

CSIE

## 無線網路多媒體系統 Wireless Multimedia System

**Radio Propagation: Issues & Models**

中央大學 吳曉光博士  
<http://wmlab.csie.ncu.edu.tw/course/wms>

Wireless & Multimedia Network Laboratory™



CSIE

## 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



Wireless & Multimedia Network Laboratory™



CSIE

## 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

Wireless & Multimedia Network Laboratory™



CSIE

## The mystery of the Radio Propagation

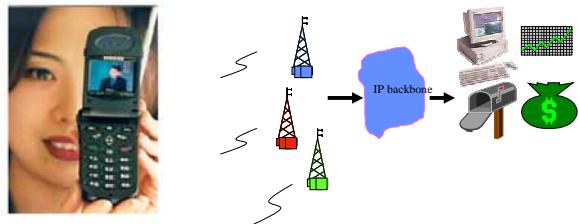


Wireless & Multimedia Network Laboratory™



CSIE

## How to deal with Radio Propagation



Wireless & Multimedia Network Laboratory™



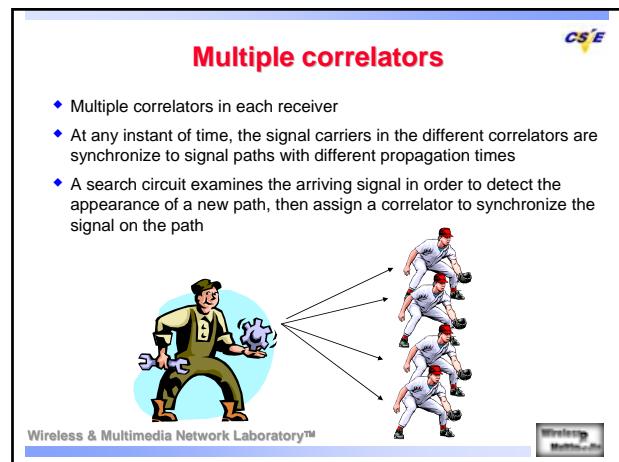
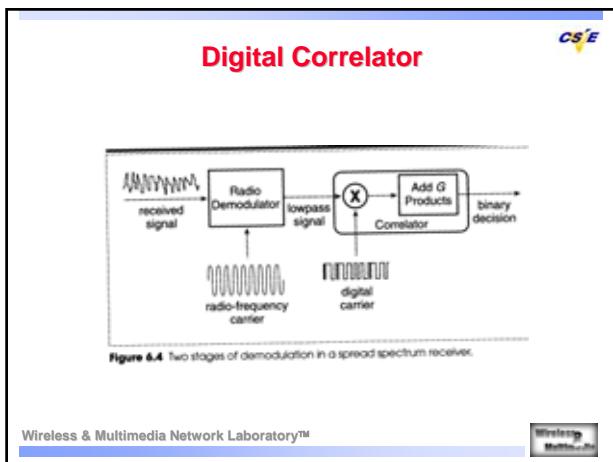
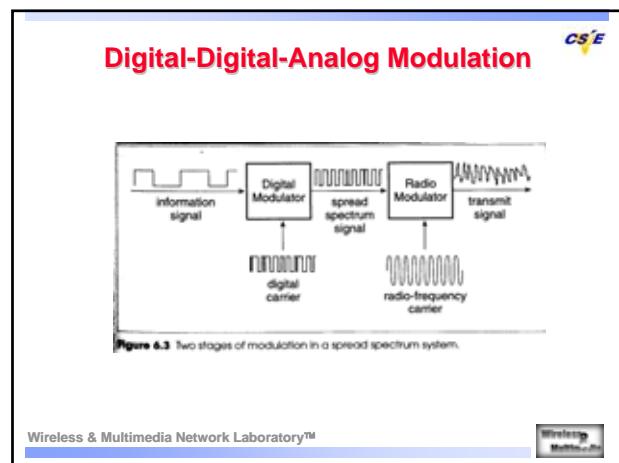
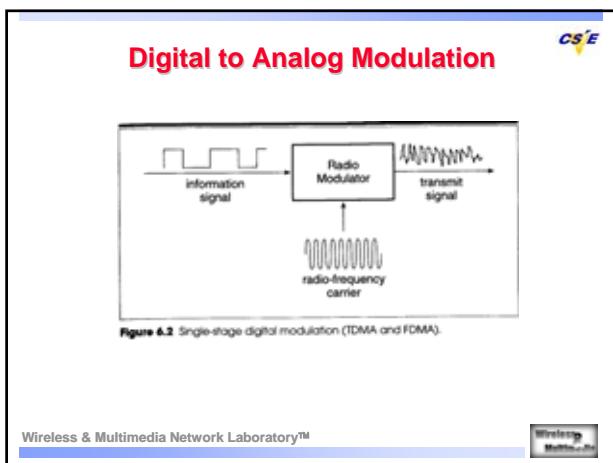
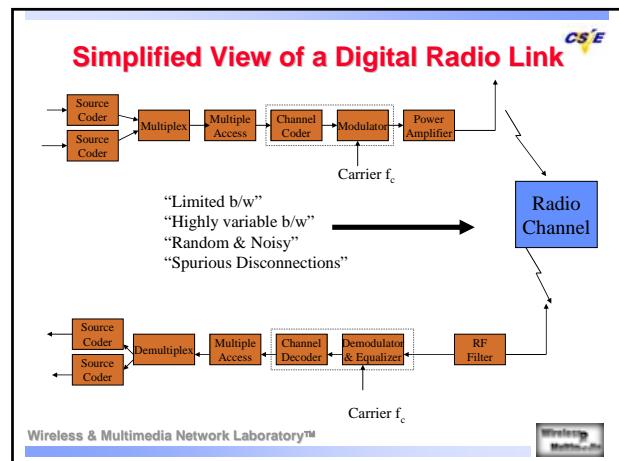
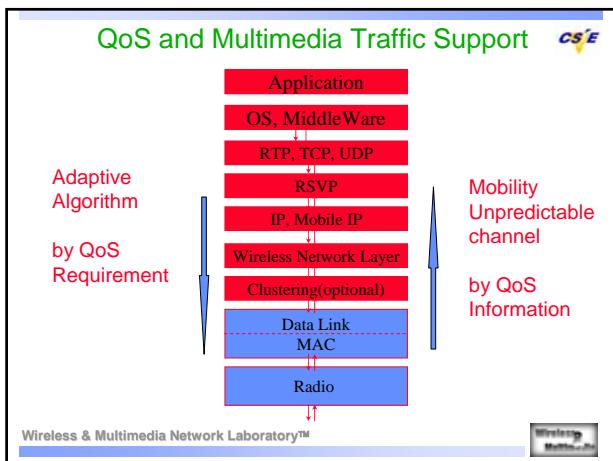
CSIE

