

## 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>



## 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

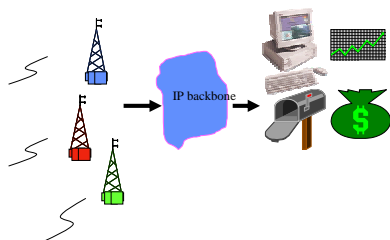
### Further Reading

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

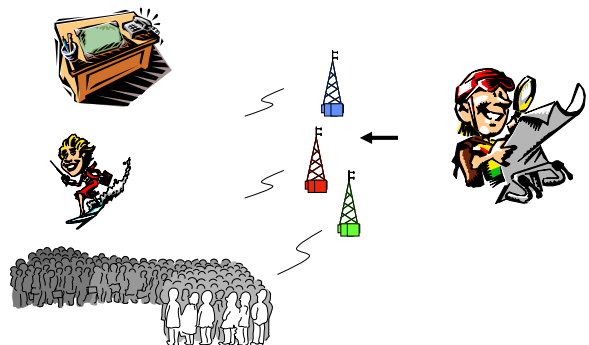
## The mystery of the Radio Propagation



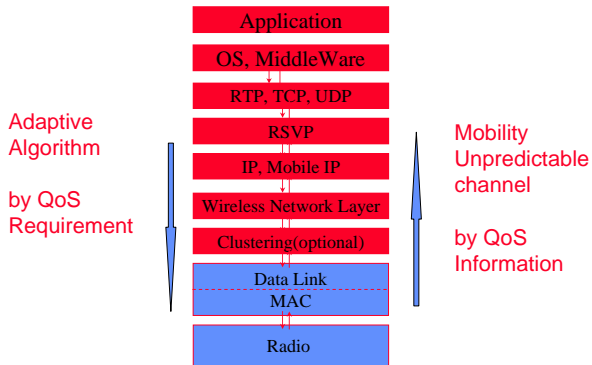
## How to deal with Radio Propagation



## Where are you from?



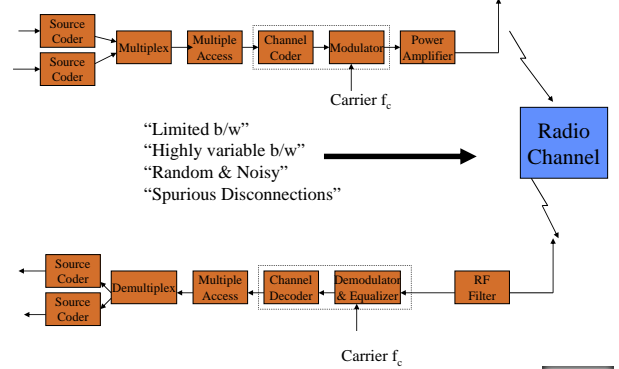
## QoS and Multimedia Traffic Support CS'E



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## Simplified View of a Digital Radio Link CS'E



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## Digital to Analog Modulation CS'E

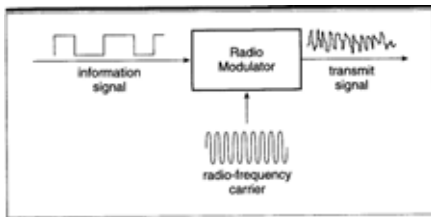


Figure 6.2 Single-stage digital modulation (TDMA and FDMA).

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## Digital-Digital-Analog Modulation CS'E

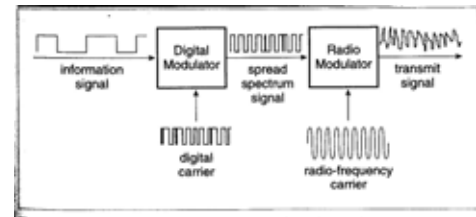


Figure 6.3 Two stages of modulation in a spread spectrum system.

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## Digital Correlator CS'E

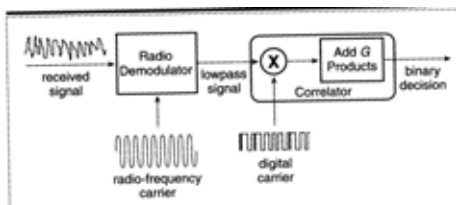


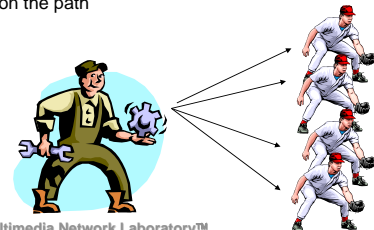
Figure 6.4 Two stages of demodulation in a spread spectrum receiver.

