆ Signal fades rapidly as receiver moves, but the local average signal changes much more slowly



# Path Loss (Free-space)

- Definition of path loss  $L_p$ :

$$L_P = \frac{P_t}{P_r},$$

Path Loss in Free-space:

$$L_{PF}(dB) = 32.45 + 20 \log_{10} f_c (MHz) + 20 \log_{10} d(km),$$

where  $f_c$  is the carrier frequency.

This shows greater the  $f_c$ , more is the loss.

# Land Propagation

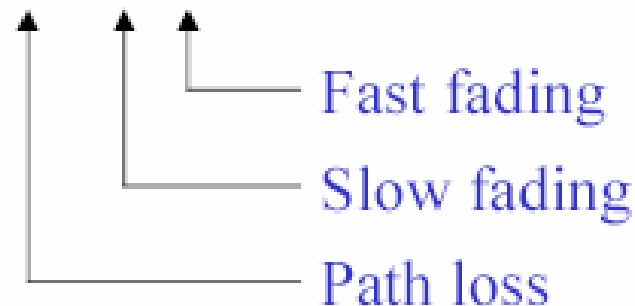
- The received signal power:

$$P_r = \frac{G_t G_r P_t}{L}$$

where  $G_r$  is the receiver antenna gain,

$L$  is the propagation loss in the channel, i.e.,

$$L = L_p L_S L_F$$



# Path Loss (Free-space)

- Definition of path loss  $L_p$ :

$$L_p = \frac{P_t}{P_r},$$

Path Loss in Free-space:

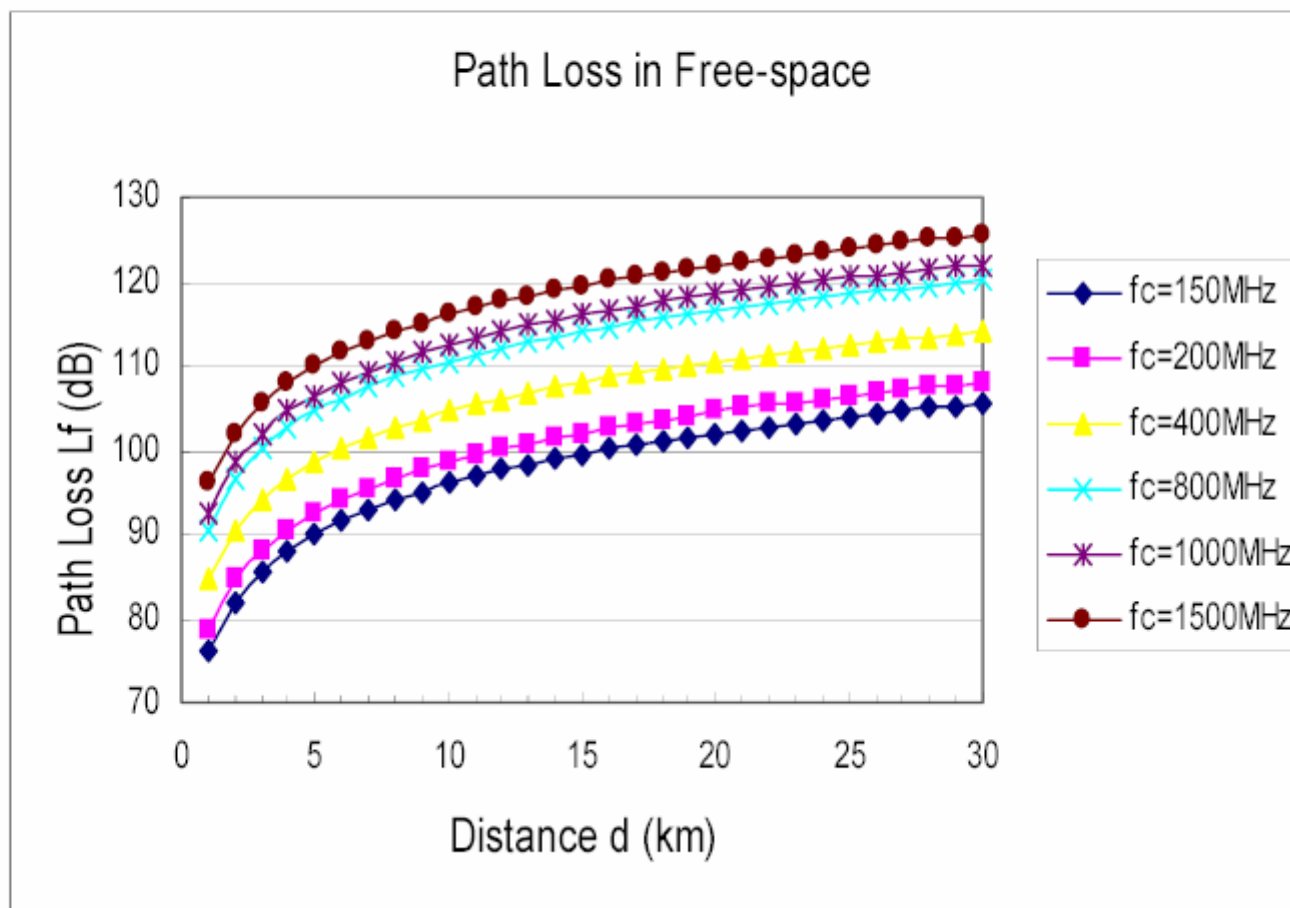
$$L_{pF} (dB) = 32.45 + 20 \log_{10} f_c (MHz) + 20 \log_{10} d (km),$$

where  $f_c$  is the carrier frequency.

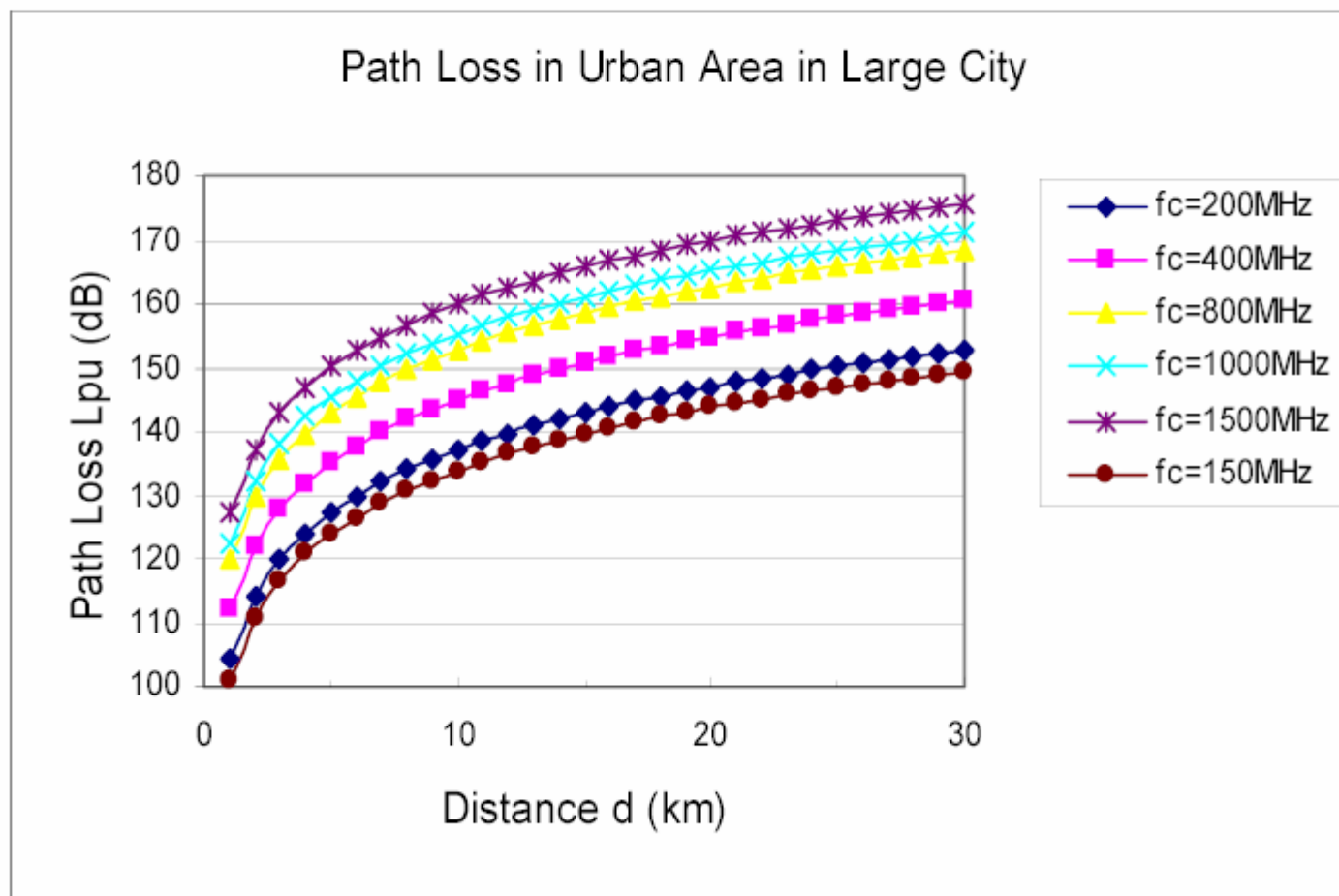
This shows greater the  $f_c$ , more is the loss.



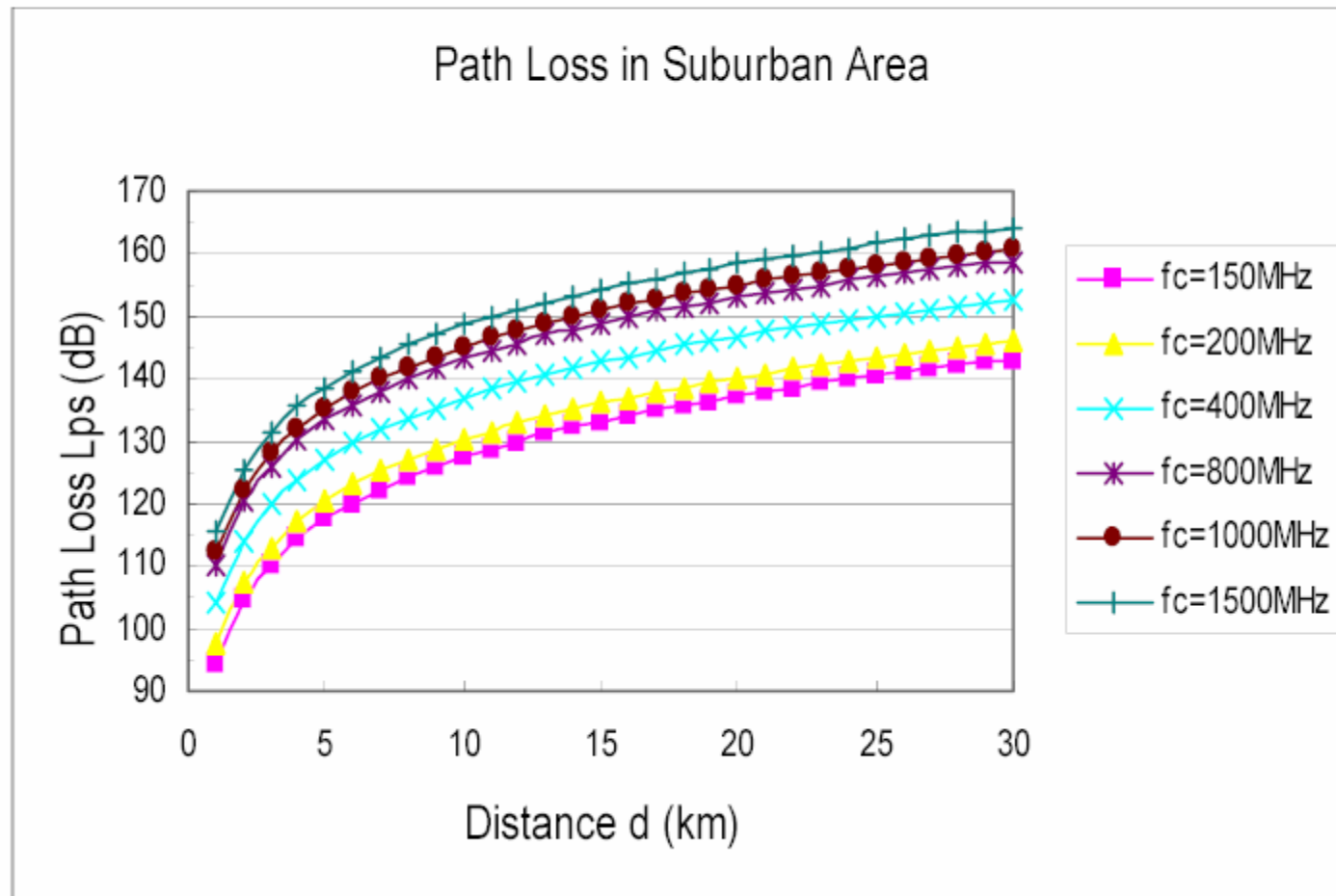
# Example of Path Loss (Free-space)