## Where are you from?



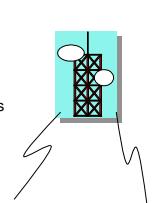
Wireless & Multimedia Network Laboratory™





## 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




Wireless & Multimedia Network Laboratory™

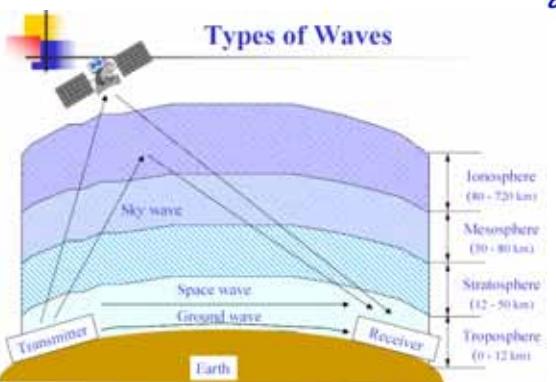
## Speed, Wavelength, Frequency

Light speed = Wavelength x 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

Wireless & Multimedia Network Laboratory™

## Types of Waves



Wireless & Multimedia Network Laboratory™

## 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	

Wireless & Multimedia Network Laboratory™

## Radio Channel

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



Wireless & Multimedia Network Laboratory™

## Some Distributions

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



Wireless & Multimedia Network Laboratory™

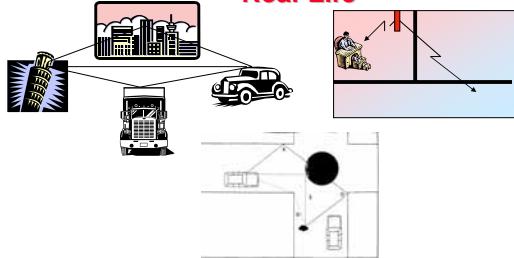
## Propagation Mechanisms in Space with Objects

- 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

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

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



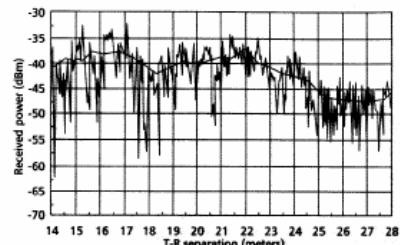
- Received signal often a sum of contributions from different directions
- Random phases make the sum behave as noise (Rayleigh Fading)

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

## Small-scale and Large-scale Fading

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



Wireless & Multimedia Network Laboratory™

Wireless Multimedia

## 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.

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

## Land Propagation

- The received signal power:

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

where  $G_t$  is the receiver antenna gain,  
 $L$  is the propagation loss in the channel, i.e.,

$$L = L_p L_s L_f$$

Fast fading  
 Slow fading  
 Path loss

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

## Path Loss (Free-space)

- Definition of path loss  $L_p$

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

Path Loss in Free-space:

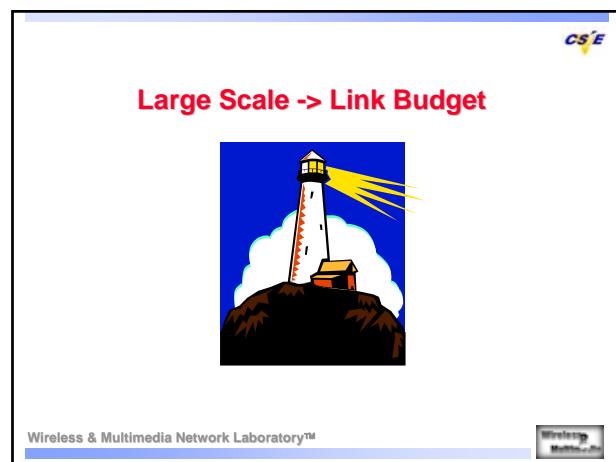
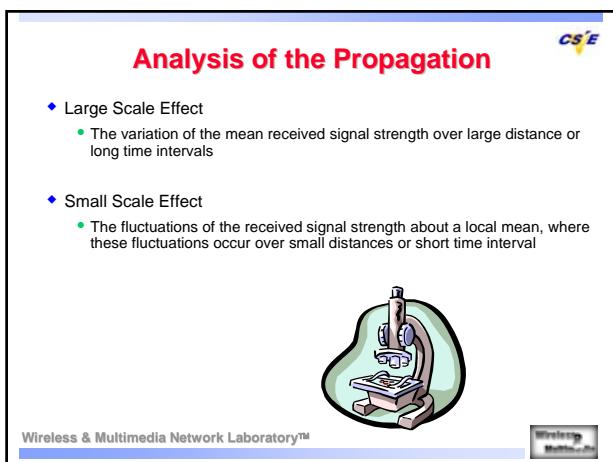
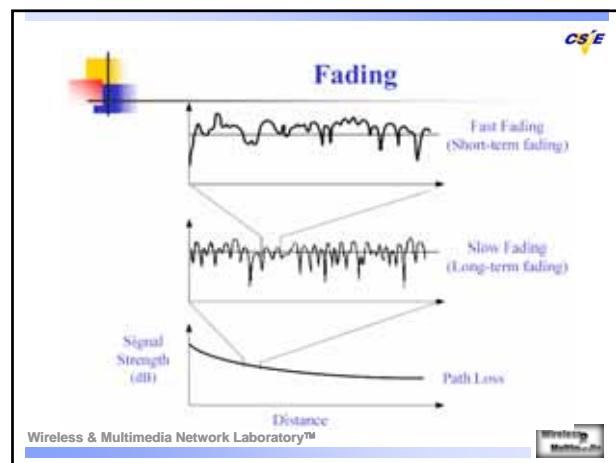
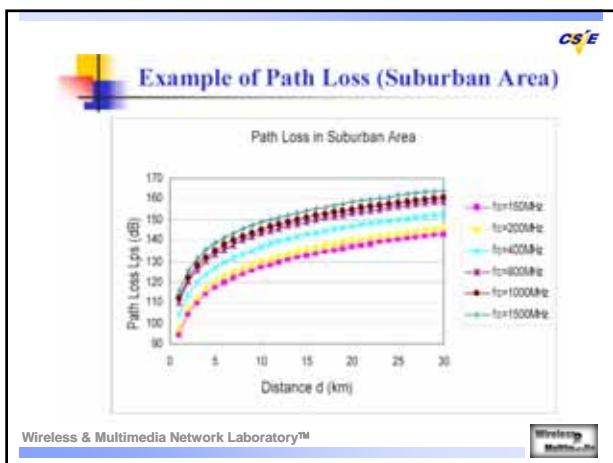
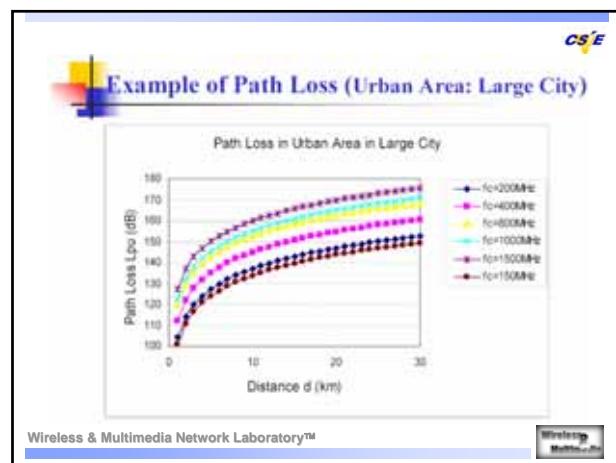
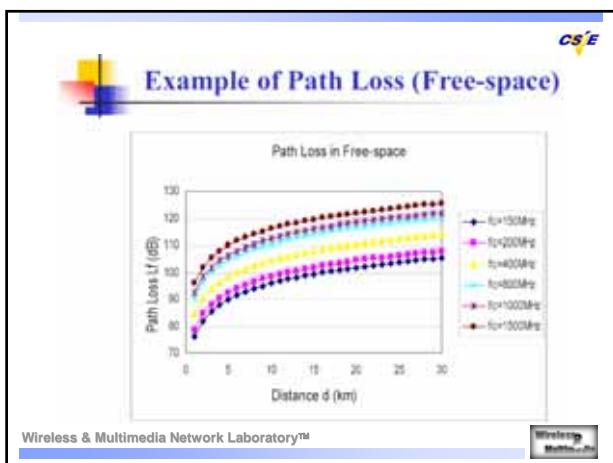
$$L_{PF}(dB) = 32.45 + 20 \log_{10} f_c(MHz) + 20 \log_{10} d(km),$$

where  $f_c$  is the carrier frequency.