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## Multiple correlators CS'E

- ◆ 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



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## Key role for the radio propagation

CS'E

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



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## Speed, Wavelength, Frequency

CS'E

$$\text{Light speed} = \text{Wavelength} \times \text{Frequency}$$

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

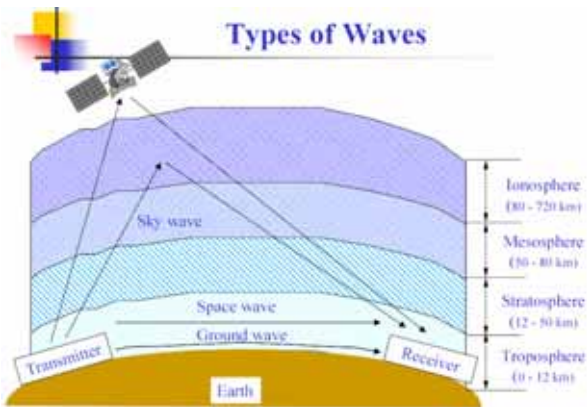
System	Frequency	Wavelength
AC current	60 Hz	5,000 km
FM radio	100 MHz	3 m
Cellular	800 MHz	37.5 cm
Ka band satellite	20 GHz	15 mm
Ultraviolet light	$10^{15}$ Hz	$10^{-7}$ m

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## Types of Waves

CS'E



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## Radio Frequency Bands

CS'E

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	

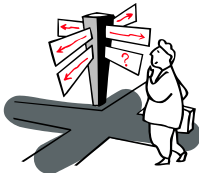
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## Radio Channel

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



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## Some Distributions

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



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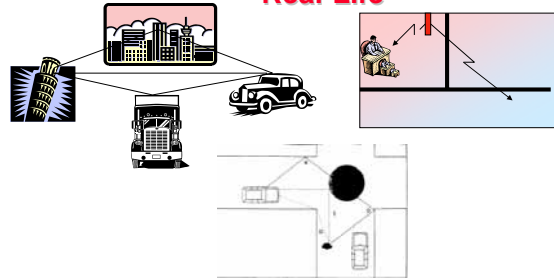
## Propagation Mechanisms in Space with Objects

- ◆ 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

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## Reflection, Diffraction, and Scattering in Real-Life



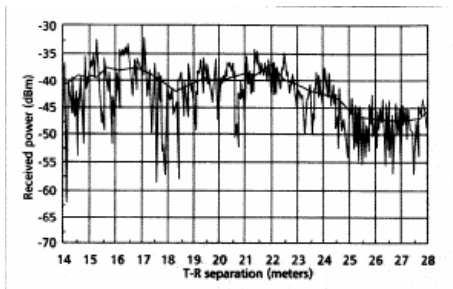
- ◆ Received signal often a sum of contributions from different directions
- ◆ Random phases make the sum behave as noise (Rayleigh Fading)

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## Small-scale and Large-scale Fading

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



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## 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.

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## 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.,

$$L = L_p L_S L_F$$

$L_p$  → Path loss  
 $L_S$  → Slow fading  
 $L_F$  → Fast fading

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## Path Loss (Free-space)

- ◆ Definition of path loss  $L_p$ :

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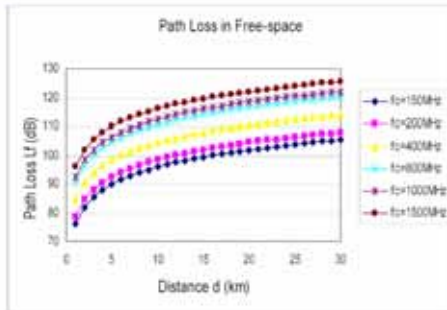
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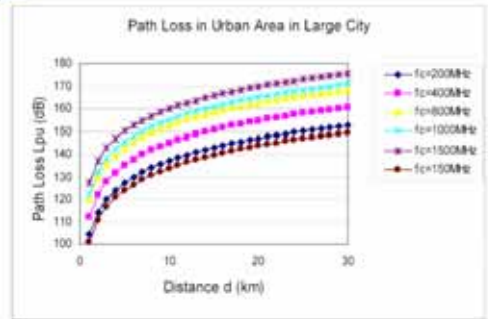
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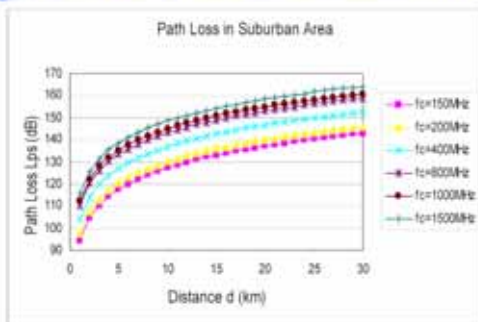
### Example of Path Loss (Free-space)