# Example of Path Loss (Urban Area: Large City)

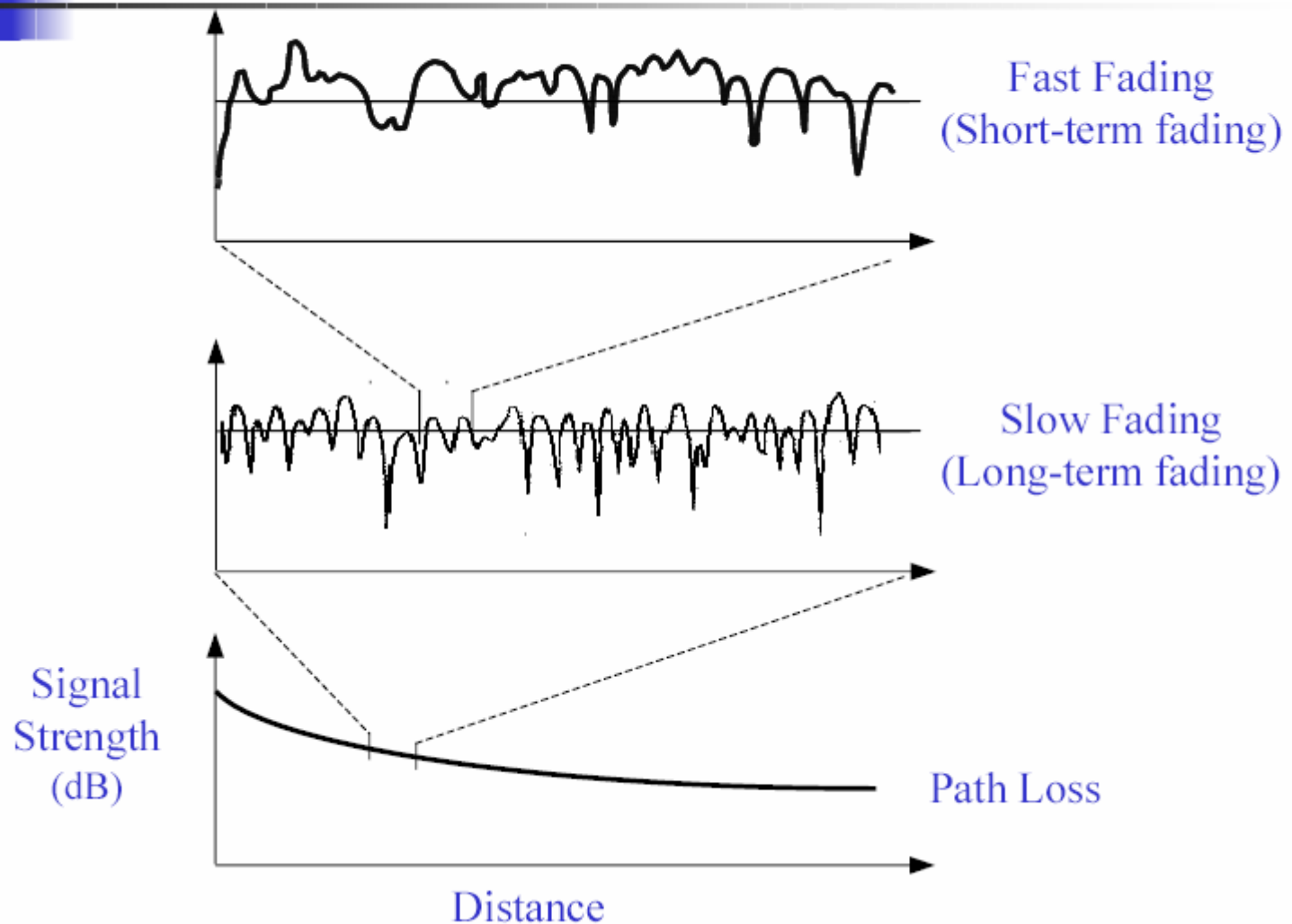


# Example of Path Loss (Suburban Area)



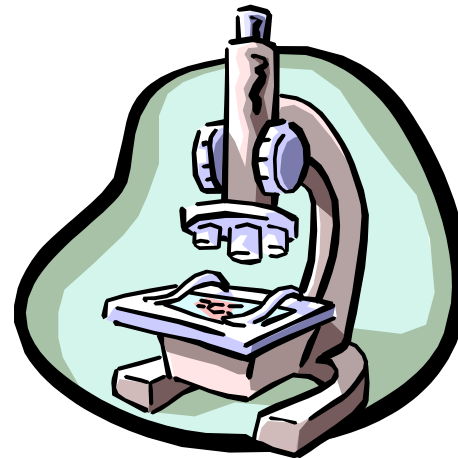


# Fading



# Analysis of the Propagation

- ◆ Large Scale Effect
  - The variation of the mean received signal strength over large distance or long time intervals
- ◆ Small Scale Effect
  - The fluctuations of the received signal strength about a local mean, where these fluctuations occur over small distances or short time interval



# Large Scale -> Link Budget



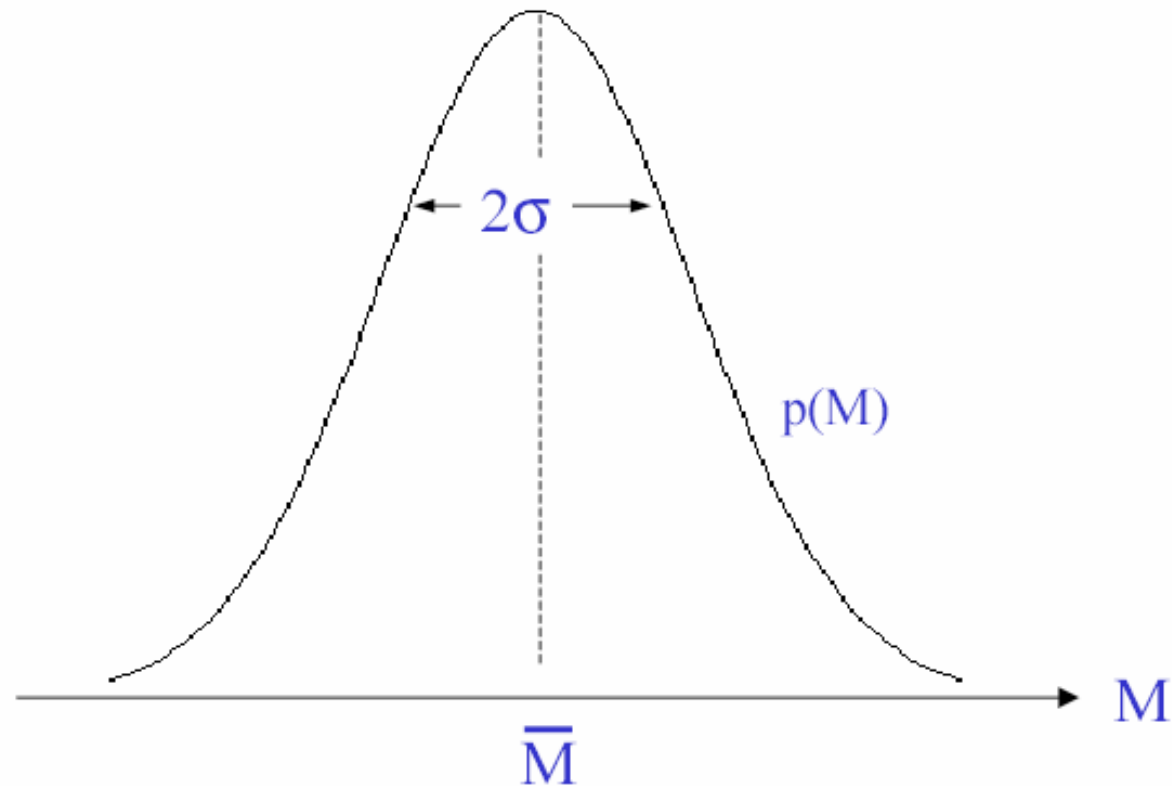
# Slow Fading

- The long-term variation in the mean level is known as slow fading (shadowing or log-normal fading). This fading caused by shadowing.
- Log-normal distribution:
  - The pdf of the received signal level is given in decibels by

$$p(M) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(M-\bar{M})^2}{2\sigma^2}},$$

where  $M$  is the true received signal level  $m$  in decibels, i.e.,  $10\log_{10}m$ ,  
 $\bar{M}$  is the area average signal level, i.e., the mean of  $M$ ,  
 $\sigma$  is the standard deviation in decibels

# Log-normal Distribution



The pdf of the received signal level



# Free Space Propagation Model

- ◆ Used when Transmitter and Receiver have a clear, unobstructed, line of sight (LOS) path
  - e.g. satellite channels, microwave LOS radio links

- ◆ Free space power at a receiver antenna at a distance  $d$  from transmitter antenna is