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

Wireless & Multimedia Network Laboratory™

Wireless Multimedia



## 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.

Wireless & Multimedia Network Laboratory

## Log-normal Distribution

The pdf of the received signal level

Wireless & Multimedia Network Laboratory

## 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
 
$$P_r(d) = \frac{P_t G_t \lambda^2}{(4\pi)^2 d^2 L}$$
 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
 
$$PL(dB) = 10 \log \frac{P_r}{P_t}$$

$$P_r(dBm) = 10 \log \frac{P_r(mW)}{1mW}$$

Wireless & Multimedia Network Laboratory

## Radio Propagation Effects

Wireless & Multimedia Network Laboratory

## 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
 
$$P_r(d) = \frac{P_t G_t h_t^2 h_r^2}{d^4}$$
- Much more rapid path loss than expected due to free spaces

Wireless & Multimedia Network Laboratory

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

Wireless & Multimedia Network Laboratory

## 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

Wireless & Multimedia Network Laboratory™

CSE

## 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



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

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

$$N = KT_0BF$$

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

Wireless & Multimedia Network Laboratory™

Wireless & Multimedia Network Laboratory™

## 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 dBm + 10 log 30000 + 10 dB
    - For SNR > 25 dB, we must have Pr > (-119+25) = -94 dBm
    - Pt=0.6W = 27.78 dBm
    - This allows path loss PL(d) = Pt - Pr < 122 dB
      - for free space, n=2, d < 33.5 km
      - for shadowed urban with n=4, d < 5.8 km