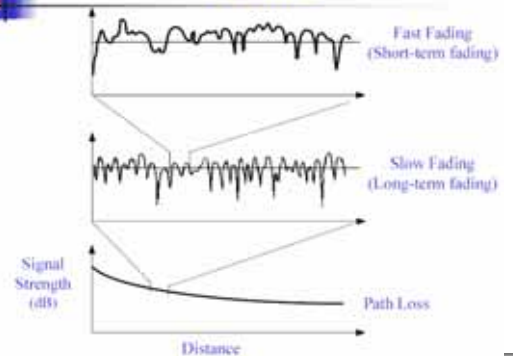
### Example of Path Loss (Urban Area: Large City)



### Example of Path Loss (Suburban Area)

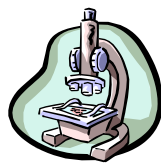


### Fading



### 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

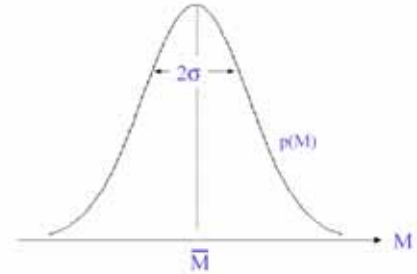
- The long-term variation in the mean level is known as slow fading (shadowing or log-normal fading). This fading caused by shadowing.
- Log-normal distribution:
  - The pdf of the received signal level is given in decibels by

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

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

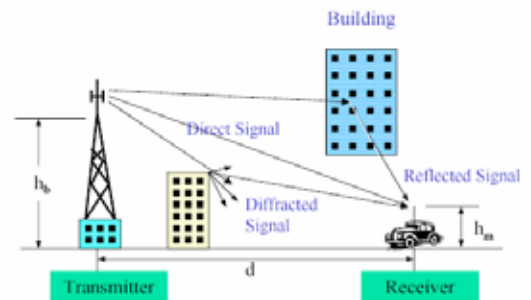
- Path loss = signal attenuation as a positive quantity in dB

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

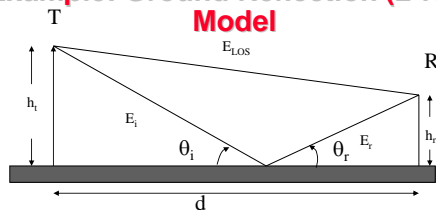
$$P_r(dBm) = 10 \log [P_t(mW) / 1mW]$$



## 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

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

- 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)

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





## 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



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

$$P_r(dBm) = (P_t) + (G_t) + (G_r) - (PL(d))$$

$$N = KT_0BF$$

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



## Example Link Budget Calculation



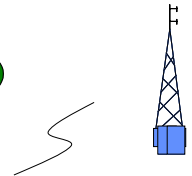
- Maximum separation distance vs. transmitted power (with fixed BW)
  - Given
    - Cellular phone with 0.6W transmitted power
    - Unity gain antenna, 900 MHz carrier frequency
    - SNR must be at least 25 dB for proper reception
    - Receiver BW is B=30KHz, noise figure F=10 dB
  - What will be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



## Link Budget (SNR)



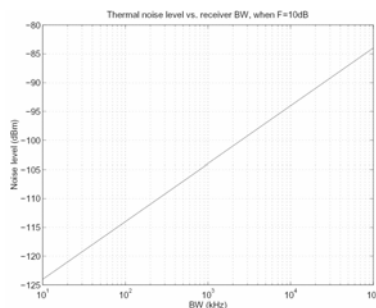
- Frequency
- Power
- Distance
- Environments
- Bandwidth