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

where,

$G_t$  and  $G_r$  are antenna gains

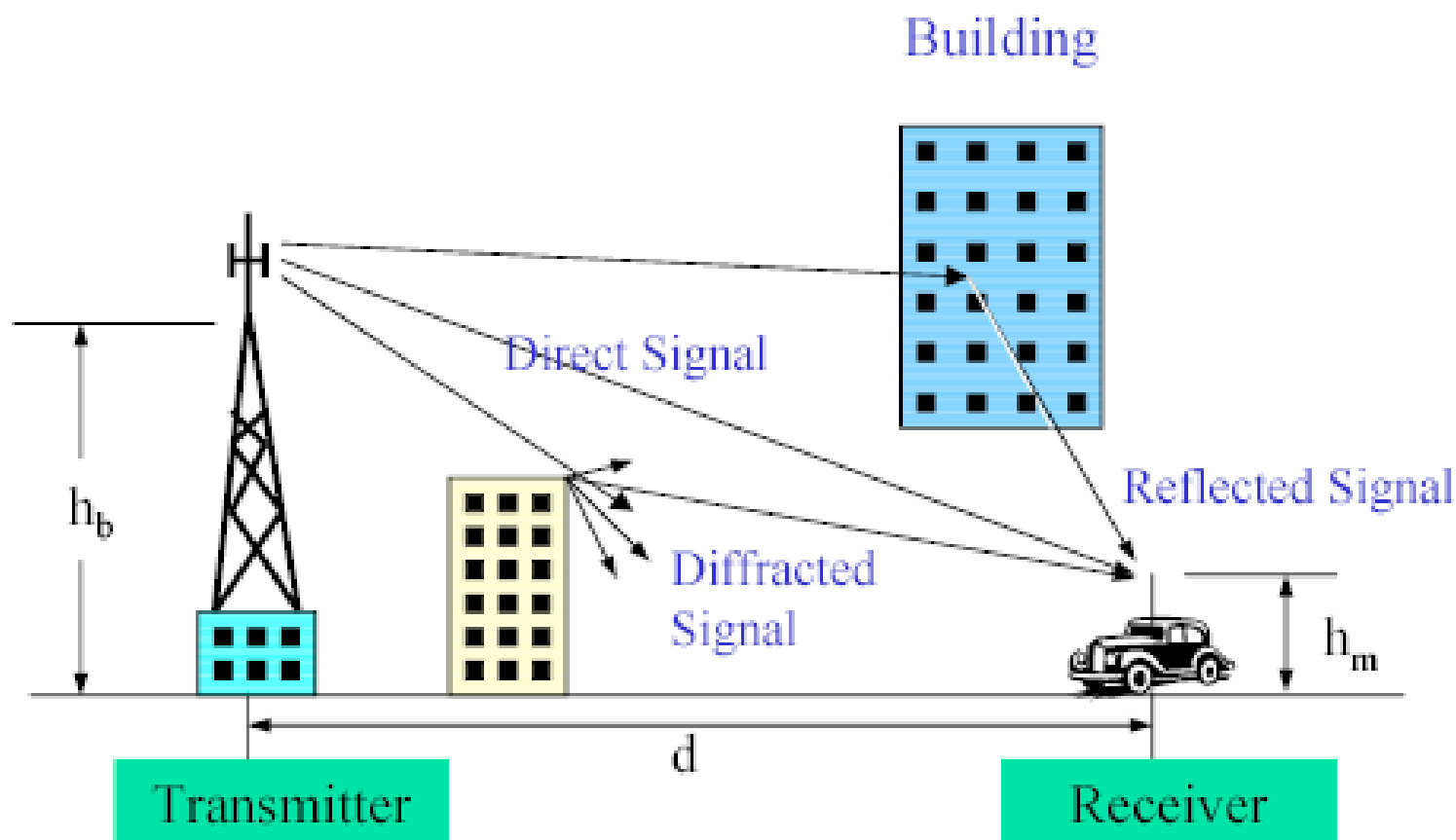
$L \geq 1$  is the system loss factor not related to propagation  
(e.g. loss due to filter losses, hardware)

- ◆ Path loss = signal attenuation as a positive quantity in dB

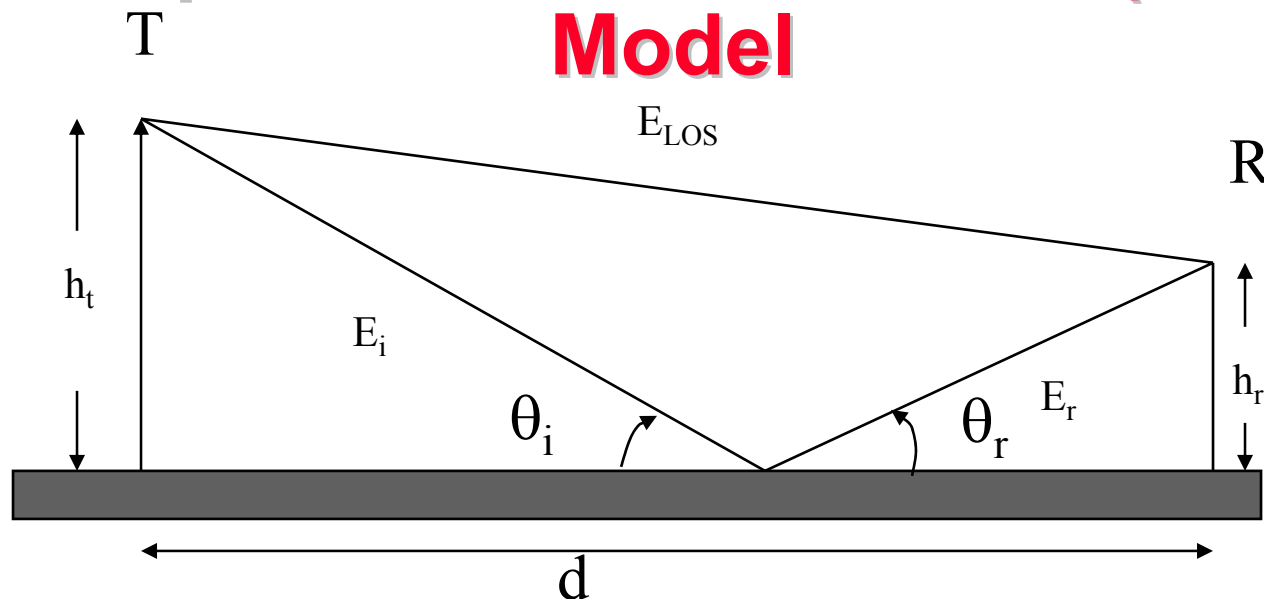
$$Pl(dB) = 10 \log \frac{P_t}{P_r}$$

$$P_t(dBm) = 10 \log [P_t(mW) / 1mW]$$

# Radio Propagation Effects



# Example: Ground Reflection (2-Ray) Model



- ◆ Model found a good predictor for large-scale signal strength over distances of several kilometers for mobile systems with tall towers (heights > 50m) as well as for LOS microcell channels
- ◆ Can show (physics) that for large  $d$

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4}$$

- ◆ Much more rapid path loss than expected due to free spaces

# Log-Distance Path Loss Model

- ◆ Assume average power (in dB) decreases proportional to log of distance

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n \log\left(\frac{d}{d_0}\right)$$

- ◆ Justification?
  - Measurements
  - Intuition/theory.. Recall; free space, ground-reflection model
- ◆ Problem: “Environment Clutter” may differ at two locations at the same time (Log-normal Shadowing)

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n \log\left(\frac{d}{d_0}\right) + X_\sigma$$

# Typical Path Loss Exponent, $n$

Environment	Path Loss Exponent, $n$
Free Space	2
Urban area cellular / PCS	2.7 to 4.0
Shadow urban cellular / PCS	3 to 5
In building line of sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

# Practical Link Budget Design Using Path Loss Models

- ◆ Bit-Error-rate is a function of SNR (signal-to-noise ratio), or equivalently CIR (carrier-to-interference ratio), at the receiver
  - The “function” itself depends on the modulation scheme
- ◆ Link budget calculations allow one to compute SCR or CIR
- ◆ Battery Life-> Talk Time -> received/Transmitted power -> Path Loss Models



$$SNR(dB) = P_s(dBm) - N(dBm)$$

$$P_s(dBm) = (P_t) + (G_t) + (G_r) - (\overline{PL}(d))$$

$$N = KT_0BF$$

$$N = -174(dBm) + 10\log_{10} B + F(dB)$$

# Example Link Budget Calculation

- ◆ Maximum separation distance vs. transmitted power (with fixed BW)
  - Given
    - ◆ Cellular phone with 0.6W transmitted power
    - ◆ Unity gain antenna, 900 MHz carrier frequency
    - ◆ SNR must be at least 25 dB for proper reception
    - ◆ Receiver BW is  $B=30\text{KHz}$ , noise figure  $F=10\text{ dB}$
  - What will be the maximum distance?
  - Solution:
    - ◆  $N = -174\text{ dBm} + 10 \log 30000 + 10\text{ dB}$
    - ◆ For  $\text{SNR} > 25\text{ dB}$ , we must have  $P_r > (-119+25) = -94\text{ dBm}$
    - ◆  $P_t = 0.6\text{W} = 27.78\text{ dBm}$
    - ◆ This allows path loss  $PL(d) = P_t - P_r < 122\text{ dB}$   
 for free space,  $n=2$ ,  $d < 33.5\text{ km}$   
 for shadowed urban with  $n=4$ ,  $d < 5.8\text{ km}$

# Small Scale -> Quality of Service





# Small-Scale Fading Effects (over small $t$ and $x$ )



- ◆ Fading manifests itself in three ways
  - Time dispersion caused by different delays limits transmission rates
  - Rapid changes in signal strength over small  $x$  or  $t$
  - Random frequency modulation due to varying Doppler shifts
- ◆ In urban areas, mobile antenna heights  $\ll$  height of buildings
  - Usually no LOS from base station
- ◆ Moving surrounding objects also cause time-varying fading

# Factors Influencing Small-Scale Fading

- ◆ Multi-path propagation
- ◆ Speed of Mobile
- ◆ Speed of surrounding objects
- ◆ Transmission bandwidth of the signal

# Fast Fading

- The signal from the transmitter may be reflected from objects such as hills, buildings, or vehicles.
  - When MS far from BS, the envelope distribution of received signal is Rayleigh distribution. The pdf is

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, \quad r > 0$$

where  $\sigma$  is the standard deviation.

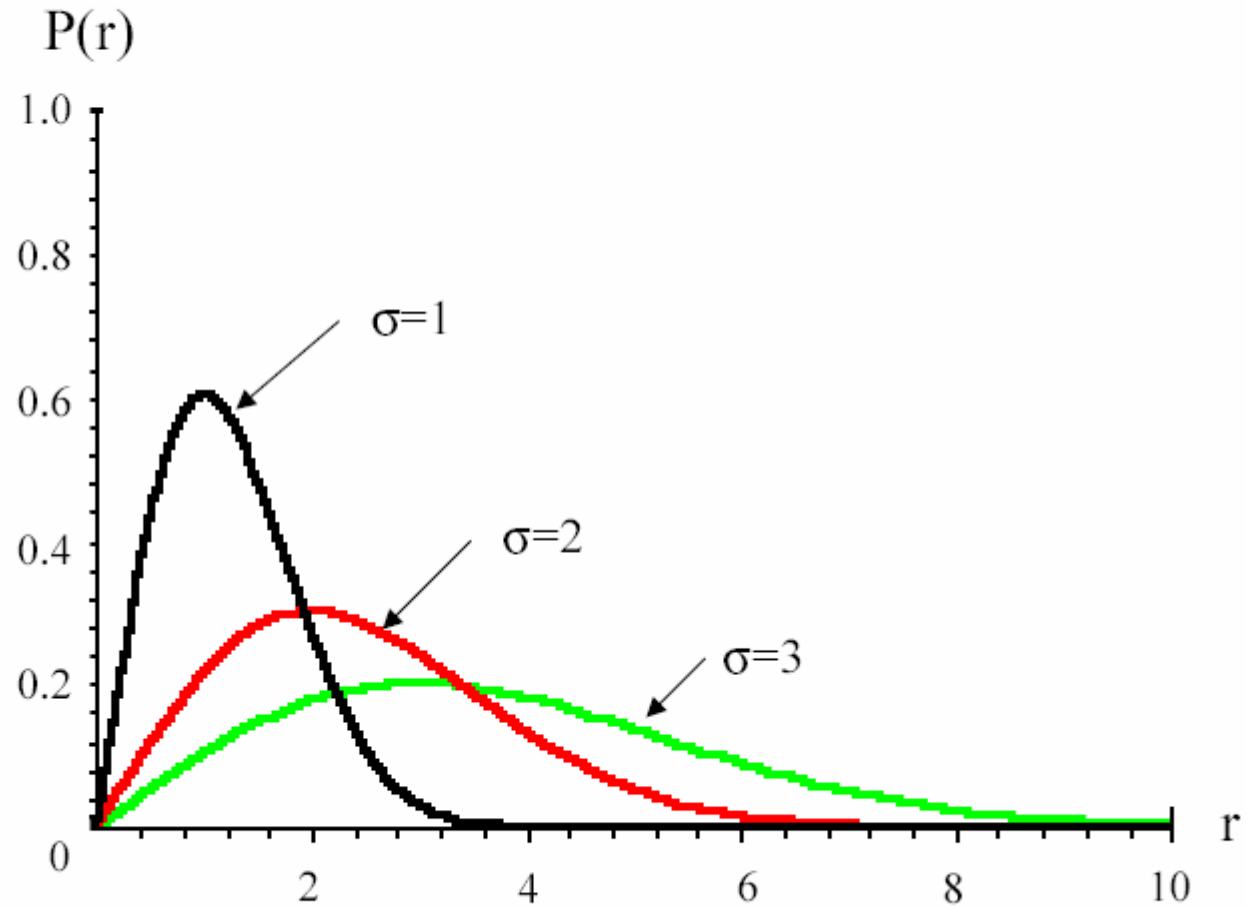
- Middle value  $r_m$  of envelope signal within sample range to be satisfied by