Wireless & Multimedia Network Laboratory™

CSE

## Link Budget (SNR)

- Frequency
- Power
- Distance
- Environments
- Bandwidth

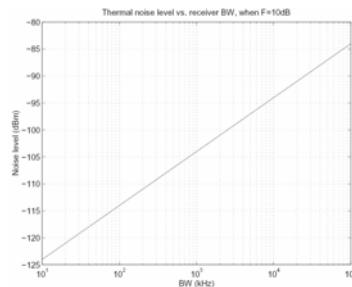


Wireless & Multimedia Network Laboratory™

Wireless & Multimedia Network Laboratory™

## Noise

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

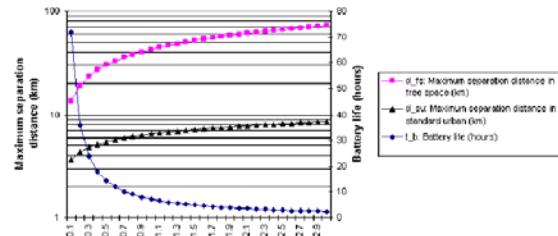


Wireless & Multimedia Network Laboratory™

CSE

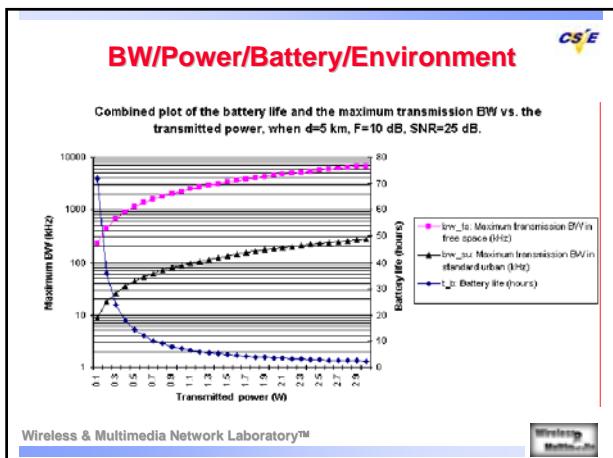
## Distance/Power/Battery/Environment

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

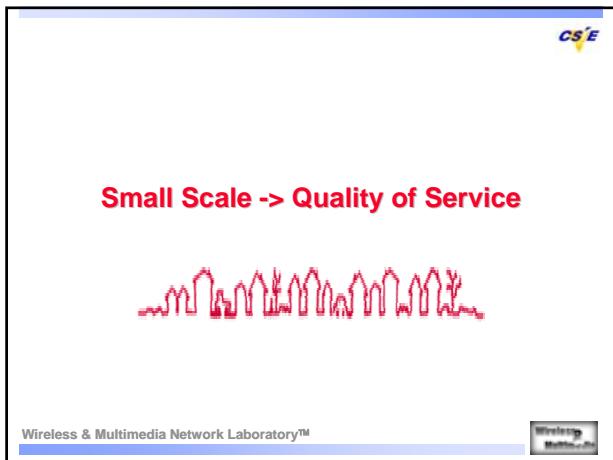


Wireless & Multimedia Network Laboratory™

Wireless & Multimedia Network Laboratory™

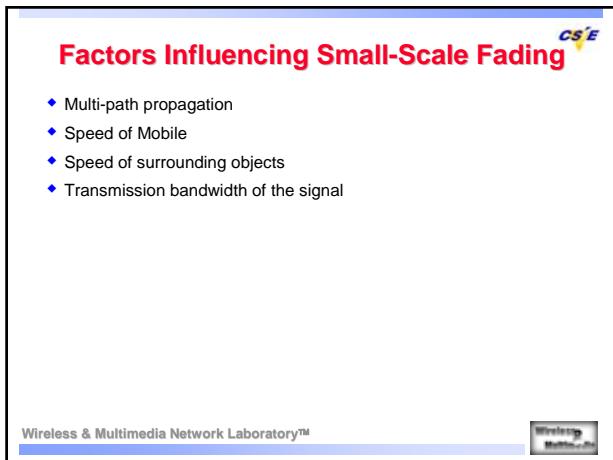


TYPICAL RMS DELAY SPREADS IN VARIOUS ENVIRONMENTS					
Environment	Freq. (MHz)	$\sigma_r$ (ns)	Notes	Source	
Urban – New York City	910	1300	Average	[23]	
Urban – New York City	910	600	Standard Deviation	[23]	
Urban – New York City	910	3500	Maximum	[23]	
Urban – San Francisco	892	1000-2500	Worst Case	[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]	



## 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 << height of buildings
  - Usually no LOS from base station
- ◆ Moving surrounding objects also cause time-varying fading





## Fast Fading

CSE

- 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 follows Rayleigh distribution. The pdf is

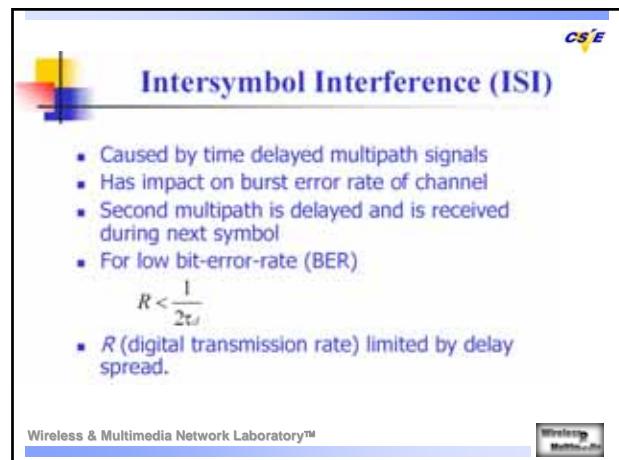
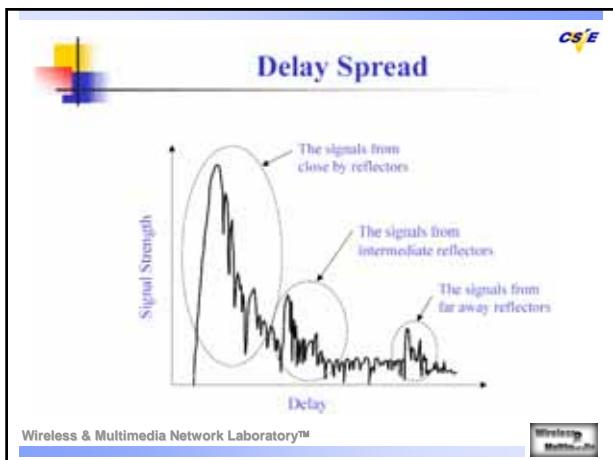
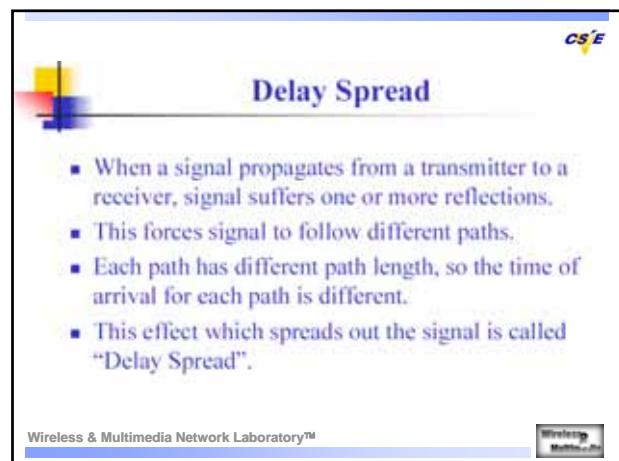
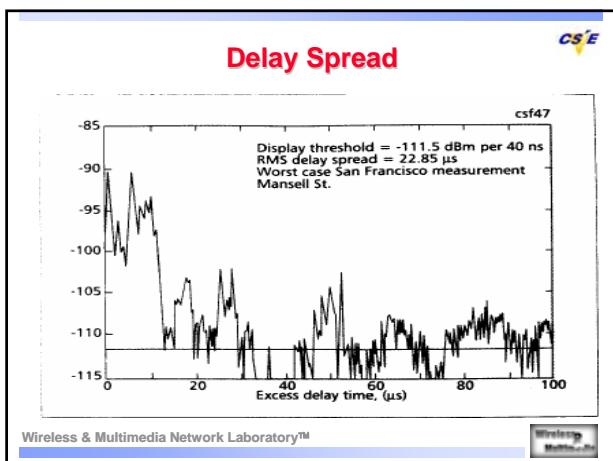
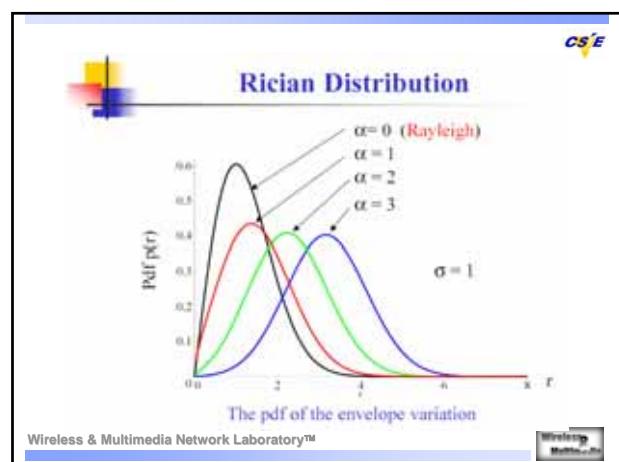
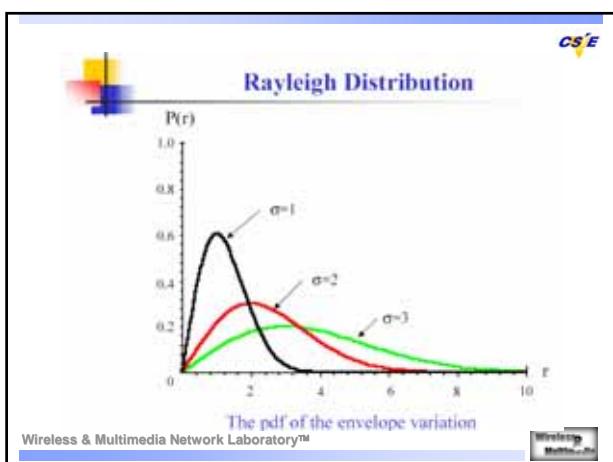
$$$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, \quad r > 0$$$$