## Noise



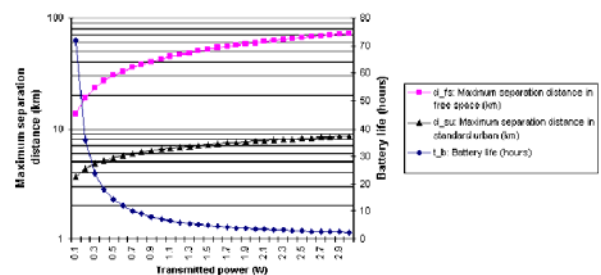
- $N = KT_0BF$  ( $K = 1.38 \times 10^{-23} \text{ J/K}$  Boltzmann's constant,  $T_0 = 290K$ )
- $N(dBm) = -174(dBm) + 10\log_{10} B + F(dB)$



## Distance/Power/Battery/Environment



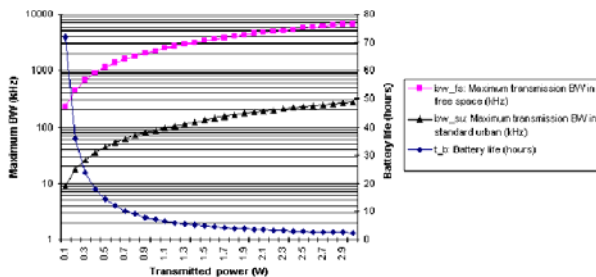
Combined plot of the maximum separation distance and the battery life vs. transmitted power, when BW=30kHz, F=10 dB, SNR=25 dB.



## BW/Power/Battery/Environment



Combined plot of the battery life and the maximum transmission BW vs. the transmitted power, when  $d=5$  km,  $F=10$  dB,  $SNR=25$  dB.



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## RMS Delay Spreads



TYPICAL RMS DELAY SPREADS IN VARIOUS ENVIRONMENTS.

Environment	Freq. (MHz)	$\sigma_r$ (ns)	Notes	Source
Urban - New York City	910	1300	Average	[23]
Urban - New York City	910	600	Standard Deviation	[23]
Urban - New York City	910	3500	Maximum	[23]
Urban - San Francisco	892	1000-2500	Worst Case	[24]
Suburban	910	200-310	Averaged Typical Case	[23]
Suburban	910	1960-2110	Averaged Extreme Case	[23]
Indoor - Office Building	1500	10-50		[25]
Indoor - Office Building	1500	25	Median	[25]
Indoor - Office Building	850	270	Maximum	[26]
Indoor - Office Buildings	1900	70-94	Average	[27]
Indoor - Office Buildings	1900	1470	Maximum	[27]

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## Small Scale -> Quality of Service



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## 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

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## Factors Influencing Small-Scale Fading



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

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## 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  $s$  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