$$P(r \leq r_m) = 0.5.$$

- We have  $r_m = 1.777 \cdot \sigma$



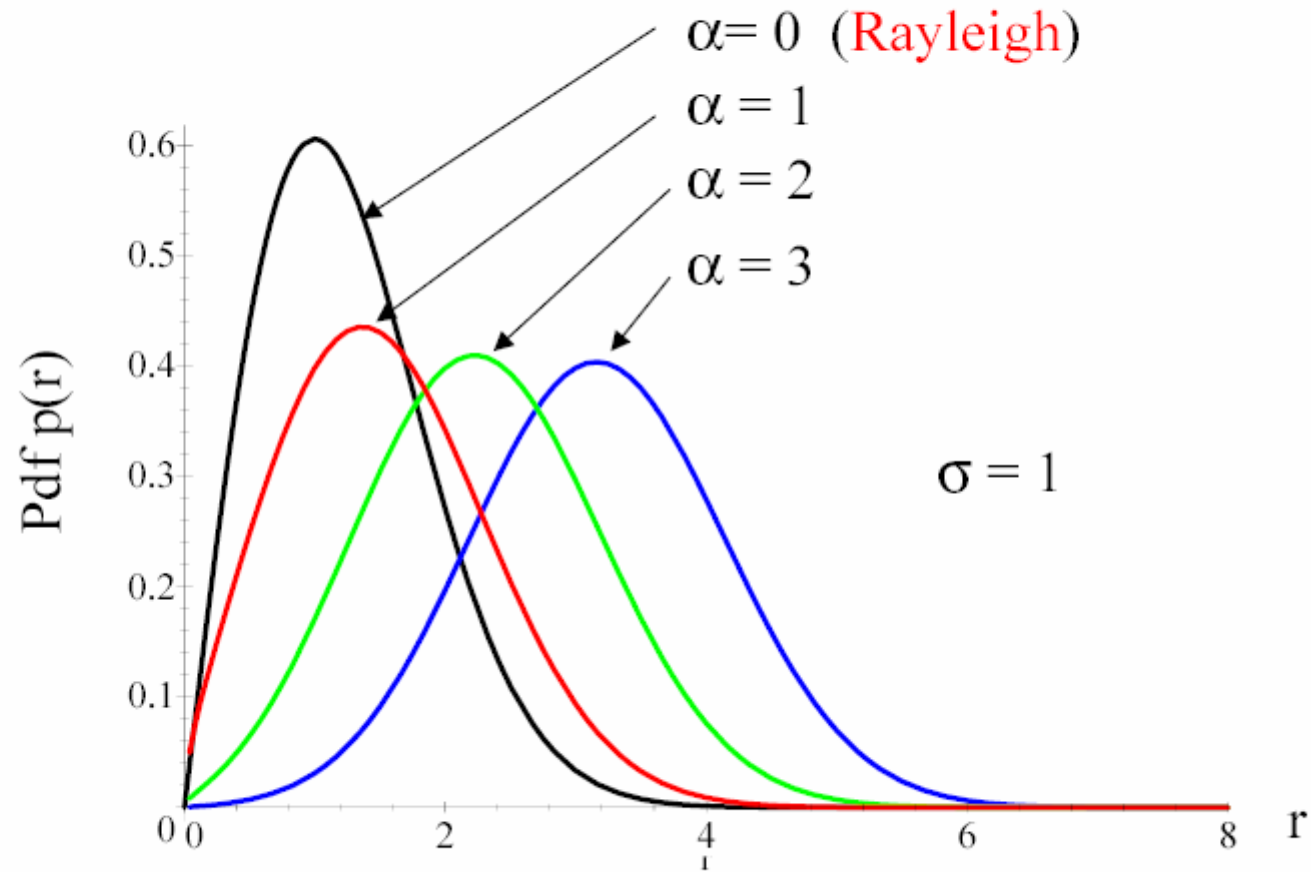
# Rayleigh Distribution



The pdf of the envelope variation

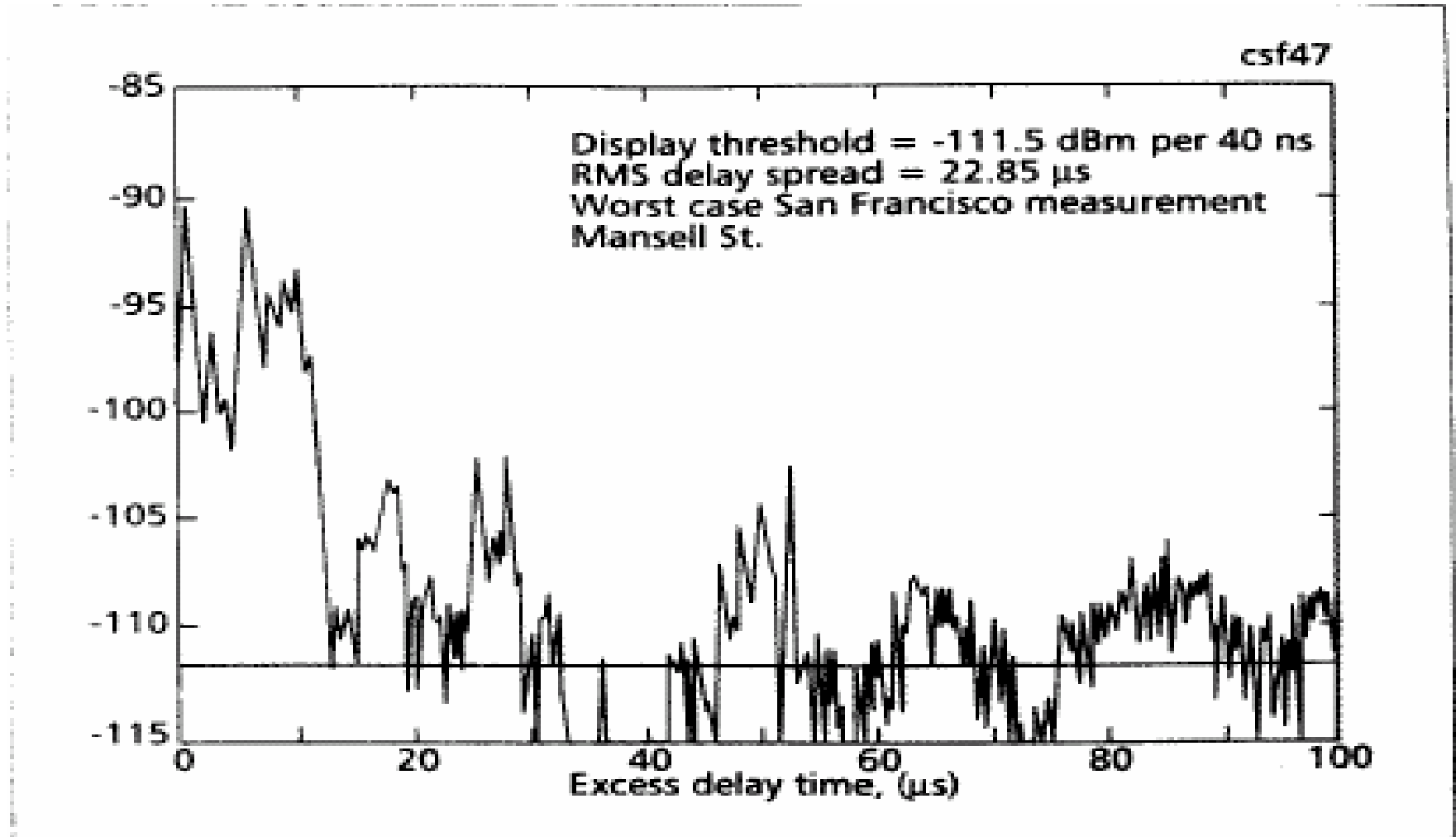


# Rician Distribution



The pdf of the envelope variation

# Delay Spread



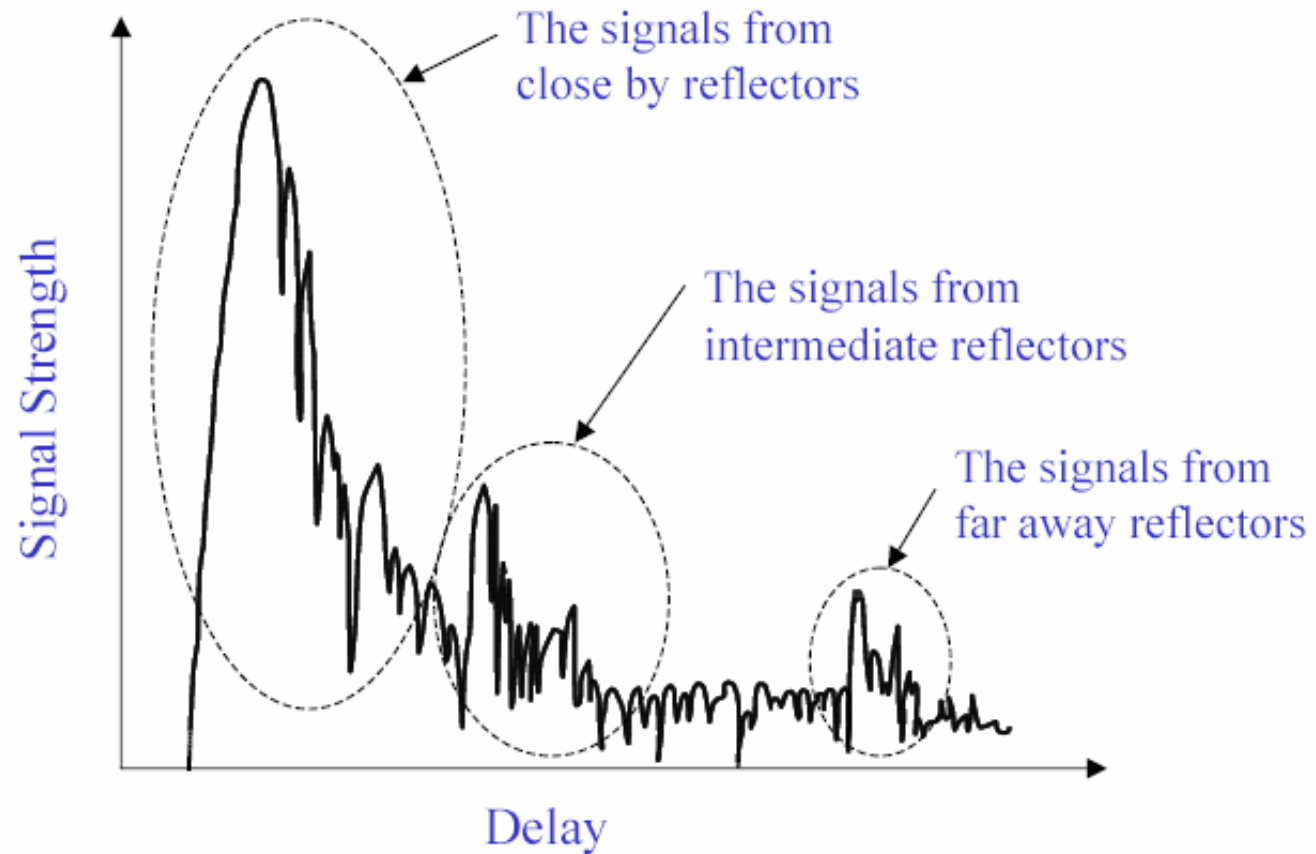


# Delay Spread

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- When a signal propagates from a transmitter to a receiver, signal suffers one or more reflections.
- This forces signal to follow different paths.
- Each path has different path length, so the time of arrival for each path is different.
- This effect which spreads out the signal is called “Delay Spread”.