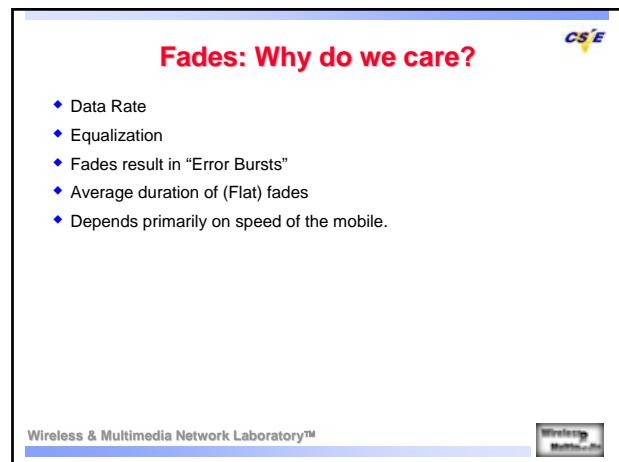
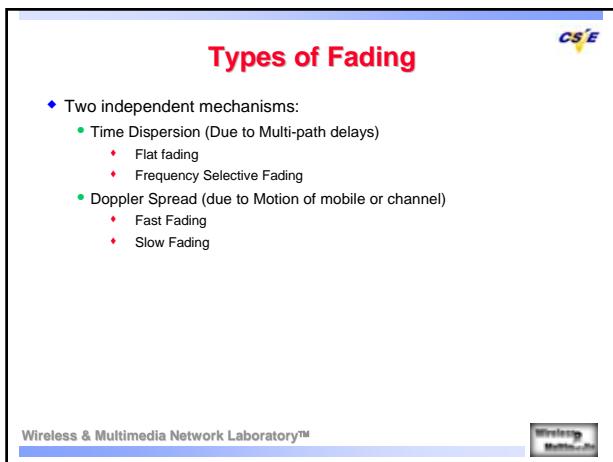
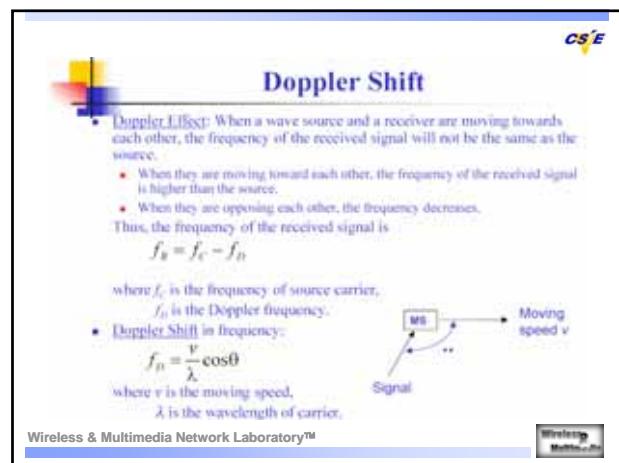
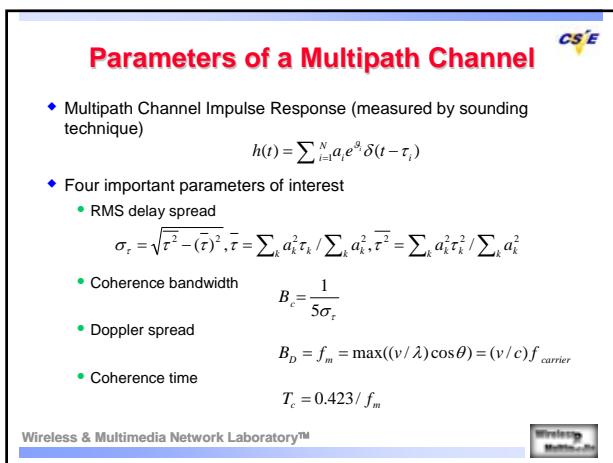
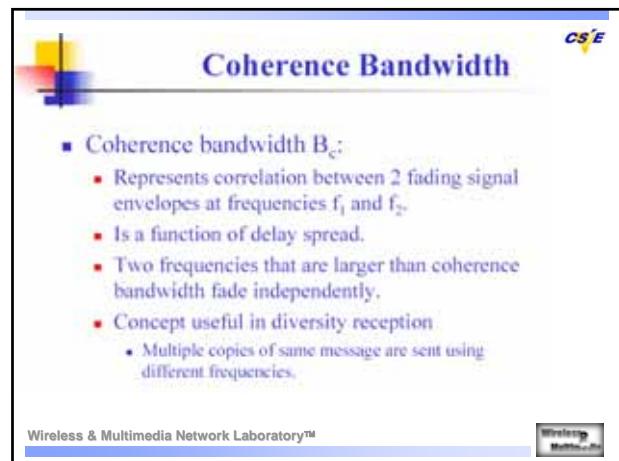
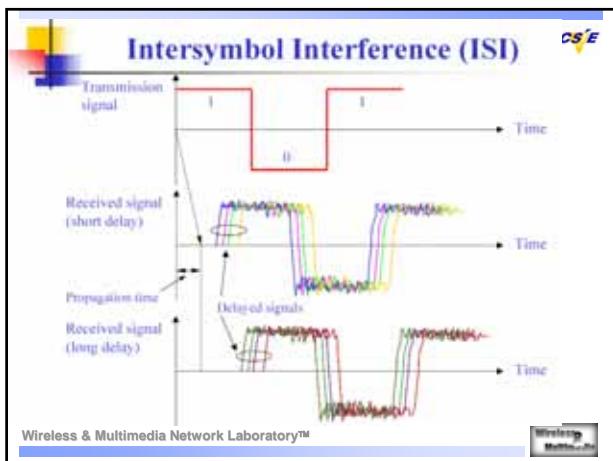
where  $\sigma$  is the standard deviation.