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

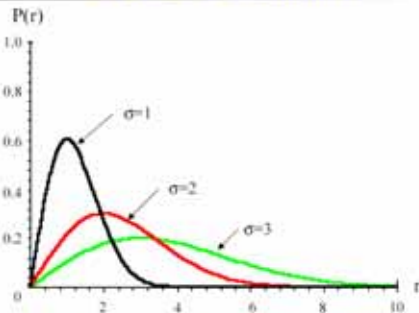
- We have  $r_m = 1.777 \cdot \sigma$

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## Rayleigh Distribution

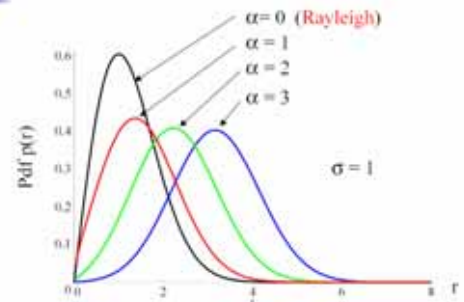


The pdf of the envelope variation

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## Rician Distribution

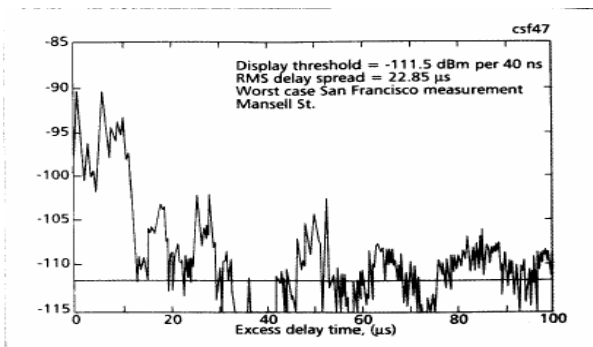


The pdf of the envelope variation

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## Delay Spread



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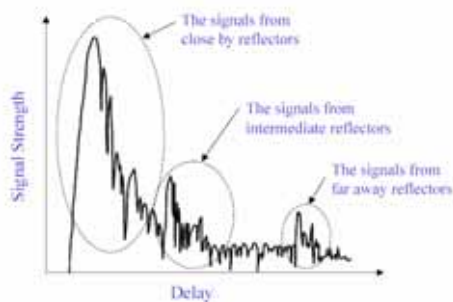
## Delay Spread

- 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".

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## Delay Spread



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## Intersymbol Interference (ISI)

- 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)

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

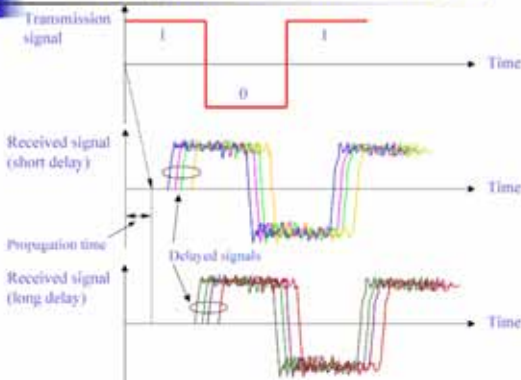
- $R$  (digital transmission rate) limited by delay spread.

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## Intersymbol Interference (ISI)

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## Coherence Bandwidth

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- 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.

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## Parameters of a Multipath Channel

CS'E

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

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

- ◆ Four important parameters of interest

- RMS delay spread

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

- Coherence bandwidth

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

- Doppler spread

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

- Coherence time

$$T_c = 0.423 / f_m$$

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## Doppler Shift

CS'E

- **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,

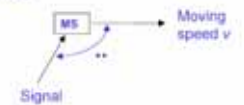
$f_D$  is the Doppler frequency.

- **Doppler Shift in frequency:**

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

where  $v$  is the moving speed,

$\lambda$  is the wavelength of carrier.



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## Types of Fading

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- ◆ 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

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## Fades: Why do we care?

CS'E

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

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## The Design of Wireless Modem

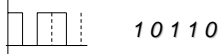


## Combating Errors

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

## Direct Sequence Spread Spectrum

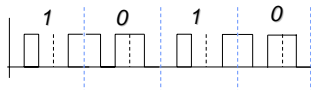
To transmit a 0 the station use a unique "chip sequence":



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

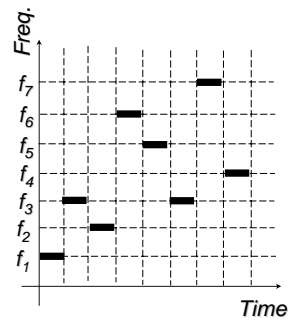


Therefore if data is 1010 it will transmit:



## 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

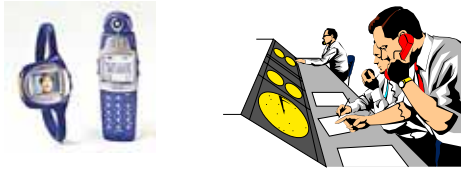


Location Service

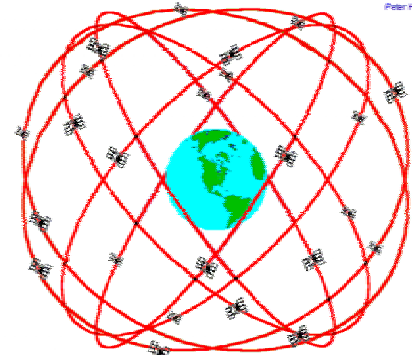
## E-911 Requirement for Location Service