# Delay Spread







# Intersymbol Interference (ISI)

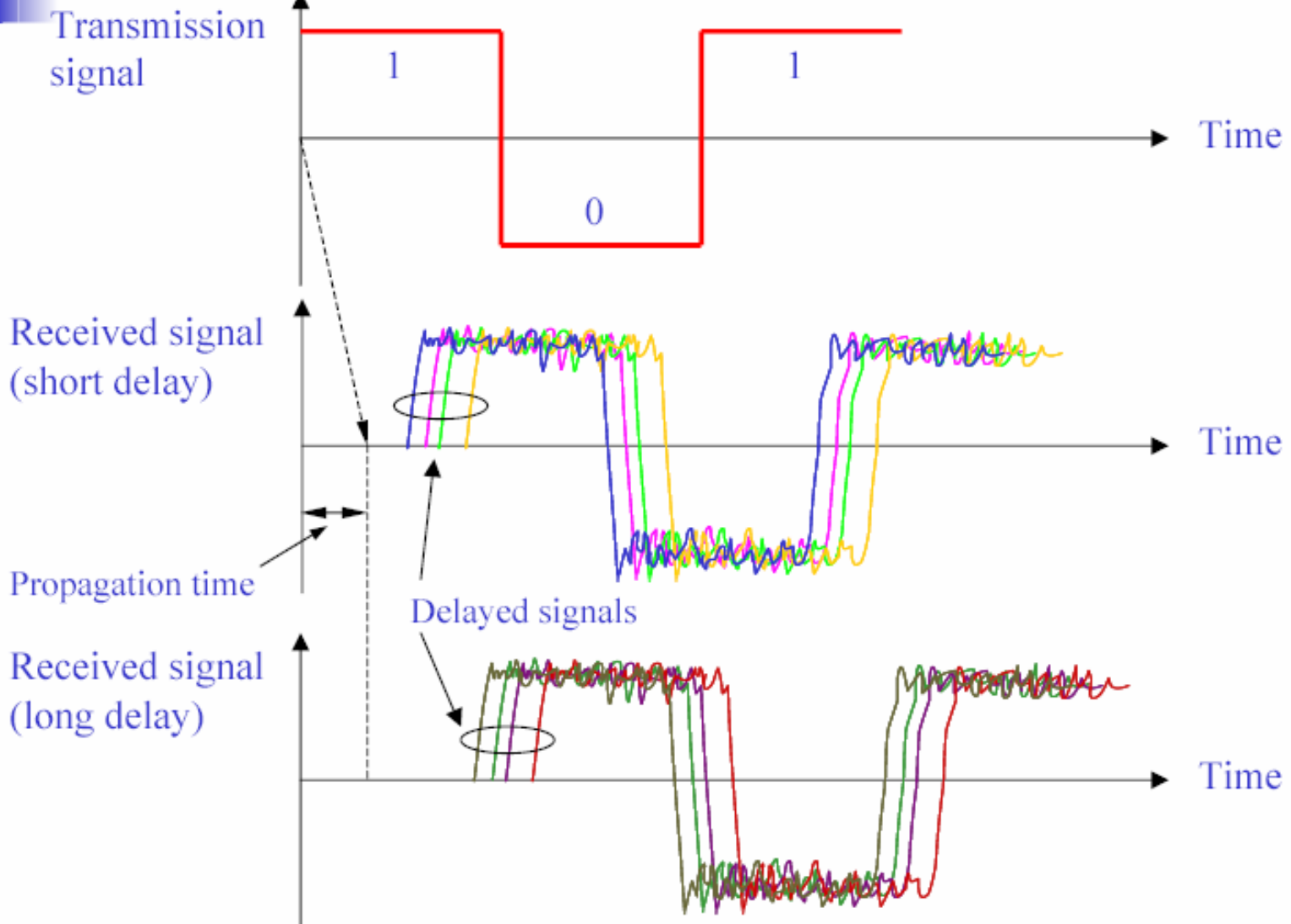
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- Caused by time delayed multipath signals
- Has impact on burst error rate of channel
- Second multipath is delayed and is received during next symbol
- For low bit-error-rate (BER)

$$R < \frac{1}{2\tau_d}$$

- $R$  (digital transmission rate) limited by delay spread.

# Intersymbol Interference (ISI)



# Coherence Bandwidth

- Coherence bandwidth  $B_c$ :
  - Represents correlation between 2 fading signal envelopes at frequencies  $f_1$  and  $f_2$ .
  - Is a function of delay spread.
  - Two frequencies that are larger than coherence bandwidth fade independently.
  - Concept useful in diversity reception
    - Multiple copies of same message are sent using different frequencies.

# Parameters of a Multipath Channel

- ◆ Multipath Channel Impulse Response (measured by sounding technique)

$$h(t) = \sum_{i=1}^N a_i e^{j\theta_i} \delta(t - \tau_i)$$

- ◆ Four important parameters of interest

- RMS delay spread

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\overline{\tau})^2}, \overline{\tau} = \sum_k a_k^2 \tau_k / \sum_k a_k^2, \overline{\tau^2} = \sum_k a_k^2 \tau_k^2 / \sum_k a_k^2$$

- Coherence bandwidth

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

- Doppler spread

$$B_D = f_m = \max((v/\lambda) \cos \theta) = (v/c) f_{carrier}$$

- Coherence time

$$T_c = 0.423 / f_m$$

# Doppler Shift

- Doppler Effect: When a wave source and a receiver are moving towards each other, the frequency of the received signal will not be the same as the source.
  - When they are moving toward each other, the frequency of the received signal is higher than the source.
  - When they are opposing each other, the frequency decreases.

Thus, the frequency of the received signal is

$$f_R = f_C - f_D$$

where  $f_C$  is the frequency of source carrier,

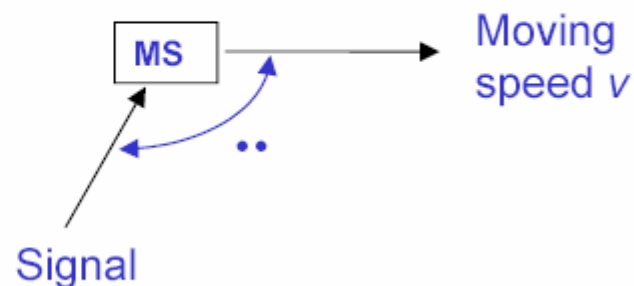
$f_D$  is the Doppler frequency.

- Doppler Shift in frequency:

$$f_D = \frac{v}{\lambda} \cos\theta$$

where  $v$  is the moving speed,

$\lambda$  is the wavelength of carrier.



# Types of Fading

- ◆ Two independent mechanisms:
  - Time Dispersion (Due to Multi-path delays)
    - ◆ Flat fading
    - ◆ Frequency Selective Fading
  - Doppler Spread (due to Motion of mobile or channel)
    - ◆ Fast Fading
    - ◆ Slow Fading

# Fades: Why do we care?

- ◆ Data Rate
- ◆ Equalization
- ◆ Fades result in “Error Bursts”
- ◆ Average duration of (Flat) fades
- ◆ Depends primarily on speed of the mobile.

# The Design of Wireless Modem



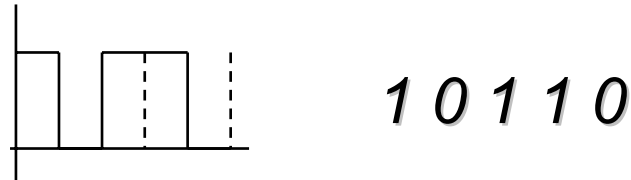


# Combating Errors

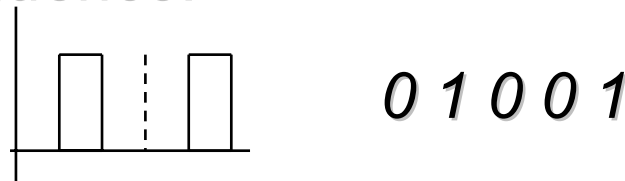
- ◆ Increase transmitted power
- ◆ (Adaptive) Equalization
- ◆ Antenna or space diversity for “Multipath”
- ◆ Forward error correction
- ◆ Automatic Repeat Request (ARQ)

# Direct Sequence Spread Spectrum

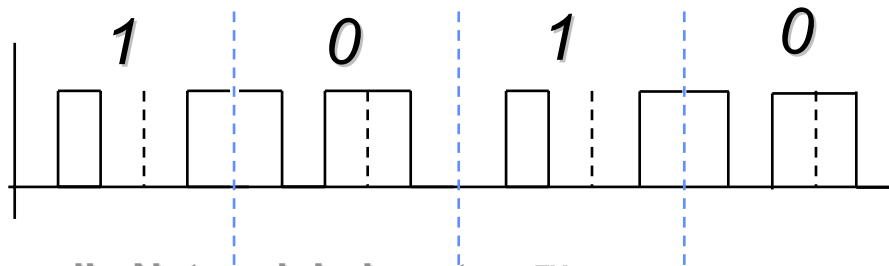
To transmit a 0 the station use a unique “chip sequence”:



To transmit a 1 the station use the one’s complement of its chip sequence:

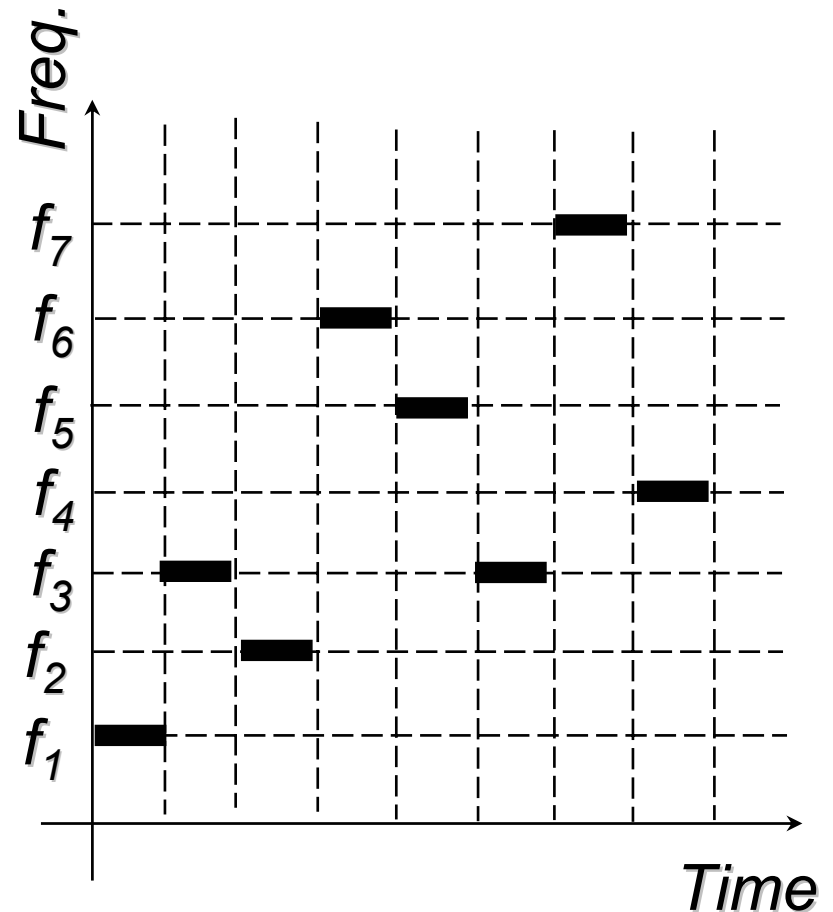


Therefore if data is 1010 it will transmit:



# Frequency Hopping Spread Spectrum

- ◆ Transmitted signal is spread over a wide range of frequencies. (i.e. 2.400-2.485 GHz)
- ◆ Transmission usually hop 35 times per second.