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

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

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





**The Design of Wireless Modem**



Wireless & Multimedia Network Laboratory™

Wireless Multimedia

**Combating Errors**

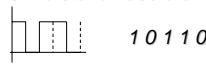
- ♦ Increase transmitted power
- ♦ (Adaptive) Equalization
- ♦ Antenna or space diversity for "Multipath"
- ♦ Forward error correction
- ♦ Automatic Repeat Request (ARQ)

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

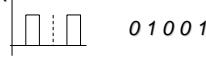
**Direct Sequence Spread Spectrum**

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



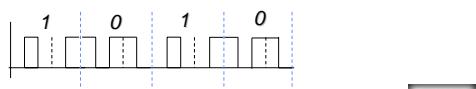
1 0 1 1 0

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



0 1 0 0 1

Therefore if data is 1010 it will transmit:

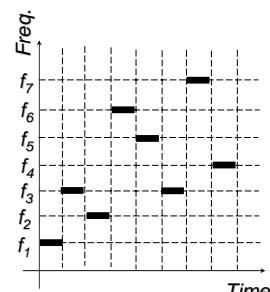


Wireless & Multimedia Network Laboratory™

Wireless Multimedia

**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.



Wireless & Multimedia Network Laboratory™

Wireless Multimedia

**Antenna Types**



■ Omni Directional Antenna



♦ YAGI Directional Antenna

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

**Modern Applications: 911 Service**



Location Service

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

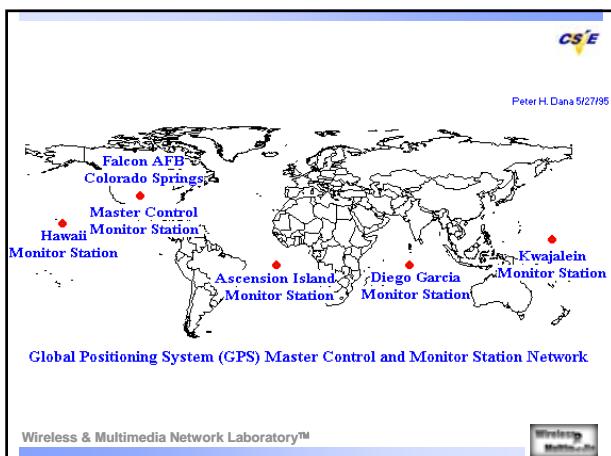
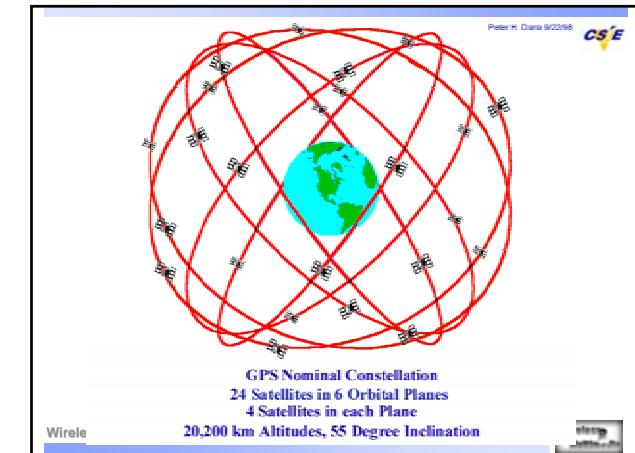
## E-911 Requirement for Location Service