CS/E

- ◆ 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



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Peter H. Dana 9/22/95 CS/E

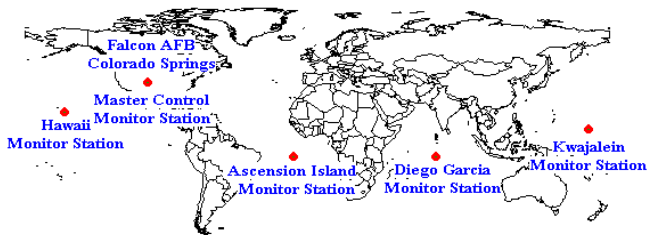
GPS Nominal Constellation  
24 Satellites in 6 Orbital Planes  
4 Satellites in each Plane  
20,200 km Altitudes, 55 Degree Inclination

Wirele



CS/E

Peter H. Dana 5/27/95



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

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## GPS (cont.)

CS/E

- ◆ 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.

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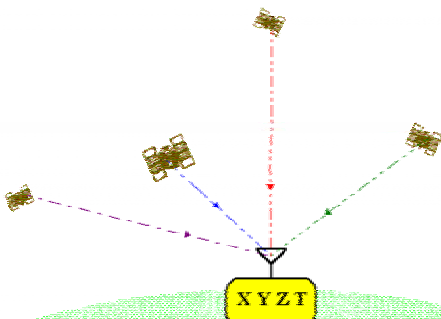


## Introduction

CS/E

- ◆ 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.

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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).

Wi

P. H. Dana 9/22/95

## 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 :

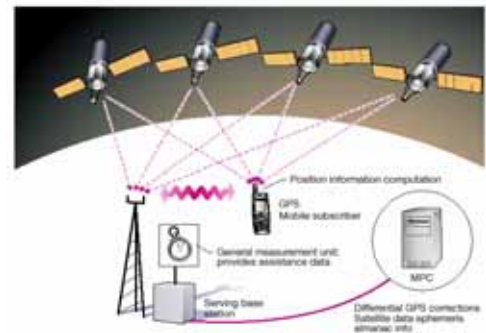
- Positioning intelligence is stored in the terminal or its SIM card.
- Network-assisted global positioning system (A-GPS).

Network-based :

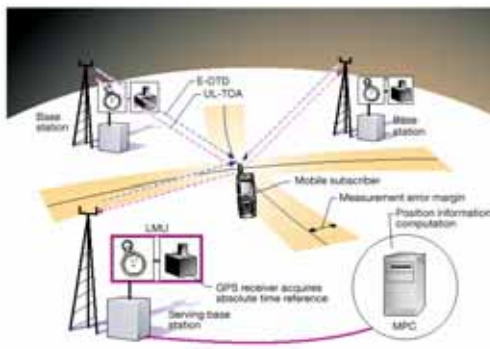
- Positioning intelligence isn't built into the handset.
- Measurement of Cell global identity and timing advance(CGI+TA), uplink time of arrival (UL-TOA).



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 :

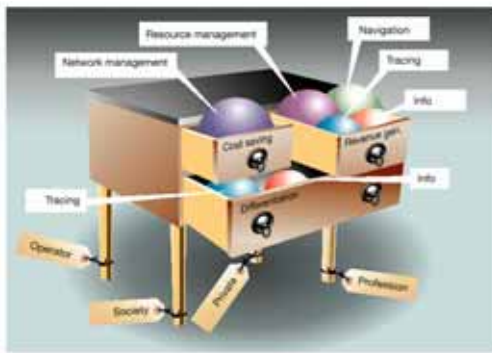
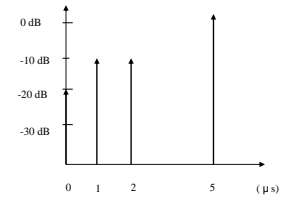
- Vehicle or pedestrian navigation.



## 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

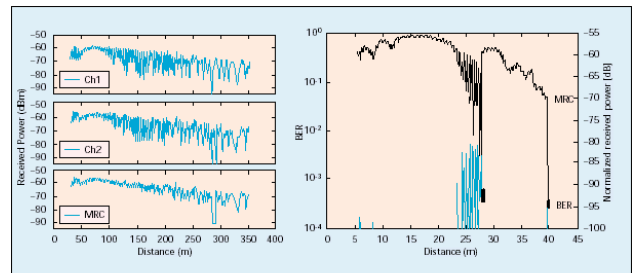


Figure 4. Received power as a function of distance: in a street (left), in a pavilion (right); BER and handover (right).