# Antenna Types



- *Omni Directional Antenna*



- ◆ YAGI Directional Antenna

# Modern Applications: 911 Service

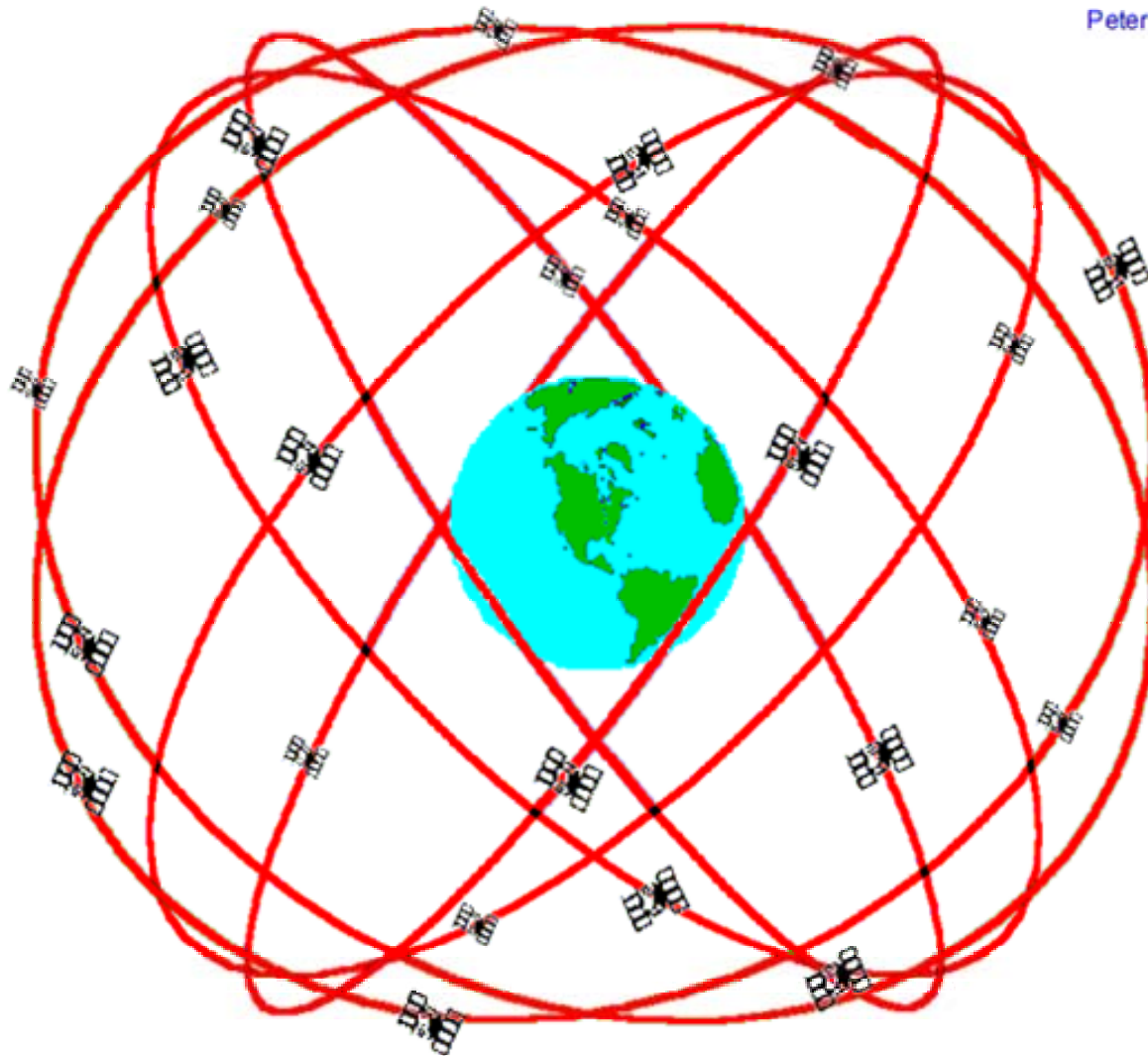


Location Service

# E-911 Requirement for Location Service

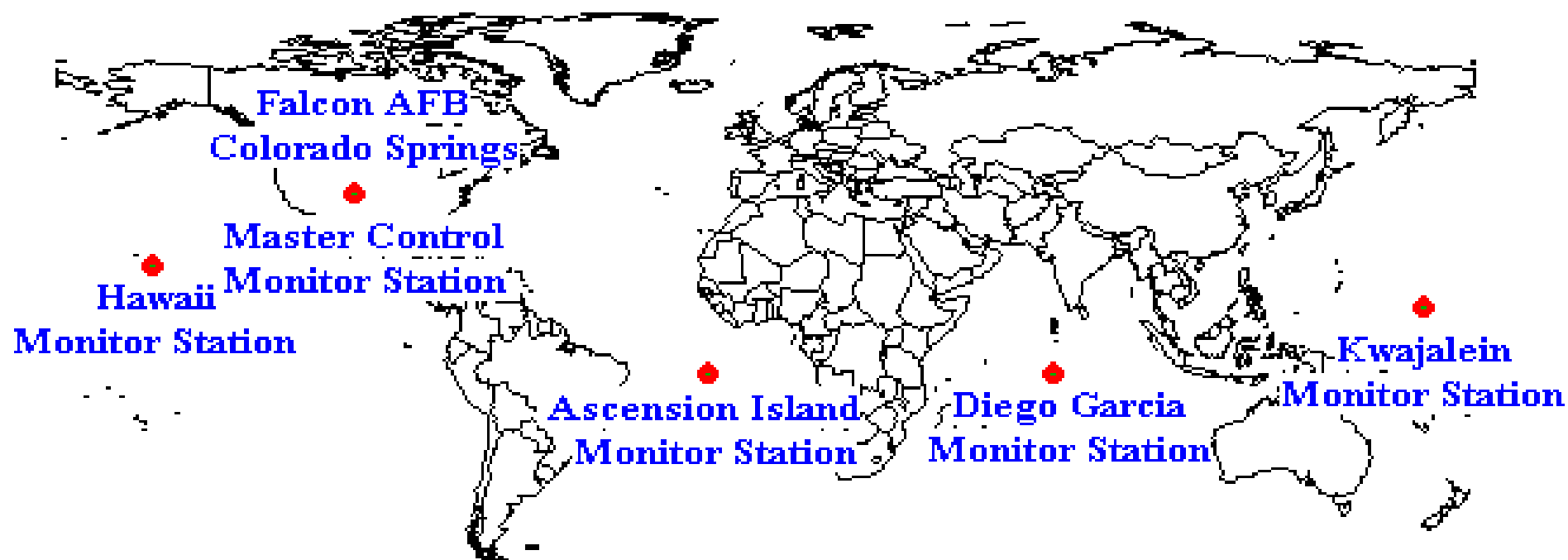
- ◆ 1996, FCC (Federal Communications Commission) announced its mandate for enhanced emergency services for cellular phone callers.
- ◆ The current deadline for this capability is October 1, 2001





**GPS Nominal Constellation**  
**24 Satellites in 6 Orbital Planes**  
**4 Satellites in each Plane**

**20,200 km Altitudes, 55 Degree Inclination**



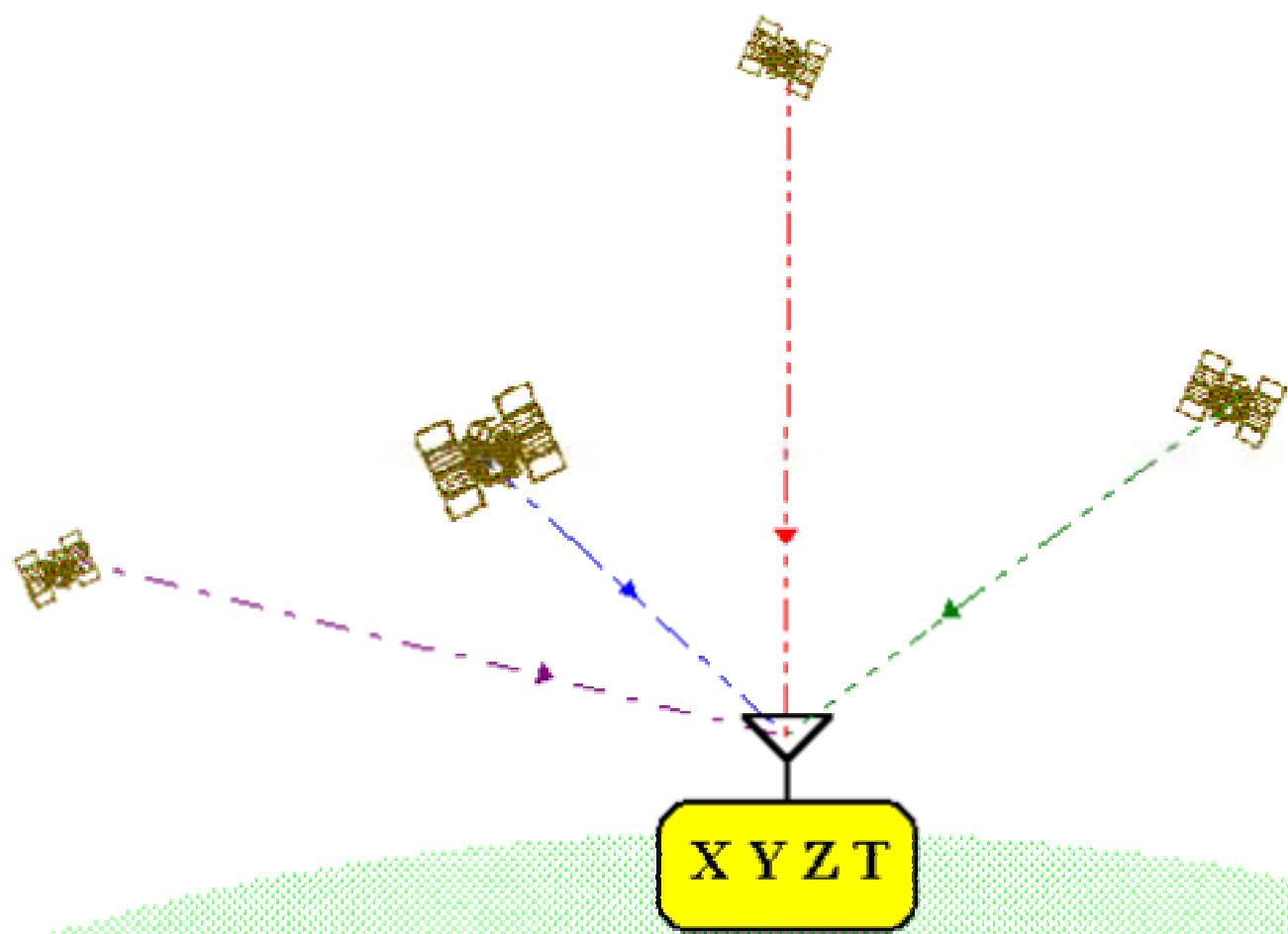
## Global Positioning System (GPS) Master Control and Monitor Station Network



# GPS (cont.)

## ◆ Position location

- 3-D 座標 (x,y,z) 需要3個獨立方程式可解.
- 三個GPS衛星得到三個距離量度，可設定所需的三個方程式.
- 需要第四個衛星來求得另一距離量度以建立第四個方程式 ( $T_{error}$ )
- 這樣就可定位出他的位置
- With accuracy of approximately 100 m.