- 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



Wireless & Multimedia Network Laboratory

Wireless Multimedia

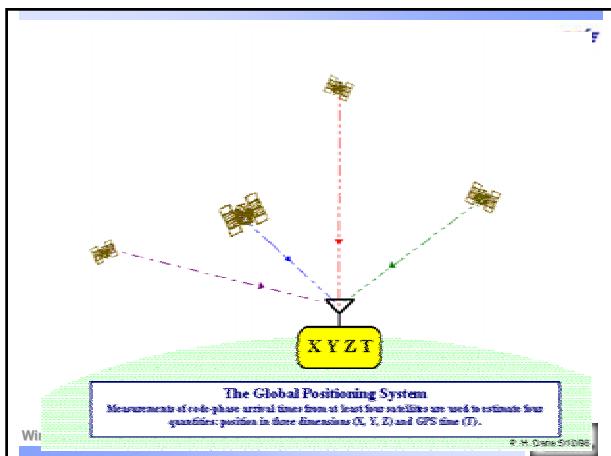


## GPS (cont.)

- 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.

Wireless & Multimedia Network Laboratory

Wireless Multimedia



## 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.

Wireless & Multimedia Network Laboratory

Wireless Multimedia

## 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.

Wireless & Multimedia Network Laboratory™

CS'Ε

## 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).

Wireless & Multimedia Network Laboratory™

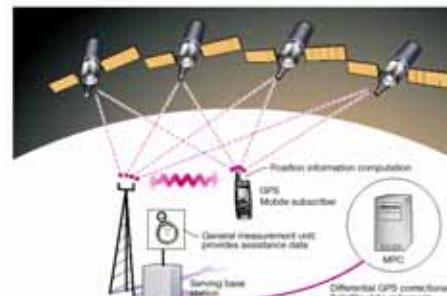
CS'Ε



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

Wireless & Multimedia Network Laboratory™

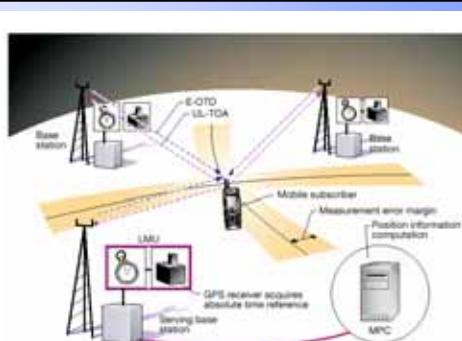
CS'Ε



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

Wireless & Multimedia Network Laboratory™

CS'Ε



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

Wireless & Multimedia Network Laboratory™

CS'Ε

## 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).

Wireless & Multimedia Network Laboratory™

CS'Ε

## Location applications (cont.)

CS'9

### Resource management :

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

### Navigation :

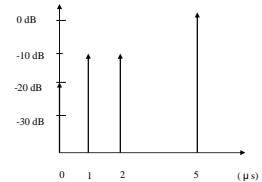
- Vehicle or pedestrian navigation.

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

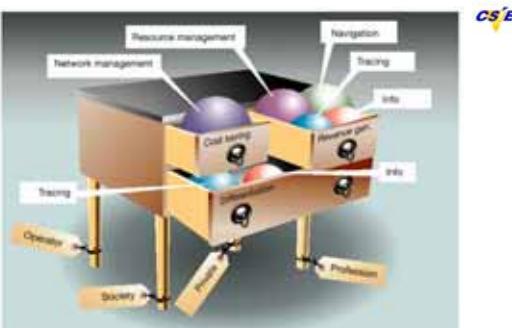
## Small Scale Fading

### ♦ Mean Excess Delay, rms delay spread



Wireless & Multimedia Network Laboratory™

Wireless Multimedia



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

Wireless & Multimedia Network Laboratory™

Wireless Multimedia

## Channel Propagation and Fading

CS'9

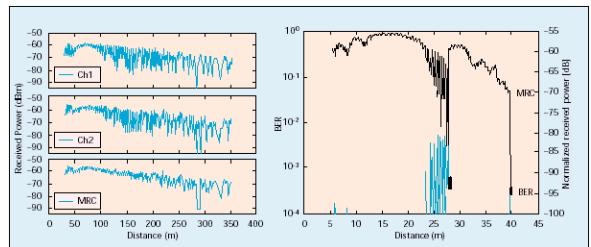


Figure 4. Received power as a function of distance: in a street (left), in a pavilion (right). BER and handover (right).

Wireless & Multimedia Network Laboratory™

Wireless Multimedia