**The Global Positioning System**  
Measurements of code-phase arrival times from at least four satellites are used to estimate four quantities: position in three dimensions (X, Y, Z) and GPS time (T).

# Introduction

- ◆ Safety is the primary motivation for vehicle position location.
- ◆ Landline telephone companies to provide 911 emergency service .
- ◆ 1994, begin investigating similar service for U.S cellular and PCS providers.
- ◆ E-911 service include caller's ANI and street address information.

# Mobile Location Solution

## Driving Force :

### Legal aspects :

- Fire brigades, hospitals and other emergency centers.

### Commercial aspects :

- Differentiation : new and attractive services.
- Reduced costs : operators can adapt their network to match calling patterns.
- Increased revenues : commercial services that use positioning information is infinite.

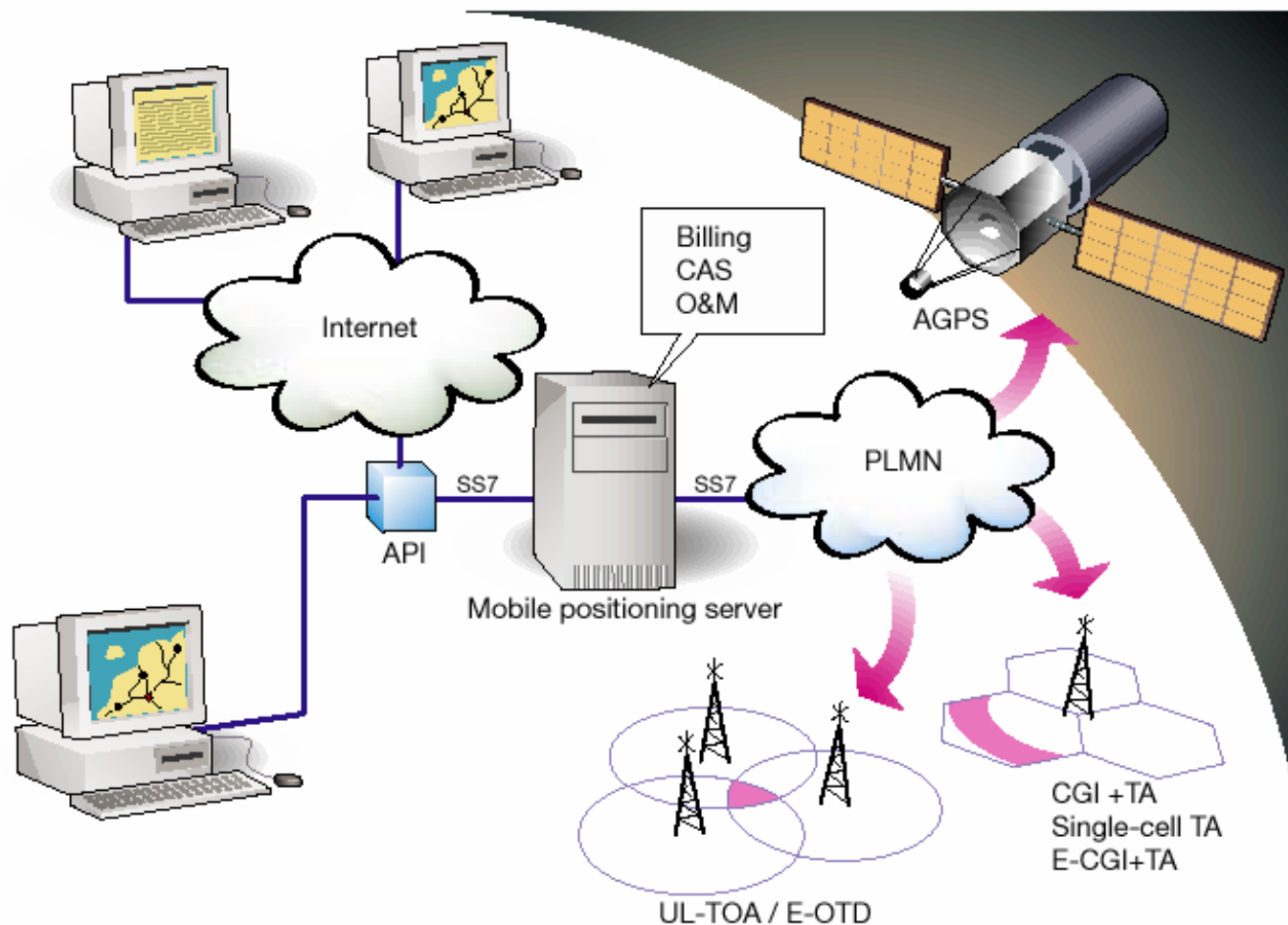
# Positioning mechanism and requirement

## Terminal-based :

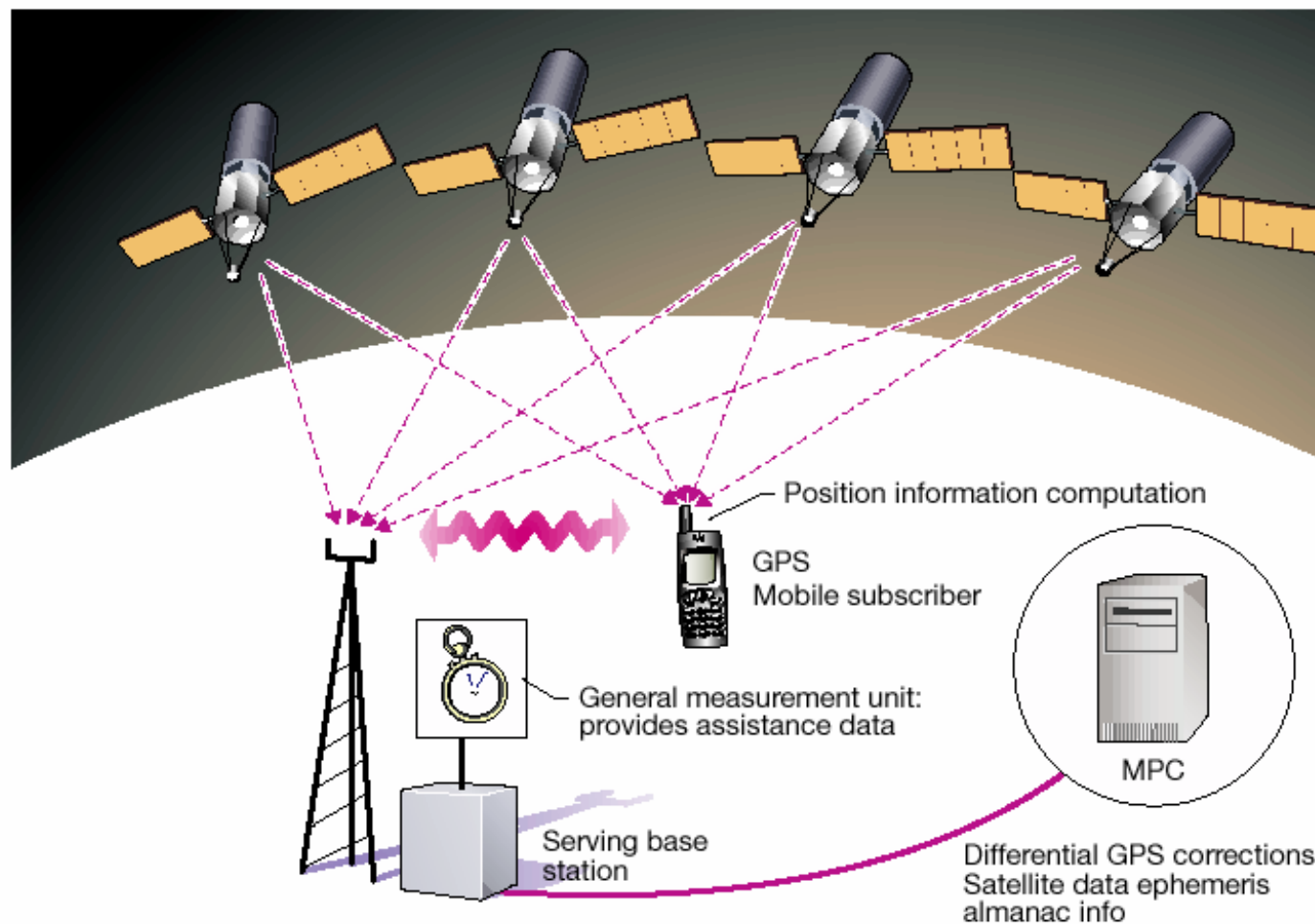
- Positioning intelligence is stored in the terminal or its SIM card.
- Network-assisted global positioning system (A-GPS).

## Network-based :

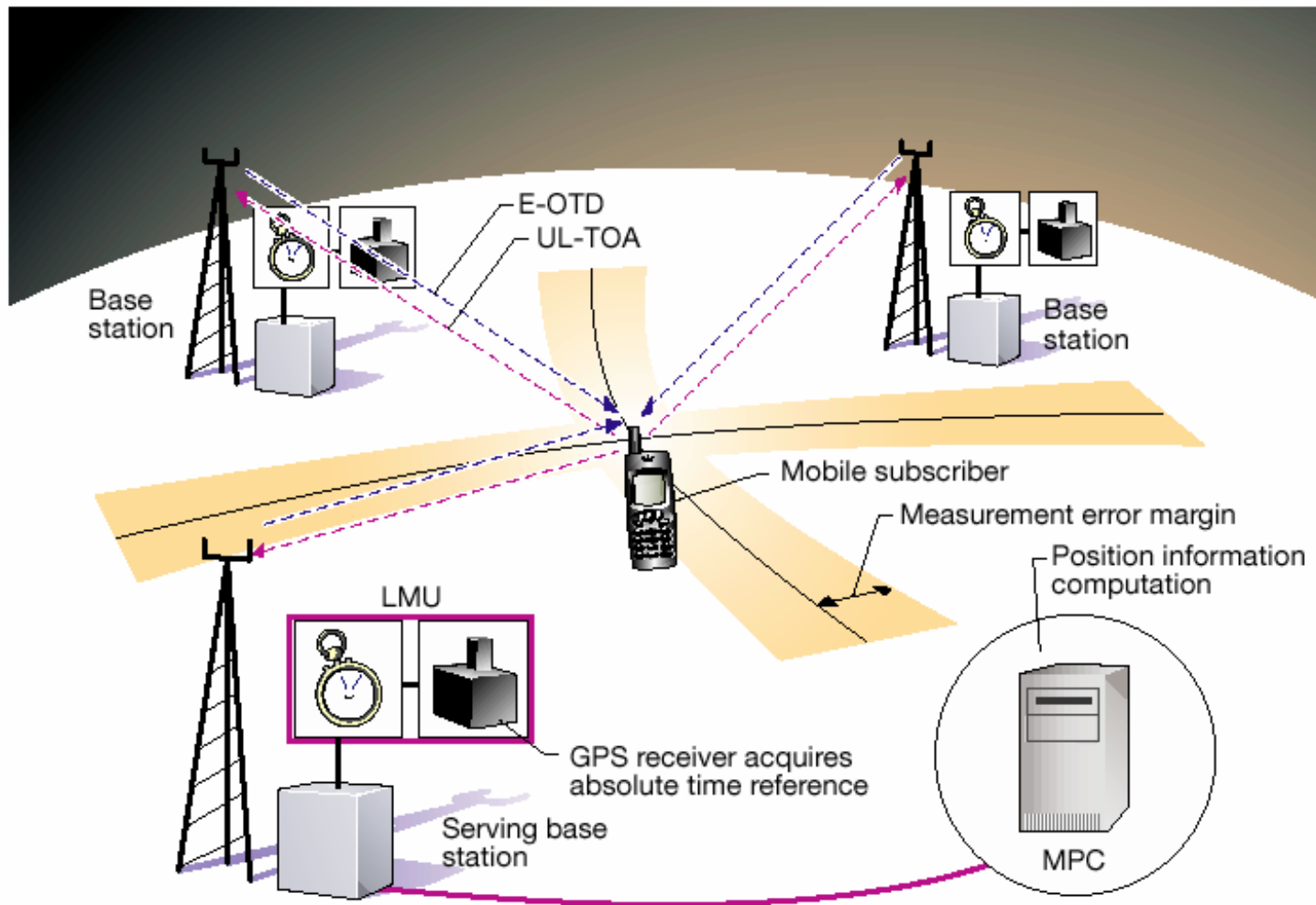
- Positioning intelligence isn't built into the handset.
- Measurement of Cell global identity and timing advance (CGI+TA) 、 uplink time of arrival (UL-TOA).



Mobile location solution has been designed to handle a variety of positioning methods and application interfaces.



Network-assisted GPS (A-GPS) is a positioning product with very attractive characteristics.



UL-TOA and E-OTD methods each use the triangulation of time difference between base stations and the terminal to determine positions.



# Location applications

## Information services :

- Location-based yellow pages, events, and attractions (ex. What is happening today in town near here?) .

## Tracing services :

- Tracing of a stolen car, helping paramedics to locate persons quickly in an emergency situation, and giving a towing service or automobile repair shop the location of a motorist in need (out of gas, flat tire, dead battery).

# Location applications (cont.)

Resource management :

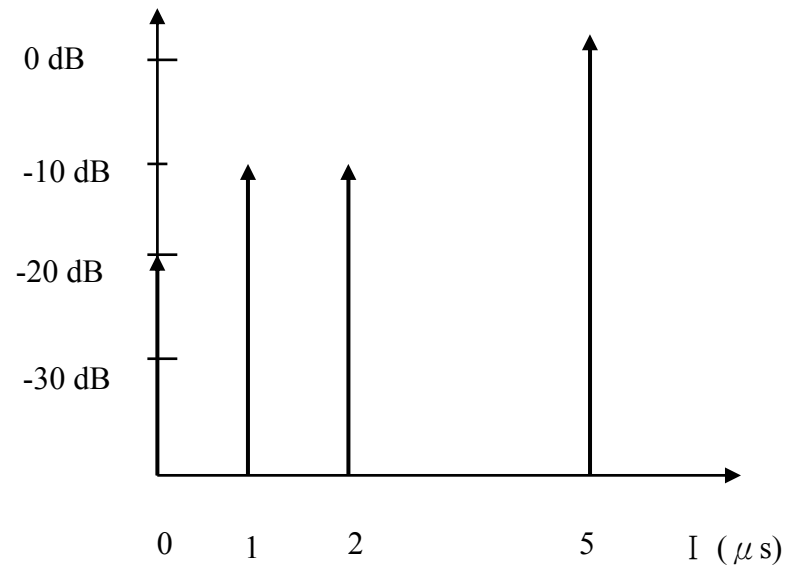
- Taxi fleet management, the administration of container goods, and the assignment and grouping of railway repairmen.

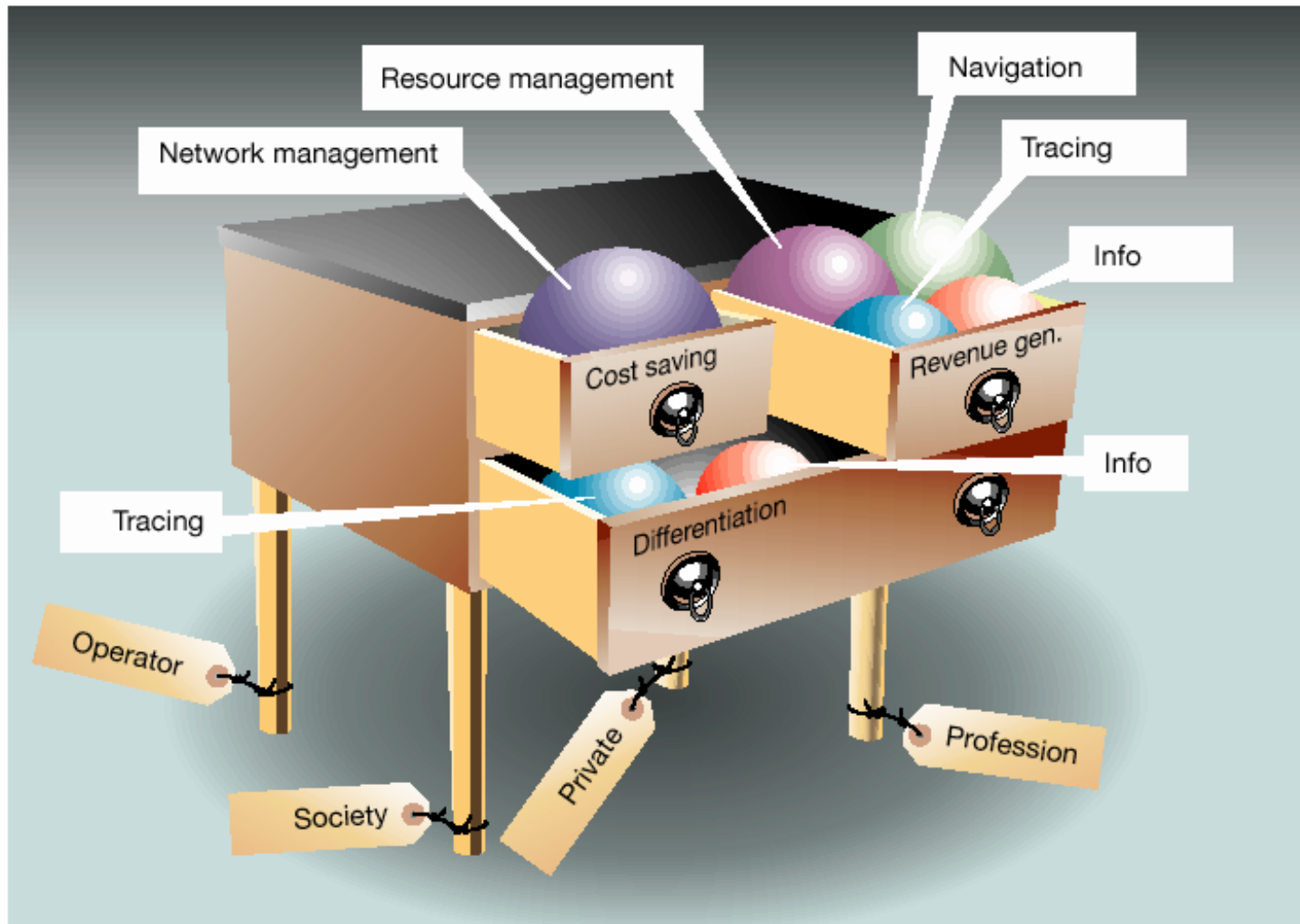
Navigation :

- Vehicle or pedestrian navigation.

# Small Scale Fading

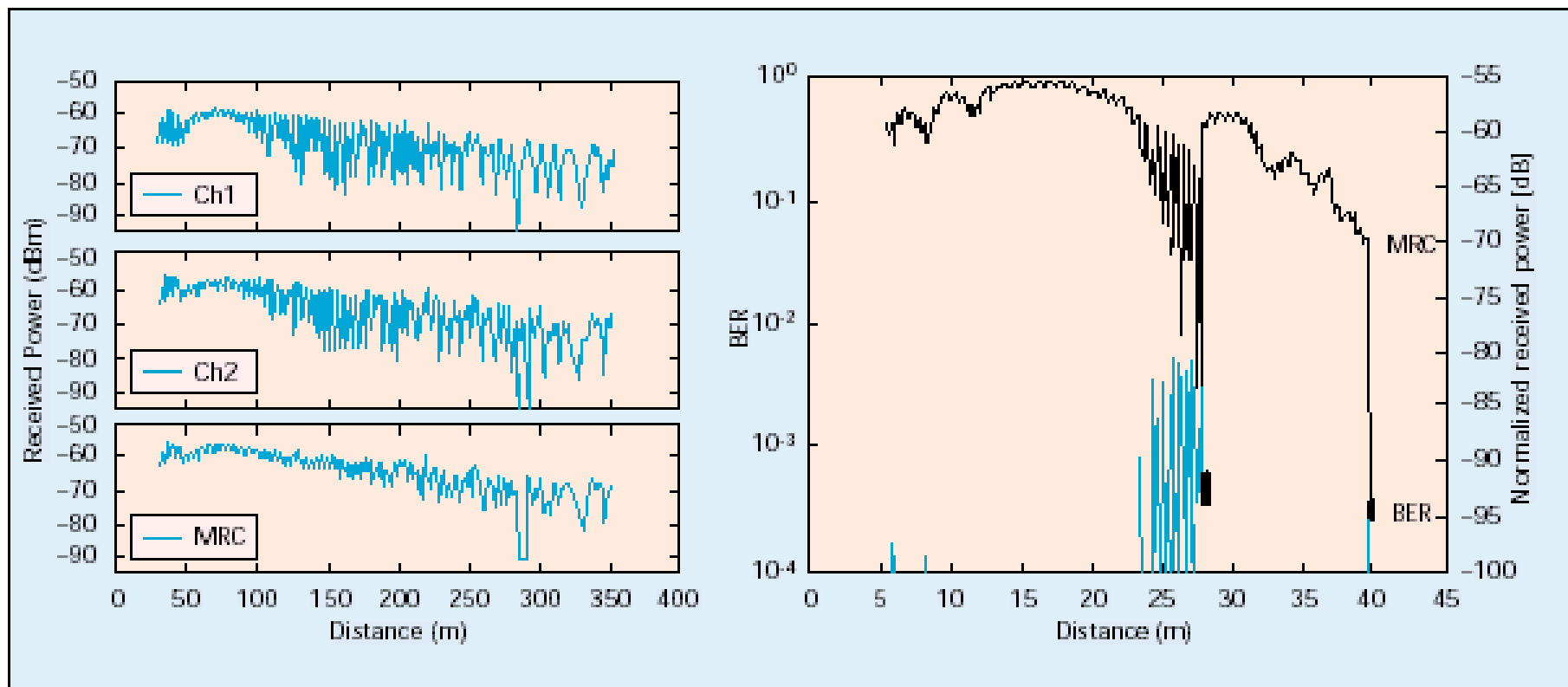
- ◆ Mean Excess Delay, rms delay spread





The chest of drawers illustrates how different applications can be grouped strategically for use by their beneficiaries.

# Channel Propagation and Fading



■ Figure 4. Received power as a function of distance: in a street (left), in a pavilion (right); BER and handover (right).